TAHMOOR SOUTH COAL PROJECT GROUNDWATER ASSESSMENT INDEPENDENT REVIEW (STAGE 1)

Prepared for:	NSW Department of Planning and Environment	29 May 2019

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 email: hugh@hydrogeologic.com.au mobile: +61 438 983 005	
Authors	Hugh Middlemis (HydroGeoLogic)	
Version 1	17 April 2019	Initial draft (some issues requiring discussion)
Version 2	29 May 2019	Updated draft (after discussion of issues log April-May 2019)

This report should be cited/attributed as:

Middlemis H (2019). Tahmoor South Coal Project Groundwater Assessment Independent Review (Stage 1). Prepared by HydroGeoLogic for NSW Department of Planning and Environment. Version 2, 29 May 2019.

1. Introduction

1.1 Tahmoor South Coal Project

The proposed Tahmoor South Coal Project is a longwall underground mining extension to the existing underground Tahmoor (North) Coal Mine that has been mined since the late 1970s. The site is about 80 km southwest of Sydney in the Southern Coalfields (Southern Sydney Basin) of New South Wales, and is also close to the WaterNSW drinking water catchment 'Special Areas' and the Thirlmere Lakes National Park (Figure 1).

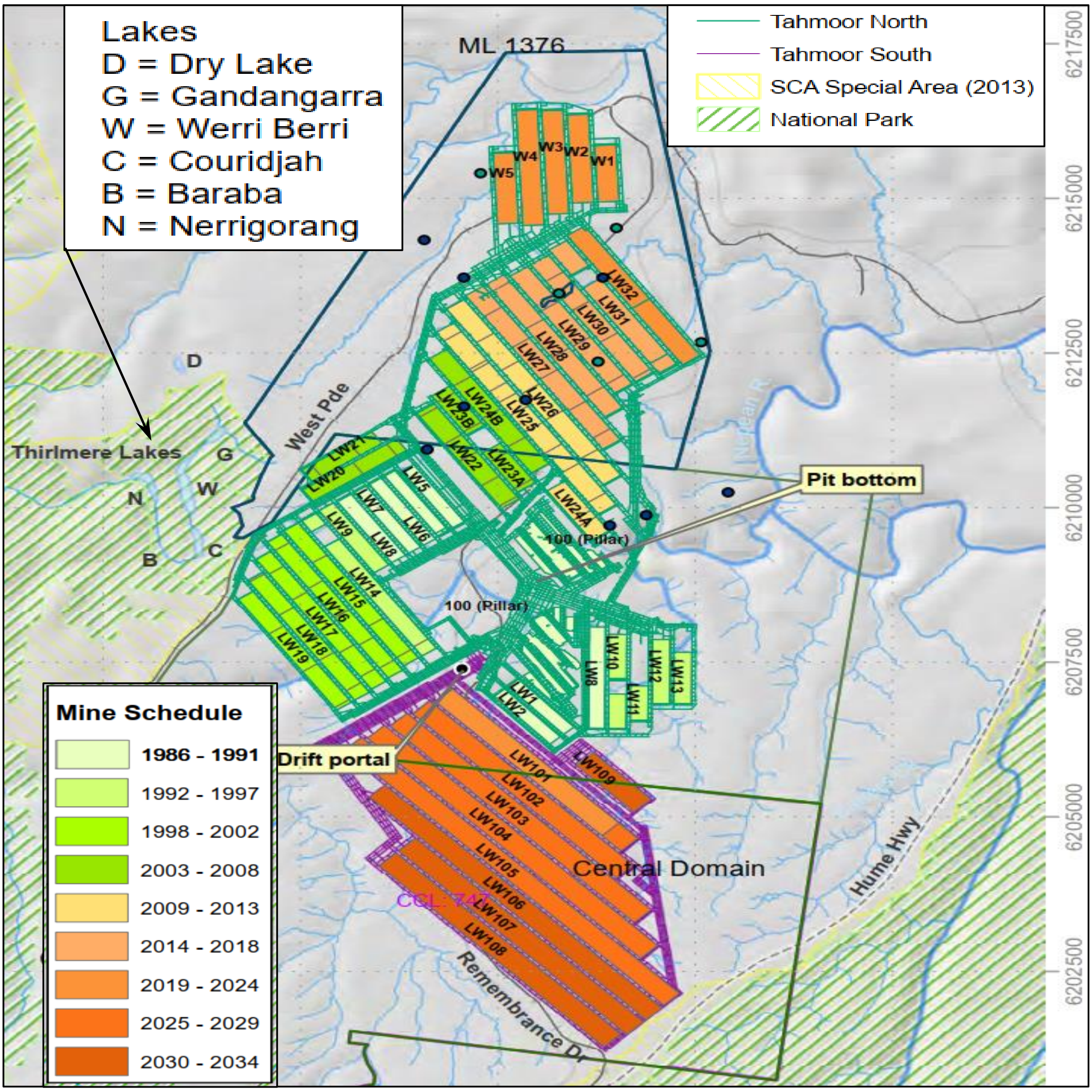

Figure 1 - Tahmoor Mine and Thirlmere Lakes (after HydroSimulations 2018)

The Tahmoor South ('Central Domain') project targets the Bulli Seam coal resource at about 375-500 metres depth, with nine longwall panels (101-109) having cutting heights typically 2.5-2.9 metres (similar to Tahmoor North) and widths of 285-305 metres (Tahmoor North widths are 280 m since panel 22). Tahmoor South has an expected mine life of about 13 years (2023-2035), planned to follow on after cessation of mining at Tahmoor North. It is understood that an amended Development Application (DA) is in preparation, which may involve some changes to these details.

The Thirlmere Lakes are a series of shallow freshwater bodies located along a horseshoe bend in Blue Gum Creek, within the Thirlmere Lakes National Park, which is part of the Greater Blue Mountains World Heritage Area. Figure 1 shows that the easternmost lake (Couridjah) is about 650-750 m from the nearest Tahmoor North longwalls (mined in the late 1990s to early 2000s), and at least 3.5 km from the proposed Tahmoor South longwalls.

There are several other mines in current operation within about 15-20 km to the east and south of Tahmoor, the closest being Appin at 2km distance, part of the Bulli Seam Operations ('BSO': Appin, West Cliff and Tower Mines) operated by South32/Illawarra Coal along with their Dendrobium and Cordeaux mines up to 15 km further east/south. Further east/south again are the Russell Vale, Wongawilli/Eloura, Avondale and Huntley operations. These mines form part of the cumulative assessment of groundwater impacts.

1.2 Independent Peer Review Process

This report summarises the outcomes of an independent peer review of the Tahmoor South Coal Project hydrogeological and groundwater modelling assessment conducted by HydroSimulations (2018).

This desktop review was conducted by Hugh Middlemis (HydroGeoLogic), in accordance with the best practice principles and procedures of the Australian Groundwater Modelling Guideline ('AGMG'; Barnett et al. 2012), and with consideration of the IESC report on groundwater modelling uncertainty analysis (Middlemis and Peeters, 2018). The review outcomes are summarised in section 2, including the AGMG compliance summary checklist (Table 1).

The main evidentiary basis for this review is the groundwater assessment report (report referred to herein in abbreviated form as 'HS'):

- HydroSimulations (2018) Tahmoor South Project EIS: Groundwater Assessment. Prepared for Tahmoor Coal. December 2018. Presented as Appendix I to the Tahmoor Coal Project Environmental Impact Statement.

Several other reports from the Tahmoor Coal Project Environmental Impact Statement were also considered, as listed in the references.

This peer review sometimes adopts the general label 'Tahmoor groundwater model' as it includes the existing Tahmoor North and the proposed Tahmoor

South mines (plus the nearby mines for cumulative impact assessment, of course).

Additional information was provided by HydroSimulations via a presentation at DPE offices on 2 April 2019, also attended by Department of Industry Water representatives. A preliminary issues log was then prepared by this reviewer and submitted to DPE on 9 April 2019, with responses received from HydroSimulations via DPE on 15 May 2019, leading to this version 2 of the Stage 1 review report. Most issues related to report documentation, and HydroSimulations indicated that action is in hand via the amended DA. Material issues related to the representation of Thirlmere Lakes in the groundwater model and the GoldSim water balance model for the Thirlmere Lakes (not the GoldSim mine water balance model), as well as the interface (transfer of data) between the two models; for example (see section 3.1 later):

- the specification of levels in the groundwater model to represent the lake beds and potential overflow points are currently not consistent with surveyed levels, at least for some scenarios used to generate the flux versus level relationships for input to the GoldSim model;
- detailed arrangements within the GoldSim model are currently inadequately reported but appear *prima-facie* to be inconsistent with physical reality and lake-groundwater interaction processes.

2. Review Outcome Summary

As a summary of the conditional findings of this peer review, the AGMG 10-point essential issues compliance checklist (Barnett et al. 2012) is presented in Table 1, with detailed discussion of some aspects presented in Section 3.

My professional opinion is that the Tahmoor South Coal Project hydrogeological and groundwater modelling assessment (HydroSimulations 2018) is fit for the purpose of mine dewatering environmental impact assessment (including cumulative impacts) and informing management strategies and licensing (allowing for amended DA refinements to come).

Flaws have been identified in the methodology and results of the GoldSim water balance modelling for Thirlmere Lakes, and the reporting (HEC 2018) is currently inadequate to resolve the issues (further detail is needed via the amended DA). However, the rates and volumes of exchange fluxes between the lakes and groundwater are relatively small, such that they would not be expected to greatly affect the impact assessment in terms of drawdowns and dewatering rates. There would likely be some material effects in terms of lake levels and water balances, and water accounting for licensing purposes.

Table 1 – AGMG Groundwater Model Compliance: 10-point summary – Tahmoor South

Question	Y/N	Comments re Tahmoor groundwater model
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Class 2-3 model confidence level is claimed (HS s4.1). Independent analysis for this review indicates that a Class 2-3 level is justified (independent assessment in Table 2 below).
2. Are the objectives satisfied?	Yes	Competent hydrogeological conceptualisation, model design and calibration to existing Tahmoor dewatering stresses and groundwater levels, and nearby influences from operating mines, Thirlmere Lakes leakage and mapped faults, demonstrating fitness for purpose. Sound application to mine dewatering scenarios, impact assessment, mitigation & management, and licensable takes. Some minor issues to be resolved via amended DA. GoldSim water balance analyses (by HEC 2018, in Appendix J to EIS) questionable re Thirlmere Lakes levels and processes.
3. Is the conceptual model consistent with objectives and confidence level?	Yes	Groundwater model conceptualisation is mature, based on investigations over at least 20 years, consistent with data, objectives and Class 2-3 confidence level for mining impact assessment & licensing purposes. GoldSim model conceptualisation questionable (needs more information via amended DA).
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	HS report lists studies over about 20 years which have been carefully considered and combined with the available data (good coverage since 2008) to develop a sound groundwater conceptual model. Competent hydrogeologists and modellers have evaluated the data, conceptualisation, model design, execution & outcomes. Good graphical presentation of conceptual models (e.g. HS figures 3-36 & 3-37) and discussion or the various elements (e.g. HS s3). GoldSim model conceptualisation questionable (needs more information via amended DA).
5. Does the model design conform to best practice?	Yes	The groundwater model software, design, extent, layers, grid, boundaries and parameters are consistent with best practice design and execution. Modelling approach accounts for existing Tahmoor Mine effects, and includes effects of nearby operating mines. Issues raised by DoI Water re modelling of shallow surface cracking and transient watercourses to be addressed by amended DA. GoldSim model implementation questionable (needs more info via amended DA).
6. Is the model calibration satisfactory?	Yes	Automated PEST and manual groundwater model calibration over period of significant hydrological variability 1980-2018 which helps minimise non-uniqueness. Sound calibration performance to multiple criteria: a) matches to groundwater levels (SRMS error 3.7%, unweighted); b) matches to existing Tahmoor mine inflows (1-4 ML/d over 1995-2018; HS fig 4-14), and to flow/salinity of discharge to LDP1 (HS fig 5-9), and to Dendrobium & Appin inflows; c) model parameters consistent with aquifer property values, including excellent data on 'height of fracturing (HoF)' effects at Tahmoor TBF040c above longwall 10A (HS figs 3-34 & 4-11); and c) adequate matches to lesser target of baseflows (which cannot be measured directly and are estimated via hydrograph analysis). Time series groundwater level matches mostly good (2008-2018), with divergences cogently justified with reference to measurement errors, spatial & temporal discretisation effects & structural issues. Time series matches at Thirlmere Lakes bores should be improved. GoldSim model calibration questionable (e.g. lake bed levels incorrect HEC (2018) Fig 32; Nerrigorang only losing; volume mis-matches Figs 34 & 37), to be addressed via amended DA.

Question	Y/N	Comments re Tahmoor groundwater model
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	Model parameter values are consistent with drilling & testing information. Inflow rates at Tahmoor Mine (around 1-4 ML/day) and other mines help constrain potential model flux non-uniqueness, along with matches to baseflow estimates and constraints to recharge estimates. Thirlmere Lakes assessed as mostly losing, with leakage volumes benchmarked to sensitivity analysis, and adequate matches to measured groundwater levels. Issues raised re levels applied to Lakes (HS Table 5-5) and Thirlmere Lakes processes applied to GoldSim water balance model (HEC section 8) to be addressed by amended DA.
8. Do the model predictions conform to best practice?	Yes	Overall methodology (allowing for refinements via amended DA) is consistent with best practice and suitable for dewatering impact assessment, management plans and licensing decision making. Future predictions of Tahmoor South inflows of 4-6 ML/d are consistent with existing Tahmoor experience (i.e. model projections are not out of range of the stresses applying to the calibration). Careful consideration was applied to changes to aquifer properties due to fracturing above longwalls (Tammetta model adopted, consistent with IEPMC requirements). Cumulative impacts benchmarked to effects from existing Tahmoor Mine and nearby mines.
9. Is the uncertainty associated with the simulations/predictions reported?	Yes	Effect of uncertainties considered via deterministic rather than stochastic groundwater model scenarios, which is suitable for the brownfields site and mature hydrogeological understanding and data available. Linear uncertainty analysis of calibration Kh & Kz for all units from surface to coal seam (HS s4.10), indicating good parameter identifiability for units down to the Bulgo Sandstone (i.e. units below the Bulgo Sst are a target for future data acquisition and/or uncertainty analysis). Prediction sensitivity runs rightly focus on causal pathways for higher inflows or more connection to surface, notably 1.5 times the Tammetta height of fracturing, more transmissive faults and lake leakage effects. This confirms relatively low sensitivity and provides adequate information on the effects of uncertainties, suitable to support decision making.
10. Is the model fit for purpose?	Yes	My professional opinion is that the Tahmoor South Coal Project hydrogeological and groundwater modelling assessment (HydroSimulations 2018) is fit for the purpose of mine dewatering environmental impact assessment (including cumulative impacts) and informing management strategies and licensing (allowing for amended DA refinements to come). Flaws have been identified in the methodology and results of the GoldSim water balance modelling for Thirlmere Lakes, and the reporting (HEC 2018) is currently inadequate to resolve the issues (further detail is needed via the amended DA). However, the rates and volumes of exchange fluxes between the lakes and groundwater are relatively small, such that they would not be expected to greatly affect the impact assessment in terms of drawdowns and dewatering rates. There would likely be some material effects in terms of lake levels and water balances, and water accounting for licensing purposes.

3. Discussion

The groundwater assessment and modelling report (HydroSimulations 2018) is well-written, lucid and logical, and provides detailed and cogent explanations of the hydrogeological understanding and conceptual model, and the numerical model design and execution. The conceptualisation is mature and sound, based on a range of investigations over many years, and has been implemented aptly in the model.

Having said that, some issues identified are in the process of being addressed by the amended DA, notably the groundwater modelling of shallow surface cracking in potential subsidence areas, transient watercourses (i.e. seasonally variable water levels) and Thirlmere Lakes levels. Some issues with the processes applied to the GoldSim water balance model (HEC 2018 section 8), also discussed in section 3.1, should also be addressed by amended DA, along with report documentation issues in both cases.

The 3D MODFLOW-USG model domain, layer setup, grid design, boundary conditions and parameters applied are largely consistent with the available information and conceptualisation. A bias has been invoked towards conservative assumptions where warranted that would tend to over-estimate mine dewatering effects. This includes adoption of the Tammetta model for height of fracturing (HoF) above longwalls (more on this later), consistent with IEPMC 2018 recommendations, treating the Nepean Fault as transmissive in the base case, and an uncertainty scenario that also assumes a transmissive T2 fault. Based on information available, the Tahmoor modelling and results are considered fit for purpose.

The USG grid design could possibly be optimised with a view to reducing the number of model cells from 2 million towards 1 million or less, such that it may be more amenable for stochastic uncertainty analysis. However, the level of effort is arguably not warranted at this stage, given the multi-criteria constrained calibration, and the stated focus on the model design and execution to carefully address Aquifer Interference Policy (AIP) requirements and IEPMC (2018) recommendations. This review endorses the HS recommendation for future work to further reduce the effects of uncertainty on simulations through pilot points and/or regularisation methods, which would require revisions to the model and refinement of the grid, reducing the number of cells.

While questions remain on the complexities of the Thirlmere Lakes system (OEH 2016), the Tahmoor model has been carefully designed and executed based on the available data and understanding. These elements are also in the process of further refinement under the amended DA, based on issues raised during this Stage 1 review and by DoI Water. It is recommended that the results from the Tahmoor model be considered in due course (i.e. after further refinements) by the Thirlmere Lakes Inter-Agency Working Group, which may invoke some recommendations in due course for future investigations and/or modelling at Tahmoor.

3.1 Thirlmere Lakes and WaterNSW 'Special Areas'

The Thirlmere Lakes are a series of shallow freshwater bodies located along a horseshoe bend in Blue Gum Creek, within the Thirlmere Lakes National Park, which is part of the Greater Blue Mountains World Heritage Area (Figure 1).

Thirlmere Lakes are listed as a High Priority groundwater-dependent ecosystem (GDE) in the Greater Metropolitan Region Groundwater Sources (GMRGS) Water Sharing Plan (WSP). Other high priority GDEs in the area are 20-25 km distant from Tahmoor (HS Figure 3-4), although GDEs can also be presumed to be associated with groundwater discharge areas along incised creeks and rivers.

Thirlmere Lakes are clearly the highest priority ecological system at most potential risk from mining at Tahmoor, as the easternmost lake (Couridjah) is about 650-750 metres from the nearest Tahmoor North longwalls (Figure 1). However, Tahmoor North was mined (under approval) in the late 1990s to early 2000s, and the 2012 Thirlmere Lakes Inquiry concluded that, while there is evidence to suggest that mining has contributed to changes in groundwater tables and hydraulic gradients in the Hawkesbury Sandstone, it is not possible to say whether that is temporary or long-lasting (NSW Chief Scientist and Engineer 2013). Further, it is not possible disentangle groundwater changes due to mining from those due to private bores, natural climate change (droughts), and anthropogenic climate change (primarily increased temperature). It also concluded that substantial research was required to understand lake levels and groundwater interactions (IEPMC 2018).

There is a longitudinal section for the lakes (Figure 2), which identifies the bed and crest/overflow levels for the Thirlmere Lakes. There is also data available from four monitoring bores drilled in the Thirlmere Lakes area since 2011 (OEH 2016). The time series data are presented in Figure 3-16 (and Appendix H) of the groundwater assessment (HS 2018), which notes that these are for 'post-mining' conditions only.

The data indicates that alluvial groundwater levels in GW75409/1 vary around 299-301 mAHD, consistently about 2 metres below the adjacent lake level at Lake Couridjah (nearest to Tahmoor). Although the groundwater level is often above the bed level of Lake Couridjah of about 300 mAHD (Figure 2), the lake level is consistently above the groundwater level, indicating losing lake conditions. The groundwater levels in GW75411 near Lake Gandangarra range through 294-299 mAHD, 4-6 metres below the lake level, also indicating losing conditions and clearly lower than the bed of Lake Gandangarra of about 301 mAHD, although this is less definitive as GW75411 monitors the Hawkesbury Sandstone, not the alluvium. The levels in GW75410 near Lake Nerrigorang, however, range through 297-306 mAHD, compared to its lake levels of around 299.5-301.5 mAHD, indicating variably gaining to losing conditions.

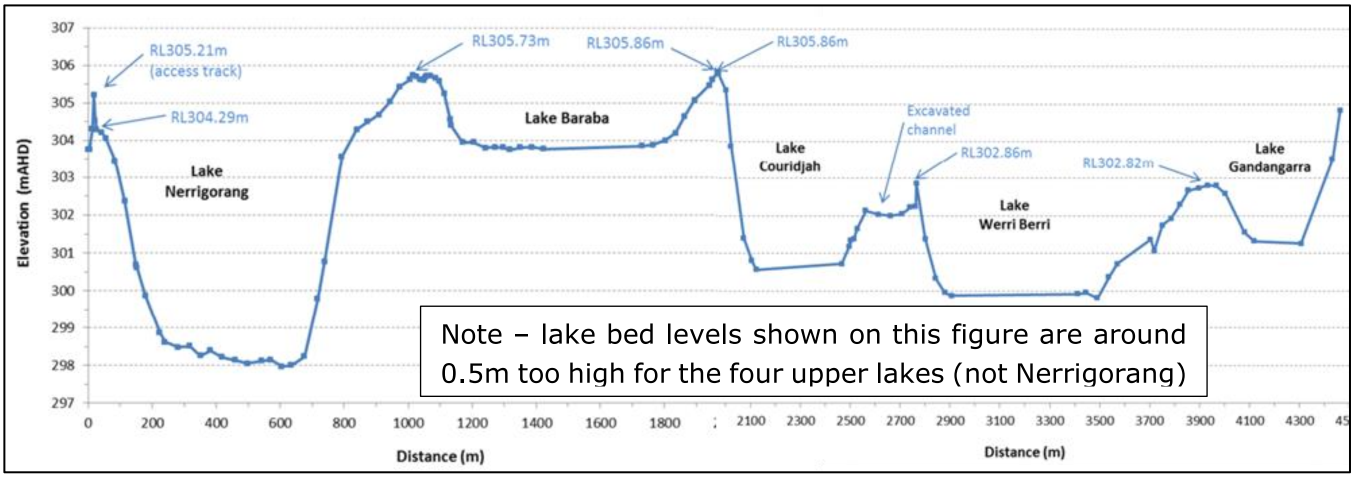

Figure 2 - Thirlmere Lakes longitudinal section (after HEC 2018, Figure 29)

Given the above conceptualisation of mostly losing lake conditions (except for a variably losing/gaining Lake Nerrigorang), it can be argued that an appropriately simple/robust approach has been applied to specifying constant lake levels in the groundwater model to represent typical (median) operational conditions (i.e. rather than transient/dynamic lake levels). The model performance adequately represents these groundwater levels in terms of the losing condition of most lakes, but does not perform as well for the variably losing-gaining Lake Nerrigorang, especially as that modelled constant lake level of 301 mAHD (HS section 4.4.3) is similar to the modelled groundwater level at GW75410 (HS Appendix H), which does not reflect the more variable measured range (297-306 mAHD). Although performance could be regarded as adequate, the time series matches to measured groundwater levels should be improved, given the importance of the Thirlmere Lakes. It is also recommended that the groundwater modelling report be updated to include some data/graphs on the variation of the wetted lake area with the lake level, with commentary on implications for the scenario settings.

This review identified some issues with the reported levels of the lake beds and overflow points, and their sometimes inconsistent representation in the groundwater model, and, more importantly in the GoldSim water balance model for Thirlmere Lakes, which should be addressed by the amended DA, as discussed below.

3.1.1 Lake Gandangarra overflow level

HS section 4.4.3 states that the Lake Gandangarra level was set to 304.6 mAHD in the groundwater model (long term 'median' level). This is about 1.8 m higher than the overflow point to Lake Werri Berri (302.82 mAHD). Subsequent discussions confirmed that is a typographical error and the value in the model data set is, in fact, 303 mAHD, which is still 0.18 m above the overflow level. While this means that Lake Gandangarra is effectively kept above full for all the simulations, the way this was implemented in the groundwater model means that it does not overflow (it simply over-estimates leakage from the lake due to the higher driving head). The other two upper lakes that connect with Gandangarra above its overflow (Werri Berri and Couridjah) have levels specified below their overflows. The proposed amended DA refinement of specifying time-varying lake levels consistent with records would adequately address the issue.

3.1.2 Lake bed levels

The lake bed levels specified in the HS groundwater model were provided by HEC, but have not been listed in either report. Subsequent discussion on this issue identified that the four upper lakes have bed levels around 0.5 metres lower in the model than the levels indicated in the lake long-section (Figure 2 above). The problem is mainly with the figure rather than the model and is presumably partly due to the 2012 LiDAR survey picking up the low lake level rather than the bed level, but this has not been explained in the reports. Several figures in the groundwater and surface water modelling reports also show incorrect bed levels and should be corrected via the amended DA. It is worth noting that the model results are unaffected by this issue, as they are based on the correct lake bed information and a steady 'median' lake level. The proposed specification of time-variable lake levels in the model will probably have a small effect on the rates and volumes of flux exchanges with groundwater.

3.1.3 Lake level versus flux relationship

HS Table 5-5 identifies the leakage rates from the lakes to groundwater calculated by the groundwater model for a series of lake levels. The level versus flux relationship data was used as input to the GoldSim water balance model for Thirlmere Lakes (HEC 2018). However, the range of lake levels specified in the groundwater model is not consistent with the lake bed or overflow levels (e.g. the minimum level of 298 mAHD is lower than the bed of the upper four lakes, which are all above 299.4 mAHD, and all lakes spill below 306 mAHD).

Subsequent discussions indicated that the model scenario used to generate this table involved artificially lowering the lake bed levels, as HEC requested information on water balance processes below the lake beds. This violates a fundamental principle of groundwater modelling of realistically representing the physical framework (Barnett et al. 2012), and it raises questions about the detailed elements of the GoldSim model that cannot be resolved with the currently inadequate (HEC 2018) documentation. It is understood that this issue does not affect the groundwater modelling impact assessments as such as the assumption affects only the lake level-flux relationship scenario.

HS Table 5-5 also lists only (losing) leakage rates from Lake Nerrigorang, whereas it is known to be a variably losing/gaining lake, depending on whether the groundwater levels are lower/higher than the lake level (respectively). The data presented in HS Figure 3-16 and HS Appendix H show that groundwater levels are sometimes higher than lake levels, causing gaining conditions. The groundwater model has not been properly setup for the purpose of establishing the variably losing/gaining Lake Nerrigorang flux versus level relationship (but this does not affect the setup for other scenarios).

3.1.4 GoldSim water balance for Thirlmere Lakes

Given the previous point, it appears that the GoldSim model for Thirlmere Lakes (not the mine water balance model) uses invalid data for two key elements:

- allowing lake leakage when lake levels fall below the bed of the lake;
- treating Lake Nerrigorang as a losing lake when groundwater levels are sometimes higher than the lake level, causing gaining conditions.

The upper four lakes are known to be losing lakes since at least 2012 when detailed data is available. Under these conditions, when there is no water in the lakes, the leakage flux from the lakes should be zero, but it appears that GoldSim does not invoke such appropriate constraints. While the GoldSim model does allow for evaporation up to 1m depth below the lake bed level, that occurs at the same steady rate as applies to the lake water surface, which is a questionable assumption. It should also be confirmed that the groundwater model does not include evaporation under the lakes, as that would invoke a double-counting issue in the GoldSim model.

The lack of a potentially gaining flux in the Lake Nerrigorang column of HS Table 5-5 appears to indicate that the data input to the GoldSim model allows only for a losing condition, which does not represent reality for this lake. There is a lack of detail provided in the HEC (2018) report to resolve this issue.

The fluxes associated with these issues may not be large, but as the issues apply to the highly sensitive Thirlmere Lakes, much more careful GoldSim model execution is warranted, rather than it being affected by such questionable assumptions. It is understood that the issues will be addressed by the amended DA.

3.2 Model Confidence Level Classification

The groundwater assessment report claims an AGMG Class 2 model confidence level (Barnett et al. 2012), consistent with the study purpose of impact assessment and management, and related licensing.

This review conducted an independent assessment of the model confidence level, consistent with the AGMG and applying the refinements outlined in the IESC uncertainty guidance (Middlemis and Peeters 2018). This review finds that a Class 2/3 model confidence level is clearly justifiable (Table 2).

Table 2 – Tahmoor South groundwater model confidence level

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

3.3 Calibration and Prediction

The history match calibration applied to 1980-2018, a period of substantial hydrological variability. The model performance is sound in relation to the mine inflow record since 1995 and the high quality groundwater level data record since 2008. This use of groundwater levels and fluxes as calibration targets helps resolve non-uniqueness issues because the sensitivity of fluxes to parameters differs from the sensitivity of levels to fluxes (Barnett et al. 2012).

Model calibration performance is acceptable statistically in terms of the 3.7% scaled RMS value, well within the AGMG criterion of 5%. The performance is sound in terms of the multiple criteria applied (groundwater levels, mine inflow fluxes, dewatering discharge salinity, height of fracturing, aquifer properties, baseflow flux estimates and hydrological variability). The methodology applied is well-executed to reduce potential non-uniqueness, with conservative assumptions applied where warranted (e.g. transmissive faults), consistent with best practice and confirming the model as a fit for purpose predictive tool.

The simulated groundwater flow system contours (HS Figure 4-12) are consistent with measured levels (HS Figures 3-18 & 3-21), reflecting the hydrogeological conceptualisation, including the 'saddle' in the groundwater levels apparent in the Thirlmere Lakes area.

The time series matches to groundwater level data (HS Appendix H) are mostly good, although the time series matches at the Thirlmere Lakes bores should be improved (e.g. via time-variable lake levels as is proposed for the amended DA). The reasons for divergences from measurements are cogently discussed (HS s.4.8.2) and are justified in relation to the parsimonious modelling approach of generally uniform aquifer properties per layer, apart from the HoF changes (discussed below), and variabilities in shallow layers and outcrops in incised rivers. This robust approach is consistent with AGMG principles, which allow for parsimonious approaches, warn against 'overfitting' (e.g. invoking parameter variability to improve statistical performance) and endorse multiple criteria calibration methods (Barnett et al. 2012 section 5.4).

The overall prediction scenario methodology and results presentations are consistent with best practice (scenario differencing between a base/null case and mine dewatering scenarios with/without Tahmoor South). The results are suitable for guiding dewatering impact assessment and management plans and licensing decision making. The modelling assessments provide good detail on water balance issues and drawdown impacts on third party bores, with consideration of impacts on potential groundwater dependent ecosystems. The analysis quantifies volumes affected in terms of the Aquifer Interference Policy and groundwater management zones, such that the results should be adequate for licensing purposes.

The impact assessments and interpretations are supported by the data available and the evidence presented, and the ongoing monitoring and other investigations will provide additional data for future model refinements and improvements in performance and/or comprehensive uncertainty analysis that should, in turn, be used to guide future monitoring and management programs.

3.4 Height of Fracturing (HoF) above longwall panels

Spatial and temporal variability of parameters has been invoked appropriately to represent the HoF above longwalls (HS Figures 4-6 to 4-8) according to the Tammetta method, consistent with IEPMC (2018) advice. The methods and data applied are indeed consistent with the details from the geotechnical report (SCT 2013 & 2014; presented as Appendix G to EIS).

For example, HS Figure 4-5 shows that the basic model parameter values are indeed consistent with the packer testing and core testing results. HS section 4.6 explains clearly that the parameters applied to the 'enhanced permeability zone (EPZ)' in the model are consistent with the geotechnical report data (SCT

2013 and 2014). HS Figure 4-7 shows that the ratio of the height of the fractured zone (calculated by the Tammetta method) to the panel width is 0.38 to 0.87 across Tahmoor (higher in the south where the cover is thinner), with the fracturing extending up into the lower Hawkesbury Sandstone (layer 3 of the model) at the southern end of Tahmoor South.

An uncertainty scenario was conducted by applying a 1.5 factor to the Tammetta-calculated height of fracturing, which resulted in mine inflows increasing from the base case of around 4-6 ML/d up to around 7-10 ML/d (HS Figure 5-1). Results were also presented in terms of groundwater level time series in Figures 5-2 to 5-6, which allows comparison with the other mining and non-mining scenarios and fault sensitivity runs.

This review takes issue with some aspects of the advice from the IESC on Tahmoor South. Under the 'General Issues' section, item 5 includes the misrepresentation that that the height of vertically connected factures equates to the longwall panel width. While the panel width is indeed a key factor, the statement makes no mention of the influence of other key factors, notably the seam extraction height and the depth of overburden (IEPMC 2018). The advice correctly points out that the model does not include shallow surface cracking, but then extends the false premise of the 'underestimation' of the height of fracturing to suggest that the groundwater assessment has overlooked the potential 'connectivity between surface water and deep strata via tortuous flow paths'. There is evidence presented in the geotechnical report and groundwater assessment (EIS Appendix G and I) on the intervening constrained zone that shows a clear separation between the potential shallow surface cracking horizon and the fractured zone above the longwalls.

Despite the lack of evidence to support the IESC hypothesis of 'connectivity' and its basis on a false premise as argued above, there is further conflation with other spurious issues, for example:

- incorrectly suggesting that the porous medium modelling methods are inadequate and do not allow for temporal changes to parameters (inconsistent with IEPMC 2018 and the time-varying material properties capability of the modelling software applied in this case), and,
- the logically flawed suggestion that lack of 'an adequate uncertainty analysis' means that the model 'cannot be used to evaluate cumulative impacts',

leading to unwarranted statements of 'low confidence in groundwater model predictions'. This is worthy of discussion with the IESC or OWS staff.

3.5 Sensitivity and Uncertainty

It should be understood that even the most comprehensive modelling and uncertainty analysis study cannot completely rule out the potential for unwanted outcomes (Middlemis and Peeters 2018). In this case, the risk context is established by the proximity of the Thirlmere Lakes to the Tahmoor mining, as discussed in section 3.1 above.

The groundwater assessment (HS 2018) established that the Thirlmere Lakes is characterised as largely a losing system as groundwater levels since at least 2012 are several metres below the level of most lakes (except for the western-most and variably losing-gaining Lake Nerrigorang).

Given that the Tahmoor North longwalls closest to the Thirlmere Lakes were mined (under approval) more than 15 years ago, and that the nearest Tahmoor South proposed longwalls are more than 3.5 km from the nearest lake, there appears to be a relatively low risk groundwater impact context to the proposed Tahmoor South project. This includes consideration of the issues raised above regarding the Thirlmere Lakes representation in the models, in that the flux exchange rates and volumes are relatively small and it is this reviewer's expectation that the amended DA refinements would not substantially change the predicted effects. It can be argued that, under a nominal low risk context, a comprehensive/stochastic uncertainty analysis is not strictly warranted at this stage in terms of the IESC uncertainty analysis guidance (Middlemis and Peeters 2018). The reasoning is expounded in the following points.

The groundwater assessment is well-constrained to data on inflows, groundwater levels and fracturing above longwalls from existing mining, and has a sound multi-criteria calibration performance and linear uncertainty analysis that reduces non-uniqueness and establishes key parameter identifiability (i.e. there is adequate data to benchmark the model as a fit for purpose predictive tool).

This review accepts as reasonable the arguments put forward in the groundwater assessment that a comprehensive stochastic uncertainty analysis is not warranted at this time. It is acceptable given the brownfields setting (i.e. mature conceptualisation and good data set on the effects of mining), the multi-criteria calibration performance and its linear uncertainty analysis. The selected sensitivity scenarios are targeted at key uncertainties (e.g. as discussed herein: 1.5x HoF, transmissive faults, notably the T2 fault, and higher Sy) and cumulative impacts that would tend to over-estimate mining impacts, and the results provide suitable information to assist decision makers. The sensitivity analysis notably included applying more transmissive parameters to the T2 fault, which does address the potential causal pathway for impacts, contrary to the IESC suggestion that it 'has not been quantified', and confirming that it is indeed not material.

A linear uncertainty analysis of the horizontal and vertical hydraulic conductivity calibration parameters (Kh and Kz) was conducted for all units from the surface to coal seam (HS s.4.10, Figure 4-15). The results indicated a parameter identifiability index value of 1 (or close to it) for units down to and including the Bulgo Sandstone, but low index values below that. A parameter identifiability index of 1 indicates that the model calibration is sensitive to that parameter, but that the measurements have provided enough information to adequately constrain (but not eliminate) the uncertainty. An index of zero indicates that the model calibration is not sensitive to the parameter because the measurements do not inform/constrain the calibration (e.g. the hydraulic conductivity of units below the Bulgo Sandstone is a target for future data acquisition and/or uncertainty analysis).

The prediction uncertainty runs conducted rightly focus on causal pathways for higher inflows or more connection to surface, notably 1.5 times the Tammetta-calculated height of fracturing (HoF), more transmissive faults, higher unconfined specific yield values and lake leakage effects.

Confined aquifer storativity has not been tested for uncertainty, which is acceptable because:

- modelled inflow is usually not highly sensitive to confined storage (most dewatering volume is drawn from unconfined storage),
- the latest research (Rau et al. 2018) establishes that the confined specific storage (Ss) has a limited range (Tahmoor calibrated Ss values lie within the Rau-limited range of 1.3×10^{-5} m^{-1} to 2.3×10^{-7} m^{-1}), and,
- assuming a constant Ss value (as applied to Tahmoor), rather than a time-variable value, would over-estimate drawdown and inflow due to mining (David et al. 2018).

While the model does not include non-mining groundwater pumping, this is arguably warranted/justified because there is substantial data uncertainty on the actual extraction volumes and the pumping schedules. As the cumulative impact simulations do not account for this unmetered non-mining extraction, the model has isolated the effect of mining on groundwater levels, which is appropriate for impact assessment purposes. The alternative of including an estimate of the non-mining pumping would invoke further data uncertainty, and would result in a prediction of non-mining drawdown impacts that would not be validated in that there is no data on measured drawdowns at pumping bores. The predicted effects of drawdown due to mining are documented for registered and unregistered bores at HS Table 6-6, which is suitable for the purpose of Aquifer Interference Policy assessments. The hydrogeological principle of superposition allows that the mining drawdown predictions are also suitable for make good procedures in that it can be added to any non-mining drawdown data that becomes available.

This review finds that the investigation has provided information that is suitable for impact assessments and management plan development, and for licensing decisions. Having said that, it may be that the regulator could be assisted with further model scenarios and uncertainty analyses.

The ongoing monitoring program is well-designed to provide the data in due course for further model improvements and assessment of uncertainties (e.g. as recommended, by applying pilot points and/or regularisation methods, and/or detailed uncertainty analyses with a refined model) as recommended by best practice guidelines.

3.6 Other Issues

While the report is generally well-written, there are some minor matters where the report is deficient in its explanation or justification, or where some graphical figures require some improvement. These issues have been raised via an issues log that has been discussed with the principal modeller, facilitated by DPE, and action is in hand to address the issues during the amended DA.

There are two key issues that have been raised by others, with whom this reviewer concurs, that are being addressed by the modeller:

- Shallow surface cracking: while advice from the IESC (2019) pointed out that shallow surface cracking has not been included in the model, HydroSimulations indicated at the meeting on 2nd April 2019 that action was in hand to propose additional scenarios to address the oversight.
- Transient Watercourses: the HS report conceptualises streams as switching between losing and gaining (HS s.3.10.1), albeit losing for a substantial portion of the time in many areas, and yet there are other statements about discharge from the aquifer system being primarily to streams (HS s.3.10.2); and yet (as NRAR pointed out) headwater streams are implemented in the model as gaining only, while larger downstream rivers can be variably losing or gaining, depending on whether groundwater levels are below or above the stream level (HS s.4.4.2); HydroSimulations indicated at the meeting on 2nd April 2019 that action was in hand via the amended DA to revise the model to address the oversight.

4. Conclusion

Notwithstanding the above outstanding issues, or assuming that they can be addressed as part of an amended DA, the following summary statement on this peer review outcome.

My professional opinion is that the Tahmoor South Coal Project hydrogeological and groundwater modelling assessment is fit for the purpose of mine dewatering environmental impact assessment (including cumulative impacts) and informing management strategies and licensing (allowing for amended DA refinements to come).

Flaws have been identified in the methodology and results of the GoldSim water balance modelling for Thirlmere Lakes, and the reporting (HEC 2018) is currently inadequate to resolve the issues (further detail is needed via the amended DA). However, the rates and volumes of exchange fluxes between the lakes and groundwater are relatively small, such that they would not be expected to greatly affect the impact assessment in terms of drawdowns and dewatering rates. There would likely be some material effects in terms of GoldSim-calculated lake levels and water balances, and water accounting for licensing purposes.

The recommended monitoring program and ongoing hydrogeological investigations are well-designed and will provide additional data for future model refinements and uncertainty assessments.

5. Declarations

For the record, the peer reviewer, Hugh Middlemis, is an independent consultant specialising in groundwater modelling. He is a civil engineer with a masters degree in hydrology and hydrogeology and more than 38 years' experience. Hugh was principal author of the first Australian groundwater modelling guidelines (Middlemis et al. 2001) that formed the basis for the AGMG (Barnett et al. 2012), and he was awarded a Churchill Fellowship in 2004 to benchmark groundwater modelling best practice. He is co-author of the IESC report on uncertainty analysis guidance for groundwater modelling within a risk management framework (Middlemis and Peeters 2018) and of the related NCGRT report on the groundwater modelling uncertainty workshop (Middlemis et al. 2019).

Hugh Middlemis has not worked on the Tahmoor Coal Project or for SIMEC, nor for or with Mr Will Minchin (Principal Modeller at HydroSimulations), and we assert no conflict of interest issues in relation to this work.

We note the following in relation to previous interactions with Dr Noel Merrick (principal of HydroSimulations, the consultant acting for Tahmoor Coal):

- Mr Middlemis has reviewed groundwater assessments led by Dr Merrick:
    - Vickery Coal Extension Project (2018-19; DPE).

  - Hume Coal Project (2018; DPE).
  - Wambo longwall panel 10A expansion (2015, DPE).
  - Mulgrave River model report (2016).
- Dr Merrick has completed peer reviews of groundwater models developed for catchment and salinity management purposes in South Australia and Victoria conducted by Aquaterra when Mr Middlemis was Technical Director at Aquaterra:
  - Adelaide Plains solute transport model (2011);
  - Padthaway solute transport model (2008);
  - Eastern Mallee models EM2.1 (2008) and EM2.3 (2009).
- Previously, Mr Middlemis has worked directly with Noel Merrick, notably:
  - to write the 2001 guidelines on groundwater modelling and prepare and deliver some related conference papers (Middlemis et al, 2001, 2004);
  - for a few semesters across about 1996-2005, Mr Middlemis worked as the distance education tutor for Dr Merrick's Groundwater Modelling subject at UTS (i.e. marking assignments and helping students via email and telephone);
  - during about half of the period 1986-1989 when Mr Middlemis was at an early/mid-career stage at the Department of Water Resources, he was seconded from the Hydrology unit to work in the Hydrogeology Unit on groundwater modelling projects, supervised directly by Mr Merrick.

6. References

Barnett B, Townley L, Post V, Evans RE, Hunt R, Peeters, L, Richardson S, Werner A, Knapton A and Boronkay A (2012) Australian Groundwater Modelling Guidelines. Waterlines report 82, National Water Commission, Canberra. 203pp. http://webarchive.nla.gov.au/gov/20130420190332/http://archive.nwc.gov.au/library/waterlines/82.

David K, Timms W, Barbour S, Mitra R (2017) Tracking changes in the specific storage of overburden rock during longwall coal mining. Journal of Hydrology, 553, 304–320. https://doi.org/10.1016/j.jhydrol.2017.07.057

HEC (2018) Tahmoor South Project Surface Water Impact Assessment. Prepared for Tahmoor Coal. December 2018. Presented as final part of Appendix J to the Tahmoor Coal Project Environmental Impact Statement. 98pp.

HydroSimulations (2018) Tahmoor South Project EIS: Groundwater Assessment. Prepared for Tahmoor Coal. December 2018. Presented as Appendix I to the Tahmoor Coal Project Environmental Impact Statement. 280pp.

Independent Expert Panel for Mining in the Catchment (IEPMC) (2018) Initial report on specific mining activities at the Metropolitan and Dendrobium coal mines. Prepared for the NSW Department of Planning and Environment. 12 November 2018.

Middlemis H, Merrick N, Ross J, and Rozlapa K (2001) Groundwater Flow Modelling Guideline. Prepared for Murray–Darling Basin Commission by Aquaterra. January 2001. 133pp. www.mdba.gov.au/sites/default/files/archived/mdbc-GW-reports/2175_GW_flow_modelling_guideline.pdf.

Middlemis H and Peeters L (2018) Uncertainty analysis—Guidance for groundwater modelling within a risk management framework. A report 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. 74pp. 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. National Centre for Groundwater Research and Training, Australia. April 2019. 87pp.

NSW Chief Scientist and Engineer (2013) NSW Chief Scientist and Engineer, 2013. Thirlmere Lakes Inquiry – Review of the Final Report of the Independent Committee. February 2013. http://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0020/29621/CSE-Review-of-Thirlmere-LakesInquiry-Final-Report.pdf

Office of Environment and Heritage (2016) The mysterious hydrology of Thirlmere Lakes. A report by Thirlmere Lakes Inter-Agency Working Group. November 2016.

Rau GC, Acworth RI, Halloran LJS, Timms WA, Cuthbert MO (2018) Quantifying compressible groundwater storage by combining cross-hole seismic surveys and head response to atmospheric tides. Journal of Geophysical Research: Earth Surface, 123. https://doi.org/10.1029/2018JF004660

Riley S, Finlayson M, Gore D, McLean W and Thomas K (2012) Thirlmere Lakes Inquiry – Final Report of the Independent Committee. Independent Thirlmere Lakes Inquiry Committee unpublished report, October 2012, 474pp. www.environment.nsw.gov.au/resources/water/ThirlmereReport2012.pdf

SCT (2013) Review of the Hydraulic Conductivity and Geotechnical Characteristics of the Overburden at Tahmoor South. Prepared for Tahmoor South Project. 4 December 2013.

SCT (2014) Longwall 10A Height of Fracture Borehole for Tahmoor South Project – Observations, Measurements, and Interpretation. Prepared for Tahmoor South Project. 7 March 2014.