## 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:*
>
> o *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.<br>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.<br>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.<br>• p.128 – bullet 1.<br>• 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: |

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| | • p.130 – bullet 1.<br>• Exec Summary. | *The performance measures for surface flow losses are not explicitly related to materiality of flow losses, limiting the objectivity of performance evaluation.*<br><br>*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<br>• use of upstream-downstream flow differentials for TARPs on Wongawilli Creek. The opportunities for this sort of measure are limited.<br>• investigating accuracy of flow data, as well as of control-impact site comparison.<br>• Further updating the Dendrobium Mine AWBM (Australian Water Balance Model). |
| 6 | • p.128 – bullet 2.<br>• 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'.<br>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<br>• .p.91 – s4.6 | *….field investigations quantify the height of complete drainage at the Dendrobium Mine…*<br>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.<br>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<br>• 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. |

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| 10 | • p.128 – bullet 4<br>• 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.*<br>*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.<br>Illawarra Coal is currently undertaking investigations into geological structures (faults, shear planes) and lineaments around Area 3B and Lake Avon.<br>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.<br>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.<br>Groundwater ingress continues to be calculated from a detailed mine water balance.<br>'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.<br>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.<br>The next major revision of the Dendrobium groundwater model will rely on data from Dendrobium, BSO/Appin and Tahmoor mines. |

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| 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.<br>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. |

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| 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*.<br><br>*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.<br><br>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.<br><br>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.<br><br>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.<br><br>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 |

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| | | *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.<br>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<br>• 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.*<br>*"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<br>• 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".*<br><br>*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).**<br>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.<br>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. |

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| 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.<br>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<br>• 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<br>• 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.*<br>*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. |

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| 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.<br>• p.90 – s4.5.3 | *Why has the migration to MODFLOW-USG stalled?*<br><br>*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.<br>• MODFLOW-SURFACT (Coffey 2012).<br>• MF-SURFACT with unsaturated flow simulation (HydroSimulations, 2014).<br>• switched to MF-USG and Connected Linear Networks (CLN) in LW14 SMP (HS, 2016).<br>• continued MF-USG for LW16 SMP but removed CLNs (due to stability issues). (HS, 2018) (same for LW17 SMP (HS, 2019).<br>• The next major revision of the Dendrobium Mine model will use MF-USG with an unstructured mesh.<br>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.<br>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 |

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| | | | 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<br>• p.91 – s4.6 | *Continued migration to MODFLOW-USG should progress only if benefits can be demonstrated.*<br><br>#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:<br>• A code may provide features that allow more accurate or realistic simulation of specific boundaries or phenomena (e.g. fracturing); and<br>• A code may provide features that allow more efficient (faster) model runs, thereby allowing further analysis of predictive uncertainty.<br>• Keeping the model current (older versions of code may not be supported by the supplier or understood by younger staff).<br>Sometimes the benefits (or costs) are not fully apparent or proven until implemented.<br>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).<br><br>Some of the benefits of MODFLOW-USG are that it allows:<br>• Unstructured mesh (vertically and laterally).<br>• Removal of inactive cells from simulation/files.<br>• Distribution of runs across many computers<br>• The use of other packages (CLNs).<br>But there are costs in terms of:<br>• pre-processing unstructured mesh (especially SFR stream-flow routing). |

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| | | | • complex packages / familiarity / numerical stability (these also apply to MF-SURFACT).<br>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.<br>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.<br>• p.103 – s5.2.1.1.<br>• p.108 – s5.2.3.1.<br>• p.120 – s5.7.1 | *Comments regarding availability of higher accuracy gauging stations.*<br><br>*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.*<br><br>*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.<br>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. |

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| | | *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.<br>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.<br>• 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".*<br>*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<br>• 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 |

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| | | *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.<br>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.<br>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.<br>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.<br>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):<br>*"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). |

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| 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.<br>Furthermore, there has been consistent work since LW11 to improve model low-flow accuracy for all sites.<br>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.<br>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*<br>*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.<br>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.<br>For context, the modeller's experience is that DCU catchment flows are the most difficult to calibrate the AWBM model to.<br>Conclusions are based on changes between pre- and post-mining periods. Even where the conclusions have been that the TARPs are |

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| | | | 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:<br>• Transient environmental effects, i.e. slow propagation of mining effects.<br>• Transient weather conditions that may 'reveal' effects under different conditions.<br>• Changes to method of analysis, e.g. modelling, use of control sites.<br>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.<br>• 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"*<br>*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.<br>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 |

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| | | | groundwater model cannot cover the full catchment to all the nearby reservoirs. |

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