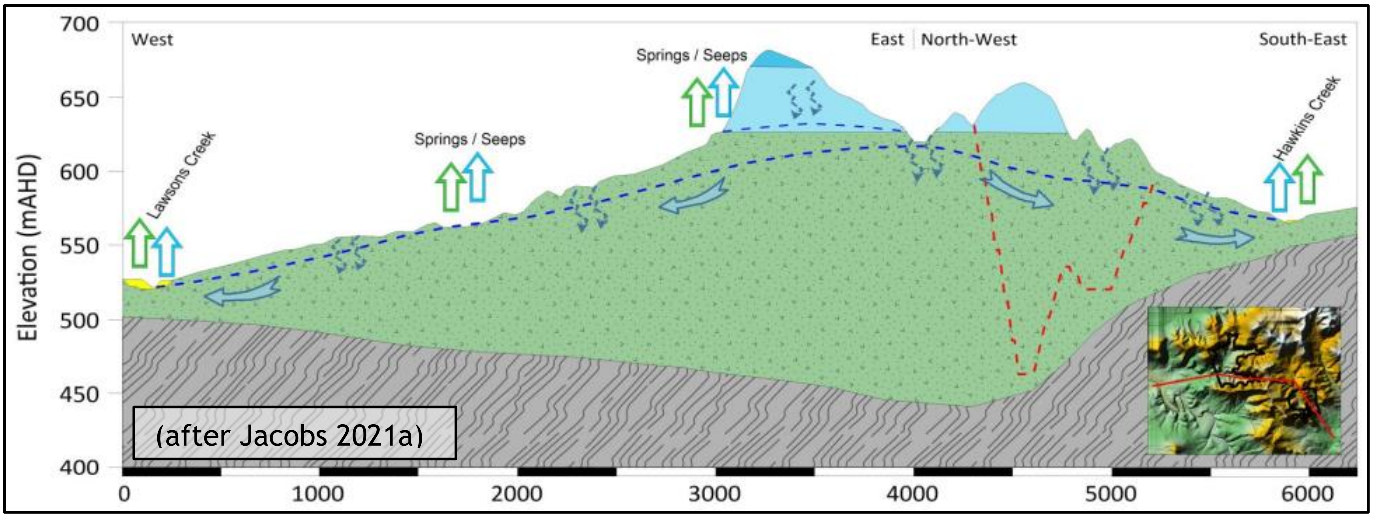
Bowdens Silver Project
Groundwater Assessment Review

Prepared for:	NSW Department of Planning and Environment (DPE)	19 December 2022



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Version 1	21 July 2020	Initial draft
Version 2	12 July 2021	Updated, with consideration of Submissions Report (June 2021)
Version 3	1 April 2022	Updated, with consideration of the Updated Groundwater Assessment, presented as Appendix 4 to the Water Supply Amendment Report (March 2022)
Version 4	23 May 2022	Updated, post-meeting with Bowdens team 16 May 2022 & receipt of WRM (2021)
Version 5	19 Dec. 2022	Updated, considering final void geometry and uncertainty analysis (Corkery 2022b,c)

THIS REPORT SHOULD BE CITED/ATTRIBUTED AS:

Middlemis H (2022). Bowdens Silver Project Groundwater Assessment Review (version 5). Prepared by HydroGeoLogic for NSW Department of Planning and Environment. 19 December 2022.

1. INTRODUCTION

1.1 Bowdens Silver Project Overview

Bowdens Silver Pty Ltd propose to develop the Bowdens Silver project, sited about 25 km south-east of Mudgee in New South Wales (Corkery 2020, 2021, 2022a,b,c).

The project involves a conventional open cut mining process to about 200 m maximum depth (Figure 1) over about 15 years, with out-of-pit waste rock emplacements (WRE) and a Tailings Storage Facility (TSF). Groundwater pumping is required for mine dewatering, with drawdown impacts extending roughly radially out to about 2 km, potentially impacting on two existing third party bores.

Post-mining groundwater inflows to the final pit void lake and evaporation discharge are predicted to result in: a range of long term final void lake levels of around 10-35 m below natural surface and from unchanged to up to 25 m below pre-mining groundwater levels on the south-east (Hawkins Creek) side of the pit for conditions ranging from a throughflow lake to a local sink; for sink conditions, increasing lake salinity is predicted to more than about 5000 mg/L (stock water quality) after 500 years (but no detailed geochemical analysis of pit water quality is reported); and a maximum extent of the 1 m drawdown contour to about 2-3 km radius after about 50 years.

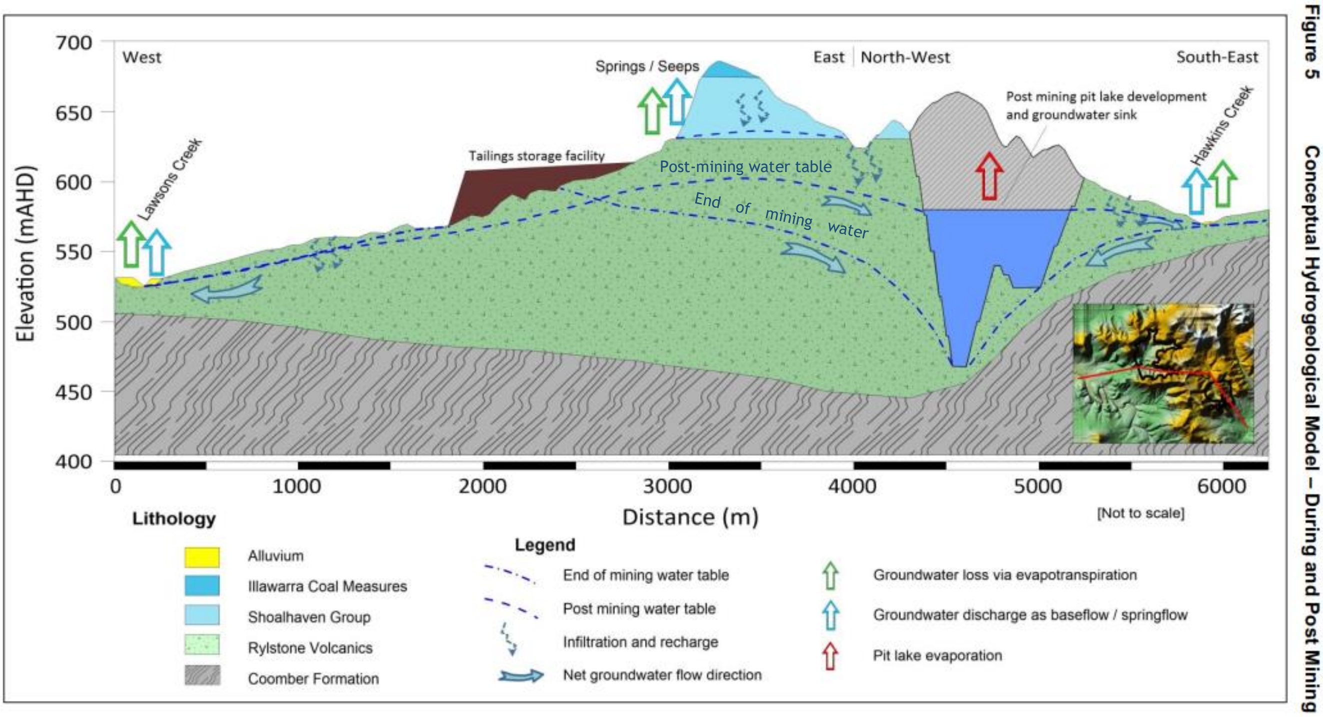


Figure 1 – Bowdens Silver project groundwater schematic (after Jacobs 2021a)

1.2 Peer Review methodology

This report documents the findings of an independent peer review of the groundwater and modelling investigations that form the quantitative basis for the Bowdens Silver Project groundwater assessment.

This report integrates the findings of the peer review process conducted by Hugh Middlemis that considered the following:

- the initial Groundwater Assessment ('GA') (Jacobs 2020) that supported the Environmental Impact Statement (Corkery 2020);
- the subsequent Submissions report (Corkery 2021), notably the first Updated Groundwater Assessment ('UGA'; Jacobs 2021a), presented as Appendix 3 to the Submissions report, and its Annexure 9 that presents the Technical Modelling Report ('TMR');
- two separate Memoranda (Jacobs 2021b,c) were also considered, as they respond to issues raised in the 2020/21 peer review reports versions 1 and 2;
- the 2022 Water Supply Amendment Report (Corkery 2022a), notably the second Updated Groundwater Assessment (Jacobs 2022), presented as Appendix 4 to the Water Supply Amendment Report, and its Annexure 9 that presents the detailed Groundwater Model Report ('GMR');
- three videoconference meetings with the Bowdens team, facilitated by DPE staff, held on 14 September 2021, 16 May 2022 and 1 September 2022, to discuss the peer review reports and to provide feedback on key issues;
- further documents were subsequently provided including
    - a memorandum on climate change effects on 16 May 2022 (WRM 2021),
    - a final void uncertainty analysis report (Corkery 2022b) on 14 October 2022,
    - a letter on the feasibility of an extension to the open cut pit area to increase the likelihood of a final void sink (Corkery 2022c).

This independent review effectively forms advice to the NSW Department of Planning and Environment (DPE) on whether the groundwater 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.

This peer review report has progressed through five versions since 2020:

- the initial desktop review of published EIS reports on groundwater issues was conducted during July 2020;
- in July 2021 version 2 of this report was prepared with reference to the Submissions Report (Corkery 2021);
- in March 2022 version 3 of this report was prepared with reference to the Water Supply Amendment Report (Corkery 2022a);
- in May 2022, version 4 of this report was prepared with reference to the meeting on 16 May 2022 and provision of the WRM (2021) memorandum;
- in December 2022, version 5 of this report was prepared with reference to the meeting on 1 September 2022, provision of the report on the final void uncertainty analysis (Corkery 2022b), and the pit area extension letter (Corkery 2022c).

The best practice principles and procedures of the Australian Groundwater Modelling Guideline (Barnett et al. 2012) were applied, as there are no standard procedures for peer reviews of groundwater investigations and impact assessments as such. Consideration was also given to recent guidance on uncertainty analysis (eg. Middlemis and Peeters, 2018, which has a focus on coal mines and CSG; and Middlemis et al. 2019, which is more generally applicable and actually was the basis for the former). Discussions were facilitated by DPE representatives and held via telephone and video.

The review considered the hydrogeological conceptual model (HCM), its implementation in a numerical groundwater model and then its fitness for the purpose of groundwater impact assessment via simulations of mine dewatering effects, related water management and mitigation actions, and mine closure scenarios. Conformance with best practice guidelines was assessed in relation to: HCM and model design, grid and boundaries; layering and parameterisation; model calibration performance; non-uniqueness and sensitivity-uncertainty prediction scenarios and results; and related analyses, including water balance assessments and final void lake modelling.

The review outcomes are summarised in section 2, including the modelling guideline compliance summary checklist (Table 1), while some elements are discussed in more detail in section 3.

2. BOWDENS PEER REVIEW OUTCOME SUMMARY

This review finds that the Bowdens groundwater modelling has been conducted competently in general and is (overall) fit for the purpose of impact assessment. Noting the moderately low risk context (AIP level 1), the basic sensitivity analysis likely provides a reasonable indication of the range of groundwater impacts from the mine dewatering.

The uncertainty analysis of post-mining final void lake scenarios (Corkery 2022b) has adequately investigated effects in terms of groundwater levels and water balances, indicating a more than 50% probability of throughflow lake conditions, which would be associated with groundwater outflow towards Hawkins Creek, unless mitigation action is taken, such as to extend the pit area and thus increase evaporation to drive lake levels lower such that a sink develops (Corkery 2022c). The lake water quality has been assessed for the final void sink scenario only, and even then simplistically, only in terms of salinity. This means that the lake source concentrations have not yet been established for any source-pathway-receptor impact assessment that might be needed for any final void throughflow condition. However, the transport and fate of outflow from a (very unlikely 95th percentile) full pit void lake has been assessed using particle tracking, along with mitigation options of constructed wetlands and increasing the pit area to increase evaporation. Corkery (2022c) confirmed the feasibility of the mitigation measure of increasing the pit geometry to increase the evaporative discharge and thus lower the final void lake level to below the 579mAHD throughflow threshold. A post-mining groundwater sink would thus be likely, and this would arguably reduce the need for a detailed geochemical analysis of pit water quality because there would be very low potential for outflow from the final void lake.

Noting the probability of throughflow conditions without mitigation measures, it is also worth noting that the groundwater model is suitable for investigation of post-mining scenarios, including particle tracking analysis, combined with a detailed geochemical analysis of the final void water quality and conservative and/or reactive 1D transport models. Depending on the results of any initial investigation (eg. probability and magnitude of impacts on Hawkins Creek), it may become necessary to conduct complex reactive transport simulations, and/or further uncertainty analysis.

This reviewer has identified a tendency towards bias in some aspects of the reporting, in terms of its generally positive narrative and often dismissive treatment of negative implications. For example, asserting 'no spatial bias' in the model calibration performance when it is, in fact, apparent, and (prior to the final void uncertainty analysis) not fully investigating key factors and/or combinations that may affect the final void lake scenario uncertainties nor providing detailed plots of those results (eg. sub-area water balances and fine interval contours). At the 16 May 2022 meeting, questions were posed about how the final void lake predictions could change so much despite few changes to the GoldSim water balance model and none to the groundwater model. The Bowdens team reported that it was due to an error discovered in the GoldSim catchment runoff calculation (WRM 2021). This was corrected, such that the Water Supply Amendment assessment reports (Jacobs 2022, WRM 2022) present validated information, but the error should have been disclosed in the reports.

This reviewer finds that the final void uncertainty analysis report (Corkery 2022b) also exhibits a tendency towards bias. For example, the crucial Figure 7 plot of the predicted final void lake water level (presented herein as Figure 8) does not show the incipient throughflow lake level of 579mAHD on the plot. Further, the caption initially discusses the 95% probability of levels not exceeding 589.3mAHD, stating that '*This means that it is unlikely that peak lake levels would exceed 589.3mAHD*'. It does not note that this level is 10m above the throughflow threshold (but it should). The last line on the caption does point out that there is a more than 50% chance of exceeding the 579mAHD throughflow threshold level, but again does not note (but it should) that this is the key metric.

The lack of clear and transparent reporting is problematic and is not consistent with best practice (Barnett et al. 2012; Middlemis et al. 2018, 2019).

This reviewer admits to a bias himself in highlighting such 'negative' issues where they have not been adequately explored, but also admits to trying to present a balanced view of the strengths and the weaknesses of the assessment, and to providing justifications for review assertions (with apologies for the focus on esoteric details that is necessarily involved).

The review outcomes are summarised below in terms of the modelling guideline compliance summary checklist (Table 1), while some elements are discussed in more detail in section 3.

Table 1 - Groundwater Model Compliance: 10-point essential summary: Bowdens Silver

Question	Y/N	Comments re Bowdens Silver groundwater model
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Objectives clearly stated for groundwater assessment and modelling of mining and post-mining impacts. Model confidence level 2 target. This review assessed that Class 2 has been achieved (see Table 2).
2. Are the objectives satisfied?	Yes (but execution flawed, so there is low confidence in some predictions)	Method suitable for groundwater impact assessment purposes in principle. 3D model design consistent with basic best practice but not every aspect of its execution, notably on aquifer layers/properties (see item 5 below, and section 3.3) and the final void lake water quality (section 3.6); ie. low confidence in some predictions. Steady state and transient calibration to datasets available from 2011, plus basic level sensitivity-uncertainty analyses are reasonable for assessing impacts during the mining period. Post-mining final void uncertainty analysis (Corkery 2022b) evaluates water level and balance impacts, and feasible mitigation measures are proposed to increase pit area and evaporation to develop final void sink conditions (Corkery 2022c).
3. Is the conceptual model consistent with objectives and confidence level?	Yes	Hydrogeological Conceptual Model (HCM) consistent with data, objectives and Class 2 confidence level, suitable for mining project impact assessment.
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	Reasonable knowledge base presented, based on investigations in 1998, 2003, 2011, 2013, and 2014 to 2020. Data includes 3-day pumping tests at 5 L/s on 2 bores, airlift tests, packer testing, core sampling and lab testing, comprehensive hydrochemical sampling and analysis, and structural geological analysis of fracture systems. Appropriate external review conducted.
5. Does the model design conform to best practice?	Yes (but some issues re aquifer layering in mine area)	The model software (Modflow-USG and Vistas), model design, extent (44x44 km), layers (8), grid (30-250m), boundaries and parameters, and methodology are consistent with basic best practice design. Latest modelling (Jacobs 2022) retains unchanged model domain, grid, layers/topology, boundary conditions, parameters and calibration performance, but adds two dewatering wells on the northern pit perimeter to augment the pit floor sump drainage. Main input is recharge from rainfall and main outputs are groundwater baseflow to rivers/creeks and depth-dependent evapotranspiration. Groundwater pumping includes existing users (~5 ML/d estimate). Significant deviations applied to regional geological layering at mine site, identified in review versions 1 & 2 and presumed based on faulting. However, Jacobs (2022) states with ref. to Figures 15/16, that '*layering in the vicinity of mining was altered to readily allow variation to the mine plan*', which was not yet finalised. The problem is that the offsets appear to be large/unrealistic and laterally juxtapose aquifer layers with significantly different hydraulic conductivity values. However, sensitivity analysis results probably give a reasonable indication of the likely range of impacts; discussed further in section 3.3.

Question	Y/N	Comments re Bowdens Silver groundwater model
6. Is the model calibration satisfactory?	Yes (largely)	3D model calibration in steady state and transient 2011-2018. Statistical performance OK; Steady state sRMS=1.7%; Transient sRMS=1.4%, partly due to high range of 446m, but minor bias apparent in mine area (model over-estimates groundwater levels; Figs 22, 24). Steady state sensitivity test for hydraulic conductivity (K) and recharge (RCH). Steady state Jacobian (Table 11-12) helpful, but narrative overlooks point that (null space) parameter uncertainty may be high (ie. a low composite sensitivity value indicates calibration is not sensitive to the parameter because measurements do not inform or constrain the calibration, so the effect on predictive uncertainty should be evaluated; Middlemis & Peeters 2018). UGA (Jacobs 2021a) has improved uncertainty analysis, but still basic level; may be deemed OK for moderately low risk setting (AIP level 1) for mining operations. Post-mining final void uncertainty analysis conducted (see section 3.6). Transient water balance is presumed to be average for 2011-18 (poor documentation). Baseflow adequately matched (very close match is not warranted). Time series groundwater levels match patterns OK, but not closely to absolute levels, partly due to fractured rock aquifer characteristics, estimated (not measured) pumping, and short term dynamics not captured by monthly stresses. Overall: acceptable/reasonable match (but not 'good match'). Extended history match period (7 years to late 2018, with very wet 2016 and very dry 2017-18) improves model capability and helps address non-uniqueness.
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	Model parameter values are adequately consistent with drilling and testing information. Fluxes plausible and benchmarked where possible to measurements/estimates (eg. baseflow, pumping).

Question	Y/N	Comments re Bowdens Silver groundwater model
8. Do the model predictions conform to best practice?	Yes for mine dewatering (but not for post-mining final void lake water quality)	Drain cells applied to pit floor progressions with average climate stresses and scenario differencing (mining case minus null case) consistent with basic practice. TSF parameters are low-ish and justified by tailings specialist. TSF variant setup and parameters OK, with sensitivity test of K and RCH. GoldSim catchment water balance model used to estimate post-mining recovery rate and long term lake level (WRM 2022; Corkery 2022b), with climate change testing of sensitivity to rainfall and runoff. GoldSim predicts pit lake level average ≈580 mAHD (Corkery 2022b Fig.7); 5%-95% uncertainty range ≈565-590 mAHD. Modflow groundwater model identified 579 mAHD as threshold to throughflow condition; consequences of discharge to Hawkins Creek have not been investigated. Mitigation measure feasibility shown for increased final pit area to increase evaporation and thus reduce lake level below threshold to achieve final void sink conditions (Corkery 2022c). Final void lake water quality character assessed simply, only in terms of salinity for sink condition. See section 3.6 for discussion. Otherwise, and notwithstanding layering flaws (item 5 above), mine dewatering prediction uncertainty arguably not greatly affected by non-uniqueness, given: inclusion of estimated (not metered) 3rd party extraction data at ~5ML/d (albeit distributed); mine dewatering predictions of 2-4 ML/d (albeit focused on mine site); high Kh scenario inflows of 5-10 ML/d reasonably described as extremely unlikely; prediction duration only two times the 7-year history match period (range not greatly stretched). Post-mining scenarios more affected by uncertainties such as final void lake sink or thru-flow character, although feasible mitigation measure designed to develop long term sink (Corkery 2022c).
9. Is the uncertainty associated with the simulations/predictions reported?	Yes (as a basic level sensitivity analysis assessment, rather than detailed uncertainty analysis for mining period; final void lake uncertainty analysis OK)	Composite sensitivity analysis indicates quantitative uncertainty analysis may be worthwhile (see item 6 above). But impacts were assessed via basic (one at a time) sensitivity analysis only. This may be deemed adequate in the moderately low risk context (AIP level 1) for mining operations. Post-mining final void prediction uncertainty investigated (Corkery 2022b, see item 8 above), but water quality not yet assessed. Mitigation measure shown to increase pit area and lower lake level below thruflow threshold, thus developing long term sink (Corkery 2022c). Selected limitations and uncertainties for mining period addressed via targeted (one at a time) sensitivity analyses to explore mining risks, identifying key factors of high and low values for K, RCH, aquifer storage (unconfined specific yield Sy and confined specific storage Ss), evapotranspiration (ET) and stream bed conductance (C). Jacobs (2022) Figure 44 shows mine inflow sensitivity is low for parameters other than Kh. Qualitative uncertainty assessment commentary on mining scenarios can be characterised as at a basic level, suitable for a moderately low risk context groundwater assessment, consistent with AIP minimal impact considerations for mining operations. Post-mining uncertainty analysis reasonably well executed (Corkery 2022b).

Question	Y/N	Comments re Bowdens Silver groundwater model
10. Is the model fit for purpose?	Yes • Suitable for mining impacts in context of moderately low risk (AIP Level 1). • Suitable for investigating post-mining final void lake scenarios.	My professional opinion is that the Bowdens Silver groundwater modelling assessment has been conducted generally consistent with basic best practice, except for: • the aquifer layering implementation close to the mine site (see item 5 above and section 3.3); although sensitivity analysis results probably give reasonable indication of likely range of impacts; • inadequate investigation of the final void lake water quality and outflow implications if thruflow conditions eventuate, although mitigation measures proposed to develop long term final void sink (Corkery 2022c) in which case implications are moot (see item 8 above and section 3.6). If the reasonable model calibration performance is deemed acceptable for the moderately low risk context (see section 3.2 below), then the model may be deemed fit for the purpose of guiding mining project groundwater assessments and AIP minimal impact considerations. Post-mining scenarios show likely throughflow conditions without mitigations (Corkery 2022b), but demonstrate feasible mitigation measures such as increasing pit area and thus evaporation to lower lake level and develop long term groundwater sink (Corkery 2022c).

3. DISCUSSION

The groundwater assessment reports (Jacobs 2020, 2021a, 2022) provide adequate but not always high quality explanations of the hydrogeological setting, the conceptual model, the numerical model design and execution, the mining project stresses and simulations, the sensitivity and uncertainty analyses and the predicted impacts. The Submissions Report and Water Supply Amendment Report updates (Jacobs 2021a,b; 2022) provided largely adequate clarifications of most documentation issues, except layering in the mine area (see section 3.3) and some aspects of the post-mining final void scenarios (see section 3.6).

While the initial reviews (Middlemis 2020, 2021, 2022a,b) found that the technical justifications for some elements of the report, the model parameters and/or results warranted improvement, the fundamental predictions were considered likely to be reliable indicators of the impacts for the mining period, given the lack of obvious technical fatal flaws and the low variability indicated by the sensitivity tests. It was difficult to be wholly definitive on this point, given the level of detail in the report presented at the initial review stage, but the recommended corrective actions have since been mostly addressed in the subsequent updates (Jacobs 2021a,b; 2022). The final void uncertainty analysis (Corkery 2022b) addressed a significant study limitation and concluded that there is a more than 50% chance of the final void lake level exceeding the throughflow threshold of 579mAHD (unmitigated). Subsequent analysis showed the feasibility of mitigation via reducing the open pit area (Corkery 2022b) which would increase evaporation and reduce the pit lake level below the throughflow threshold, creating a long term groundwater sink and thus removing the long term risk of outflow from the pit lake.

3.1 Model Confidence Class

The Australian Groundwater Modelling Guidelines ('AGMG'; Barnett et al. 2012) set out a model confidence classification framework, based on considerations underpinning the hydrogeological conceptual model (HCM) and the data available, especially aquifer responses to hydrological stresses, as well as the model design, construction and performance. It is expected that any model will have attributes that fall into more than one 'class', with the overall 'confidence level' indicated from the weight of criteria that are met. The AGMG 'confidence classification' framework is being revised and it is expected to be discontinued.

For the record, this peer review conducted an independent assessment of the model confidence level (see Table 2 on last page), consistent with the AGMG but based on the method outlined in Middlemis et al. (2018). This review finds that a Class 2 model confidence level is justified, with some elements of Class 3, confirming its fitness for the investigative modelling purpose. As the model structure, parameters, performance and impact predictions have not changed materially (Jacobs 2021a, 2022), this assessment remains valid, and, along with this review report, provides information in response to the modelling issues raised by the Lue and District Community (Jacobs 2022, Table 1).

3.2 Model design and capability, including AIP issues

The groundwater system is characterised as predominantly a fractured rock aquifer system, with minor alluvium associated with some creeks. An equivalent porous medium (EPM) approach has been adopted. This is consistent with best practice principles, and is adequately justified with reference to the hydrogeological investigations, pumping test results, conceptualisation and model calibration.

The project context suggests a moderately low risk setting for potential groundwater-related impacts associated with mining operations, in that the groundwater assessment reports (Jacobs 2020, 2021a, 2022) indicate that, within the area of drawdown impacts:

- there are few existing groundwater users,
- there are no mapped high priority groundwater dependent ecosystems (GDEs),
- the terrestrial vegetation has been assessed as comprising non-obligate GDEs, and
- springs are assessed as largely perched-type systems mostly unaffected by water table drawdown.

It is important to understand the risk context when considering the level of effort required for conducting sensitivity and uncertainty analyses (Middlemis and Peeters, 2018; Middlemis et al. 2019). In this case, it can be argued that an adequate level of effort has been applied to the model design and execution for the moderately low risk context applying to the mining period. For the post-mining period, the final void lake uncertainty analysis (Corkery 2022b) has confirmed the more than 50% likelihood of a transition from a terminal sink to a throughflow system. However, left unmitigated, such assessment has not adequately investigated the consequences in terms of source-pathway-receptor impacts on Hawkins Creek (requires a pit lake geochemical analysis as a first step) (see details in section 3.6 below), which has implications for some Aquifer Interference Policy (AIP) issues. Subsequent analysis (Corkery 2022b) showed the feasibility of mitigation via reducing the open pit area which would increase evaporation and reduce the pit lake level below the throughflow threshold, creating a long term groundwater sink and thus removing the long term risk of outflow from the pit lake.

The groundwater assessment details on how the Bowdens project would meet with the AIP Level 1 Minimal Impact Considerations for highly productive aquifers (alluvial, porous rock and fractured rock aquifers) are outlined in Annexure 1 to the UGA (Jacobs 2021a; 2022). This review has not identified any other material flaws in the AIP assessment for the mining period conditions. However, it has not been demonstrated that a final void sink (Corkery 2022c) would not cause any changes to groundwater quality beyond 40 metres from the pit (ie. to meet AIP Level 1 criteria for post-mining conditions), in terms of a potential halo of poor quality water around the pit lake, nor has qualitative uncertainty analysis documentation been provided to assess whether or not this may be a material issue.

It is notable that a parsimonious approach has been applied to the model design and parameterisation (eg. generally uniform aquifer property zones), which is consistent with best practice modelling principles for a moderately low risk context (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.’

These parsimony principles were established when uncertainty analysis methods were not in common practice, whereas the recent improvements in uncertainty analysis allow for efficient treatment of spatial variability in parameters, such that parsimony may no longer be a highly valued principle (Middlemis and Peeters 2018, and update in press). The application of a highly parameterised final void uncertainty analysis method (Corkery 2022b) has addressed this issue for the post-mining period. As the outcome was somewhat surprising (>50% probability of final void lake throughflow), it would be prudent to conduct a similar uncertainty analysis for the mining period.

Prior to the final void uncertainty analysis, several model variants were designed and applied to assess long term post-mining recovery and residual impacts, and to investigate seepage from the Tailings Storage Facility (TSF). These variants appear to have been designed and executed consistent with best practice guidance, notwithstanding the aquifer layering issues discussed next.

3.3 Geological layering at Bowdens site

Figure 51 of the EIS groundwater assessment (Jacobs 2020, excerpt shown in Figure 2 below; shown as Figure 15 of Jacobs 2022) shows geological cross-sections that are based on regional data from the Western Coalfield Geological Modelling Project (NSW Dept of Resources and Energy), supplemented by mine site data. These figures show considerable layer deviations at the mine site, but there was no commentary provided to justify this representation as reasonably representing the geological system. For example, the role of the mapped fault structures is not discussed, although that could justify the mismatch between the site data and the regional data.

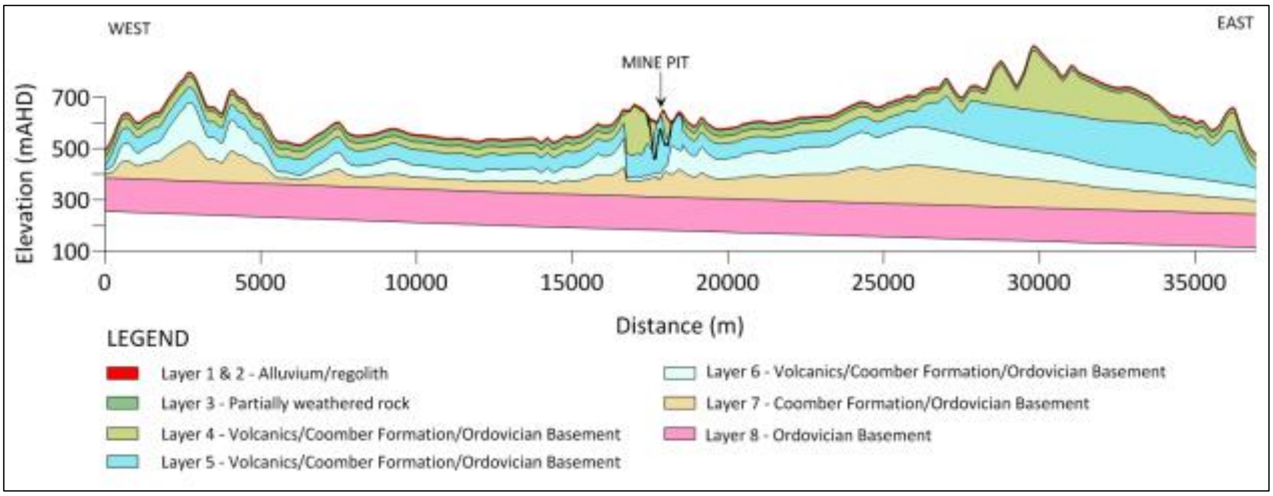


Figure 2 - geological cross-section (after Jacobs 2020, Figure 51)

The Submissions report and Updated Groundwater Assessment ('UGA'; Jacobs 2021a) did not present any additional explanation, despite this issue being raised by the initial review as requiring corrective action. The Memorandum accompanying the UGA (Jacobs 2021b) does offer this response: "*The perturbations to regional geological layering are left over from the early construction of the groundwater model prior to confirmation of the final mine design. The layering was to allow for simplification and versatility if an expansion of the preliminary mine design was to be adopted. It is noted that due to the adopted parameter zonation in the mining area, the perturbations are of little consequence to predictions of mine dewatering or associated groundwater drawdown and impacts.*"

Similar comments appear in Jacobs (2022), which effectively acknowledges (or does not disagree) that the layer deviations in the mine area are physically unrealistic. The layer deviations have not been justified on the basis of geology, as would be expected. The problem is that the layer deviations substantially offset and laterally juxtapose aquifer layers with hydraulic conductivity (K) values that change by up to a factor of 6 across the deviation, although it is difficult to be definitive due to the compressed scale of the hydraulic property zones plot and the complex table of values (Jacobs 2022, Figure 18 and Table 9). The assertion that the perturbations would be 'of little consequence to predictions' is not objectively justified and is questionable, as outlined below, although it is acknowledged that the interpretations involved may be flawed due to the lack of detail provided in the reporting.

For example, with reference to Figure 2 above and Figure 3 below, layer 6 across most of the mine area is very thin, which creates a very low transmissivity unit across the base of the mine area (transmissivity ('T') is the product of thickness with hydraulic conductivity ('K'), and indicates the groundwater transmission capacity of the layer). The layer deviations applied have resulted in zones of a thin layer 5 in some areas (Figure 3), and thus very low T values where associated with low K values.

Across the outer mine area the K value is low for layer 6 (0.01 m/d) and for layer 5 (0.02 m/d). Along with the layer deviations, the low K or T in layers 5 and 6 in the mine area has the effect of limiting the regional groundwater flow at depth towards the pit, as it would tend to be conveyed by the (3 to 6 times) higher K layer 4 (0.06 m/d), despite its variable thickness. Low K or T values are also associated with steeper hydraulic gradients, which may help explain the uneven spacing of drawdown contours in some areas. For example, contours are moderately spaced in most areas but are stacked closely together in some areas, giving a 'box-like' appearance to the contours (see Figure 4 below).

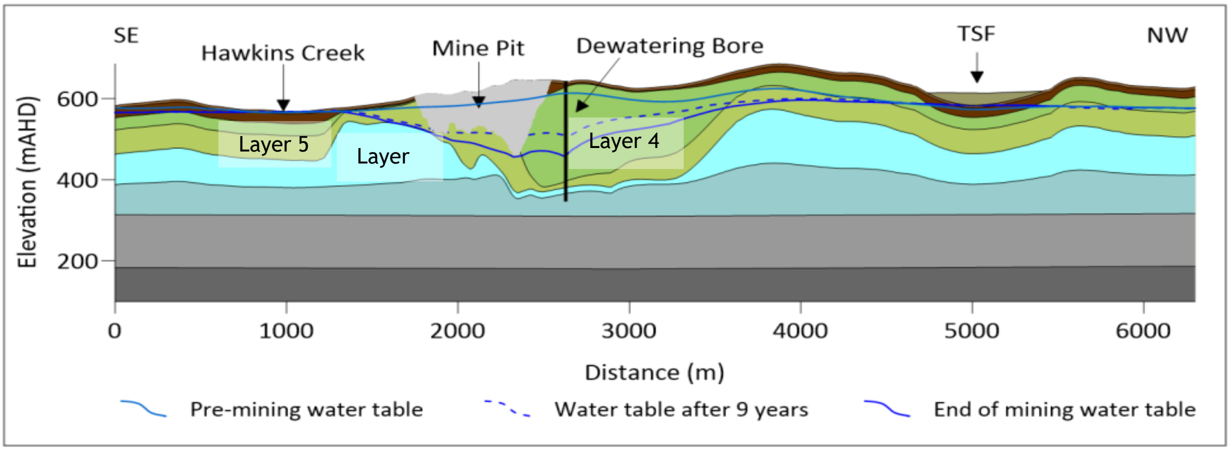


Figure 3 - layer deviations in mine area (after Jacobs 2022 Fig.37)

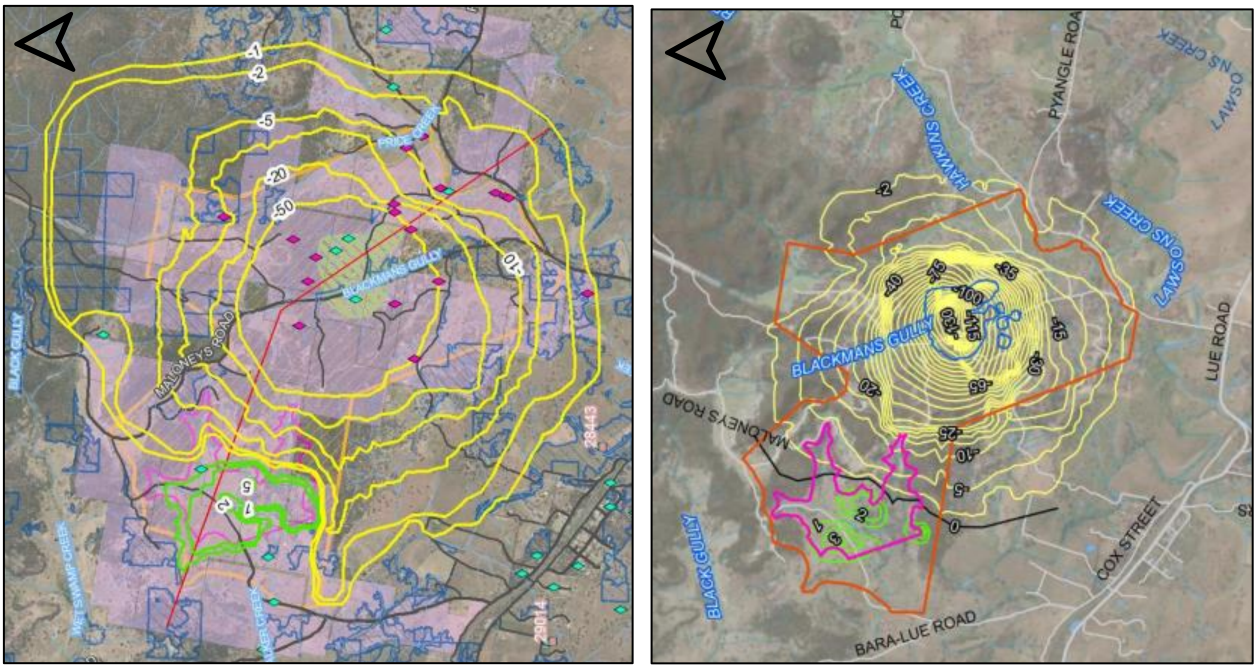


Figure 4 - example of uneven drawdown contour gradients (Jacobs 2022, Fig.36, Fig. A1-6)

It is difficult to discern whether this uneven drawdown contour pattern matches the zones of uniform hydraulic conductivity, due to the compressed plot scales (Jacobs 2022 Figure 18). However, it does not seem to align with the mapped fault structures (Jacobs Figure 11), and there is no other geological justification provided. It is possible that the effect is a manifestation of some other (unexplained?) detail. In any case, the layer deviations and the steep drawdown effect have not been adequately explained.

Noting that Modflow simulates groundwater flow as horizontal within a model layer and allows for flux exchange between layers only on a vertical basis (unless unstructured grid methods are applied), the effect of the layer juxtaposition is difficult assess without careful consideration of aquifer layer thicknesses (not presented) and/or running test simulations (not conducted). A recent paper investigated layer-based and voxel-based geological modelling methods and showed that the method adopted can have a significant impact on the model predictions, with voxel methods typically better for simulations where aquifer units with different properties are laterally juxtaposed (Enemark et al. 2022). It is concluded that the model layering has been poorly executed.

Having said that, the sensitivity-uncertainty analysis (Jacobs 2022 section 6, Figure 44) tested the effect of varying the hydraulic conductivity by an order of magnitude higher and lower, so the results may give a reasonable indication of the likely range of drawdown impacts, even though there is still a large difference in K values across the juxtaposed layers. It may be reasonable to apply experienced judgement in this case and to speculate, for peer review purposes, and with an understanding of the moderately low risk context (see previous section), that if corrective action were taken to improve the melding of the regional data on aquifer layering with the local mine area data, it would probably not materially affect the model performance or predictions. Such speculation should not be needed in order to provide review advice to the DPE or to evaluate the adequacy of the groundwater assessment.

3.4 Calibration performance and prediction implications

The Bowdens model calibration performance is adequate (but not ‘reasonably good’ or ‘very good’ as described in Jacobs (2020, 2021a), later revised to ‘a good correlation’ and ‘a reasonable match’ in Jacobs (2022)). The scaled RMS statistic of 1.7% for steady state and 1.4% for transient (Jacobs 2022 Tables 10 and 15) does suggest good performance in relation to the 5% criterion often applied (Barnett et al. 2012). However, applying that metric to the Bowdens model involves dividing the RMS errors (7.74m and 6.26m, resp.) by what is a very wide range of heads across the entire model domain (446m). The Figure 22 scatter plot shows that the range of heads in the Bowdens sub-area is much less at about 100m, which would result in a scaled RMS of around the nominal guideline value of 5% if the RMS was about 5m for this data subset (the RMS for this sub-area is not reported, but the overall standard deviation is stated as 8m).

Jacobs (2021c) provides some reasonable explanations for the large residuals (differences between measured and modelled levels) at bores in the mine area. However, the assertion that the model statistical performance has ‘no material effect on model reliability of predictive outcomes’ is not justified and it does not acknowledge the data and modelling uncertainties that do affect model reliability. The Bowdens sub-area is actually the key area where very good model performance is required for mine dewatering impact assessment purposes, and while the scatter plot (Figure 22; see Figure 5 below) shows most residuals within ±10m, two residuals are excessive (10m over-prediction and 20m underprediction). Jacobs (2022) claims incorrectly that ‘*there is no spatial bias in the magnitude or sign of the residuals*’. The Figure 22 scatter plot shows that the model tends to over-predict groundwater levels (more dots above the 1:1 dashed line than below it), while the very poorly presented Figure 24 (Figure 5 right) shows a spatial bias in the residuals (few orange and red dots but many yellow, green and blue dots). This issue was discussed at the meeting on 16 May 2022, but the data presented simply confirmed to this reviewer that there is indeed a small spatial bias in the magnitude and the sign of the residuals.

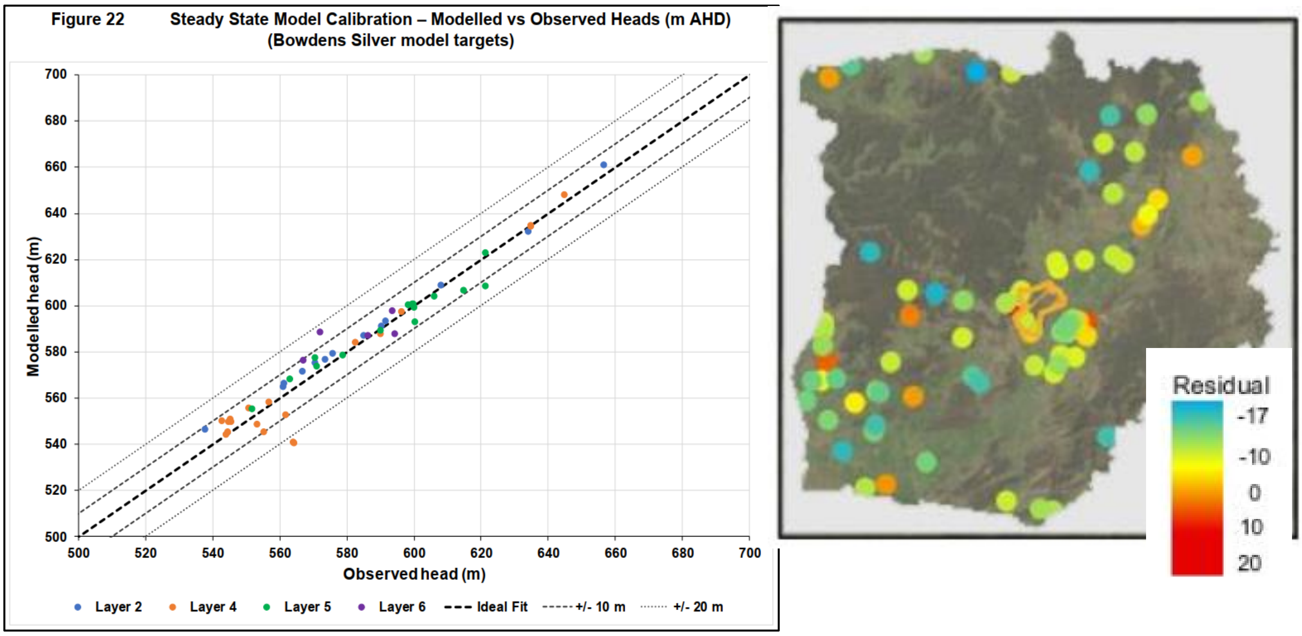


Figure 5 - evidence of bias in model calibration (after Jacobs 2022, Figs 22, 24)

Other measures of calibration performance assessment are presented in Jacobs (2022), and this review considers them to indicate adequate but not good performance as such (ie. adequate given the moderately low risk context; see section 3.2 above; and reasonable for the fractured rock system setting). For example, the scatter plot of residuals (Figure 22 and related Table 10) show minimum and maximum residuals of -17m and +24m (standard deviation of about 8m) across the domain in a sparse pattern, albeit with some spatial bias apparent. The time series hydrographs of groundwater levels at 16 monitoring bores (Figures 25-30) show that, while trends are generally replicated adequately, mis-match errors are typically at least 2-3m, and peaks due to rainfall and troughs due to short term pumping are not able to be captured accurately by the regional scale model.

The history match period of 7 years to October 2018 includes a very wet 2016 and a very dry 2017-18 period (refer to Figure 7a of Jacobs 2022), which improves model capability, in that it helps to address non-uniqueness (the principle that multiple combinations of parameters may be equally good at fitting historical measurements) by calibrating over a period of wide-ranging hydrological stress. Other methods to address non-uniqueness (Barnett et al. 2012; Middlemis and Peeters, 2018) have also been applied to the Bowdens assessment, including using fluxes in the calibration process (eg. baseflow and third party pumping), and applying pilot point methods and/or regularisation.

The match to estimated baseflow (Figure 32) is adequate, as is typically achieved for most models. It should be remembered that baseflow cannot be measured directly, but must be estimated via digital filter methods from stream flow data, as was done for the Bowdens project. Interestingly, it was recently established during a NSW Land and Environment Court case into alleged water theft on the Barwon-Darling River (WaterNSW v Harris [2018] NSWLEC 188) that stream gauging estimates are subject to data uncertainty of ±12.4% (with 95% confidence). This means that the derived baseflow estimates must be even more uncertain, and hence they are a ‘soft’ calibration target, albeit an important one.

It is common that mining projects have limited data available to benchmark the modelled aquifer system response to the scale of the proposed pumping to try to establish confidence in the model results. In this case, the sensitivity tests indicate predicted mine dewatering rates generally in the range of 2 to 4 ML/d, while the upper and lower inflow scenarios indicate 5-10 ML/d (high permeability) and 1 ML/d (low permeability)(Jacobs 2021a, Annexure 9, Figure 42; Jacobs 2022 Figure 44). These rates are of a similar scale to the roughly 5 ML/d of pumping by existing third party users that has been included in the model. Including flux rates in the model calibration helps address model non-uniqueness, and provides some confidence that the calibrated Bowdens model is a suitable predictive tool for impact assessment. The sensitivity scenarios confirm a relatively small range of predicted inflows and drawdown impacts, which improves confidence.

Regarding topographic data and its use to define surface water drainage networks, the Submissions report (Jacobs 2021a) confirmed at Annexure 11 that the topographic data set over the mining lease is the publicly available LiDAR data on a 2m gridded DEM, which was merged with the regional 1:25,000 topographic dataset. The Memorandum (Jacobs 2021b) confirmed that LiDAR data covers the mine site and the reaches of Hawkins and Lawsons Creeks from Hawkins Creek upstream of the mine site to Lawsons Creek below the confluence with Walker Creek (below the TSF). This addresses issues identified at the initial review stage (Middlemis 2020) regarding the key data need for LiDAR to help define in a physically realistic way the shallow groundwater and surface water interactions (eg. variably gaining and/or losing creeks across the Hawkins Creek and Lawson Creek systems), and depth-dependent evapotranspiration (eg. surrogate for terrestrial GDEs).

The results of The composite sensitivity analysis of hydraulic conductivity and recharge parameters for the steady state model are presented in Jacobs (2020) Figures 59 and 60, and Jacobs (2022) Tables 11 and 12. Jacobs state (correctly) that '*A composite sensitivity value of zero indicates that changing the parameter value neither degrades nor improves calibration (i.e. the objective function is unaffected)*.' However, this reviewer considers this to be another example of the bias or 'positive spin' in the reporting, which is not consistent with the recent uncertainty guidelines that encourage discussion of the potential effects of bias (Middlemis et al. 2018, 2019). The narrative in this case overlooks the crucial point that the calibration is not sensitive to the parameter because the measurements available do not inform or constrain the calibration. This means that the effect on predictive uncertainty should be evaluated (Middlemis and Peeters 2018). A comprehensive uncertainty analysis has not been conducted, and while this may be deemed acceptable given the moderately low risk context (AIP level 1) applying to mining operations, such a justification of the modelling methodology has not been attempted in the reporting, and as the risks associated with the post-mining scenarios are not low, detailed uncertainty analysis of those conditions is warranted, and has since been conducted (see also section 3.6.5).

3.5 Evapotranspiration ('ET')

The Submissions reporting (Jacobs 2021a) provided generally improved details on the ET parameters for the mining and post-mining periods, including the post-mining final void lake ET setup in the Modflow model, addressing most issues raised at the initial review (Middlemis 2020). The post-mining scenarios are discussed in the next section. The final void uncertainty analysis (Corkery 2022b) provides further details and justifications on the ET setup in the GoldSim water balance model.

The basic depth-dependent ET process appears to have been reasonably well executed in the Bowdens Modflow model. For example, the 3m extinction depth generally is a reasonable setting, and the maximum ET rate is set generally at 40% of the SILO FAO56 rate (SILO dataset). The model is described as 'insensitive' to that setting, and although the ET rate and extinction depth parameters were not included in the sensitivity analysis, the ET rate was included in the uncertainty analysis, confirming low sensitivity in relation to mine inflows (Jacobs 2021a, Figure 42; Jacobs 2022, Figure 44).

There are limited implications in terms of ET parameter settings for the impact predictions on terrestrial GDEs as there are no high priority GDEs within the area of predicted drawdown.

The final void lake water balance scenarios involve the application of a pan factor to account for the effects of shading and wind shielding on pit lake evaporation, which is reasonable in principle (WRM 2022, section 7.7). Prior to the final void uncertainty analysis (Corkery 2022b), the factor ranged from 0.5 at the bottom of the void to 0.95 at the top of the void (Jacobs 2022), which would mean that the factor would be roughly 0.85 at the final void lake level, which is also reasonable in principle for the initial analyses. However, research that uses floating instrument platforms to measure pit lake evaporation (McJannet et al. 2017) has shown that the evaporation rate and/or the pan factor should be calculated on a daily basis (for application to the daily GoldSim water balance model), rather than adopting an annual average factor. This becomes especially important when the final void lake level prediction sensitivity scenarios indicated the potential for throughflow conditions to develop (ie. evaporation uncertainty is a key factor that should have been carefully explored). These issues were adequately addressed in the subsequent final void uncertainty analysis (Corkery 2022b).

Prior to the final void uncertainty analysis, a limited sensitivity analysis of the final void water balance had been conducted in relation to the pan factor, with a key metric noted as the final void lake level of 579 mAHD that the groundwater model predicted would generate throughflow conditions (Jacobs 2022, p.5-337). The WRM (2020) analysis adopted a maximum pan factor of 0.8 (with a sensitivity test at 0.7), while the WRM (2022) analysis adopted a maximum pan factor of 0.95 (with a sensitivity test at 0.8), but there is no explanation or justification given for the change. The effect of higher pan factors in the 2022 assessment is to increase the evaporation flux and thus depress the final void lake level (from to 574.5 to 569.8 for the HI.H climate scenario, and from 583.3 to 578.9 mAHD for the pan factor sensitivity run). This indicates that throughflow conditions would develop for the lower pan factor cases, which are within a reasonable range of uncertainty. In addition to a lower pan factor, sensitivity runs assuming only 1.5x higher groundwater inflows gave higher lake levels (ie. 586 mAHD in WRM 2020, or 581.6 mAHD in WRM 2022) that exceed the 579 mAHD metric for throughflow. This indicates a material likelihood for final void lake throughflow conditions to develop, with implications discussed in the next section. These issues were adequately addressed in the subsequent final void uncertainty analysis (Corkery 2022b), which confirmed that there is a more than 50% chance of the final void lake level exceeding the 579mAHD throughflow threshold.

3.6 Post-mining final void scenarios

There is some justification provided in the Submissions report (Corkery 2021, section 5.22.8) in relation to the adoption of a post-mining final void as part of the final landform, notably that further mineralisation below the pit floor has been identified.

The post-mining final void modelling was conducted iteratively using the groundwater flow model (Jacobs 2022) and the GoldSim final void lake water balance model (WRM 2022; Corkery 2022b). One of the key inputs to the GoldSim model was the groundwater inflow versus pit lake level relationship that was developed from the groundwater flow modelling (WRM 2022, Figure 7.4; subsequently updated in Corkery 2022b, Fig.3). Other inputs to and/or calculations by the GoldSim final void water balance model included final void geometry, evaporation, rainfall and runoff. Key outputs included lake water balance components and the long term equilibrium lake water level, which was itself input to some post-mining simulations using the groundwater flow model. The final void uncertainty analysis (Corkery 2022b) used the same methods, with updated input data and relationships, and with testing of a wide range of uncertainty in parameter values, augmented by the feasibility assessment of extensions to the open pit area (Corkery 2022c).

3.6.1 Post-mining model variants ('A' and 'B')

Two post-mining model variants ('A' and 'B') of the Bowdens numerical groundwater flow model were used to assess the recovery of water levels in the final void lake and in the surrounding groundwater system under a range of scenario assumptions, as summarised below (Jacobs 2021a, 2022).

- Variant A applied the 'high K' approach (high permeability and storage parameters assigned to the final void) and with the ET rate set to 4.15 mm/d (mean daily ET from SILO data). This was also applied to the final void uncertainty analysis (Corkery 2022b), but with no ET on the pit lake, which is reasonable.
- Variant B applied a fixed head boundary condition to represent a full pit void lake at a representative long term level based on the initial findings from the post-mining water balance model (WRM 2020, 2022). The fixed head value in Variant B was set to quite different values for the various assessments, but no reasoned explanation was given for the significant change in the final void lake water levels specified:
    - 574.5 mAHD for the 2021 Submissions report;
        - reported in section 5.4.7 (p.5-337) of Jacobs (2021a), which is consistent with the final void water balance model prediction for the 'existing (SILO) climate' (WRM 2020);
    - 571.7 mAHD for the 2022 Water Supply Amendment assessment;
        - reported on page 5-338 and in Table 19 of Jacobs (2022) as the median pit lake water level for the average climate scenario from the final void water balance model.

Variant A was used for the post-mining final void uncertainty analysis (Corkery 2022b), with reasonable parameter settings applied to estimate the uncertainty range for the relationship between groundwater levels and inflows to the final void, for input to the GoldSim water balance model.

3.6.2 Variant A

Variant A was also used for the initial and updated groundwater assessments (Jacobs 2020, 2021a, 2022) to simulate the process of gradual recovery of water levels post-mining, and the magnitude and extent of the related aquifer drawdown impacts and water table levels. Variant A was also used to define the relationship between groundwater inflows and lake levels, for input to the post-mining GoldSim water balance model (WRM 2020, 2022), including the final void uncertainty analysis (Corkery 2022b). This is common practice and reasonable in that it is simpler to do mine water balances analytically (eg. spreadsheet/GoldSim style) with inputs from separate rainfall-runoff and groundwater models, rather than invoke that complex functionality in a numerical model. The time taken for water level recovery to a new equilibrium condition, and the dynamic range of the long term final void lake level itself, was estimated for the various versions of the groundwater assessments by the post-mining water balance modelling using the GoldSim package (Figure 7.7 in WRM 2020 and WRM 2022; noting the significant but unexplained differences between these two plots), with results also summarised in Jacobs (2021a) Figure 38, and Jacobs (2022) Figure 39.

The final void uncertainty analysis (Corkery 2022b) resolved these inconsistencies.

3.6.3 GoldSim water balance model issue

Although there appeared to be no reported change to GoldSim model inputs or parameters, the range of final void lake levels and the median level were significantly reduced in the initial 2022 results compared to the previous results (Figure 7.7 in WRM 2020 and 2022).

An explanation was provided at the 16 May 2022 meeting, when questions were posed about how the final void lake predictions could change so significantly despite few reported changes to the GoldSim water balance model and no parameter changes to the groundwater model. The Bowdens team reported that it was due to an error discovered in the GoldSim catchment runoff calculation (WRM 2021). This was corrected, such that the Water Supply Amendment assessment reports (Jacobs 2022, WRM 2022) presented validated information, but the error should have been disclosed in the reports.

It was strongly recommended at that time that a detailed independent review of the surface water analysis be conducted to validate the analyses, and that has since been curated by the DPE.

3.6.4 Variant B

Variant B for the Submission report assessment (Jacobs 2021a) involved a fixed head level of 574.5 mAHD applied to the final void lake, representing a long term lake level based on the initial post-mining water balance model (Jacobs 2021a, section 5.4.7, page

5-337); note that this was subsequently updated with an uncertainty analysis methodology (Corkery 2022b). The corresponding water table contours for the initial assessment (Figure 39) showed that the final void lake does not remain as a groundwater sink, and an arrow indicated outflow to groundwater in the direction of Hawkins Creek (see Figure 6 below, left frame). The description of a 'partial groundwater sink' in Jacobs (2021a) is nonsense, and is not consistent with the evidence presented. Jacobs (2021c) attempt a semantic justification that is not consistent with the surface and groundwater interaction framework illustrated in Figure 11-1 of the Australian Groundwater Modelling Guidelines (Barnett et al. 2012); see Figure 7 below. The final void lake was indeed predicted to be a groundwater throughflow lake under the specified conditions, not a sink of any sort (eg. McCullough and Schultze 2015). For the record, the subsequent final void uncertainty analysis (Corkery 2022b; note that this used Variant A) has since confirmed that there is a more than 50% chance of the final void lake level exceeding the 579mAHD throughflow threshold. However, the subsequent feasibility assessment of extending the open pit area (Corkery 2022c) demonstrated the feasibility of that mitigation measure to develop a final void sink rather than throughflow conditions.

The Variant B results from the Water Supply Amendment assessment (Jacobs 2022) showed a similar contour plan at Figure 40, but it also showed a groundwater divide towards Hawkins Creek (Figure 6, right), which was indicative of final void lake terminal sink conditions, due to the specification of a lower final void lake level of 571.7 mAHD. This result was subsequently overturned by the final void uncertainty analysis (Corkery 2022b), which predicts a more than 50% probability of the final void lake level exceeding the throughflow threshold level of 579mAHD. Again, the subsequent assessment (Corkery 2022c) demonstrated the mitigation feasibility of developing a final void sink rather than throughflow conditions.

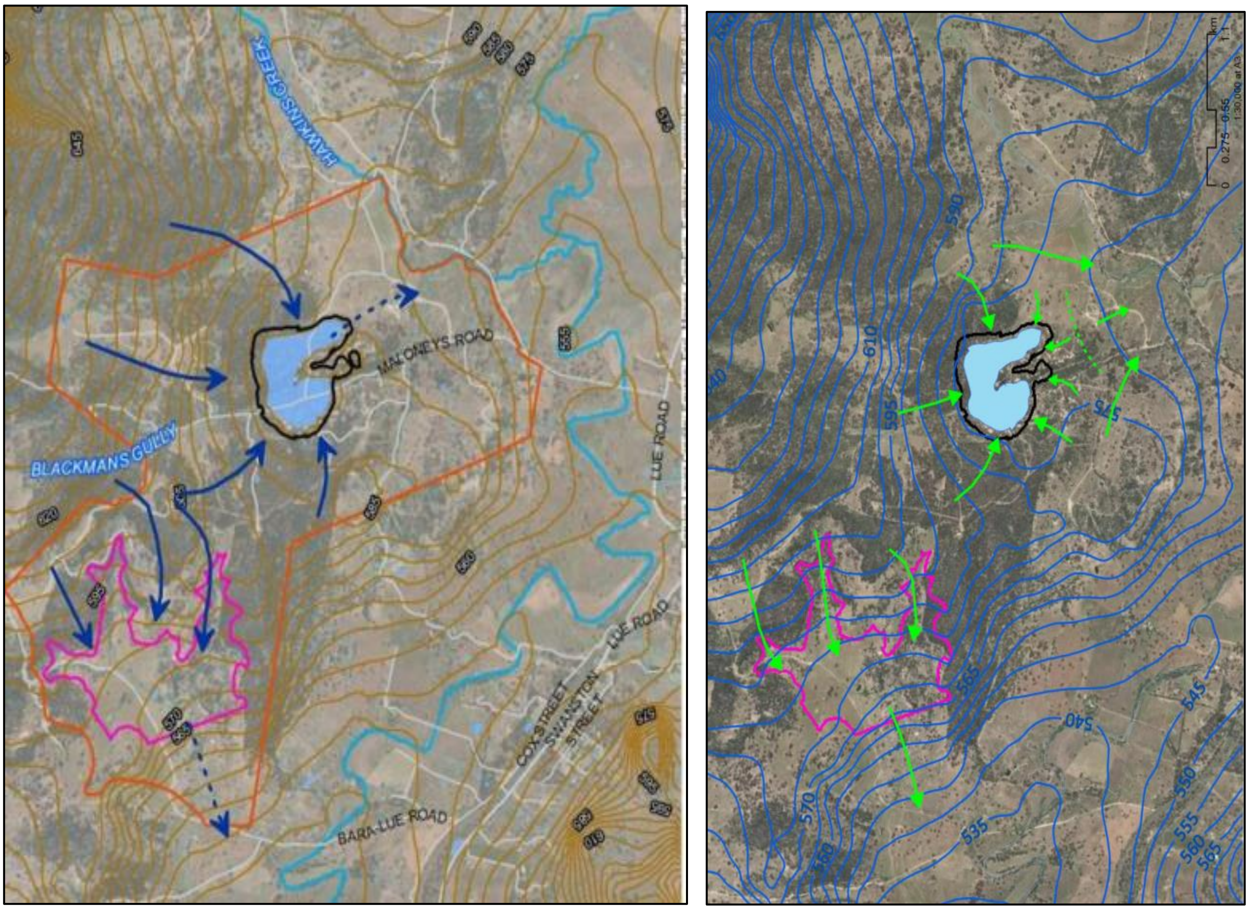
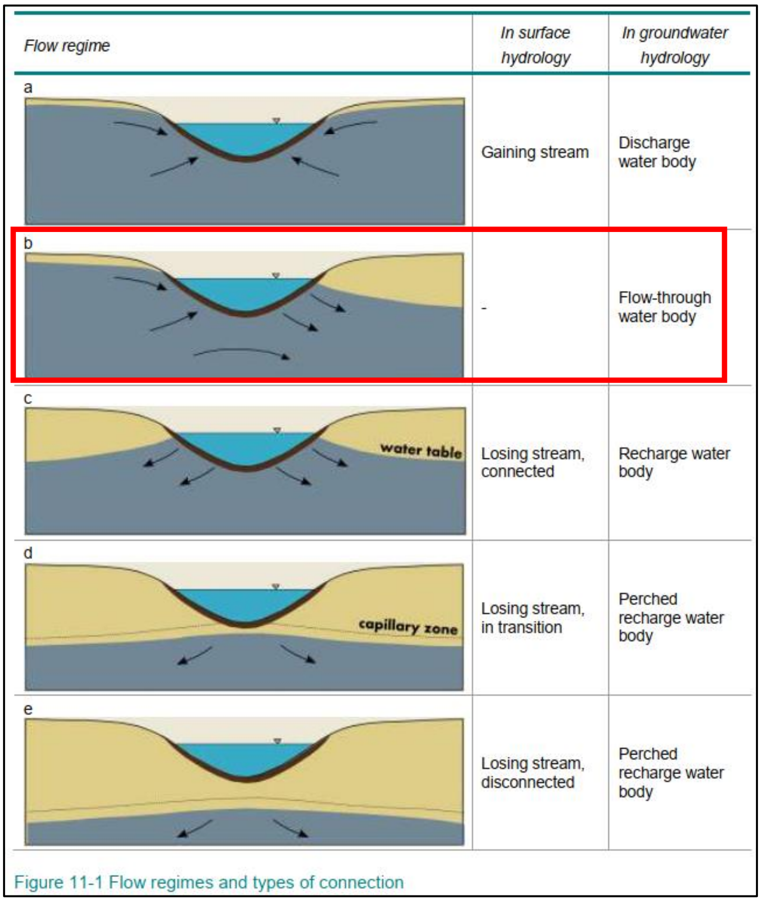


Figure 6 - initial versions of post-mining final void scenarios (after Jacobs 2021a Fig. 39 (left); Jacobs 2022 Fig 40 (right))



Flow regime	In surface hydrology	In groundwater hydrology
a	Gaining stream	Discharge water body
b	-	Flow-through water body
c (water table)	Losing stream, connected	Recharge water body
d (capillary zone)	Losing stream, in transition	Perched recharge water body
e	Losing stream, disconnected	Perched recharge water body

Figure 11-1 Flow regimes and types of connection

Figure 7 - AGMG hydrogeological regimes for surface-groundwater interaction (Barnett et al. 2012, Fig.11-1)

3.6.5 Final void lake scenarios

It is important to understand that, as described above, and prior to the final void uncertainty analysis (Corkery 2022b), the groundwater model was otherwise unchanged between these two scenarios in terms of the grid, layers, parameters, boundary conditions, calibration performance and so on. Similarly, the GoldSim water balance model was reportedly unchanged in terms of the key inputs of rainfall and groundwater inflow (eg. Figure 7.6 of WRM 2021 and 2022), although different evaporation parameters were applied and an error in the GoldSim model was corrected (see section 3.6.3).

Whether or not an adequate explanation may be provided for these differences, and they seemed to be at the meeting on 16 May 2022, that information may not be in the public domain. The results of the sensitivity scenarios presented showed a range of final void lake levels that warranted investigation of the effects of groundwater outflow from the final void. The GoldSim model sensitivity test results indicated an equilibrium lake level range of 579-584 mAHD (WRM 2022, section 7.11). The groundwater flow modelling sensitivity testing itself identified 579 mAHD as the lake level where the final void lake transitions from a terminal sink to a throughflow condition (Jacobs 2022, section 5.4.6, p. 5-337). These results indicated a reasonable potential for throughflow final void lake conditions to develop, which would result in outflow from the final void to the groundwater system, on a flowpath towards Hawkins Creek (ie. similar to that shown above in Figure 6 left frame). However, the groundwater model was not used to investigate the consequences of the discharge to Hawkins Creek of likely poor quality water.

There was inadequate assessment in the 2021 Submissions assessment of impacts that may arise from the final void throughflow conditions, and there was none at all in the 2022 Water Supply Amendment assessment, although this was partly addressed by the final void uncertainty analysis (Corkery 2022b).

Statements were made in the Jacobs (2021a) report (p. 5-337), but without supporting evidence, to suggest negligible impacts due to groundwater outflow from the final void lake. For example: '*Given the distance to Hawkins Creek coupled with the indicative travel times, and including allowance for dilution and attenuation of any seepage along the flow path, the degradation of water quality in Hawkins Creek or surrounding groundwater due to seepage from the final void is considered unlikely*.' There was no evidence presented on the source water quality in the final void lake (other than stock quality salinity of around 5000 µS/cm after 500 years, increased to 8500 µS/cm in Jacobs 2022), although it would be reasonable to expect some contaminant issues such as high metals concentrations. There was no analysis presented of dilution or attenuation processes along the seepage pathway, or of the effects at the creek receptor, that would adequately justify such a conclusion. This remains the case even after the final void uncertainty analysis (Corkery 2022b).

The final void uncertainty analysis (Corkery 2022b) has been conducted consistent with best practice methods, including the combination of Modflow groundwater modelling and

GoldSim water balance modelling. The results confirmed that there is a more than 50% chance of the final void lake level exceeding the 579mAHD throughflow threshold (see Figure 8 below, after Corkery et al. Fig.6). Adequate detail is provided on the assumptions, parameters and modelling methods, although the report could have been improved by the presentation of more results (eg. contour plans, pit lake water balance details). Particle tracks for other final void lake level scenarios should have been presented, such as the 65th percentile, noting that the 33rd-67th percentile range of outcomes are classified 'as likely as not' to occur; Middlemis and Peeters 2018, Table 2).

As discussed above, the subsequent feasibility assessment of extending the open pit area (Corkery 2022c) demonstrated the feasibility of that mitigation measure to develop a final void sink rather than throughflow conditions.

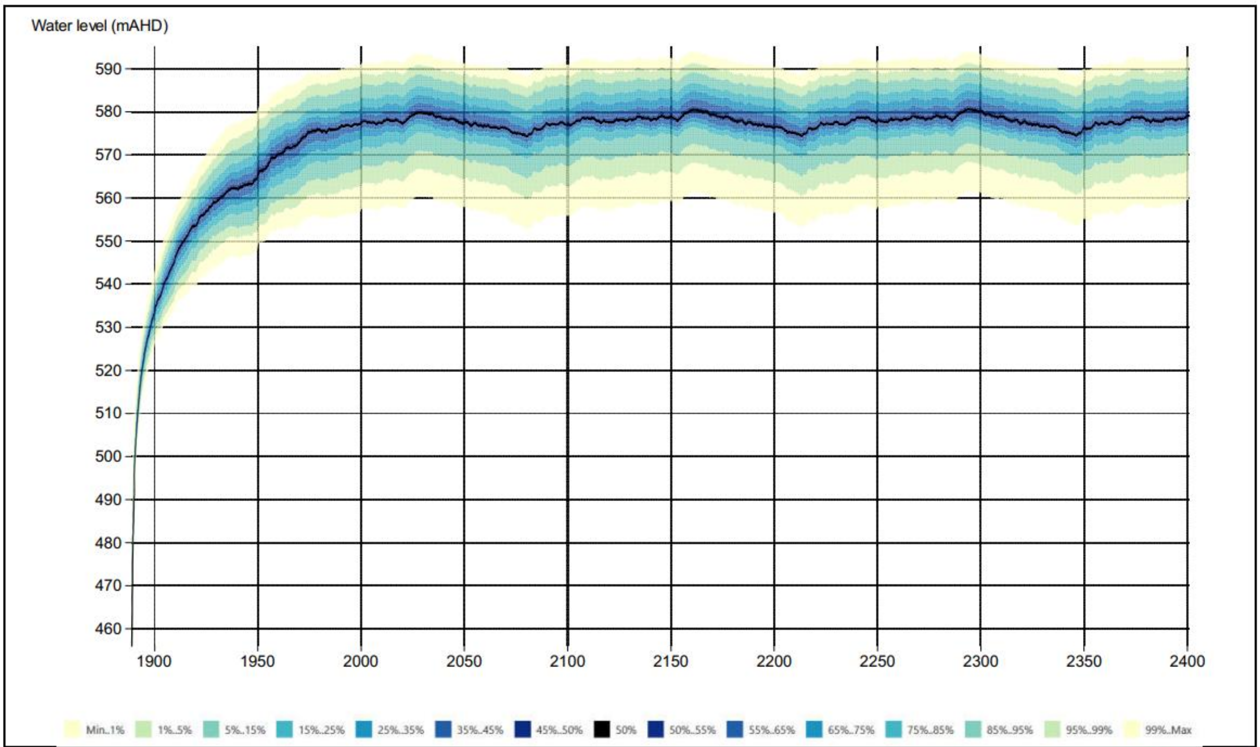


Figure 6
Results of Monte Carlo analysis – final void water level

Figure 8 - final void uncertainty analysis lake levels (after Corkery 2022b)

Particle tracking assessments (Corkery 2022b) showed the transport and fate of (unmitigated) outflows from the final void lake towards Hawkins Creek, and the effect of a mitigation treatment of a constructed wetland, based on a very unlikely 95th percentile (high) lake level of 589.3mAHD. The predicted particle tracks reach Hawkins Creek within a range of 100 to 1,000 years, depending on locations (it is not possible to be specific because the particle track plots do not show time markers, but they should).

This is a very unlikely or extreme scenario, and it is presumed that the intent was to demonstrate that the effects of a full pit void lake could be mitigated by a constructed wetland, but this argument was not clearly made. It would have been insightful for the particle tracking analysis to also present results for the 'as likely as not' scenario of the

65th percentile (Middlemis and Peeters, 2018, Table 2), which involves a pit lake level of around 585mAHD and thus throughflow conditions (>579mAHD).

Given the likelihood of (unmitigated) throughflow conditions, a detailed geochemical analysis of the final void lake water quality is warranted to establish the source concentrations for a source-pathway-receptor assessment of the transport and fate of potential outflow from the final void lake. Such assessment should use particle tracking and conservative and/or reactive 1D transport models as an initial investigation. Depending on the results of the initial investigation (eg. probability and magnitude of effects on Hawkins Creek), it may become necessary to conduct complex reactive transport simulations, and/or further uncertainty analysis.

Again, as the subsequent assessment (Corkery 2022c) demonstrated the mitigation feasibility of increasing the pit area to increase evaporation and thus to develop a final void sink rather than throughflow conditions, such complex assessments may not be warranted.

In the event that complex assessments of throughflow conditions may be required, best practice source-pathway-receptor impact assessment methods, such as the risk-based mining project methods of Howe et al. (2010) that were curated by the National Water Commission, should be applied. The first step is to establish the pit water quality source concentrations, as recommended in version 4 of this review report. It is worth noting that these source-pathway-receptor methods are consistent with the risk-based causal impact pathway aspects of the best practice groundwater modelling guidelines (Barnett et al. 2012) and the recent uncertainty analysis guidance (Middlemis et al. 2018 and 2019).

Assertions in versions 1 and 2 of this peer review report about the equilibrium extent of the mining drawdown impacts at around 50 years are incorrect, as pointed out by the Jacobs (2021c) response, and these are withdrawn, with apologies for my misinterpretation. Similarly, version 3 of this peer review report incorrectly listed (at section 3.3) hydraulic conductivity values in the 'outer mine area', which has been corrected in this version (4), pursuant to discussions at the meeting on 16 May 2022.

4. CONCLUSIONS

While this review finds that the Bowdens groundwater modelling has been conducted competently in general and is (overall) fit for the purpose of impact assessment, some aspects of its execution warrant improvement.

Despite such limitations, and noting the moderately low risk context (AIP level 1), the sensitivity analysis likely provides a reasonable indication of the groundwater-related impacts associated with mining operations.

For post-mining conditions, the final void uncertainty analysis (Corkery 2022b) addressed a significant study limitation and concluded that there is a more than 50% chance of the final void lake level exceeding the throughflow threshold of 579mAHD.

However, the subsequent assessment (Corkery 2022c) demonstrated the mitigation feasibility of increasing the pit area to increase evaporation and thus to develop a final void sink rather than throughflow conditions.

The model calibration performance ostensibly meets guideline criteria, and analysis of the details indicates reasonable calibration. This may be regarded as an acceptable basis for application of the model to impact assessments during the mining operations, given the moderately low risk setting (eg. consistent with uncertainty analysis principles; Middlemis and Peeters, 2018), in that, within the area of drawdown impacts:

- there are few existing groundwater users and AIP Level 1 impacts are predicted,
- there are no mapped high priority groundwater dependent ecosystems (GDEs),
- the terrestrial vegetation has been assessed as comprising non-obligate GDEs, and
- springs are assessed as largely perched-type systems mostly unaffected by water table drawdown.

Accepting the model performance as adequate for the moment, given the moderately low risk context for mining operations, the mine dewatering and the TSF simulations, and related sensitivity scenarios, appear to have been well designed and executed for the intended purposes. Noting that the outcome of the final void uncertainty analysis (Corkery 2022b) was somewhat surprising (>50% probability of final void lake throughflow), it would be prudent to conduct a similar highly parameterised uncertainty analysis for the mining period.

Ongoing monitoring and other investigations will provide additional data for future model refinements and improvements in performance and for comprehensive uncertainty analysis. Such progressive updates should, in turn, be used to guide future monitoring and management programs.

Issues with the adequacy of the documentation that do not appear to be fatal flaws technically were identified at the initial review stage, but have been largely adequately addressed in the Submissions report process (Jacobs 2021a), and the subsequent Water Supply Amendment report (Jacobs 2022). The exception is the inadequate justifications for the deviations to the regional geological layering that are apparent in the mine site area (discussed in section 3.3).

5. DECLARATIONS

For the record, the peer reviewer, Hugh Middlemis, is an independent consultant specialising in groundwater modelling. He has a degree in civil engineering and a master's degree in hydrology and hydrogeology, and more than 40 years' experience. Hugh was principal author of the first Australian groundwater modelling guidelines (Middlemis, Merrick et al. 2001) that formed the basis for the latest guidelines (Barnett et al. 2012) and was awarded a Churchill Fellowship in 2004 to benchmark groundwater modelling best practice. He is principal author on two recent guidance reports on modelling uncertainty (Middlemis and Peeters 2018; and Middlemis et al. 2019).

We assert no conflict of interest issues in relation to this work. Hugh Middlemis has not worked on the Bowdens Silver project or their consultants Corkery and Jacobs.

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Table 2 - Model Confidence Class Characteristics - Bowdens Silver Project (2022)

Model Confidence Class characteristics: Bowdens Silver project (2022)

Class		Data		Calibration		Prediction		Quantitative Indicators
1 (simple)		Not much / Sparse coverage		Not possible (not attempted in this case)		Timeframe >> Calibration		Predictive Timeframe >10x Calib'n.
	√	No metered usage (in local area)		Large error statistic.		Large stresses/periods.		Predictive Stresses >5x Calib'n.
		Low resolution topo DEM.		Inadequate data spread.		Poor/no verification.		Mass balance > 1% (or one-off <5%)
		Poor aquifer geometry.		Targets incompatible with model purpose.		Transient prediction but steady-state calibration.		Properties <> field values.
		Basic/Initial conceptualisation.						Poor performance stats / no review
2 (impact assessment)	√	Some data / OK coverage.	~	Weak seasonal match.	√	Predictive Timeframe > Calib'n.	~	Predictive Timeframe = 3-10x Calib'n.
	~	Some usage data (estimated).	~	Some long term trends wrong.		Different stresses &/or periods.	√	Predictive Stresses = 2-5x Calib'n.
	~	Some Baseflow estimates and some K & S measurements.	√	Partial performance (e.g. some stats / part record / model-measure offsets).	√	No verification but key simulations constrained by data	~	Mass balance < 1% (all periods) (OK at times reported; probably all time)
	~?	Some high res. topo DEM (minesite) and adequate aquifer geometry.	√	Head & Flux targets constrain calibration.	√	Calib. & prediction consistent (transient or steady-state).	~	Some properties maybe <> field values. (possible in frac. rock setting)
	√	Sound conceptualisation, reviewed & stress-tested.	~	Non-uniqueness, sensitivity and qualitative uncertainty addressed. (some aspects OK)	√	Magnitude & type of stresses outside range of calib'n stresses.	√	Some poor performance (but no coarse discretisation in key areas/times).
3 (complex simulator)	~	Plenty data, good coverage.	~	Good performance statistics (large range 446m)	x	Timeframe ~ Calibration	~	Predictive Timeframe <3x Calib'n. (OK except of course for post-mining)
	x	Good metered volumes (all users).	x	Most long term trends matched (some OK	~	Similar stresses &/or periods.	~	Predictive Stresses <2x Calib'n.
	~	Local climate data & baseflows.	x	Most seasonal matches OK (some OK).	x	Good verification or all simulations constrained by data	~	Mass balance < 0.5% (all periods) (probably; insufficient detail in report)
	~	Kh, Kv & Sy measurements from range of tests.	~	Calibration to present day head & flux targets.	NA	Steady state prediction only when calibration in steady state.	~	Properties ~ field measurements. (OK; complex frac. rock setting / EPM)
	x	High res. topo DEM all areas & good aquifer geometry.	x	Non-uniqueness minimised &/or parameter identifiability &/or minimum variance or RCS assessed.	√	Suitable computational methods applied & parameters are consistent with conceptualisation	x	No poor performance or coarse discretisation in key areas (grid/time). (inadequate detail in report to confirm)
	x	Mature conceptualisation.	~	Sensitivity &/or Qualitative Uncertainty	~	Quantitative uncertainty analysis	√	Review by experienced Hydro/Modeller.

(after Table 2-1 of AGMG (Barnett et al. 2012) and Figure 5 of IESC uncertainty guidance (Middlemis & Peeters 2018))

	Criterion met at higher Class
~	Criterion partially met at relevant Class
√	Criterion met at the relevant Class
x	Criterion not met by current model study