TAHMOOR MINE

Groundwater Modelling Plan

Prepared for:

SIMEC Mining
2975 Remembrance Driveway
Tahmoor NSW 2573

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BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with SIMEC Mining (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of the Client. No warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR.

SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work.

DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
665.10010-R03-v2.0	3 August 2020	Braiya White, Jackson Newton, Will Minchin (Watershed HydroGeo)	Ines Epari	Ines Epari
665.10010-R03-v1.0	28 July 2020	Braiya White, Jackson Newton, Will Minchin (Watershed HydroGeo)	Ines Epari	Ines Epari

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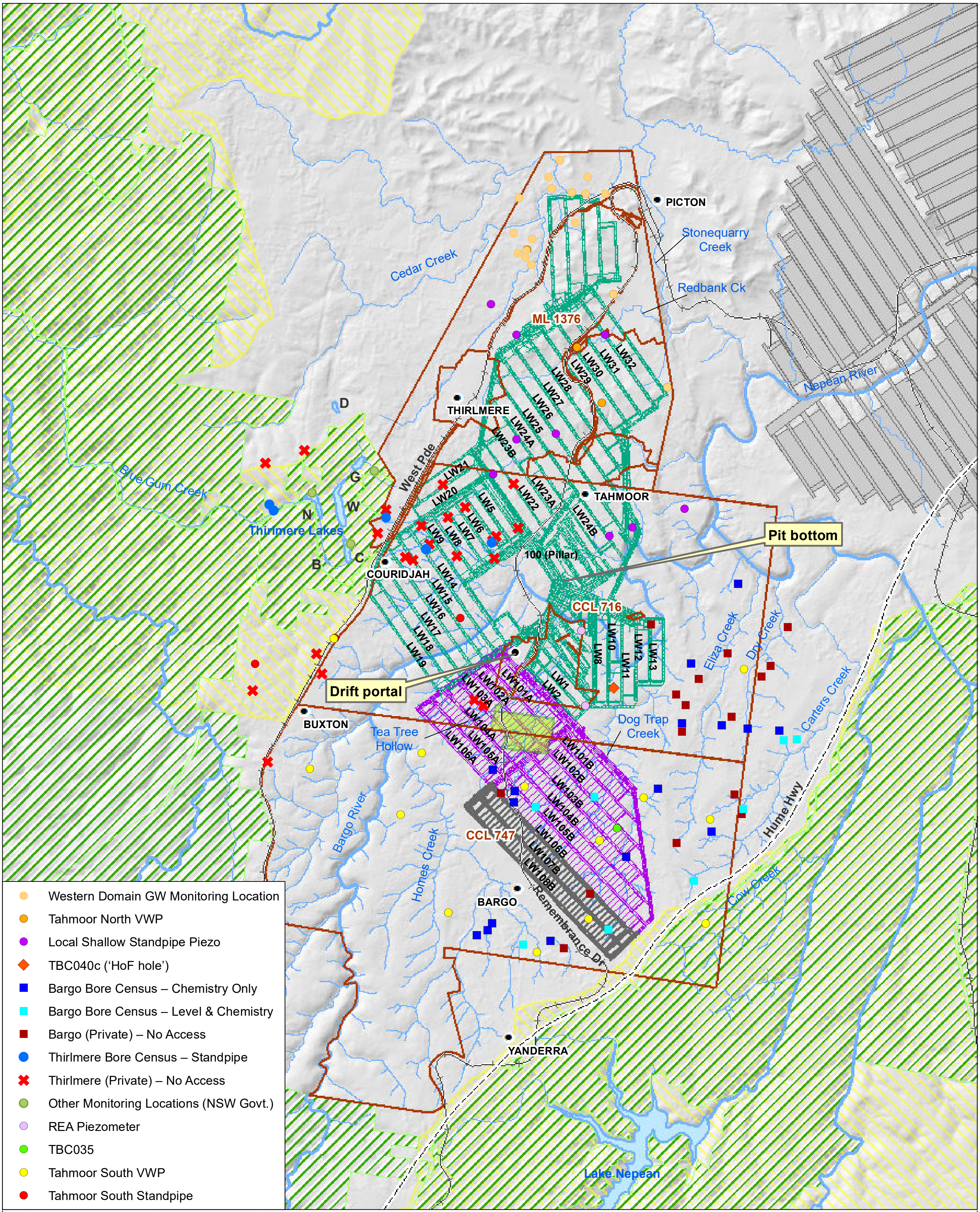
1 Introduction

SLR Consulting Australia Pty Ltd (SLR) was engaged to develop a Groundwater Modelling Plan for the Tahmoor Coal Mine on behalf of SIMEC GFG.

The Tahmoor South Project (the Project) is an underground coal development project targeting the Bulli Coal seam coal resource within Consolidated Coal Leases (CCL) 716 and 747 in the Southern Coalfield, 80 km southwest of Sydney (see **Figure 1**). Tahmoor Coal Pty Ltd (Tahmoor Coal) is seeking development consent for the continuation of mining at Tahmoor Mine, extending underground operations and associated infrastructure south, within the Bargo area. The proposed development seeks to extend the life of underground mining at Tahmoor Mine.

This Groundwater Modelling Plan (GMP) has been developed in response to recommendations made by the NSW Department of Planning, Industry and Environment (DPIE) for the Tahmoor South Coal Project (SSD 8445). Section 2.2 of the joint submission made by DPIE-Water and the Natural Resource Access Regulator (NRAR) (DPIE-Water, 2020) requested that SIMEC develop a '*clear plan for model re-build and calibration*', pending approval of the Tahmoor South Project.

The plan to address this recommendation and the specific tasks required to do so will be outlined within this document.



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Coordinate System:	GDA 1994 MGA Zone 56
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SLR

- Town
- Watercourses
- Railway
- Tahmoor / Tahmoor North
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- Tahmoor South Workings Removed in Second APR
- Lakes
- Tahmoor Coal Titles
- National Park
- WaterNSW Special
- Wirrimbirra Sanctuary
- Other Mine Workings

Lakes:
D = Dry Lake
G = Gandangarra
W = Werri Berri
C = Couridjah
B = Baraba
N = Nerrigorang

TAHMOOR COAL
TAHMOOR SOUTH PROJECT

Mine Layout and Groundwater Monitoring Locations

FIGURE 1

H:\Projects-SLR\620-BNE\665-WOL\665.TAH05 Tahmoor GWMP\GIS\66510010 Fig1_66510010_PeerReviewRTS.mxd

2 Statutory Requirements

The DPIE-Water has requested that the Numerical Groundwater Model for Tahmoor Coal Mine be rebuilt within two years of the project determination (Section 2.4 DPIE-Water, 2020). Attachment B of the submission outlined the specific recommendations regarding the rebuild of the Groundwater Model. These recommendations are outlined below under three key headings – Model development, Calibration and Forecasting. These headings refer to the three major phases of numerical groundwater model development.

Model development:

- Refinement of the model mesh to implement an unstructured grid approach.
- Refinement of 'solver settings' applied to the numerical model to address issues that arose in relation to model confidence, performance and predictions presented for scenarios testing the sensitivity of results to the stage height applied to lakes.
- Incorporation of data and findings from the NSW government's Thirlmere Lakes Research Program (TLRP). This will be important for setting context and informing the conceptual model.
- Adoption of transient potential evapotranspiration estimates in modelling.
- Incorporation of any future geological structure mapping and information that is relevant to transmission of groundwater effects.

Calibration:

- Better representation of heterogeneity using available data and 'pilot point' parameterisation and calibration. At the same time, the relationship of properties, especially Kh, to depth should be accounted for.
- Incorporate new data, including any from TLRP, for model calibration.
- Calibration to historical surface water losses around Tahmoor North, if the gauging data and analysis of that allows.

Forecasting:

- Inclusion of additional uncertainty analysis scenarios that investigate parametric sensitivity of applied Riverbed conductance (used for simulating watercourses and lakes/reservoirs).
- Inclusion of additional uncertainty analysis scenarios that investigate parametric sensitivity of applied Drain conductance (used for mine dewatering).

3 Consultation

The first Groundwater Assessment for the Tahmoor South Project EIS was prepared by HydroSimulations in 2018 (HydroSimulations, 2018). Following the submission of the project EIS to the NSW State Government for approval a number of submissions were made regarding the groundwater assessment and modelling predictions. In response to this a revised EIS was required to be prepared incorporating the relevant recommendations. The Tahmoor South Amended Project Report (APR) Groundwater Assessment was prepared by HydroSimulations in 2019 (HydroSimulations, 2019). HydroSimulations was incorporated into SLR in March 2019. The APR report was recently revised following further comments (HydroSimulations, 2020).

Responses to the Tahmoor South APR were received in June 2020 from the NSW DPIE, and are being addressed in EMM (2020a). This Groundwater Modelling Plan (GMP) has been developed in response to Section 2.2 of recommendations made by the DPIE-Water for the Tahmoor South Coal Project (SSD 8445).

Further amendments to the APR mine plan are now proposed, which will be described in the Second Amended Project Report (EMM, 2020b). Those amendments are not relevant to this plan, other than there will be a requirement to incorporate and represent those in future modelling.

4 Aquifer Identification

A brief summary of the geology is provided here. More detail is available in various reports for Tahmoor Coal (e.g. HydroSimulations, 2020).

4.1 Geology

The Tahmoor Mine is situated within the Southern Coalfield in the sedimentary Sydney Basin (University of Wollongong [UOW], 2012). Locally at the Tahmoor Mine, the underlying geology consists of interbedded Permo-Triassic strata, primarily sandstones, siltstones, claystones and coal seams, with the Bulli and Wongawilli Coal Seams being the main economic seams in this area.

The strata dips down towards the north and the centre of the Sydney Basin, with a mild dip in the east towards the Illawarra Escarpment. The fluvially-deposited Triassic Hawkesbury Sandstone is the dominant outcropping stratigraphic unit in this region and has thicknesses of up to 300 m. The Wianamatta Formation, composed of soft shales, overlies the Hawkesbury Sandstone and is more apparent to the north of the mine. Due to the high silica content of this sequence, the Hawkesbury Sandstone exhibits higher resistance to erosion than the Wianamatta Formation. As such, soil production on the Hawkesbury Sandstone is low and the sandstone is the common bed material for the watercourses in this region (UOW, 2012), with the Wianamatta Formation typically appearing as capping material at higher elevations.

The Bald Hill Claystone occurs at subcrop for much of the area, usually beneath a significant thickness of outcropping Hawkesbury Sandstone. Toward the west and the south this unit is closer to or at surface, or even eroded away, exposing the Bulgo Sandstone or older formations in the Narrabeen Group.

Within the Illawarra Coal Measures (ICM), the Bulli and Wongawilli Coal seams are the main deposits of economic significance in this region. The Bulli Coal Seam is the youngest coal seam of the ICM and is approximately 2-4 m thick. This is the seam targeted by Tahmoor Coal and the neighbouring Bulli Seam Operations (BSO) Mine. The Bulli Coal seam is present at depths of approximately 200 m near the Nattai River, deepening to around 400 m through Buxton and within the axis of the Camden Syncline. East of the syncline and toward the escarpment, the depth of this seam remains relatively constant. In a north-south direction, the seam is closest to surface in the south, and almost 500 m deep in the north. In the south, the shallower nature of the Permian Coal measures means that other coal seams, including the Wongawilli seam, are closer to the surface.

The region is dissected by several faults, folds, and dykes of volcanic origin, varying in age from Jurassic to Tertiary. The Nepean Fault is the major structural feature of interest to operations conducted by Tahmoor Coal. This fault is part of the Lapstone Structural Complex and extends 160 km from Bargo in the south to Penrith and Richmond in the north. The Nepean Fault has a throw of up to 26 m at the Bulli Seam within the Tahmoor South Project area (Velseis, 2013), and is likely not to be a single continuous fault, but a series of *en echelon* faults, which can be effectively mapped within a single linear fault zone. The Eastern Fault is the 'fault ramp' of the southern-most end of the Nepean Fault, where fault displacement is in the order of 5-10 m.

Recent mapping in SCT (2018) indicates that the Nepean Fault extends along the full length of the eastern edge of the Tahmoor North mine footprint and is approximately 10 km in length. This significant structural feature is known to be transmissive, and mine workings that intersect this zone can produce more water, i.e. be wetter than areas that are located away from this zone.

Other features of note are:

- the Camden Syncline, which plunges from south to north, and is located about 3.3 km east of the eastern-most Tahmoor South longwall panels, and more or less coincident with the Nepean River at this point;
- Bargo Fault, heading more or less west, which diverges from the Nepean Fault and crosses the mined area of Tahmoor North;
- the Central and Western Faults, which trend NW-SE, just off the proposed southern limit of the Tahmoor South longwalls. There are other smaller faults mapped within the extent of the historical Tahmoor workings. The alignment of the Central Fault is essentially congruent with the course of Horne's Creek, suggesting that the creek exists at this location due to the influence of this structural feature; and
- Victoria Park Fault, lying near to the west of the Tahmoor North Longwalls 26-31.

The 'T1' and 'T2' faults are present at the western edge of the previously mined out Tahmoor longwalls between the mine and the Thirlmere Lakes. These faults lie to the north and northwest of the proposed Tahmoor South longwalls. These faults are postulated by Pells Consulting (2011) to be:

- more continuous than suggested by the current mapping;
- more permeable than the host rock; and therefore:
- connect the area around (under) the Thirlmere Lakes with the Tahmoor Mine. This is pertinent to the historically mined longwall areas, namely potentially allowing hydraulic connection to the Lakes from:
    - Tahmoor Longwalls LW21-24/25, mined out in 2003-2008, along the T1 fault;
    - Tahmoor Longwalls LW14-16, mined out in the mid-1990s, along the T2 fault.

Tahmoor Coal confirmed that no unusual conditions were encountered when this area was mined. There is evidence that the T2 fault might be conductive at LW16, but not so at neighbouring longwalls.

Mount Tomah Monocline, and other monoclines (Nepean, Balmoral) with similar orientation to the Central and Western Faults, also lying to the south of the proposed Tahmoor South workings. Monoclines, unlike faults, are likely to have a continuation of the warped geological units (e.g. coal seams), rather than having these displaced and truncated.

Sill and dyke intrusions have been identified from surface mapping and drilling records.

4.2 Hydrogeology

The major hydrostratigraphic units that characterise the area around the Tahmoor Mine are the Sydney Basin Triassic and Permian rock units, with the Hawkesbury Sandstone being the primary aquifer. These aquifers fall within the *Sydney Basin Nepean Sandstone Groundwater Source* and have been classified as being 'Highly Productive' by the NSW Government based on considerations of bore yield and groundwater quality. The Bulgo Sandstone (within the Narrabeen Group) is the source of some water taken from this system; however, contributions are substantially lower. Other than mining and some gas extraction, there is little to no use from the Illawarra Coal Measures.

Further discussion on each of the key hydrogeological units relevant to Tahmoor and the greater region is included below.

4.2.1 Alluvium

The alluvium is composed of two main units – the Thirlmere Lakes alluvium and the Quaternary to modern alluvium.

The modern to Quaternary aged alluvium typically exists within watercourses to the north of the mine lease. Groundwater conditions are likely to be unconfined. Recharge to the alluvium is expected to be predominantly from rainfall and peak streamflow events.

The Thirlmere Lakes alluvium is Cretaceous in age and are positioned within the narrow valley of Blue Gum Creek, located to the west of the Tahmoor Mine. It has been described as 'laterised alluvium' (Moffit, 1999) and is characterised by clayey sands and sandy clays with maximum thicknesses of 40 m to 60 m. Investigations by Vorst (1974) and others, including the TLRP, show it is lithologically complex. Data from the recent and on-going TLRP and other literature may require incorporation into modelled geometry and properties of this alluvial unit. Recharge to this alluvium is likely to be dominated by direct rainfall recharge and leakage from the lake system.

4.2.2 Wianamatta Formation

The Wianamatta Formation shales have been largely eroded and are present as hill cappings overlying the Hawkesbury Sandstone in the northern region of the Tahmoor Coal leases. The shales have poor permeability and water quality, however, can lead to the development of springs in areas in contact with the Hawkesbury Sandstone.

4.2.3 Hawkesbury Sandstone

The Hawkesbury Sandstone is a porous rock aquifer of moderate resource potential. In areas where secondary porosity is apparent, such as in structural zones such as the Nepean Fault zone, higher resource potential can be achieved.

The groundwater in this unit generally flows in an east to north-easterly direction over the mine and is closer to the ground surface in areas where surface water drainage exists. As such surface drainage has the potential to contribute baseflow to the Hawkesbury Sandstone aquifer. Due to the number of watercourses surrounding Tahmoor Mine and the regional topography the depth from the ground surface to the water table is shallower compared to the surrounding region.

The Hawkesbury Sandstone exhibits a range of salinities (fresh to saline) with a median value of approximately 500 mg/L (GeoTerra, 2013a). Publicly available data from AGL's Camden Gas Project indicated an average TDS of about 380 mg/L for Hawkesbury Sandstone groundwater (Parsons Brinckerhoff, 2013). These values are supported by the data collected in the recent bore census for the Western Domain (GeoTerra, 2019), where three of the four samples of groundwater EC were <1,700 µS/cm (approx. 1,000 mg/L).

4.2.4 Illawarra Coal Measures

Groundwater levels in the Illawarra Coal Measures follows a regional south-to-north gradient. However, as this aquifer is targeted for coal extraction at Tahmoor and several other nearby mines this gradient is reversed indicating flow towards the relevant mine footprints. The radius of influence around the mine workings, in the Bulli seam, appears to be around 600-1,000 m. SCT (2013) also analysed groundwater pressures and observed pressure reduction at 700-1,200 m from the nearest longwall.

This aquifer is not targeted for use as the water quality is poor. The Illawarra Coal Measures have an average TDS of 11,000 mg/L and a range 3,200-27,500 mg/L was reported for groundwater from the Illawarra Coal Measures, which includes the Bulli Coal Seam.

5 Aquifer Monitoring

The Tahmoor Mine has an extensive groundwater monitoring network across the mine layout and surrounds. Much of the instruments used for the operational monitoring have been installed since 2012 or earlier. This section is intended to serve as a summary of the known monitoring capabilities at Tahmoor Mine. Future works will provide a more comprehensive summary of the groundwater monitoring that occurs at the site, with a focus on reviewing and, where necessary, revising monitoring around Tahmoor South.

5.1 Deep / full sequence monitoring

For the existing and approved Tahmoor North mine area, the monitoring network consists of five bores with multiple vibrating wire piezometers (VWP) in hydrostratigraphic units of various depths from the Bulli Coal Seam to Hawkesbury Sandstone. The monitoring frequency at these instruments is sub-daily. There is also one centreline bore with multiple VWP instruments located over LW10A (TBF040c). This is monitored monthly.

For the proposed Tahmoor South Project, 30 monitoring bores have been installed. 17 of these are 'dual' piezometer installations, usually monitoring the Bulli Coal seam and the Wongawilli Coal seam. The remaining 13 sites are VWP installations with between 5 and 11 instruments in each bore. A number of the VWP installations have ceased operating, and some are providing suspect data.

5.2 Shallow monitoring

There are nine shallow bores (P1-P9) that have been used for monitoring the effects of mining for Tahmoor North. Installation and monitoring of these instruments occurred progressively from 2004-05 to 2017, and all and all but two remain active. There are five shallow bores (P12-P17) that were installed in 2019 near the Tahmoor Western Domain, monitoring the shallow Hawkesbury Sandstone and regolith.

Further bore installations have been conducted along Redbank Creek (P10-P11, P19) and Myrtle Creek (P18, P20-P25) near Tahmoor North. The data loggers in these shallow bores have been recording groundwater levels since mid- to late-2019.

There are seven bores monitoring groundwater levels within the Reject Emplacement Area (REA1-REA7) at Tahmoor Mine. Groundwater level data was collected at REA1-REA2 from July 2013 to mid-2019 and commenced at RE3-REA7 since August 2019. Pit Area monitoring bores (PT1-PT4) located at Tahmoor North (early historical workings area) have two single measurements in September 2019. Note that PT3 collapsed on drilling and no piezometers was installed.

5.3 Government monitoring

In addition, there are four NSW Government monitoring bores at Thirlmere Lakes. These were installed in mid-2011 and monitor the shallow Hawkesbury Sandstone and/or alluvium. In future, data from additional monitoring bores may be available from the NSW Government (TLRP).

5.4 Water quality

Sampling of groundwater quality has been carried out at 29 local bores since early 2013, six of which are Tahmoor Coal monitoring bores and the remainder being private landowner bores (see GeoTerra, 2013a). Additionally, there is monitoring of water quality within deeper horizons of the stratigraphic sequence. This is done via sampling of TBC035 (see GeoTerra, 2013a) and also monthly sampling, since January 2012, of the water pumped out of the mine, which is primarily groundwater.

Monitoring of water quality at the discharge point (LDP1) has been carried out since 2008.

5.5 Data Management Procedures

Monitoring data should be collected and stored in databases (databasing software or spreadsheets) that allow data quality to be assessed at the time of collection and with a record of data quality that can be used to describe confidence for input to further analysis, including the numerical modelling process.

This may mean that entire records from certain monitoring instruments are identified as clearly suspect or 'bad' data and so not used, or where specific records or periods are identified in the same manner. Where possible, the QA process should be carried out once by those responsible for data collection and maintenance, and then again by any subsequent users of the data, with a centralised record data quality.

6 Conceptual Model

The conceptual hydrogeological model for the Tahmoor Coal Mine and surrounds has been developed using information derived from geological and topographical maps, seismic and airborne electromagnetic surveys, bore log geological data, packer testing, other regional hydrogeology reports, and data from the groundwater monitoring network. The following sections will discuss the key components of the conceptual groundwater model.

6.1 Hydraulic conductivity

Across all formations, hydraulic conductivity has a general trend of decreasing with depth. The trends of hydraulic conductivity measurements from the site indicate that the rock units can be set into three broad groups:

- The Hawkesbury Sandstone, which is relatively permeable, with secondary porosity from both natural porosity, such as joints and bedding planes, and subsidence induced fracturing above longwalls, contributing heavily to its ability to transmit water;
- The Narrabeen Group strata, which are relatively tight formations that are less permeable than the surrounding strata, especially the Hawkesbury Sandstone; and
- the Illawarra Coal Measures that are slightly more permeable than the overlying Narrabeen Group.

The Hawkesbury Sandstone and Bulgo Sandstone have the greatest potential as 'aquifers', although the Bulgo Sandstone exhibits a wide range of hydraulic conductivities based both on core and packer testing. The lower Scarborough Sandstone has a lesser potential to act as an aquifer.

Of the claystone units, all exhibit lower vertical conductivities (based on core testing) than the neighbouring sandstones, however packer testing does not indicate as much variability. This is possibly because the 'sandstone' units, which are typically much thicker than the claystone units, have laminations of siltstone and claystone within them, meaning that core samples taken from these units, and therefore the lithology tested, will be more variable. In the presence of secondary porosity, such as from jointing and bedding planes, packer testing is less affected by such differences in lithology because of the dominance of flow through this secondary porosity at the larger scales over which packer testing is effective.

Packer testing is considered more reliable for characterising horizontal hydraulic conductivity, while core testing of vertical conductivity is considered a good guide to characterising the lower bounds on vertical conductivity.

Sands in the upper horizons of alluvial deposits at the Thirlmere lakes will have, by implication, relatively high conductivity. However, the sandy clays which seem to dominate the rest of the alluvial sequence will be far less permeable.

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 North Longwall 16). Other mapped faults have been encountered during mining, with no observable increase in inflow, as is the case for most structures in the Southern Coalfield (Tonkin and Timms, 2015). Thus, most of the faults in the area are thought to act as barriers to flow, emphasising the conceptualisation that they are not impermeable, just less permeable than most of the surrounding rock mass.

6.2 Subsidence and deformation

Following an extensive review of literature and regional and site data the representation of subsidence and deformation in site conceptual and numerical model has been defined by several conceptual zones. These conceptual zones used to simulate the changes that occur to the geological strata around the Tahmoor Mine, are:

- the caved zone (including the extracted panel of coal);
- the fractured zone, consisting of:
    - a lower zone of vertically connected cracking;
    - an upper zone of disconnected-cracking, but where horizontal conductivity is enhanced;
    - the constrained zone; and
    - the surface cracking zone.

The current conceptualisation also considers a zone underlying the goaf, where unloading of 'floor' strata causes some deformation (Meaney, 1997 and Karacan et al, 2011). This has been termed this deformed "floor" strata.

The strata movements and deformation that accompany subsidence will alter the hydraulic and storage characteristics of aquifers and aquitards. As there will be an overall increase in rock permeability, groundwater levels will be reduced either due to actual drainage of water into the goaf or by a flattening of the hydraulic gradient without drainage of water in accordance with Darcy's Law.

The rocks in the connective-cracking part of the fractured zone will have a substantially higher vertical conductivity than the undisturbed host rocks, encouraging groundwater to move out of rock storage downwards towards the goaf. In the upper zone of disconnected fracturing the vertical movement of groundwater will be enhanced but should not be significantly greater than under natural conditions. This is consistent with observations by SCT (2014) at the "Height of Fracture" (HoF) hole, where it was clear that a downward gradient existed in the lower Hawkesbury Sandstone, but there was neither the connectivity nor gradient strong enough to alter groundwater levels to any observable degree within the Hawkesbury Sandstone.

The height of connected and disconnected fracturing are estimated based on the width of the longwall panels, cutting height and the depth of mining. Depending on these zones and the presence of low permeability lithologies, there can be a zone of 'disconnected' fracturing (or a 'constrained zone') in the overburden that acts to mitigate the upward migration of depressurisation. Rock layers are likely to sag without breaking, and bedding planes are likely to open. As a result, some increase in horizontal conductivity could still be expected, but the less frequent vertical fracturing will lead to disconnection in that direction, meaning there is little change in vertical conductivity.

In the surface zone, near-surface fracturing can occur due to horizontal tension at the edges of a subsidence trough. Cracking at the surface will typically be 20 to 30 m. McNally and Evans (2007) stated this is usually but not always transitory, due to increased porosity that may not be connected below or beyond the area of disturbance. The effects of this process on surface water are discussed further in **Section 6.4**.

Outside the footprint of longwalls, advice from geotechnical engineers will be required to better understand (and possibly simulate) the potential role of basal shears, valley closure at Tahmoor Mine.

6.3 Height of connected fracturing

As discussed above, the height of connected fracture is estimated based on the width of the longwall panels, cutting height and the depth of mining. The deformation of and vertical drainage of water through the fractured zone will result in areas of the fractured zone to have groundwater pressures reduced towards atmospheric pressure (i.e. zero pressure head). This does not mean that these areas are dry, simply that there is free drainage through the cracks and fractures, and that recharge from above is insufficient to match downward drainage.

Empirical models can be used to estimate the vertical height to which this occurs. At this mine both the Ditton Geology Model (Ditton and Merrick, 2014) and Tammetta (2013) method appear suitable. Based on the conclusion of SCT (2014) [at Longwall 10A] and SCT (2013) [geotechnical modelling for Tahmoor South], as well as recommendations from the IEPMC (2019), the Tammetta method has been used at this site.

Calculation of the likely height of fracturing above the Tahmoor South longwalls is provided in SCT (2013), and this indicates that for 300 m longwall panels (as per the original EIS mine plan), a 2.4 m mined seam thickness and a 400 m depth of cover, the height to which the fractured zone would extend is around 200 m above the seam. This would place the top of this zone somewhere in the mid-upper Bulgo Sandstone, and into the Bald Hill Claystone or even into the base of the Hawkesbury Sandstone in the southernmost panels of the Tahmoor South Mine. As discussed in **Section 6.2** observations by SCT (2014) at the "Height of Fracture" (HoF) hole support this by indicating that although a downward gradient existed due to deformation there was an absence of connectivity and observable impacts to groundwater levels within the Hawkesbury Sandstone.

6.4 Surface water systems

Mining induced deformation of the surface cracking zone may result in leakage of surface water into the surface zone.

At Tahmoor, it is highly likely that much of the water lost from surface features into the cracks will not continue downwards towards the goaf and mine workings but return to surface somewhere down-gradient. This low potential for connectivity to mine workings is based on the geotechnical and groundwater investigations at Tahmoor, the recommended assumptions of IEPMC (2019), and has been reviewed and commented on in HydroGeoLogic (2020).

Cracking causing surface water to be lost from watercourses and transmitted through fresh fracture networks in the shallow subsurface can result in the water quality of any re-emergent water being inferior to that of surface flow in an undisturbed environment (McNally and Evans, 2007;). Effects of mining-induced subsidence have been reported as occurring at Redbank Creek near Tahmoor North (e.g. Geoterra, 2019 and Morrison, Reynolds and Wright, 2019). The assessment of Morrison *et al.* (2019) found that the quality of surface waters was degraded in the direct vicinity of surface cracking features along Redbank Creek, with higher salinity and metal concentrations measured compared to an unaffected reference site. In order to assess future impacts of subsidence, monitoring and analysis of both ground and surface water quality is essential to determine whether subsidence has occurred.

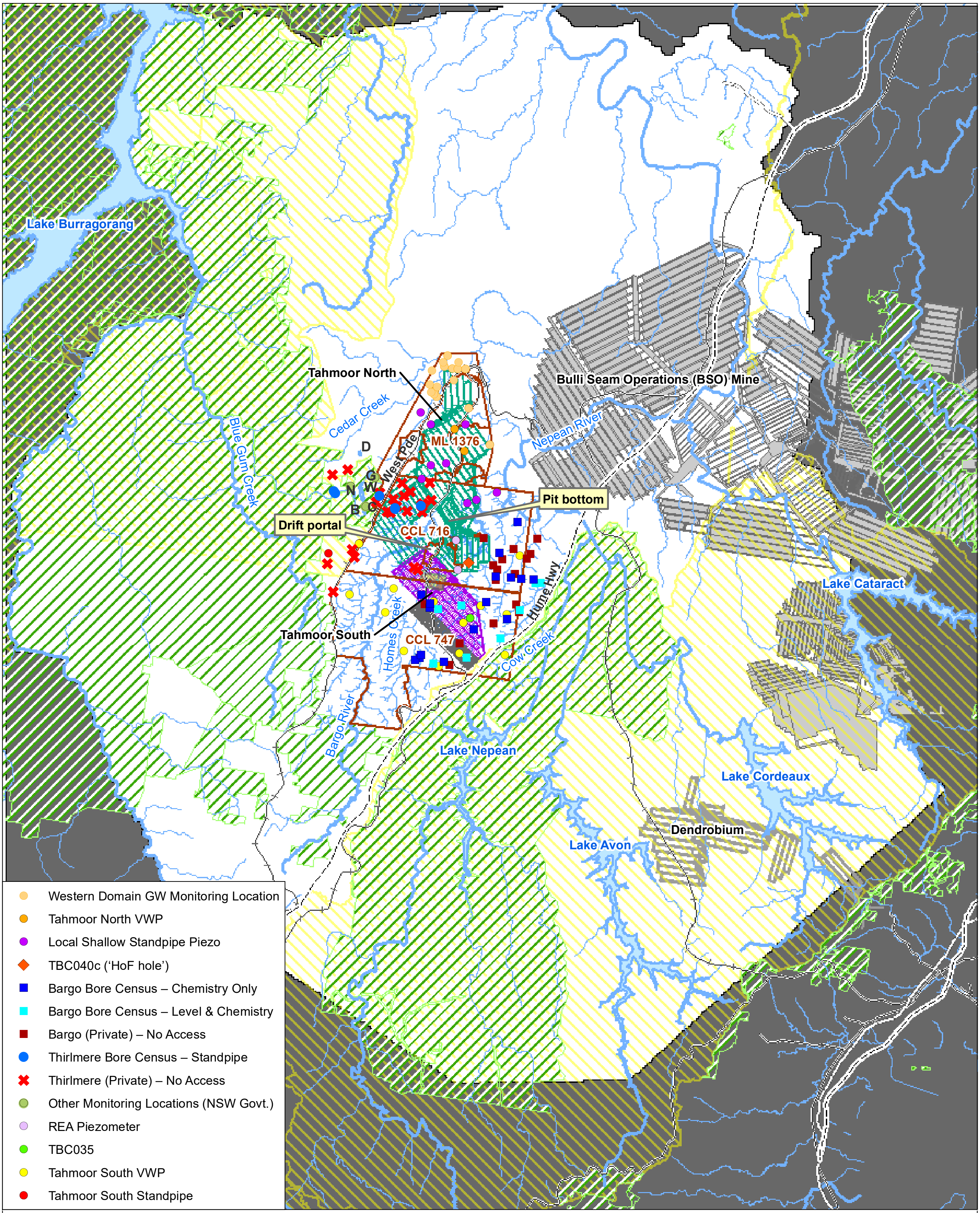
6.5 Concepts for development

A number of features of the conceptual model are known to require review in future, and some of these are (but not limited to):

- Findings and data from the TLRP (**Section 2**) require review and incorporation into conceptual modelling, and perhaps into numerical modelling. This would include alluvial geometry and lithology and properties, the water balance and model representation of lakes.
- Analysis of permeability data that is available from Southern Coalfield mines to apply hydraulic conductivity and storage properties in a manner that is appropriate for the Tahmoor area and for the Southern Coalfield as a whole. IEPMC (2019) made a comment that there should be more consistency or clearer justification for parameters (this comment was made regarding modelling at other mines in the Southern Coalfield and is applicable to Tahmoor as well).
- Analysis of surface cracking depths and hydraulic conductivity changes is required to improve confidence in the simulation of this conceptual zone. This will include data from Tahmoor and from other sites (e.g. Dendrobium, BSO).
- Updated data and improved knowledge in all areas regarding hydraulic conductivity enhancement due to longwall subsidence, especially from mines in the Southern Coalfield. This would include data on all processes related to subsidence and deformation, including the potential for basal shears to occur at Tahmoor and what role they might play.

7 Numerical Groundwater Model

The recommendations for changes to the numerical groundwater model is to be discussed under three key headings – Model development, Calibration and Forecasting. These sections address the specific recommendations regarding the rebuild of the Groundwater Model made by DPIE-Water (see **Section 2**). The current numerical groundwater model referred to below was developed for the Groundwater Assessment component of the Tahmoor South Amended Project Report (HydroSimulations, 2020). This report should be referred to for complete details relating to the numerical groundwater model. **Figure 2** identifies the current numerical model domain and mine layout.



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TAHMOOR COAL
TAHMOOR SOUTH PROJECT

Numerical Groundwater Model Domain and Mine Layout

FIGURE 2

H:\Projects-SLR\620-BNE\665-WOL\665.TAH05 Tahmoor GWMP\GIS\66510010 Fig2_Numerical groundwater model domain and mine layout.mxd

7.1 Model Development

Table 1 summarises the key structural features of the computer simulation development, identifying methods and processes used in the current model and outlining recommendations for updates to be made in future groundwater modelling.

Table 1 Groundwater Model Development – current features and future updates

Feature	Current Model (HydroSimulations, 2020)	Future Modelling
Software	MODFLOW-USG Transport.	Likely this will remain the same, but there is potential for future releases of MODFLOW6 to be used, if functionality allows.
Settings	The current model has 'solver' settings where the head close (HCLOSE) criteria is currently set to 0.04 m.	In order to improve model confidence and error future modelling should be attempted to be reduced the HCLOSE towards 0.01 m. Model stability should be emphasised during the attempt to reduce the HCLOSE criteria. Numerical stability is essential for future use of automated calibration and uncertainty methods.
Grid/mesh	The groundwater model domain represents an area 3, 237 km^2 in size. Rectilinear structured grid composed of 612 rows, 529 columns with uniform cell sizes (100 x100 m) across 16 model layers. Minimal refinement has been applied to the Thirlmere Lakes and upper Blue Gum Creek, with cells sizes of 25 x 25 m. This results in a total of 2, 877, 930 active model cells.	Recommendation for an unstructured mesh with a reduced cell count yet greater refinement over features of importance (e.g. watercourses, reservoirs, mine areas). The variation in fine/coarse cell size should be applied in a manner to minimise cell count in areas that are not considered critical for calibration/prediction. Use of the MODFLOW-USG 'pinch-out' functionality may be employed to reduce overall cell count.
Model layering	Regional stratigraphic sequence is represented by 16 model layers (refer to **Table 2**). All layers are fully present across the model domain with inactive cells applied to represent the absence of stratigraphy. Where layers are absent cell thickness is set to 1 m. Layers represent either several 'lumped units' (i.e. layer 1 as alluvium, regolith and outcropping sandstone/claystone) or sub-sections of one unit (i.e. Scarborough Sandstone upper and lower). Mean thicknesses are used to define height extent of each layer. Thicknesses of coal seams are representative of total ply thicknesses. The Southern Coalfield mapping of outcrop geology was used to constrain the subsurface extent of each modelled hydrostratigraphic unit.	Model layering should be revised. Firstly, if findings from future geological investigations and the NSW government Thirlmere Lakes Research Program suggest substantial differences to current conceptualisation. This may include a new layer used to represent alluvial deposits at Thirlmere Lakes. Secondly, there should be a clearer distinction between the units currently simulated in Layer 1, meaning that the representation of the Wianamatta Formation in a single layer instead of being grouped with other lithologies. **Table 2** outlines the current model layering, comparing it to *possible* future modifications. As mentioned above, use of the MODFLOW-USG 'pinch-out' functionality should be used to remove the need to have a minimum thickness and layer continuity where a stratigraphic unit is absent. This will assist in reducing the overall model cell count.

Feature	Current Model (HydroSimulations, 2020)	Future Modelling
Boundary conditions		
Evapotranspiration	Simulated as a *constant* potential ET rate from groundwater.	Potential ET from groundwater to be simulated considering historical variation in this parameter. This should be estimated using a water/energy balance model that considers historical rainfall/ET patterns.
Rivers	Transient River stage applied, with conductance estimated from simulated hydraulic conductivities.	Rivers to be simulated in the same manner, but with conductance allowed to vary (as a calibration parameter) from initial estimates. Future modelling should attempt to allow for variable groundwater and surface water interaction at the lakes and watercourses.
Lakes	Thirlmere Lakes represented using River package.	Use of alternative packages for simulating lakes can be considered (e.g. MODFLOW Lake package), however the current representation via Rivers and possibly more detailed representation of local alluvium should be appropriate. The lakes, generally, receive little groundwater, and are not considered at risk of Tahmoor South operations, so the use of Rivers is appropriate as long as there are clearly parameterised linkages and reporting to describe interaction between groundwater (MODFLOW) and surface water (e.g. Goldsim) models.
Drains (mine dewatering)	Drain conductance estimated from simulated hydraulic conductivities.	Drain conductance allowed to vary (as a calibration parameter) from initial estimates.
Drains (mine operations)	Simulation of mining based on mine plans that may now be out of date, based on our understanding of recent changes to plans and approvals.	Historical and approved mine plan data to be sought by Tahmoor Coal (with assistance from agencies) in order to simulate up-to-date mine plans. For Tahmoor, the simulation of up-to-date BSO plans is most important.
Groundwater pumping	Groundwater pumping by third party bores users is highly uncertain (in terms of rates). As such, bore use was only considered as a deterministic scenario.	If more confident data is available from WaterNSW/DPIE-Water, groundwater pumping via MODFLOW Wells should be included in calibration and prediction.
Hydraulic properties		
Hydraulic properties	Properties applied as zones of 'piece-wise constancy' based on conceptualisation	Properties assigned to the model to consider any relationship of properties to depth, and likely to be applied using a pilot point approach. One issue that will need to be investigated is how to apply pilot points along with transient material properties (i.e. TVM).Further discussion of hydraulic properties is included in **Section 7.1.1**.

Table 2 Stratigraphic Framework and Model Layer Assignment

Current Layer	Current Model Lithology / stratigraphy	Mean Thickness (m)	Potential Future Layer	Potential Future Model Lithology / stratigraphy
1	Alluvium / basalt / Wianamatta Formation / Hawkesbury Sst	30	1	Regolith, alluvium or basalt
			2	Wianamatta Formation
2	Wianamatta Formation / Hawkesbury Sst	40	3	Hawkesbury Sst Upper
			4	Hawkesbury Sst
3	Hawkesbury Sst (lower)	55	5	Hawkesbury Sst (lower)
4	Bald Hill Claystone	20	6	Bald Hill Claystone
5	Bulgo Sandstone	55	7	Bulgo Sandstone
6	Bulgo Sandstone	55	8	Bulgo Sandstone
7	Stanwell Park Claystone	13	9	Stanwell Park Claystone
8	Scarborough Sandstone	12	10	Scarborough Sandstone
9	Scarborough Sandstone	12	11	Scarborough Sandstone
10	Wombarra Claystone	19	12	Wombarra Claystone
11	Coal Cliff Sandstone	1m at Tahmoor, otherwise 20 m	13	Coal Cliff Sandstone
12	Bulli Coal seam	2.2	14	Bulli Coal seam
13	Loddon / Lawrence Sandstones	40	15	Loddon / Lawrence Sandstones
14	Wongawilli Coal seam	5	16	Wongawilli Coal seam
15	Kembla Sandstone	10	17	Kembla Sandstone
16	Older units (lower Permian Coal Measures and Shoalhaven Group)	100	18	Older units (lower Permian Coal Measures and Shoalhaven Group)

7.1.1 Representation of hydraulic properties

The hydraulic properties in the current model is currently assigned using zones based on stratigraphy and lithology. For future numerical modelling it is recommended that this representation be improved by utilising:

- 'pilot point' approach (in part, this is in response to recommendation by DPIE-Water); and
- application of hydraulic properties, notably Kh, with depth.

The combination of the above methods allows for greater representation of the heterogeneity of hydraulic properties at various depths and lithologies, and in turn may assist in improving the history-matching of the model to observations. Further, the use of pilot points can assist in forecasting (**Section 7.3**).

The conductivity and role of geological structures (i.e. faults) has been discussed in **Section 6.1**.

The representation of subsidence and deformation (**Sections 6.2** and **6.3**) has been applied to the current numerical model through the use of the MODFLOW Time-Varying Materials (TVM) package. The empirical method of Tammetta (2013) has been employed in the current numerical model to estimate the connected fracture zone. A recent assessment from the IEPMC (IEPMC, 2019) recommends the adoption of that method in the representation of the connected fracture zone due to the conservative estimate this provides.

Changes in hydraulic properties have also been implemented in the current numerical model to simulate the surface cracking zone in areas it is likely to occur (**Section 6.4**). This is also represented using the MODFLOW TVM package. This zone has currently only been applied to areas over longwall panels that were calculated as having a likelihood for surface cracking to occur. Where this zone was represented in the TVM hydraulic properties were enhanced by a factor of 10 to enhance hydraulic conductivity.

The hydraulic conductivity and storage enhancements in the various zones described above is open for further refinement, based on improved understanding and future model calibration.

7.2 Calibration

The current numerical model has been calibrated to mine inflows, groundwater levels and baseflow. Future modelling works should retain calibration to mine inflows and groundwater levels, however, there should be an attempt to calibrate model results for drawdown (especially within the Hawkesbury Sandstone and nearby alluvial deposits) due to mining and historic surface water losses (should a reliable dataset be available). However, performing a calibration to drawdown requires better estimates or constraints to be put on third-party groundwater abstraction history by WaterNSW and/or DPIE-Water.

Any additional data collected by the groundwater monitoring instruments operated by Tahmoor Mine and by other parties, including the TLRP, government monitoring sites and data shared with nearby mining operations (e.g. BSO, Dendrobium) should be used to further calibrate modelled groundwater levels and fluxes to observed data.

As discussed in **Section 7.1.1** future numerical modelling should employ a 'pilot point' approach to apply hydraulic properties with depth throughout the groundwater model. This will allow a better representation of the natural heterogeneity of aquifer properties and in turn is likely to result in simulations with low error variance (i.e. better calibration).

This approach to parameterisation and model calibration should be carried out using PEST/PEST-PP (Doherty, 2018 and White *et al*, 2019) software and associated utilities. Parameters including horizontal and vertical hydraulic conductivity (Kh and Kv, including of structural zones), aquifer storage properties (Sy and Ss), recharge and boundary condition conductance can be varied by the PEST tools.

As requested by DPIE-Water modelling and parameterisation should investigate the parametric sensitivity of the river and lake bed conductances applied in the MODFLOW River (RIV) package, and drain conductance applied in the MODFLOW Drain (DRN) package (for mine dewatering), and include these as parameters in calibration.

7.3 Forecasting

Forecast modelling is to be focussed on the predictions of interest to Tahmoor Mine operators, and relevant agencies. These predictions will include the following, but may evolve in future:

- Groundwater levels and groundwater drawdown.
- Drawdown at specific environmental features, e.g. within the Thirlmere Lakes alluvium, at other identified GDEs or nominated sites (e.g. Wirrimbirra Sanctuary).
- Modified groundwater gradients that may result in groundwater quality changes.
- Drawdown at private or third-party bores.
- Mine inflow to all domains at Tahmoor Mine.
- Capture of surface flow, via the reduction in baseflow to or induced leakage from watercourses. This includes losses from surface cracking effects (usually above or adjacent to longwall areas) and losses from groundwater drawdown.
- Potential induced losses from reservoirs, of which Lake Nepean is the closest.
- Assessment of fault parameters (e.g. conductivity) to be included in future predictive sensitivity and uncertainty analysis.

The predictive groundwater modelling should be carried out with adherence to the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012). Predictive uncertainty analyses should be carried out consistent with the IESC guidelines on Uncertainty Analysis in Groundwater Modelling (Middlemis and Peeters, 2018).

Future groundwater modelling should utilise several deterministic scenarios as well as a stochastic approach, using PEST/PEST-PP (Doherty, 2018 and White *et al*, 2019), following on from the use of such software in the calibration phase (**Section 7.2**). This means that uncertainty in the parameters (hydraulic properties and boundary conditions) can be assessed in formal uncertainty analysis.

8 Implementation of the Groundwater Modelling Plan

Tahmoor Coal are the managers of the Groundwater Modelling Plan. Tahmoor Coal will engage suitably qualified practitioners to carry out further data analysis, conceptualisation and numerical modelling activities.

As outlined in DPIE-Water’s request, the modelling should be updated (i.e. new data reviewed, conceptual model updated and the numerical model revised to the point of having been re-calibrated) within 2 years of Project determination (**Section 2**). Reporting on this phase is to be provided to DPIE, DPIE-Water, BCD, WaterNSW, and the Commonwealth Department of Agriculture, Water and Environment.

Forecast modelling should then be carried out with that calibrated model when there is a suitable requirement for predictions by agencies, such as the next Extraction Management Plan.

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