Central Queensland Coal Project

Appendix 6e – Groundwater Model Peer Review

Central Queensland Coal

CQC SEIS, Version 3

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Memorandum

Project number G2001

To Mr Nui Harris

Company Waratah Coal Pty Ltd

From Keith Phillipson/Andrew Durick, AGE Consultants Pty Ltd

Date 16 July 2020

RE **Central Queensland Coal groundwater model peer review – Stage 4**

1 Introduction and scope

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) were commissioned by Waratah Coal Pty Ltd in November 2019 to a undertake peer review of the Central Queensland Coal (CQC) Project groundwater model being constructed by HydroAlgorithmics (HA) as part of an EIS for the project.

This memo summarises the findings of the final stage (Stage 4) of the peer review, the scope of which was defined in AGE's proposal (AGE letter dated 12 November 2019) and comprised the review of final report sections and model files relating to the model build, calibration, numerical model predictions and uncertainty analysis. The Stage 4 review predominantly comprised a review of an updated version of the draft HA Numerical Groundwater Model and Groundwater Assessment Report dated May 2020.[1] This version of the report incorporated a number of changes and some additional modelling work resulting from previous stages of the review process.

The other ancillary documents not directly linked to the project that were used during this peer review were:

- Barnett, B, Townley, LR, Post, V, Evans, RE, Hunt, RJ, Peeters, L Richardson, S, Werner, AD, Knapton, A, & Boronkay, A (2012), *Australian groundwater modelling guidelines*. Waterlines report, National Water Commission, Canberra.
- Commonwealth of Australia (CoA), (2018), *Information guidelines for proponents preparing coal seam gas and large coal mining development proposals*, Commonwealth of Australia, May 2018.
- Middlemis H and Peeters LJM (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 2018.

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[1] HydroAlgorithmics, May 2020, Numerical groundwater model and groundwater assessment report – for the Central Queensland Coal Project Supplementary EIS – Responses to submissions, Version 4- Draft for final stage peer review.

2 Review findings

2.1 Review of the hydrogeological conceptualisation

The hydrogeological conceptualisation is presented in Section 6 of the HA report. This section includes a generally clear summary of the distribution and thickness of hydrostratigraphic units in the area and their hydraulic properties. There is an appropriate focus on surface water and groundwater interactions along the two creeks immediately adjacent to the proposed mining activity. The presented conceptual model is plausible and has identified the components responsible for bulk water movement into, though and out of the aquifers associated with the CQC project. There are some aspects of the conceptual hydrogeological model that could be improved, and these are discussed below.

2.1.1 Data Availability

Hydrological, hydrogeological and other data of relevance to the groundwater assessment are described in some detail in Section 5 of the HA report and data and other limitations which have the potential to affect model predictions are discussed in Section 8.12.

Substantial additional data has been collected since completion of the previous groundwater impact assessment (GIA) for the project[2] including the installation of:

- additional groundwater monitoring bores in both the Styx Creek Coal Measures and underlying Back Creek Group; and
- surface water flow and level monitoring stations installed on Tooloombah Creek and Deep Creek downstream of the proposed mine workings.

Water quality monitoring has also continued in these and other existing facilities and hence sub-surface salinity variations are also now better understood.

Remaining data limitations with the potential to affect the current conceptualisation, the majority of which are also recognised in the reporting include:

- the relatively short period of record currently available for the gauges on Tooloombah Creek and Deep Creek, the monitored period only includes a single recent flow event;
- flow gauging on Toolombah Creek upstream of the proposed mine workings; and
- a historic groundwater level data set comprising predominantly monthly manual dips, groundwater level loggers have currently only been installed in a small number of recent installations.

Additional data of this type would likely greatly assist with quantifying surface water – groundwater interactions in the vicinity of Tooloombah Creeks.

2.1.2 Hydrostratigraphic Units

The segregated hydrostratigraphic units (HSU) adopted in the conceptual model appear plausible and represent an improvement on the previous numerical model conceptualisation. In particular separate numerical model layers have been used to represent the three major coal seams (the Red Lower 2, Blue Lower 2 and Violet Lower 2) as well as overburden, interburden and underburden units.

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[2] CDM Smith, 2018d, Central Queensland Coal Project Supplementary Environmental Impact Statement: Appendix 6 – Groundwater Technical Report, Draft. 30 November 2018.

In total seven layers have been used to represent the Permian Styx Creek Coal Measures with a further four layers for the overlying Quaternary and Tertiary aged strata and three layers for the underlying Back Creek and Volcanic groups. The coal measure stratigraphy is shown in Figure 6-3 in the HA report. Consistent with peer review comments relating to previous iterations of the model, coal seam permeability has been assumed to reduce linearly with depth from 0.22 m/d at outcrop to a minimum of 0.002 m/d at around 250 m depth. Relationships between depth and coal seam permeability are well documented in the literature and most recent models (including OGIA, 2019[3]) developed for EIS and other purposes adopt similar depth dependent declines in hydraulic conductivity. Conceptually this is thought to be related to progressive compression and closure of the coal cleats as the weight of the overlying overburden increases.

2.1.3 Aquifer parameters

Substantial additional field hydraulic conductivity and storage data have been collected for the site since the previous EIS iteration, including continuous packer testing and laboratory analysis of core samples taken from the Styx Coal Measures to the base of the proposed open cut. Reference to Table 6-4 in the HA report indicates that relatively low initial anisotropy ratios (i.e. ratios between vertical and hydraulic conductivity) of between one and 25 were adopted for modelling purposes, based predominantly on results from core tests. In particular anisotropy ratios of two have been adopted for the interburden and underburden layers in the Styx Coal Measures. Given that the thickness and hence likely heterogeneity of these model layers is substantially greater than the scale of the core measurements used to derive the ratios, it is considered likely that these initial values represent under-estimates. However, the adoption of relatively low values is considered conservative, since it reflects modelled formation scale vertical hydraulic conductivity values which are likely to be higher than a representative value for strata of this type. Furthermore, as reported in Table 7-12 of the HA report, anisotropy ratios of up to 250 were permitted during the calibration and hence these values are able to increase where necessary to match observed groundwater level data. An initial anisotropy value of one has been assumed for each of the coal seam layers. In this case, however, given that these layers are relatively thin and therefore more likely to be relatively homogenous, this initial conceptualisation is supported.

For layers other than the coal, single hydraulic parameter values based on the available testing data were assumed initially. Spatial variability in hydraulic parameters (horizontal hydraulic conductivity (Kh), vertical hydraulic conductivity (Kv), specific storage (Ss) and specific yield (Sy)) has therefore only been introduced where necessary to explain the observed data. Initial parameterisation of coal seam hydraulic conductivity is described above in Section 2.1.2. This parameterisation approach is considered to be consistent with good modelling practice whereby additional complexity, in this case spatial variability in modelled hydraulic parameters, is only introduced where necessary to fit the data.

As shown in Table 6-4 of the HA report initial Kh values for each of the three coal seam layers are one to two orders of magnitude higher than the adjacent overburden, interburden or underburden units. This is considered to be consistent with both test data and modelling studies undertaken in similar sedimentary basin settings elsewhere in Australia. In most cases the coal seams represent the most permeable part of the coal measures.

Initial specific yield and specific storage values are also reported in Table 6-4. In terms of specific yield values of 0.5% (or 0.005) were adopted initially for all consolidated layers and between and 0.5 and 2 % (0.005 to 0.02) for the overlying unconsolidated Quaternary and Tertiary aged units. The initial specific yield values adopted for the unconsolidated units are considered to be at or close to the lower end of typical ranges identified in the literature for such strata.

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[3] Office of Groundwater Impact Assessment, 2019, Groundwater Modelling Report, Surat Cumulative Management Area.

For instance, Johnson (1967)[4] suggests values ranging from 1 to 5% for clay, 3 to 12% for sandy clay and 10 to 28% for fine sand. As reported in Table 7-11 some adjustment of these low initial values is allowed during the calibration, however, the adopted upper bound used for calibration is only twice the initial value and hence maximum values allowed during calibration range from 1 to 4% for unconsolidated strata. Given that the unconsolidated strata present in the area are considered to be relatively poor aquifers and include relatively high proportions of clay then relatively low specific yield values are justified to some extent. Sensitivity of model predictions to specific yield values of up to 10% for unconsolidated strata in some instances has also been assessed further as part of the uncertainty analysis (Section 2.2.11).

2.1.4 Seawater intrusion and density dependent flow

Theoretical relationships to estimate the location of the freshwater/saline interface are presented in Figure 6-11 and discussed in the HA report. At the location of the proposed open cut and based on the Ghyben-Herzberg relationship the saltwater interface is reported to be likely to be more than 500 mbgl, more than 300m below the base of the proposed open cut. Accordingly, it is considered unlikely that the position of the saline interface would be affected by dewatering operations. Similarly, the coastal boundary is located sufficiently far from the proposed open cut that the precise nature and location of this boundary condition, which is largely unknown, are considered unlikely to affect predicted impacts significantly. This has also been tested further by the inclusion of an additional predictive scenario incorporating an increased coastal boundary condition elevation (Section 2.2.12).

However, as reported in Section 5.5, many groundwater samples taken in the area in the Quaternary, Tertiary and underlying Permian aged units are highly saline, whilst surface water systems are relatively fresh. These observed density differences and their potential impacts on flows from more saline to less saline areas are not represented in the numerical model. Related to this and as outlined in Section 8.12.3 of the HA report observed groundwater levels have not been adjusted for salinity to produce an equivalent freshwater head on the basis that high groundwater salinities dominate even in alluvial aquifers adjacent to the creeks.

2.1.5 Faults

The most significant fault with respect to propagation of impacts from the proposed open cut is the major fault which marks the edge of the Styx Basin to the east. This fault is intersected by a regional scale section included on the published 1:100,000 scale geological mapping for the area which is reproduced in Figure 4-3 in the HA report. As discussed in Section 4.1.4 of the HA report the estimated displacement of this fault exceeds the thickness of the entire Styx Coal Measures sequence and hence on the upthrown side of the fault to the east the Cretaceous target coal seams (model layers 6, 8 and 10) are in contact with the generally low permeability strata associated with the late Permian Back Creek Group (i.e. model layer 12). Accordingly as shown in Figure 7-2 of the HA report all model layers have been shifted upwards to the east of the fault and a series of MODFLOW-USG 'non-neighbour connections' have been added along the fault contact to create a modelled connection between these strata. As reported in Table 7-11, calibrated Kh for the layer 12 is 0.0004 m/d, whilst the mean calibrated Kh for the coal seams on the other side of the fault is reported to be in the range 0.06 to 0.15 m/d. Hence whilst the fault has not been assumed to be a barrier in the model, the horizontal hydraulic conductivity contrast across it is sufficient to limit the propagation of drawdown impacts (Section 2.2.9).

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[4] Johnson, A. I., 1967, Specific Yield – Compilation of Specific Yields for Various Materials, Hydrologic Properties of Earth Materials, Geological Survey Water-Supply Paper 1662-D, United States Government Printing Office, Washington.

2.1.6 Surface water groundwater interactions

Additional information on surface groundwater interactions in the project area is now available from two level, flow and electrical conductivity (EC) gauging stations installed on Tooloombah and Deep creeks downstream of the proposed open cut. Data for these stations are available for the period from October 2019 to February 2020 and are shown in Graphs 3-6 and 3-7 in the HA report. Data for both gauges show no flow during the period from October 2019 to mid January 2020, and therefore suggests that flow in both creeks is highly ephemeral. This is consistent with estimated flow duration curves for each location, shown in Graphs 3-7 and 3-8 of the HA report, and which suggest flow occurs less than 25% of the time at both sites. However, a series of persistent pools are also observed along both creeks suggesting that even where no flow is occurring the underlying alluvial strata remain close to fully saturated. Monitoring of levels at the Tooloombah Creek gauge site suggests that the pools here are semi-permanent, declining only very slowly (less than around 0.5m in a three month dry period from mid October 2019 to mid January 2020). Well conceived conceptual diagrams showing groundwater-surface water interactions at Tooloombah Creek under a range of different flow conditions are also shown in Figure 6-4 (i to iv).

Two high value wetland areas are also present in close proximity to the proposed open cut. Simple conceptualisation diagrams for these areas are presented in Figure 6.5 (a and b) in the HA report. Multiple lines of evidence are referenced in the report, including isotopic analysis and groundwater level monitoring, and appear to suggest that the water table is more than 10 m below ground level within these wetland areas. Accordingly, the wetlands are thought to be disconnected from regional groundwater systems and largely dependent on surface water sources.

2.1.7 Conceptual water balance

Section 6.3.7 of the HA report presents a partial conceptual water balance. Ideally this section should present pre-modelling estimates of all key inflows and outflows from/to the domain of the numerical model based on the available hydrological and hydrogeological data. Such a balance can identify if there are missing components of the conceptualisation, and whether the assumptions inherent in the conceptual model are plausible. Some estimates of evaporation rates and total volumes of groundwater recharge are provided but there is no tabulation of estimated inflow and outflow terms. In particular a conceptual model of the key discharge components and their relative magnitudes is not provided, although a simple schematic providing basic information is provided in Figure 6-1 of the HA report.

2.2 Review of numerical groundwater model reporting

The development and deployment of a numerical groundwater flow model based on the conceptual model reviewed above is described in Chapters 7 and 8 of the HA report. This forms the detailed reporting of the groundwater modelling and is set out in a logical sequential order and includes a description of the model design and build, the calibration, the predictions and then the model sensitivity and uncertainty analysis.

2.2.1 Model confidence level

For impact assessments the model should be aiming for a Class 2. This is especially the case where, as in this case, sensitive environmental receptors are present in close proximity to the proposed workings.

The assessment completed by HA suggests that the model achieves or even exceeds the targeted Class 2 model confidence level in all categories. For the most part we would concur with this assessment. Two exceptions are described below. Overall, given the targeted confidence level has been achieved for the majority of criteria included in the modelling guidelines, we also conclude that the model can be considered a Class 2 model.

With regard to the adequacy of the streamflow data set we would argue that the current data should be assessed as being Class 1, rather than Class 2 as assessed by HA. Whilst two gauges have been installed on Tooloombah and Deep Creek downstream of the proposed workings only a short period of record is currently available and has not currently been used to calibrate the model, since the only recorded flow event occurred after the end of the model calibration period. Gauges are also not available upstream of the site and hence the rate of actual flow gain or loss from each creek is not known. Hence the Class 2 criteria that reliable streamflow data and baseflow estimates are available at a few points have not been met and the Class 1 criteria of there being little or no useful data on river flows and stage elevations is more appropriate, especially given the limited use which has currently been made of the available data. We note that a comparison of model input creek stages with observed pool levels has been added to the latest version of the report provided for review, for the purposes of model validation. However, this has little/no bearing on this criteria which relates to the availability and use of streamflow data and baseflow estimates.

With regard to the availability of reliable soils and land use data, the HA assessment suggests that the Class 3 requirements have been met. However, as discussed further in Section 2.2.3.3 whilst land-use data is available and is described in Section 3.4 of the HA report it appears not to have been used to parameterise the MODFLOW evaporation package. This has led to the potential simulation of evaporation losses to 8 m below ground level even in areas which have been cleared for grazing and there are few if any deep rooted trees. Accordingly, this is an area where the self-assessed Class 3 requirements have not been achieved, nor for that matter the targeted Class 2 requirements, noting that there is no reference to Class 2 soils and land use data requirements in Table 2-1 in the Australian Groundwater Modelling Guidelines. Fortunately, as discussed in Section 2.2.12, key model predictions appear to be relatively insensitive to the extent of the area modelled using an 8 m extinction depth.

2.2.2 Model structure

Given the objectives of the numerical model and the type and setting of the Project the choice of MODFLOW-USG is considered sound. Similarly, the development of a highly refined mesh in and around the primary areas of interest using HA's AlgoMesh software is commended. Both the particular variant of MODFLOW-USG (USG-Transport) used for the project and AlgoMesh are in widespread use within the groundwater flow modelling industry and as such have been found to be fit for purpose for use in EIS and other projects.

Further utilising MODFLOW-USG capabilities so-called non-neighbour connections have been introduced into the model to allow simulation of areas where hydrostratigraphic units pinch out across mapped faults.

Both the model extent and mesh design are considered to be appropriate based on the predicted extent of impacts. If anything, the model domain is perhaps more extensive than strictly necessary. As mentioned above a variable model mesh has been implemented using AlgoMesh resulting in very small cells of less than 50 m in and around the proposed open cut, faults and nearby creeks increasing to 450 m in other areas more distant from the proposed workings.

2.2.3 Model boundary conditions

2.2.3.1 Coastal boundary condition

The surface processes in the tidal zone of Styx River are dynamic, however on the timeframes that the groundwater model operates it is entirely appropriate to represent this as a constant head and evidence is presented to support the adopted 3.5 mAHD head and extent of the boundary condition. The sensitivity of key model predictions to this adopted value has also been tested by testing higher and lower boundary elevations as part of the scenario based sensitivity analysis (Section 2.2.12). This analysis concluded that key model predictions were insensitive to this boundary assumption. This finding is considered to be consistent with the elevated distance (around 25 km) of this coastal boundary from the proposed open cut pit.

2.2.3.2 Creek boundary condition

As shown in Figure 7-4 of the HA report, the lower sections of Tooloombah Creek from just upstream of the proposed open cut to the tidal limit has been represented using the MODFLOW river package and assuming a river stage which is 1 m above the top of the modelled river bed. River cells parameterised in this way effectively represent a form of constant head boundary where the volume of flow gained or lost by each river cell is governed by: i) the head difference between the river and the 'underlying' model layer; and ii) the river bed conductance. Given the proximity of Tooloombah Creek to the proposed open cut the choice of boundary condition for this water course is a key component of the model design. In particular the choice of a boundary condition which represents an infinite source of water so close to the open cut has the potential to lead to under-estimation of the potential impact zone. Typically, the river package would be used to represent perennial water courses where the volume of flow in the water course is orders of magnitudes higher than the stress being assessed. In this case however, as discussed in Section 2.1.6, Tooloombah Creek is highly ephemeral and flows for less than 25% of the time. Accordingly, for more than 75% of the time there would be little to no flow available to leak into the underlying aquifer. The use of MODFLOW river cells which represent a potentially infinite source would not normally be advisable in such a scenario since in reality the volume of water which can leak from the creek is likely to be limited by the flow in the creek for the majority of the time. However, as discussed in Section 2.1.6 monitoring of surface water levels in Tooloombah Creek also suggests the existence of semi-permanent pools which in turn indicates that the underlying strata remain saturated even during extended dry periods. Furthermore, the predicted volumes of seepage (see Section 2.2.8) represent only a small proportion of estimated average flow in the creek. The use of the MODFLOW river boundary condition at this location is therefore considered to be defensible, although an additional impact sensitivity run was recommended in the Stage 3 peer review to confirm the degree to which model predictions are sensitive to the use of this boundary condition. The results of this additional run are presented in Attachment 18 of the HA report and discussed further in Section 2.2.12.

All other river cells in the model domain have been parameterised such that they act like drains (by setting the river stage and modelled river bed to the same value) and can only remove water from the model domain. This is considered to be consistent with the ephemeral nature of these creeks, the lack of permanent pools, and in terms of lateral propagation of impacts is also considered to represent a conservative approach.

2.2.3.3 Evaporation

Extinction depths used to parameterise the MODFLOW evaporation package are reported to be based on maximum rooting depths for different vegetation types reported in Canadell et al (1996) and Shah et al. (2007). Canadell et al (1996) suggest maximum rooting depths for trees of 7-8 m, shrubs 5-6 m, herbaceous plants 2.5 m and crops 2 m. These depths are considered to be reasonably consistent with other similar studies and suggest that root depth and hence evapotranspiration losses are related to the type of ground cover or land use. As described in Section 3.4 of the HA report, land use in the model domain is dominated by agriculture (78%) predominantly grazing. However, rather than base modelled extinction depths on land use mapping it would appear based on Table 7-6 in the HA report that they have been based on outcrop geology mapping such that all areas mapped as Qpa, Qr, Qf and Qa on regional geology maps have been assigned extinction depths of 8 m. As shown in Figure 2.1 this results in extinction depths of 8 m being assumed across the majority of the modelling domain, despite clearing of the majority of this area for grazing purposes. Accordingly the Stage 3 review recommended a further impact sensitivity run be undertaken to confirm the sensitivity (or otherwise) of model predictions to the current extinction depth assumptions. The results of this additional run are presented in Attachment 18 of the HA report and discussed further in Section 2.2.12.

The very high evaporation losses predicted in isolated areas, particularly towards the southern boundary of the domain shown in Figure 2.2, were also queried with the modelling team during the Stage 3 review and attributed to high modelled water tables in Tertiary outcrop areas. Given the distance of these areas from the proposed mining operations this is considered unlikely to materially affect predictions.

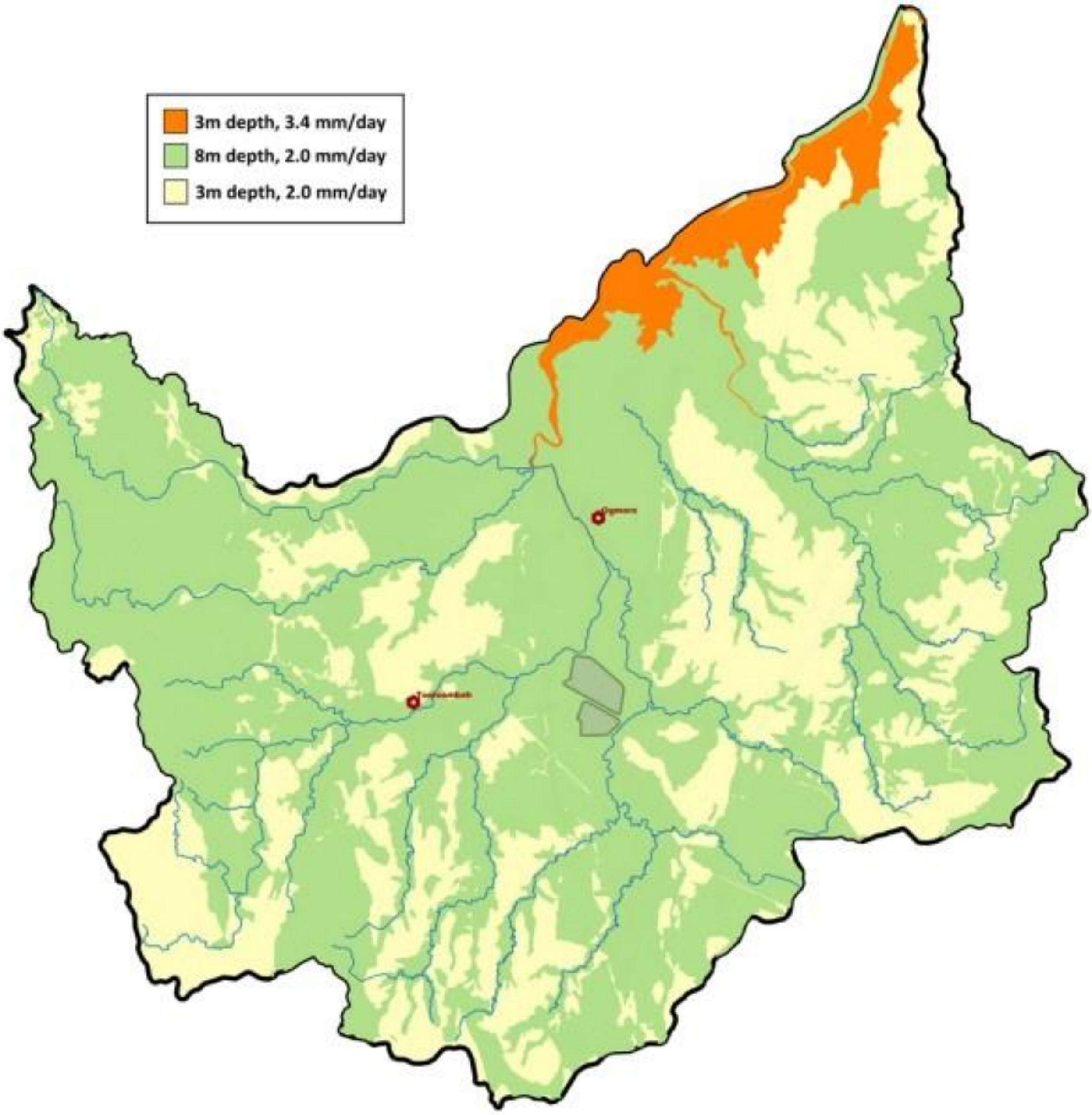

Figure 2.1 Maximum rate and extinction depths applied across the model domain (Figure 7-7, HA report)

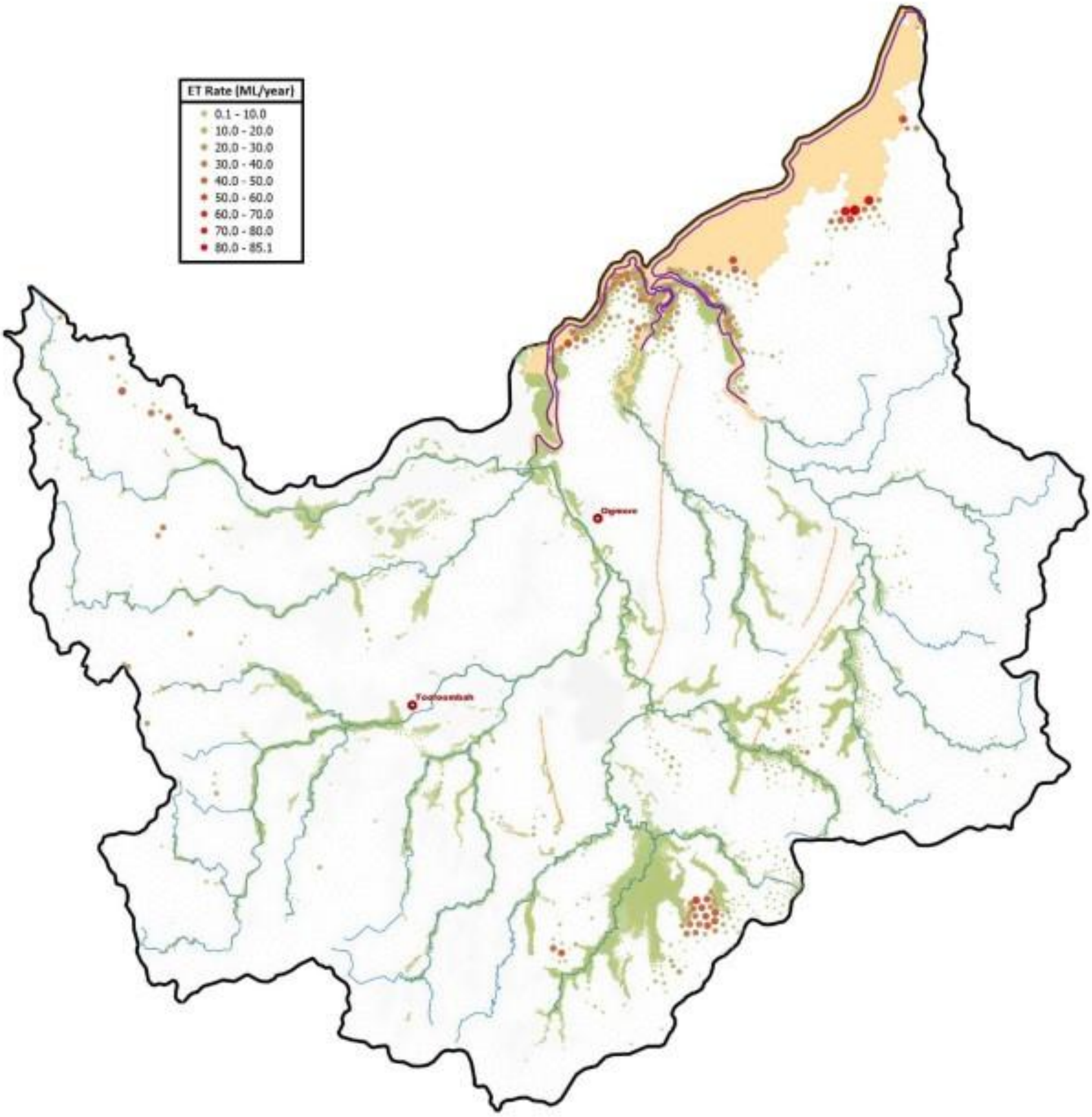

Figure 2.2 Modelled evapotranspiration flux rates across the model domain (Figure 7-11, HA report)

2.2.3.4 Groundwater extraction

Existing groundwater extraction from landholder bores has not been included in the model. Existing extraction is, however, understood to be limited to a relatively small number of stock and domestic extractions. The exclusion of these bores is considered to be a reasonable simplification and unlikely to affect the ability of the model to predict project impacts.

2.2.4 Representation of dewatering

Proposed open cut mining is represented in the model using the MODFLOW drain package which is an appropriate approach for the likely dewatering method being a pumped sump within the working pit. As described in Section 8.3.1 of the HA report, advanced dewatering using groundwater extraction bores is under consideration but would involve the construction of sacrificial bores within the proposed open cut footprint, rather than outside it. Accordingly, assuming that these bores are not drilled more than say one year in advance of the proposed open cut then no material effects on either the magnitude or timing of impacts would be expected.

2.2.5 Model approach and steady state

The calibration simulation is reported to comprise a steady state calibration to provide initial conditions prior to two transient models of the historic period as follows:

- an initial transient model of the period from 1919 to December 2010 include representation of historic mining activities in the vicinity of Bowman (1918 to 1948) and Ogmore (1924 and 1964); and
- a second transient model of the period from January 2011 to September 2019.

As there is no historic groundwater level data prior to January 2011, then only the steady state model and the second transient model of the more recent period have been calibrated. The transient simulation of the period from 1919 to 2010 therefore acts to provide realistic water levels for the start of the second transient calibration. Both steady state and transient calibration models have been calibrated to groundwater levels only. No flux or head difference targets at nested monitoring locations have been included in the calibration, although observed head differences were compared to modelled equivalents post calibration as shown in Graph 7-4 in the HA Report.

2.2.6 Backfilling, final voids and elevated landforms

Progressive backfilling of the open cut using coal rejects and waste rock blended with overburden spoil has been simulated using the time-varying material (TVM) package to simulate the change in hydraulic properties that will occur as natural strata are replaced with backfill. Consistent with the unconsolidated nature of the material emplaced, relatively high hydraulic conductivity (Kh = 1 m/d) and storage properties (Sy = 20% and Ss = 1.3×10^{-5} 1/m) have been assumed for the backfill. Previous work undertaken by Dawkins (1998)[5] is referenced as being the basis of the Kh value adopted. An increased recharge rate of 5% of rainfall has also been assumed for backfilled areas (i.e. 3 to 8 times higher than adjacent unconsolidated Quaternary strata) on the basis that the backfill will likely comprise broken rock with limited fine material.

The same hydraulic conductivity, storage, recharge and evaporation parameters described above have also been assumed to apply to two out of pit waste rock emplacement areas which form part of the final landform. These waste rock areas, which attain elevations of around 75 m above pre-mining levels in places, have been simulated in layer 1 of the model and lead to predicted post development increases in discharge to local water courses. This is discussed further in Section 2.2.9 below.

All open cut areas are to be backfilled during mine closure, presumably to above the water table. Accordingly, no simulation of long term water levels in residual mine voids have been undertaken.

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[5] Hawkins, J.W. (1998) Hydrogeologic Characteristics of Surface-Mine Spoil. In Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania, ed. Brady, Smithy and Schueck. Harrisburg, Pennsylvania.

2.2.7 Model calibration

Calibration of the model was undertaken by varying model parameters relating to horizontal hydraulic conductivity (Kh), anisotropy, specific yield, specific storage and recharge (via calibration of the modelled ratio between modelled Kh and rainfall infiltration rate). Modelled conductance values assigned to river cells were not adjusted during the calibration on the basis that no flow events were observed during the calibration period.

A range of outputs are provided in the HA report from which the calibration performance can be assessed, although only limited information is provided on how the calibration was achieved. The reporting suggests that the model was calibrated manually initially before being subject to automated calibration using the PEST suite of software. No further information on the precise methodology adopted (PEST supports a range of different approaches) or on matters such as observation weighting which can significantly affect the success of the calibration are provided. Nevertheless, a low calibrated Scaled RMS (SRMS) statistic of 2.0% is reported for the transient calibration, which suggests that across the model domain as a whole the model is able to replicate observed heads relatively well. The availability of calibration data in the Styx Coal Measures particularly in and around the proposed open cut area has been substantially improved compared to previous iterations of the project EIS.

Maps showing modelled head residuals in various model layers are shown in Figures 7-9 and 7-10 in the HA report. For the most part few if any spatial patterns, which can indicate systematic errors in the model, are evident. However, Figure 7-10b which shows modelled residuals in the Styx Coal Measures suggests a tendency for the model to systematically either under (or over-predict) observed heads in this unit. It is not clear from the legend on these figures whether negative values indicate under prediction or vice versa, although this has been clarified in the accompanying text.

As mentioned previously in Section 2.2.5 the current calibration relies solely on absolute groundwater level observations and is therefore likely to be prone to a relatively high degree of non-uniqueness, compared to a model that has been calibrated to a range of different observation types. Accordingly, the predictive uncertainty analysis is considered to be particularly important for this model. Additional data which could have used for model calibration include observed:

- flows at the recently installed Tooloombah and Deep Creek gauges, although it is recognised that this would have required extension of the current model calibration period after completion of the bulk of the modelling work;
- water levels in semi-permanent pools along the Tooloombah and Deep creeks; and
- head differences in nested monitoring points.

In the reviewer's opinion, the inclusion of these additional targets would likely have improved the overall calibration and reduced predictive uncertainty by reducing the potential for non-uniqueness in the solution.

Calibrated hydraulic parameters for each layer are summarised in Tables 7-12 and 7-13 and in maps included as Attachment 12 in the HA report. For the most part the final calibrated values are considered plausible. In some cases reported mean values for layers are at either the adopted upper and lower bounds suggesting that the ranges adopted for calibration may have been too restrictive. However, the sensitivity of model predictions to this restriction was subsequently assessed during the uncertainty analysis by assessing a range of parameters either side of the calibrated value (Section 2.2.11).

2.2.8 Modelled water balance

A modelled water budget for the transient calibration period is presented in Table 7-15 in the HA report. The dominant modelled output is reported to be evapotranspiration (67.7 ML/day) which represents around 83% of the modelled total inflows. Further information on the distribution of these evaporation losses is provided in Figure 2.2. For the most part the distribution of evaporation losses shown in Figure 2.2 appears sensible and is largely confined to topographically low areas where the water table is likely to be relatively high allowing groundwater supported evapotranspiration to take place. Water budget results also show only minor discharge (3.2 ML/day) to surface water courses (i.e. baseflow) suggesting that the majority of water is lost as evapotranspiration in the riparian corridor before entering the creeks. This is consistent with the highly ephemeral nature of the creeks in the area. Elevated evapotranspiration losses are, however, modelled in isolated areas in cells adjacent to the coastal fixed head boundary condition towards the north of the model. The elevated losses close to the northern boundary related to evaporation being applied to cells adjacent to the constant head boundary elevation of 3.5 mAHD. To meet this evaporation demand water is being pulled from the offshore area which explains the relatively large volume of inflow (19.1 ML/day) from constant head cells reported in the modelled water budget. It seems unlikely that this flow is actually occurring in practice, however, given that the proposed open cut is some distance from this coastal boundary this is unlikely to affect any of the key impact predictions.

2.2.9 Predictions

As reported in Table 7-9 of the HA report impact predictions have been derived based on a comparison of modelled heads and flows in two scenarios: a transient prediction model (in which the Project is represented) and a transient null model (which excludes the Project). This approach is consistent with guidance included in the Australian groundwater modelling guidelines since this differencing approach can reduce uncertainty in the drawdown estimates.

Predicted groundwater inflow to the two proposed open cuts is presented in Graph 8-1 of the HA report, a snapshot of which is presented below (Figure 2.3). The pattern of flows presented is plausible suggesting a relatively rapid increase in inflow during the initial development period, falling gradually thereafter as areas are progressively backfilled.

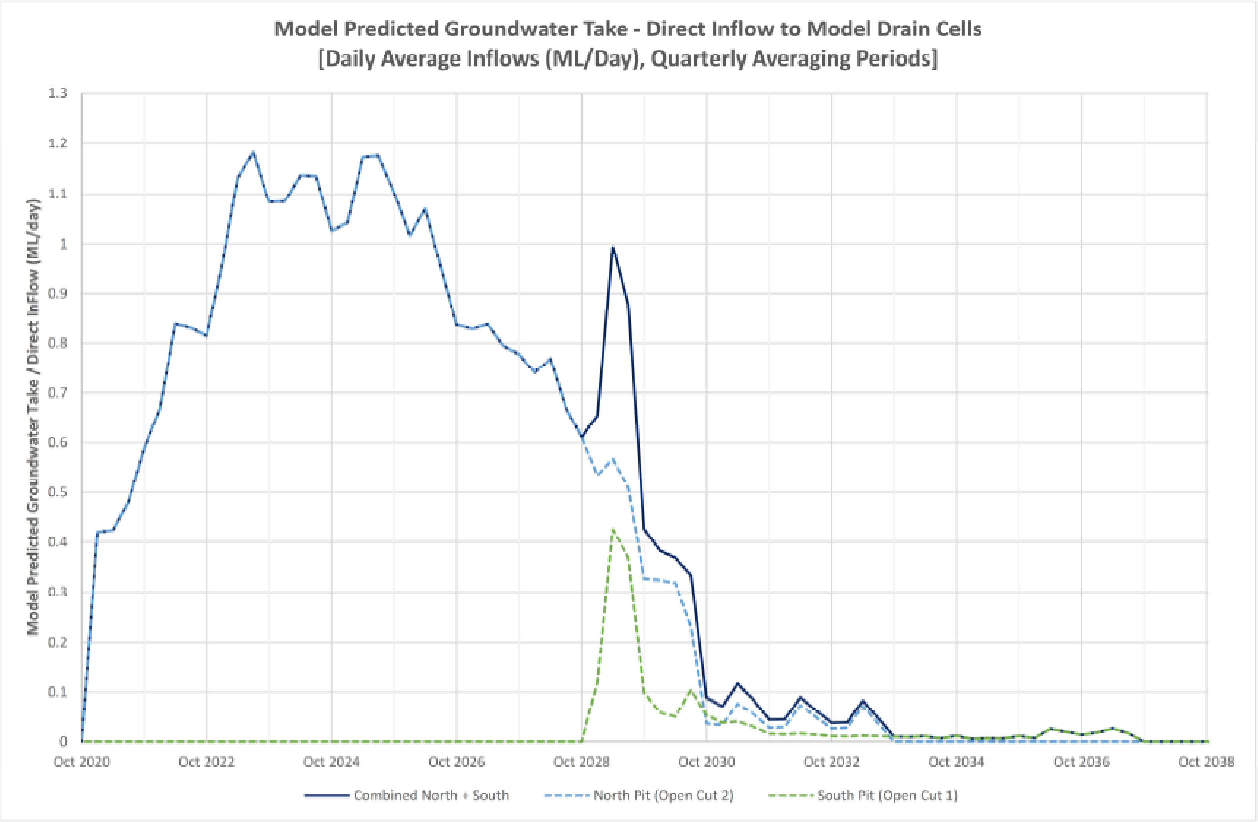

Figure 2.3 **Modelled predicted groundwater take – direct (daily average) inflow to Modelled Drain Cells [2020 to 2038] (Graph 8-1, HA report)**

It should be stressed, however, that this plot is reported to be based on modelled drain flows only. Elsewhere the reporting suggests that evaporation may also be occurring from those parts of the open cut areas which have been backfilled. However, subsequent analysis of the raw model files provided suggests that this is not the case and that evaporation would only occur from backfilled areas once groundwater levels rise to within 8 m of the final post development ground level. As this is likely to only occur well after mining operations cease then modelled evaporation losses from the open cut area during mining are likely to be insignificant.

Maps showing predicted drawdown in most model layers at various times as well as maximum all-time drawdown contours are presented in Attachment 14 of the HA report. Predicted maximum impacts at four nearby private landholder bores are tabulated in Table 8-4 of the HA report. Of these only one bore is listed as being potentially impacted by more than the relevant Water Act 2000 trigger threshold of 5 m for consolidated strata.

Predicted reductions in groundwater flow to Tooloombah and Deep creeks and other water courses are shown in Graph 8-3 of the HA report, a snapshot of which is presented below (Figure 2.4). As shown maximum impacts of up to 0.009 m^3/s (equivalent to 0.78 ML/d) are predicted during mining in Tooloombah Creek, up to around 0.006 m^3/s (equivalent to 0.52 ML/d) in Deep Creek and little or no impacts on groundwater discharge to other creeks. During the review process it was noted that these predicted impacts represent a significant proportion of the predicted mine inflows (Figure 2.3) particularly towards the end of the mine life. However, subsequent sensitivity runs testing different river bed conductance values (Section 2.2.12) suggested that the similarity of these flows was coincidental.

Post mining predictions suggest slight increases in flow to both Tooloombah and Deep creeks due to additional groundwater discharge from two out of pit waste rock emplacement areas which form part of the final landform. As discussed previously in Section 2.2.6 this is in part due to the relatively high recharge rates assigned to these waste rock emplacement areas.

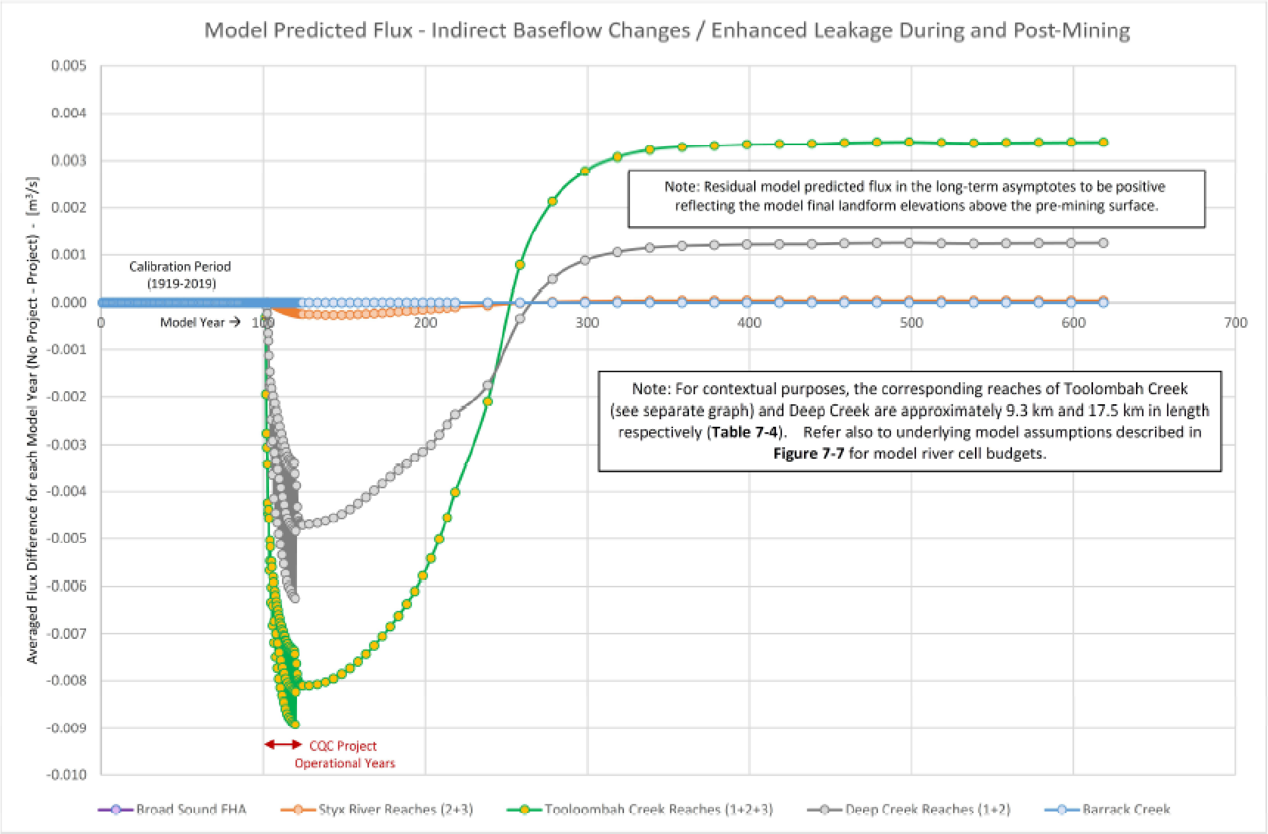

Figure 2.4 Model predicted flux – indirect baseflow changes/enhanced leakage during and post mining (Graph 8-3, HA report)

2.2.10 Identifiability analysis

The fatal flaw checklist provided in the IESC Uncertainty Analysis Guidance Note (Middlemiss and Peeters, 2018, Section 2.4) includes a requirement that a parameter sensitivity and/or parameter identifiability analysis be completed and the implications discussed. In this case a parameter identifiability analysis has been undertaken. In keeping with the rest of the technical report a wealth of detail on the results of this analysis are presented in Section 8.11.1 and Attachment 16 of the HA report. Some of the implications of this analysis are also discussed as required by the IESC.

However, it should be noted that this analysis has been limited to the same parameters which were varied during the calibration (i.e. horizontal hydraulic conductivity, anisotropy, specific yield and specific storage, and recharge, Section 2.2.7). Accordingly, the sensitivity of observations to a number of other model parameters including river bed conductance in particular do not appear to have been assessed.

2.2.11 Uncertainty analysis

An uncertainty analysis has also been undertaken using a stochastic modelling approach which is considered to represent the most robust of the three techniques identified in the IESC guidance note. The results of the quantitative analysis based on 602 calibration constrained predictive model runs are presented in Section 8.11.2 and Attachment 11 of the HA report. The attachment in particular provides a large amount of detail and output relating to the analysis.

This includes a detailed consideration of whether or not sufficient predictive runs were undertaken to generate reliable statistics. Key results are also well presented in summary form in Table 8-8.

The Stage 3 peer review highlighted three aspects of the uncertainty analysis relating to the model parameters and parameter ranges investigated and the SRMS cut off applied which were discussed further with the HA modelling team and ultimately satisfactorily resolved as described below.

With regard to the parameters assessed as part of the uncertainty analysis this was limited to the same parameters assessed during the calibration and identifiability analysis (i.e. horizontal hydraulic conductivity, anisotropy, specific yield, specific storage and recharge parameters). River bed conductance was therefore excluded from analysis. However, the sensitivity of key predictions to this parameter has now been assessed via an additional sensitivity scenario, as described in Section 2.2.12.

With regard to appropriate parameter ranges and SRMS cut offs there is no specific advice in the relevant guidelines as to what ranges or cut offs should be used and the guidelines recognise that the modellers themselves are best placed to make such subjective decisions, since they have the most complete understanding of the model sensitivities. In this case the modellers have investigated a range of alternative parameter sets 95% of which fall within one order of magnitude of the calibrated value for all parameters excluding specific yield. For specific yield a narrower range of alternative parameters with 95% of values falling within a factor of two of the calibrated range has been assessed. It is noted that in some cases the parameter ranges explored in the uncertainty analysis are more restrictive than those considered acceptable in the model calibration (Table 7-12 in the HA report).

Furthermore, a relatively narrow calibration constraint has also been adopted, whereby any run where the SRMS exceeds 3% has been excluded from the analysis on the basis that it is inconsistent with the observations. It is recognised that a SRMS value of 3% represents a calibration that is statistically 50% worse than the fully calibrated model, which achieved a SRMS of 2%. However, a SRMS of up to 10% is often considered acceptable in many modelling studies and hence a model achieving a SRMS of 3% would still generally be considered to be very well calibrated and hence not inconsistent with the data.

The review process also investigated why outputs generated using the baseline fully calibrated (LF3) parameter set to the 90th percentile of some key impact metrics (see Figure 2.5 and Figure 2.6) and close to the 10th percentile in others (see Figure 6 in Attachment 11 of the HA report). Given the approach adopted to generate alternative parameters for the uncertainty analysis described above, whereby the generated parameters were centred on the calibrated value, this was thought to be somewhat unusual, suggesting a possible bias in the values generated. However, subsequent analysis of the full parameter set generated for all 1,000 uncertainty analysis runs provided by HA confirmed that this was not the case. The only systematic 'bias' evident in the parameters sets related to the anisotropy of layers 12, 13 and 14. For these three layers an anisotropy value of one was calibrated and any parameters of less than one generated during the uncertainty analysis were justifiably rejected as being unrealistic. All 1, 000 alternative anisotropy values generated for these layers in the uncertainty analysis were therefore higher than the fully calibrated LF3 parameter set.

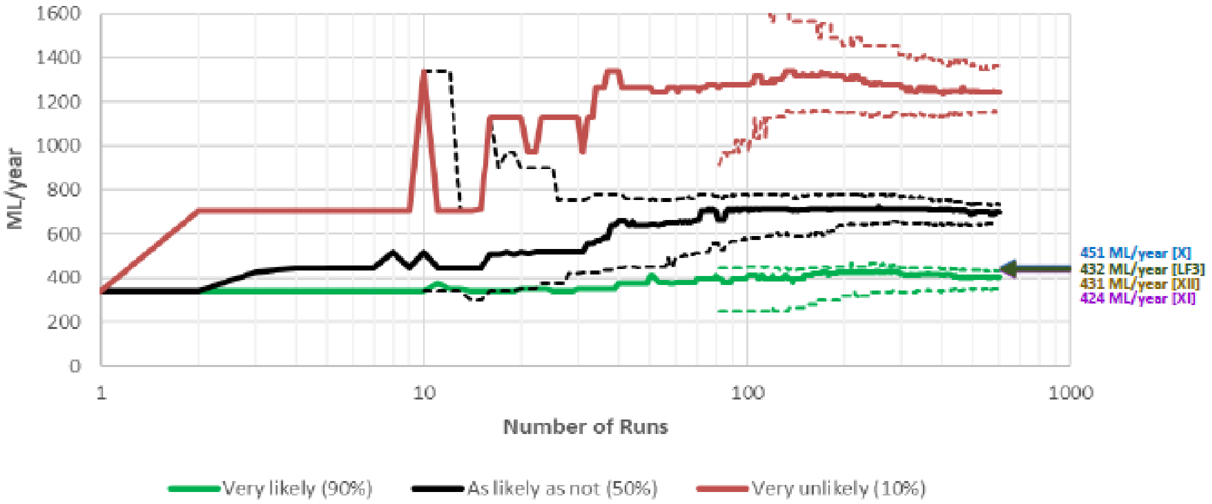

Figure 2.5 99.7% Confidence Intervals of Probability of Exceedance – Peak Mine Inflows [Combined] – Additional Parameter Analysis Comparison with LF3 (Graph 8-6, HA report)

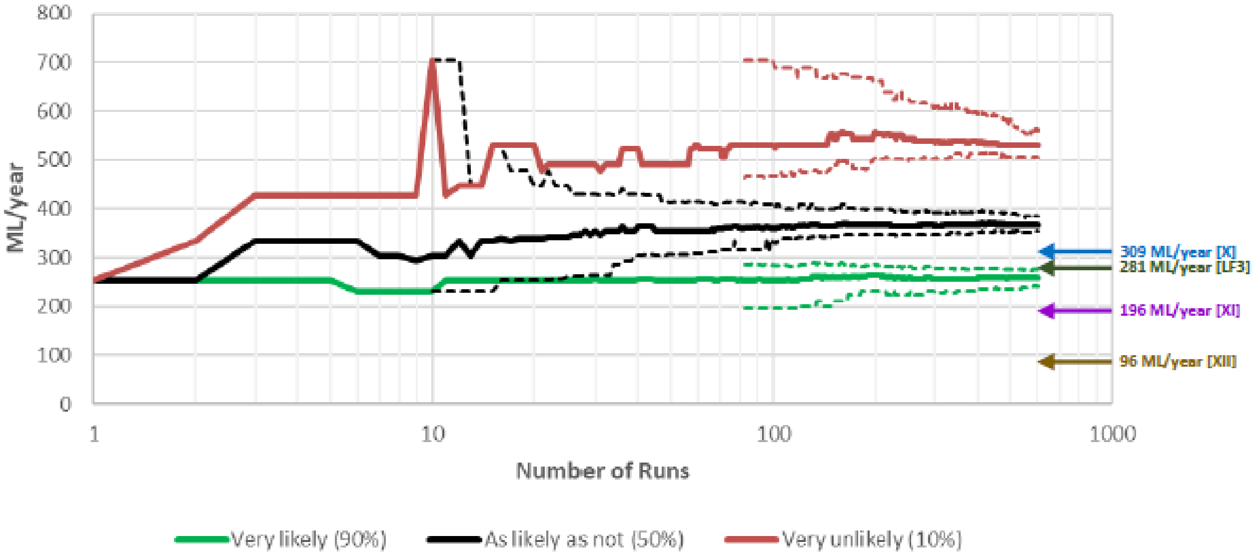

Figure 2.6 99.7% Confidence Intervals of Probability of Exceedance – Peak Baseflow/Leakage Change for Tooloombah Creek– Additional Parameter Analysis Comparison with LF3 (Graph 8-7, HA report)

2.2.12 Scenario based sensitivity analysis

A series of additional scenarios were undertaken as described in Section 8.11.3 of the HA report to assess the impacts of different coastal boundary and fault connectivity assumptions and potential climate changes. A further three scenarios (Scenarios X, XI and XII) were also undertaken as described in Section 8.11.6 of the HA report to assess the degree of sensitivity of key model predictions to:

- the 8 m evaporation extinction depth applied across large parts of the model domain (Section 2.2.3.3), Scenario X;
- test an alternative boundary condition assumption or conceptual model, in which leakage from Tooloombah Creek is assumed to be insignificant (Section 2.2.3.2), Scenario XI; and
- modelled river bed conductance, since this parameter was not included in the predictive uncertainty analysis (Section 2.2.11), Scenario XII.

Revised predictions based on these three additional scenarios are summarised in Attachment 18 of the HA report and also in Figure 2.5 and Figure 2.6 (above). Results for Scenario X tend to confirm that key model predictions are relatively insensitive to the extent of the area modelled using an 8 m extinction depth. However, results for Scenarios XI and XII suggest that key modelled predictions are relatively sensitive to the river bed conductance parameter. As would be expected reducing the river bed conductance generally results in less predicted leakage from the Tooloombah Creek (Figure 2.6) but also results in a more extensive area predicted to experience more than 2m of drawdown than that predicted using the fully calibrated LF3 parameter set or the 10th percentile of the uncertainty analysis output.

2.3 Review of model files

The review of the supplied model files involved rerunning the models locally and comparing the model files against what has been reported. This was undertaken, and the model output was extracted from the model output files (such as heads) and examined in a GIS package. The reported water balance in the model output 'listing' files were also examined from the supplied model runs. Some aspects of the detail of the evaporation package were also confirmed through examination of the relevant MODFLOW input files.

No significant discrepancies between the model reporting and model files were identified. Some minor differences in the modelled water balance were identified between output generated by an AGE re-run of the transient model with output provided by HA. However, this re-run was undertaken using a standard version of MODFLOW USG and a standard CPU based solver, whilst the HA output was generated using a proprietary GPU based solver developed by HA. Whilst this bespoke solver does result in significantly lower run times is does appear to come at the cost of slightly higher modelled water balance errors. However, errors using both solvers were substantially less than the 1% threshold typically considered acceptable in similar numerical modelling studies.

2.4 IESC Uncertainty Analysis Guidance Note review checklist

As mentioned previously in Section 2.2.10 the IESC Uncertainty Analysis Guidance Note includes a review checklist which it is recommended be applied to projects which include an uncertainty assessment. This checklist includes the following items:

1. Is there evidence of engagement ("without prejudice") between the project proponent and regulatory agencies from the project outset and at subsequent key stages
2. Is the modelling and uncertainty analysis methodology designed to provide information for decision makers on the effects of uncertainty on the project objectives (echoing the definition of risk in AS/NZS ISO31000:2009) and on the effects of potential bias?
3. Are the adopted conceptual model, complexity–simplicity balance and applied modelling package capabilities commensurate with the overall risk context and the models purpose of investigating the uncertainty/risk issues (i.e. based on the evidence available of engagement identified in item 1)?
4. Has the uncertainty assessment and modelling methodology been designed and implemented using all the available data? Detailed consideration of the hydrological stressors arising from the development and of natural stressors, including climate variability, and unbiased consideration of water-related asset values and causal pathways for potential impacts (direct, indirect and cumulative) should be provided.
5. Where history-match conditional calibration is undertaken, has it minimised non-uniqueness and error variance (using approaches recommended in the AGMG)? If not, is a reasoned justification provided? Is an acceptable level of model-to-measurement mismatch defined for the conditional calibration?

6. Are all simulations consistent with all relevant information/data (using approaches recommended in the AGMG)? If not, is a reasoned justification provided?
7. Has the model been submitted to stress testing in which a number of extreme parameter combinations (representing a computationally intensive automated conditional calibration or stochastic model evaluation) are tested for model convergence?
8. Has a parameter sensitivity analysis and/or a parameter identifiability analysis been completed to identify which parameters can be constrained by the available observations and which parameters affect the simulations the most? Are the implications discussed?
9. Have all reports been prepared in an open, honest and transparent way that is:
    i. open to independent scrutiny and not prone to misinterpretation;
    ii. based on agreed and transparent model objectives;
    iii. tailored to decision-makers' needs (focusing on messages relevant to their decisions); and
    iv. presented in plain and clear language (precise, jargon-free, calibrated), with useful graphics.

Inevitably any assessment of whether or not a modelling study meets a set of criteria is subjective. For the most part, in the opinion of the peer reviewers, the modelling study at least partially meets the requirements as laid out in the IESC Uncertainty Analysis Guidance Note. however, two areas where this assessment is not clear cut are discussed below.

2.4.1 Checklist Item 3 – development of models commensurate with the overall risk context

Given the sensitivity of some of the potential impact receptors of the project which include high priority wetlands and the Great Barrier Reef Marine Park (i.e. a high overall risk context) then it could be argued that development of more integrated surface water and groundwater models should have been undertaken. However, it is understood that this is being addressed by the development of a separate integrated surface water – groundwater model developed by Eco Logical Australia Pty Ltd, although the peer reviewers have no direct knowledge of this work.

2.4.2 Checklist Item 5 – has the calibration minimised non-uniqueness

As discussed in Section 2.2.7 due partly to data limitations calibration has been undertaken to observed groundwater levels only and is likely therefore to be more prone to non-uniqueness than if other types of calibration data were available. The sensitivity of key model predictions to non-uniqueness has been assessed through the development of more than 600 alternative calibration parameter sets as part of the uncertainty analysis (Section 2.2.11). However, not all parameters were included in this analysis and the parameter ranges used were arguably too narrow. This has been addressed, to some extent, through the completion of two additional scenarios to assess the sensitivity of key predictions to the river bed conductance parameter (Section 2.2.12).

3 Concluding statement

The groundwater assessment and supporting groundwater modelling work described in the HA report and various attachments have been carried out in a professional and rigorous manner that meets current industry standards. The modelling work has generally been completed in line with the Guiding Principles included in the Australian Groundwater Modelling Guidelines and in the IESC Uncertainty Analysis Guidance Note and we have not identified any fundamental flaws in the work which are likely to significantly effect model predictions. We note that Section 10.9 of the HA report includes a commitment to review the project numerical model at least every three years from the commencement of open cut mining. We agree with this approach and based on the findings of this review we suggest as a minimum that the following two items below be addressed in the first such iteration:

- Re-calibration of the groundwater flow model to observed head differences in nested monitoring facilities and to estimated baseflow at the Tooloombah Creek and Deep Creek gauges; and
- Re-running the predictive uncertainty analysis including the river bed conductance parameter, assessing a wider range of parameter values and adopting a higher SRMS cut off.