Review of Groundwater Issues Associated with the Proposed Bylong Project

prepared for:

Independent Planning Commission NSW

by:

Dr Lloyd Townley

GW-SW Pty Ltd

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GW-SW Pty Ltd
PO Box 6589
UNSW Sydney NSW 1466
ABN: 54 069 270 846

1. Introduction

This report has been prepared in response to a request from the Independent Planning Commission (the Commission), received on 4 December 2018, with a Consultant Brief attached.

The Brief asked for a review of documents of three types:

(i) documents prepared by consultants (Hansen Bailey and others) on behalf of KEPCO Bylong Australia Pty Ltd (the Applicant),
(ii) documents prepared by the Department of Planning and Environment (the Department), its consultants and other agencies, and
(iii) documents prepared by consultants on behalf of the Bylong Valley Protection Alliance (BVPA) and by other individuals.

In addition, the Brief asked for:

(iv) a summary of inconsistencies within reviewed documents, and identification of the most appropriate approach for assessment, based on accepted best practice, published scientific literature and evidence, and referring to BVPA's request for consideration of groundwater model parameters.

The focus of this review is on "groundwater issues associated with the proposed Bylong Coal Project". However, groundwater issues are intimately linked to issues associated with mining and processing, surface water management and irrigation of farmland within and beyond the Project Boundary. Recognising that groundwater management must be considered in the context of integrated water management in mining, this review refers to other aspects of the proposed project, as necessary.

The review has involved:

(i) an initial briefing (teleconference) on 20 December 2018;
(ii) review of documents and preparation of this report; and
(iii) a final meeting (teleconference) on 27 February 2019.

During the initial briefing, the Commissioners asked that this review make comments on each of the following topics:

(i) potential impact on neighbouring properties and bores;
(ii) rehabilitation and groundwater recovery; and
(iii) potential cumulative impacts.

2. Source Materials

Most of the documents reviewed were downloaded from the Department of Planning & Environment's website: http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=6367. Some were provided as attachments to emails. Many documents are significant in length. The Commission's Brief included references to specific sections of interest in some reports.

The primary source documents are listed in Attachment 1, in the three categories defined by the Commission. Some documents were provided after the start of this review. A response by AGE (2018b) to Anderson's (2018) submission was provided by the Commission on 24 January 2019, after the reviewer had reached and reported an independent and similar view. Formal references have been provided, so that the sequence of studies and documents can be clearly understood. Short names (acronyms) used for references in this review are defined at the start of Attachment 1.

Some additional documents have been sourced, including other Appendices to the Environmental Impact Statement (HB, 2015) and scientific literature. Additional references not suggested directly by the Commission are listed in Section 9.

No attempt has been made to seek project-related documents written earlier than the Environmental Impact Statement prepared by HB (2015).

3. Structure of This Review

Section 4 of this review introduces the proposed project, provides a list of potential "groundwater issues" and summarises the history of groundwater-related investigations and reports. The purpose of this section is to demonstrate that a significant level of understanding has been gained during the process of this review. Its purpose is also to introduce terminology and concepts referred to in Sections 5 to 8.

Section 5 provides comments on submissions prepared on behalf of BVPA and by other individuals.

Section 6 focuses on the challenges associated with numerical groundwater modelling, the methodology used to assess potential groundwater impacts of the proposed project. Consultants undertaking investigations on behalf of the Applicant have found the task of groundwater impact assessment challenging. Government agencies and members of the community have found the task of assessing the merits of the groundwater impact assessment similarly challenging, at least in part because of open discussions about uncertainty in modelling.

Section 7 focuses on three topics identified by Commissioners in the initial briefing.

Section 8 considers the comments and recommendations that have been made by the Department, the Planning Assessment Commission and their consultants, during the assessment process.

The order of Sections 5 to 8 was chosen so that the more detailed issues are discussed before consideration of the "big picture" in Sections 7 and 8.

Section 9 provides a summary of the review.

Section 10 lists references not listed in Attachment 1.

4. Proposed Project, Potential Groundwater Issues and History of Groundwater Investigations

4.1 The proposed project

4.1.2 The Project Area

The proposed Bylong Coal Project lies in a system of valleys, as shown in Figure 1 below. The Project Boundary (shown in red) is the boundary of mining tenements held by the Applicant. In this review, the term Project Area is used to describe the area inside the Project Boundary.

Figure 1 is useful because it allows the reader to visualise:

- the main rivers and streams (Bylong River flowing from southeast to northwest towards the Goulburn River, Lee Creek flowing from south to north, Growee River flowing from the southwest, and Dry Creek carrying surface runoff from the Bylong State Forest towards Bylong River, downstream of its confluence with Growee River), and
- the main land use classifications (forested hills and ridgelines, undulating pastoral lands, and flat pastoral grazing lands and irrigated pastoral agricultural lands).

Figure 1 shows a combination of topography, hydrology, vegetation, land use and water use. The irrigated pastoral agricultural lands along Bylong River and Lee Creek are used to grow crops, including fodder for horses. The locations of the proposed mines, based on the revised mine plan, have been superimposed based on Figure 1 in HB (2018b) (indicative and not to scale).

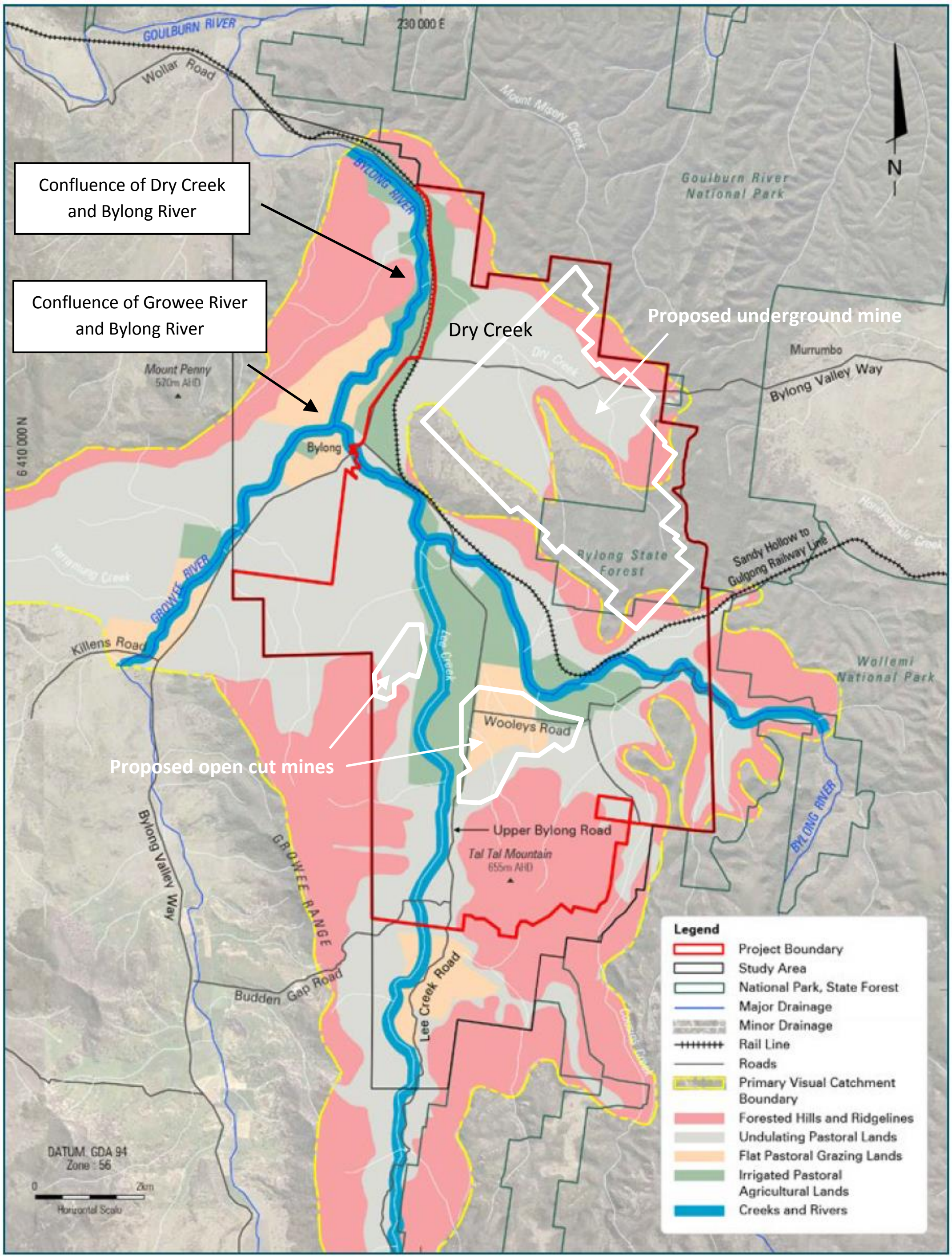

Figure 1: Visual Character Units, Figure 66 in HB (2015)
(proposed mine locations from Figure 1 in HB (2018b) are indicative and not to scale)

4.1.2 Mine plan and schedule

The mine plan and schedule are the fundamental causes of impacts on groundwater, so an understanding of the mine plan and schedule are essential for assessment of groundwater issues.

The proposed project includes both open cut and underground mining of coal. Open cut mining is proposed in relatively shallow pits in two areas, to the west of Lee Creek, and in an area east of Lee Creek and south of Bylong River, just upstream of their confluence. Longwall mining is proposed to the east of the Bylong River, beneath the catchment of Dry Creek and the Bylong State Forest.

Section 3 of HB (2015) describes the project, as originally proposed, including mine plans and schedules. Table 6 of HB (2015) suggests that open cut mining will commence in year 3, while underground mining will commence in year 7 of the project. The schedule is “indicative”, because all plans and schedules change, as more information becomes available and depending on earlier progress.

HB (2018b) describe a revised mine plan for open cut mining, with a substantial reduction in footprint and volume mined. The plan and schedule for underground mining remain unchanged.

A report by Mine Advice Pty Ltd (2015, Appendix E in the original EIS prepared by Hansen Bailey, 2015) provides more information and insight than is normally provided into the way mine plans and schedules are developed. Many alternative designs were considered and compared, even before the revisions described by HB (2018b). Section 2.1 explains that the Coggan Seam is the main economic target, since the Ulan Seam (mined at the Ulan and Wilpinjong Mines) is split into thin uneconomic plies in the Project Area. Section 7.1 explains that by selective mining and processing, some of the Ulan plies can be mined in open cut pits. Figure 11 shows the elevations of coal seams, dipping to the east and north; an extract from Figure 11 is shown here in Figure 2: East-West Section 12 in Figure 11 shows that to the west of Lee Creek, the target seams are above the elevation of the creek, while to the east of Lee Creek and south of Bylong River, the target seams are below the creek and river. The elevation of these seams is important because it defines the depth of mining.

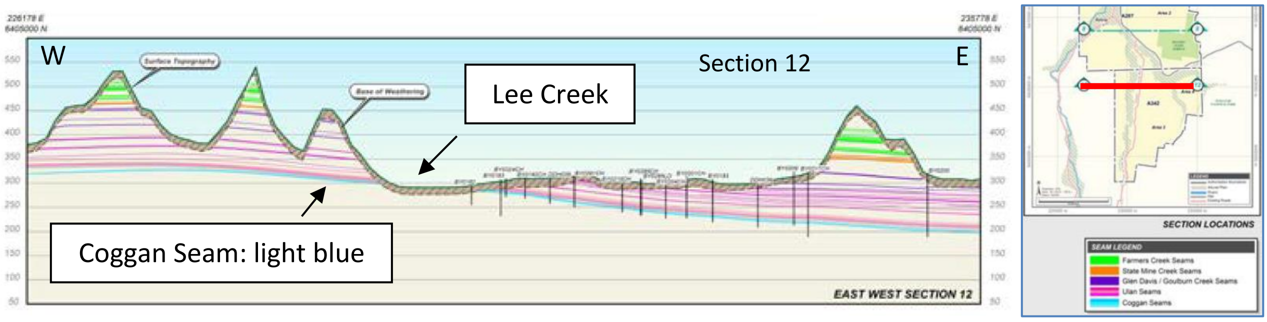

Figure 2: Elevation of target seams in open cut mining area, from Figure 11 of Mine Advice Pty Ltd (2015)

Section 8 in Mine Advice Pty Ltd (2015) explains how the plan and schedule for underground mining were developed. Their Figure 17 shows the underground mine plan and schedule proposed in 2015: it is reproduced in Figure 3 below. Not all of the details are explained in the original report or here, but a few details are important, for an understanding of how the mine will cause subsidence and affect groundwater. The proposed panel width is 304 m in the southern part of the mine and 344 m in the northern part. The 15 panels cover an area[1] of most of 17 km^2. Preparations for underground mining will take 3 years, with longwall mining starting in year 4 of the period of underground mining. Each panel will be mined from northeast to southwest, i.e. from the deepest part of each panel towards the shallowest.

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[1] It is difficult to find a clear statement of the area (the footprint) of the proposed underground mine. The Subsidence Study Area is defined (HB 2015, Section 3.1 and Figure 18) based on a 26.5-degree angle of draw from longwall extraction, where the maximum subsidence is predicted to be 20 mm. This area is 1714 ha or 17.14 km^2.

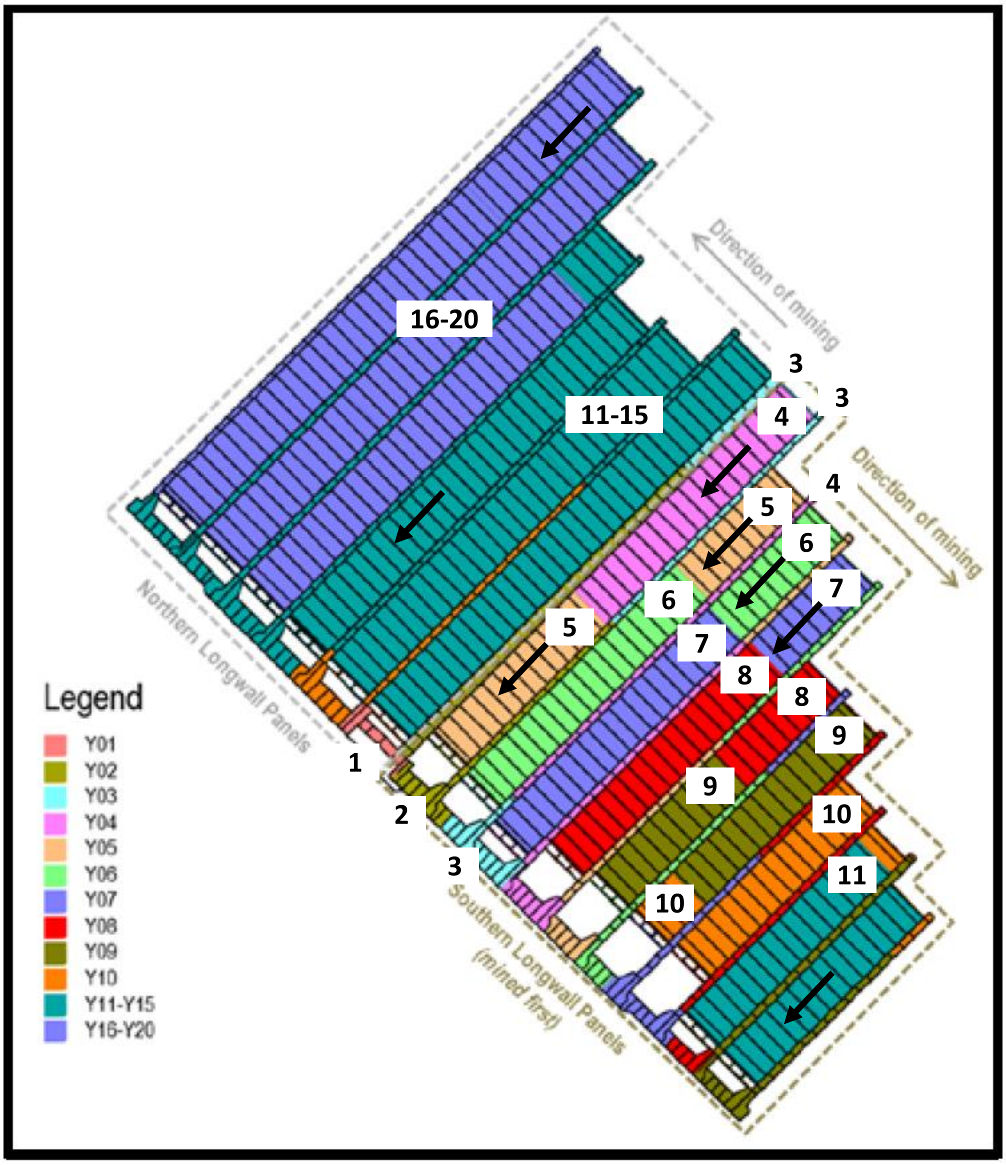


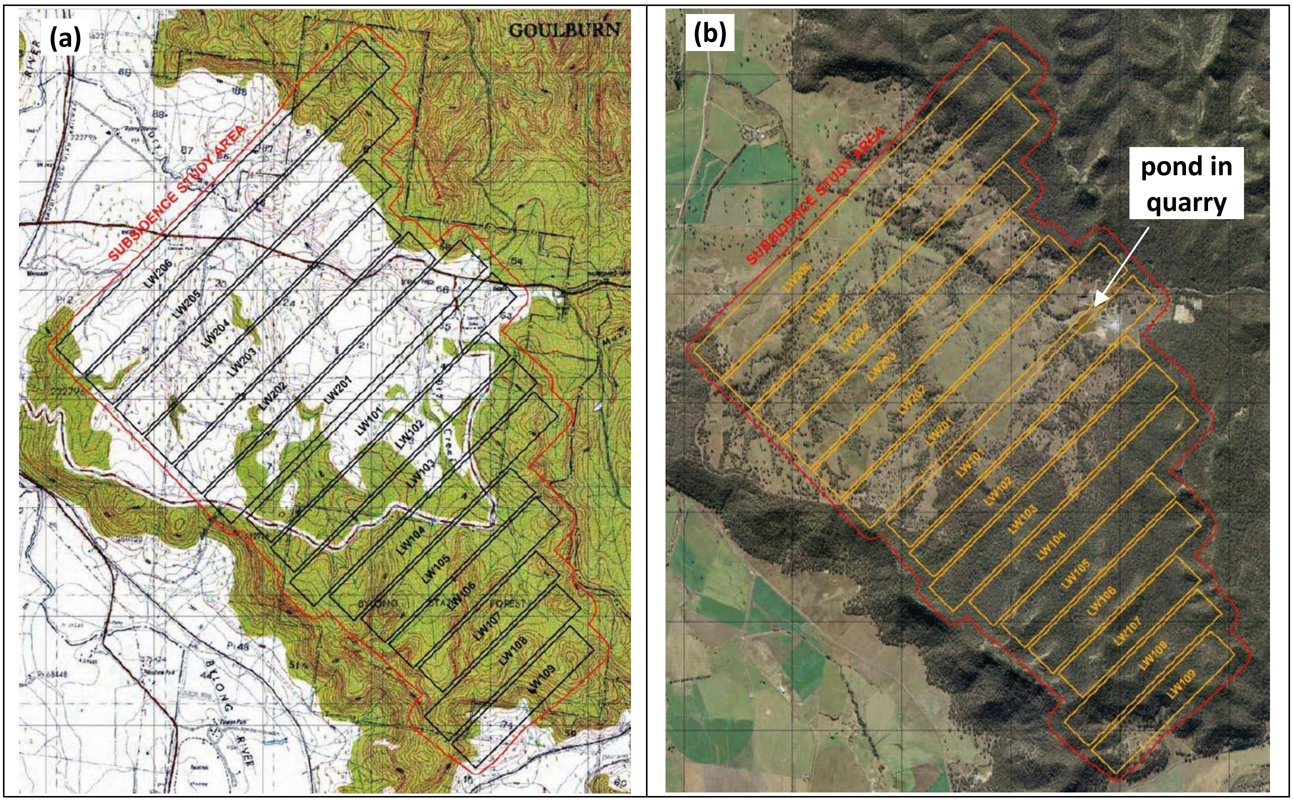
Figure 3: Proposed underground mine plan and schedule, Figure 17 of Mine Advice Pty Ltd (2015)

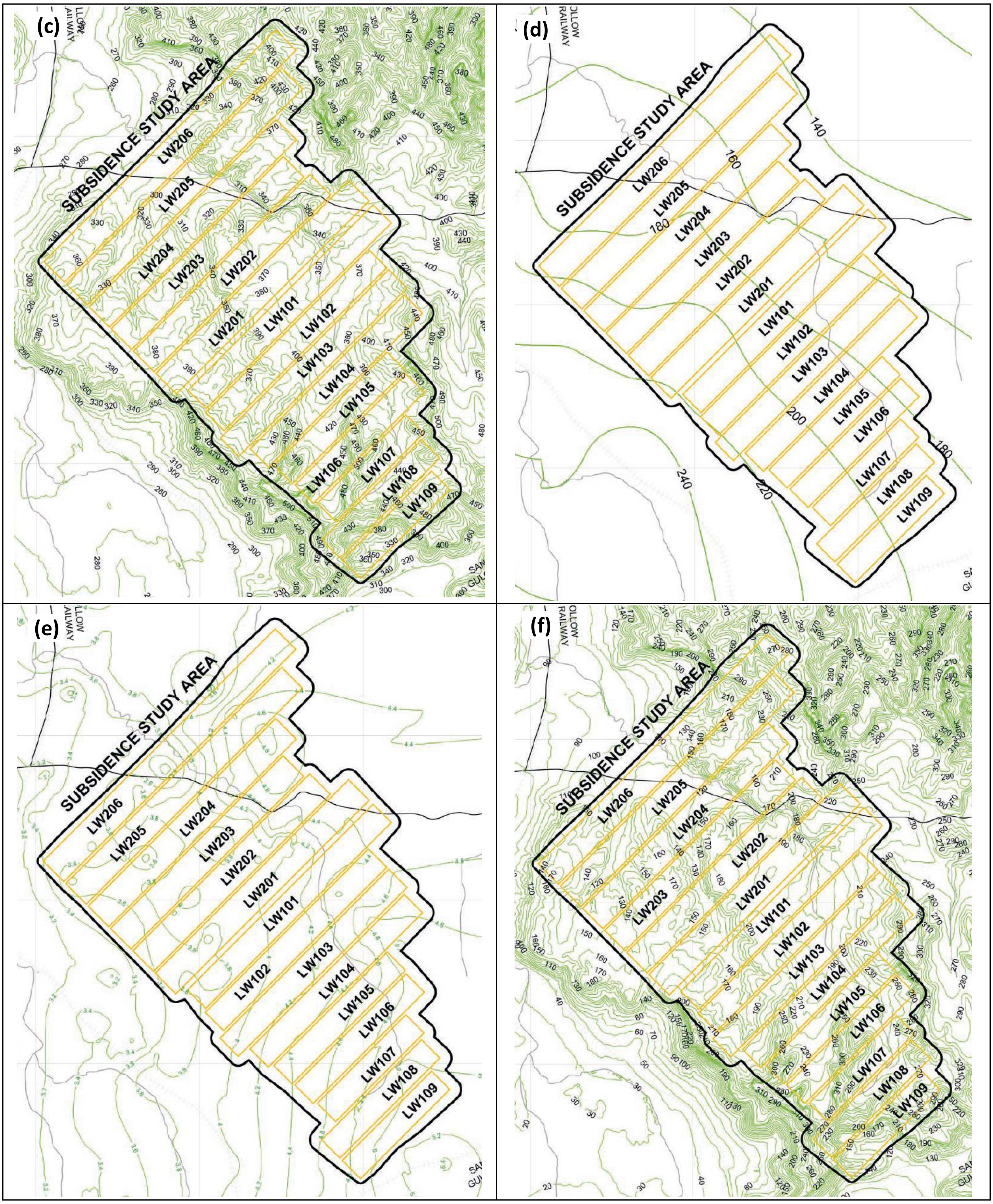
The underground plan and schedule are overlain on surface topographical features in Figure 26 of HB (2015). But numerous useful Figures are also provided by Mine Subsidence Engineering Consultants Pty Ltd (MSEC) (2015). Figure 4 below shows extracts from Figures 2.1 and 2.2 and Figures in Appendix E of MSEC (2015). These extracts are not to scale and are provided without full legends. They allow stakeholders to visualise the following features of the proposed underground mine:

- The mine is located beneath the valley of Dry Creek;
- The land surface is forested in the southeast and cleared in the northwest;
- The bed of Dry Creek is at about 275 mASL at its lowest point above the longwall mining, and about 240 mASL at its confluence with Bylong River;
- The base of the Coggan Seam dips from an elevation of about 220 mASL near the portal (the southwestern end of LW101) to just under 140 mASL in the northeast (where mining will start in LW206 in the second last year of longwall mining);
- The Coggan Seam is between 3.2 and 5.1 m thick (about 4.5 m thick at the northeastern end of LW101 where mining will commence);

- Depth of cover above the mine (the difference between land surface elevation and the top of the mined seam) varies between 120 and 300 m (about 210 m at the northeastern end of LW101 where mining will commence); and
- Panel LW101 starts almost beneath the Bylong Valley Way, passes beneath basalt, a quarry (with an associated surface dam, possibly ponding in a previously quarried area) and Dry Creek.

One of the reasons for showing all the component Figures in Figure 4, prepared by specialists in mine planning and assessment of subsidence, is that the geometry of a mine has a strong influence on potential hydrological and hydrogeological impacts. Mine plans and schedules (geometry and timing) must be represented in a regional-scale groundwater model to assess potential impacts.




(c)
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SUBSIDENCE STUDY AREA
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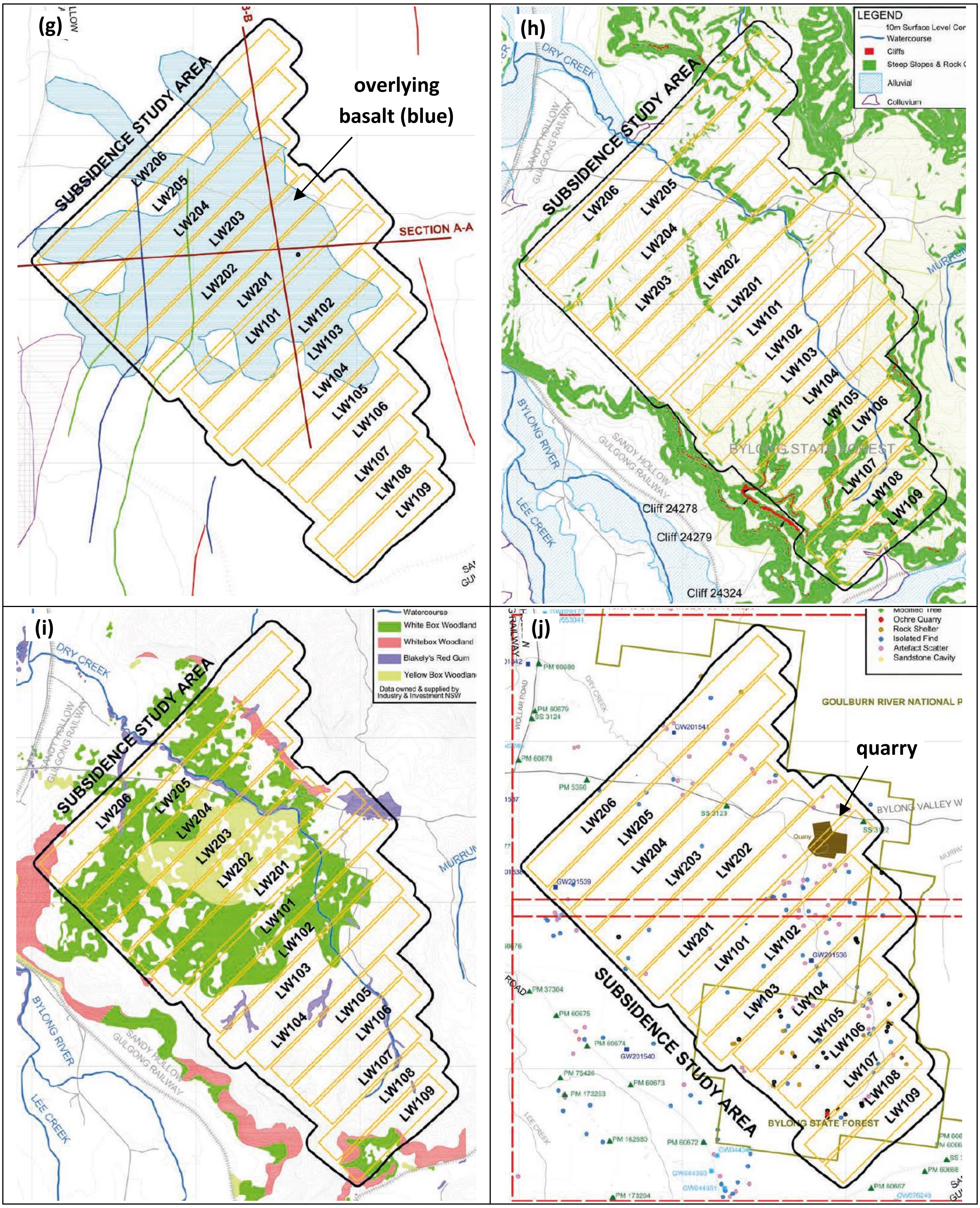

Figure 4: Proposed underground mine, from Figures 2.1, 2.2 and Appendix E of Mine Subsidence Engineering Consultants (2015): (a) an overlay on Central Mapping Authority map 89333S, (b) an overlay on an aerial photograph, (c) surface level contours (topography, mAHD), (d) seam floor contours (mAHD), (e) seam thickness contours (m), (f) depth of cover contours (m), (g) geological structures, (h) natural features, (i) threatened ecological communities and (j) archaeological sites, survey marks, groundwater bores & exploration bores

4.2 Potential "groundwater issues"

There are many ways to consider integrated water management in mining, but it is useful to distinguish between three periods of importance: pre-mining, during mining operations, and post-closure, and to discuss the importance of each of these periods separately. Understanding processes in each period is an essential part of the "conceptual model" required for assessment of groundwater issues in mining.

4.2.1 Pre-mining

It is important to understand the hydrogeological system and its interactions with surface water, prior to mining. In many places, the elevation of the water table is said to be a "subdued reflection of the topography"; this means that the shape of the water table follows the land surface but is more smooth, it lies just below the land surface in valleys and alluvial flood plains, and somewhat further below the tops of hills. Consultants for the Applicant have argued, albeit with a limited number of measurements, that the regional water table does not rise high in the area beneath Dry Creek, above the proposed longwall mine. In this area, the water table is a "*very* subdued reflection of the topography", with levels rising not far above the Bylong River. Groundwater flows from locations with high piezometric head[2] (a measure of gravitational potential energy) to areas with lower piezometric head.

In general, for most of the year between rainfall-runoff events, groundwater would be expected to discharge from surrounding hills to the alluvium along Bylong River and Lee Creek, and then to the pools or flowing surface water, in which case groundwater is said to be contributing baseflow. In times of high surface flow, there would be a tendency for the river and creek to lose some water to the alluvial aquifer, primarily by lateral flow into the alluvium, thereby recharging the aquifer and increasing the water table elevation near the river and creek. If flooding occurs above stream banks, additional recharge could occur, by vertical infiltration.

The alluvial aquifer has been used as a source of groundwater for irrigation of crops. The bores are relatively well separated from each other and have small yield. The water balance of the alluvial aquifers should be relatively easy to explain, with a balance between rainfall-recharge, groundwater inflows and outflows, surface water – groundwater interaction, and pumping for irrigation. It is important to note that the water table in each alluvial aquifer of interest has a natural pre-mining gradient[3]; the water table in the Lee Creek alluvium drops about 60 m over a distance of 8 km, while the water table in the Bylong River alluvium drops 30-35 m over a distance of 5.3 km and another 20 m over a distance of 4.25 km. The gradient in the Growee River alluvium is similar to that in the Bylong River alluvium.

The natural hydrological system pre-mining involves a surface hydrological system and a hydrogeological system. The two are interconnected, since: (i) infiltration of recharge becomes percolation below the root

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[2] Piezometric head $h(x,y,z,t)$ at any location and time is defined as the sum of elevation at that point z and pressure head, which is equal to pressure P divided by the density of water ρ and acceleration due to gravity g. At any point on the water table, $P = 0$ atm, so $h = z$.

[3] In the Lee Creek alluvium, the water table drops about 60 m over a distance of 8 km, a gradient of 0.75%, between boreholes A12 and A10 (AGE (2015) Figure 6-1, Table 6.1 and Figure 7-10). In the Bylong River alluvium, the water table drops 30-35 m over a distance of 5.3 km, a gradient of 0.6% "as the crow flies" between boreholes A15 and A08-S at the confluence of Lee Creek and Bylong River (AGE (2015) Figure 6-1, Table 6-1 and Figure 7-9) and another 20 m over a distance of 4.25 km, a gradient of 0.5% "as the crow flies" between boreholes A08-S and A19 near the confluence of Dry Creek and Bylong River (AGE (2015) Figure 6-1, Table 6-1 and Table 3 in Douglas Partners (2014)). From the Growee River alluvium to the Bylong River alluvium, the water table drops about 30 m over a distance of 7.5 km, a gradient of 0.5% between boreholes A14 and A19 (AGE (2015) Figure 6-1 and Table 3 in Douglas Partners (2014)). A revised version of Figure 6-1 in AGE (2015) is provided as Figure 2 in AGE (2016a).

zone and ultimately recharge to the water table; (ii) stream levels affect the exchange of water between surface water and groundwater, with streams either gaining or losing water, while aquifers are discharging to streams or being recharged by them; and (iii) groundwater is pumped to supply irrigation at the land surface.

4.2.2 During mining operations

Mining operations cause changes in hydrogeological and hydrological systems.

- Mining operations need water supply for dust suppression and for operation of the coal handling and preparation plant (CHPP). It is proposed to draw water from new mine bores in the alluvial aquifer of the Bylong River and Lee Creek.
- Open cut mining will cause groundwater to flow into each mine. Since the mine will extend to the base of the Coggan Seam, this will cause depressurisation in the Coggan Seam, and in hydrostratigraphic units above and below the Coggan Seam. The depressurisation will propagate in all directions from each open cut mine, and notably to the northeast, beneath the Bylong River alluvium and towards the future underground mine. Depressurisation in the Coggan Seam will therefore affect natural groundwater flows that were probably towards the alluvium in the pre-mining situation. The initial effect is to reduce upward leakage (discharge of groundwater to the alluvium) but later there may be a local reversal in the direction of flow, such that there may be flow from the alluvium towards depressurised layers.
- Underground mining, of which longwall mining is a special kind, also causes depressurisation. While the working levels of a mine need to be “dewatered”, for safety and trafficability, the hydrostratigraphic layers (aquifers and aquitards) above and below an underground mine are generally not “dewatered”. Pressure and piezometric head are lowered, and this affects flow directions and rates, but the strata often remain saturated. Longwall mining is different, because the collapse of the roof over each panel causes formation of a “goaf”, a volume filled with rubble, which is rapidly drained. Fracturing extends some distance above the goaf, possibly to the land surface, and unsaturated flow conditions frequently develop as fractures drain while the primary porosity in unfractured rock initially retains most of its moisture. As depressurisation radiates outwards from an underground mine, the effects propagate in all directions, including up-dip, and possibly beneath nearby alluvium. As in the case of open cut mining near alluvium, the initial effect is to reduce upward leakage (discharge of groundwater to the alluvium) but later there may be a local reversal in the direction of flow, such that there is flow from the alluvium towards depressurised layers.
- Construction of overburden emplacement areas (OEAs) above the pre-mining land surface, placement of coarse and fine rejects via co-disposal in mined open cut mines and other surface activities can also affect groundwater and surface water during mining.

4.2.3 Post-closure

- At the end of mining, when mine dewatering ceases, groundwater continues to flow into mines (into open cut mines, backfilled open cut mines, underground mines and the goaf) and water levels in formerly drained volumes slowly rise. This water must come from somewhere. While the water table elevation and piezometric heads near a mine rises, the water table elevation and piezometric heads far away may continue to decline. The time at which maximum drawdown (of the water table) or maximum depressurisation (reduction in piezometric head) occurs can be long after closure.
- After the end of open cut mining, some water may be stored in open cut pits, as storage for mine water management. At the end of underground mining, or even earlier if there is excess water at the surface,

it may be necessary to pump water into underground storage. Addition of water in any storage will cause some recharge of surrounding groundwater.

- Potential impacts on water quality can also increase after closure. Degradation of water quality inside a Project Boundary may be of less concern than the impacts of release of poor quality water offsite. For release to occur, there needs to be a source of poor quality water, such as an OEA or a backfilled pit, and a pathway along which poor quality water can flow towards a receptor. The depressurisation caused by mining often means that poor quality water is drawn towards the mine for a long time after mining.

4.3 History of groundwater-related investigations and reports

4.3.1 History of investigations and reports

The Environmental Impact Statement (HB, 2015) includes a Groundwater Impact Assessment (GIA) prepared by AGE (2015). AGE relied on field studies by Douglas Partners starting in 2011, including the studies reported by Douglas Partners (2014), being Appendix B in AGE (2015). No earlier reports have been sighted during this review.

The GIA presented the development of a numerical groundwater flow model developed using MODFLOW-SURFACT. Since then, the model has been reviewed and revised several times by AGE (2016, 2017, 2018a), HS (2015, 2016) and KA (2015, 2016a, 2016b). HS provided a review and a model audit for AGE; KA provided reviews for the Department.

The history of groundwater impact assessment and modelling is summarised in Figure 2.1 of AGE (2017), which is reproduced in Figure 5 below, extended and annotated to show specific documents sighted during this review (see also Department of Planning and Environment, 2018, Figure 5). The vertical axis (scaled 0 to 5) appears to have no meaning. Additional reports have since been prepared by AGE (2018a, 2018b).

In some respects, the amount of modelling is unusual and disproportionate to the complexity of the proposed project. The iterative approach and the fact that several models have been developed and calibrated using different software packages (MODFLOW-SURFACT and MODFLOW-USG) add confidence to the modelling results. At the same time, the relatively public nature of the iterations, due to reports submitted by the Applicant to Government and subsequent requests for more information, may increase uncertainty in the eyes of some stakeholders. The fact that HS undertook a model audit, which involved viewing and working with model data files, and developing and comparing additional models, also adds confidence.

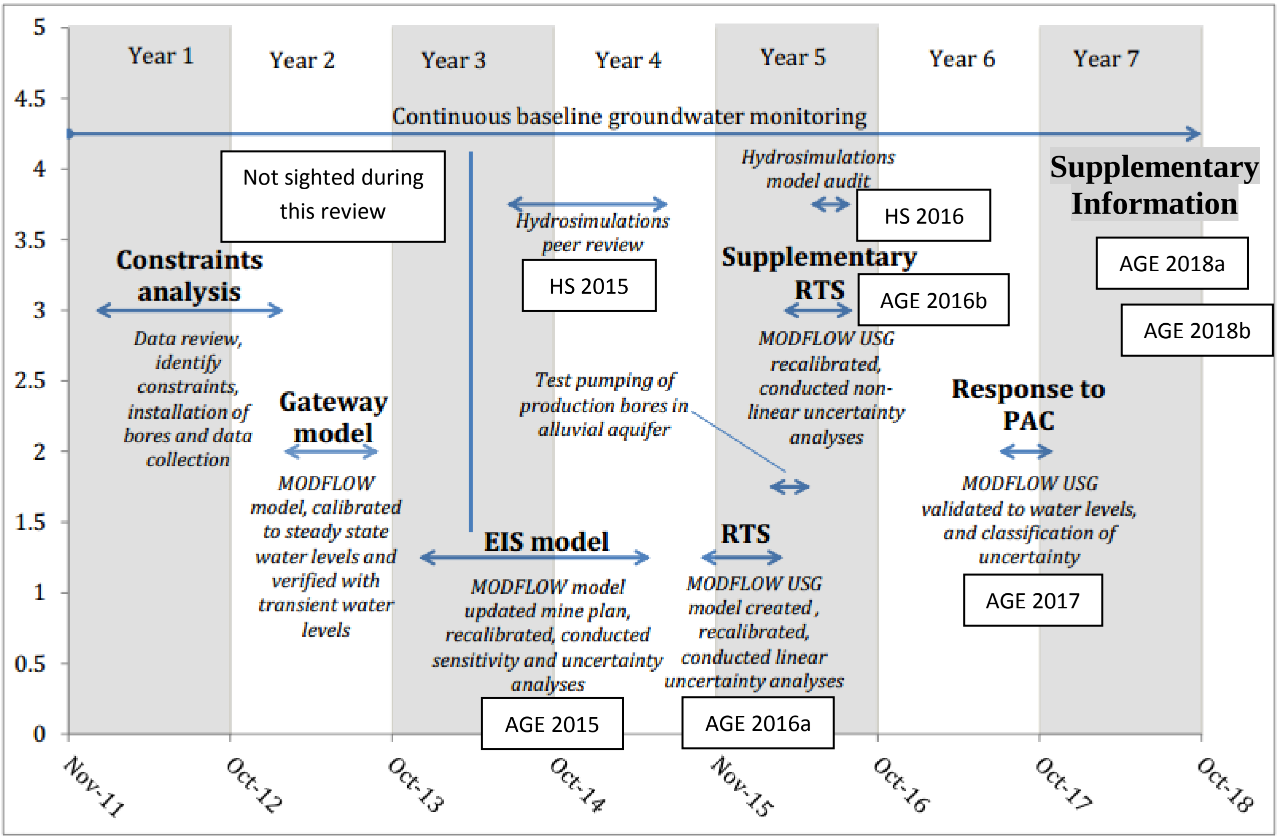

Figure 5. History of groundwater investigations and numerical modelling, based on Figure 2.1 in AGE (2017)

4.3.2 Relevance of investigations to "groundwater issues"

The purpose of this Section, which concludes the introduction to this review, is to explore whether or not the "groundwater issues" that need to be considered have been considered.

The objectives of the original Groundwater Impact Assessment are defined in Section 3 of AGE (2015). The objectives of modelling are defined separately in Section 8.1: "the primary objective of the groundwater modelling was to quantify the impact of the proposed mining…". The objective could have been expanded to explain that open cut and underground mining would affect the regional groundwater differently, and that critical parts of the model would be (i) representation of the mine plans and schedules, so that groundwater inflows to mines could be estimated, (ii) representation of alluvium and colluvium in the river and creek channels, and the hydrogeological connections between the mine, the alluvium and the surface water, and (iii) representation of bores operated by irrigators and as part of a mine borefield. Objectives need to be explicit, to focus attention on the types of predictions that need to be made.

According to Section 6 of AGE (2015), a "conceptualisation of the groundwater regime within the Project Boundary" was developed in an earlier Preliminary Hydrogeological Assessment and Water Monitoring Plan (WMP) developed by Douglas Partners in 2013 (not sighted during this review). This conceptualisation was "continually updated in consultation with" NSW Office of Water, since its development in 2011.

The "conceptual hydrogeology" is described in Section 7.1 of AGE (2015), with reference to Figure 7-21, reproduced as Figure 6 below. The Figure is described as a "schematic section showing conceptual hydrogeology". It is quite common for a conceptual model to be presented using a single cross-section of this kind, or an oblique three-dimensional block diagram, showing hydrogeological structure and flow directions. Section 3 of the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) describes the development of conceptual models. Nearly all models are designed to predict the future response of a system, following changes. The Guidelines try to explain that a “conceptual model” is more than a diagram, and most importantly that it must explain processes that are currently taking place, as well as the processes that are expected to take place in the future. Figure 6 tries to show the current situation and the future in one diagram.

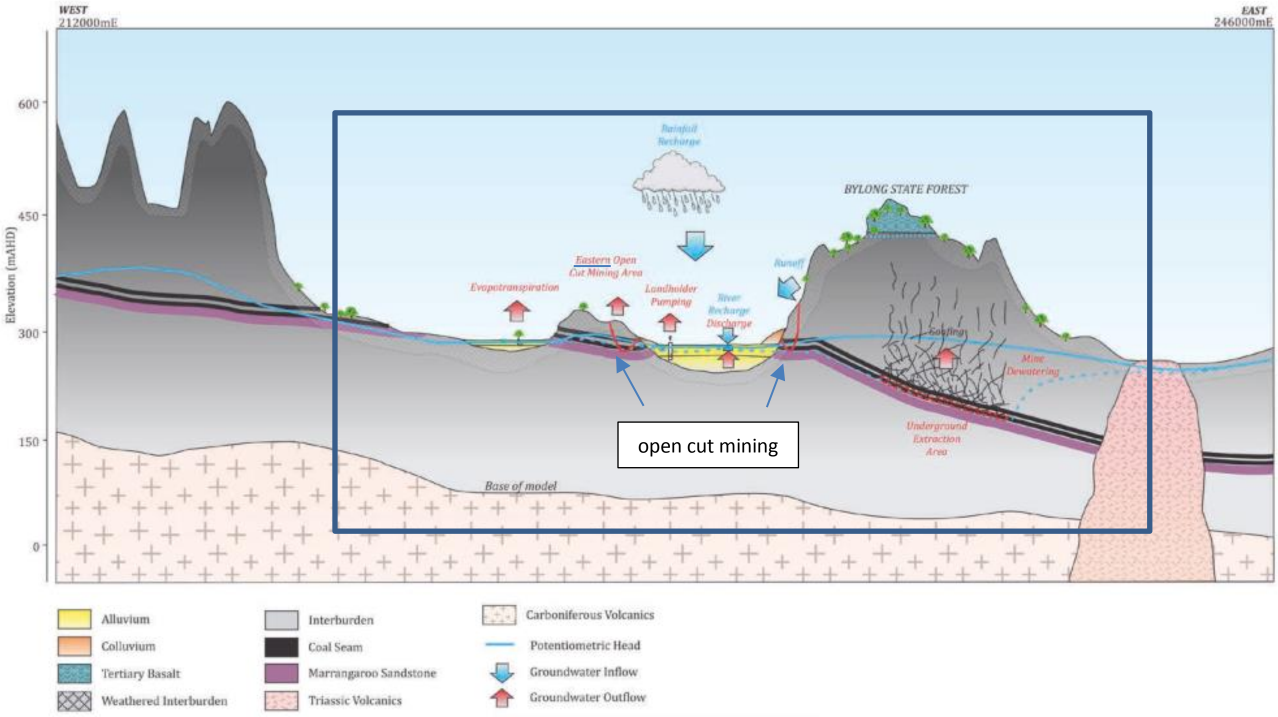

Figure 6: Schematic section showing conceptual hydrogeology, based on Figures 7-21 in AGE (2015)

Figure 6 is not a particularly good schematic, as it leaves many questions open. The Figure shows the water table before and after mining, and processes during mining. If the two areas of alluvium are intended to represent Lee Creek and Bylong River, they should have been labelled, and it would then make sense to show the Western Open Cut Mining Area to the west of Lee Creek and to remove what appears to be open cut mining on the Bylong State Forest side of Bylong River. It is not clear that this Figure communicates to stakeholders that the authors understand the full range of “groundwater issues” listed in Section 4.2 above, before, during and after mining, or other issues not identified by the reviewer. A sequence of Figures at different times could explain a lot more.

If the process of “conceptual modelling” or “conceptualisation” had been described more completely and with more Figures, it is conceivable that all steps in the groundwater impact assessment might have proceeded more smoothly. A good list of issues provides structure. A list provides an opportunity to explain which issues can be addressed using a regional scale groundwater model, and which issues need to be addressed differently, with a different type of modelling, or even without modelling.

Table 1 is a list of issues discussed in Section 4.2. A list of this kind allows one to check that the design of a numerical groundwater model is suitable to address all issues, or at least to identify which issues cannot be addressed by the model.

Table 1. List of potential groundwater issues

Timing	Groundwater issue
Pre-mining	Understand the hydrogeological flow system, including recharge and discharge mechanisms and flow in alluvial aquifers, under pre-mining conditions
	Understand surface-water groundwater interaction in alluvial aquifers under pre-mining conditions
	Understand the impact of pumping for irrigation, and the water balance of alluvial aquifers under pre-mining conditions
During mining	Predict the potential additional impact of mine bores in alluvial aquifers
	Predict potential groundwater inflows to open cut mines, lowering of the water table near the mines, depressurisation in deeper confined aquifers, and the impact of depressurisation beneath alluvium, with possible impacts on surface water – groundwater interaction
	Predict potential groundwater inflows to longwall mine panels, both laterally and from above, due to collapse of the goaf and fracturing above the goaf; predict depressurisation in deeper confined aquifers, and the impact of depressurisation beneath alluvium, with possible impacts on surface water – groundwater interaction
	Predict the possible impact of management of overburden, coarse and fine rejects at the surface, especially after they resaturate, at which time the flow of water through waste is a type of groundwater flow
After mining	Predict the rate of recovery of pressures and piezometric heads in confined aquifers and the rate of recovery of the water table, including the continued expansion of cones of depression of the water table and cones of depressurisation in deeper aquifers, as water continues to flow towards former mines, and also taking into account storage of excess water in open cut mines while underground mining is continuing, and in the underground mine if the project water balance requires pumping into underground storage during and/or after mining
	Predict potential impacts on groundwater quality and ultimately on surface water quality, long after mining

All of these issues have been addressed in some way, during the last seven years of studies. Some were addressed by AGE (2015) in the Groundwater Impact Assessment, and further clarified in later reports. Some were addressed in more detail in responses to questions. If the project is allowed to proceed, a list of this kind should be expanded and kept up to date, as part of an operational Groundwater Management Plan.

5. Comments on Submissions Prepared on Behalf of BVPA and Others

Submissions by Anderson (2018) and Pells Consulting (2018) were prepared for the Environmental Defender's Office (EDO) in NSW, on behalf of BVPA. Submissions by Imrie (2018) and Anonymous (2018) were not prepared for BVPA but are included in this Section largely because of the time when they were submitted.

5.1 Submission by Anderson (2018) (UNSW Water Research Laboratory)

- Anderson's most significant comment relates to the appropriateness of values specific storage Ss. Anderson quotes a recent paper authored by colleagues at UNSW Water Research Laboratory (Rau et al., 2018), which argues that under certain conditions, there is a theoretical lower bound for Ss, being about 1.3 x 10^{-5} m^{-1}. This comment is made in numerous places: in paragraphs 19-23, at the start of his Summary; in paragraph 37(g), with reference to comments by Pells and Pells in 2017 and perhaps also in

2015 (not sighted during this review); in Section 4.1.3 and 4.1.4; and in slides 13-22 from a presentation to the Commission on 12 November 2018. There are also several references to a conference paper by Evans et al. (2015), for which no reference is given (hence not sighted during this review). The paper by Rau et al. (2018) is a recent paper, and while it may be a significant contribution to the scientific literature, there will no doubt continue to be discussion and debate on the range of possible values of specific storativity.

- The following two equations appear in the Anderson's paragraph 42 and on his slide 16:

$$\nabla h^2 = \frac{dh}{dt}\frac{Ss}{K} + R - D$$

$$\frac{dh}{dt} = \nabla h^2 \boxed{\frac{K}{Ss}} + r - d$$

The Laplacian operator is normally written ∇^2 and sometimes Δ; it is never written ∇. Assuming homogenous and isotropic hydraulic conductivities, the groundwater flow equation (which is not normally referred to as a transport equation) has a term $\nabla^2 h$ or $\nabla^2 \phi$ when ϕ is used to represent piezometric head rather than h. In the special case of one- or two-dimensional aquifer flow, where h represents water table elevation in an unconfined aquifer, h is measured relative to datum at the base of the aquifer, and T=Kh, the equation can include $\nabla^2 h^2$, because $T\nabla^2 h$ can be written as $(K/2)\nabla^2 h^2$. However, there are no circumstances in which Anderson's equations, as presented, are correct.

The aquifer flow equation for one- and two-dimensional flow in a homogeneous isotropic confined aquifer can be written:

$$S\frac{\partial h}{\partial t} = T\nabla^2 h + R$$

where the aquifer storage coefficient S=SsB [-] is dimensionless, Ss [m^{-1}] is specific storage or specific storativity, B [m] is constant aquifer thickness (not varying in space), K [m/d] is a constant value of hydraulic conductivity (not varying in space), T=KB [m^2/d] is constant, and R [m/d, or m^3/d per m^2 in plan] is recharge or prescribed (not head-dependent) leakage into the confined aquifer, from above and below.

It is true that under these idealised homogeneous isotropic conditions, one can divide by B and obtain:

$$S_s\frac{\partial h}{\partial t} = K\nabla^2 h + \frac{R}{B}$$

Dividing again by Ss gives:

$$\frac{\partial h}{\partial t} = \frac{K}{S_s}\nabla^2 h + \frac{R}{S_s B}$$

although it is rare to see the equation in this form. This may be the equation that Anderson was planning to present. When making arguments about hydraulic diffusivity (K/Ss), it is common to assume that R is zero, in which case:

$$\frac{\partial h}{\partial t} = \frac{K}{S_s}\nabla^2 h$$

In fact, in a three-dimensional porous medium, there is no recharge term in the groundwater flow equation. This is because recharge and other fluxes into and out of the groundwater system are represented as boundary conditions on the boundaries of the three-dimensional domain. In three dimensions, it is common to use ϕ rather than h, and the flow equation in the interior of a homogeneous isotropic domain can be written:

$$\frac{\partial \varphi}{\partial t} = \frac{K}{S_s} \nabla^2 \varphi$$

The point that Anderson tries to make is that the response time (responsiveness) of a confined aquifer is controlled by hydraulic diffusivity. One way this is often explained is with reference to a non-dimensional ratio u defined by Theis (1935, cf. Anderson's slides 13 and 15, with the reference to Theis given in the paper by Rau et al., 2018):

$$u = \frac{L^2 S_s}{Kt}$$

Whenever this ratio has the same value (in a homogeneous isotropic confined aquifer), the response of the aquifer to forcing is in some sense the same. The response time is proportional to L^2 and Ss and inversely proportional to K. Anderson is correct in saying that responses or signals propagate faster (i.e. the response time is less) when Ss is smaller.

- The analysis presented by Anderson in his paragraphs 49 and 50 is an attempt to explain the effects of errors in Ss. See also his Figure 4.4 (note that the formatting of paragraph 49 is corrupted, it fills the top half of the page above paragraph 50) and his slide 22.

  Comment 1: In Anderson's analysis, a one-dimensional aquifer is subjected to a sudden stress, in the form of pumping or withdrawal starting instantaneously at one end of the domain and continuing. This analysis is potentially relevant to consideration of the potential impact of pumping, in a shallow alluvial aquifer; the geometry is always more complicated, and a radial solution (Theis' solution) may be better than a one-dimensional solution; nevertheless, this analysis correctly illustrates the effects of "storage" relative to hydraulic conductivity. In assessing the potential impacts of groundwater extraction on other users of alluvial groundwater, the relevant storage coefficient is, Sy, not specific storativity, Ss. Anderson has used an example based on a prescribed boundary flux and specific storativity, when a more relevant example to illustrate the potential impact of mining on alluvial aquifers would be based on a prescribed boundary flux and *specific yield*.

  Comment 2: The potential impact of deep open cut mining and underground mining is somewhat different from pumping in a shallow aquifer. When one turns on a pump, the pump attempts to withdraw water at a desired rate. If the nearby aquifer can deliver water at the desired rate, by a combination of lateral flow and changes in storage, then the aquifer will respond and heads will change at all distances and times. When one mines to the base of a specific seam, there is no attempt to draw water at a particular rate; rather, there is a need to remove material (soil and rock) to a specific level; the rate at which water flows into the mine depends on that level, and on the capacity of the subsurface to deliver groundwater via a combination of lateral flow and changes in storage. In the language of groundwater modelling, pumping is simulated using a prescribed flux boundary condition, while mining is simulated using a prescribed head boundary condition. This second case is different from that shown in Anderson's Figure 4.4. Anderson has used an example based on a change in prescribed boundary flux and specific storativity, when a more relevant example to illustrate the impact of underground mining would be based on a *change in prescribed piezometric head* and specific storativity.

  In summary, Anderson has provided an example which is intended to show the effect of specific storativity, but the example is not directly applicable to situations of interest for the Bylong Coal Project.

- Anderson is concerned about the values of Ss used in model layers 1, 2 and 3 (alluvium and colluvium). Anderson's Figure 4.1 is based on Figure 19 in the report (Response to Submissions) by AGE (2016).

  It is very important to understand how storage coefficients are assigned and used in a numerical groundwater flow model, whether the software is MODFLOW-SURFACT, MODFLOW-USG, or any other.

  In regional scale groundwater flow models, a few shallow layers at the surface tend to act as one. The transmissivity of layers 1 to 3 is effectively the sum of the three transmissivities, from the base of layer 3 to the water table. The storage coefficient that dominates the behaviour of these layers is specific yield Sy at the elevation of the water table. If the water table is locally in layer1, then Sy in layer 1 is used and Sy in layers 2 and 3 are not used at all. The role of specific storage in shallow aquifers is small, as explained below.

  Suppose that the water table drops in layer 1 by 2 m. Most modelling software disables Ss in any layer where Sy is active, so if Sy = 0.1, the amount of water released in layer 1 is 2 m x 0.1 = 0.2 m = 200 mm. Now consider the importance of Ss in layers 2 and 3, assuming that piezometric head drops 2 m in each layer. If layer 2 is 6 m thick, with Ss = 0.001 m^{-1} (see Section 8.2.3 and Table 9.1 in AGE, 2015), the amount of water released would be 2 m x 6 m x 0.001 m-1 = 0.012 m = 12 mm. If layer 3 is 20 m thick, with Ss = 2 x 10^{-4} m^{-1}, the amount of water released would 2 m x 20 m x 2 x 10^{-4} m^{-1} = 0.008 m = 8 mm. Given uncertainties in all hydrogeological properties, the 20 mm would normally be considered negligible relative to. If Ss were limited to 1.3 x 10^{-5} m^{-1}, then the amount of water released from specific storage in layers 2 and 3 would be 2 m x 26 m x 1.3 x 10^{-5} m^{-1} = 0.00068 m ~ 0.7 mm.

  Anderson is correct in explaining that if Ss were smaller, the amount of water released would be smaller. However, even if the 20 mm of release from confined storage is an overestimate, the effect on the effective aquifer diffusivity of the upper three layers is less than 10%. This difference is small compared to uncertainty in hydraulic conductivities, specific yield, recharge and all other parameters affecting the behaviour of the shallow aquifer.

  In Section 4.4.2 of their Response to Submissions on Groundwater, AGE (2016) explain that uncertainty analysis included varying values of specific storativity by a factor of 5. An increase by a factor of 5 is a 400% increase; a decrease by a factor of 5 is an 80% decrease. Either way, the uncertainty analysis probably spanned a greater range than that implied by the ~10% difference in specific storage that would be required to match the limit proposed by Gau et al. (2018).

  The response to Anderson (2018) provided in Section 3.1.5 of AGE (2018b), received after the above explanation was written, is simple and consistent with expectations.

- Anderson is concerned about the values of Ss used in layers 7 and 8 (interburden and the Coggan Seam), but he has not explained which specific aspect of model predictions could be affected by any "error" in Ss in these layers.

  Anderson is correct in suggesting that if Ss is too large in deep confined layers, the effect of changes will propagate more slowly in those layers. Layers 7 and 8 have a combined thickness of 4 m + 5 m = 9 m in the original model (Section 8.2.3 in AGE, 2015). Their combined storage coefficient is 4 m x 7.6 x 10^{-5} m^{-1} + 5 m x 2 x 10^{-4} m^{-1} = 0.0013. The thickness of the Coggan Seam varies from 3.2 to 5.1 m inside the footprint of the proposed longwall mine, so the regional scale model approximates the thickness of the seam. Variations in Ss need to be considered in the context of uncertainty in the thickness B of layers, and with a clear understanding of which predictions could be sensitive to (affected by) errors in SsB.

The fact that the model is shown to be relatively insensitive to Ss is not surprising. It is difficult (almost impossible) to stress an aquifer prior to mining in such a way that Ss can be estimated accurately, and in terms of sensitivity of predictions to Ss, some predictions do not depend on Ss. The effect of Ss is usually seen in short-term transient responses. As a system starts to approach steady state, i.e. when heads vary slowly, the storage term becomes less and less important, and sensitivities to the storage term approach zero.

The uncertainty analysis undertaken by AGE appears to be systematic and has been audited by HS. The range of solutions spanned by parameters far from their best estimates provides reasonable confidence in the range of predictions of the response of the deep confined aquifers to longwall mining.

- With reference to paragraph 29, multiple models and revisions can indeed be useful.

5.2 Submission by Pells Consulting (2018)

- The submission by Pells Consulting (2018) is concise and well-written. The author refers in Section 2 to previous reports by Pells Consulting, dated 4 November 2015 and 18 May 2017. These have not been sighted.
- Clearly the earlier documents prepared by Pells Consulting raised a number of issues, such as the whether or not impacts were less significant because the Applicant owns the land, the degree of confidence in the ability of alluvial aquifers to provide mine water supply, and the nature of Triassic aquifers.
- At the end of Section 2, Pells Consulting indicate that “in general, we find that the PAC final assessment report demonstrates appropriate understanding and response to the issues identified above”.
- In Section 3a, Pells Consulting indicate that “we consider that, in general hydrogeological studies for the Project have been undertaken to an acceptable standard”. The only additional comments relate to impacts on the Applicant’s land (as noted above), and the difficulty of interpreting modelling reports, which has led at least in part to this review.
- Many of the comments made by Pells Consulting relate to subsidence, cracking and impacts on environmental flows, i.e. not specifically to groundwater.
- The reviewer agrees that there is always a challenge regarding the lack of absolute criteria for assessment of acceptability of impacts.

5.3 Submission by Imrie (2018)

- The document entitled “Cumulative hydrological impacts of coal mining in the upper Goulburn River, Hunter Valley NSW” may contain useful information, but has not been sighted. It is not easy to make direct comparisons between what has occurred at Ulan, Wilpinjong or Moolarben Mines, even if other mines target coal seams with the same name. Hydrogeological properties, proximity to alluvium and surface water, mine plan and schedule etc., are different at every mine.

- With reference to paragraph 3, Imrie is correct in saying that the predicted impact of the mine includes drawdown in the Coggan Seam that extends westwards beneath the Bylong River, and beneath the alluvium and colluvium that separate the coal seam from the river.

- Imrie's paragraph 6, regarding the suggestion that excess water could be stored in the goaf following longwall mining, raises an important issue. The possibility of storing water in the goaf is referred to in Section 2.6 of Appendix J in HB (2016c), with a simple reference to "managing some of the mine water within the underground goaf areas". Appendix B to Appendix J, being a letter report from WRM dated 17 August 2016, makes no reference to this concept. Further references to storage in the goaf can be found in Section 4.2.1.8 of HB (2018a), including a reference to "WRM's Response to the PAC Review Report (Appendix M)", so this may be what Imrie refers to.

  Section 4.2.1.8 explains that "An additional 5,000 ML of storage capacity for excess mine water has also been indicatively allowed for within the goaf from Project Year 17 (at the completion of the 100 series of longwall panels (LW101 to LW109). This is a conservative figure as it assumes that water is only accumulated up to the highest point of the goaf floor in the 100 series longwall panels." The additional 5000 ML is shown in Figure 3 in that report. Under the heading "Water balance and management of excess water", the Department (2018, p.34 and Figure 11) explains that "bulkheads would be installed in the gate-roads between the 100 and 200 series of panels" and that "underground storage in the goaf is standard practice at many underground mines".

  It is correct to suggest that storage in the goaf is possible, however storage in the goaf during mining is more likely if the goaf is at the lowest point in the mine. This is not a groundwater issue *per se*, but it is an important issue related to mine water balance, and ultimately any water stored in the goaf would be considered to be groundwater.

  Figure 4(d) above shows the elevation of the base of the Coggan Seam. If longwall mining commenced at the northeast end of LW206, at the deepest part of the underground mine, then for practical and safety reasons, storage in the goaf of this deepest part of the mine may be feasible. The Applicant's mining engineers must be aware of the possible need to store excess water in the underground mine and of practical issues. Mine plans and schedules can be adjusted when there is a reason to do so, even if there is an associated cost. If the mine is approved, the Applicant will learn a lot during mining of the first panel LW101. The mine will be found either to be relatively dry or relatively wet, and new predictions of water balance throughout the life of mine will be possible. By starting at LW101, as planned, the Applicant would have enough time to adjust the mine schedule in response to what is learned.

5.4 Submission by Anonymous (2018)

- The author makes many comments about many aspects of the project.

- With reference to paragraph 2, the author's concerns about the risk of drought, and the adequacy of water supply, particularly in the early years of the project when it will rely on alluvial groundwater, are reasonable.

- With reference to paragraph 3, storage of excess water in the goaf is good practice. As indicated above, this may only be possible with a change in mine schedule, because it is unlikely that miners would choose to work in panels at lower elevations, at elevation lower than flooded parts of the mine. The Applicant should be given the opportunity to consider this possibility, and to choose to "seal" higher parts of the mine if there are proven methods to do so.

Storage of mine inflows in the underground mine is unlikely to have environmental impacts in the future. The water flowing into the mine is already in the environment and has water quality characteristic of regional groundwater. Travel paths and travel times to the biosphere will be long, and any release would be at such a slow rate that its quality would be unlikely to adversely affect receiving waters in the future.

- With reference to paragraph 4, it appears that there will be significant impacts on the alluvium for a long period of time. However, the alluvium would almost certainly recover to a new equilibrium, very similar to the pre-mining situation, after storage in the alluvium has recovered.

6. Challenges Associated with Numerical Groundwater Modelling

The groundwater modelling undertaken by AGE and HS is worthy of discussion, even though modelling *per se* is not a “groundwater issue”. Numerical groundwater modelling is the only methodology that can be used to predict the future behaviour of groundwater systems. The Commission asked that this review consider and provide comments on scientific issues and parameters. Parameters affect the modelling that has been undertaken, so this review discusses groundwater modelling and parameter uncertainty here, partly to explain the role of modelling in assessment of groundwater management issues.

Ultimately, it is important that stakeholders have confidence in predictions. Nevertheless, a numerical groundwater flow model has many parts, and even for professionals with many years of experience, there are always challenges that lead to uncertainties. In the remainder of this Section, a few specific issues challenges will be discussed.

6.1 Confidence-Level Classification

Based on criteria proposed in the Australian Groundwater Modelling Guidelines (Barnett et al., 2012), AGE (2015) suggested that their model had a Class 2 Confidence-Level Classification. In fact, the intention of the authors of the Guidelines was that all models of greenfields mining projects would have a Class 1 Confidence-Level Classification, based on the fact that stresses during the prediction period, caused by the excavation far below the pre-mining water table, are more than five times higher than stresses during the calibration period. This aspect of the Guidelines has not been well understood. There is no suggestion that a Class 1 model cannot be used to assess the potential impacts of mining. The authors of the Guidelines were simply trying to communicate to all stakeholders that in these circumstances, model predictions must be uncertain. This is precisely why the Guidelines recommend formal uncertainty analysis and why such analysis has been undertaken for this project. There are many aspects that need to be taken into account in determining confidence level, as shown in Attachment 2 to this report.

6.2 Regional water table

The regional water table is shown in Figure 7 below, extracted from Figure 7-8 in AGE (2015). According to this map, there is only one borehole (CP035/BY0001) inside the area of the proposed longwall mine; Table 6.1 in AGE (2015) shows that this borehole is screened in the Coggan Seam, so it is likely to measure a value of piezometric head lower than the water table elevation at this location. According to Figure 6-1 in AGE (2015) and Figures 2 and 3 in AGE (2016a), there are several other boreholes inside the area of the proposed longwall mine (CP014/BY0010, CP028/BY0007, BY0011, BY0080 and BY0091); CP014 and CP028 are closer to the Bylong River, so they provide less information about heads far from the river; piezometric heads are measured using vibrating wire piezometers (VWPs) at the other locations.

Figure 7 in a Geology Report prepared by Cockatoo Coal Limited (2014) shows many exploration drillholes prior to the end of June 2014 (see Figure 8 below). Section 7.5 in Cockatoo Coal Limited (2014) explains that Douglas Partners installed standpipe piezometers in exploration drillholes. Raw data (to June 2014) are reported by Douglas Partners (2014), see Tables 2 and 3 in Appendix B in AGE (2015); the water table elevation in CP035 is about 273 mAHD (105 m below ground level), about 12 m higher than CP045 (12 m below ground level) and 20 m higher than in CP028 and CP027.

Neither Douglas Partners (2014) nor AGE (2015) discuss why it was not possible to choose more drillholes in the area of the proposed longwall mine for monitoring. Exploration geologists rarely collect data that would be useful for hydrogeological and environmental impact studies, because their focus is on finding a mineralised target. Retrofitting exploration holes to make them suitable for water level monitoring is often impossible. Nevertheless, this opportunity should be taken whenever possible.

AGE (2017) do not update their interpretation of the regional water table. Figure 4-1 in this report shows depth to water table in the Coggan Seam. The smoothness of the colours in the top right of Figure 4-1 suggests that the water table is still believed to be as shown in Figure 7 below.

Knowledge of the shape of the regional water table above the proposed longwall mine is important because it affects the potential for groundwater inflows to the underground mine, especially by vertical drainage if goafing causes fracturing to and above the elevation of the water table.

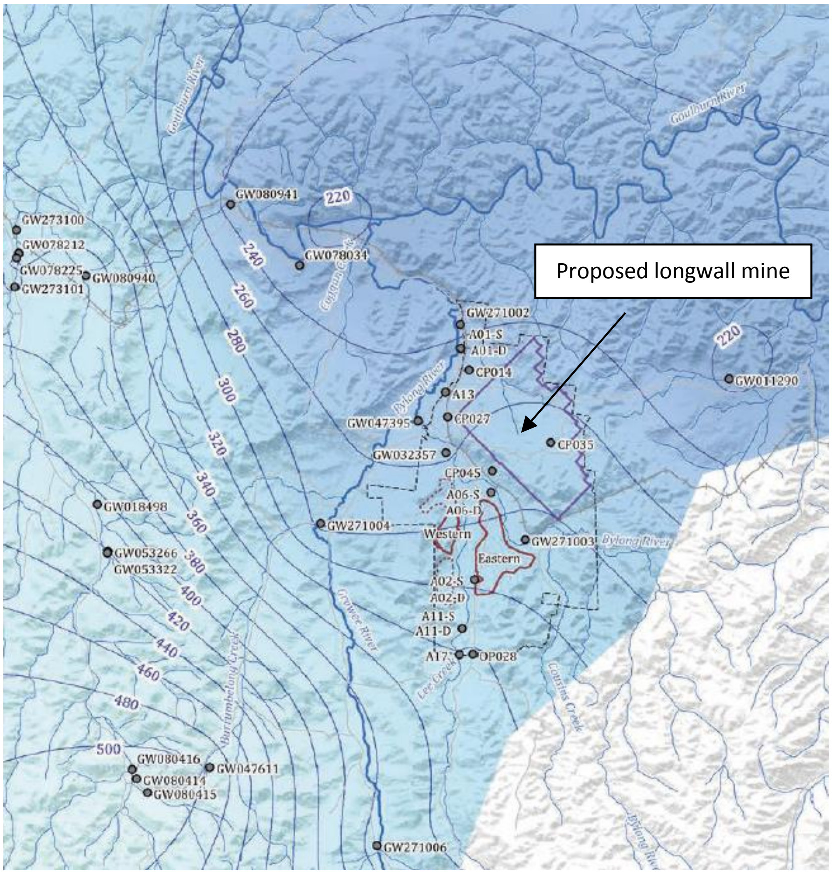

Figure 7: Regional water table, Figure 7-8 in AGE (2015)

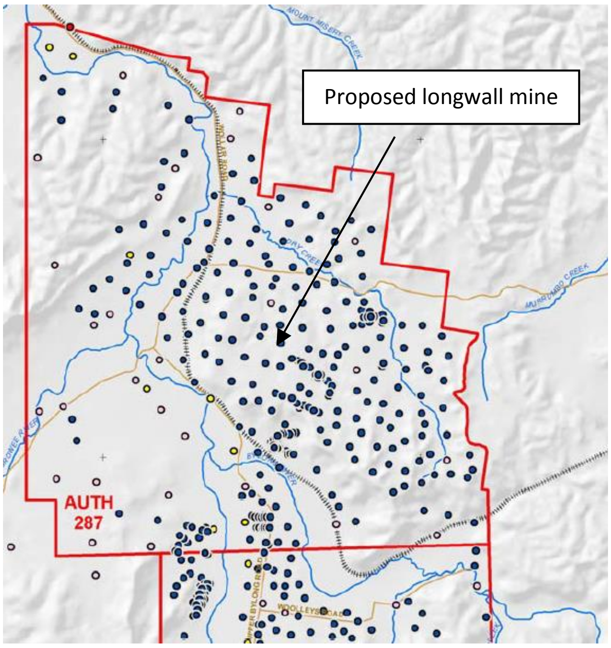

Figure 8: Exploration drillholes to end of June 2014, Figure 7 in Cockatoo Coal Limited (2014)

6.3 Choice of groundwater modelling software

Stakeholders who read the sequence of reports prepared by AGE, with reviews by HS and KA, will note the transition from the use of MODFLOW-SURFACT to MODFLOW-USG, and ongoing discussion about how to represent the unsaturated or vadose zone, using either a pseudo-soil approach or an approach based on the physics of unsaturated flow in soil. The pseudo-soil approach in MODFLOW-SURFACT and the upstream weighting used in MODFLOW-USG were in fact written by the same developer, Dr Sorab Panday, who worked at HydroGeoLogic Inc. on initial development of MODFLOW-SURFACT, so the methods are surely similar (see also KA, 2016b, p.5).

Stakeholders who have read Groundwater Impact Assessments for other underground mines will know that another option is to use software called FEFLOW. FEFLOW is still used by some modellers, thought its developers now only recommend an approach based on the physics of unsaturated flow. This is always difficult for underground mining projects because it is never possible to have as many model layers as desired; this means that the method that has a more theoretical basis must still be approximated in practice.

In fact, no groundwater modelling software has been written specifically to handle the challenges of longwall coal mining, or many other situations where caverns or tunnels are excavated deep below the water table. This does not mean that the software cannot be used. It means that care is required, and many repetitions of model runs are required to test the robustness of the modelling method in each situation.

The experience reported by AGE throughout this project is not unusual. What is unusual is the openness with which the challenges have been discussed, and the thoroughness of the audit by HS (2016).

6.4 Representation of goafing and unsaturated flow above the goaf

The various reports by AGE describe the way that longwall mining has been represented, but more information would have been helpful. The description of how open cut and underground mines are represented in the initial groundwater flow model is relatively brief (see AGE, 2015, Sections 10.1, 10.2.6).

In various iterations of the modelling, so-called “drain” nodes have been turned on and off at different times. The purpose of these nodes is to set piezometric head to the elevation of the base of the coal seam, essentially to create the low point towards which will flow. It is important to conceptualise the impacts of the mine schedule in order to implement it correctly in a model. It would have been useful to estimate total inflows into the underground mine, based on the thickness of the saturated zone above the panels and the extent to which this zone might drain. So-called “back-of-the envelope” calculations are useful during the process of conceptualisation, as a check on the water balance eventually calculated by a numerical model.

A considerable amount of research has been undertaken in recent years by Gale (2004, 2005, 2006, 2008, 2011), Guy et al. (2006), Seedsman and Dawkins (2006), Guo et al. (2007), Tammetta (2013, 2015, 2016) and Adhikary et al. (2017). This research links geomechanical deformation above longwall mining and hydrogeological properties. It does not solve the problem of representation of unsaturated flow above longwall panels, using the type of software generally available for regional groundwater modelling. Nevertheless, at least some of this work could have been referenced, to demonstrate the extent to which there is good scientific basis for the predictions being made.

In general, the amount of subsidence at the land surface, as a fraction of thickness of seam, depends on panel width relative to depth of cover. If panel width is 1.5 or 2 times the depth of cover, subsidence is generally 0.5 to 0.7 of the thickness of the seam. Since subsidence occurs dynamically, as each panel is mined, overlying strata bend and may crack. The cracks may subsequently close as mining progresses, and bending is reversed.

Figure 3(a) in Tammetta (2013) suggests that for a typical coal seam 3 m thick, the height of a desaturated zone over a longwall panel approaches the panel width. Figure 9 below (Tammetta’s Figure 7, based on data from Guo et al., 2007, and elsewhere) illustrates the type of situation that can arise, in this case with desaturation at depth and water supported near the surface. If damage and fracturing extend to a height equal to panel width, drainage and desaturation would be expected to extend to the surface. In spite of extensive modelling with different software, there is little discussion in the various reports by AGE about what is actually expected to occur, i.e. what is the conceptual model for desaturation above the longwall panels. It is important to note that desaturation does not mean “dry”, it simply means that moisture content in pores and fractures is less than 100%.

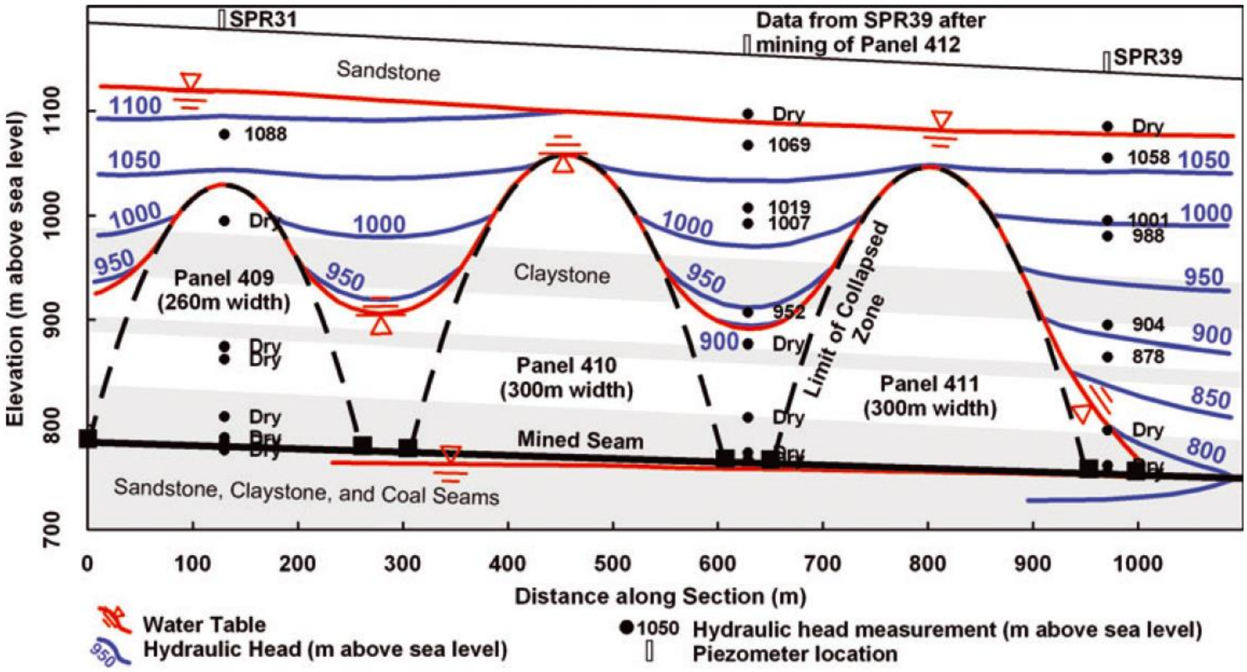

Figure 9: Example of how desaturated zones above longwall panels can support a water table above (Figure 7 from Tammetta, 2013)

The report by SCT (2015) referred to in Section 10.2.8 of AGE (2015) has not been sighted, but the likelihood of fracturing extending to the surface (which is generally less than 260 m above the Coggan Seam) is consistent with the various reports by Gale (of SCT) referred to above. The adjustment of hydraulic conductivities and storage coefficients described in Section 10.2.8 of AGE (2015) is reasonable and consistent with other studies, but it is not clear that the large values of specific yield (1 and 0.25 in the mined seam during the period of mining and after collapse of the goaf) would affect the results, since they would only affect cells where the water table is actually drawn down into the layer representing the Coggan Seam.

While AGE has not explained their modelling in the context of recent research, one submission on the EIS referred to Tammetta (2015), and Section 5.9.18 of HB (2016a) therefore discusses the Applicant's modelling in the context of this work. The response points to Figure 10.15 and 10.18 in AGE (2015), where drawdown over the mine panels is "complete". In fact, Figure 10.15 shows depressurisation in the Coggan Seam, which is necessary for mining, but the remaining question is whether a water table remains above the mine, or not. Figure 10.18 suggests that the water table would indeed be drawn down, because MODFLOW-SURFACT was being run in a mode that did not support an unsaturated zone, or a perched saturated zone above an unsaturated zone.

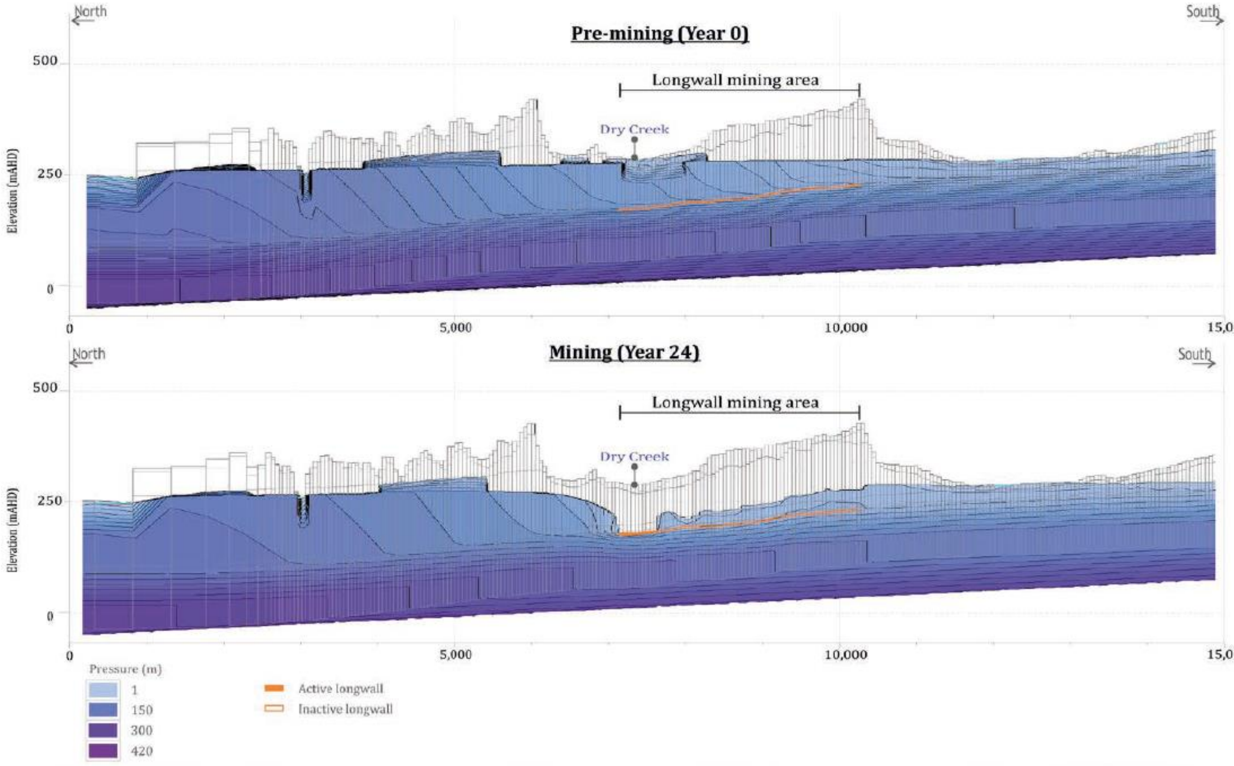

Figure 10: Predicted contours of pressure head beneath the water table (Figure 10.18 from AGE 2015)

The model audit undertaken by HS (2016) involved comparisons between MODFLOW-SURFACT and MODFLOW-USG, both attempting to represent the unsaturated zone, and focusing on movement of the water table. Several Figures in Section 7 of HS (2016) are useful, but none provide a direct comparison with Figure 10 above. The best conclusion that can be drawn is that considerable uncertainty remains about the geomechanical deformation that will occur above the longwall panels, and this leads to considerable uncertainty in how groundwater will move. The large number of simulations, with many combinations of parameters, provides confidence that predicted rates of flow are reasonable.

6.5 Representation of the water table near the surface

While there has been considerable discussion about the way the unsaturated zone is represented, it is not clear whether model runs failed to converge because of the unsaturated zone above the goaf, or simply because the water table was swapping between shallow model layers near the surface in other parts of the model, e.g. in alluvial valleys or beneath areas of high ground far from Dry Creek.

There is no specific need to explore this issue here. The large number of model runs that have been successfully completed by AGE and HS, and reviewed by KA, is evidence that the model is running sufficiently well to allow predictions to be made.

6.6 Representation of alluvium and surface water – groundwater interaction

The model appears to represent interaction between alluvium and underlying strata sufficiently well. The model does not and probably does not need to represent surface water – groundwater interaction at Goulburn River, as this is too far away to be directly affected.

The model is certainly capable of representing bores in shallow aquifers, although given the fact that drawdown sometimes exceeds 10 m, little has been said about the fact that layers 1 and 2 in the model must drain, with the water table moving to layer 3. The software should handle this transition easily, nevertheless it would be reasonable to explain that this is the case. It is also difficult to calibrate a model with the water table maintained in a thin upper layer. More could have been written about this challenge, and about the "RIV" boundary conditions used to represent Bylong River and Lee Creek in the model (see AGE 2015, Section 8.2.5.4), especially during predictions of future behaviour when stage height is not known.

Following comments by KA (2015), AGE subsequently implement MODFLOW's "STR" package to represent streams and rivers, rather than RIV.

6.7 Representations of water balance

A regional scale model is appropriate for assessing the potential impacts. Once a model exists, stakeholders tend to expect that the model can answer all types of questions, including questions that the model was not designed to answer. However, fundamentally, the model appears to have been designed to answer the right kinds of questions.

It would have been useful at different stages of the project if the water balance had been presented for sub-regions of the model, in an attempt to separate the different issues such as the effect of open cut mining on alluvium and surface water, the effect of underground mining on alluvium and surface water, and the effect of irrigation bores and mine bores on the alluvium and surface water. It is not always easy to separate components, however aggregating all flows in and out of all RIV or STR nodes in the whole of the model domain does not allow stakeholders to see the water balance at more local scales.

7. Potential Impacts of the Proposed Bylong Coal Project

Many aspects of the proposed project have been discussed above. The purpose of this Section is to consider the topics of interest to the Commissioners, as listed in Section 1.

7.1 Potential impact on neighbouring properties and bores

The Applicant describes the potential impact on neighbouring properties in the report by HB (2016a). Sections 5.9.2 to 5.9.5 discuss potential impacts on groundwater in Tarwyn Park, Murrumbo Station, Locaway Pty Ltd and the Budden Property, responding directly to submissions on the EIS.

Reliance on groundwater in alluvial aquifers can be seen in Figure 9 below (not to scale, and without legends). The Applicant has sought to define the extent to which the alluvial aquifer is already used.

In Figures 11(a) and 11(b), the blue shaded area surrounded by yellow areas represents the Tinka Tong property. This property was acquired by the Applicant in 2016 (see Section 2.1 in HB, 2016d).

The Eagle Hill property identified in Figure 11(c) is described by HB (2016d, Section 2.1) as the closest property to the mine with non-mine bores.

The Tarwyn Park property is now excluded from the mine plan. It is difficult to estimate impacts on groundwater within Tarwyn Park, from the reports available. However, there will clearly be drawdown in alluvium along Lee Creek and Bylong River, and significantly less drawdown in the area south of the alluvium, in the area that would have been mined. There is likely to be some drawdown of the water table, and depressurisation in the Coggan Seam, near the southern boundary of Tarwyn Park which is near the Eastern Open Cut Mining Area. If this matter is of specific interest, the Groundwater Management Plan should include predictions within Tarwyn Park, with a requirement that sensitive vegetation be monitored for signs of stress, and managed appropriately.

The regional scale groundwater model includes representations of irrigation bores and mine water supply bores, at different locations and pumping at different rates. Figure 38 in AGE (2016a) shows the location of 16 bores in the alluvium of Bylong River and Lee Creek. The most recent results provided by AGE (2018b) include maximum drawdown in the base case, shown in Figure 11(d).

It is useful to discuss the meaning of drawdown plots. First, Figure 11(d) shows maximum drawdown, but the same drawdown does not occur at the same time at all locations. Second, it is tempting to visualise a cone of depression as “hole” or low point in the water table, but in fact drawdown must be superimposed on the pre-mining water table in the alluvial aquifer. As explained in Section 4.2.1 above, the water table in the Bylong River alluvium drops 30-35 m over a distance of 5.3 km, from upstream of the mining-affected area to the confluence of Lee Creek and Bylong River. At an unspecified time, when drawdown is 10 m at a location between the eastern open cut mine and the longwall mine, the water level would be 10 m lower roughly halfway between A15 and A08-S, so the rate of flow in the alluvium would be faster from A15 towards that location, and slower between there and A08-S.

The impact of drawdown on bores within the affected area is not completely clear. To see the details, it would be necessary to examine model output in other ways, looking at long-sections at different times, and examining the water balance of the alluvial system. Figures 7-1 to 7-4 in HS (2016) are a good way to visualise the alluvial aquifers. It is not clear whether the water table is in layer 2 or 3 of the model at the time of maximum drawdown. Nevertheless, the fact that maximum drawdown of 1 m is not predicted to extend to the confluence of the Growee and Bylong Rivers suggests that the Applicant is right to believe that there will be no effect on irrigation bores in the Eagle Hill property.

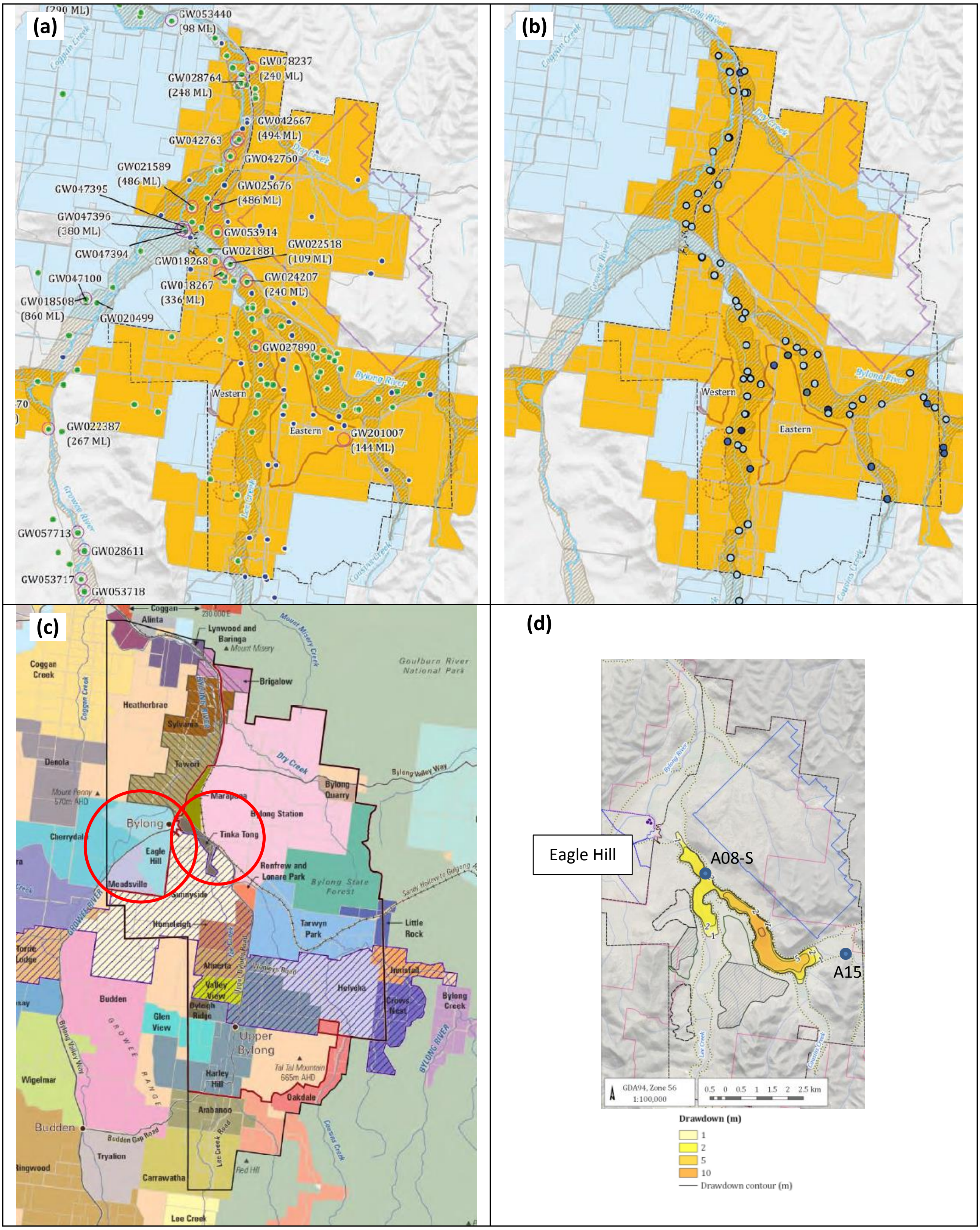

Figure 11: (a) Groundwater users and entitlements, (b) locations of bores and wells from census, (c) Bylong Valley Landholdings and (d) maximum drawdown in the alluvium (base case), from Figures 7-4 and 7-6 in AGE (2015), Figure 3-6 in AGE (2017) and Figure 1 in AGE (2018b), respectively

7.2 Rehabilitation and groundwater recovery

This section focuses on groundwater recovery, i.e. rehabilitation of the hydrogeological system rather than of vegetation at the land surface.

The regional groundwater system will recover in time to a new quasi-equilibrium, in equilibrium with the climate at that time, rather than today. In order for recovery to occur, the total amount of groundwater pumped from storage during the life of the project, as evidenced by drawdown of the water table and depressurisation below the water table, needs to be replaced. This occurs through shifts in the water balance, e.g. some rainfall on the land surface will infiltrate rather than becoming surface runoff or will infiltrate further below the water table rather than evaporating or transpiring.

AGE (2015) simulated the recovery of the regional aquifer for a period of 1000 years after mining. With reference to their Table 10.6, they suggest that most of the recovery occurs in the first 100 (or arguably 150) years. Their Figure 10-27 shows final "groundwater levels" 1000 years after mining, with a slight lowering in the area of longwall mining, and a rise in the area of overburden emplacement areas and backfilled open cut mines. AGE do not explain, but presumably "groundwater level" means "water table elevation", which is a better term. It is not clear whether there is any expectation that recharge through the land surface above the longwalls panels would be expected to increase post mining. It also is not clear whether the rates of flow in Table 6 are integrated over the whole model domain, including areas far from the proposed mines. Nevertheless, the results seem reasonable.

AGE (2018a) revisited the question of recovery. This time, in their Figure 3-5, they show "groundwater levels" in the Coggan Seam, and the model (using different software) includes the revised mine plan. Showing "groundwater levels" in the Coggan Seam is not nearly as useful a measure of recovery, as stakeholders generally interpret this term to be "water table elevation" rather than a measurement of piezometric head at a location far below the water table. It would have been more useful to show water table elevation again, as in AGE (2015).

AGE (2015) predicted that the water table above the longwall mine would hardly be affected by mining, while drainage and partial refilling would lead to significant depressurisation in the Coggan Seam after the same period of 25 years (see their Figures 10-12 and 10-14). Given the interaction between AGE and HS during the audit undertaken by HS (2016), and the significant drawdown shown in Figure 7-10 of the audit report, for example, it is surprising that more detail has not been given to illustrate what is expected.

AGE do not discuss the phenomenon whereby drawdown and depressurisation tend to increase away from a mine for a considerable period of time after the end of mining. The phenomenon is analogous to what happens when a single bore in alluvium has been pumping for some time and is then turned off. In order for groundwater to flow into the cone of depression, so that the water table near the borehole rises, groundwater must flow, almost radially, towards the borehole from further away. This means that the water table elevation further away will continue to decline, until the aquifer reaches a new equilibrium. In the case of a mine, with a cone of depression at the water table, and cones of depressurisation in deeper aquifers, the same phenomenon occurs. The implication is that impacts can slowly increase after mine closure and rehabilitation. In the case of the Bylong Coal Project, the most likely effect will be in deep aquifers with a growing cone of depressurisation further the to the east, away from surface drainage lines. Although the issue is not discussed, it is unlikely to have significant consequences.

7.3 Potential cumulative impacts

There is no risk of direct groundwater impacts of the project on groundwater near other existing mines (Ulan, Wilpinjong or Moolarben Mines), in the sense that the water table at these mines will not be affected by the Bylong Coal Project, and depressurisation will not extend that far. The only potential cumulative impact would be an indirect impact, if drawdown in the alluvium of Bylong River were to cause a reduction in streamflow, either at times of low flow or on an annual basis, such that the impacts of all mines were felt concurrently in the Goulburn River, downstream of its confluence with Bylong River.

It is conceivable that there could be such an effect, but even if coupled groundwater and surface hydrological models could be built to represent surface water – groundwater interaction at a regional scale with reasonable accuracy, the spatial and temporal variability of rainfall are unknown tens of years into the future, and the characteristics of surface soils and vegetation which affect water balance at the land surface are also unknown and unlikely to predicted with accuracy. This suggests that the level of uncertainty in model predictions would be extremely high.

There is a similar possibility that slight changes in water quality could occur. The most likely potential source of contamination in the long term will the overburden emplacement areas, composed of geological materials similar to the surrounding hills, and coarse and fine rejects placed in the eastern open cut mine. If these areas are designed, constructed and rehabilitated according to best practices, it seems unlikely that cumulative water quality impacts will be observable at the Goulburn River. In Section 4.16.2 of HB (2016a), the Applicant argues that contaminant transport modelling would be premature, prior to the collection of data on leaching rates from coal rejects. Section 5.24.3 provides a good discussion of issues associated with salt migration. Significant impacts seem unlikely, as long as waste materials are managed well and in accordance with best practice.

8. Comments on Recommendations by the Department and the PAC

8.1 State Significant Development (SSD) Assessment

The SSD Assessment (Department of Planning and Environment, 2017) was prepared after submission of (i) the EIS (HB, 2016), (ii) the Response to Submissions (HB, 2016a), (iii) the Supplementary Response to Submissions (HB, 2016b) and (iv) a letter to the Department (HB, 2016e). The Department played an active role in all stages of the assessment process prior to preparation of the SSD Assessment. The Department acknowledges the fact that the Applicant had responded to submissions and the project had therefore changed as a result of the impact assessment process.

In its Executive Summary, the Department (2017) states:

"Impact on water resources was a key concern raised in submissions on the project, particularly by landowners who rely on water from the Bylong River alluvial water source for irrigation of crops and water supply for stock."

"The groundwater modelling undertaken for the project predicts that there would be minimal drawdown impacts on privately-owned bores, such that the project would comply with the minimum impact criteria of the NSW Aquifer Interference Policy. This follows additional peer reviews of the groundwater model, independent expert review on behalf of the Department, and expert advice from the Department of Primary Industries – Water (DPI-Water)."

"Following advice from the independent expert ad DPI-Water the Department accepts that the groundwater assessment provides a conservative assessment of drawdown impacts, including comprehensive sensitivity and uncertainty analysis."

"The modelling showed that under the worst-case scenario model run, there is no predicted drawdown in the alluvium at the closest privately-owned bore, locatezd on the Eagle Hill property. KEPCO also redesigned its borefield layout, reducing the number of bores it needed ad located the borefield further away from landowners located in the nearby Growee River catchment."

"The Department has recommended an etensive groundwater monitoring network continue to be developed, ongoing model calibration and validation be undertaken, and that in the unlikely event that there are impacts from the project on private water users, compensatory water supply be provided."

"KEPCO currently holds sufficient water licences to account for all the water required for the operation of the mine from the productive alluvial aquifers, but may require additional licences associated with the interactions of the mine with the deeper and poorer quality hard rock aquifers at som stage during the project. Both the Department and DPI-Water consider there is sufficient depth in the market to accommodate the water take from the project. However, the Department has reommended that KEPCO be required to demonstrate that it has adequate water supply prior to commencing both the open cut and underground operations."

"Overall, the Department considers that KEPCO has designed the project to avoid significant impacts on key water resources, particularly by avoiding direct disturbance of the highly productive aquifers and optimising the borefield to avoid impacts on other groundwater users…"

"The impacts on … the environment are acknowledged, and a range of etailed conditions are recommended to esnure that these impacts are effectively minimised, mitigated and/or compendated for. These conditions incorporate the recommendations of relevant government authorities where appicable."

"With the implementation of these conditions, the Department considers that the project achieves a reasonable balance between recovering the coal resource and avoiding, minimising and/or offsetting adverse social, amenity and environmental impacts."

"On this basis, the project is approvable, subject to the recommended conditions."

Detailed discussion of water resources issues is provided in Section 6.3 of the SSD Assessment (Department of Planning and Environment, 2017, pp. 56-75). The Department acknowledges that uncertainties in modelling remain.

Based on review of the same series of submissions, listed in Attachment 1, the Department's summary is a good summary, and its conclusions are justified.

8.2 PAC Review

The Planning Assessment Commission (PAC), the predecessor to the current Independent Planning Commission (the Commission) released its Review in July 2017 (PAC, 2017). The PAC (Section 2.1 of its Review) had been asked to *"assess the merits of the project as a whole having regard to all relevant NSW Government policies, and paying particular attention to: the impacts on the water and agricultural resources of the Bylong Valley"* and three other matters.

Section 3.1.1 of the Review (PAC, 2017, pp.5-10) lists the PAC's concerns about impacts on water resources. The interaction between water and agriculture is summarised in Section 3.1.3. The PAC made brief comments on:

- Prediction of groundwater impacts using a peer-reviewed numerical model;
- The potential risk of impacts to the alluvial aquifer;
- Uncertainty around potential impacts to the alluvium;
- Effects of inflows to the underground mine on the Permian aquifer;
- The fact that at that time the Applicant had not yet acquired shares in the Permian resources;
- The proposed surface water management strategy being based on the concept of nil-discharge;
- Uncertainty around the potential for mine water discharges; and
- Other matters to be considered in any future decision.

Section 4 (PAC, 2017) presents a summary of the Commission's findings. These include:

"The Commission notes from multiple iterations of the groundwater model that doubt persists about the availability of water resources to the project and for other land and environmental uses. In view of the characteristics of the alluvial aquifer relied upon by the project, the Commission considers there is uncertainty around the probability of impacts and the potential consequences. Similarly, the probability of mine water discharge and the potential consequences for the wider catchment presents risks that are sufficient to warrant a detailed evaluation prior to a determination."

…"As a result all aspects of the project will need to be comprehensively and cautiously considered, carefully weighted, and balanced one against another at the determination stage."

The PAC highlighted a number of issues, that influenced subsequent work described in Section 8.3.

8.3 SSD – Final Assessment Report

The SSD Final Assessment (Department of Planning and Environment, 2018) was prepared after (i) the PAC Review (PAC, 2017), (ii) submissions following that Review and (iii) substantial changes by the Applicant to the proposed mine plan, in response to that Review. The Executive Summary (pp.ii-xix) is 18 pages in length, and includes two pages related to water. The SSD Final Assessment includes the Department's assessment of the impacts of proposed changes.

Table 4 in the SSD Final Assessment explains that the new mine plan leads to a small reduction in maximum groundwater inflows to the open cut mine, a slight reduction in maximum drawdown in alluvium, and little or no change in the effects of underground mining. These predictions seem reasonable and consistent with expectations.

Section 2.2 in the SSD Final Assessment summarises the key issues raised by the PAC (PAC, 2017). Section 2.4 (Department of Planning and Environment, 2018, pp.24-42) systematically addresses concerns expressed by the PAC about impacts on water resources and incorporates the responses of the Applicant and its consultants to those concerns. The PAC's concerns are paraphrased and discussed in six groups.

- In response to a suggestion by the PAC, the Department used a Figure provided by AGE (2017), reproduced in Figure 5 above, with additional annotation, to explain the history of hydrogeological investigations and modelling during the project. This Figure is very useful, however as suggested in Section 4.3.2 above, it would have been useful to expand the description of the conceptual hydrogeological model, to explain the processes that are expected to occur. It is no doubt still difficult for many stakeholders to visualise how water table will move above longwall panels, whether dewatering of the underground mine will cause the evolution of a deep unsaturated zone from the surface to the mined seam or whether a water table will remain at some elevation above the mine, and how dewatering of longwall panels will affect pressures and piezometric heads in the Coggan Seam and adjacent hydrostratigraphic layers beneath the alluvium of Bylong River. The Applicant could improve the conceptual model in a future Water Management Plan.

- In response to the PAC's comments on uncertainty in groundwater modelling, the Department has summarised efforts by the Applicant to explain uncertainty, in particular the report by AGE (2017), which introduces a "likelihood scale" from the domain of climate change analysis; this scale attempts to explain the meaning of various probabilities, expressed as percentages. The Department is comfortable with the Applicant's explanations. Uncertainty analysis is indeed a form of quantitative risk analysis, because it allows estimates of the probability (likelihood) of different events, each of which has a consequence. There are many sources of uncertainty, but formal uncertainty analysis of the kind undertaken by AGE gives confidence in the likelihood of different outcomes.
- Regarding the issue of water supply from the alluvium and entitlements, the Department accepts explanations provided by the Applicant. Risk management is a part of every project. The Department clearly believes that the risk can be managed, and that the onus should be placed on the Applicant to ensure that water supply is adequate and within entitlements.
- On the issue of water take from Permian and Triassic aquifers (the latter including both basalt and sandstone), the Department accepts explanations provided by the Applicant and accepts that the water take can be licensed appropriately.
- Regarding water balance and management of excess water, the Department has summarised additional reports provided by the Applicant. The Department recognises that "underground storage in the goaf is standard practice at many underground mines" and "considers that mine water could be effectively managed in surface storages and the mined underground workings without the need to discharge to receiving waters". "Water storage in the series 100 goaf should be prioritised over surface storage". There appears to be good support for the proposal to contain water on site. Accurate monitoring of the site water balance and regular updates of the water balance model will be required to be part of a Water Management Plan.
- Other matters raised by the PAC are comprehensively addressed by the Department in Table 7 entitled Residual Water Issues.

Section 4 of the SSD Final Assessment presents the Department's conclusion, that "based on its assessment of the project, the Department of Planning and Environment considers that the project is approvable, subject to the stringent conditions of consent outlined in Appendix H" to its report.

The recommended conditions provided in Appendix H of the SSD Final Assessment include conditions relevant to the management of potential groundwater issues.

- Schedule 3 relates specifically to underground mining. The Applicant is required to develop an Extraction Plan, which includes a Water Management Plan (Condition 8(f)(iii), p.11).
- Schedule 4 is about performance measures.
    - Condition 23 requires the Applicant to ensure that it has sufficient water supply for all stages of development. This puts the onus on the Applicant to undertake additional work in the Bylong alluvium to demonstrate that it can supply predicted water demand in the early years of open cut mining.
    - The second row in Table 8 in condition 27 requires the Applicant to ensure that impacts in the alluvium are no greater than predicted. This condition is typical of conditions imposed on other

    mining operations, but is difficult to audit, largely because the predictions made in the EIS and all subsequent reports (see Figure 5 above) are not presented in a form that is easily auditable. The same comment about auditability can be made in relation to the third row in Table 8, because there are no individual quantitative predictions for Bylong River, Lee Creek, Dry Creek and Growee River, and it is almost impossible to audit against predicted statistics.
  - Condition 28(c)(iv) requires a Groundwater Management Plan within a Water Management Plan, and again there is a requirement for monitoring to agree with predictions, which may not be available
  - Condition 62 on rehabilitation is useful, however minimising groundwater seepage from site is not consistent with the need for groundwater discharge to return towards larger pre-mining discharge.
  - Condition 64 requires a Rehabilitation Management Plan, including management of water in the final void (even though there will be no final void, at the end of the project) and in the goaf.
- Schedule 6 covers environment management, reporting and auditing.
  - Condition 7 explains says that the Water Management Plan required under Schedule 4 covers everything that is not included in the Water Management Plan required under Schedule 3. While there may be good administrative reasons for defining the names and contents of documents, the most important aspect of a Water Management Plan within a mining operation is that it be focused on operational needs, so that it readily understood by all teams working on site, to ensure that water-related risks are understood and managed. There should be one integrated Water Management Plan, not two.
  - Condition 11 again requires comparison with “relevant predictions in the EIS”.
  - Condition 12 requires an independent environmental audit, after 1 year and every 3 years thereafter.

The conditions recommended by the Department are consistent with those imposed on other projects and put the onus on the Applicant to manage water effectively. The following comments could be taken into account in any revision of these recommended conditions.

- First, references to predictions in the EIS should be interpreted to include the EIS and all subsequent predictions provided by the applicant during the assessment process.
- Second, most of the predictions made are not easily audited.
  - Groundwater models predict piezometric heads at many (generally hundreds of thousands) of locations, as a function of time. These predictions are used to produce plots of heads at the elevation of the water table (the water table elevation), within model layers (some of which truly function as aquifers) and in cross-sections. The model acts as an interpolator, ensuring water balance throughout the model domain. Contouring software also interpolates, but differently from the model. It is true that predicted piezometric head can be read from a contour plot and compared with measurements, but usually contour plots are not provided at enough times to allow additional interpolation in time.
  - The need for sensitivity and uncertainty analysis means that many sets of model predictions are made. When the results of an ensemble of predictions are presented, e.g. with contours showing maximum drawdown, or the drawdown exceeded only 5% of the time, these plots cannot be directly compared with observations. Figure 6 in the SSD Final Assessment shows contours of likelihood of 2 m drawdown in alluvial aquifers; a plot of this kind cannot easily be used by auditors; it would only be useful if drawdown of 2 m or more was observed very early in the project, in a location where the probability is predicted to be very low, but by this time, the impact would already have occurred. Figure 7 in the SSD Final Assessment shows predicted drawdown in alluvium, with different probabilities; in this case the plots are even more difficult to use in auditing, because they only show

the effect of mining (assuming that effects of mining and pumping from a borefield, can be decoupled), and this situation will never arise.

- Since models predict heads at specific locations, the best way to present predictions in a form that can easily be compared with the results of monitoring is in time series plots. The Applicant should be encouraged to choose the locations of monitoring bores, and the elevations of screened intervals in specific hydrostratigraphic units, and predictions should be made of at those (x,y,z) locations as a function of time. It is still possible, indeed advisable, to present an ensemble of predictions, i.e. many time series superimposed, as a form of uncertainty analysis. An auditor can easily check to see that measurements fall within the bounds predicted at any time.
- The locations of monitoring bores should be chosen to answer specific questions. To see the effects of open cut mining (especially the eastern open cut which mines the Coggan Seam to elevations below the nearby alluvium) on the alluvium in Lee Creek and Bylong River, a transect of bores should be chosen orthogonal to the alluvial channel centreline, between the alluvium and the open cut mine. Even though the impacts of underground mining on the alluvium of Bylong River are predicted to be much less, a transect between the proposed underground panel LW101 and Bylong River, screened in the Coggan Seam, would allow the effects of mining to be tracked.

9. Summary of Review of Groundwater Issues

The large body of work prepared by consultants on behalf of the Applicant and reviewed by the Department and its consultants has led to a recommendation by the NSW Department of Planning and Environment (2018), that the proposed project can be approved and managed in the usual way.

In spite of an unusual amount of public discussion of the challenges with modelling, the outcome of this review of reports, without additional hands-on review of the modelling, is that there is no reason to change this conclusion. The assessment of potential groundwater impacts is defensible and consistent with other similar projects.

The Brief for this review asked for “a summary of inconsistencies within reviewed documents, and identification of the most appropriate approach for assessment, based on accepted best practice, published scientific literature and evidence, and referring to BVPA’s request for consideration of groundwater model parameters”.

- The many documents listed in the first two groups in Attachment 1 were prepared between June 2015 and October 2018. The documents should be read almost as a public conversation between the Applicant and its consultants and the Department, its consultants and other stakeholders. Predicting the movement of groundwater near mining projects is challenging, and the modelling of flow above longwall mining is especially challenging. Uncertainty remains, but there are no glaring inconsistencies that suggest that the outcome of the assessment should be different.
- The Applicant has prepared an assessment of groundwater impacts using methodologies that are accepted in Australia as best practice.
- The Applicant could potentially have referred to more scientific literature, especially related to the behaviour of groundwater above longwall mines.
- Questions raised by consultants on behalf of BVPA, about groundwater model parameters, should not affect the outcome of the assessment. Uncertainty analysis undertaken by the Applicant spans a wide

range of conditions and parameter values. Uncertainty in other aspects of the modelling is potentially more important than values of specific storativity.

If the project is approved, the Groundwater Management Plan should include a list of potential groundwater issues similar to that proposed in Table 1, and the plan should explain how each potential issue will be managed. The Groundwater Management Plan should include descriptions of the conceptual hydrogeological model in layman's language, so that all stakeholders, including operational staff, can understand the most important issues and how they will be managed.

The Applicant has committed to "ongoing" groundwater modelling at 5-yearly intervals (HB, 2016a, Section 4.3.12.1, based on AGE, 2016a, Section 7.2.3). The recommended conditions on the project (Department of Planning and Environment, 2018, Appendix H) also require regular auditing of observations against model predictions. It would be possible to be more prescriptive about how monitoring and modelling should be undertaken. At present, there are few graphs or Tables in the documents submitted by the Applicant that could be used by an auditor to show that impacts are occurring as expected, or not as expected. The Groundwater Management Plan needs to address this issue by identifying specific locations where stakeholders would be interested in tracking the water table elevation and piezometric heads, and by making predictions of hydrographs at each measurement location. Possible locations include transects along lines between proposed open cut mines and the nearest river or stream (two or three observations per transect), at least one transect between the proposed longwall mine and Bylong River (perhaps near LW101), and at least one borehole located within panel LW201 (perhaps near Dry Creek) to measure how the water table responds to the mining of LW101.

10. References

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Attachment 1. Source Materials Provided by the Commission

In the main body of this report, the following abbreviations are used:

AGE: Australasian Groundwater and Environmental Consultants Pty Ltd
Department: NSW Department of Planning and Environment
HB: Hansen Bailey
HS: HydroSimulations
IESC: Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
KA: Kalf and Associates Pty Ltd
WRM: WRM Water & Environment Pty Ltd

Category	**Reference**	**Sections of Interest**
By consultants on behalf of the Applicant (2015-18)	*Hansen Bailey (2015)*, Bylong Coal Project, **Environmental Impact Statement**, Main Report, September, 452 pp.	Sections 3.7. 7.6, 9.4.1
	Australasian Groundwater and Environmental Consultants Pty Ltd (2015), Bylong Coal Project Groundwater Impact Assessment, June, 678 pp. Appendix M, entitled Groundwater Impact Assessment, in Hansen Bailey (2015).	All
	HydroSimulations (2015), Peer Review - Bylong Coal Project Groundwater Impact Assessment, Letter report, 17 July, 12 pp. Appendix N, entitled Groundwater Peer Review in Hansen Bailey (2015).	All
	Hansen Bailey (2016a), Bylong Coal Project, Environmental Impact Statement, **Response to Submissions**, Main Report, March, 551 pp.	Sections 4.2.16, 4.3, 4.11.7, 4.15, 4.16, 4.18.3, 5.9, 5.28 and 6
	Australasian Groundwater and Environmental Consultants Pty Ltd (2016a), Bylong Coal Project, Response to Submissions on Groundwater, 22 March, 96 pp. Appendix H in Hansen Bailey (2016a).	All
	Hansen Bailey (2016b), Bylong Coal Project, Environmental Impact Statement, **Supplementary Response to Submissions**, Volume 1, Main Report & Appendices A-I, 346 pp.	General information
	Hansen Bailey (2016c), Bylong Coal Project, Environmental Impact Statement, Supplementary Response to Submissions, Volume 2, Appendices J-M, 412 pp.	Appendix J Appendix L
	Hansen Bailey (2016d), Response to Department of Primary Industries - Water Submission, August, 168 pp. Appendix J in Hansen Bailey (2016c).	All
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	Hansen Bailey (2018d), Bylong Coal Project (SSD 3367), Response to IPC Request for Additional Information, December, 40 pp.	All
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Attachment 2. Confidence Level Classification (Table 2.1 in Barnett et al., 2012)

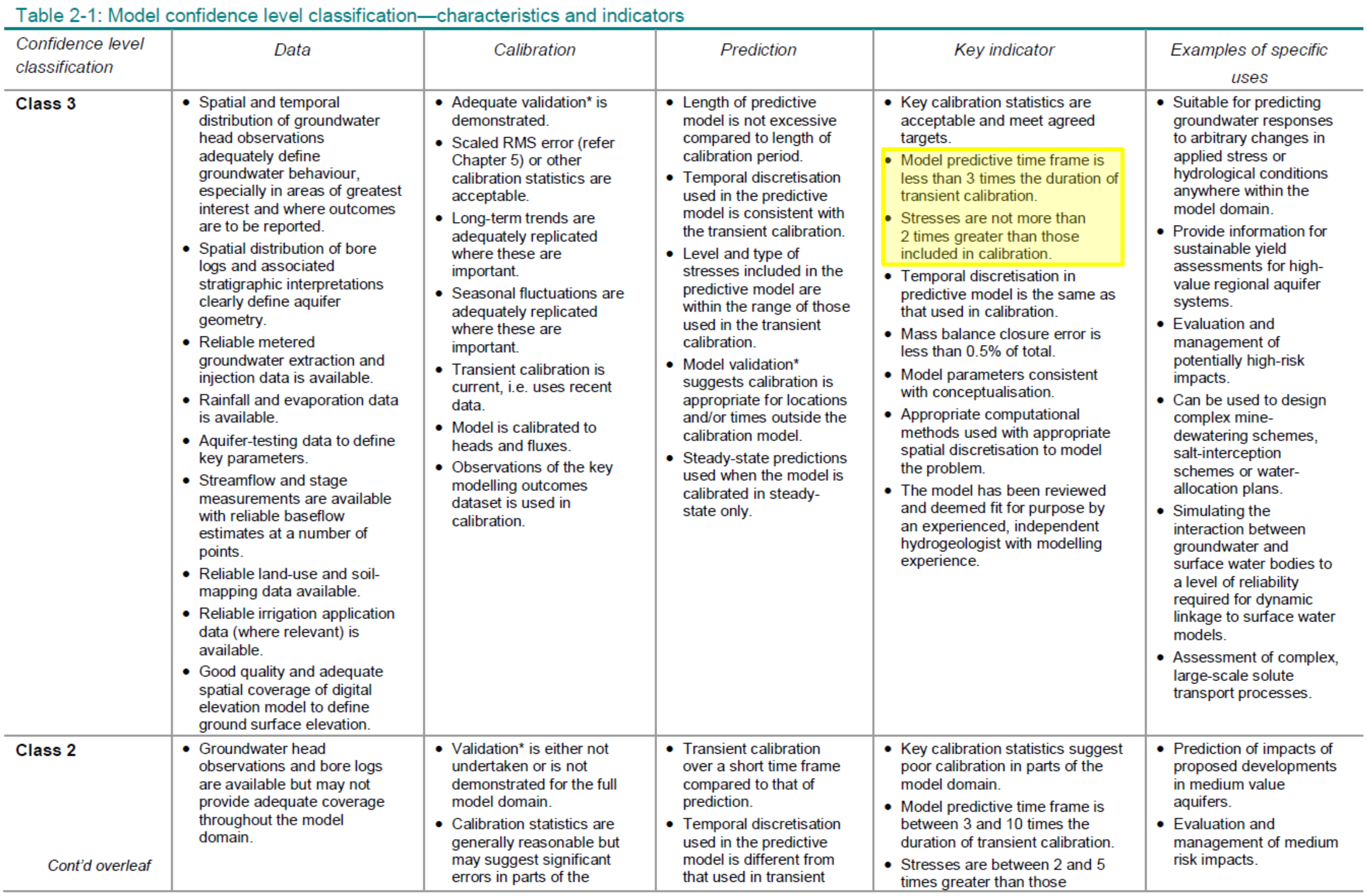
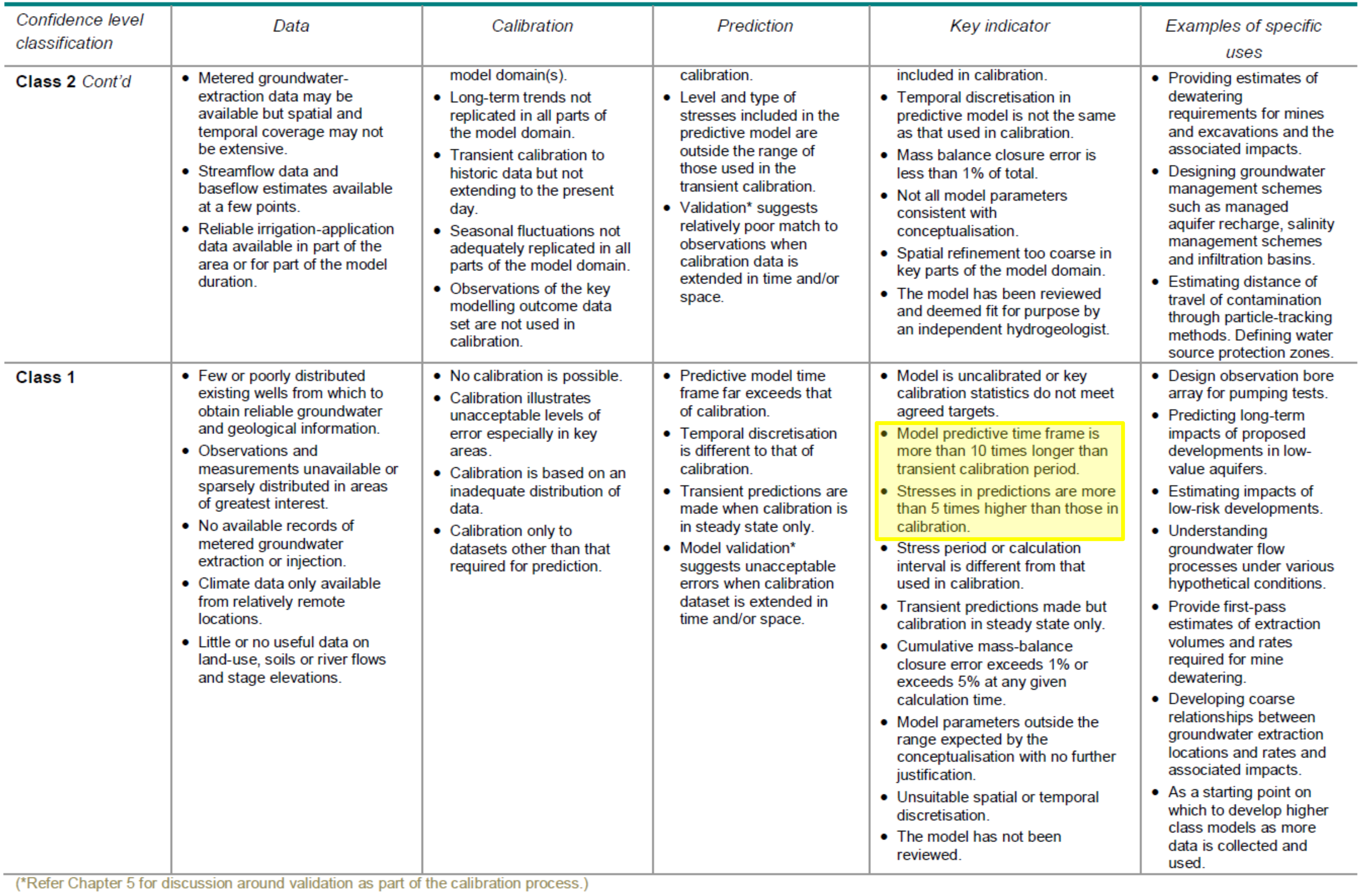


Table 2-1: Model confidence level classification—characteristics and indicators

Confidence level classification	*Data*	*Calibration*	*Prediction*	*Key indicator*	*Examples of specific uses*
Class 3	• Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported. • Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry. • Reliable metered groundwater extraction and injection data is available. • Rainfall and evaporation data is available. • Aquifer-testing data to define key parameters. • Streamflow and stage measurements are available with reliable baseflow estimates at a number of points. • Reliable land-use and soil-mapping data available. • Reliable irrigation application data (where relevant) is available. • Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation.	• Adequate validation* is demonstrated. • Scaled RMS error (refer Chapter 5) or other calibration statistics are acceptable. • Long-term trends are adequately replicated where these are important. • Seasonal fluctuations are adequately replicated where these are important. • Transient calibration is current, i.e. uses recent data. • Model is calibrated to heads and fluxes. • Observations of the key modelling outcomes dataset is used in calibration.	• Length of predictive model is not excessive compared to length of calibration period. • Temporal discretisation used in the predictive model is consistent with the transient calibration. • Level and type of stresses included in the predictive model are within the range of those used in the transient calibration. • Model validation* suggests calibration is appropriate for locations and/or times outside the calibration model. • Steady-state predictions used when the model is calibrated in steady-state only.	• Key calibration statistics are acceptable and meet agreed targets. • Model predictive time frame is less than 3 times the duration of transient calibration. • Stresses are not more than 2 times greater than those included in calibration. • Temporal discretisation in predictive model is the same as that used in calibration. • Mass balance closure error is less than 0.5% of total. • Model parameters consistent with conceptualisation. • Appropriate computational methods used with appropriate spatial discretisation to model the problem. • The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience.	• Suitable for predicting groundwater responses to arbitrary changes in applied stress or hydrological conditions anywhere within the model domain. • Provide information for sustainable yield assessments for high-value regional aquifer systems. • Evaluation and management of potentially high-risk impacts. • Can be used to design complex mine-dewatering schemes, salt-interception schemes or water-allocation plans. • Simulating the interaction between groundwater and surface water bodies to a level of reliability required for dynamic linkage to surface water models. • Assessment of complex, large-scale solute transport processes.
Class 2 *Cont'd overleaf*	• Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain.	• Validation* is either not undertaken or is not demonstrated for the full model domain. • Calibration statistics are generally reasonable but may suggest significant errors in parts of the	• Transient calibration over a short time frame compared to that of prediction. • Temporal discretisation used in the predictive model is different from that used in transient	• Key calibration statistics suggest poor calibration in parts of the model domain. • Model predictive time frame is between 3 and 10 times the duration of transient calibration. • Stresses are between 2 and 5 times greater than those	• Prediction of impacts of proposed developments in medium value aquifers. • Evaluation and management of medium risk impacts.



Confidence level classification	Data	Calibration	Prediction	Key indicator	Examples of specific uses
Class 2 *Cont'd*	• Metered groundwater-extraction data may be available but spatial and temporal coverage may not be extensive. • Streamflow data and baseflow estimates available at a few points. • Reliable irrigation-application data available in part of the area or for part of the model duration.	model domain(s). • Long-term trends not replicated in all parts of the model domain. • Transient calibration to historic data but not extending to the present day. • Seasonal fluctuations not adequately replicated in all parts of the model domain. • Observations of the key modelling outcome data set are not used in calibration.	calibration. • Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration. • Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space.	included in calibration. • Temporal discretisation in predictive model is not the same as that used in calibration. • Mass balance closure error is less than 1% of total. • Not all model parameters consistent with conceptualisation. • Spatial refinement too coarse in key parts of the model domain. • The model has been reviewed and deemed fit for purpose by an independent hydrogeologist.	• Providing estimates of dewatering requirements for mines and excavations and the associated impacts. • Designing groundwater management schemes such as managed aquifer recharge, salinity management schemes and infiltration basins. • Estimating distance of travel of contamination through particle-tracking methods. Defining water source protection zones.
Class 1	• Few or poorly distributed existing wells from which to obtain reliable groundwater and geological information. • Observations and measurements unavailable or sparsely distributed in areas of greatest interest. • No available records of metered groundwater extraction or injection. • Climate data only available from relatively remote locations. • Little or no useful data on land-use, soils or river flows and stage elevations.	• No calibration is possible. • Calibration illustrates unacceptable levels of error especially in key areas. • Calibration is based on an inadequate distribution of data. • Calibration only to datasets other than that required for prediction.	• Predictive model time frame far exceeds that of calibration. • Temporal discretisation is different to that of calibration. • Transient predictions are made when calibration is in steady state only. • Model validation* suggests unacceptable errors when calibration dataset is extended in time and/or space.	• Model is uncalibrated or key calibration statistics do not meet agreed targets. • Model predictive time frame is more than 10 times longer than transient calibration period. • Stresses in predictions are more than 5 times higher than those in calibration. • Stress period or calculation interval is different from that used in calibration. • Transient predictions made but calibration in steady state only. • Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time. • Model parameters outside the range expected by the conceptualisation with no further justification. • Unsuitable spatial or temporal discretisation. • The model has not been reviewed.	• Design observation bore array for pumping tests. • Predicting long-term impacts of proposed developments in low-value aquifers. • Estimating impacts of low-risk developments. • Understanding groundwater flow processes under various hypothetical conditions. • Provide first-pass estimates of extraction volumes and rates required for mine dewatering. • Developing coarse relationships between groundwater extraction locations and rates and associated impacts. • As a starting point on which to develop higher class models as more data is collected and used.

(*Refer Chapter 5 for discussion around validation as part of the calibration process.)