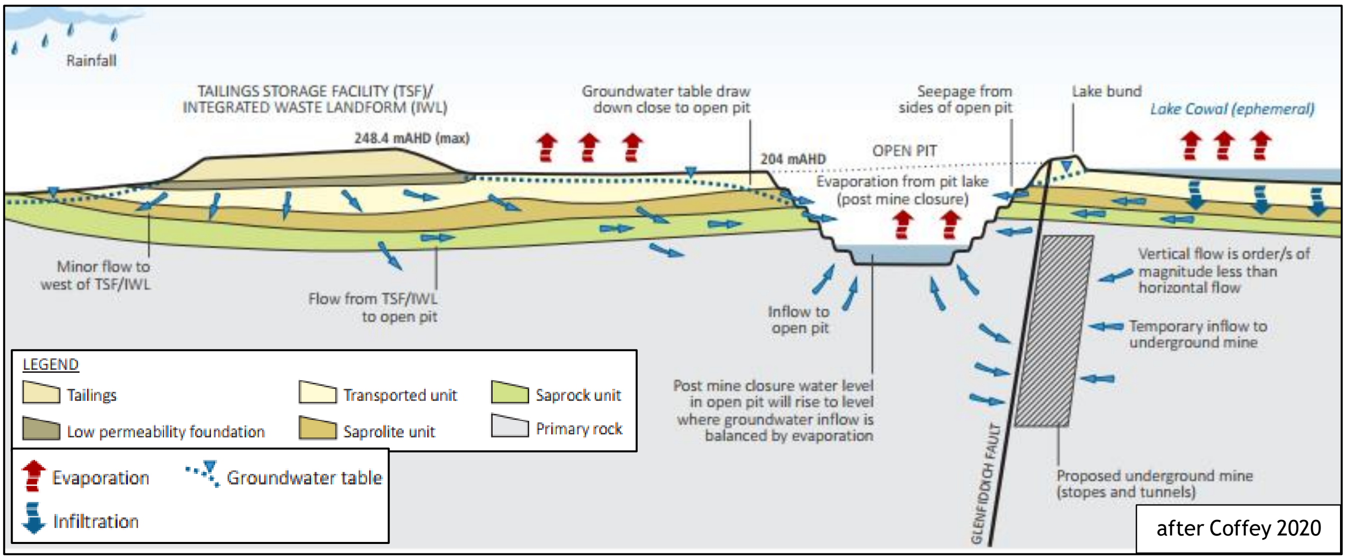
Cowal Gold Underground Development Groundwater Assessment Peer Review

Prepared for:	NSW Department of Planning Industry and Environment	20 May 2021 (Final Review)



after Coffey 2020

HydroGeoLogic

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

CONTENTS

HydroGeoLogic

Prepared by:	HydroGeoLogic Pty Ltd (ABN 51 877 660 235). PO Box 383, Highgate, 5063, South Australia. Author: Hugh Middlemis email: hugh@hydrogeologic.com.au mobile: 0438 983 005	
Version 1	9 December 2020	Initial draft
Version 2	10 December 2020	Final version of Initial Review
Version 3	20 May 2021	Final Review, considering Responses to Submissions

THIS REPORT SHOULD BE CITED/ATTRIBUTED AS:

Middlemis H (2021). Cowal Gold Underground Development Groundwater Assessment Peer Review (Final). Prepared by HydroGeoLogic for NSW Department of Planning, Industry and Environment. 20 May 2021.

1. Introduction

1.1 Cowal Gold Operations Underground Development

Cowal Gold Operations (CGO) is an existing open cut gold mine, owned and operated by Evolution Mining. It is sited on the western shore of the ephemeral Lake Cowal, between West Wyalong and Forbes in the Central West Region of New South Wales (Figure 1).

CGO has been operating since 2005, including two water supply borefields to the north-east of Lake Cowal. CGO is now seeking development consent for the construction and operation of an underground mine at the site (Figure 1). This review considers the groundwater assessments of the mine site and the borefields.

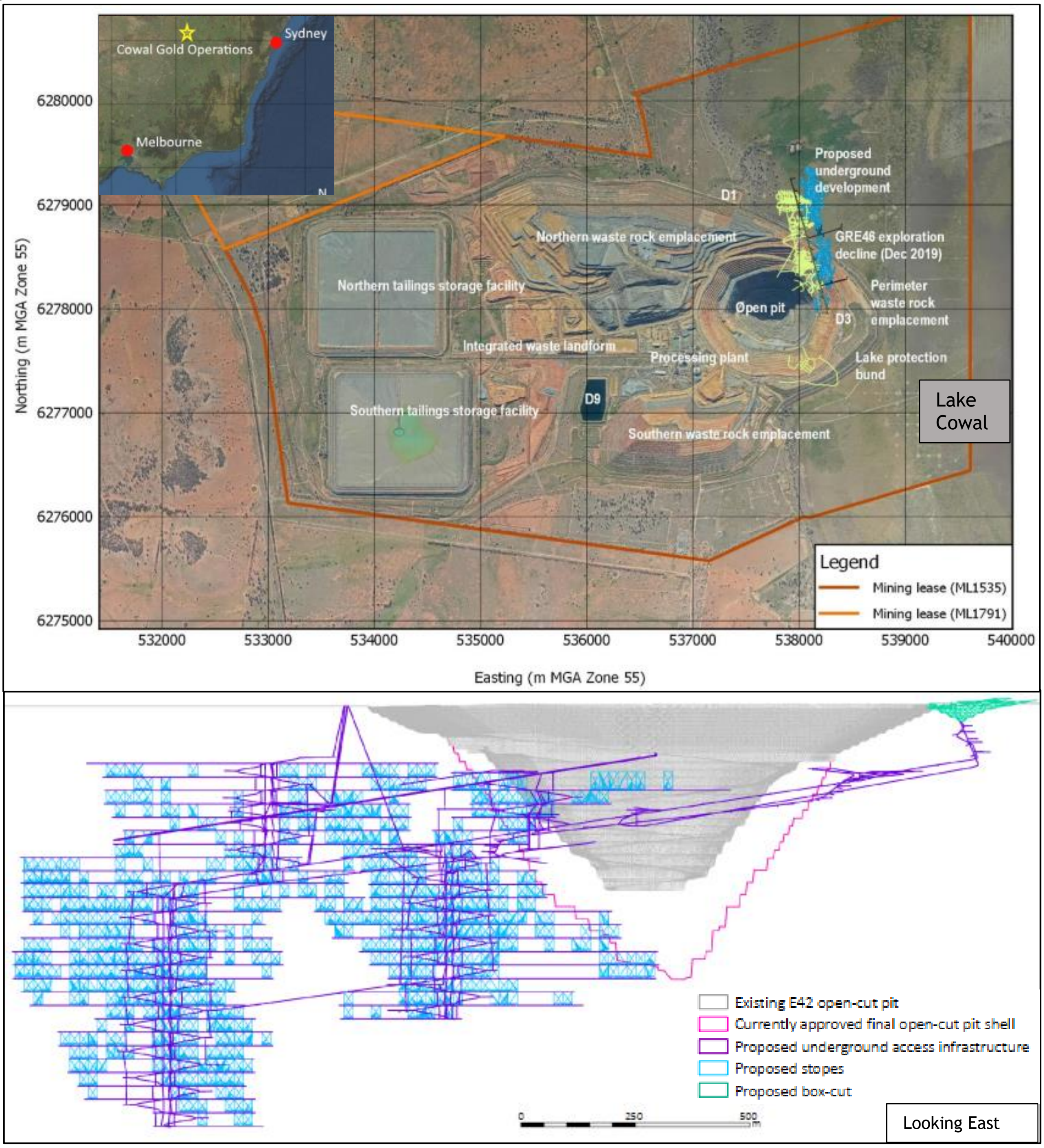


Figure 1 CGO location, open cut mine site and proposed underground (after Coffey 2020)

1.2 Peer Review Methodology

This report presents the findings of an independent peer review of the groundwater and modelling investigations that form the quantitative basis for the proposed CGO Underground development groundwater assessment (Coffey 2020a), and related borefields assessment (Coffey 2020b). The two groundwater assessment reports support the Environmental Impact Statement for the proposed CGO Underground development (EMM Consulting, 2020).

This independent review forms advice to the NSW Department of Planning, Industry and Environment (DPIE) on whether the groundwater assessments are supported by the evidence presented, and/or whether additional information, monitoring, assessment and/or modelling may be required to inform the assessment.

The best practice principles and procedures of the Australian Groundwater Modelling Guideline (Barnett et al. 2012) were applied to conduct this review, 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, regarding coal mines and CSG; and Middlemis et al. 2019, which is more generally applicable and actually was the basis for the former). A key principle in these guidelines is that assumptions and simplifications should be justified and clearly reported in an open manner that is amenable to review.

This desktop review was conducted mainly in November-December 2020 by Hugh Middlemis of HydroGeoLogic; brief bio information is provided in section 4. A video conference discussion on 25 November 2020 was facilitated by the DPIE with representatives from CGO, and their consultants Coffey (groundwater) and EMM (EIS), essentially as a Q&A session to provide the opportunity for Coffey to clarify several issues of detail. Two subsequent video conference discussions were held during 2021:

- 2 February 2021, to discuss the DPIE Water advice dated 22 January 2021;
- 30 March 2021, to discuss the proponent's Submissions Report (EMM 2021a), which included responses to the DPIE Water advice of 22 January (Coffey 2021).

1.3 Evidentiary Basis

The main evidentiary basis for this peer review is the mine site groundwater assessment report (listed as Appendix F to the EIS; EMM 2020), and the related borefields groundwater assessment report (listed as 'accompanying the mine site assessment'):

- Coffey (2020a). Cowal Gold Underground Development, Mine Site Hydrogeological Assessment. Prepared for EMM Consulting / Evolution Mining, 10 September 2020
- Coffey (2020b). Cowal Gold Operations Underground EIS, Bland Creek Palaeochannel Borefield and Eastern Saline Borefield Groundwater Assessment. Prepared for EMM Consulting / Evolution Mining, 27 August 2020.

Other reports on the CGO assessment were considered notably:

- EIS report (EMM 2020), providing an overview of the project and its assessment.

- Appendix G Surface Water Assessment (HEC 2020), mainly in relation to the post-mining final void lake water balance modelling.
- DPIE Water advice letters to DPIE (22 January and 29 April, 2021);
- EMM (2021a), the Proponent's Submissions Report (26 February 2021);
- Coffey (2021), the response to residual issues raised by DPIE Water (8 April 2021);
    - includes two Addenda prepared by EMM (EMM 2021b,c).

Some reports from the previous impact assessments were also considered, notably in relation to the final void investigations (see section 2.6 for details).

2. Discussion

2.1 Model Confidence Level Classification

The Australian Groundwater Modelling Guidelines (Barnett et al. 2012) present a schema for model confidence level classification. The schema is 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 groundwater assessment reports claim a Class 2 model confidence level classification, with some aspects of Class 3, for both the Cowal Gold mine site model (Coffey 2020a) and the related borefields model (Coffey 2020b). This peer review concurs with that assessment, confirming the models as fit for purpose in principle, and suitable for impact assessment scenario modelling purposes.

2.2 Fitness for Purpose

Both assessment reports provide reasonable explanations for the conceptual model and the numerical model design and execution. For some details, however, the reader must refer back to previous assessment reports. While this is not a fatal flaw as such, best practice does recommend that reports are as self-contained as possible.

The mine site assessment report (Coffey 2020a) is not as well-written as the borefields model report (Coffey 2020b), and the mine site report documentation was initially assessed as lacking adequate detail on several specific issues. However, the facilitated discussion on 25 November 2020 allowed Coffey representatives to present further information. The initial review (Middlemis 2020) recommended that the proponent provide improved documentation, and this was indeed provided in the responses to submissions (EMM 2021a,b,c and Coffey 2021).

The conceptualisation basis for both models is sound, based on a range of investigations over many years, and has generally been implemented aptly in the models. The 3D model domain, layer setup, grid design, boundary conditions and parameters applied to both models are generally consistent with the available information and conceptualisation, with some exceptions identified below in parts of sections 2.3, 2.4, 2.5 and 2.6.

The FEFLOW software applied to the mine site assessment is up-to-date. While the MODFLOW-2000 software applied to the borefields model is not the latest version of that industry-leading platform, it does have suitable capability. Although it is not specifically stated in the report, it is presumed that the MODFLOW-2000 software was adopted for the latest borefields modelling (Coffey 2020b) because the 2020 modelling program was essentially a verification of the calibration performance of the previous borefields model (Coffey 2013), rather than an updated calibration as such, which would typically involve parameter changes. There is more discussion on this topic in section 2.3.1 below.

The model calibration performance is adequate statistically in each case, with performance benchmarked against operational mine dewatering and water supply borefield extractions, and related aquifer responses. The time series matches to monitoring data are mostly good to adequate, and the simulated groundwater flow patterns reflect the hydrogeological conceptualisation.

The groundwater assessments are fit for purpose in principle, with some corrective action subsequently provided on the mine site assessment.

2.3 Calibration, Prediction and Uncertainties

The borefields assessment is discussed before the mine site assessment because this review has not identified any major issues with the borefields assessment that warranted corrective action.

2.3.1 Borefields Model

Coffey (2020b) reports on the 3-layer numerical groundwater flow model used for the assessment of the Bland Creek Palaeochannel Borefield (BCPB) and Eastern Saline Borefield (ESB) located north-east of Lake Cowal and CGO (Figure 2).

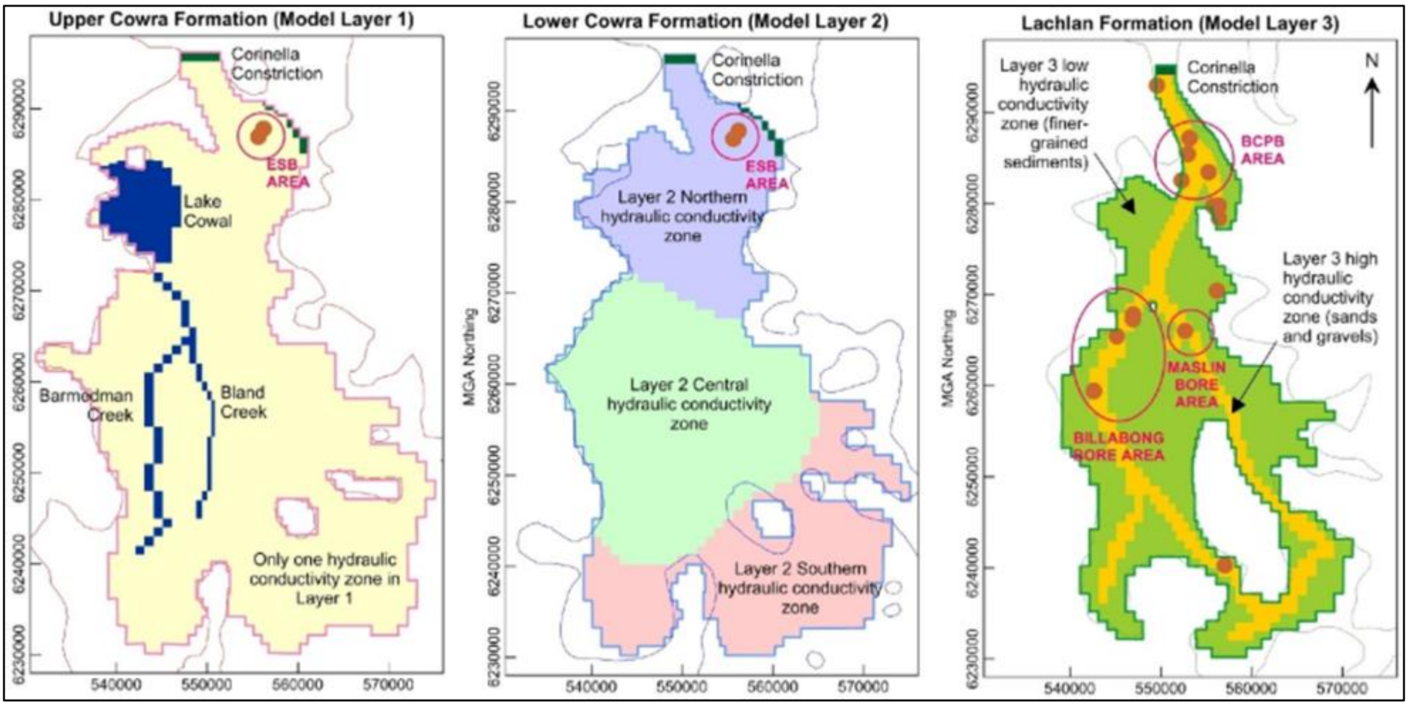


Figure 2 - Bland Creek Palaeochannel Borefield model (after Coffey 2020b)

The borefields model includes extractions for irrigation, stock and domestic, and industrial purposes in the BCPB/ESB areas, as well as in the Billabong and Maslin areas south-east of CGO. While the borefields model includes Lake Cowal and extends west to the CGO mine site (Figure 2), it does not include mine site extractions. This appears to be justified in principle, in that the deep Lachlan Formation (layer 3) that is the focus of most of the borefields extractions does not extend to the mine site. The overlying Lower Cowra Formation (layer 2), which shows significant drawdown responses for borefields extraction, has a western 'embayment' that aligns roughly with the eastern edge of the CGO lake bund. Overlying that in the borefields model is the shallow Upper Cowra Formation (layer 1), with a western 'embayment' extending across the open pit area, but not as far as the tailings storage facilities.

There are inconsistencies between the borefields model and the mine site model in the treatment of the Upper Cowra Formation at the mine site, which is discussed further in section 2.4. These issues were adequately addressed by the response to submissions (eg. Addendum 1, item 7; EMM 2021b). In principle, the significant drawdown in the Upper Cowra Formation at the CGO mine site should ideally be included in the borefields model, even though it is predicted not to extend beyond the mine lease area. Despite the inconsistencies, the borefields model is assessed as fit for purpose in and of itself, based on the following findings.

The 2020 borefield modelling program was effectively a verification of the calibration performance of the previous borefields model (Coffey 2013), rather than an updated calibration as such. This means that the model parameters were not changed, but new model input data was added for the period up to 2020 in terms of rainfall (recharge) and extractions. For some private bores, there is no recorded data on the extraction volumes, which required assumptions to be made, and thus the latest model performance is somewhat reduced compared to previous assessments.

Nevertheless, the borefields model has an adequate history match calibration to the data record 2006-2020, good water balance performance, and aquifer parameters that are adequately benchmarked, confirming the model as a suitable predictive tool. Model calibration performance is acceptable at 9.2% sRMS (all bores/times), which is within the guideline statistical criterion of 5-10% scaled RMS (Barnett et al. 2012).

The time series plots (Appendix G to Coffey 2020b) show generally good agreement between modelled and measured groundwater levels, with reasonable justifications provided for the few exceptions. Discrepancies between measured and modelled water levels at key bores were used to estimate an offset to the trigger level, to facilitate assessment of compliance with an offset trigger that accounts for the less than ideal model performance. This is essentially consistent with the best practice principle that differences between model scenarios can involve reduced uncertainty compared to predictions of groundwater levels in absolute value terms (Barnett et al. 2012).

A limited assessment of deterministic uncertainty identified that the model predictions are more sensitive to the private bore pumping rates than key parameter values (Cowra Formation Kz and Lachlan Formation Kh), which points to a data uncertainty rather than a model uncertainty as such. More comprehensive uncertainty analysis is recommended in future modelling programs.

2.3.2 Mine Site Model

The mine site model has a sound and mature conceptual basis (Figure 3). The mine site model shows a good history match calibration to the data record 2004-2020, and aquifer parameters that are adequately benchmarked to what amounts to a very wide range of parameter values, although there are issues with the model water balance (discussed further below). This suggests that the model may be affected by model non-uniqueness (the principle that multiple combinations of parameters may be equally good at fitting historical measurements). This implies low to medium confidence in the results as presented, as the uncertainty assessment conducted is somewhat limited. A comprehensive uncertainty assessment would improve confidence.

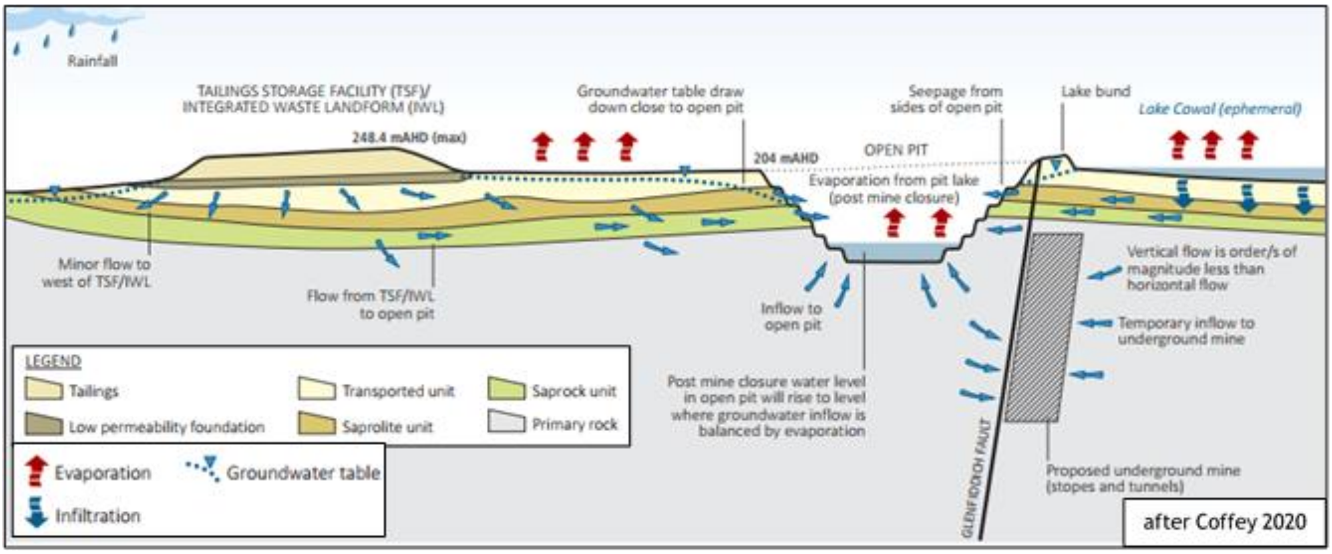


Figure 3 - CGO mine site conceptual model (after Coffey 2020a)

2.3.2.1 Water Balance Issues

A key criterion for model performance is to ensure that the water balance error term is maintained below 1% (Barnett et al. 2012). While the mine site model performance for the history match period water balance is adequate (<1%), the prediction period water balance performance is poor, with a 1% to 3% water balance error term post-2038 (Coffey 2020a, Figure 8-16). At the facilitated discussion on 25 November, Coffey representatives indicated that further model calibration updates had been conducted and the water balance error term is now well below 1% for all simulations. The proponent subsequently provided appropriate documentation on the updated model calibration and prediction results via an addendum to the response to submissions report (EMM 2021b, item 1).

2.3.2.2 Calibration Performance

Noting that the water balance error term for the model calibration history match period is acceptable (less than the 1% criterion), the calibration performance is also otherwise acceptable in terms of being within the guideline statistical criterion of 5-10% scaled RMS. The transient history match simulation 2004-2020 achieved an sRMS of 4.5%. The time series plots (Appendix B to Coffey 2020a) also show good agreement between modelled and measured groundwater levels, with reasonable justifications provided for the few exceptions. However, some bores near the eastern edge of the lease (GW704031, GW704252, GW703223, GW703225, shown in Figure 6-7 of Coffey (2020a)), appeared to have been excluded from assessment. The proponent subsequently confirmed that no data is available for these bores (EMM 2021b, item 2). Consequently, this review supports the DPIE Water recommendation (29 April 2021) for the installation of at least two monitoring bores in this area, and for the validation of model performance at year 2 of mining, and at subsequent at 5-year intervals.

2.3.2.3 Open Pit Inflows

The modelled open pit 'groundwater inflow' rates are typically around 0.8-1.0 ML/day (red line in Figure 4, next page), and are adequately consistent with the reported volumes during low rainfall periods (yellow shapes in Figure 4), such as 2018-2020. The report (Coffey 2020a) shows that the recorded pit dewatering volumes are quite variable (green line in Figure 4), ranging from around 1 ML/day or less during low rainfall periods, up to 8 ML/day during very wet periods (eg. 2010-2012, 2014, 2016).

The report suggests erroneously that recorded pit dewatering does not correlate well with rainfall, as it is clear from Figure 4 that pit dewatering historically increased greatly during wet periods, typically by a factor of 4 or 5 times, and sometimes up to 8 times. The response to submissions (EMM 2021b, item 4) provides a reasoned clarification that groundwater inflows are less variable than pit dewatering rates, and it is inflows that do not correlate strongly with rainfall.

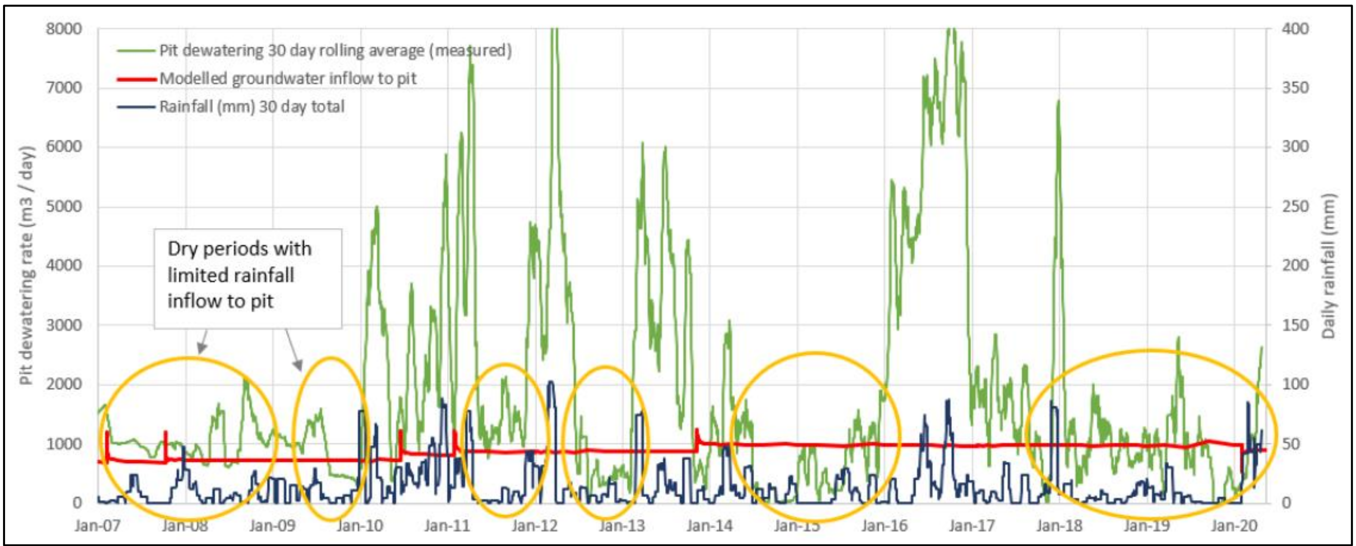


Figure 4 - pit dewatering and rainfall (after Coffey 2020a, Figure 8-18)

It is not clearly stated in the mine site assessment report what are the underlying processes driving this variability. For example, the report states that '*Groundwater seepage into the open pit, groundwater flows from in-pit horizontal drains, and rainfall runoff in the pit are directed to pit sumps [reviewer emphasis] before being pumped to water storage dams.*'

However, the (Coffey 2020a) report indicates that open pit dewatering is modelled by:

- pumping from vertical dewatering bores and from sumps,
- specified head boundary conditions applied to the pit floor,
- seepage face boundary conditions ('drain features') applied to the pit walls,
- seepage faces also applied to horizontal drains.

The report does not explain whether the modelled 'groundwater inflow to the pit' (Figure 4 above) represents some or all of those dewatering features, or what proportion is formed by rainfall runoff during high rainfall periods. Related descriptions such as at sections 8.3 and 10.3 of Coffey (2020a) suggest somewhat unusual parameter adjustment methods, but the explanations are largely incomprehensible and warrant a rewrite.

As requested at the initial review stage, the proponent subsequently provided further detail on the components of 'groundwater inflow to the pit' in the response to submissions reports (EMM 2021a, section 4.1.1), and also in Addendum 1 (EMM 2021b, item 3) and Addendum 2 (EMM 2021c, sections 4.1 and 4.9.6), which also provided at item 4 a cogent explanation as why it is acceptable for the model to be benchmarked to 'groundwater inflows' only during dry periods.

2.3.2.4 Lake Cowal

A time-varying specified head boundary condition was applied to Lake Cowal, based largely on the recorded lake water level, which is fine in principle. However, during extended dry periods, the specified head is up to 1.5 metres below the lake bed, with inadequate explanation provided in the report (Coffey 2020a, section 8.1.2.4). At the facilitated discussion on 25 November 2020, representatives from Coffey suggested that this feature represents potential leakage not only from Lake Cowal when it holds water, but also from the partially saturated sediments under Lake Cowal when it is empty, again fine in principle. Model predictions are shown to be not sensitive to lake full or empty scenarios, and while inadequate explanations were initially provided in the EIS reports, it is presumed that a key reason is the very low hydraulic conductivity value applied to the Upper Cowal Formation (more discussion on this in section 2.4 below). The Hydrogeological Assessment report (Coffey 2020a) provides some justification in terms of observations from the mine site that mine inflows reportedly do not vary markedly whether the lake is full or empty. However, inadequate detail was initially reported in terms of modelled leakage volumes from the lake during wet and dry periods, in terms of pit dewatering components (previous section), and in terms of model performance at the bores on the eastern side of the mine lease area (eg. section 2.3.2.2). In response to initial review stage recommendations, the proponent provided detailed information on these aspects in the response to submission reports, notably in Addendum 2 (item 4.9.4 of EMM 2021c) and also in Addendum 1 (EMM 2021b, item 3).

On a related matter, this review considers that the model features for Lake Cowal have been adequately designed and executed, which appears to differ from the initial DPIE Water advice (January 2021). This review interprets the view from DPIE Water as suggesting that there should be some significant relationship between the lake and the mine inflows, although evidence to date indicates that the flux exchanges involved are minor in relation to the mine dewatering volume history and very minor indeed in relation to the lake water balance. The groundwater assessment reports provided adequate documentation on Lake Cowal processes, which are dominated by inputs from surface runoff and stream flow, and outputs from evaporation. Details on these processes are presented in the original EIS assessment reports (notably section 6.7 of Coffey 2020a, and related section 4.3 of the BCPB report, Appendix F to the EIS). The details provided demonstrate that the water level recession from a full lake is consistent with evaporation once the lake is below the spill level and that there is a lack of significant mine dewatering response to lake full conditions. Additional comments are provided on page 9 of the Coffey response to residual issues (Coffey 2021), and in sections 4.1.2 and 4.9.4 of the related Addendum 2 (EMM 2021c). Hence the model scenario setup with a lake full or empty condition is appropriate for the impact assessment.

2.3.2.5 Sensitivity and Uncertainty

A basic parameter sensitivity analysis was conducted in relation to the key parameters of horizontal and vertical hydraulic conductivity (Kh and Kz) and the specific storage (Ss) for the four main mine site units of the Transported, Saprolite, Saprock and Primary Rock, showing roughly equal sensitivity.

The mine site assessment report (Coffey 2020a) is a little difficult to understand at times, but it is understood that the subsequent uncertainty analysis used a set of 690 parameter realisations to identify four sets of model parameters that constrain the model simulations to meet criteria for maximum or minimum mine inflows, or to the groundwater level at UG-BH-02 near the proposed underground. Other sensitivity/uncertainty scenarios were simulated, including assuming a full or empty Lake Cowal, increasing the Kh and Kz of the Transported unit underlying Lake Cowal by a factor 10, and also applying a factor of 10 to the Primary Rock unit Kh and Kz in the area of the underground stopes to investigate enhanced fracturing. The predictive uncertainty simulation results do not indicate high sensitivity, in that the drawdown extent is predicted to be limited largely to the lease area, and the underground mine inflows are predicted to increase from around 1 ML/day to 2.8 ML/day up to 2039, with an uncertainty range of 1.65 to 3.4 ML/day (Coffey 2020a, Figures 10-6, 10-7).

The Coffey (2020a) report contains arithmetical errors when discussing:

- the specific storage parameter calculation to represent the paste-backfilled stopes and tunnels (report section 9.1.8).
- the maximum rate of inflow as 100,000 times less than the estimated evaporation from Lake Cowal (report section 10.5); in fact, the ratio is about 200 times.

Neither error was considered at the initial review stage to materially affect the predictions, and the subsequent response to submissions report addressed the issue and confirmed low sensitivity in model results, including revised post-mining simulation scenarios (EMM 2021a, section 5).

2.3.2.6 Contaminant Migration

The contaminant migration simulations appear to have been conducted competently, but the results were not considered reliable at the initial review stage until corrective actions to the flow model were implemented. The response to submissions report (EMM 2021a) confirmed that appropriate corrective action had been taken and the results showed low sensitivity, as expected.

2.3.2.7 Summary

At the initial review stage, the mine site model was considered to be nominally fit for purpose, but the mine site groundwater assessment was described as providing only an indicative (low confidence) prediction of the likely groundwater impacts.

Corrective action was subsequently implemented by the proponent and their specialist consultants to address the mine site assessment issues raised above, and adequate documentation was provided via the responses to submissions (EMM 2021a, Coffey 2021, EMM 2021b,c).

2.4 Inconsistencies between Borefields and Mine Site Models

The shallow Upper Cowra Formation, which is extensive across the borefields model (Figure 2 above), has a lateral equivalent in the Transported unit, which extends '*over most of the CGO mine site and surrounding area*' (Coffey 2020a) (see also Figure 3 above). The reports provide consistent lithological descriptions for the Upper Cowra Formation and the Transported unit. For example, the Upper Cowra is described as '*isolated sand and gravel lenses in predominantly silt and clay alluvial deposits*', while the Transported unit is described as '*thick clay sequences and more permeable zones of gravel within a sandy clay matrix*'.

The other lithological units at the mine site relate to the deep Primary Rock unit and its overlying weathering products of the Saprock and Saprolite. The Saprock and Saprolite are not directly relevant to the borefields model, although including them could be accomplished with the existing borefields model layer structure, which may allow for an assessment of cumulative impacts (see also section 2.5 below).

However, there are inconsistencies between the two models in relation to the Upper Cowra unit having a more limited westwards extent over the CGO site area in the borefields model, and it having quite different values for its key properties (horizontal hydraulic conductivity Kh, and unconfined specific yield Sy), as shown in Table 1.

Table 1 - Upper Cowra Formation parameter inconsistencies

	Kh (m/d)	**Sy**
Borefields Model	1.0	0.04
Mine Site Model	0.02	0.2
Ratio of Borefields to Mine Site value	50x	1/5th

A related parameter inconsistency issue is that the Upper Cowra Kh value in the mine site model is 50 times smaller than the Kh value in the borefields model, while the Sy value is 5 times larger in the mine site model than the borefields model. This parameter inconsistency means that a cumulative impact assessment is problematic.

Some basic concepts are worth noting at this stage. In simple terms, the unconfined specific yield (Sy) property describes volumetric drainage under gravity with values typically in the order of 0.01 to 0.2, and it is a key factor in mine dewatering. In comparison, the confined specific storage (Ss) property governs the water released from elastic storage (related to the very low compressibility of water and of the aquifer skeleton). This means that Ss has values of around 10^{-7} to 10^{-5} m^{-1}, which is many orders of magnitude lower than Sy. The lower volumes released from elastic storage usually renders Ss not critical to mine dewatering. This issue becomes important also to the discussion on the post-mining simulations (section 2.6).

The Sy is considered to be equivalent to effective porosity for most lithologies except clay. In a simple and practical sense, porosity is the proportion of the void volume that contributes to percolation or drainage under gravity (Spitz and Moreno 1996). Aquifer units with low hydraulic conductivity (Kh) are also likely to have low Sy in practical terms due to their common fundamental dependence on porosity, although clay formations can complicate matters in theory. Perversely, clays have a low Kh but high total porosity, and yet clays also have a low Sy due to their very poorly interconnected pore structure and the molecular attraction of water to clay minerals. This means that they retain moisture rather than allowing it to drain under gravity. In a practical sense, if a unit has a low Kh (mine site Transported unit), it is also likely to have a low Sy, which is not the case here (Table 1).

In summary, there is no physically realistic justification for such an inconsistency between the models. While assuming a high value for Sy in the mine site model could be argued as being conservative in terms of over-predicting dewatering volumes, it could also be argued from hydrogeological principles that such an assumption may limit the lateral extent of drawdown. Such issues of potential bias are not explored in the assessment reports, although best practice suggests otherwise (Middlemis et al. 2019).

Notwithstanding the inconsistency issue between the two models, the borefield model design, performance and predictions are assessed as fit for purpose. Given that a range of corrective actions were recommended for the mine site model, the initial review suggested that any adjustments of parameter values, such as may be warranted to rationalise parameter values and allow for an assessment of cumulative impacts (borefields plus mining) as further discussed below, should probably be applied to the mine site model, but that is entirely up to the proponent and their consultant. In any event, these issues were adequately addressed in the response to submissions reports (EMM 2021a, pp.79-84, and EMM 2021b, item 7).

2.5 Cumulative Impacts

The borefields model (Coffey 2020b) extends part way across the mine site and includes part of the shallow Upper Cowal Formation / Transported unit, but it does not include the effects of mine dewatering extractions.

The CGO mine site model (Coffey 2020a) does not extend as far as the BCPB and the ESB centres of extraction, nor to the south to the Billabong and Maslin centres of extraction. This means that the mine site model also does not (cannot) assess the cumulative impacts of borefield extractions.

Although neither the CGO mine site nor the borefields modelling assessments evaluated the cumulative impact effects, it is possible (barely) to infer from the reports that including those effects would not materially change the impact predictions, notwithstanding the parameter inconsistency issues. While it is clear that the mine site drawdown is mostly constrained to the lease area, the borefields model water level contour plots are at a scale and contour interval that is not helpful for detailed interpretation.

It would have been helpful for the assessment to prepare some figures to show the indicative cumulative impacts on the water table drawdown by simply applying the hydrogeological principle of superposition and adding the predicted impacts using GIS methods. Even so, that would arguably not be definitive, given the hydrogeological structure and the model inconsistencies (see also section 2.4). A definitive assessment would necessarily involve a model that integrates the mine site hydrogeology and stresses with the palaeochannel system and borefields hydrogeology and stresses.

However, based on the results presented, this reviewer believes that the effort required for integrated modelling may not be commensurate with the groundwater-related risks and uncertainties predicted for the proposed development. Nevertheless, it was recommended at the initial review stage that the proponent provide an objective assessment of the magnitude and extent of cumulative drawdown impacts (mining and borefields). Adequate information was indeed subsequently provided in the response to submissions reports (EMM 2021a, pp. 84-85; EMM 2021b item 8).

2.6 Post-Mining Final Void

2.6.1 Final Void Lake

It is understood that the existing CGO approval allows for a post-mining final void lake. The CGO Underground assessment (Coffey 2020a) includes a final void lake, along with paste backfill to the underground voids.

The post-mining modelling has been conducted generally consistent with best practice, although the mine site assessment report (Coffey 2020a) included some arithmetical errors in the volumetric calculations at section 9.1.8 regarding the specific storage parameter for the backfilled underground voids. A related issue is that the head range used in the Ss calculation was specified as from -300 to 120 mAHD, whereas the base of stopes extend from about -700 to about 150 mAHD. These issues were discussed and clarified at the facilitated meeting on 25 November 2020, when it was suggested that applying the correct parameter values would likely not materially change the predictions.

An issue not discussed on 25 November was about the FEFLOW model setup for the post-mining aquifer recovery simulations, in terms of whether the flow system was set up as saturated or unsaturated. It appears from the narrative at sections 9.1.8 and 8.1.1.2 (Coffey 2020a) that a confined/saturated setup may have been applied to the Primary Rock layers, in which case the questionable paste backfill Ss parameter has governed the recovery of groundwater levels, at least as high as the base of the open pit. The question remained as to whether the recovery simulation started from the base of the underground dewatered stopes at around -700 mAHD, as this could be confirmed from the report at the EIS stage (Coffey 2020a). From the base of the open pit, it appears from the narrative relating to Figure 9-2 of Coffey (2020a) that specified levels were applied to represent the final pit void lake level, based on iterative water balance modelling between the groundwater and surface water teams. This is arguably consistent with best practice, as discussed further below.

The initial review recommended action to correct the backfilled underground void properties arithmetical errors and provide detailed documentation on implications for the post-mining predictions. The arithmetical error was addressed in the response to submissions reports, along with the other technical issues raised, and the Ss value sensitivity was further tested, confirming low sensitivity in the results (EMM 2021a, pp.75-78; EMM 2021b item 5).

2.6.2 Final Void Water Balance and Salinity

The post-mining final void prediction and assessments methodology is based on water balance modelling (HEC 2020). It used output from the groundwater model on the relationship between lake level and inflow rates to the final void. That was combined with a 131-year rainfall dataset (1889-2020) to simulate runoff from catchments contributing to the final void lake, and reasonable assumptions for evaporation from the final void lake. The results indicate a long term final void lake and terminal groundwater sink at a level of about 148.6 mAHD (about 60 metres below spill level), which is understood to be basically consistent with the parameters for the existing approvals.

This review finds that, notwithstanding the modelling issues discussed herein, and particularly the underground backfill issue discussed in section 2.6.1, which was subsequently addressed, the 2020 post-mining final void water balance assessment has otherwise been conducted consistent with best practice.

The final void water quality aspect, however, was assessed as inadequate by the initial review, in that the report (Coffey 2020a) indicates only that salinity '*is predicted to increase trending to hyper-salinity in the very long term*.' It did not quantify what is the value of hyper-salinity, nor what time frame is predicted, nor the rate of trend, nor indeed whether there is a long term stable value for the final void lake salinity. The assessment has not reported on what other hydrochemical processes may be expected, nor indicated what will be the long term hydrochemical character of the final void lake.

However, previous assessments have provided more detailed information that could be deemed adequate. For example, the 1997 water management study (Gilbert and Sutherland 1997) estimated that the long term pit lake water level would be around 180 mAHD, or 22-24 metres below the full storage, and that it would take about 114 years post-mining to achieve a pit lake salinity of 62,000 mg/L, which is around double the ambient groundwater salinity. The 1997 assessment (Resource Strategies 1997) did not project further on the trend towards hypersalinity, other than to indicate that it would take hundreds of years. It indicated that geochemical studies concluded that '*the void water quality would not be acid due to the characteristics of the wall rocks and would be dominated by the overriding influence of saline groundwater to the void*.' The 1997 assessment also indicated that it was '*likely that the final void will support salt tolerant species of phytoplankton similar to those found in Australia's natural salt lakes*', and '*specialised macrophytes may establish around the voids edges*', or '*may require introduction to the void from other regions (eg. natural salt lakes)*'.

The response to submissions report provided some justification on the adequacy of the previous assessments (EMM 2021a, pp.85-86; EMM 2021b item 9).

2.6.3 Final Void Sustainability Issues

Finally, and without seeking to challenge existing approvals, this reviewer outlines below some post-mining groundwater issues that may be worthy of consideration by DPIE.

Best practice mine water management suggests that reduced long term risks to water resources could be achieved by backfilling the pit to the pre-mining groundwater level to minimise final void lake evaporation and salinisation impacts, subject to careful evaluation of potential leachate risks, along with consideration of community views (Johnson and Wright, 2003; Younger and Wolkersdorfer, 2004).

While some international standards (eg. current South African legislation) require that pit lakes should be backfilled for the mine to achieve closure, this is can involve considerable financial liabilities, in comparison to environmentally stable pit lakes that can offer a sustainable closure option and may avoid the expense of continual water treatment (Johnstone 2019; McCullough et al. 2013).

These issues, and related uncertainties, do not appear to have been adequately explored to identify optimal closure options for the CGO underground development, and few details are provided to justify the position in environmental management terms for protecting regional groundwater environments from leachate risks, unless the previous assessments are considered to have addressed those issues adequately in relation to the latest CGO Underground proposal details.

In any case, the CGO mine site model is suitable for scenario modelling to investigate a range of closure options for the final void (from partial to total backfilling to none), to identify an optimum scenario to minimise risks to groundwater, and to evaluate how those predictions are affected by uncertainties. The model could be applied to investigate closure options in order to provide quantitative information to justify the closure plans and to support decisions on licensing.

3. Conclusion and Recommendations

The CGO borefields groundwater modelling and assessment (Coffey 2020b) has been conducted consistent with best practice and is fit for the purpose for guiding impact assessment, mitigation and management planning and licensing.

While the mine site model (Coffey 2020a) is nominally fit for purpose, a wide range of corrective actions were recommended at the initial review stage, because the groundwater assessment (Coffey 2020a) was considered adequate only in terms of an indicative (low confidence) prediction of the likely impacts.

The initial review argued that the mine site groundwater assessment was not yet adequate for decision-making, as corrective action was warranted regarding a number of issues. These issues are listed in the response to submissions reports (EMM 2021a,b,c) and the response to residual DPIE Water issues report (Coffey 2021), and they have all been adequately addressed.

This final review finds that, taken together, the mine site groundwater assessment and subsequent report documents now provide a medium confidence prediction of the likely impacts, and sufficient information for decision-making.

We note that the DPIE Water Response to Submissions letter (29 April 2021) indicated general satisfaction with the proponent's responses, and recommended the post-determination installation of at least 'two nested monitoring bore sites parallel to and adjacent to the proposed underground mine alignment within the mining lease'.

This review endorses that monitoring recommendation, and suggests that the bores should be sited on the eastern side of the Glenfiddich Fault.

This review also endorses the DPIE Water recommendation for validation of the groundwater model(s) after two years of the project commissioning, and every five years thereafter throughout the life of the mine.

It was also recommended at the initial review stage, and is now re-confirmed, that a comprehensive quantitative uncertainty assessment (Middlemis and Peeters 2018) be conducted during future modelling programs to improve confidence in the model and results.

4. 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, 40 years' experience, and established the HydroGeoLogic independent consultancy in 2013. Hugh was principal author of the first Australian groundwater modelling guidelines (Middlemis 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).

Hugh Middlemis has not worked on the Cowal Gold Operation project nor for Evolution Mining, nor for Coffey Services who conducted the groundwater assessments, and we assert no conflict of interest issues in relation to this work.

We note that Hugh Middlemis was appointed to the NSW Mining and Petroleum Gateway Panel in December 2020.

We note the following in relation to previous interactions with the consultants preparing the overall EIS (EMM Consulting):

- The expert reviewer has been engaged several times by EMM Consulting, the consultant responsible for preparing the overall EIS for the CGO Underground, to conduct peer reviews of EMM groundwater assessments:
    - McPhillamys Gold (NSW) groundwater model review (2019-20, for EMM).
    - New Cobar Complex groundwater assessment review (2021, for EMM).
    - Eastern Mallee EM1.3 model (Vic/NSW) for salinity management in Sunraysia region (2019-20; for EMM).
    - Burrawang-Avon Tunnel (NSW) groundwater model review (2020; for EMM).
    - Snowy 2.0 (NSW) pumped hydro tunnel model review (2018-19; for EMM).
    - Chandler Salt Project (NT) groundwater assessment (2016-17; for EMM).
- The expert reviewer has also been engaged by third parties to conduct expert reviews of groundwater modelling investigations conducted by EMM:
    - Hume Coal project (NSW) groundwater assessment (2017-19; for NSW DPE).
    - Fingerboards mineral sands (Vic.) groundwater assessment (2018-19; for Kalbar).

We note that the expert reviewer's son (Roger Middlemis) has worked for EMM Consulting since March 2019 as an environmental engineer in their Adelaide office, but he also has not worked on the Cowal Gold Project.

5. References

Barnett B, Townley L, Post V, Evans R, Hunt R, Peeters L, Richardson S, Werner A, Knapton A, Boronkay A (2012). Australian Groundwater Modelling Guidelines. National Water Commission. http://webarchive.nla.gov.au/gov/20130420190332/http://archive.nwc.gov.au/library/waterlines/82.

Coffey Geotechnics (2013). Final Hydrogeological Assessment, CGO Extension Modification. Report GEOTLCOV21910AW-AI. Prepared for Resource Strategies. September 2013.

Coffey (2020a). Cowal Gold Underground Development Mine Site Hydrogeological Assessment. Prepared for EMM Consulting on behalf of Evolution Mining, 10 September 2020

Coffey (2020b). Cowal Gold Operations Underground EIS Bland Creek Palaeochannel Borefield and Eastern Saline Borefield Groundwater Assessment. Prepared for EMM Consulting on behalf of Evolution Mining, 27 August 2020.

Coffey (2021). CGO Underground Development – Response to residual issues raised by DPIE Water. Letter to DPIE, 8 April 2021. Accompanied by two Addenda: EMM 2021b,c.

EMM Consulting (2020). Cowal Gold Operations Underground Development Environmental Impact Statement Main Report. Prepared for Evolution Mining. October 2020.

EMM Consulting (2021a). Cowal Gold Operations Underground Development and Modification 16 Submissions Report. Prepared for Evolution Mining, 26 February 2021.

EMM Consulting (2021b). CGO Underground Development EIS - Addendum 1 of the Hydrogeological Assessment. Response to groundwater independent peer review (Coffey ref: 754-SYDGE206418-3-AP-Rev1), 22 February 2021.

EMM Consulting (2021c). CGO Underground Development EIS - Addendum 2 of the Hydrogeological Assessment. Groundwater Responses (Coffey ref: 754-SYDGE206418-3-AS-Rev1), 24 February 2021.

Evolution Mining (2019). Cowal Gold Operations Rehabilitation Management Plan. February 2019.

Gilbert and Sutherland (1997). Cowal Gold Project Water Management Study.

HEC (2016). Cowal Gold Operations Mine Life Modification Hydrological Assessment. Prepared for Resource Strategies on behalf of Evolution Mining. November 2016.

HEC (2020). Cowal Gold Operations Underground Mine Project Hydrological Assessment. Prepared for Evolution Mining. September 2020.

Johnson SL and Wright AH. (2003). Mine void water resource issues in Western Australia. Water and Rivers Commission, Hydrogeological Record Series, Report HG 9, 93pp.

Johnstone A. (2019). Are pitlakes an environmentally sustainable closure option for South African coal mines? Proceedings International Mine Water Association 2019 Conference. www.imwa.info/docs/imwa_2019/IMWA2019_Johnstone_469.pdf

McCullough C, Marchand C, Unseld J. (2013). Mine closure of pit lakes as terminal sinks: best available practice when options are limited? Mine Water Environment (2013) 32:302-313. https://doi.org/10.1007/s10230-013-0235-7

Middlemis H, Merrick N, Ross J, and Rozlapa K. (2001). Groundwater Flow Modelling Guideline. Prepared for Murray–Darling Basin Commission by Aquaterra, January 2001. URL: www.mdba.gov.au/sites/default/files/archived/mdbc-GW-reports/2175_GW_flow_modelling_guideline.pdf.

Middlemis H, Peeters L. (2018). Uncertainty analysis—Guidance for groundwater modelling within a risk management framework. Prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018. www.iesc.environment.gov.au/publications/information-guidelines-explanatory-note-uncertainty-analysis

Middlemis H, Walker G, Peeters L, Richardson S, Hayes P, Moore C (2019) Groundwater modelling uncertainty – implications for decision making. Summary report of the national groundwater modelling uncertainty workshop, 10 July 2017, Sydney, Australia. Flinders University, National Centre for Groundwater Research and Training. https://dspace.flinders.edu.au/xmlui/handle/2328/39111

Resource Strategies (1997). Cowal Gold Project Environmental Impact Statement.

Spitz K and Moreno J (1996). *A practical guide to groundwater and solute transport modelling*. Wiley.

Younger PL and Wolkersdorfer C. (2004). Mining impacts on the fresh water environment: Technical and Managerial Guidelines for Catchment Management. Prepared by the Environmental Regulation of Mine Waters in the European Union (ERMITE) Consortium, a project of the European Commission’s 5th Framework R&D. Journal of Mine Water and the Environment (2004) 23: pp. S2–S80.