ATTACHMENT 1 – KEY COMMENTS

1. Potential for IEP to Overstate Surface Water Losses

In regard to potential losses of surface water to the groundwater system, the IEP estimates historic losses of between 2.1 ML/day to 3 ML/day (refer to Section 4.5.1 of the Initial Report).

It is unclear how these values have been derived.

South32's groundwater modelling indicates losses have been 0.9 ML/day, peaking at 1.6 ML/day. These modelling estimates include conservative assumptions, including the modelling assumption that water is always present in the drainage lines overlying the longwall panels, whereas, in reality many of these drainage lines are ephemeral.

It is noted the IEP commends the significant effort that has been undertaken to develop the Dendrobium Mine groundwater model:

> *There have been major efforts over the last decade by both Dendrobium Mine and Metropolitan Mine to employ up-to-date 3-dimensional groundwater models and best practice modelling methods undertaken by specialists, with expert peer review.*

In addition, the IEP's upper estimates would mean 40 to 50% of groundwater inflow to mine workings is from surface water. Although there is some uncertainty with water fingerprinting (methods to measure the source of water) science, this level of modern water entering the mine is not supported by water geochemistry.

The regional groundwater model remains the best available integrated tool to estimate surface water losses, as it is informed and constrained by site specific data (e.g. groundwater inflows, groundwater levels, pre- and post-mining porosity and permeability data etc). The results of the groundwater model are likely to be conservative and overstate losses, for the reasons outlined above.

Clearly, surface water losses are of significant concern to stakeholders. South32 seeks to ensure that estimates reported by the IEP are not overstated and/or clear context of the significant uncertainty of any IEP estimates are stated, including by providing direct comparison to average and peak predictions from South32's detailed models (which the IEP acknowledges are best practice, prepared by specialists and have been the subject of peer review).

2. Reconsideration of target of 200 mm closure

The IEP recommends:

> *The concept of restricting predicted valley closure to a maximum of 200 mm to avoid significant environmental consequences should be revised for watercourses*.

The closure impact model has been successfully used at Dendrobium Mine to date, with the target value of 200 mm predicted closure resulting in a low-likelihood of impact (consistent with the model predictions).

South32 has adopted 200 mm predicted closure as a key design constraint for the setback of longwall panels from named watercourses at Dendrobium Mine. It is noted the empirical data used to develop the 200mm target at Dendrobium includes only streams with a setback from mining, rather than streams that had been mined under.

When applied on a case-by-case basis, the closure impact model can be refined and continued to be used to achieve a specified level of impact likelihood.

While ongoing review of data to refine the closure impact model is supported, a reduction in the long-accepted target of 200 mm predicted closure for designing setbacks for named streams at Dendrobium Mine would have material implications for South32, and is not supported.

3. References to Springvale Mine

The Initial Report states (Section 2.3.4):

> *A need was identified in 2009 to increase surface subsidence predictions by the order of 30% across lineament zones at Springvale Mine. Subsequently, significant drops in water level in watercourses and swamps hosted by major lineaments have been recorded when longwall mining was up to 700 m away (as the crow flies), well outside the range of conventional angles of draw …*

In addition, the Initial Report states (Section 3.2):

> *The Panel considers this to be a reasonable conclusion under normal circumstances but notes that the exceedance* [of subsidence predictions at Dendrobium Area 3B] *is the same magnitude (30%) to that experienced in lineament zones at Springvale Mine (see Section 2.3.4).*

In response to this comment in the IEP, Professor Bruce Hebblewhite states (refer to Enclosure 1):

> *This point is not considered to be of any relevance as it stands, unless it can be substantiated by much more convincing evidence regarding impacts of lineaments in the Southern Coalfield – which, to date, do not exist.*

South32 agrees with Professor Hebblewhite's comments and considers the inference that the need for refinement of subsidence predictions at Dendrobium Area 3B and specific subsidence behaviour at the Springvale Mine could be related to similar far-field reductions in water levels to be incorrect. It is considered the following should be considered and reported by the IEP:

- The effects observed at the Springvale Mine have not been observed at the Dendrobium Mine or the Southern Coalfield.
- As per Professor Hebblewhite's review, there are geological differences between the Western and Southern Coalfields which are likely to result in differences in the mechanisms and behaviour of mining interactions with lineaments.
- The need to increase subsidence predictions at the Dendrobium Mine was more likely due to the changes in mining geometry, rather than the effects of lineaments, given:
  - The Dendrobium model provided reliable predictions of vertical subsidence in Area 3A, at lower depths of cover and narrower longwall widths, but initially under-predicted the vertical subsidence in Area 3B due to changes in mining geometry/parameters (e.g. higher depth of cover and wider longwall widths).

- The exceedance in the subsidence predictions at Springvale Mine were localised at the lineaments, whereas the measured vertical subsidence at Dendrobium Mine occurred consistently above the mining area.

4. Recommendation for Incremental Approval of Longwall Management Plans

The Initial Report states:

> *The Panel endorses the Department of Planning and Environment's approach for dealing with legacy issues and evolving knowledge bases whereby:*
>
> - *the management plans for longwall panels at Dendrobium and Metropolitan mines are being approved on an incremental basis that provides for considering existing and emerging information and knowledge gaps that have the potential to jeopardise compliance with performance measures.*

While South32 supports robust regulatory oversight of post-approval management plans, it should be recognised that the approach of incremental secondary approval of longwalls by Government results in significant risk of time delays (e.g. due to consultation and assessment timeframes) with associated operational discontinuity, putting at risk the significant capital expenditure and time required to develop mining areas.

Furthermore, incremental secondary approvals erode the effectiveness of long-term planning for a business of South32's magnitude and as such places unnecessary risk on the future viability of the mining operations, including the continuation of employment and local investment.

ATTACHMENT 2 – ADDITIONAL COMMENTS AND CLARIFICATIONS

ID	IEP Reference	Issue raised by IEP	Response / Correction
Conclusions and Recommendations			
1	• p.127 – bullet 1.	*Field performance at Dendrobium Mine suggests that irrespective of whether the Tammetta equation is predicting the height of complete drainage reasonably accurately, its outputs can be useful as an indicator of the potential for water ingress from the surface.*	The Tammetta H calculation has been used to support the Dendrobium Regional Groundwater Model for a number of iterations. In the 2016 model (for the LW14-19 SMP GW Model), both Tammetta and Ditton methods were used. From 2018 (the LW16 SMP GW Model) the Tammetta H calculation has been used for all longwall panels less than 300m width, while for panel widths greater than 300m, a connection from the mine workings up to the surface has been assumed within the model. The Tammetta H calculation will be used in future groundwater assessments as a screening tool for water ingress, alongside width:depth ratios (as used by Gale and suggested by the groundwater model peer reviewer).
2	• p.127 – bullet 3.	*Although knowledge of the consequences of mining on surface water quantity in the Catchment Special Areas has progressed substantially over the last 10 or so years, limitations in monitoring and modelling mean that it is difficult to verify conclusions by some stakeholders that mining has had negligible consequences on surface water supplies.*	Direct monitoring of flow within watercourses is considered a more practical approach to determining consequences to surface water supplies compared to groundwater modelling, partly because groundwater modelling cannot predict short-term weather, nor specific creek-bed fractures and diversions. With an expanded and improved monitoring network, the accuracy of surface water flow loss or diversion estimates is expected to be improved. As the Panel notes, it is not possible to measure losses via leakage from reservoirs when those losses are below the resolution of catchment water balance models. Calibrated groundwater models are likely the only means of estimating this.
3	• p.127 – bullet 4.	*Knowledge of the contribution of swamps to water supplies is particularly undeveloped due to lack of integrated monitoring targeting swamp water balances.*	Understanding of the contribution of swamps to water supplies is being further investigated by a number of research projects with support and data from South32, including the WaterNSW sponsored UNSW/WRL swamp monitoring research project and the ACARP sponsored University of Queensland Swamp Hydrology Modelling Project.
4	• p.127 – last bullet.	*At both the Dendrobium and Metropolitan mines, the nature of surface water TARP triggers is not suited to determining the level of confidence that can be placed in surface water modelling results*	As discussed with WaterNSW and DPE, Dendrobium is currently investigating alternative or improved methods of modelling and comparison against controls and investigating updated TARPs.
5	• p.116 -s5.5.1.1. • p.128 – bullet 1. • p.129 – bullet 7.	*The Dendrobium Mine TARP triggers related to surface water quantity are ineffective, for the following reasons:…*	In consultation with DPE and WaterNSW the following TARP updates are currently being investigated:

ID	IEP Reference	Issue raised by IEP	Response / Correction
	• p.130 – bullet 1. • Exec Summary.	*The performance measures for surface flow losses are not explicitly related to materiality of flow losses, limiting the objectivity of performance evaluation.* *TARPs should be related to the desired outcomes (such as maintenance of water flows) and be consistent both within and between mine domains. The TARP triggers for surface and groundwater should be replaced by meaningful flow loss indicators developed in consultation with relevant agencies and authorities with oversight and regulatory responsibilities for mining.*	• Use metrics such as reduction in mean and median flow, increase in cease-to-flow days, based on comparison with models and control sites • use of upstream-downstream flow differentials for TARPs on Wongawilli Creek. The opportunities for this sort of measure are limited. • investigating accuracy of flow data, as well as of control-impact site comparison. • Further updating the Dendrobium Mine AWBM (Australian Water Balance Model).
6	• p.128 – bullet 2. • p.118 -s5.6.3.	*In the present situation, TARPs classify the seriousness of events that have already occurred rather than fulfilling their more usual role of early signalling to prompt intervention that prevents escalation of impacts.*	The nature of the effects on streams directly above longwalls means that surface water TARPs may not be able to provide 'early warning'. Extensive consultation with Government Agencies during the development of the TARPs resulted in a comprehensive set of impacts associated with the Dendrobium Mine being included in the TARPs, including approved impacts. In these instances, intervention to prevent the impact is not required.
7	• p.128 – bullet 3	*it is recommended to err on the side of caution and defer to the Tammetta equation*	The Tammetta equation has been used in recent groundwater modelling at Dendrobium Mine. Refer to comment 1, above.
8	• p.128 – bullet 3, sub-bullet 1 • .p.91 – s4.6	*….field investigations quantify the height of complete drainage at the Dendrobium Mine…* 6i – *there is a need for more field investigation of the height of complete drainage / fracturing.*	An independent assessment of the height of complete drainage / fracturing is underway by Bruce Hebblewhite and is focused on fracturing above mined longwalls and the dependence on depth of cover and panel width at Dendrobium. Nine 'goaf holes' investigating pre- and post-mining conditions have now been drilled (or are planned) above Longwalls 6, 7, 9, 12, 13, 14, 15 and 16. Packer testing and piezometers have been completed and installed at most of these holes. Analysis of this data and reporting will be ongoing through 2019.
9	• p.128 – bullet 3, sub-bullet 2 • p.91 – s4.6	*…geomechanical modelling of rock fracturing and fluid flow is utilised to inform the calibration of groundwater models.*	FLAC2D modelling by SCT has been conducted and will be incorporated in the next major revision of the Dendrobium groundwater model.

ID	IEP Reference	Issue raised by IEP	Response / Correction
10	• p.128 – bullet 4 • p.128 – bullet 7, sub-bullet 2.	*The potential implications for water quantity of faulting, basal shear planes and lineaments need to be very carefully considered and risk assessed at all mining operations in the Catchment Special Areas.* *all applications to extract coal within Catchment Special Areas should be supported by independently facilitated and robust risk assessments that conform to ISO 31000 (the international standard for risk management subscribed to by Australia)*	A Risk Assessment has been completed by South32, including geotechnical, subsidence, geology and hydrogeology specialists coordinated by Axys Consulting, 04/03/2019. Illawarra Coal is currently undertaking investigations into geological structures (faults, shear planes) and lineaments around Area 3B and Lake Avon. Risk Assessments of known and possible geological features linking the goaf and the Reservoir were previously undertaken associated with Dendrobium Area 1, 2, and 3A and reported to government.
11	• p.128 – bullet 8, sub-bullet 1.	*the monitoring standard in relation to groundwater should include… Installation of multi-level piezometers on the centreline of panels at Dendrobium … in order to monitor pore pressure changes associated with subsidence. These should include at least five transducers per borehole…at least two years in advance of being undermined*	This is being carried out by Illawarra Coal in Dendrobium Area 3B. In addition, post-mining investigations are being conducted above older longwalls (see above).
12	• p.128 – bullet 8, sub-bullet 2 (actually on p.129)	*Daily monitoring of local rainfall and mine water ingress from overlying and surrounding strata, and separation of rainfall correlated inflows for base flow volumetric analyses*	Illawarra Coal record daily rainfall at 5 locations around Dendrobium and Cordeaux mine areas. Groundwater ingress continues to be calculated from a detailed mine water balance. 'Baseflow analysis' is a worthy exercise and has been done via digital techniques. However, like 'baseflow analysis' for watercourses, we recommend chemically-constrained techniques to assess the provenance of the water.
13	• p.129 – bullet 1.	*surface water monitoring requirements should include… [6 sub-bullets with recommendations]*	All these items are currently being addressed or investigated at Dendrobium.
14	• p.129 – bullet 3	*There is a need for groundwater modellers to address apparent inconsistency in the hydrogeologic parameters used to model Dendrobium and Metropolitan mines as it calls into question the robustness of current model predictions*	Differences could occur due to differing facies and differing cover depths. However, a study to characterise hydraulic conductivity, and to a lesser extent, storage properties, should be carried out for the Southern Coalfield using data held by mines, WaterNSW, and from any other sources. Data-sharing arrangements will be sought with other parties to obtain and analyse such data. The next major revision of the Dendrobium groundwater model will rely on data from Dendrobium, BSO/Appin and Tahmoor mines.

ID	IEP Reference	Issue raised by IEP	Response / Correction
15	• p.129 – bullet 4.	*Research needs to be progressed into the use of tritium for calculating 'modern' water contributions at Dendrobium Mine, including the potential for results to be affected (skewed) by adsorption*	Trials have been undertaken to assess other isotopes which may be used to 'date' the age of the mine water including sulphur and oxygen, without success. Research is currently underway into the application of tracers of groundwater age (Carbon-14 and Chlorine-36), isotopic composition (Strontium-87/86, Lithium-7/6) and chemistry (major and trace ions) in understanding groundwater pathways. It is anticipated that a combination of techniques will be used to constrain water pathways and complement the existing chemistry and tritium database.
Subsidence			
S1	• p.35 – s2.3.4	*In recent years, it has been identified in the Western Coalfield (which adjoins the Southern Coalfield of NSW) that surface subsidence, groundwater and surface water responses to longwall mining can be significantly modified in the vicinity of lineaments* (with) *significant drops in water level in watercourses and swamps hosted by major lineaments have been recorded when longwall mining was up to 700 m away* (and) *in the case of one swamp, water levels started to drop quickly very soon after the host lineament was intersected by a longwall goaf more than 1,200 m further upstream Investigations into this behaviour are ongoing and it is too early to know the extent, if any, of similar behaviour in the Southern Coalfield*.	The subsidence data for Areas 1, 2, 3A and 3B do not show any correlation with lineaments. It is considered that the most appropriate approach is the ongoing review of the latest monitoring data and ongoing investigation of the influence of lineaments on far-field effects.
S2	• p.42 – s3.2	*Avoidance of significant impacts arising from valley closure was based on the earlier noted criteria of predicted closure to be less than 200 mm.*	A target value of 200 mm closure represents a low-likelihood of impact (i.e. approximately 10 %) rather than avoidance of impact or negligible impact. The performance criteria for Wongawilli Creek in Area 3B at Dendrobium Mine is for minor impacts on surface water flows. It is therefore considered appropriate to adopt a target value of 200 mm closure in this case. We consider that the rate of impact along Wongawilli Creek, to date, is very low and consistent with the rockbar impact model.

ID	IEP Reference	Issue raised by IEP	Response / Correction
S3	• p.43 – s3.2	*The IPM was recalibrated on the basis of surface subsidence contours generated over Areas 2 and 3A and LW9 and LW 10 in Area 3B" as "the maximum observed subsidence exceeded predictions in many locations, typically being up to 1.3 times predicted*. *It was considered that the exceedances were probably due to the greater depths of cover and wider longwall panels. The Panel considers this to be a reasonable conclusion under normal circumstances but notes that the exceedance is the same magnitude (30%) to that experienced in lineament zones at Springvale Mine*.	The accuracy of prediction methodologies are generally considered to be between ±15% and ±25% of the maximum vertical subsidence. The accuracy of these methods can be improved as further ground monitoring data are collected and the ongoing review and refinement of the model. The original subsidence model for Dendrobium Mine over-predicted the component of vertical subsidence due to sagging of the overburden and under-predicted the component due to pillar compression. This model therefore provided more reliable predictions of vertical subsidence in Area 3A, at lower depths of cover and narrower longwall widths, but initially under-predicted the vertical subsidence in Area 3B at higher depth of cover and wider longwall widths. All subsidence prediction methodologies (empirical, analytical and mechanistic) must be reviewed as the mining geometry changes, to assess the contributions of each component of vertical subsidence, and be re-calibrated where required. These contributions can be determined based on the ongoing review of the available monitoring data and refinement of the method. The subsidence models at Dendrobium Mine are continually reviewed as further monitoring data are obtained. It is considered that this remains the most appropriate approach to improve the reliability of the subsidence predictions. The exceedance in the subsidence predictions at Springvale Mine were localised at the lineaments, whereas the measured vertical subsidence at Dendrobium Mine were more consistent above the mining area. It is therefore considered that the exceedance at Dendrobium Mine was more likely due to the changes in mining geometry, rather than the effects of lineaments.
S4	• p.51 – s3.3	*Given the uncertainty associated with reliably predicting valley closure and its impacts, the Panel is of the view that the*	The appropriate target value for predicted closure should be determined on a case by case basis. This includes the stream

ID	IEP Reference	Issue raised by IEP	Response / Correction
		historic criteria of a maximum of 200 mm predicted closure for avoiding significant environmental consequences should be revised downwards, at least for watercourses.	characteristics, mining geometry and acceptable level of impact. The closure impact model should not be used when "negligible" impact is required. The adoption of a target value of 200 mm predicted closure represents low-likelihood of impact (i.e. approximately 10 %) based on the historical data. Where negligible impact is required, other approaches should be used, which can include the appropriate mining setbacks based on historical data, case studies of previously recorded impacts and the application of adaptive management plans.
Groundwater			
GW1	• p.35 – s2.3.4 • p.114 – s.5.4	*Geological structures can transmit or cause impacts to swamps at distance beyond the angle of draw, e.g. at Springvale Mine impacts have been recorded at 700-1200 m from longwalls.* *"This is of particular importance where impacts may begin to occur when mining is well distant from the swamp, as is the case at the Dendrobium Mine (Sullivan and Swarbrick 2017)".*	Such an effect has not been observed at Dendrobium. The analysis of geological structures and apparent lineaments forms part of the geological assessment prior to mining. A recent review of swamp impacts found no correlation between impact distance from longwall goaf and proximity to mapped structures.
GW2	• p.47 – para.3 • p.88 – s4.5.1	*"However, the Panel foresees that faulting, basal shear planes, lineaments and the potential to unclamp and reactivate fault planes will need to be very carefully considered and risk assessed prior to finalising the mine layout for LW 17 and LW 18".* *S4.5.1, k. Alternative interpretations of data and/or the influence of geological structures in future mining panels could produce larger estimates of leakage from water storages.*	This has been considered during the Longwall 17 Subsidence Management Plan Risk Assessment – see **Conclusion #11 (above).** Illawarra Coal is currently investigating the hydrogeological characteristics of the Elouera Fault. As of March 2019, five diamond core holes had been drilled at two sites. Four holes intersect the fault allowing detailed analysis of the geotechnical and hydrogeological characteristics of the fault plane. Groundwater pumping tests and tracer tests are underway which will allow assessment of the permeability of the structure of the fault at the two sites. Further drill holes are planned. The findings from the Elouera Fault investigations will provide further knowledge of fault structures and practical techniques for fault zone characterisation. The potential for 'unclamping' was assessed in the recent Risk Assessment. The view of the specialist geotechnical engineers is that previous mining at Elouera Mine, including panels within tens of metres of the fault zone, would have caused relaxation of the fault zone already, and should be apparent in the current investigations.

ID	IEP Reference	Issue raised by IEP	Response / Correction
GW3	• p.47 – para.3	*"It is expected that the effects of shearing and valley bulging will be exacerbated with additional longwalls in Area 3B and therefore simple linear extrapolation of these findings as undertaken in SCT (2016) are likely to underestimate the impact." (Sullivan & Swarbrick, 2017)*	Valley closure surveys do not indicate significant progressive closure across the Native Dog Arm. The AD series of monitoring holes are re-drilled after mining to assess any ongoing changes in permeability.
GW4	• p.47 – para.5	*"It is anticipated that decision making for LW 17 and LW 18 will be guided and better informed than in the past by the outcomes of investigations, monitoring and independent reviews that DPE has incorporated into conditions of approval in recent SMPs".*	Future longwall decisions will be supported by numerous current and ongoing investigations relating to over-goaf, off-goaf and fault zone structure and hydrogeology. Previous reviews by Doyle (2007) and Tonkin and Timms (2015) concluded that virtually all faults encountered in first workings near supply reservoirs in the Southern Coalfield produce no, or very minor inflows. The importance of understanding the potential effect of mining on fault structures is acknowledged and supported.
GW5	• p.55 – para.3	*"[The PSM Review]…identified a general need for additional monitoring between Area 3B and Avon Reservoir. The Panel is in general agreement with both conclusions.*	As of February 2019, eight (8) locations have been drilled between Area 3B and Lake Avon.
GW6	• p.62 – para.3 • p.88 – s4.5.1	*The Panel considers that it is very likely that the high rate of influx at Dendrobium Mine is associated with a connected fracture regime that extends upwards to the surface, with this network providing access to the high drainable porosities present within the Hawkesbury Sandstone"*	While we agree that this mechanism explains the higher inflow rates at Dendrobium relative to Metropolitan Mine, we note also that there must be some lag in connected pathways; the young (tritium, 14C) and chemically distinct water from the shallow Hawkesbury Sandstone is yet to be identified in the inflows to Area 3B.
GW7	• p.62 – s4.2.2	*Regarding inflows to Area 2, "highlights the need to consider the runoff-infiltration component in a cumulative way since a number of small separate rainfall events occurring in close succession can, and do lead to recharge percolation and elevated mine inflows".*	This is agreed and forms part of that assessment. The "events" referred to in that assessment were where >150mm falls within a week, in recognition that some of these recharge events result from the accumulation of multiple smaller rainfall events.
GW8	• p.63 – s4.2.2 • p.88 – s4.5.1	*This inflow is more in line with the 90% contribution for some events derived by Mackie after independently assessing the mine water management data.* *In summary, total mine water ingress from January 2010 to March 2018 totals about 18 GL of which about 6 GL is attributed to rainfall percolation. This volume may be regarded as diverted surface runoff that would otherwise have reported to Wongawilli Creek or directly to either Cordeaux or Avon reservoirs.*	Future modelling assessments will include estimates of the modelled surface water loss both as a fraction of total groundwater inflow and as ML/d or ML/yr for the catchments to water supply reservoirs.

ID	IEP Reference	Issue raised by IEP	Response / Correction
GW9	• p.82 – s4.3	*The Panel notes that HydroSimulations is now calibrating its groundwater models on the basis of the Tammetta equation (HydroSimulations, 2017b).*	This is mainly correct – for recent Dendrobium groundwater modelling, the approach for simulating the height of connected fracturing is to use the Tammetta H for all panels, and then over-ride that for panels >300 m wide, where the connected fracture zone is forced to intersect the surface cracking zone, thereby simulating enhanced connection from surface down to seam, as per PSM's conclusion for Longwall 9.
GW10	• p.83 – s4.4.1	*the 2016 model adopts the earlier Coffey Geotechnics (2012b) rectilinear model grid design75 and could be more appropriately described as a 'structured grid' model offering little (if any) efficiency advantage associated with domain discretisation.*	Improvements to the model have been made in stages for practical reasons (see also comment GW11). The first stage retained the grid structure but transitioned the model to MODFLOW-USG which resulted in numerical efficiencies and improvements. MODFLOW-USG allows the complete removal of 'inactive' cells from the model, improving filesize requirements and computation time by allowing the software to completely ignore such cells. Earlier versions of MODFLOW did not allow this (inactive cells have a demand on PC memory and disk space).
GW11	• p.84 – s4.4.1. • p.90 – s4.5.3	*Why has the migration to MODFLOW-USG stalled?* *The migration of the models to using an unstructured grid (MODFLOW-USG) is recognised as having potential for addressing the current limitations. This migration was progressed for the Dendrobium Mine since 2016 but seems to have stalled. Continued migration to MODFLOW-USG should progress only if benefits can be demonstrated.*	The following is a broad summary of the 3D groundwater modelling at Dendrobium. • MODFLOW-SURFACT (Coffey 2012). • MF-SURFACT with unsaturated flow simulation (HydroSimulations, 2014). • switched to MF-USG and Connected Linear Networks (CLN) in LW14 SMP (HS, 2016). • continued MF-USG for LW16 SMP but removed CLNs (due to stability issues). (HS, 2018) (same for LW17 SMP (HS, 2019). • The next major revision of the Dendrobium Mine model will use MF-USG with an unstructured mesh. The structured mesh was retained in 2016-2019 models, however a large number of other changes were made, such as the incorporation of basal shears, additional layering and changing methods for connected fracturing. When groundwater modelling is required to support incremental approvals, it makes sense to use a similar model structure to the previous model for comparison. Large changes to the model (e.g. grid structure) should be introduced when mine plans extend beyond

ID	IEP Reference	Issue raised by IEP	Response / Correction
			those incremental approvals at Area 3B (as is being done for the next revision), if the changes are warranted.
GW12	• p.84 – s4.4.1	*The GWMMP document also states that the fractured zone height and its uncertainty are best calculated by the DGS model as described by Ditton and Merrick (2014)*	There is a need to update the GWMMP with respect to the method for estimating height of connected fracturing.
GW13	• p.88 – s4.5.1	*J: based on the information reviewed by the Panel to date, it is considered plausible that an average of around 3 ML/day of surface water could be currently diverted into the workings of Dendrobium.*	3 ML/d represents about 40-50% of the total inflow. Chemical analysis of mine ingress to date is not consistent with such a high component of direct surface water inflow.
GW14	• p.90 – s4.5.3 • p.91 – s4.6	*Continued migration to MODFLOW-USG should progress only if benefits can be demonstrated.* #8ii – models to "*be migrated from MF-SURFACT to MF -USG only if significant benefits can be demonstrated*"	The change in modelling approach or software code is driven by three main considerations: • A code may provide features that allow more accurate or realistic simulation of specific boundaries or phenomena (e.g. fracturing); and • A code may provide features that allow more efficient (faster) model runs, thereby allowing further analysis of predictive uncertainty. • Keeping the model current (older versions of code may not be supported by the supplier or understood by younger staff). Sometimes the benefits (or costs) are not fully apparent or proven until implemented. MF-SURFACT and MF-USG software are both appropriate for use in this application, and both are (co-)written by the same author (S. Panday). Some of the benefits of MODFLOW-USG are that it allows: • Unstructured mesh (vertically and laterally). • Removal of inactive cells from simulation/files. • Distribution of runs across many computers • The use of other packages (CLNs). But there are costs in terms of: • pre-processing unstructured mesh (especially SFR stream-flow routing).

ID	IEP Reference	Issue raised by IEP	Response / Correction
			• complex packages / familiarity / numerical stability (these also apply to MF-SURFACT). An even more recent platform in the MODFLOW family, "MODFLOW-6", could become the industry-standard in the near future (it is now the "core" version supported by USGS). One of the potential benefits of MF6 is that sub-models (e.g. swamps, streams or reservoirs) may be added to the base model and run in parallel to obtain better detail when and where needed. A disadvantage is that MF6 file structures are significantly different to earlier versions.
GW15	• p.124 – s6.4	*Regarding cumulative impacts, it would be "more useful and appropriate comparison would require the groundwater model to cover the groundwater catchment area of the reservoir and include cumulative losses due to mining".*	This has been done with the existing groundwater model in the Dendrobium LW17 assessment for Lake Avon and Lake Cordeaux. Other catchments are only partially within the groundwater model domain.
Surface Water			
SW1	• p.97 – s5.1.3	*Significant losses have been observed at 1st and 2nd order watercourses but monitoring of 3rd and 4th order watercourses shows no strong evidence that there are losses significant for surface water supplies. However, the absence of strong evidence does not necessarily mean that significant consequences do not exist.*	Watershed (2018) study on Wongawilli Creek flows showed that baseflow depletion is likely to occur at a rate of about 0.2 ML/d along the middle reach of Wongawilli Creek, but with no discernible effect at the downstream gauge WWL, where 'discernible' means considering the magnitude of the impact compared to the measurement/model error. This study highlighted that it is easier to detect changes at low flows – the impacts themselves may be lower as ML/d but higher as % of flow at the time.
SW2	• p.99 – s5.1.4. • p.103 – s5.2.1.1. • p.108 – s5.2.3.1. • p.120 – s5.7.1	*Comments regarding availability of higher accuracy gauging stations.* *The Panel agrees with Professor McMahon's statement and that the analysis of flow monitoring errors and their impact on assessing compliance should be published and peer reviewed.* *Errors in flow monitoring should be assessed, reported and reduced where feasible.*	Illawarra Coal is currently upgrading gauging station infrastructure that will provide more accurate flows. Hydrographers ALS are undertaking this work. The panel was shown examples of the new gauges in the LA2 catchment tributaries in a recent site visit. Illawarra Coal, with ALS and Watershed, are conducting a review of gauging accuracy. This has commenced with identification of the likely sources of error (e.g. temperature variations, equipment error etc). The intent is to quantify error at a range of flows for each gauging station.

ID	IEP Reference	Issue raised by IEP	Response / Correction
		iii. publishing of rating curve data (including the manually gauged reference data) and photographs of flow gauges, so that accuracy can be judged when interpreting performance reports	
SW3	• p.100 – s.5.1.4	*"There are no published measurements of evapotranspiration"*	Consultants rely on SILO 'data drill' products for estimates of potential evaporation.
SW4	• p.100 – s.5.1.4	*there has been minimal investigation of swamp sedimentary characteristics, such as porosity, to estimate swamp soil water-holding capacity.*	The sedimentary sequence in the swamps is complex, ranging from high porosity peat (Sy ~50%) to sands (Sy ~20%) to silts (Sy ~5%). The relative thickness of these is likely to change within and between swamps, and therefore the weighted average likely to be significantly different. Recent modelling assumes bulk Sy for all swamps is 30%.
SW5	• p.100 – s.5.1.5	*"Groundwater models focus on accurate modelling of groundwater pressures and underground mine inflows, and their surface flow results tend to have low accuracy."*	This is broadly correct, and the latest rounds of groundwater modelling at Dendrobium do not attempt to simulate surface flow. However, by constraining recharge and hydraulic conductivity using available field data and calibrating to GWLs and known fluxes, groundwater models remain the best way of estimating changes to groundwater-surface water interaction.
SW6	• p.103 – s5.2.1.1	*Regarding gauge accuracy, "If it is feasible to install weirs or flumes, it is reasonable to expect a greater accuracy".*	This is underway. Flumes are being installed by ALS at a series of existing and new monitoring sites, including at four new sites in Area 3B installed in February 2019.
SW7	• p.103 – s5.2.1.1	*it would not be appropriate for every potentially impacted watercourse feeding Lake Avon to be monitored. Instead, conclusions for monitored sites may be transferred to non-monitored sites where it may reasonably be judged that impacts are similar.*	Gauges are being installed on a number of Lake Avon tributaries.
SW8	• p.104 – s5.2.1.1. • p.119 -s5.7.1	*Use other techniques to.. "supplement to rainfall-runoff modelling. This has been done in some EOP reports, including for LW …but has been excluded from the LW12 and LW13 EOP reports".* *vi. consistent use of inter-site comparisons using suitable control sites to complement rainfall-runoff modelling*	Comparisons against control sites will be reported in the next EOP Report.
SW9	• p104 – s5.2.1.1 • p.108 – s5.2.3.1	*"The length of baseline monitoring is variable and in cases insufficient."*	Where possible, baseline data is collected for a period longer than 2 years. This is not always possible for new Area 3B monitoring sites

ID	IEP Reference	Issue raised by IEP	Response / Correction
		Action should be taken to ensure at least two years of pre-mining data for new monitoring sites in Area 3B and at least four years for priority sites around future mining areas	installed in response to incremental requirements and recommendations from Government Agencies and the IEP.
SW10	• p104 – s5.2.1.1	*The EOP report for LW 13 shows two rain gauging stations; however this may not be sufficient considering the strong precipitation gradients*	Dendrobium currently records rainfall at 5 stations, however the records are of variable length, so are not all suitable for use in rainfall-runoff modelling. The use of additional rainfall data sources (SILO versus Dendrobium gauging stations) is also being investigated.
SW11	• p.107 – s5.2.3	*With reference to GW model representation of watercourses: "there are a number of scale related issues that complicate representation of surface drainage lines. These include stream bed conductance's that regulate infiltration, and the assignment of reference heads that drive the exchange of stream/river waters with the underlying aquifer system. It is therefore highly likely that a high level of uncertainty is associated with the simulation of channel flows and rock pool water budgets at the regional scale."*	The estimation of modelled watercourse 'conductance' is based on hydraulic conductivity data (from packer and core testing), and has been peer-reviewed by Kalf & Associates. The current GW model does not represent flow along channels. With respect to the fluxes between groundwater and surface water, it is not considered that there is a high level of uncertainty associated with watercourse water budgets on a regional scale. There is more uncertainty associated with the water budgets of local scale features, such as pools. These cannot be represented in the regional GW model, nor are they claimed to be.
SW12	• p.107 – s5.2.3	*This recognises that the increasing hydraulic gradients from Wongawilli Creek to the groundwater may cause losses from the creek.*	Watershed (2018) expanded upon this process, identifying losses along the 'middle' reach of Wongawilli Creek (between Areas 3A and 3B), but with no discernible effect at WWL. Inferred losses along that reach were within losses predicted by previous groundwater modelling, and are a result of groundwater drawdown rather than subsidence-cracking.
SW13	• p.108 – s5.2.3.1	*no validation on flow measurements from outside the calibration period.*	Validation (via split periods) will be included in future modelling where this is possible. Validation has not been reported previously for the reason that, as noted independently by eWater (2012): *"If a poor validation is achieved, and re-calibration is necessary, then the validation dataset has now been used to change the calibrated parameters, it is no longer an independent dataset and has become part of the calibration dataset."*
SW14	• p.108 – s5.2.3.1	*"errors in rainfall inputs and other sources of data" to be reported.*	A section of the EOP report will be included to discuss the meteorological data available, and available and quantify the errors within that (as far as possible).

ID	IEP Reference	Issue raised by IEP	Response / Correction
SW15	• p.108 – s5.2.3.1	*The inability to accurately determine low flows is the basis for the mine's conclusion that there is no evidence of non-negligible flow consequences at the WWL monitoring site and no TARP triggers at either the WWL or DCU monitoring sites.*	This statement is not supported because the existing TARP rules with respect to flow or yield are focussed on average flow, not low flow. Furthermore, there has been consistent work since LW11 to improve model low-flow accuracy for all sites. Regarding DCU, EOP-13 included comments that undermining has affected the pattern of flows and increased cease to flow periods.
SW16	• p.108 – s5.2.3.1	*given the criticality of low flows for this project, attempts to improve the low flow modelling should continue, and should be reported and peer reviewed.*	The modelling has been updated and improved from EOP-11 to EOP-13 and these improvements will continue.
SW17	• p.109– s5.2.3.1	*The groundwater models should not be relied upon to give accurate estimates of future surface water losses. Complementary approaches should be investigated. This may include adjusting groundwater model results according to their under- or over-estimation of losses for previous LWs.*	This is not supported as there is no alternative method (e.g. a surface water model) that can incorporate mine workings, groundwater drawdown and subsidence effects. Part of the issue is that losses during longwall/EOP periods are governed in part by meteorological conditions, where groundwater models cannot accurately incorporate future weather events. However, as noted, there is merit in future to compare and adjust losses from groundwater models.
SW18	• p.109– s5.2.3.1 (and footnote 109)	*In instances where the model performs poorly (i.e. has important errors), it has been claimed to perform well* *e.g. Low flows are well matched" p27 of HGEO (2017c). Poor calibration R2 value (~0.32 in LW11 and 0.50 for LW12) for DCU and for WC15S1.*	R2 has been used for convenience in Excel, and is just one measure of calibration. This is why we present calibration via multiple methods (R2, X:Y, hydrograph, flow duration curve, transient ratio). In future, alternative statistical measures (e.g. Nash-Sutcliffe efficiency) will also be considered. EOP reporting has included comments such as "*moderate fit to observed data*", "*good match between modelled and observed flows for the pre-mining period, with the main weakness being the lower end of the flow duration curve*", "*the fit is somewhat mixed, with periods where there is a very good match to observed flows (e.g. ...) and other periods where the fit is not as good (e.g. ...)*". However, less use of subjective descriptions would be better, although not always avoidable. For context, the modeller's experience is that DCU catchment flows are the most difficult to calibrate the AWBM model to. Conclusions are based on changes between pre- and post-mining periods. Even where the conclusions have been that the TARPs are

ID	IEP Reference	Issue raised by IEP	Response / Correction
			not triggered, a comment has been made on where an effect on the pattern of flows has occurred or is inferred.
SW19	• p.109– s5.2.3.1 (and footnote 110)	*Between Longwall 12 and 13 the modellers modify their conclusion.*	Changes in conclusions between two assessment periods can be due to: • Transient environmental effects, i.e. slow propagation of mining effects. • Transient weather conditions that may 'reveal' effects under different conditions. • Changes to method of analysis, e.g. modelling, use of control sites. Regarding the modifying of conclusions between reporting periods, the Panel's point about new data leading to a potential change in conclusion is noted, but it needs to be accepted that an outcome of improving methods is that conclusions may also change. Nevertheless, the reason for the modified conclusion is a combination of all three effects, i.e. the nature of the impact over time, the weather conditions, and updated modelling.
SW20	• p.109– s5.2.3.1. • p.119 -s5.7.1.	*there are conclusions for WWL that appear to be on the conservative side and are not consistent with the "reverse onus of proof"* *iii. the principle of 'reverse onus of proof' is applied, whereby the mining company should demonstrate that on the balance of probabilities there is no significant consequence.*	In line with discussions with DPE/WaterNSW, findings of 'impact' or 'no impact' will be strengthened by renewing and improving the comparison against a suitable control site.
SW21	• p.118 -s5.6.2	*d. Models "have low accuracy during very low flow periods, despite efforts by the mining companies to address this. This low accuracy increases ambiguity about the relative impacts of climate and mining. Only relatively large losses in low flows may be attributed to mining with confidence. Attempts to improve low flow accuracy should continue and be reported and peer-reviewed."*	There could be some over-expectation of the level of calibration that can be achieved, and the accuracy to which effects can be identified, given uncertainties in measurement and distribution of rainfall, flow, and other parameters. EOP reporting of the GW model predictions of losses at sites, as a means of understanding whether losses are within/beyond prediction, will be considered
Catchment, Groundwater and Reservoir Water Balance			
C1	p.124 – s6.4	*A more useful and appropriate comparison would require the groundwater model to cover the groundwater catchment area of the reservoir and include cumulative losses due to mining.*	This has been included for both Lake Avon and Lake Cordeaux in the LW17 SMP Groundwater Model. This will be carried out for future modelling assessments at Dendrobium, noting that the

ID	IEP Reference	Issue raised by IEP	Response / Correction
			groundwater model cannot cover the full catchment to all the nearby reservoirs.

ATTACHMENT 3 – REVIEW OF INITIAL REPORT BY PROFESSOR BRUCE HEBBLEWHITE (FEBRUARY 2019)

REPORT TO: **South32 Illawarra Coal**
PO Box 514
UNANDERRA NSW 2526

ATTN: Mr Gary Brassington

Review – Independent Expert Panel Report on Mining in the Catchment

REPORT NO: **1708/03.3**

PREPARED BY: **BRUCE K HEBBLEWHITE**

DATE: **19th February 2019**

B K HEBBLEWHITE BE (Min.) PhD
Consultant Mining Engineer
B K Hebblewhite Consulting

ABN 85 036 121 217

5 Plant St
Balgowlah NSW 2093
AUSTRALIA

Mobile: +61 (0) 417 267 876
Email: hebble@bigpond.com

1. INTRODUCTION

1.1 Background and Scope of Work

South32 Illawarra Coal has requested an independent review of the recently released Initial Report prepared by the Independent Expert Panel on Mining in the Catchment (IEPMC), to be submitted in conjunction with their submission that will be made to the Panel in February 2019. The following documents are considered as part of this review:

- The Southern Coalfield Inquiry Report (2008)
- The PSM "Height of Cracking – Dendrobium Area 3B" Report (2017)
- The Independent Expert Panel Report on Mining in the Catchment (Dendrobium and Metropolitan Mines) (November 2018).

The submission to the Panel is in response to the invitation for submissions by the Panel and is intended to be considered as part of the Panel's response to their second Term of Reference, viz:

> *"2. Undertake a review of current coal mining in the Greater Sydney Water Catchment Special Areas with a particular focus on risks to the quantity of water available, the environmental consequences for swamps and the issue of cumulative impacts", including,*
>
> *(a) A review and update of the findings of the 2008 Southern Coalfield Inquiry (Impacts of Underground Coal Mining on Natural features in the Southern Coalfield – Strategic Review) …."*

My review commentary in this report will be primarily focused on, but not limited to mine subsidence issues and related factors.

I have included in this review report some previously reported material (Sections 2 and 3 below) prepared for the Department of Planning and Environment (DPE) as part of my role as an independent reviewer for South32's Dendrobium Mine Area 3B mining Conditions of Approval imposed by DPE. I believe these comments address many of the relevant topics and provide important background information. This independent reviewer role for Dendrobium has a particular focus on the issue referred to as "height of fracturing" which is also the focus of the 2017 PSM report. This issue is central to understanding the impact of longwall mining on overlying groundwater. It is therefore explained further in the following sections.

Section 4 of this report provides a commentary on the IEPMC Report released in November 2018. Section 5 of this report provides a summary of important issues arising from the IEPMC Report, having taken into account all of the previous background material.

2. HEIGHT OF FRACTURING CONCEPT

Knowledge of the detailed nature of rock deformation and failure above any form of large-scale underground mining is always going to be limited to interpretation from a very incomplete set of data. It is extremely difficult, if not impossible, to directly measure the detailed nature of the rock failure, fracture networks and deformational behaviour above an extracted mining area. Limited techniques such as borehole extensometry can provide some evidence of relative or incremental deformation in the direction of the borehole (usually vertical). However, such data cannot assist below the horizon where full caving has caused major rotation and dislocation of rock blocks and effectively destroyed the instrumentation borehole. Above such a horizon, the data is only valid along the axis and in the direction of the borehole, and to the level of detail defined by the extensometer anchor spacing intervals.

Other direct measurement techniques include borehole inclinometers which can assist with measuring shearing across the line of the instrumentation borehole, usually, but not always associated with bedding plane horizons. Coupled with an extensometer to provide movements in the borehole axis direction, the combination of extensometers and inclinometers provides a “coarse” level of deformation measurement along the axis of the instrumentation borehole. This direct borehole monitoring data can also be complemented by down-hole geophysical and calliper logging to provide further fracturing information along the axis of the borehole, together with various forms of borehole wall inspection or scanning devices. However, none of these different borehole techniques assist with detection of the laterally dispersed deformation and failure taking place away from the individual instrumentation boreholes. The result is therefore a very incomplete dataset that relies heavily on in-fill estimation and interpretation.

Why then is there a need for an improved knowledge of such regional deformation and failure above the mining location – in particular, above underground longwall mining panels? The answer can relate to a number of important issues:

(a) To consider the effect of mining taking place at one horizon on a higher horizon within the overburden (either mined previously, or planned to be mined in the future);
(b) To assist in developing predictive models for estimating surface subsidence;
(c) To develop an understanding of, and predictive model for the impact of underground mining on groundwater present within the overburden.

It is this third issue that has taken on increased importance in recent years. In fact, the reason for trying to define regions of fracturing above a longwall panel is not typically about defining the deformation and fracturing specifically, but actually about interpreting the impact of such deformation and fracturing on the groundwater regimes.

Furthermore, at the present time, it is often the measurement of groundwater data which is used to infer the different fracture zones – so the whole argument becomes a circular one. We measure groundwater pressures and related data to infer overburden fracture zones in order to estimate groundwater impact levels and regions. Why not simply refer to the parameters we can measure –

groundwater pressures and properties – rather than making arbitrary distinctions regarding the level of rock fracturing that is not clearly defined. This question of definition is revisited later in this report.

However, there is often a desire to assess a number of rock deformation and fracturing parameters in the overburden above longwall mining, specifically:

- The height of connective cracking (or fracturing);
- Extent of surface cracking;
- Potential connections with horizontal partings.

It is therefore important to have a clear understanding of what is meant by these terms and how they relate to each other and to the mining process.

Firstly, fracture patterns associated with overburden rock strata subjected to longwall mining can be extensive and quite variable, ranging from complete rock failure in the immediate caving zone above the coal seam, through to some level of near-surface tensile cracking within the subsidence impacted zones of curvature. It must be understood that these two extremities of the fracturing regime are normally isolated from each other, and subject to quite separate or independent mechanisms. It is simply not possible to fully analyse or characterise all fracture patterns throughout the overburden – either pre- or post-mining. It is considered more important to focus on what is commonly referred to as the *"height of connective cracking, or height of fracturing",* which are widely-used terms. The issue of surface cracking is also of interest, but as a separate fracture region within the overburden, as noted above.

Even the concept of height of fracturing is difficult to fully and accurately *"analyse and characterise"* and remains a subject of some debate amongst the geotechnical and hydrogeological community (see PSM (2017), Galvin (2017) & Mackie (2017)). However, it is accepted as being very important to gain a meaningful understanding and best-estimate analysis of such a region of fracturing and *"connective cracking"* within the overburden, using whatever practical means available.

It is important when discussing the height of fracturing zone to establish some common and consistent terminology. The actual nature of the fracturing above a longwall panel cannot be directly measured but can generally only be inferred from indirect observations and measurements, as discussed above. The conceptual model of the fracture zone has been discussed internationally by many authors through the use of a number of simplified conceptual models which describe a series of zones of different types of rock failure, fracturing and deformation above longwall panels.

Figure 1 is one such conceptual model, quite widely-accepted, for representing or describing the zones of fracturing above a single longwall panel. In this model, four major, different zones are identified (note – this diagram is not necessarily to scale, with respect to the height of the different zones). Other models, from both Australia and internationally, similarly describe four, or sometimes five different zones.

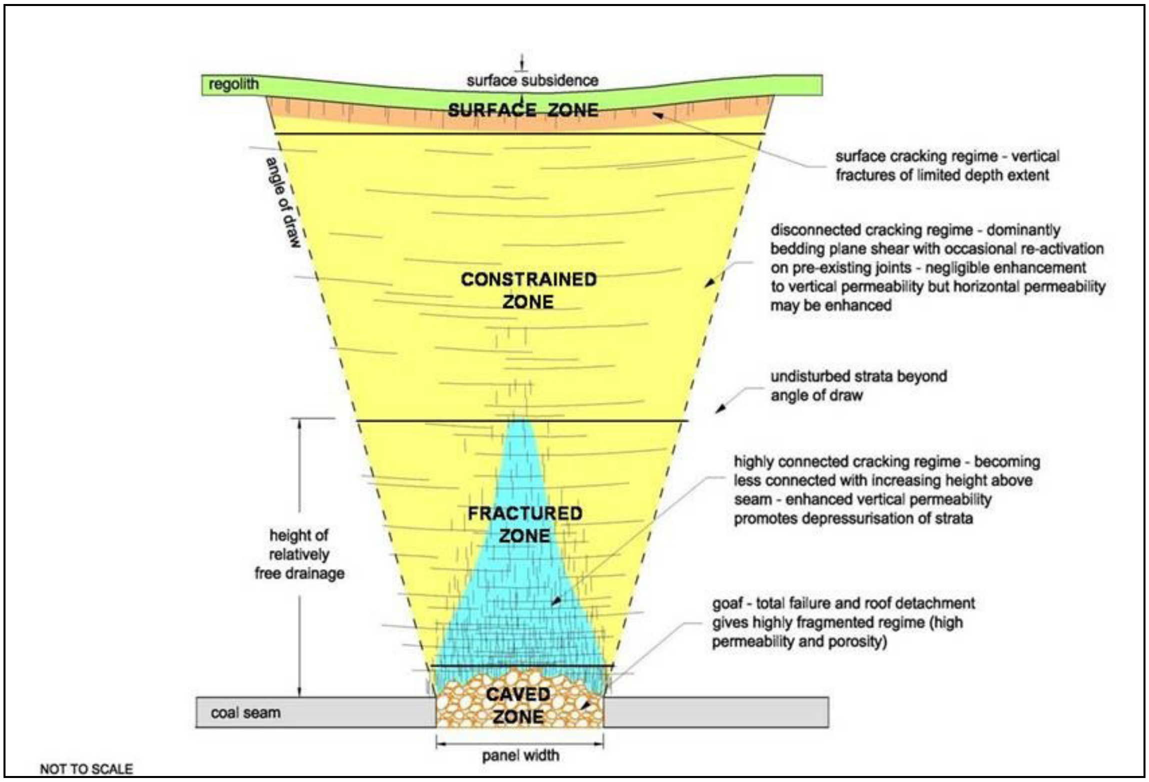

Figure 1. "Height of Fracturing" concept.
(source: NSW Dept of Planning, 2008)
(original source: Dr C Mackie)

- **caved zone –** where there is complete rock failure and large-scale downward movement and some rotation of rock blocks, resulting in a significant amount of void space. There is obviously complete groundwater depressurisation and dewatering/drainage from within this zone. The height of this zone is affected by the type of immediate roof above the coal seam, and mining height, which will define the available void space created by mining.

- **fractured zone** – where the rock has undergone significant vertical and horizontal deformation, with dilation of some discontinuities (bedding planes and joints) and also incurred connective cracking of intact rock. The result is a fractured rock mass that allows increased permeability permitting depressurisation of groundwater in this zone. The term "height of fracturing" refers to the height above the mined seam to the top of this zone, where there is enhanced vertical permeability due to the fracturing, allowing groundwater depressurisation. It is also understood that within this fractured zone there may be increased porosity due to the fracture network, which may also contribute to depressurisation. (This is a matter for further consideration by hydrogeological investigations and analysis).

- **constrained zone** – contains deformation, but significantly less cracking, without extensive connective fracturing occurring, such that depressurisation does not occur to a significant extent. The deformation includes a significant extent of bedding plane shear as the layers of rock strata bend. (In some conceptual models the constrained zone is divided into two different zones where the upper region consists of much more simple strata unit bending, without any major fracturing, but also with shear movement on bedding planes).

- **surface zone** – the near-surface region where cavities associated with tensile fractures open up as the surface strains create a limited depth of open vertical fractures and horizontal cavities in the shallow strata. These cavities are often said to lie within a zone 10m to 20m below ground level (this should be validated on a site by site basis).

On the basis of this form of conceptual model and definitions, the term *"height of fracturing"* is used to refer to the region of connective fracturing and structural deformation (bedding planes, joints etc) leading to increased permeabilities which will result in significant depressurisation of the strata. For this reason, groundwater pressure monitoring can be used as a means of detection of the upper limit of this fracturing zone, rather than relying on direct, but limited deformation and fracture monitoring, which as discussed above, is extremely difficult.

Figure 2 shows another conceptual model of ground behaviour above a series of adjacent longwall panels.

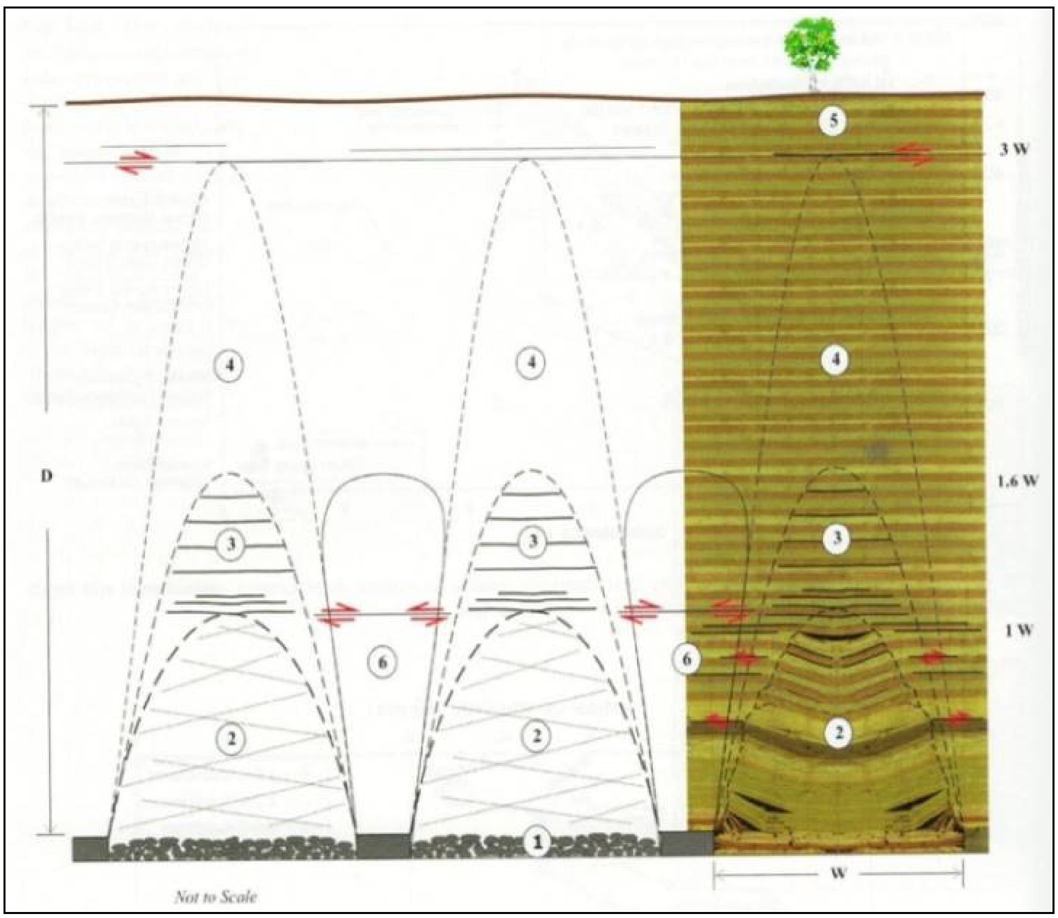

Figure 2. Conceptual model of overburden caving above multiple longwall panels
(source: Galvin (2016), based on Mills (2012))

The legend from this figure has been removed, and is reproduced in the text below, for greater clarity.

The legend for Figure 2 contains the following descriptions of the numbered zones:

1. Zone of chaotic disturbance immediately above mining horizon (0-20m).
2. Zone of large downward movement (->1.0 x panel width).
3. Zone of vertical opening of bedding planes (1.0W – 1.6W).
4. Zone of vertical stress relaxation (1.6W – 3.0W).
5. Zone of no disturbance from sag subsidence (>3.0W but shear along bedding planes for subsidence of multiple panels).
6. Zone of compression above chain pillars.

Although the description of the zones and their geotechnical behaviours differ somewhat from that in support of Figure 1, zone (2) in Figure 2 is of a similar nature to the above fractured zone shown in Figure 1. The diagram is also reflected in a scaled physical model, also shown.

On the basis of these and similar models, several empirical prediction models have been developed in Australia to estimate height of fracturing based primarily on mining geometries (depth, panel width and mining height). Two such empirical models are the Tammetta and the Ditton models – both of which have been applied at a number of Southern Coalfield mines, and elsewhere. These are discussed further, later in this report.

Some important summary points to note in relation to the above concepts:

- These are concepts only, representing hypotheses regarding the nature of fracturing above an extracted longwall panel. They have been developed as conceptual artefacts, in order to describe the type of deformation and fracturing of the overburden strata, and how it is made up of different zones or different types and intensities of deformation and fracturing.
- These concept models have been developed based only on indirect or very incomplete data sets, be they data from geotechnical monitoring, groundwater monitoring or numerical and physical modelling.
- The gradation from one zone to another in any of these models, whilst appearing distinct within the concept diagrams, may well be quite gradual and transitional, rather than distinct boundaries, and may be highly impacted by localised geological factors such as specific strata units present, or other structural defects including bedding planes, joints and major structures (faults, dykes etc.).

Based on the above points, caution is urged in use of these model concepts, without significant qualification, and/or detailed analysis of the underpinning data. The breakdown of the overburden into distinct zones should only be regarded as an artefact or concept, to aid in understanding, rather than an exact definition of what is occurring in the ground.

It is further proposed that there should be a change in the terminology used in future – for all of the reasons discussed above, relating to both the nature of the deformation and fracturing characteristics; as well as the means of measurement or estimation. For use of this concept for groundwater impacts, it is proposed that the term ***"height of depressurisation"*** be adopted in future, rather than the terms *height of fracturing*, or *height of connective cracking*. This proposed terminology is directly linked to the application of the term for groundwater purposes, as well as being directly linked to the means of measurement or estimation. It is also consistent with the findings of the 2017 PSM Report discussed later – see PSM conclusion 3.

It is also noted that some authors are making reference to this zone as a height of drainage. However, a caution is raised with such a term, which is discouraged. Whilst it is acknowledged that some increased level of free drainage will occur in this zone (to enable depressurisation to occur), the word drainage can sometimes be interpreted to refer to total dewatering, which is certainly not always the case within the depressurisation zone. From a groundwater perspective, the height of drainage where complete dewatering is always expected would more commonly be allied to the immediate caving zone, as illustrated in Figure 1.

3. PSM REPORT - HEIGHT OF FRACTURING - DENDROBIUM AREA 3B

An independent investigation was commissioned by DPE following publication of the DPE 2015 Report to Government on Mining Impacts from Dendrobium Area 3B.

PSM was appointed to conduct the investigation into fracturing above Dendrobium Area 3B, with a very broad scope that included assessment of data, investigation techniques, prediction models and outcomes – all relating to impact on both groundwater and surface features as a result of longwall mining.

3.1 PSM Report Conclusions and Summary Discussion

This section of this report is not intended to be a comprehensive or critical review of the PSM Report (PSM (2017)) but is simply intended to summarise the key conclusions and findings of PSM in the context of this current review.

The PSM conclusions are reproduced (indented) below, for this purpose:

> PSM Conclusions
>
> The investigations, modelling and monitoring carried out to date in Area 3B and the wider Dendrobium Mine area, have been insufficient for the scale and complexity of the technical issues. This means there are still a number of gaps and uncertainties. Notwithstanding this, it is considered sufficient work has been carried out in the available time to provide answers and guidance on the principal questions posed for this study.
>
> However, at the same time, given the ramifications and importance of the issues raised by this study it is essential that further work is undertaken to confirm the findings.
>
> It is considered the monitoring and investigations of real and potential mining effects and their impacts could have been improved if the overall geological, geotechnical, hydrogeological and mining context was better investigated, modelled and monitored. This would have included detailed geotechnical models followed by numerical modelling of the caving and subsidence behaviour of the rock mass, then validated using the site specific investigations and monitoring data as it became available from each longwall panel or area.
>
> In summary the conclusions from this study are:
>
> 1. In general subsidence engineering recognises a zoned fracture model that comprises:
>   a) Caved Zone, comprising completely fractured rock of High permeability and porosity.

b) Fractured Zone, with highly connected cracking that is relatively free drainage, and with enhanced vertical permeability.

c) Constrained Zone, with a zone of disconnected cracking and negligible enhancement of vertical permeability.

d) Surface Zone; a zone close to the surface with some deformations and local water impacts.

2. The important elements of this conceptual model for this study are related to two zones:

   a) The Constrained Zone is where deformations of the rock mass are sufficiently low as to cause little depressurisation and pre-mining groundwater pressures are essentially maintained.

   b) The Caved and Fractured Zones, where deformations to the rock mass are sufficient to cause full depressurisation. The rock mass becomes desaturated or fully (100%) depressurised.

3. There has been ongoing debate focussed in part on the accuracy of the height of fracturing models used to predict the height of cracking at Dendrobium. The term cracking implies that intact rock is broken, but it is more instructive to think in terms of cracking, fracturing and or dilation of existing geological defects. This is because even small increases in the aperture of a crack or geological defect are important for groundwater flow.

4. In the height of fracturing models and general subsidence engineering the Constrained Zone was thought to largely isolate the upper layers of strata from the impacts of drainage and depressurisation at depth, thus limiting impacts on ground and surface water.

5. At Dendrobium two height of cracking/fracturing (HoF) models have been applied; Tammetta (2013) and Ditton and Merrick (2014). The Tammetta (2013) model is derived from direct observations from 18 locations worldwide. The Ditton and Merrick (2014) model was derived from examination of 34 observations, 32 of which were from NSW.

6. Both model approaches assume the inputs from these databases are independent variables. These input values have been examined using a matrix scatter plot and show:

   - The Dendrobium longwall geometries are well outside the database;
   - The input parameters are not independent, and
   - Extrapolation beyond the database centroid will see the accuracy and standard deviation of the fit decay significantly leading to over extrapolation.

7. The Tammetta (2013), Ditton and Merrick (2014) and DGS (2016) models all have the following limitations in addition to the above:
   - They are empirical models designed to give a best fit to their respective databases;
   - The models ignore any site specific geological conditions;
   - The models require significant error corrections;
   - The prediction error is significant considering the small sample size and relatively large standard deviations; and
   - The observations are based mainly on interpretation of extensometer or piezometer responses, which are non-definitive information;
8. A key conclusion regarding all the height of fracturing models is that contrary to predictions the groundwater response at Dendrobium has not exhibited full depressurisation (desaturation) at any height apart from the near surface zone.
9. Investigations were carried out in only one location in Area 3B above LW9 to directly assess the height of fracturing. However it is clear from this investigation that increases in fracturing are evident in all units up to the ground surface. The 'height of fracturing' at least over LW9 is 100% of the cover. The debate then centres on whether this fracturing is or isn't connected. The groundwater data shows that post mining depressurisation is occurring long term right through the vertical profile so the fracturing in the rock mass taken as a whole is connected; at least to a level that allows some depressurisation.
10. The assessment of the deep to intermediate groundwater system in Area 3B shows:
    a) Substantial depressurisation (40%) of a major proportion of the stratigraphic profile, from the coal to the upper sandstone, had already occurred before mining started in Area 3B and records indicate this was from at least the start of any mining in Area 2.
    b) Groundwater reactions to mining occur due to mining in both Area 2 and Area 3A.
    c) As mining in Area 3B starts, depressurisation increases right through the profile but also into the overlying sandstones.
    d) Depressurisation is continuing but by the end of mining in Area 3A, this is substantial and ranges from around 30 to 70%.
    e) Depressurisation is occurring right through the profile, which shows there is some connectivity.

11. There is no evidence of desaturation, rather the data shows the rocks remain saturated but with very significant depressurisation.

12. The SOW refers to desaturation, complete drainage of the rock mass such that groundwater pressure is close to zero. However groundwater pressures can reduce, but the rock mass may remain fully saturated. Under such conditions there will be a component of downwards vertical flow. Thus ground and surface water losses from the system may still occur.

13. If depressurisation occurs, a portion of the water that infiltrates below the ground surface will eventually report to the major permeable units at depth, the caved and fractured rock mass and the mine. This will occur as pressure pulses, driven by transient pore pressure rises from rainfall recharge events and or reservoir level increases. However the actual transit time of a particle of water entering the system at the surface then exiting into the mine may be very long.

14. There is no widespread evidence of a Constrained Zone limiting effects of mining and impacts on the more shallow ground and surface water systems.

15. The patterns of mine inflow for each area are very different and it is not clear why this should be the case. Comparison of mine inflows for each area with climatic wetting and drying cycles; and rainfall shows:

    - Area 2 has a markedly 'peaky' response to all significant rainfalls and broader response to climate patterns with a change after 2010 with the start of mining in Area 3A;
    - Area 3A shows a correlation with the climate cycles and or Cordeaux Reservoir level; and
    - Area 3B shows a long term increasing inflow, but there is insufficient information available to properly understand the long term increases.
    - It is considered likely that Areas 1 and 3B show rainfall recharge responses.
    - There are a number of apparent anomalies in the data and these are not readily explained by comparisons of mine inflows with screened rainfall data alone.

16. The pattern of groundwater responses in space and time for many piezometers located close to Cordeaux Reservoir are very different to the general piezometer behaviour throughout the other mining areas. The interpretation from these patterns is that pressure levels in the geological units under the reservoir are being increased and or maintained by recharge through the rockmass. This is as a result of mining induced effects on the rockmass around and probably under the reservoir. This effect dissipates further away from the reservoir. The interpretation is that

effects on the rockmass around and probably under the reservoir. This effect dissipates further away from the reservoir. The interpretation is that this pattern is consistent with some losses from the reservoir into the groundwater through the rock mass. It is considered that Area 2 and 3A mine inflows are also anomalous and probably reflect some losses, of both ground and surface water, from the catchments and or reservoir. Given the regional depressurisation these losses will eventually report to the lowest pressure point, Dendrobium Mine.

17. Detailed investigation of the height of fracturing has only been carried out at one site at Dendrobium and this is near the start of Area 3B in LW9. Given the scale of mining in Area 3B this is considered insufficient investigation as the results from LW9 need to be confirmed in the remaining part of Area 3B.

The following summary comments are provided in response to the PSM Report and the conclusions drawn by it:

- It is agreed that there is still a considerable amount of investigation and further monitoring to be carried out in order to develop a reliable level of understanding about the deformation and fracture network within the overburden above longwall mining at Dendrobium, and its impact on groundwater, surface water and other features. The call for further investigation work is supported.

- Whilst PSM recommends that there should have been more detailed numerical modelling of the caving and subsidence behaviour to assist in understanding – this would be useful but is far from straight-forward. It requires quite specialised numerical coding to be used and needs a good level of calibration to be useful – also requiring further data. Some numerical modelling can appear to be effective and meaningful, but unless it includes appropriate constitutive behavioural representation for rock deformation and failure, and appropriate failure criteria, it can actually be quite misleading. Caution should be exercised.

- Conclusions 1 and 2 adopt the zones discussed in section 2 of this report. However, the implication that the caved plus fractured zones (or material within the height of fracturing) results in 100% depressurisation is challenged, without some time context being introduced. What is agreed is that there is enhanced vertical permeability such that the groundwater pressure levels will be reduced. However, this may occur over some considerable time, and certainly not instantly, such that 100% depressurisation may take many years to occur. The overlying constrained zone is where there is far less fracturing and deformation such that vertical permeabilities are largely unchanged, and so groundwater pressures in the constrained zone are not impacted greatly.

- Conclusion 3 refers to the models for prediction of height of fracturing, and rightly asserts that connectivity and impacts on groundwater are not just caused by intact rock fracturing but can also arise due to rock or bedding plane dilation. In addition, bedding plane shear, which is a critical, and ever-present component of subsidence effects from underground mining, can also contribute to increased permeability, and possibly porosity. This has often been overlooked in the past. Bedding plane shear occurs around the edges of the caved and fractured zones, but also in all of the overlying zones through to the surface. However, the extent to which bedding plane shear contributes to increased horizontal permeability is likely to vary considerably depending on the properties of the shear planes, and the nature of any clamping forces acting across the shear planes. Some planes may undergo significant shear but remain quite tightly closed with limited change to permeability or porosity, whilst others may result in considerable horizontal flow pathways and storage.

- Conclusion 4 quotes the concept of a constrained zone being defined to represent a zone which restricts further depressurisation, thereby isolating the above overburden from subsidence-induced depressurisation (and by definition, dewatering). This is a correct interpretation of the concept model, although the same caution as before is given here – such models are only concepts and should be validated by the groundwater data itself, which is ultimately the means by which we define such zones in the first place. The notion of a complete isolation barrier to flow is probably at one extreme end of likelihood, only if there is a distinct aquiclude strata unit present, otherwise the constrained zone should be regarded more as a significant step-down in vertical permeability, in comparison to the strata regions below it.

- Conclusions 5 to 7 discuss the relative features and merits (or otherwise) of the so-called Tammetta and Ditton models for prediction of height of fracturing. PSM points out the limited number of data points in the databases used to develop these empirical techniques, which is a valid criticism. PSM then argues that the Dendrobium longwall parameters are "well outside the database". In terms of mining height in particular, it is agreed that the quite limited empirical databases used have limited data points for mining heights as high as those at Dendrobium. In fact, without the inclusion of the recent Dendrobium data points (i.e. using the databases to make predictions for Dendrobium prior to any validated Dendrobium experience), the Tammetta database is limited to maximum data points of just over 4m; and the Ditton database is similarly limited to upper mining height data of less than 4m (with the exception of one isolated and, in my view, possibly questionable 6m data point) – see PSM (2017), Figures 25 and 26.

  The issue of mining height is certainly one that is very important in relation to the formation of caving above a longwall (as is panel width), and will clearly impact on height of fracturing, so this is a valid criticism of the models, in their present forms.

  Other criticisms by PSM include the fact that the parameters are not independent variables, and also that the models ignore site-specific geological conditions. This conclusion regarding dependency of input parameters (being panel width, depth and mining height) is considered quite inappropriate and incorrect. Firstly, there is a difference between correlation and dependency. Correlations can exist between any disparate datasets, regardless of dependency or otherwise. In the body of the report (p26), PSM states *"These correlations indicate that the input parameters are not necessarily independent but are somewhat correlated to each other. This is not surprising as deeper longwalls are often associated with thicker seams and wider panels due to technological advances …"*. Firstly, the observation that deeper longwalls are often associated with thicker seams is an observation that is probably not supported by the evidence – either within Australia or internationally. There are many thick seam operations around the world at relatively shallow depths, and vice-versa. The initial observation is therefore challenged. But more importantly, the assertion that there is a correlation, and then further, a dependency between depth, mining thickness and panel width, cannot be accepted. By definition, these are absolutely independent variables or parameters – which may from time to time exhibit some correlations in the broader database, but in themselves, they are totally independent of each other, being functions of the coal seam geology (depth, and to some extent, mining height); and mine operator selected mining geometries (panel width and mining height).

These conclusions also comment on the lack of site-specific geology considerations in the Tammetta and Ditton models. In fact, the Ditton model does have a fairly simplistic consideration of geology in one version of the model, but it is agreed that the level of local geological input to the models, especially regarding massive overburden strata units, is limited.

- Conclusion 8 claims that the evidence from Dendrobium contradicts the previously discussed height of fracturing predictive models, since the data does not indicate complete depressurisation in any strata units, other than the near surface zone. As discussed earlier in this report, total depressurisation may take some time to occur (could be years or tens of years in some strata), but this should not be regarded as being in conflict with the concept of a fractured zone existing. PSM has adopted a definition that included total depressurisation, which has led to the apparent contradiction of the data, but this has ignored the time factor, for gradual depressurisation, and so the data is not considered to be in conflict with the models.

- Conclusions 9 and 10 consider the Dendrobium Longwall 9 post-mining monitoring data and reach the conclusion that depressurisation is occurring through 100% of the strata through to the surface. This leads to a conclusion that height of fracturing extends through to the surface, through some form of connected cracking network. This is accepted (and discussed later in this report). It may not be appropriate to describe it as connected cracking, since it may be flow of water through opened joints, for example. The exact nature of the cracking is unknown. However, based on the groundwater evidence, there is clearly some degree of increased vertical permeability.

- Conclusions 11 and 12 draw the distinction between desaturation and depressurisation and confirm that only partial depressurisation has occurred, and so this does not result in desaturation. They also note that depressurisation is sufficient to result in ground and surface water losses from the system. Conclusion 13 does acknowledge the time factor discussed previously, and notes that the time for a particle of water entering the system near surface to reach the mining, or lower strata horizons may be "very long".

- Conclusion 14 is an obvious outcome based on the above connectivity conclusions, being that there is no widespread evidence of the presence of a constrained zone that does not depressurise vertically, and therefore prevents downward water flow from higher strata units. This is a valid conclusion – but is currently based on quite limited data points and should be subject to further investigation and validation. It should also be used to further inform and develop any predictive models.

- Conclusions 15 and 16 discuss the variable nature of groundwater response evidence across all areas of Dendrobium Mine, noting considerable variability, and the need for further investigation. This conclusion is noted and supported.

- Conclusion 17 notes that the detailed post-mining monitoring study above Longwall 9 in Area 3B is the only detailed "height of fracturing" investigation in Area 3B to date, and the findings from this study (as discussed above) should be confirmed through further studies in the Area. This conclusion is also supported and is the basis for a program of further monitoring investigation currently in progress by South32. Given the limited extent of the results to date, caution should be exercised in drawing broader or more generic conclusions about groundwater impacts above Dendrobium at this point in time.

3.2 Galvin and Mackie Reviews of PSM Report

It is understood that the two independent reviews of PSM by Galvin (2017) and Mackie (2017) were prepared based on a draft version of the PSM report, which has not been sighted. The final PSM report was prepared once the Galvin and Mackie reviews had been provided. However, it is not known how much the PSM report was modified in the light of their review comments.

Galvin (2017) focuses primarily on the geotechnical aspects of the study, whilst Mackie focuses more on the hydrogeological aspects, although clearly there is a lot of overlapping or common ground. As with the above PSM report commentary, this is not intended to be a detailed review of the documents, but rather a high-level summary of significant issues.

3.2.1 Galvin Report

I am in agreement with the overall findings of the Galvin review, which, in particular, provide a detailed commentary on the Tammetta and Ditton "H of F" prediction models. Many of the points made by Galvin coincide with points addressed above. However, I do have a number of differences of opinion of relevance to the understanding and prediction of height of fracturing which are as follows:

- On p17 of the report (and also discussed on p13), it is stated that none of the piezometer monitoring holes are in a suitable position over any Dendrobium Mine longwall panels to fully assess the hydrogeological response of the strata to mining. In fact, the detailed study conducted by Parsons Brinkerhoff (2015) included a range of different monitoring systems (extensometers, piezometers, packer tests and tracer tests) conducted in boreholes above and adjacent to Longwall 9. Figure 3 shows the grouping of boreholes which included a group located directly over the centreline of Longwall 9, as well as some holes away from the panel edges. The centreline studies included both pre-mining and post-mining holes and monitoring investigations.

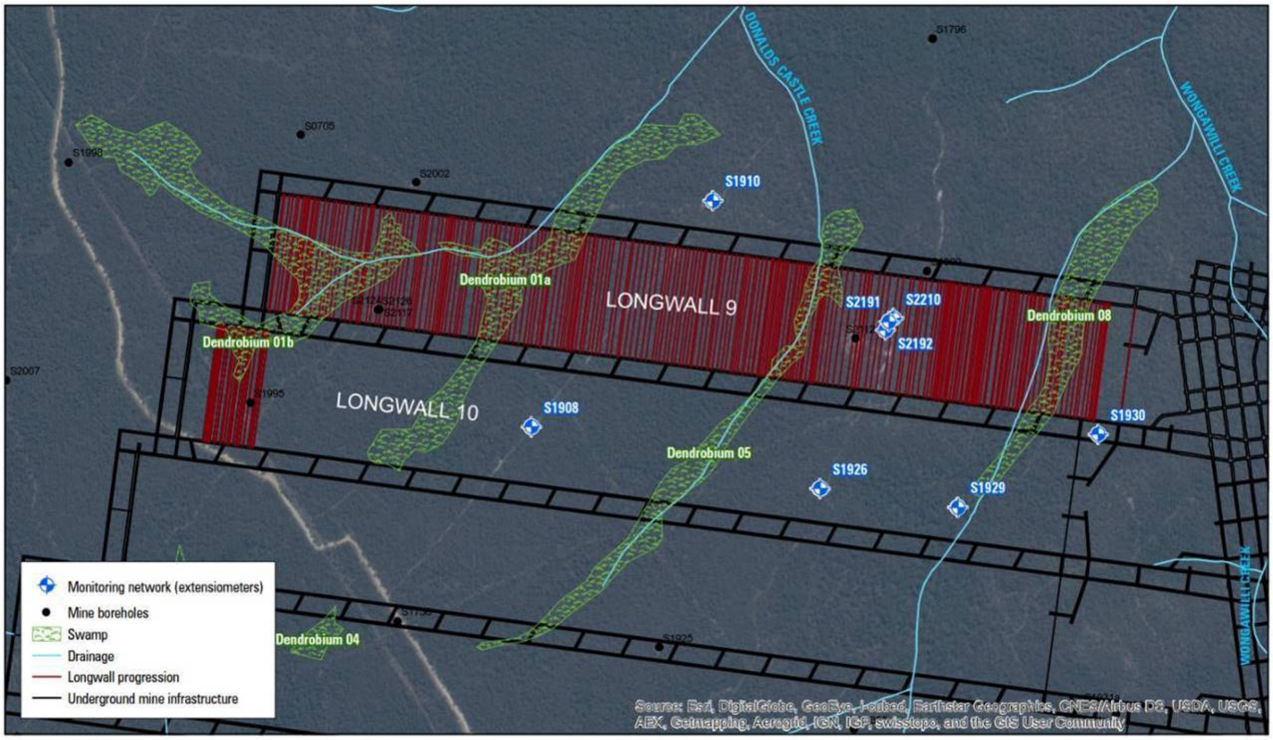

Figure 3. Longwall 9 Investigation Site *(source: Parsons Brinkerhoff (2015))*

- The second point of difference relates to the discussion about factors contributing to height of fracturing, and the higher-level effects and impacts of mining on overlying strata, including groundwater, surface subsidence and surface water impacts. Galvin rightly points out the significance of factors such as Panel Width (W), Mining Height (h), Depth (H) and critical geological factors. He then argues the importance of considering the ratio of W/H, or panel width to depth ratio.

  On page 9 of his review report, he writes:

  > *"Consideration of panel width, in isolation of consideration of the depth of the panel, and vice-versa, is important but it is also essential that the two parameters are considered together when evaluating rock mass response to mining and its impacts on the subsurface and surface."*

  He then goes on to say:

> *"Hence, for a given set of site-specific conditions (geology, stress field etc.), the mode of failure and the extent of disturbance of the overlying strata extent caused by forming an excavation is strongly controlled by the ratio of panel width-to-mining depth, W/H".*

I am in full agreement with regard to the importance of W/H with respect to the overall effect of mining on the overburden through to manifestation of subsidence on the surface. However, I would argue that below a certain depth, where proximity to surface is not significantly influencing the mining-induced stress field, an incremental change in depth, for a given panel width, will only have a very slight influence on the more localised "height of fracturing" zone above the mining panel. This rock deformation and fracturing behaviour, for a given set of geological, stress and mining height conditions, is likely to be largely dependent on panel width (and mining height) and is independent of small to moderate incremental changes in depth. This is consistent with the conceptual model of Mills, as shown in Figure 2. Of course, the situation is never as simple as many empirical models might suggest, and this whole field of understanding the formation of such fracture zones is very complex and requires much more detailed study based on good quality monitoring data, and calibrated parametric numerical modelling studies.

- The third point of some difference, but also agreement, relates to the role of empirical models. I strongly support the Galvin view that mechanistically-based models built around a sound understanding of the mechanisms involved, and a good quality database, are far superior to simple statistically-derived empirical models which do not necessarily honour the behavioural mechanisms. Having said that, if an appropriate, improved empirical model is derived, and applied within the database range on which it has been built - with due consideration for the site geology - then this is a very powerful predictive tool and does have a place in forward planning and design.

  Galvin is highly critical of both the Tammetta and Ditton models, and I do not have significant disagreements with his criticisms. However, I believe there is scope to continue working on development of improved empirical predictive models. There is no reason why Dendrobium and others should not proceed to develop such improved mechanistically-based models that are also based on, and applicable to, the overburden geology above the Wongawilli Seam in the Southern Coalfield of NSW.

  In his final paragraph, Galvin then writes:

  > *"Numerical modelling of the mechanical and hydrogeological response of the rock mass to mining may also aid in the design, notwithstanding that this approach also has limitations and the need for calibration against field performance."*

  I do not disagree with this statement, and there will be an increasing role for numerical modelling – probably as a complement to empirical modelling rather than a replacement, particularly to conduct comparative parametric studies. However, I would place greater emphasis, and hence caution, on recognition of the limitations and simplifications in current modelling being conducted, as well as the importance of good calibration.

3.2.2 Mackie Report

The Mackie (2017) review of the PSM report is primarily focused on hydrogeological matters which are largely beyond my particular mining and geotechnical expertise. I am therefore not in a position to provide a detailed response or offer any significant over-arching commentary. However, the following comments do relate to the subject-matter currently under discussion:

- On p2, in discussing the zones of fracturing in the overburden, as defined in the various conceptual models, Mackie notes

  > *"I concur that fracture connectivity is best perceived as a continuum migrating from highly connected pathways in lower parts of the fractured zone to weakly connected and disconnected pathways in upper parts of the zone".*

  This understanding aligns well with the gradation between zones discussed previously and supports the view that these relatively simplistic conceptual models, while having a role to understand the overburden behaviour, should not be assigned too much importance. It is far more important to interpret the monitored, or modelled results directly to determine the nature of the effects and impacts of mining within the strata.

- On p5, Mackie discusses the important role of time-dependant water flow through the fracture networks which may take many years for water to move through the overburden. He notes that this time effect is not well recognised in some of the existing models and interpretations, as discussed earlier. He also uses a very effective terminology to describe this form of low permeability, but nevertheless, connected fracture network, when he says:

  > *"If the network remains connected but has tortuous flow paths with smaller fracture apertures, then drainage may be slowed – complete drainage may take many years".*

  The term "tortuous flow paths" is a good one to describe some of these grey areas within and between the simplistic fracture zones of the conceptual models.

4. REVIEW OF INITIAL REPORT BY INDEPENDENT EXPERT PANEL

4.1 Background

The Independent Expert Panel for Mining in the Catchment was commissioned by the NSW Government in November 2017, through the Office of the Chief Scientist and Engineer. The Panel has released its *"Initial report on specific mining activities at the Metropolitan and Dendrobium coal mines"*, dated 12 November 2018, with a specific focus on the Panel's Term of Reference 1 (IEPMC, 2018).

The following sections provide a summary technical review of the IEPMC report with a focus on the geotechnical content and related matters of hydrology/groundwater that are linked to geotechnical factors. Detailed mine-specific review comments are not offered in this current review document, although some points that have broader application are included.

For clarity, in relation to the independence of this current review with respect to the IEPMC report, it is noted in Appendix 1 of the IEPMC Report that Professor Bruce Hebblewhite was a member of the IEPMC from the time it was established, up to 8 April 2018. The development of all findings, conclusions and recommendations by the Panel, as well as the preparation of this IEPMC Initial Report, all took place after 8 April 2018. As such, Bruce Hebblewhite had no involvement in the preparation or any of the content of the IEPMC Report.

(Note: the following review comments also form part of a current Stage 2 report being prepared for DPE as part of the ongoing independent review role for Dendrobium Mine).

4.2 IEPMC Conclusions and Recommendations

The conclusions and recommendations from the IEPMC Report (Section 7 of the report) are reproduced below, in full, to provide context to this review:

7 CONCLUSIONS AND RECOMMENDATIONS

In this report, issues have been discussed and conclusions and recommendations have been developed under the relevant specialist discipline headings. Some of these issues were originally envisaged to fall under Term of Reference 2 but have needed to be considered, at least in part, under Term of Reference 1 in order to properly inform the Panel and the reader and to contextualise the Panel's observations and findings. Regard to a range of reports including those specified in the Panel's Terms of Reference is embedded throughout this document.

There is universal agreement that the issues are complex and complete reading of the detail contained in chapters is needed to understand the full range of the Panel's conclusions and recommendations. Therefore, for the benefit of the non-specialist reader, the principal conclusions and recommendations have been extracted and summarised in this chapter under headings that give them context in terms of mine design, mine approval and monitoring and performance.

MAJOR CONCLUSIONS

Mine Design

- The knowledge base regarding mining-induced subsidence and its impacts on groundwater and surface water continues to grow. In some cases, these advances have identified aspects not appreciated at the time of mine approval and may require the originally proposed mine layouts to be revised in order to satisfy performance measures
- The existing development consent for Dendrobium Mine was granted almost two decades ago and expressly allows mining in Areas 1, 2, 3A, 3B and 3C, with LW 14 currently being extracted in Area 3B. The consent conditions only place performance measures on three watercourses and one reservoir and offset provisions are in place to compensate for any exceedance of swamp performance measures. These legacy mine approval conditions are embedded and provide a significant degree of flexibility in mine planning. They provide considerable scope for maximising mining dimensions which, in turn, is reflected in the high percentage extraction of the coal resource, the high level of vertical surface displacement and the significantly higher daily water inflow than at Metropolitan Mine
- There has been a major effort over the last decade by Metropolitan Mine and Dendrobium Mine to employ up to-date 3-dimensional groundwater models and best practice modelling methods undertaken by suitable experts, with expert peer review. The models have improved in accuracy and predictive capacity and peer reviews of the models and modelling have provided valuable direction without which the process may have been less focussed
- The modellers, peer reviewers and the Panel recognise the fundamental limitations of the groundwater models for predicting impacts and consequences of mine subsidence, including those related to grid scales, computation time, and hydrogeologic parameter estimation
- The height of complete groundwater drainage is an important consideration in groundwater modelling and the Tammetta equation and the Ditton equations were developed in Australia for this purpose some 5 years ago. There are significant and fundamental differences between the characteristics of the Tammetta and DGS (Ditton) databases which preordain that, irrespective of the methodologies adopted to process this data, the respective predictions of the height of complete drainage based on the data are likely to be very different

126

- Field performance at Dendrobium Mine suggests that irrespective of whether the Tammetta equation is predicting the height of complete drainage reasonably accurately, its outputs can be useful as an indicator of the potential for water ingress from the surface

Mine Approval

- The Panel endorses the Department of Planning and Environment's approach for dealing with legacy issues and evolving knowledge bases whereby:
  - the management plans for longwall panels at Dendrobium and Metropolitan mines are being approved on an incremental basis that provides for considering existing and emerging information and knowledge gaps that have the potential to jeopardise compliance with performance measures
  - conditions are attached to approved Subsidence Management Plans and Extraction Plans that require mine operators to undertake a range of investigations and monitoring and engage independent experts to review and prepare advice to address geotechnical and hydrogeological information and knowledge gaps
  - some mining applications are being referred to independent experts and bodies, including the Panel, for advice

Monitoring and Performance

- Although knowledge of the consequences of mining on surface water quantity in the Catchment Special Areas has progressed substantially over the last 10 or so years, limitations in monitoring and modelling mean that it is difficult to verify conclusions by some stakeholders that mining has had negligible consequences on surface water supplies.
- Knowledge of the contribution of swamps to water supplies is particularly undeveloped due to lack of integrated monitoring targeting swamp water balances.
- Supported by its own analysis, the Panel concludes that in the case of Dendrobium Mine:
  - water inflow into all four mining areas (Areas 1, 2, 3A & 3B) exhibits some correlation with rainfall, ranging from weak in Area 3B to strong and rapid for Area 2
  - it is very likely that the high rate of influx is associated with a connected fracture regime that extends upwards to the surface
  - it is plausible that an average of around 3 ML/day of surface water and seepage from reservoirs is currently being diverted into the mine workings
- In the case of Metropolitan Mine:
  - The average daily water inflow of about 0.5 ML/day displays no evidence of a connected fracture regime to surface or correlation with rainfall
  - the potential for water be diverted out of Woronora Reservoir and into other catchments through valley closure shear planes and geological structures including lineaments will require careful assessment in the future because it is planned that most of the remaining longwall panels in the approved mining area will pass beneath the reservoir
- At both the Dendrobium and Metropolitan mines, the nature of surface water TARP triggers is not suited to determining the level of confidence that can be placed in surface water modelling results

- The performance measures for surface flow losses are not explicitly related to materiality of flow losses, limiting the objectivity of performance evaluation.
- In the present situation, TARPs classify the seriousness of events that have already occurred rather than fulfilling their more usual role of early signalling to prompt intervention that prevents escalation of impacts

MAJOR RECOMMENDATIONS

Mine design

- Notwithstanding that uncertainty is associated with both the Tammetta and the Ditton height of complete drainage equations, it is recommended to err on the side of caution and defer to the Tammetta equation until:
    - field investigations quantify the height of complete drainage at the Dendrobium Mine and Metropolitan Mine, and/or
    - alternative geomechanical modelling of rock fracturing and fluid flow is utilised to inform the calibration of groundwater models
- The potential implications for water quantity of faulting, basal shear planes and lineaments need to be very carefully considered and risk assessed at all mining operations in the Catchment Special Areas
- The concept of restricting predicted valley closure to a maximum of 200 mm to avoid significant environmental consequences should be revised for watercourses

Mine Approval

- Government should verify that sufficient entitlements are retained by Dendrobium and Metropolitan mines to cover surface water losses resulting from mining-induced effects.
- The Panel recommends that in future:
    - mine design methodologies and procedures that underpin critical aspects of mining proposals should be supported by robust, independent peer review and/or a demonstrated history of reliability when applications are submitted to government
    - all applications to extract coal within Catchment Special Areas should be supported by independently facilitated and robust risk assessments that conform to ISO 31000 (the international standard for risk management subscribed to by Australia)
    - government needs a sustainable mechanism for accessing objective expert advice when assessing mining applications.

Monitoring and Performance

- In future, mines operating in the Catchment Special Areas need to develop, in consultation and with the agreement of regulators and key stakeholders, a standard for field investigations, data collection, and data processing that provides for and integrates the interests of all stakeholders and facilitates the sharing of the information by being presented on a common platform. This should be canvassed in submissions to inform Term of Reference 2
- This monitoring standard in relation to groundwater should include provision for:
    - Installation of multi-level piezometers on the centreline of panels at Dendrobium and Metropolitan mines in order to monitor pore pressure changes associated with subsidence. These should include at least five transducers per borehole with installation being completed at least two years in advance of being undermined

- Daily monitoring of local rainfall and mine water ingress from overlying and surrounding strata, and separation of rainfall correlated inflows for base flow volumetric analyses
- Dendrobium Mine and Metropolitan Mine to develop site-specific databases in relation to the height of complete drainage in-lieu of relying on height of drainage equations

- In future, surface water monitoring requirements should include:
  - a distinction between primary watercourse monitoring sites, which are the sites at which performance measures are specified; and secondary watercourse monitoring sites, which will provide additional information identified as necessary as the mine plan evolves
  - a specification of the minimum flow measurement accuracy required at the primary and secondary sites
  - the identification of the primary sites in proposed future mining areas and the installation of flow monitoring at these sites at least four years in advance of mining activities
  - the identification of the secondary sites as the mine plan evolves and the installation of flow monitoring at these sites at least two years in advance of mining activities or a shorter time if approved as part of the mine plan approval
  - paired piezometers in swamp sediments and nearby bedrock, and flow gauges at the swamp exit stream, complemented by soil moisture sensors at selected sites.
  - consistent use of inter-site comparisons using suitable control sites to complement rainfall-runoff modelling
- Surface flow monitoring associated with mining should be required to be continued until the consequences of mining (including any rehabilitation) have stabilised or the mine is considered by the relevant regulatory authorities to be closed. This requires clear metrics of stabilisation
- There is a need for groundwater modellers to address apparent inconsistency in the hydrogeologic parameters used to model Dendrobium and Metropolitan mines as it calls into question the robustness of current model predictions
- Research needs to be progressed into the use of tritium for calculating 'modern' water contributions at Dendrobium Mine, including the potential for results to be affected (skewed) by adsorption
- A reservoir water balance model needs to be developed. A limitation of using either groundwater or rainfall-runoff models as currently applied is that these models do not necessarily correspond to the space or time scales relevant for quantifying water losses to the Sydney drinking water supplies. Water balances should include drought periods and results for these periods should be highlighted
- In setting performance measures, government should have regard for those measures relevant to strategic resources (such as flow to storage) and to sanctions which rapidly prevent escalation of impacts and consequences if there are exceedances, clearly linked to monitoring results. Future consent conditions should clearly specify the acceptable levels of impacts and consequences on catchment resources, and that assessment of these should continue at strategic locations beyond the life of mine
- TARP triggers should be based on meaningful surface water loss performance measures developed in consultation with relevant agencies with oversight and regulatory responsibilities for mining

- TARPs should be related to the desired outcomes (such as maintenance of water flows) and be consistent both within and between mine domains. The TARP triggers for surface and groundwater should be replaced by meaningful flow loss indicators developed in consultation with relevant agencies and authorities with oversight and regulatory responsibilities for mining
- In situations where performance measures of negligible or minor environmental consequences are set by government, mine planning should incorporate appropriate factors of safety to avoid marginal situations associated with gaps in the current knowledge base.

4.3 Review Comments

The following summary comments are provided in the order in which the related issues appear in the body of the IEPMC Report. The order of the comments therefore does not necessarily reflect any priority of issues. Many of the points made are of a quite specific or detailed technical nature and do not change the overall conclusions of the report. However, they are included here as a matter of record arising from this review.

1. Introduction

- P10 - It is noted that the Panel is tasked to consider, but not be confined to, risks to the total water quantity and holding capacity of both surface and groundwater systems.

- P10 - This is an initial report and further consideration will be given to feedback received from stakeholders prior to finalising conclusions in the next report.

- P13 - The importance of consideration of cumulative impacts from past, present and future mining (and other land uses) is stated and this view is supported. However, in doing so, the difficulty of securing accurate and meaningful data – especially with respect to past impacts, should be recognised. The report also recognises difficulties associated with future impacts due to potentially long timeframes that can be involved. This point is also supported.

- P14 - Discussion is provided on the trend towards use of outcomes-based regulation, as opposed to the more traditional, previous prescriptive approach. Overall, it is agreed that this is a more appropriate and manageable approach, and one where Australia is considered a leader, internationally. It is noted by the Panel that approvals or development consents are now typically defined by conditions which include outcome-based targets, or performance measures, specifying acceptable levels of adverse impacts which must then be managed by the mine. This brings with it a challenge for the approval agencies to deliver specific, meaningful and measurable acceptance targets, which has not always been the case in the past. It is also noted that in addition to outcome-based assessment, approvals have become more iterative. This is also considered reasonable, provided the significant lead-times and all related timeframe issues associated with a major mining operation are recognised and the approval process does not incur excessive delays that can jeopardise responsible mine planning and implementation processes.

- P16 - The final sentence in paragraph one refers to the factors which can influence the extent of caving, fracturing and subsidence, listing mining dimensions and geology. This list of factors should also include depth, especially with regard to surface subsidence.

2. <u>Mining-Induced Ground Subsidence Effects</u>

- P23 - The acceptance and ongoing adoption of the terms – effect, impact and consequence – associated with mine subsidence, as defined by the 2008 Southern Coalfield Report, is commended. Consistency in terminology is important in this field where there is often unnecessary confusion and at times contradiction created by use of alternative terminologies by different parties.

- P24, Fig. 6 - It is acknowledged that this Figure is a direct extract from a Hydrosimulations 2016 report. However, it is considered that the extreme exaggeration of the vertical scale in this diagram may create some misconceptions by some lay-readers about the extent of variable surface topography relative to seam and strata horizons. It may be more beneficial to replace or at least supplement this diagram with a more regular vertical scale with little or no vertical exaggeration.

- P25 - The comments regarding the roles of geological defects or discontinuities is quite appropriate and correct. I would suggest adding the term "structural discontinuities" as another term used to describe these. In relation to the final sentence of the second last paragraph, I believe it is important to acknowledge that it is not just the opposing "face rocks" that can impact on the permeability or otherwise of the structures, but also, very importantly, the properties of any in-fill gouge or intrusion material.

- P26 - An important point is made regarding excavation span. This is that *"when the width of an excavation (or panel) is small, the immediate roof strata will bridge across it and there is negligible disturbance of the surrounding strata"*. Whilst this point may not be of direct relevance to Dendrobium, it is certainly important in some other mining contexts where there are current misconceptions that any mining excavation will lead to strata fracturing/disturbance of overlying strata and hence potentially also groundwater impact. This is clearly an incorrect perception, as is made clear by this statement from the Panel.

- P26 and following, Section 2.3.1 - There is discussion here about the various forms of conceptual models for zones of fracturing and constraint above extraction panels. This issue has already been discussed earlier in this report (Sections 4 and 5). In discussion (p27) the Panel notes that these zones *"are not based on groundwater response to mining but rather on rock deformation inferred from surface and underground observations"*. In many reported instances, whilst this might be a desirable means of determining such zones, it is not commonly carried out in this manner, but if it is, the geotechnical data from which zones are inferred is extremely limited and not necessarily regionally representative. For this reason, and for the more common use of such zones to infer groundwater impacts, it is more common to use groundwater data to infer the presence and boundaries or transitions between such zones. In this case, and for the reasons previously outlined, it is more appropriate to refer to the important parameter of height of fracturing as a height of depressurisation – as discussed earlier.

- P28 - Reference is made to classical subsidence theories and performance from Britain and Europe. It seems remiss not to acknowledge specifically the extensive work of the National Coal Board (NCB) in Britain, and in particular, the NCB's "Subsidence Engineer's Handbook (1975)" which was the basis for much of the early international subsidence engineering experience and original prediction capabilities.

- P29 - The discussion on conventional subsidence includes reference to horizontal bedding plane shear occurring between different strata layers (which may or may not be "basal planes"). It is noted that such shear movement *"may or may not significantly enhance horizontal permeability"*. This statement is correct but could be extended further. In fact, it is reasonable to say that it may not enhance horizontal permeability at all – depending on a range of factors such as confining stresses, geological properties, geometry etc.

  The issue of bedding plane shear has gained significant attention in recent years as a potential source for groundwater movement and hence possible water loss. Whilst this may be a hypothetical possibility, the fact is that there has been very little investigation to date to either substantiate or contradict this hypothesis. Clearly this is a matter for further investigation. In the interim, caution should be exercised to give too much credence to this hypothetical scenario until there is compelling evidence to support it or otherwise.

- P32 - Discussion and data is presented regarding empirical predictions of maximum subsidence above mining panels having a particular width (W) at a depth (H), hence the important W/H ratio. The classical curves used by many are presented in Figure 12 – although the vertical axis showing maximum surface subsidence as V_z is more commonly referred to as S_{max}. This discussion should make clear that such curves are for single panels only, and not the cumulative effect of multiple adjacent panels. This point is made later in the text but it would be beneficial to be included earlier, for clarification.

- P33 - Section 2.3.3 introduces the concept of Non-Conventional Subsidence, including valley closure, valley floor uplift (or upsidence) and other effects including basal bedding plane shears (see earlier comment – these are not always just basal bedding planes). The section title introduces an alternative terminology of "site-centric subsidence". The terminology of both conventional and non-conventional subsidence was introduced and accepted following the Southern Coalfield Report in 2008. As with other terminology discussed earlier, it is important to stay with consistent terminology. For this reason, the unusual and rather confusing "site-centric" terminology included here is discouraged from further use.

- P34 - Two issues already referred to above are covered on this page. Firstly, the statement that *"basal shear planes can enhance hydraulic conductivity"* is made. However, as previously stated, there is only very limited data available, to date, to verify this claim, and so it should be couched in a less definitive manner and a comment made to indicate that there is limited data at present. If the Panel has substantial convincing data to support this claim, then it should be included in the report. (This same issue is also referenced on P35). Secondly, the use of the term *"site-centric"* is again questioned.

- P35 - The term "unconventional" subsidence should be replaced with "non-conventional" subsidence, to be consistent with the accepted terminology.

- P35 - The role of geological structures is discussed, and examples given of up to 30% above predicted subsidence occurring in the presence of lineament zones at Springvale Colliery in the Western Coalfield. Lineaments are major surface topographic features or surface manifestations of major structural defects (such as valleys, gorges or cliff lines) caused by underlying regional geological structures. The Panel suggests that investigations should address the potential similar role and impact of lineaments on subsidence in the Southern Coalfield. This is a reasonable recommendation, but caution should be exercised.

  There is no argument about the impact of lineaments in the Western Coalfields on strata behaviour generally, including not just subsidence, but major zones of adverse underground mining conditions when mining through such zones. However, the lineaments in the Western Coalfields are believed to have their origins in the underlying igneous basement rock which, in the west, lies at quite shallow depths below the sedimentary coal seam strata (tens of metres). However, in the Southern Coalfield it is understood that the basement rocks are some hundreds of metres below the coal seams and therefore the mechanisms and scale of behaviour involved are likely to be quite different between the two regions. There is also believed to be far less evidence of underground impact of lineaments on mining conditions at mines in the south. Caution is therefore recommended in making direct comparisons between the impact of Western Coalfield lineaments and similar features (if they exist at all) in the Southern Coalfield. Nevertheless, it is appropriate to investigate this issue further.

- P36 - Section 2.3.5 is discussing the rock mass response to underground mining with respect to individual panel geometries. A list of five bullet point factors is provided. There is no argument with four of the five but point 4 states that *"as depth of mining increases, surface subsidence over panels of the same W/H ratio increases"*. The basis of this statement is challenged. It is contrary to the fundamental principles of the role of W/H ratio, as was presented in Figure 12 of the Panel Report which shows that maximum subsidence over a panel is a function of mining height and W/H ratio, but for a given geology, the value of subsidence at a constant W/H is constant for a particular mining height. What is true is that the surface area, and underlying volume of rock influenced by subsidence will increase, as depth increases for a constant W/H ratio – since panel width must increase by a commensurate amount to the depth increase, to maintain a constant value for W/H, but the maximum value of subsidence will not increase.

- P37 - The report returns to the issue of hydrogeological models and rightly points out that zones which often provide hydrological barriers between the model zones – especially what is referred to as the constrained zone – more likely consist of aquitards rather than aquicludes.

- P38 - The Panel emphasises and supports the same point made earlier in this report (Section 4) and is therefore supported. The Panel stated that:

  > *"models of sub-surface behaviour zones can be useful for conceptualising the impacts of mining on the surrounding rock mass and groundwater system but it is important to appreciate their limitations. In particular, while it is convenient to divide subsurface behaviour into a series of zones with distinct physical and/or hydrogeological characteristics, in reality changes in ground behaviour and fracturing, permeability and the lateral extent of affected areas occur gradationally rather than as step changes. The so-called 'fractured zone' is a misnomer. Fracturing still develops above this zone and may be connected."*

  In fact, from a groundwater perspective, water flow and hence depressurisation or dewatering can also occur not just through fractured rock but also if geological structures such as bedding planes, joints, faults etc are impacted by mining and dilate, resulting in increased permeability. Hence, linking zones of groundwater behaviour solely to fracture zones can be quite misleading, apart from the earlier discussion regarding the problems of measuring such fracture zones.

3. Ground Subsidence Effects at Dendrobium Mine and Metropolitan Mine

- P40 – It is noted that a value of 200mm valley closure has been widely used as an upper acceptable limit in order to avoid significant impacts, although it was an empirical value derived from early work at a number of mines in the Southern Coalfield. It is understood that this prediction methodology has evolved over time as additional data has been acquired and analysed.

- P42 and following – The results of early predictions made by MSEC on maximum subsidence relative to panel width and depth and also potential height of fracturing are discussed and are a matter of record. It is noted that actual subsidence data from Areas 3A and 3B at Dendrobium were found to be up to 30% greater than the original predictions. Updated prediction models based on the available Dendrobium data were then developed by MSEC and used subsequently.

- P43 – In the continuation of the above discussion, the Panel notes that the 30% increase in actual maximum subsidence above the original predictions for Dendrobium is the same magnitude as the exceedance measured in lineament zones at Springvale Mine. This point is not considered to be of any relevance as it stands, unless it can be substantiated by much more convincing evidence regarding impacts of lineaments in the Southern Coalfield – which, to date, does not exist.

4. Groundwater Impacts at Dendrobium Mine and Metropolitan Mine

- Pp58, 59 – The Panel is discussing modes of groundwater flow from near-surface water aquifers by means of horizontal flow along bedding planes into valley sides, and cites the evidence presented in Figure 10 which showed seepage from a very shallow bedding plane in the exposed strata of a railway cutting over the Dendrobium lease (less than 5m of cover depth). This is a reasonable example, but it should not be used to form a generalised model of flow along bedding planes, where at greater depths there will be significant vertical confinement/clamping of bedding planes due to overburden weight, which will no doubt reduce the permeability and hence flow paths available along bedding planes.

- P60 – The discussion has returned to the conceptual models of zones above a mined panel or goaf region – this time in relation to hydrological parameters. There is no dispute here with the content other than suggesting that the first dot point on P60 should also include the role of joints and other structures on potential flow paths, rather than just fracture surfaces and bedding planes.

- P60 – The desire and value of using groundwater monitoring along panel centrelines through systems such as borehole piezometers – both pre- and post-mining – is supported, although the difficulties in establishing and maintaining such boreholes and instrumentation should not be under-estimated. The Panel has acknowledged this as well as the difficulties of dealing with knowledge gaps between different monitoring installation systems.

- P64 – The Panel refers here and subsequently to a "height of complete drainage". This is certainly more appropriate than using the term "height of fracturing" or "height of connective cracking", but as discussed earlier in Section 2, the use of the term "complete drainage" can lead to a perception of total dewatering and lack of any residual groundwater. Once again, the argument is put forward to use the term "height of depressurisation" instead, which can be defined to represent significant reduction in water head levels, approaching zero, without the implication of no water present at all.

- P64 – The Panel notes that theoretically, coupled solutions incorporating both geomechanically behaviour and groundwater models can be adopted. It then cites computing power, especially when attempting true 3D modelling, as the major limitation. This is certainly true as being one major limiting factor, but it is important to note also that there remain other ongoing difficulties – at least with the geomechanical models – in developing appropriate constitutive behaviour models to represent the appropriate rock response to stress; and further, to represent the rock mass in a meaningful and sufficiently detailed manner on this scale, including the complex discontinuity regime, to a level that can realistically be linked to groundwater flow modelling. This is ideally the route to follow, but we are still a long way from having meaningful modelling capacity to achieve these objectives.

- P64 and following – There is an extended discussion of the available empirical prediction equations, namely the Tammetta model and the Ditton or DGS model. It is not intended to conduct a detailed analysis of the documented Panel analysis here. Suffice to say that the overall content of the Panel report on this issue is supported.

- Pp68, 69 – The Panel returns to the conceptual model of zones above a mining panel and reinforces the Mackie concept of "tortuous flow" being particularly applied to the region above the "fractured zone" into a region where mining-induced fractures are isolated and unconnected. The Panel also agrees that the definitions used by the Woronora Reservoir Strategy Report – Stage 1 (2017) are consistent with their views, i.e.:

  "… the term "height of fracturing" is used herein to refer to the region of connected fracturing which results in significant depressurisation of the strata.

  The constrained zone tends to maintain the in situ (i.e. pre-mine) vertical permeability of the strata and therefore continues to restrict vertical flow but can display an increase in horizontal permeability within and above the parabolic fracture zone that has however little effect on vertical groundwater flow rate".

- P74 – As part of the analysis of the Tammetta equation, Galvin and Mackie are quoted by the Panel as re-analysing the available database and reducing the Tammetta equation to a simpler form, being:

  $$H_{cd} = 0.3 * h * W^{'} (m)$$

  where
  H_{cd} *is the Height of complete drainage (or preferably now referred to as the Height of depressurisation) (m);*
  h is the mining height (m);
  $W^{'}$ *is the effective panel width, reaching a maximum defined by the critical width for maximum subsidence (assume to be approximately 1.4 H, where H is depth (m))*

  This finding by Galvin and Mackie confirms that the height of depressurisation is essentially a function of mining height and panel width and is largely independent of depth or W/H (apart from setting an upper value for effective panel width). This outcome is supported, although it is in contrast to the previous position expressed in the response to the PSM Report by Galvin on this issue. See Section 3.2.1 of this report for earlier review discussion).

- P88 – In the Panel conclusions from this section of the report, the Panel notes the following significant findings which are fully supported:

> *"Based on the partial analysis of the Tammetta and DGS databases undertaken by the Panel, a full analysis of the evidentiary databases as originally requested of PSM by DPE would prove very challenging and may not yield useful outcomes"*
>
> *"The Panel considers that it would be quicker and more productive for Dendrobium Mine and Metropolitan Mine to develop their own site-specific databases".*

This second conclusion cited appears to lend support for the value of an empirical prediction approach, appropriately developed and calibrated, rather than relying on the use of numerical modelling as had been previously implied by some authors following the PSM Report.

- P90 – A significant recommendation from this section of the report relates to standards for field investigations and data collection, analysis and reporting. The Panel stated:

  > *"In future, mines operating in the Catchment Special Areas need to develop, in consultation and with the agreement of regulators and key stakeholders, a standard for field investigations, data collection, analysis and reporting that provides for and integrates the interests of all stakeholders and facilitates the sharing of the information by being presented on a common platform".*

  This is a commendable recommendation, in principle, although the ability for it to be implemented is questionable, with a requirement for all key stakeholders to agree on all of these aspects of the proposed standard. Certainly, input from key stakeholders is of value, as is the subsequent reporting/communication using a common platform. However, the requirement for all parties to agree on every aspect of investigation and data collection and analysis may prove to be an unworkable objective.

  The subsequent discussion on P91 about groundwater monitoring focuses on adequate advance data, prior to mining commencement, but it appears to neglect the all-important post-mining data collection.

- P91 – Further in the recommendations of this section of the report, the Panel notes that it will defer to the use of the Tammetta equation until further monitoring at each of the mines quantifies the height of complete drainage, and/or a coupled geomechanical modelling of rock fracturing and fluid flow model is utilised to inform the groundwater models. Both of these findings are supported, albeit that each of these end-point objectives are difficult to achieve – at least in the short-term.

5. Surface Water Impacts

Note: A significant part of this section of the Panel Report falls outside the scope for this current report, and so detailed review comments are not provided. Some geomechanics-related points are covered, and these are addressed below:

- P97 – A significant conclusion is reached by the Panel with respect to watercourse bed leakage (at catchment scale), where the Panel finds:

  > *"from material presented to the Panel, there remains no strong evidence that cracking of watercourse beds leads to significant losses of water at catchment scales relevant for water supplies".*

- P98 – In regard to swamps, the Panel states:

  > *"… the integrated monitoring and modelling needed to understand the contribution of swamps to baseflows continues to be extremely limited, and it remains the case that there is no strong evidence of consequences of swamp impacts on catchment-scale water supplies".*

  It is agreed that there is limited information available with respect to swamp impacts, however a significant amount of monitoring and investigation work is now in progress by Dendrobium over Area 3B which will hopefully provide further useful information in the future.

6. Catchment, Groundwater and Reservoir Water Balances

No comment is provided on this section, which falls outside of the scope of this report.

7. Conclusions and Recommendations

This section of the Panel report was reproduced in full in section 4.2 above, for easy reference.

- Major Conclusions – Mine Design
  - There has been continuing growth in knowledge of subsidence and groundwater/surface water impacts – agreed.
  - The Dendrobium approval consents cover a period of almost twenty years and include some performance measures and also offset provisions – agreed. They provide a significant degree of flexibility in mine planning – partially agreed. The level of flexibility is perhaps not as significant as is implied here, taking into account mine operational, timing, economic and technical factors.
  - There has been significant improvement in groundwater modelling capabilities over the last decade, but there are a number of limitations that are recognised by all parties – agreed.
  - The Tammetta and DGS (Ditton) equations for prediction for height of complete drainage (depressurisation) have a number of fundamental differences which result in different prediction outcomes, but the Tammetta model does provide a useful indicator for consideration of potential water inflow from the surface – agreed.

- Major Conclusions – Mine Approval
  - The Panel endorses the current DPE approach to approval, utilising an incremental basis, with conditions attached, and independent review of some mining applications. This approach is considered reasonable, provided the DPE and other government agencies recognise the critical time factors involved in making appropriate mine planning and operational decisions and hence approval processes must function in a timely manner accordingly.

- Major Conclusions – Monitoring and Performance
  - Knowledge of the consequences of mining on surface water quantity has progressed substantially over the last ten years, but it remains difficult to fully verify all conclusions regarding negligible consequences of mining on surface water – agreed, though data quality and quantity has improved greatly.
  - Knowledge of contribution of swamps to water supplies is undeveloped – agreed, but again, there is considerably more investigation work now in progress.

- Major Recommendations – Mine Design
  - Height of complete drainage prediction equations – defer to Tammetta until other criteria achieved (see earlier discussion) – agreed
  - Potential implications for water quantity of faulting, basal shear planes and lineaments all need to be considered and risk assessed – agreed (suggest basal shear planes be described as bedding plane shears)
  - Concept of using a 200mm limit for valley closure for avoiding significant environmental consequences should be revised for watercourses – agreed that this should be further investigated. It is understood that this concept and model are under constant review as more data becomes available.

- Major Recommendations – Mine Approval
  - Mine design methodologies and procedures that underpin critical aspects of mine proposals should be supported by robust and independent peer review and/or demonstrated history of reliability – agreed
  - Applications to extract coal in the Catchment Special Areas should be supported by independently facilitated and robust risk assessments – agreed.

- Major Recommendations – Monitoring and Performance
  - Need for a standard for field investigations, data collection, analysis and reporting – agreed to establish and implement a standard, but as discussed earlier, the expectation of requiring approval by all stakeholders may prove unworkable. As a minimum, a consultation with key stakeholders should be required. Groundwater monitoring instrumentation along panel centrelines should also address requirements for post-mining monitoring.
  - Surface water monitoring and modelling (various recommendations) - unable to comment, outside scope of this report.

5. SUMMARY COMMENTS

The following summary points are drawn from the above review documentation, specifically related to the issues addressed by the IEPMC report and represent my current views with respect to the major IEPMC report findings, conclusions and recommendations.

- Overall, the Panel Report is a sound document which provides positive confirmation of many key issues and useful conclusions and recommendations.

- More specific response to the IEPMC conclusions and recommendations is contained in section 4.3 above, specifically, the final section under the heading of *"7. Conclusions and Recommendations"*. These points are not repeated here.

- Other issues worthy of special mention include the following:

    - The importance of adopting consistent and appropriate terminology is emphasised. In relation to subsidence terms, the terminology adopted by the 2008 Southern Coalfield Report should be retained and used at all times.
    - The importance issue of what has been referred to as "height of fracturing" requires special mention again here.
        - In terms of terminology, the term "height of fracturing" or "height of connective cracking" is potentially misleading and inappropriate when referring to impact of mining on groundwater. The recommended term would be "**height of depressurisation**". This is favoured over the term used by the IEPMC of "height of complete drainage" which, whilst technically correct, has connotations of totally dewatered strata with no water present at all, which is not considered appropriate.
        - The Panel has acknowledged that the zones often described in these fracturing/groundwater models are only conceptual and caution should be used in treating them too literally; or regarding the transitions between zones to always be distinct horizons. These models or concepts are only artefacts and should be regarded as such, to aid in understanding, rather than as literal and distinct regions within the overburden.
        - The value of empirical models such as the Tammetta model have been recognised by the Panel, somewhat in contrast to earlier opinions expressed by some Panel members. This is not to say that they are adequately developed or are accurate representations at the present time, but they are a reasonable starting point for estimating the height of depressurisation. The Panel rightly acknowledges that this is a very complex field and is difficult to obtain comprehensive and reliable validation data. However, they also acknowledge that there is value in the mines continuing to develop empirical prediction models calibrated to their own mining and geological conditions.

- The Panel report makes multiple references to leakage or enhanced water flow along strata bedding planes, specifically referring to basal shears. Any bedding plane, basal or otherwise, has the potential to either remain intact and resistant to permeability at all, or allow for horizontal permeability, in either a virgin condition or when subjected to mining-induced shearing. However, there is very little data available at present to validate the nature and extent of such water flow. Caution should therefore be exercised in moving to premature conclusions about this mode of water flow/loss, without further quality data and analysis being available to substantiate such claims. Any initiatives to gather such data is encouraged.

- The Panel also makes multiple references to the potential role of surface lineaments associated with zones of major structural disturbance as being potential sources of water loss, and also potential sources of increased subsidence effects. Reference is made to experience from the Western Coalfield (Springvale Mine), with an unsubstantiated observation that the increased subsidence seen at Springvale associated with lineaments might be repeated in the Southern Coalfield. Whilst this issue warrants further investigation, it is inappropriate to draw or even infer such connections in the absence of any reported evidence. The potential different mechanisms associated with the existence of the lineaments in the Western Coalfield, understood to be mechanistically driven by the very close proximity of the underlying Basin igneous rocks, needs to be carefully considered. Caution should be exercised in making assumptions about the impact of lineaments on either subsidence or groundwater flow in the Southern Coalfield until substantiating evidence is available.

Bruce Hebblewhite
19th February 2019

REFERENCES

Galvin J M (2016). *Ground Engineering. Principles and Practices for Underground Coal Mining.* Switzerland, Springer.

Galvin J (2017). Review of PSM Report on height of fracturing – Dendrobium Area 3B. Report to DPE, Feb 2017.

Independent Expert Panel for Mining in the Catchment (IEPMC) (2018). Initial report on specific mining activities at the Metropolitan and Dendrobium coal mines. NSW Office of the Chief Scientist and Engineer. Report to the NSW Department of Planning and Environment.

Mackie C (2017). Height of fracturing at Dendrobium Mine – Peer review of PSM Report for DPE, Feb 2017.

Mills K (2012). Observations of ground movements within the overburden strata above longwall panels and implications for groundwater impacts. 38th Symposium on the advances in the study of the Sydney Basin, Hunter Valley, NSW, Coalfield Geology Council of NSW.

NSW Dept of Planning (2008). Impacts of underground coal mining on natural features in the Southern Coalfield- Strategic review.

Parsons Brinkerhoff (2015). Connected fracturing above longwall mining operations, Part 2: Post-longwall investigation. Report 2172268F-WAT-REP-002 Rev 2, to BHP Billiton Illawarra Coal (March 2015)).

PSM (2017). Height of cracking – Dendrobium Area 3B, Dendrobium Mine. PSM Report PSM3021-002R, to DPE, March 2017.

APPENDIX A

Attached is a summary Curriculum Vitae for the author of this report, Bruce Hebblewhite. Bruce Hebblewhite has worked within the Australian mining industry from 1977 to the present time, through several different employment positions. Throughout this period, he has been actively involved in all facets of mining industry operations. In addition, he has visited and undertaken consulting and contract research commissions internationally in such countries as the UK, South Africa, China, New Zealand and Canada. For the majority of his 17 year employment period with ACIRL Ltd he had management responsibility for ACIRL's Mining Division which included specialist groups working within both the underground and surface coal mining sectors, and the coal preparation industry– actively involved in both consulting and research in each of these areas.

In his current employment position with The University of New South Wales, Bruce Hebblewhite is involved in academic management, undergraduate and postgraduate teaching and research, and contract industry consulting and provision of industry training and ongoing professional development programs – for all sectors of the mining industry – coal and metalliferous.

Both past and present employment positions require regular visits, inspections and site investigations throughout the Australian mining industry, together with regular contact with mining industry management, operations and production personnel.

<u>*Disclaimer*</u>
Bruce Hebblewhite is employed as a Professor within the School of Minerals & Energy Resources Engineering, at The University of New South Wales (UNSW). In accordance with policy regulations of UNSW regarding external private consulting, it is recorded that this report has been prepared by the author in his private capacity as an independent consultant, and not as an employee of UNSW. The report does not necessarily reflect the views of UNSW and has not relied upon any resources of UNSW.

SUMMARY CURRICULUM VITAE

Bruce Kenneth Hebblewhite

(Professor, Chair of Mining Engineering),
School of Minerals & Energy Resources Engineering, The University of New South Wales

DATE OF BIRTH 1951

NATIONALITY Australian

QUALIFICATIONS
1973: Bachelor of Engineering (Mining) (Hons 1) School of Mining Engineering, Univ. of New South Wales
1977: Doctor of Philosophy, Department of Mining Engineering, University of Newcastle upon Tyne, UK
1991: Diploma AICD, University of New England

PROFESSIONAL MEMBERSHIPS; APPOINTMENTS; AWARDS & SPECIAL RESPONSIBILITIES
Member - Australasian Institute of Mining and Metallurgy
Member - Australian Geomechanics Society
Member – Society of Mining and Exploration (SME), USA
Member - International Society of Rock Mechanics (President – Mining Interest Group (2004 – 2011))
Member - Society of Mining Professors (SOMP) (President for 2008/09; Secretary-General for 2011-2018)
SOMP Emeritus Member (from 2017)
Executive Director – Mining Education Australia (July 2006 – December 2009)
Chair, Governing Board – Mining Education Australia (2015)
Member, Branch Committee – AusIMM Sydney Branch (2017-2019)

Expert Witness assisting Coroner: Coronial Inquest (2002-2003): 1999 Northparkes Mine Accident
Chair: 2007-2008 Independent Expert Panel of Review into Impact of Mining in the Southern Coalfield of NSW (Dept of Planning & Dept of Primary Industries)
Expert Witness assisting NSW Mines Safety Investigation Unit – Austar Mine double fatality, April 2014.
Member (2012 – present): Scientific Advisory Board, Advanced Mining Technology Centre, Uni. of Chile.
Trustee (2013 – present): AusIMM Education Endowment Fund
2012 Syd S Peng Ground Control in Mining Award – by SME (USA).
2017 Ludwig Wilke Award for contribution to international mining research and education (Society of Mining Professors).
Member of Independent Expert Panel for NSW Dept of Planning – Woronora Reservoir Impact Strategy – Metropolitan Colliery (2017).
2017 SME Rock Mechanics Award – for contribution to education, research and consulting in the field of mining rock mechanics and ground control.
Member of the "Southern Coalfield" Independent Experts Panel, under the direction of the NSW Chief Scientist & Engineer. February – April 2018.

PROFESSIONAL EXPERIENCE

2014 – present	University of New South Wales, School of Minerals & Energy Resources Engineering Professor of Mining Engineering (p/t)
1995 - present	B K Hebblewhite Consulting Principal Consultant Mining Engineer
2003-2014	University of New South Wales, School of Mining Engineering Head of School and Research Director, (Professor, Kenneth Finlay Chair of Rock Mechanics (to 2006); Professor of Mining Engineering (from 2006))
2006 – 2009	Mining Education Australia (a national joint venture between UNSW, Curtin University of Technology, The University of Queensland & The University of Adelaide) Executive Director (a concurrent appointment with UNSW above).
1995-2002	University of New South Wales, School of Mining Engineering Professor, Kenneth Finlay Chair of Rock Mechanics and Research Director, UNSW Mining Research Centre (UMRC)
1983-1995	ACIRL Ltd, Divisional Manager, Mining - Overall management of ACIRL's mining activities. Responsible for technical and administrative management of ACIRL's Mining Division covering both research and consulting activities in all aspects of mining and coal preparation.
1981-1983	ACIRL Ltd, Manager, Mining - Responsibility for ACIRL mining research and commissioned contract programs.
1979-1981	ACIRL Ltd, Senior Mining Engineer - Assistant to Manager, Mining Research for administrative and technical responsibilities. Particularly, development of geotechnical activities in relation to mine design by underground, laboratory and numerical methods.
1977-1979	ACIRL Ltd, Mining Engineer Project Engineer for research into mining methods for Greta Seam, Ellalong Colliery, NSW. Also Project Engineer for roof control and numerical modelling stability investigations.
1974-1977	Cleveland Potash Ltd, Mining Engineer and Department of Mining Engineering, University of Newcastle-upon-Tyne, UK - Research Associate. Employed by Cleveland Potash Limited to conduct rock mechanics investigations into mine design for deep (1100m) potash mining, Boulby Mine, N Yorkshire (subject of Ph.D. thesis).

SPECIALIST SKILLS & INTERESTS

- Mining geomechanics
- Mine design and planning
- Mining methods and practice
- Mine safety and training
- Mine system audits and risk assessments
- Mining education and training