ATTACHMENT 5

Peer Review Letters

KALF AND ASSOCIATES Pty Ltd
Hydrogeological, Numerical Modelling Specialists

South32 – Illawarra Coal
Dendrobium Mine: Plan for the Future Application

KA Peer Review of HydroSimulations Groundwater Modelling Assessment

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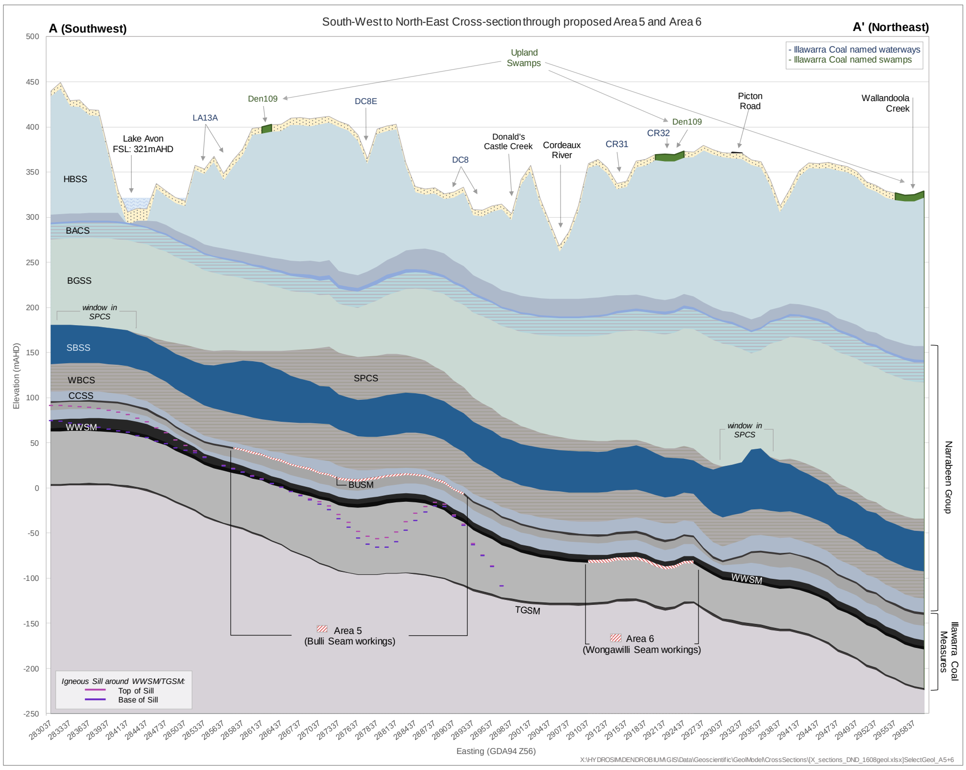
Background and Key Issues Summary

This report is the Kalf and Associates Pty Ltd (KA) peer review of the Dendrobium Mine groundwater and modelling assessment commissioned by Illawarra Coal (IC), a subsidiary of South32. The HS assessment report forms part of the application to the NSW Department for Planning and Environment (DPE) as part of the NSW State Significant Development assessment and determination process (i.e. Environmental Impact Statement – EIS).

Longwall mining has been conducted at Dendrobium since early 2005 and has included Areas 1, 2, 3A and 3B. This review report relates specifically to mining in Areas 5 and 6 (HS 2019 Figures 1-1,1-2) that also includes an intermediary Area 3C.

This KA report objective is to review the groundwater assessment and modelling completed as part background to seek approval for extraction of Longwalls in the future in Areas 5 and 6. Area 5 would extract coal from the Bulli seam up to the year 2038, whilst Area 6 would extract coal from the Wongawilli seam up to the year 2048, following mining of Area 3C.

Mining at Dendrobium occurs at depth within the Permian Illawarra Coal Measures (200 to 300m in thickness) within the Permian-Triassic stratigraphic geological sequence (HS 2019 Table 3-1 and Figure 3-1). The Coal Measures are overlain by a series of sandstone, siltstone and claystone units with thickness in the range 3m up to 100m and the Hawkesbury Sandstone typically 120m thick at the top of the sequence. A geological cross-section of the sequence illustrating the proposed seam extractions in Area 5 zone in the Coal Measures is given in HS (2019 SW-NE Section Figure 3-4 below and WE Section Figure 3-5) and an Area 6 in WE Section Figure 3-6. The section shown below indicates that Area 5 lies at a Depth-of-Cover ***(H)*** in the range 277m minimum to 398m maximum whilst in Area 6, ***H*** is in the range 374m minimum to 460m maximum. Contours of depth to proposed Bulli seams for Area 5 shown in HS (2019 Figure 3-7) and the Wongawilli seams for Area 6 in their Figure 3.8.



From Figure 3-4 HS (2019) SW-NE Section indicating extraction zones within Areas 5, 6

The seam cutting heights have over time increased although approval conditions (Condition 6, December 20 2016 SMP) has imposed a maximum future seam extraction height of 3.9m. Consequently in Area 5 the cutting height has been proposed at full seam height i.e. 3.2m and in Area 6 at 3.9m.

Longwall widths in Area 5 are proposed in the range 275m to 295m with void widths in the range 285m to 305m. In Area 6 the longwall widths are proposed at 295m and void widths at 305m (HS 2019 Table 1-7).

Modelling has included a number of separate scenarios for simulation in order to understand the response of the groundwater system to the proposed mining in Areas 5 and 6 and the separate and cumulative effects of Dendrobium areas as well as other mines in the region. A tabulation of these predictive scenarios is given in Table 8-1 (HS 2019).

A predicted mine inflow graph by area based on the calibrated base case scenario from 2005 to 2049 are provided in HS (2019) Figure 8-1. In summary, in Area 3B: maximum flow of 13 ML/day; Area 3A: 4 ML/day; Area C: 2 ML/day to 7 ML/day; Area 5: 18 ML/day maximum (2033 and in 2037), 12 ML/day on average; Area 6: 4 ML/day (2047), on average 3 ML/day.

Substantial differences of inflow between Areas 5 and 6 are due to total longwall area as illustrated by the graph shown in Figure 8-2 (HS 2019) indicating a linear relationship between inflow rate and mine footprint area (Correlation 0.98).

It has been determined, as part of the sensitivity scenarios for Areas 5 and 6 that two water supply works would incur a drawdown of greater than 2m drawdown for the 'Mean' estimate and 5m for the 'worst case', however these water supply works are predicted to experience greater than 2m drawdown from other mining operations irrespective of the Project (Table 9-2 HS 2019). Details are given in their Appendix L.

Leakage from the Cordeaux Reservoir has been determined to be 0.29 ML/day maximum (during 2050), 0.48 ML/day at the Avon Reservoir and 0.02 ML/day from the Nepean Reservoir due to the Dendrobium mining.

Water capture (i.e. 'take') from stream flow and storage (Sydney Basin South) is provided in Table 8-5 (HS 2019). Cumulative losses from the water supply catchments have been provided for the period 2000 to 2018 and 2018 to 2070 (Table 8-6 HS 2019).

Swamps deposits and their likely properties are discussed in Section 4.7.5 and Table 4-12. Groundwater dependent ecosystems are covered in Section 2.6. HS (2019) concludes *"The remote sensing data suggests that there is minimal potential for groundwater interaction across much of the study area (Figure 2.8)".*

The HS report has also noted the following regarding the presence or otherwise of shear planes that might exist near Lake Avon. *"Predictive modelling will include scenarios to test the sensitivity of model predictions to the (potential) presence of horizontal shear planes connecting the mine, goaf and reservoirs".* This sensitivity analysis is provided in HS Section 9.

Groundwater quality is outlined in their Section 4.5. Since 2004 3,200 water samples (that included surface water) have been analysed at the Dendrobium mine site. Groundwater salinity increases with depth in the geological sequence but the bulk of samples have a salinity less than 1500 mg/L (Figure 4-16) indicating a proportion of mine seepage having salinity in excess of 1500 mg/L (i.e. 2500 µS/cm).

Predicted groundwater levels are discussed and illustrated in various figures in Section 8.4 of the report, including hydrographs. Hydrographs are shown for Areas 5 and 6 respectively in Figures 8-4 and 8-5 together with specific explanations. In summary, drawdowns exceed 100m below the Bald Hill Claystone in Area 5 are predicted to reach pre-mine recovery in 2100. Drawdown up to 80m has been determined for the Hawkesbury Sandstone and 70m for the shallow watertable. Adjacent to the Avon dam wall (1000m west of Area 5 longwalls) drawdown of up to about 2m is predicted in the Upper to Middle Hawkesbury Sandstone and less in the overlying regolith.

In Area 6 drawdown in the Bulgo Sandstone is predicted to be between 140m to 180m with recovery over 50 years. Drawdown in the central Hawkesbury Sandstone above Area 6 is predicted to be 10m to 40m with somewhat higher drawdown in the lower part of that unit.

Groundwater contour maps are provided in various figures outlined in Section 8.4.2, 8.4.3 and 8.4.4 in the HS 2019 report.

Predicted losses from surface water during 2016 to 2018 are 10% to 20% of total mine inflow and average 15% by the end of mining in Area 3A. For Areas 5 and 6 the reduction in surface water flow is 25% of total mine inflow at the end of Area 6 peaking at 35% (HS 2019 Section 8.5). Details of flow reductions in key sub-catchments are listed in their Table 8-4. Leakage from reservoirs is outlined in their Section 8.6.

Peer Review Assessment

For this modelling review the available Modelling Guideline documents (NWC 2012, MDBC 2001) have been taken into consideration. A modelling appraisal checklist is provided herein as an Appendix that also has provision for a 'fit-for-purpose' at item 9.2.

Previous Studies and Reviews

The proposed mining area has had numerous assessments conducted that are listed in the reports references in Section 12 of the HS report.

Hydrogeological and Modelling Description

The hydrogeological description of the region and modelling work described in the HS (2019) report is detailed and comprehensive and contains a considerable volume of information. The report covers a wide range of topics that are included within 11 main section headings that deal with: Introduction; Topography, Climate, Drainage and Land Use; Geology and Resources; Hydrogeology; Hydrogeological Conceptual Model; Groundwater Model Development; Groundwater Model Calibration; Predictive Modelling and Impact Assessment; Sensitivity Analysis; Groundwater Monitoring and Quality Indicators as well as Conclusions, References and a Glossary.

There are also 12 Appendices dealing with: **A** Groundwater Monitoring Network at Dendrobium; **B** Spatial Variation in Horizontal Permeability from Packer Data; **C** Groundwater Level Hydrographs; **D** Relationships between Tritium and rainfall, Tritium and Mine Inflow; **E** Comparison of Seam-to-Surface Connectivity and Mine Geometry; **F** Model Stress Period Schedule; **G** Simulated Extent of Connected Fracturing and Surface Cracking; **H** Modelled Hydraulic Conductivity; Distributions; **I** Groundwater Model Calibration Hydrographs; **J** Model Confidence Classification; **K** Model Parameters for Deterministic Scenario Analysis; **L** Water Supply works predicted to be affected greater than 2m in drawdown.

Model Conceptualisation and Simulation Methods

HS have used the United States Geological Survey (USGS) MODFLOW-USG (USG) code as opposed to the well-known MODFLOW-SURFACT (MS) code because of the USG code's flexibility in representing non-rectilinear orientation and variable sized longwall panels including other geological features within layering configurations, as well as dealing more efficiently with layer 'pinch-outs' and conduits. The USG code also uses 'upstream weighting' similar to the 'pseudo soil' function in MS and therefore eliminating the need to define precisely the unsaturated/saturated properties of the media and avoiding variably saturation difficulties and consequent "dry cells".

Model conceptualisation is considered suitable as well as the model layering configuration. A total of 17 model layers were used with cell dimensions of 10m, 15m, 50m, and 60m up to 740m. There are total of 761,600 cells in the model, of which 698,211 are active, yielding a relatively high resolution model mesh. The model layer assignment (Section 6.5 HS 2019) with respect to hydrogeological units is set out in Table 6-1 in HS (2019). The model mesh resolution and layer assignment are considered suitable.

The role of 'Geological Structure' is outlined in their Section 4.7.3.

The boundaries chosen for the model area are also suitable. It is important to explain why that should be so in case there are concerns when assessing the current HS 2019 report at the Dendrobium site. There has been criticism elsewhere IESC (2018) about the placement of General Head boundaries based on the premise that these would not be required if the mine would not have direct influence on these boundaries. However, in the current South32 project this would misunderstand their purpose. Both constant heads and General Head boundaries are included in the model for representing inflow and outflow from the modelled area. They are included for completeness to represent the pre-mining flow of groundwater as it would occur in reality through the modelled area from the designated upstream inflow zone towards a downstream outflow zone with contours of head illustrated (Figures 4-10, 4-11 and 4-12). Hence mine drawdown need not affect these boundaries directly but any drawdown in such a situation would clearly receive inflow and hence underflow from the upstream boundary that could mitigate to some extent mine drawdown.

The 'River' type boundaries have been used to represent variable reservoir levels based on historical records. Watercourses, (i.e. rivers, creeks and un-named streams), were also modelled using 'river' (variable stream stage) boundaries rather than routing procedures in order to reduce simulation times, with variable stages based on runoff from the water balance model.

The model uses variable gross recharge as a percentage of rainfall and evapotranspiration as input and output respectively, which is suitable, rather than application of variable net recharge. Table 4-10 in the report indicates the various estimates made about recharge using different methods. The report has estimated recharge in the range 3 to 10% of the long term average rainfall which is plausible. Swamp area recharge is quoted in the range 25 to 30% which are a possible range of values. Evapotranspiration rates were set with extinction depths of 9m for deep rooted trees, 0.5 to 2m for swamps and 0.9 to 1.5m elsewhere.

Three different methods have been assessed to simulate mine extraction and subsequent free draining fractures zone above the caving zone (Section 6.9 HS 2019). The methods include:

1. Time-Varying hydraulic parameters
2. 'Stacked' drains
3. Connected linear Networks (CLN)

Of these 1 and 2 have been used in model application whilst CLN between cell boundaries is relatively new and largely untested and can be considered at present as a proxy and possible candidate although it needs to be tested in various environments.

Method 1 can, to a certain extent, be 'calibrated' with variable hydraulic parameters applied in the vertical direction based on piezometer pressure head response and inflow. The method utilises empirical linear (1D) regression equations of height of fracturing which has recently been criticised as not being entirely robust (Galvin 2017, MER 2017).

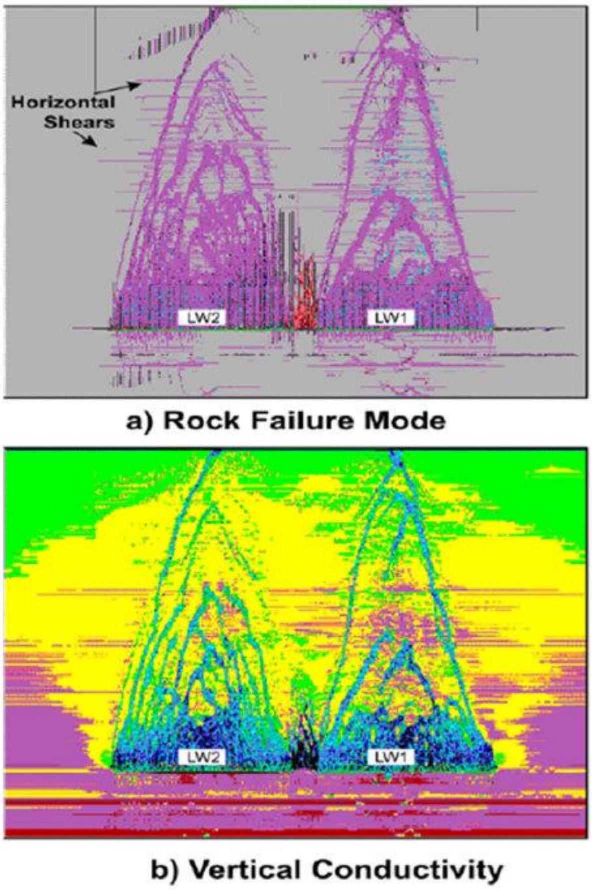
'Stacked' drains application includes setting up these above the mined out seam to a given height and are applied progressively but with changes in conductance to allow for porous media flow rather than fracture flow and other factors which are then allowed to drain as indicated by the model. HS (2019) reports that method 2 has been used largely because it provided better results for matching the 'peakiness' of Area 2 inflows and also was faster and with much improved stability. The stacked drains conductance was changed in order to match recorded inflow and to allow some control and reduction of fracture hydraulic conductivity in the vertical direction. Details are given in Section 6.9.1 in the HS report. KA has no objection to the use of this 'Stacked Drain' method as it has been used by MER for a number of years and has proved to be suitable. In addition it has been found on some projects by MER to overestimate the mining effects such as drawdown and overall inflow and therefore can be considered to be a conservative overall methodology for determining fracture propagation and associated draining in the geological profile.

The IESC (2018) document, in another coal project, has stated that USG groundwater modelling *"is incapable of realistically simulating groundwater responses to ground movement of strata."* While it is valid that USG modelling does not include simultaneous groundwater flow and geotechnical fracture simulation, it is incorrect to imply that USG groundwater modelling code cannot, based on other methods determine fracture propagation and drainage extent, in a conservative manner, within a geological profile. This is allowed by making use of the 'stacked drains' method together with an assessment of ***W/H*** ratios, seam cutting height and subsidence estimate that can provide a conservative approach that over time can be supported by ongoing monitoring.

For example the validity of the ***W/H*** methodology and other factors is illustrated by the following. In a previous KA review for Dendrobium in adjacent areas, it was determined that based on quite high width (of panel)-to-depth (of cover) (***W/H***) ratios that these were very likely indicating fracturing near to or at the ground surface. HS (2019) has now indicated that this conclusion is most likely valid in Areas 5 and 6 for all panel void widths of 305m that have yielded a ***W/H*** ratio of approaching a value of 1 (and greater than 1: KA)[1] and cutting height 3.2m to 3.9m (see Table 1-7 page 12).

HS (2019) has presented simulations previously conducted by SCT (2017, 2018b) using the geotechnical FLAC2D computer code to determine fracture propagation in Areas 5 and 6 (section 4.8.4). The conclusion from the report is that *"This modelling suggests that fracturing would extend from seam to surface in most of the cases modelled by SCT."* Results and additional explanations are provided in Appendix G (HS 2019) and representative results in their Figure 4-20 for the FLAC2D simulation a copy of which is shown below for Area 5. Similar results are presented for Area 6 in Figure 4-20 (HS 2019).

1 **Area 5 *W/H*= 1.15 Min; *W/H*=0.77 Max: Cut Height=3.2m**
Area 6 *W/H*= 0.82 Min; *W/H*=0.66 Max. Cut Height=3.9 m
All for void width= 305m. Min and Max refer to Depth of Cover.



From Figure 4-20 HS 2019. FLAC2D fracture simulation above caved zone.

Surface cracking has also been allowed for by HS (Section 6.9.2) including valley closure and floor strata modification factor. Surface cracking was simulated for the most part to a depth of 10 x the seam cutting height (see paragraph 2 page 78 HS 2019) with horizontal conductivity increase by a factor of 3 and vertical conductivity increased by 50%.

It is to be noted that the vertical fractures and vertical hydraulic conductivity shown, in the FLAC2D simulations, copied Figure 4.20 above, does not propagate upward at high elevations in a midway position and in a direct vertical direction above the panels shown, but in preferred directions along the edges of the parabolic fracture zones. It should also be noted that there is no horizontal fracture zone observed in these figures that are due to tensile forces that are typically 10 to 30m below the ground surface. It is understood that the FLAC2D code does not simulate these horizontal fractures (Gale KA pers. comm.). It is quite possible that in reality that the presence of the horizontal shallow fracturing zone would still allow in part flow downstream and likely re-emergence outside of the mining zone with a proportion of inflow migrating down to the mining zone through vertical fracture zone as depicted in HS Figure 4.20. It suggests further that the ‘stacked drains’ approach by HS would very likely capture most flow and therefore would indeed be conservative with respect to mine inflow.

For the remaining panels less than 305m wide the ‘conservative’ Tammetta equation has been used by HS. The validity of this 1D equation by regression to determine *“height of drainage/desaturation”* comes into question of what that might actually represent.

The Tammetta equation (Tammetta 2012) is given by:

$$H_d = 1438(\ln (4.315*10^{-5)} H^{0.2} T^{1.4} W + 0.9818) + 26. \qquad (1)$$

Where H_d is the height of desaturated zone, W longwall void width, H depth of cover and T seam cutting height (m). It is of interest what the Tammetta equation would produce for H_d for void widths of 305m rather than 285m since this latter depth only occurs in two instances (Table 1-7 HD 2019). These calculations indicate that for the minimum depths of cover the equation produces heights H_d within 1m to 3m of the surface while for the maximum depth of cover within 75m to 105m from the surface. Allowing for horizontal fracturing of 30m it indicates that surface cracking would extend to the surface for minimum depth of cover but approaching near to surface for maximum depth of cover in Areas 5 and 6.

Specific yield increase allowance in the HS simulation has also been accounted for in their report (Section 6.9.5).

The IESC (2018) document also makes numerous references to *'uncertainty'* regarding *"potential impacts"* that might occur in another coal project. It is important to recognise that only model uncertainty can be analysed but not true /field uncertainty (e.g. 'epistemological' uncertainty) as there would always be indeterminate local features and properties that would remain unknown (Caers 2011). This is the reason why it is important to conduct ongoing monitoring and review over time, as is often recommended by KA and authorities, over some period, usually every 3 to 5 years. The IESC in their 2018 report prefer long term case studies for comparison. However, this is in most cases impractical and idealistic and would never quite resolve the issue, therefore ongoing monitoring is much preferred.

Model Calibration and Prediction

Calibrated and modelled hydraulic parameters are presented in Table 7-1 (HS 2019). Steady-state simulation was used to set up initial conditions and was combined with transient runs in the HS model. Hydraulic parameters were based on measured values and those used in previous modelling studies of the mining site.

Manual calibration was used for the full simulation based on inflow from the Dendrobium mining areas 5 and 6 rather than a reliance only on piezometer pressure heads. It should be noted that inflow in any model simulation is directly proportional to transmissivity of the relevant water bearing geological units while piezometric heads are indirectly proportional to transmissivity. That is, inflows are far more sensitive to transmissivity than drawdowns are to transmissivity.

The different methods of simulating connective fracturing were also examined in some smaller sub models by HS.

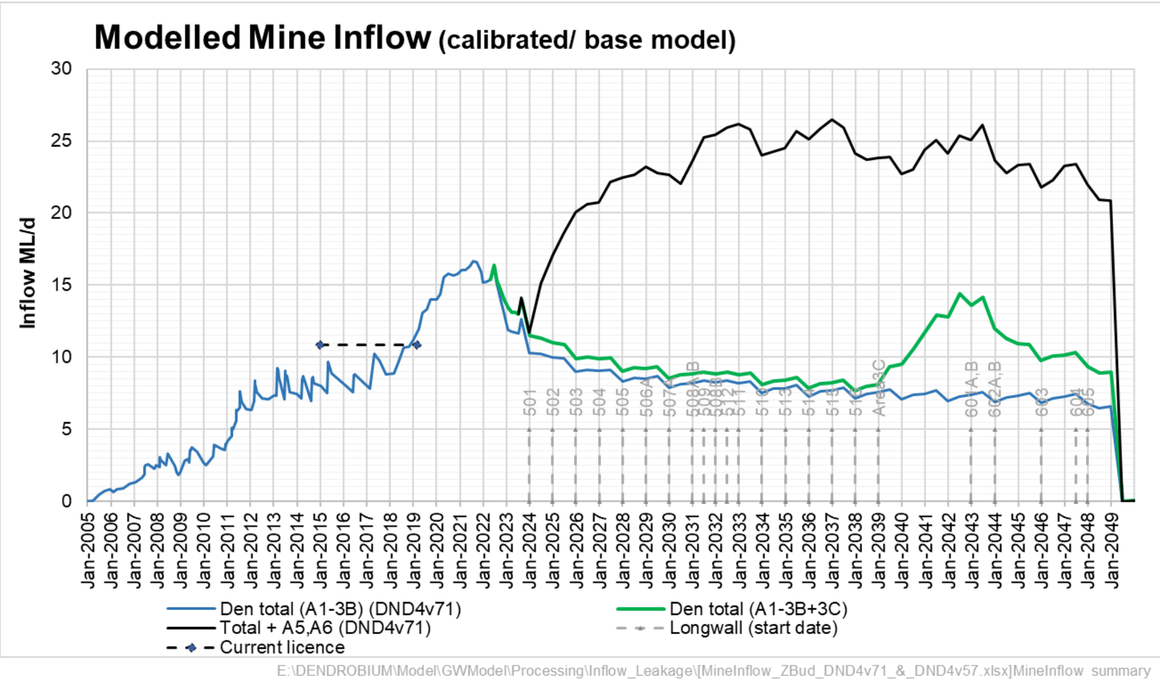
Calibration is discussed in HS 2019 in the following Sections 7.1.5 Groundwater levels; 7.1.6 Mine Inflow; 7.1.7 Baseflow; 7.1.8 Model Performance.

The total water balance for the calibrated simulation is presented in Table 7-2 in Section 7.1.4 for the period 1940 to 2018. Mine inflow constitutes close to 3.8% of the rainfall recharge according to the HS report.

Predictive Modelling and Impact Assessment

Predictive scenarios conducted to the year 2010 are provided in Table 8-1, Section 8.1. These include Full Impact; Baseline- Approved; Baseline- other mines, and Historical mining. The mining schedule is provided in Appendix F (HS 2019).

Mine inflow is summarised in their Figure 8-3 shown below and outlined in Section 8.3 (HD 2019).



From Figure 8-3 HD 2019

Groundwater levels and associated hydrographs for the full simulation at different times are discussed in Section 8.4.1. Drawdown influence within the geological profile has already been summarised above in the *'Background and Key Issues Summary.'*

Sensitivity and Uncertainty

HS (2019) have conducted *'Scenario Analysis'* using deterministic procedures that consisted of numerous computer runs as outlined in Table 9-1 with further details in their Appendix K. Given the scope and detail in the current report and simulations conducted this is considered to be adequate from a practicable point of view. Also it is evident that risk is low because HS have conducted a conservative approach and method in their fracture simulations that has been supported by geotechnical fracture modelling using the FLAC2D code. Hence the analysis has provided the important outcomes of determination of the maximum and minimum mine inflows as well as changes in the results based on variation of hydraulic parameters. These aspects are covered in their Sections 9.1, 9.2, 9.3 and 9.4.

Groundwater Monitoring

HS have provided details of groundwater quality objectives and in particular proposed management triggers for Areas 5 and 6 (Table 10-1 and Section 10). The issue of swamp monitoring is covered in Section 4.2.3 with further more detail regarding swamp responses over time with respect to mining influence in Section 4.3.3 and Table 4-3.

Conclusions and Considerations

The HS (2019) simulations and report reviewed herein, has provided considerable detailed information about the existing and proposed mining at the Dendrobium mine. The descriptions are comprehensive and simulations are considered to be more than adequate pending ongoing monitoring about model performance. The modelling described using the *'stacked drain'* approach is considered to be the most suitable for the *'full simulation'* and the additional options as outlined in the report (HS 2019).

Galvin (2017) has noted the following:
"Factors that influence the behaviour of the rock mass overlying an excavation include geology (e.g. composition of stratum, stratum distribution and thickness); the geomechanical properties of the rock mass (e.g. stratum strength and elastic modulus); pre-mining stress field; ***and, very importantly, panel width to depth ratio, W/H.*** *Consideration of panel width in isolation of consideration of the depth of the panel, and vice-versa, is important but 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.****"*** And ***"… the overlying strata extent caused by forming an excavation is strongly controlled by the ratio of panel width-to-mining depth, W/H."***

This straight forward determination and confirmation using the geotechnical FLAC2D simulations indicate that calculating the range of ***W/H***, plus taking into consideration the *'seam cutting height'* and any *'subsidence'* data is a very good approximation to determine the height of fracturing and possible desaturation in the geological profile. This can now be confirmed at Dendrobium by the geotechnical fracture modelling as conducted for Areas 5 and 6 in the HS 2019 report. It provides added confidence in the subsequent use of the USG Groundwater modelling code combined with the 'Stacked Drains' approach to obtain a practicable conservative determination of the mining influence on the groundwater and surface water systems and source of inflows. Those results plus ongoing monitoring or additional monitoring over a defined time period can provide verification of the above simulations and also deal with remaining drawdown and water source capturing uncertainty.

KA nevertheless supports continued further research by HS in assessing height of fracturing based on monitored mine inflow, pressure head profiles and making comparisons between the various modelling methods that give the best available estimates. However, despite the approaches used, the current methodology does contain remaining uncertainty that can only be resolved by those monitoring results from both deeper standpipe and multi-piezometer installations and measured inflow and shallow standpipe bore holes in the geological profile. It is clear that over time, ongoing monitoring and a re-evaluation of the modelling results will be required for both drawdown and inflow reported based on field mine inflow measurements. It is suggested that a review should be conducted every 3 to 5 years of the project outcomes and a re-evaluation of the model predictions that may be required.

References

Caers, J. 2011. *Modeling Uncertainty in the Earth Sciences. Wiley-Blackwell Pub.*

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SCT (2017) *Dendrobium Area 5 Pre-feasibility Study: Numerical Modelling Geotechnical Assessment of Bulli Seam Longwall Caving (Draft). Report 324671, December 2017.*

SCT (2018b) *Overburden Hydraulic Conductivity Assessment: Dendrobium Area 6. Report STH324727, March 2018.*

Tammetta, P. 2012. *Estimation of the Height of Complete Groundwater Drainage Above Mined Longwall Panels. Groundwater Journal, National Groundwater Association.*

Appendix
Model Appraisal

	ISSUES	Not applicable or Unknown					COMMENTS
1.0	**THE REPORT**						
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very good	
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes		
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very good	
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very good	
1.5	Are the model results of any practical use?			No	Maybe	Yes	
2.0	**DATA ANALYSIS**						
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very good	
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very good	
2.3	Has all relevant potential recharge data been collected and analysed?		Missing	Deficient	Adequate	Very good	
2.4	Has all relevant potential discharge data been collected and analysed?		Missing	Deficient	Adequate		
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very good	
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes and inflow	
2.7	Have consistent data and standard elevation units been used?			No	Yes		
3.0	**CONCEPTUALISATION**						
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	Yes	
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	Very good	
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very good	
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No		
4.0	**MODEL DESIGN**						
4.1	Is the spatial extent of the model appropriate?			No	Maybe	Yes	
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very good	
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes	
5.0	**CALIBRATION**						
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very good	
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very good	
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very good	
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes	
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very good	

5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very good	Performance criteria have been met
6.0	**VERIFICATION**						
6.1	Is there sufficient evidence provided for model verification?		Missing	Deficient	Adequate	Very good	To be determined by ongoing monitoring and review over time.
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?		Unknown	No	Maybe	Yes	
6.3	Are there good reasons for an unsatisfactory verification?		Missing	Deficient	Adequate	Very good	All data used for calibration. Verification dependent on monitoring of previous LW results
7.0	**PREDICTION**						
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very good	Climate change variability low and high rainfall
7.2	Have multiple scenarios been run for operational management alternatives?		No	Deficient	Adequate	Very good	Multiple scenarios have been run to better define outcomes
7.3	Is the time period for prediction comparable with the duration of the calibration period?		Missing	Greater than	Similar to	Less than	
7.4	Are the model predictions plausible?			No	Maybe	Yes	
8.0	**SENSITIVITY ANALYSIS**						
8.1	Is the sensitivity analysis sufficiently intensive for key parameters/		Missing	Deficient	Adequate	Very good	Sensitivity limited to different scenarios, modelling methods and previous models
8.2	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Very good	Sensitivity limited to different scenarios, and modelling methods
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very good	Sensitivity limited to different scenarios and modelling methods
9.0	**UNCERTAINTY ANALYSIS**						
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Adequate	Yes	Only in the sense of alternative scenario simulation and previous model results
9.2	**Is the model 'fit-for-purpose'?**			No		Yes	

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Dear Mr Brassington

I have completed my assessment of the Dendrobium Mine Plan for the Future Surface Water Assessment Draft Report prepared for South 32 by Hydro Engineering & Consulting Pty. Ltd. and my comments are set out below. My review consisted of reading and commenting on the draft Report Revision (c) and subsequent revisions d (26/03/2019), e (29/03/2019), f (01/04/2019) and g (06/05/2019). Based on my reading and studying the Report, I recommended a number of changes, and I can confirm that all these have been appropriately addressed by the Consultant. The Report consists of nine Sections (the last is a set of References) plus an Appendix.

Following a brief introduction to the Project, Section 1 includes the Secretary's Environmental Assessment Requirements for the Project. These are listed in an extensive Table 1, and, as far as I can ascertain, in regard to the Report all these requirements have been dealt with. (I have not checked those listed as being addressed in the EIS.)

Baseline hydrology including water quality in the Project Area is detailed in Section 2 under the following headings of Climate, and of Catchments and Surface Water Resources. Climate is described by average monthly maximum and minimum temperatures and mean conditions of wind speed and relative humidity based on four Bureau of Meteorology (BoM) stations located near the Project Area. Rainfall is described by monthly averages estimated from the Scientific Information for Land Owners (SILO) Data Drill and eight regional BoM stations. Average monthly Class A pan evaporation data were also available from the SILO data set. The data showed that the average annual rainfall and evaporation were of similar magnitude and average monthly evaporation exceeded average monthly rainfall for August through to January, and average rainfall exceeding evaporation for the remainder of months.

Section 2.2.1 provides an overview of the study area within the Avon and Cordeaux catchments including the two proposed future underground mining areas: Area 5 is located above the proposed underground mine of the Bulli Seam, and Area 6 located above the proposed underground mine of the Wongawiili Seam. The surface geology and vegetation are summarised along with a discussion of the allocation of surface water resources in the area. Water quality objectives for the study area are also described in terms of the ANZECC (2000 and 2018)

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Guidelines, the Australian Drinking Water Guidelines (2011) and the Healthy Rivers Commission (HRC) Guidelines (1998).

The remainder of Section 2 discusses a range of hydrology and water quality related details separately for Areas 5 and 6 catchments. Following a general description of the Area 5 (Section 2.2.3.1) and Area 6 (Section 2.2.4.1), the Report provides streamflow characteristics in terms of catchment area, stream order and stream gradient and length for each area (Sections 2.2.3.2 and 2.2.4.3). This is followed by flow characteristics, which were based on field stream gaugings (Sections 2.2.3.2 and 2.2.4.2). At this point in time there is insufficient data to provide estimates of mean flows at the gauged sites. (There are six and two stations associated with Areas 5 and 6 respectively.) Details about water quality follows with field data being discussed in Sections 2.2.3.4 and 2.2.4.4 and laboratory analysis results being discussed in Sections 2.2.3.5 and 2.3.4.5.

The final section in the Baseline Hydrology description (Section 2.3) provides background data on 36 Coastal Upland Swamps including swamp area, catchment area, longitudinal length of swamp and average surface longitudinal slope.

I consider the information in Section 2 of the physical features of the Mine site and Areas 5 and 6 as an adequate background to assess the Plan for the Future Surface Water Assessment that follows in this Report.

The proposed water management of the surface water facilities is discussed in Section 3 under three headings: existing situation, proposed changes, and simulated performance of proposed water management system. Section 3.1 of the Report describes the water management operations at the Dendrobium Pit Top, the Kemira Valley Coal Loading Facility, the Dendrobium Coal Preparation Plant, the West Cliff Stage 3 Coal Wash Emplacement, the ventilation shafts, Dendrobium Mine underground operations, and at the Cordeaux Pit Top. The proposed changes are outlined in Section 3.2 and include management of surface runoff in Areas 5 and 6 associated with the ventilation shafts in the form of sediment dams, managing the groundwater inflows to the underground workings expected to increase to 26.1 ML/day in 2036, and duplication of the existing LDP5 pipeline.

Section 3.3 discusses the daily water balance model that simulates the proposed water management system as displayed in Figure 14. The water balance is based on 129 years of data, thus providing 129 separate but over-lapping 29 years alternative sequences representing the period from January 2020 to December 2048. Inflows to the model included runoff, groundwater and Sydney water supply. Groundwater accounts for 98.3% of the inflows and runoff is a little more than 1%. The latter is estimated using the Australian Water Balance Model (AWBM) from rainfall and potential evaporation, in which parameters were based on experience in other projects, which is appropriate given the minor influence runoff has on the overall water balance. The major outflows from the model are the Kemira Valley Tank Discharge to LDP5, which accounts for 95.1% of the outflow, and the water entrained in the ore accounts for an additional 3.3%. The other components are evaporation, blackwater to sewer, underground ventilation net loss, dust suppression, sediment pond pit overflows to LPD 22 and LPD 23 accounting all together for 1.6% of the outflows. I agree with the approach taken to simulate the performance of the proposed water management system under a range of climatic conditions.

In Section 4, the effects of the longwall mining on surface water resources are discussed. Following a brief summary in Section 4.1 of the monitored and observed effects of subsidence of longwall mining on surface water resources in the Southern Coalfields, the monitored and observed effects at Dendrobium are discussed in Section 4.2. There are four sub-sections dealing with Past Longwall Mining Under or Near Lake Cordeaux, Past Longwall Mining Under or Near Kembla Creek, Past Longwall Mining Under or Near Wongawilli and Native Dog Creeks, and Past Longwall Mining Under or Near Donalds Castle Creek and Wongawilli Creek. The material presented in Section 4 is background information that provides the setting for Section 5 which discusses subsidence predictions and assessment of potential impacts to surface water resources.

Section 5.1 outlines the key features of the mine layout which were designed to reduce the potential impacts of the longwall mining on the major streams and associated stream features (Section 5.1.1). Predictions of subsidence, upsidence and closure are summarised for the rivers and named creeks, unnamed streams and upland swamps in Areas 5 and 6.

To assess the potential impact on the hydrology and on the water balance of the undermined upland swamps, a major modelling exercise was undertaken using the VADOSE/W model which is a finite element, two-dimensional unsaturated/saturated groundwater seepage model. Although I'm not familiar with the model, the following web site indicates the model has been applied widely and reviewed on a number of occasions:
https://scholar.google.com.au/scholar?hl=en&as_sdt=0%2C5&q=Vadose%2FW+model&oq
The VADOSE/W model appears to be a suitable model to assess the impact of the proposed Project on horizontal and vertical drainage beneath the potentially affected swamps and I am satisfied with the adopted values of the model parameters. Figure 25 provides confidence that the model is performing satisfactorily. Application of the model to swamp hydrographs with and without the Project are provided in Figures 26 to 37. I concur with the conclusions set out in Section 5.2.1.2.

A second major modelling task, which was undertaken as part of the hydrological modelling exercise to assess the impact of subsidence on streamflow in the catchments in the Project areas, is described in Section 5.2.2 and following sub-sections. The procedure required two modifications to the AWBM model which were to account for (i) the non-swamp deep drainage using drainage estimates provided by HydroSimulations (2016) (ii) the swamp seepage losses due to changes in horizontal and vertical drainage from predicted subsidence as a result of the Project. I am satisfied with the adopted modelling approach, and the changes to the AWBM model. Based on these simulations, the Report concludes that under a median climate there is "… an immeasurably small and likely indiscernible impact to Lake Avon inflow" and "… an immeasurably small and likely indiscernible impact to Pheasants Nest Weir inflow". The estimated reductions are approximately 0.49% (1.1 ML/day) and 0.47% (2.8 ML/day) respectively for Lake Avon and Pheasants Nest Weir. Based on my experience of uncertainty estimates in stream gauging and in water balance analysis, the values are not within the accuracy band that can be measured in the field or by water balance analysis and, in my judgement, are not statistically different from zero.

Section 5.3 deals with an assessment of swamp stability. Based on my limited experience in the area of erosion and landscape degradation analysis, I am satisfied with the approach adopted and the conclusions that follows. I also concur with the observations made with respect to water quality assessment provided in Section 5.4.

Section 6.0 addresses the requirement to demonstrate that the Project satisfies the neutral or beneficial ‘test’ required for all development in the Sydney Drinking Water Catchment. Based on the evidence presented in the Report, I believe the criteria have been met.

Stream remediation options and works as applied by Illawarra Coal and at other operations are addressed in Section 7.0.

The final section (Section 8) deals with monitoring. I note the recommendations to continue and expand the current monitoring programme within and adjacent to Areas 5 and 6. I concur with these recommendations.

In summary, I conclude that, overall, the study detailed in the Dendrobium Mine Plan for the Future Surface Water Assessment Draft Report was completed in a professional and detailed manner, and the conclusions in the Report are appropriately supplemented by suitable modelling studies carried out by the consultant.

Yours sincerely

T.A. McMahon
16 May 2019