TAHMOOR SOUTH COAL PROJECT GROUNDWATER ASSESSMENT INDEPENDENT REVIEW

Prepared for:	**NSW Department of Planning Industry and Environment**	**24 April 2020**

HydroGeoLogic

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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)
Version 3	25 March 2020	Addendum re Amended Project Report (APR Feb 2020)
Version 4	24 April 2020	Further comments re surface cracking & fault structures

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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, updated Amended Project layout).

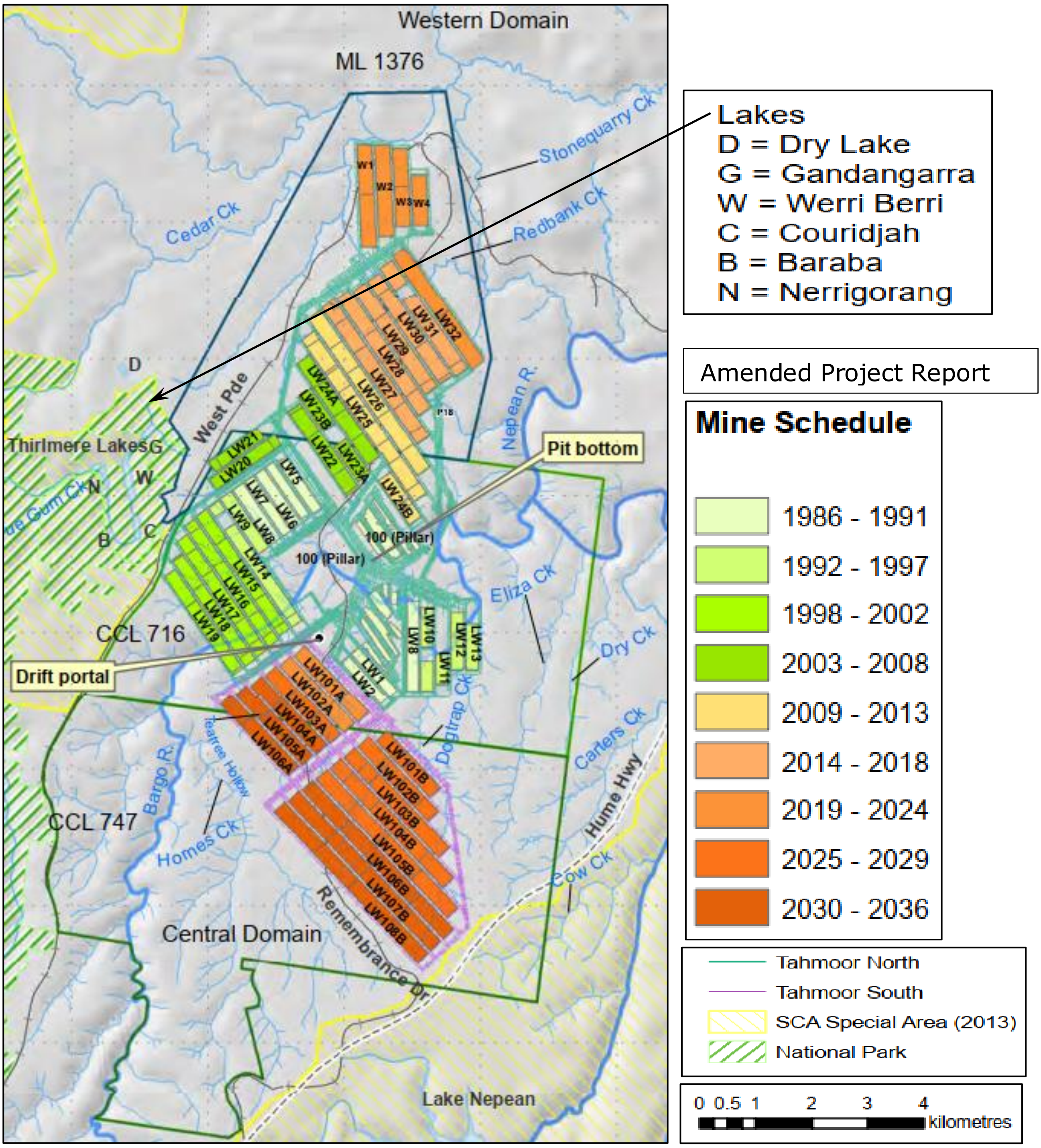


Figure 1 - Tahmoor Mine and Thirlmere Lakes (after HydroSimulations 2020)

The Tahmoor South ('Central Domain') Amended project targets the Bulli Seam coal resource at about 319-423 metres depth, with 14 longwall panels having a maximum cutting height of 2.6 metres (similar to Tahmoor North) and widths of 285 metres (HydroSimulations 2020, Table 2-2)(Tahmoor North widths are 283 m since panel 22). Tahmoor South has an expected mine life of about 13 years (2022-2035), planned to follow on after cessation of mining at Tahmoor North.

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. These mines form part of the cumulative assessment of groundwater impacts. Further east/south again are the Russell Vale, Wongawilli/Eloura, Avondale and Huntley operations.

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. The document version table (contents page) shows that the 2019 review of the EIS assessment (HydroSimulations 2019) was updated and revised in 2020 in relation to the Amended Project Report (APR) assessment (HydroSimulations 2020).

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 are the two groundwater assessment reports (often 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.

- HydroSimulations (2020) Tahmoor South Amended Project Report: Groundwater Assessment. Prepared for Tahmoor Coal, February 2020. Presented as Appendix C to the Tahmoor South Amended Project Report (APR), February 2020.

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).

During the EIS process prior to the Amended Project Report (AECOM 2020), additional information on the EIS groundwater assessment was provided in 2019 by HydroSimulations via a presentation at the then Department of Planning and Environment (DPE) offices on 2 April 2019, also attended by the then 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 version 2 of this review report. Most issues related to report documentation, and HydroSimulations indicated that action was in hand via an amended project process. Material issues at that stage 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; it appears that the APR has not completely addressed these issues, 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 slightly inconsistent 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 of Thirlmere Lakes are currently inadequately reported but appear *prima-facie* to be inconsistent with physical reality and lake-groundwater interaction processes.

Having said that, the effects are quite small in terms of the groundwater drawdown and flux volumes involved, as discussed in more detail later, and the groundwater assessment is considered adequately fit for purpose.

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 (Amended) Coal Project hydrogeological and groundwater modelling assessment (HydroSimulations 2018, 2020) is fit for the purpose of mine dewatering environmental impact assessment (including cumulative impacts) and informing management strategies and licensing.

Minor flaws have been identified in the methodology and results of the GoldSim water balance modelling for Thirlmere Lakes, and the report details (HEC 2018) are inadequate in my opinion. However, the rates and volumes of exchange fluxes between the lakes and groundwater are relatively small and not subject to significant uncertainty, 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 re water take from streams.

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

Question	Y/N	Comments re Tahmoor groundwater model 2019-20
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. EIS issues resolved via Amended Project Report. GoldSim water balance analyses (by HEC 2018, 2020) 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 but results adequate for impact assessment.

Question	Y/N	Comments re Tahmoor groundwater model 2019-20
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 (HEC 2018, 2020) conceptualisation questionable but results adequate for impact assessment.
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/DPIE Water re modelling of shallow surface cracking, transient watercourses, private bore extraction and improved model calibration performance have been addressed by Amended Project Report (HS 2020). GoldSim model implementation questionable but results adequate for impact assessment.
6. Is the model calibration satisfactory?	Yes	Automated PEST and manual groundwater model calibration over period of significant hydrological variability 1980-2019 which helps minimise non-uniqueness. Sound calibration performance to multiple criteria: a) matches to groundwater levels (SRMS error 2.8%, weighted); b) matches to existing Tahmoor mine inflows (1-4 ML/d over 1995-2019; HS fig 4-14), and to flow/salinity of discharge to LDP1 (HS fig 5-11), 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 (2008-2019), with divergences cogently justified with reference to measurement errors, spatial & temporal discretisation effects & structural issues. Time series matches at Thirlmere Lakes bores not improved by Amended Project Report. GoldSim model calibration questionable; e.g. Nerrigorang lake water levels too low by 1m in HEC (2020) Fig 54 compared to HS Fig 3-16); Nerrigorang only losing; volume mis-matches Figs 56 & 59 and modelled lake level not plotted so detailed assessment of GoldSim performance not possible.
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	Groundwater 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 at EIS stage re levels applied to Lakes (HS 2018 Table 5-5) and Thirlmere Lakes processes applied to GoldSim water balance model (HEC 2018 section 8, Table 6 & 7) have not been addressed by Amended Project Reports (HS 2020 Table 5-6; HEC 2020 s.7, Tables 11 & 12).

Question	Y/N	Comments re Tahmoor groundwater model 2019-20
8. Do the model predictions conform to best practice?	Yes	Overall methodology, with refinements via Amended Project Report is consistent with best practice and suitable for dewatering impact assessment, management plans and licensing decision making. Future predictions of Tahmoor South inflows of 4-8 ML/d are consistent with existing Tahmoor experience (i.e. model projections are not widely 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, and Ditton & Merrick model also considered, helping address structural uncertainty). 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, higher Kh for Hawkesbury Sandstone, 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, 2020) is fit for the purpose of mine dewatering environmental impact assessment (including cumulative impacts) and informing management strategies and licensing, notably including the Amended Project Report outcomes. Minor flaws have been identified in the methodology and results of the GoldSim water balance modelling for Thirlmere Lakes, and the report details (HEC 2020) are inadequate in my opinion. However, the rates and volumes of exchange fluxes between the lakes and groundwater are relatively small and not subject to significant uncertainty, 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 re water take from streams.

3. Discussion

The groundwater assessment and modelling reports (HydroSimulations 2018, 2020) are well-written, lucid and logical, and provide 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 were identified during the peer review of the 2018 EIS and Groundwater Assessment, but these were addressed by the Groundwater Assessment for the Amended Project Report (HydroSimulations 2020), notably the groundwater modelling of shallow surface cracking in potential subsidence areas, transient watercourses (i.e. seasonally variable water levels), private bore extraction and improved model calibration performance.

Some issues with the lake processes applied to the GoldSim water balance model for the Thirlmere Lakes (HEC 2018 section 8), also discussed in section 3.1 below, were not addressed by the Amended Project Report (HEC 2020 section 7). 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.

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 increased the Nepean Fault transmissive properties and also assumed a transmissive T2 fault with extension to the Thirlmere Lakes alluvium. Other sensitivity runs considered an increased height of connected fracturing and increased hydraulic conductivity of the Hawkesbury Sandstone. Based on information available, the Tahmoor modelling and results are considered fit for purpose.

The APR (HS 2020) states at section 3.10.3 (p.55) that "The only geological structures within the Study Area that are known or thought to act as conduits to flow are the Nepean Fault (high confidence of this behaviour, based on observations regarding inflows to Tahmoor North), and possibly in parts of the T2 fault (within Tahmoor LW16)". Further discussion on faulting is presented in various sub-sections below.

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, 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 (monitoring and modelling, plus research into Thirlmere Lakes) 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 were also refined in the Amended Project Report, based on issues raised during the EIS review and by DoI/DPIE Water, although the model performance in this area did not improve via the APR. 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'

Please note that, while there is a focus of review commentary on the modelling performance in relation to the lakes due to their ecological importance, data uncertainties affect our ability to comprehensively understand the lake-aquifer system (IEPMC 2018), and the drawdowns at the lake alluvium and the induced lake-aquifer exchange fluxes are also relatively small and are not significantly affected by modelling uncertainty.

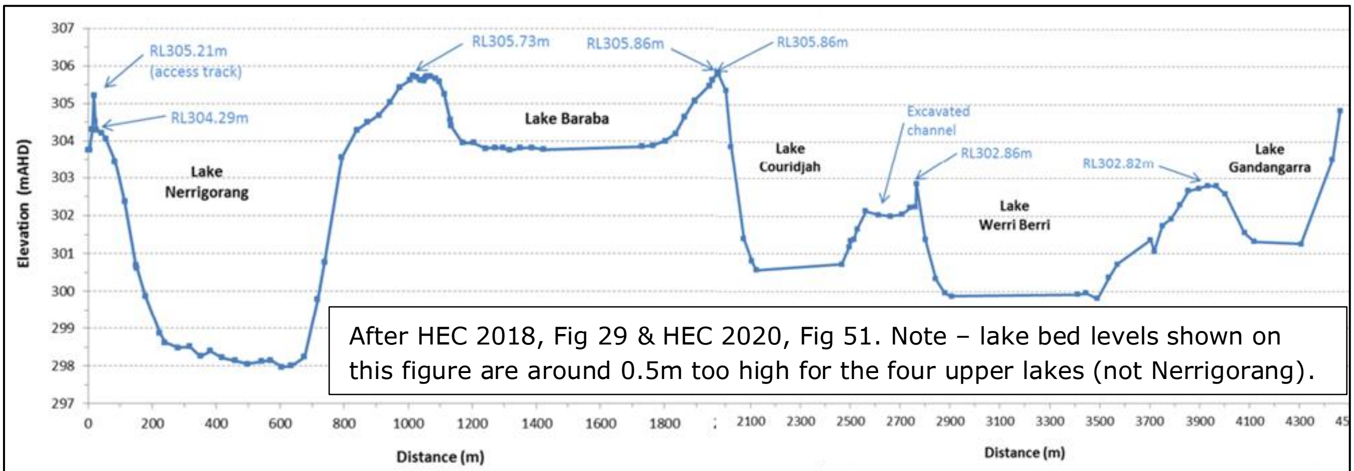
The Thirlmere Lakes are a series of shallow freshwater bodies located along a horseshoe bend in Blue Gum Creek, within the Thirlmere Lakes National Park, which is part of the Greater Blue Mountains World Heritage Area (Figure 1).

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), and thus unlikely to be impacted, 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, after HEC 2018 & 2020), 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 & 2020), which notes that these are for 'post-mining' conditions only (i.e. post-Tahmoor North mining).

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.



After HEC 2018, Fig 29 & HEC 2020, Fig 51. Note – lake bed levels shown on this figure are around 0.5m too high for the four upper lakes (not Nerrigorang).

Figure 2 - Thirlmere Lakes longitudinal section

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 the EIS groundwater assessment (HS 2018) in terms of 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). For the Amended Project Report, the groundwater model was updated with time-varying lake levels for the history-match period (HS 2020), but constant lake levels were again applied to the prediction period. This is justified with reference to the small volumes involved in the lake-aquifer exchange fluxes, whether or not the lakes are represented with time-varying levels.

The peer review of the EIS 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. These issues have not been addressed by the Amended Project Report, as discussed below, but this does not materially affect the groundwater model fitness for purpose.

3.1.1 Lake Gandangarra overflow level

HS 2018 section 4.4.3 and HS 2020 section 4.4.5 state that the Lake Gandangarra level was set to 304.6 mAHD in the predictive groundwater model scenarios (long term 'median' level). This is about 1.8 m higher than the overflow point to Lake Werri Berri (302.82 mAHD). While this means that Lake Gandangarra is effectively kept above full for all the predictive simulations, the groundwater model implementation assumes high vertical walls for each lake, which means that it does not overflow as such, it simply over-estimates leakage from the lake due to the higher driving head (and yet the fluxes involved are quite small). The other two upper lakes that connect with Gandangarra above its overflow (Werri Berri and Couridjah) have predictive levels specified below their overflows.

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 any HS or HEC report. Subsequent discussion on this issue in 2019 at the EIS stage identified that the four upper lakes have bed levels around 0.5 metres lower in the groundwater 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. It is worth noting that the model results are largely unaffected by this issue, as they are based on consistent lake bed information, measured lake levels during the history match, and a steady 'median' lake level for predictions.

3.1.3 Lake level versus flux relationship

HS 2020 Table 5-6 (same values as HS 2018 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, 2020). However, the range of lake levels specified in the groundwater model for the purpose of determining the lake level versus flux relationship is not consistent with the lake bed or overflow levels (e.g. the minimum level of 298 mAHD in the tables for the upper four lakes is lower than their bed levels, which are all above 299.4 mAHD).

Subsequent discussions in 2019 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 inadequate (HEC 2018, 2020) 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 that is used in the GoldSim modelling.

HS 2020 Table 5-6 (and HS 2018 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 Nerrigorang 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 that is used in the GoldSim model (but this does not affect the setup for other groundwater modelling scenarios). This review finds that the GoldSim methodology does not form a good example of best practice, but the results provide reasonable estimates for the impact assessment purpose.

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.

The lack of a potentially gaining flux in the Lake Nerrigorang column of HS 2020 Table 5-6 (HS 2018 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 variably losing-gaining lake. There is a lack of detail provided in the HEC (2018, 2020) 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. These issues were raised at the EIS stage, and they have not been addressed by the Amended Project Report.

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).

Class		Data		Calibration		Prediction		Quantitative Indicators
1 (simple)		Not much / Sparse coverage		Not possible.		Timeframe >> Calibration		Predictive Timeframe >10x Calib'n.
	~	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%)
		Poor aquifer geometry.		Targets incompatible with model purpose.		Transient prediction but steady-state calibration.		Properties <> field values.
		Basic/Initial conceptualisation.						Poor performance stats / no review
2 (impact assessment)	~	Some data / OK coverage.	~	Weak seasonal match.		Predictive Timeframe > Calib'n.		Predictive Timeframe = 3-10x Calib'n.
	~	Some usage data		Some long term trends wrong.		Different stresses &/or periods.		Predictive Stresses = 2-5x Calib'n.
	√	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)
	√	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.
3 (complex simulator)	~	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.
	√	Local climate data & baseflows.	~	Most seasonal matches OK.		Good validation (or all simulations constrained by data)	√	Mass balance < 0.5% (all periods)
	√	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))

Table 2 – Tahmoor South groundwater model confidence level

3.3 Calibration and Prediction

The history match calibration applied to 1980-2019, 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 2.8% weighted 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 acceptable for the data quality/availability, although the time series matches at the Thirlmere Lakes bores were not improved via the Amended Project Report process. 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 4-7 to 4-9) 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 4-6 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 4-8 shows that the vertical distance between the surface cracking zone (depth <30m) and the height of connected fracturing (calculated by the Tammetta method) ranges from about 130 to 240 metres across Tahmoor South (lower in the south where the cover is thinner), with the fracturing not extending up into the lower Hawkesbury Sandstone (layer 3 of the model) for the Amended Project.

Uncertainty scenarios were conducted by applying a 30% factor to the Tammetta-calculated height of fracturing, and a separate run to increase Hawkesbury Sandstone hydraulic conductivity by factors of 4.0, 3.5 and 5.4 (applied to the lower, mid and upper HBSS, resp.). The results were not very sensitive to the HBSS parameters, other than the increased height of fracturing resulting in mine inflows more than doubling from the base case of around 2-8 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 (and the panel width has indeed been reduced for the Amended Project), the statement does not expound upon 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 EIS model (HS 2018) does not include shallow surface cracking, although it is noted that the Amended Project Report (HS 2020) model now includes surface cracking (see further discussion in the next section). However, IESC advice then extended the false premise of the 'underestimation' of the height of fracturing (i.e. apparently without accounting for other factors that influence the HoF or without carefully considering the excellent data on HoF effects at Tahmoor TBF040c above longwall 10A; HS figs 3-34 & 4-11) to suggest that the EIS groundwater assessment had 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. A shallow surface cracking horizon (<30m deep) has been included in the Amended Project Report modelling (HS 2020), but the separation distance between the top of the HoF and the surface cracking still exceeds 130m, which greatly limits the potential for connectivity from shallow to deep horizons, consistent with longwall 10A data.

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 Surface Cracking and 'Baseflow Capture'

The maximum effect of 'baseflow capture' was defined for this project as the combined effect of the maximum reduction in baseflow to creeks and maximum increases of induced leakage from creeks occurring at any time during the predictive run for the sub-catchments reporting to specific assessment sites (HS 2020, section 5.7). The baseflow capture results are summarised in the APR Table 5-5 for the base case run that incorporates surface cracking. For example, the peak baseflow capture for Blue Gum Creek, which hosts the Thirlmere Lakes, was predicted to increase to 0.015 ML/d for the APR from the 0.011 ML/d estimated in the 2018 EIS. However, the mean impact of the Tahmoor South project APR overall is reported as around 0.005 ML/d, the same as for the 2018 EIS assessment. This is consistent with the conceptual model that any water loss from streams due to surface cracking would tend to remain within the higher hydraulic conductivity surface cracking zone and return to surface down-gradient, rather than moving downwards through the lower permeability units in the constrained zone towards the top of the HoF that is more than 130m deeper. This means that, while there may be greater baseflow capture for sub-catchments immediately overlying the longwall panels where the surface cracking parameters are applied (e.g. Dog Trap Creek and Tea Tree Hollow), there should not be significant impacts across the overall catchments.

There is a noted improvement in the APR reporting of these results; for example, Blue Gum Creek is listed in Table 5-5 of the APR, but was missing from the corresponding Table 5-4 of the EIS. There are differences between the APR and EIS results, but that cannot be attributed solely to applying surface cracking to the APR model. Due to the dynamic interactions between groundwater and surface water processes and the interplay of model parameter effects, it is not possible to unpack the cause of the differences due to any one factor, such as the reduced panel width and thus reduced HoF, or the surface cracking, or the transient levels applied to the creek features.

The groundwater model results were used as input to the surface water assessment, and the implications of the impacts are discussed there, with reference to flow-duration curves and so on. Further comment on surface water impacts is not within the scope of this groundwater review.

3.6 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, 2020) 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 the Amended Project Report refinements did not substantially change the predicted effects, as was expected. 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). Such reasoning was outlined in the groundwater assessments (HS 2018, 2020), and is expounded in the following points.

The groundwater assessment is based on a mature conceptualisation, 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).

The selected sensitivity scenarios are targeted at key uncertainties (e.g. as discussed herein: increased HoF, transmissive faults, notably the T2 fault, increased HBSS conductivity, third party bore pumping) and cumulative impacts that would tend to over-estimate mining impacts. The results provide suitable information to assist decision makers. The sensitivity analysis 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.

While the assessment has adequately investigated the mapped faults in the area (Figure 3, next page), it could be argued that the assessment has not investigated the potential for fault connection between Tahmoor South and Lake Nerrigorang.

It could be argued that investigation of such a potential connection is warranted in the context of the high value Thirlmere Lakes. Furthermore, it is noted that Lake Nerrigorang is the only lake that exhibits hydraulic connection with the water table (i.e. it is variably gaining/losing while all other lakes are above the water table and are losing). This means that there is theoretical potential for enhanced leakage from Lake Nerrigorang (and only that lake) in response to drawdown that may propagate via a theoretical fault that may connect with Tahmoor South.

A hypothetical fault connection has already been investigated in terms of extending the mapped length of the T2 fault to connect the mine workings with the Thirlmere Lakes alluvium, and applying increased hydraulic conductivity parameters to the T2 fault (Scenario v6TR073 listed in the APR Table 5-1). This scenario also increased the parameters for the other mapped faults proximal to Tahmoor; Central, Western, southern Nepean and T-faults. The model results were not sensitive to this scenario; in relation to the T2 fault extension because the Thirlmere Lakes are losing systems already at the maximum rate (except for the losing/gaining Lake Nerrigorang, which is 1-2km distant from the T2 alignment).

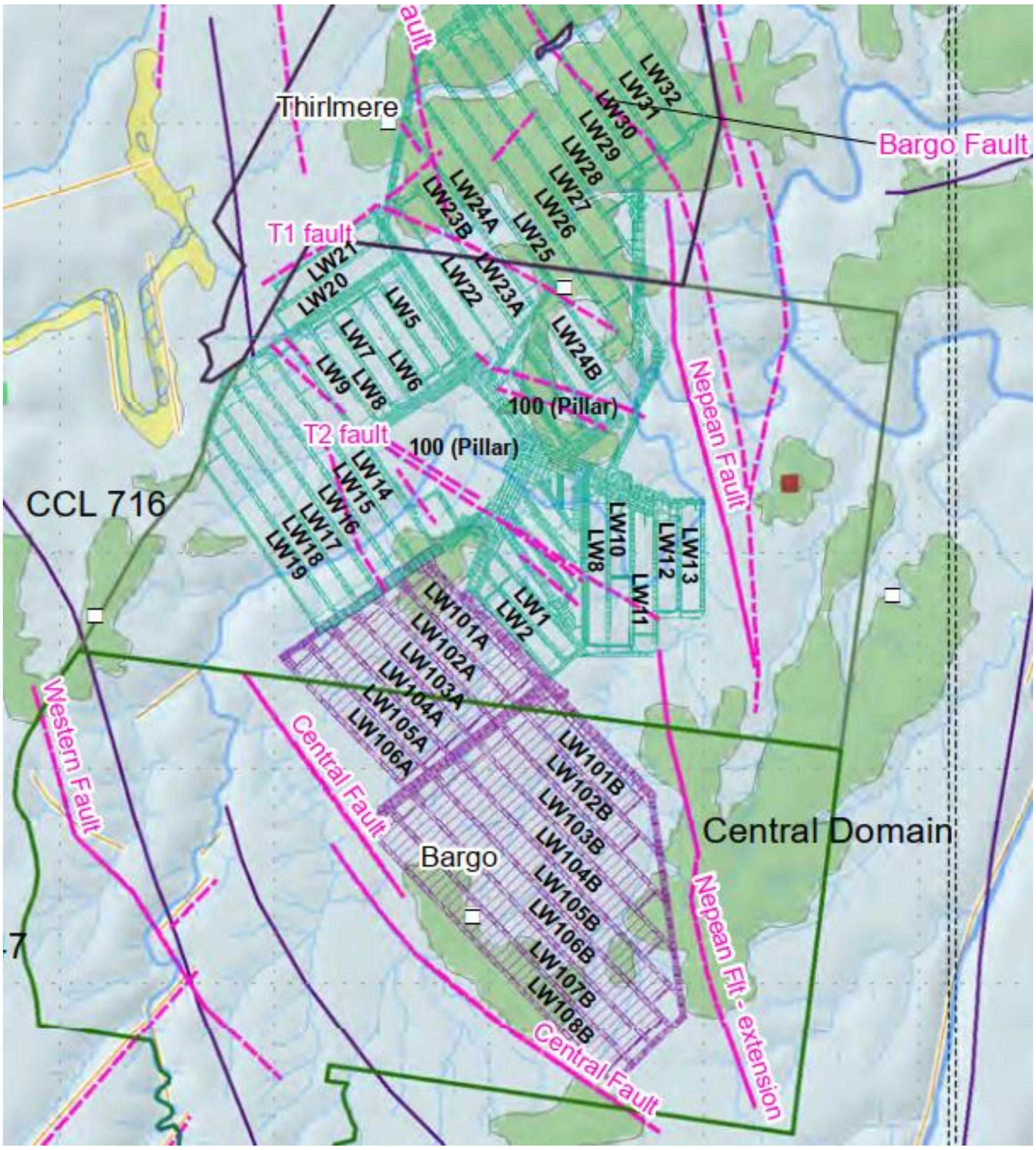


Figure 3 - mapped faults and Tahmoor longwall layout (HS 2020, fig. 3-11)

A similar scenario, albeit more hypothetical, could be envisaged to invoke a transmissive fault connection from Tahmoor South to Lake Nerrigorang. The obvious candidate with an appropriate orientation is the mapped Central Fault, the northern extent of which is level with (but west of) the northern end of the Tahmoor South panels, about 4km south the lake. It is understood that the panel layout is designed to avoid the Central Fault. While the Tahmoor model has already applied high values of hydraulic conductivity to the Central Fault as part of the T2 fault scenario, this test did not extend the fault north towards the lakes (because that is not consistent with the mapping).

This reviewer believes that the assumptions required to invoke such a hypothetical scenario regarding fault connection to Lake Nerrigorang are not justified, given that:

- there are no mapped faults that connect the lake to the mine workings and there is no secondary data (e.g. hydraulic heads or gradients) that indicate the effects of any fault in that area;

- most faults in the area are characterised as not transmissive, except for major faults (e.g. Nepean, Central), so logic would hold that there should be some evidence for such a major transmissive fault.

Having said that, it would not be a major exercise to conduct such a study of potential fault connections as part of an expanded uncertainty assessment.

A linear uncertainty analysis of the horizontal and vertical hydraulic conductivity calibration parameters (Kh and Kz) was conducted for all units extending 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/Stanwell Park Sandstones, but low index values below that and also for the alluvium Kz. 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 the alluvium and the 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 increased Tammetta-calculated height of fracturing (HoF), more transmissive faults, increased Hawkesbury Sandstone hydraulic conductivity, and third party bore pumping (the EIS (HS 2018) also considered 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 EIS model did not include non-mining groundwater pumping (HS 2018), this is arguably warranted/justified because there is substantial data uncertainty on the actual extraction volumes and the pumping schedules. The Amended Project Report (HS 2020) now includes pumping from registered bores as a predictive sensitivity scenario, with results indicating greater drawdown effect at Thirlmere Lakes due to such extraction than is predicted from the Tahmoor South or indeed the cumulative mining scenarios (HS 2020, Table 5-4). 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 invokes further data uncertainty, and results in a prediction of non-mining drawdown impacts that cannot 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 2020 Tables 6-4 and 6-5, which are 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.

3.7 Other Issues

While the EIS report (HS 2018) is generally well-written, there were some minor matters where the report was deficient in its explanation or justification, or where some graphical figures require some improvement. These issues were raised via an issues log that was discussed with the principal modeller, facilitated by DPE, and the issues were largely addressed in the Amended Project Report (HS 2020).

There are some key issues that have been raised by others, with whom this reviewer concurs, that were also addressed by the APR (HS 2020):

- Shallow surface cracking: while advice from the IESC (2019) pointed out that shallow surface cracking had not been included in the EIS model, HydroSimulations indicated at the meeting on 2nd April 2019 that action was in hand to propose additional scenarios to address the oversight. The Amended Project Report (HS 2020) included surface cracking in all scenarios.
- Transient Watercourses: the HS 2018 report conceptualised 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 were implemented in the (EIS) model as gaining only, while larger downstream rivers could be variably losing or gaining, depending on whether groundwater levels are below or above the stream level (HS 2018, s.4.4.2); HydroSimulations indicated at the meeting on 2nd April 2019 that action was in hand to revise the model to address the oversight, and this has been well documented in the Amended Project Report (HS 2020, s.4.4.4), including invoking parameters to represent the shallow surface cracking horizon.

- Third party bore extraction: the Amended Project Report now includes pumping from registered bores as a predictive sensitivity scenario (HS 2020, s.5.2 and Table 5-4), as discussed in section 3.6 above.

4. Conclusion

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.

Minor flaws have been identified in the methodology and results of the GoldSim water balance modelling for Thirlmere Lakes, and the report details (HEC 2018) are inadequate in my opinion. However, the rates and volumes of exchange fluxes between the lakes and groundwater are relatively small and not subject to significant uncertainty, 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 re water take from streams.

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 39 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/DPIE).
  - 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); Dr Merrick was engaged in 2020 by the Murray-Darling Basin Authority as the independent reviewer of the EM1 model update being conducted by EMM Consulting with Hugh Middlemis in the role of technical director.
- 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

AECOM (2020) Tahmoor South Amended Project Report. Prepared for Tahmoor Coal, 20 February 2020.

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.

HEC (2020) Tahmoor South Amended Project Surface Water Impact Assessment. Prepared for Tahmoor Coal. February 2020. Presented as final part of Appendix D to the Tahmoor South Amended Project Report. 140pp.

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

HydroSimulations (2020) Tahmoor South Amended Project Report: Groundwater Assessment. Prepared for Tahmoor Coal, February 2020. Presented as Appendix C to the Tahmoor South Amended Project Report. 284pp.

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.