ATTACHMENT D: ADDITIONAL INFORMATION REQUESTED BY DPI - WATER

> *It is recommended that Illawarra Coal firstly provide updated modelling to indicate the volumes of water taken from the surface water source, and then liaise with DPI Water to determine how best to account for this take.*

In 2016 Hydrosimulations conducted an assessment of potential take from watercourses at Dendrobium (Attachment G).

The take has been calculated based on a number of zones, which are defined by the Water Sharing Plan (WSP) for the Greater Metropolitan Region Unregulated River Water Sources 2011. Specifically, the relevant zones are, as described in the WSP:

- Avon River Management Zone, which does not include the storage of Avon Dam;
- Cordeaux River Management Zone, which does not include the storage of Cordeaux Dam; and
- Upper Nepean River Tributaries Headwaters Management Zone which includes the storages of Cataract Dam, Cordeaux Dam and Avon Dam.

The ZoneBudget mass balance software (Harbaugh, 1990) was run on the MODFLOW budget files to extract the simulated stream leakage and baseflow for each zone and for each predictive run. The results were than aggregated into 'water years'.

Attachment G assesses the net loss of baseflow in watercourses and the induced leakage from the storages.

The peak expected loss from Wongawilli Creek of up to 165 ML/a (0.44 ML/d) is approximately 1.5-2% of average flow.

The predicted losses from the Wollongong Coastal of 40ML/a are higher than expected given the amount of historical mining that has occurred between Dendrobium and the escarpment, however because Dendrobium is a longwall mine and most of the others, except Elouera/Wongawilli, are not, it may be that the operations of Dendrobium depressurise shallower strata that have been only minimally affected by earlier mining.

Illawarra Coal met with DPI Water 5 February 2016 to discuss subsidence impacts in the context of surface water take. DPI Water indicated that they would write to Illawarra Coal indicating their requirements. It was agreed that Illawarra Coal would supply a revised and updated groundwater model (Attachment G).

> *Comments from DPI Water Hydrogeologists are provided and contain background and analysis. The recommendations are presented below:*
>
> *The following recommendation is made.*
>
> *After reviewing the Hydro Simulations Memo (13/10/15) above DPI Water has concerns about the Ditton "Geology model" outlined by Ditton-Merrick (2014) not providing any margin for error in estimating the thickness of connected fractured zone. In order to resolve the above*

issue it is recommend that a detailed assessment of risk needs to be undertaken by an independent reviewer prior to approval of further mining of longwall panel 14-19.

In 2016 Hydrosimulations conducted an assessment of the height of connected fracturing above the seam at Dendrobium (Attachment G).

The extents of mining-induced fracture zones are dependent on a number of factors including the thickness and geology of the overburden material and the dimensions of the longwall.

Tammetta (2013) refers to a zone of 'Complete Groundwater Drainage' or 'Collapsed Zone', taken to be where the pressure head falls to zero (corresponding to the Ditton AA and A Zones), and a saturated Disturbed Zone (corresponding conceptually to Ditton's B Zone). Both models have a continuous fracture zone that is arched in cross-section.

Both authors have found a relation between the height of some representation of the "fracture zone" and three key attributes of the mining system:

- mining height [T (Ditton) or t (Tammetta)];
- cover depth [H (Ditton) or h (Tammetta)]; and
- longwall panel width [W (both authors)].

Ditton (2012 and then Ditton and Merrick, 2014) presents two semi-empirical formulas. The first "geometry" model uses only the parameters described above. The second, "geology" model includes a term to account for the integrity of a spanning roof block (effective spanning thickness, t').

The Ditton formulas for fractured zone height (A) for single-seam mining (Ditton and Merrick, 2014) are:

- Geometry Model: A = 2.215 W'0.357 H0.271 T0.372 +/- [0.16 - 0.1 W'] (metres)
- Geology Model: A = 1.52 W'0.4 H0.535 T0.464 t'-0.4 +/- [0.15 - 0.1 W'] (metres)

where W' is the minimum of the panel width (W) and the critical panel width (1.4H).

The 95th percentile A-Zone heights are estimated by adding aW' to A, where a varies from 0.1 for supercritical panels to 0.16 (geometry model) or 0.15 (geology model) for subcritical panels.

The Ditton models have been validated to 35 measured Australian case-studies (including Tahmoor, Dendrobium, Metropolitan, West Wallsend, Newstan, Mandalong, Springvale, Able, Ashton, Austar, Berrima, and Wollemi/North Wambo Mines) with a broad range of mining geometries and geological conditions included.

Several studies have been undertaken at Dendrobium Mine to assess the existing fracture height above mined longwalls in order to identify and calibrate the predictive height of fracturing model used. These studies present evidence in support of assumptions regarding the height of fracturing above longwalls at Dendrobium Mine.

In order to constrain estimates for heights of connective fracturing and the mechanisms for inflow to the mine, Hydrosimulations looked at the following sets of monitoring data:

- Groundwater pressure drawdown in response to mining.

- The Dendrobium Mine water balance, which provides an estimate of groundwater flow into each of the mining areas (1, 2, 3A and 3B).
- Chemical fingerprinting of various water sources which provide information on the origin of mine inflow waters.
- Available research, including the Longwall 9 height of connective fracturing research.

Together, these various lines of evidence support a model in which mine-related fracturing and depressurisation do not propagate to the surface and there is no evidence for rapid surface-to-seam water pathways. Significant depressurisation is apparent above longwall panels, extending to about the mid to upper part of the Bulgo Sandstone (in Area 3A), and locally to the lower part of the Hawkesbury Sandstone in Area 3B (Attachment G).

The groundwater pore pressure in deep formations is monitored using VWPs. The Tammetta's (2013) study on the height of fracturing above longwall mines used this approach to identify the height above the longwall goaf at which the pressure effectively dropped to zero (atmospheric pressure), indicating free drainage within a vertically connected fracture zone (analogous to the 'A' zone).

Hydrosimulations reviewed the pressure responses in the vicinity of the mine to identify the height of "significant depressurisation" above mined panels at Dendrobium Mine.

The main conclusions from this assessment are:

- There are numerous 'little or no depressurisation' points below the calculated Tammetta H level, which is conceptualised as the height of complete groundwater drainage. This suggests that the Tammetta (2013) method overestimates the height of complete drainage at Dendrobium Mine.
- The majority of points that indicate either "some" or "significant" depressurisation plot below the Ditton A 95th percentile line. However, some points plot above this line, particularly for Longwall 6 and beyond.

Possible reasons why the Tammetta (2013) H heights consistently over-estimate the heights of groundwater depressurisation at Dendrobium are:

- The database used by Tammetta (2013) did not cover the area for which we now have data (particularly Area 3B);
- There may be differences in interpretation of data in respect of what constitutes depressurisation. In the Hydrosimulations study "significant depressurisation" refers to a decline in pressure equivalent to 25 m head or more over a period of a year (including decline of pressure head to zero). It is therefore conservative with respect to "complete depressurisation".

Groundwater inflow to the underground mine cannot be measured directly, but is inferred via a detailed daily water balance for each of the four Dendrobium Mine areas.

Analysis of the inflow to each mine area shows:

- Area 1: a mild correlation with the rainfall trend but not with individual rainfall events.

- Area 2: a clear correlation with high rainfall events (>200 mm across 1-2 days).
- Area 3A: During active mining, groundwater inflow increases linearly with time and the cumulative area mined. Following the completion of Longwall 8, the rate of inflow has an apparent correlation with rainfall trends, but not clearly with individual rainfall events.
- Area 3B: There is no apparent correlation between residual or daily rainfall and mine inflow. As with the active mining phase in Area 3A, the mine inflow rate in Area 3B is most strongly correlated with the cumulative area mined, and to a lesser extent, the rate of mining.

Hydrosimulations conducted an assessment of water fingerprinting and provenance at Dendrobium Mine (Attachment G). Water quality results and interpretation from surface waters, shallow and deep groundwater and from the underground mine workings and goaf are reported monthly to Government.

Na/Cl ratio (as an indicator of major ion water chemistry) and tritium from each water source has a distinct character. Mine seepage has a composition that is consistently distinct from surface water (having an elevated Na/Cl ratio and low tritium), but is most similar to deep groundwater from the Bulli Coal Seam. Additionally, mine inflow water typically has an electrical conductivity of 800-3000 µS/cm (brackish), whereas surface water is typically fresh (<100 µS/cm).

The mine water chemistry provides a powerful natural tracer for water samples. The Hydrosimulation study concluded the following:

- Mine water is predominantly, if not entirely, comprised of groundwater from the coal seams and deep sandstone formations.
- Mine water and surface waters have distinct characteristics and mine waters do not display intermediate compositions that would indicate mixing of groundwater with a significant component of surface water.
- Due to the natural variability in tritium levels in surface and groundwater, it is not possible to rule out a small component of surface water ingress.
- There is no significant correlation between inflow rate and chemical parameters such as EC, Na/Cl and tritium content. Peaks mine inflow at Area 2 can therefore not simply be attributed to surface water inflow.

Estimates of mine inflow clearly show some correlation with rainfall trends. The correlation is distinctly related to high rainfall events for Area 2, whereas other areas show a weaker and broader correlation with cumulative residual rainfall trends. These correlations suggest a mechanism whereby mine inflows that are higher than a nominal baseline are driven by elevated piezometric heads, which in turn are caused by high net recharge compared with long term discharge from the aquifer systems.

The data do not imply a direct link between the surface and the mine. The consistency of water chemistry parameters in mine waters such as tritium, EC and Na/Cl indicates that mine inflows do not contain a significant surface water component, and high inflows cannot simply be explained by a proportional increase in surface water ingress. The data do not allow us to rule out any surface water contribution because very small fractions of surface water (<10%) may not be apparent given the limits of precision and the natural range in source compositions. However, it can be concluded that there is apparently no direct and rapid pathway between the surface and the goaf. Otherwise the changes in tritium and EC would be noticeably greater. The same conclusion was reached by Parsons Brinckerhoff (2015) in a study that showed that potassium salt and dye tracers injected into the Hawkesbury and Bulgo Sandstones directly above longwall 9 were not detected in goaf waters, even up to six months after the test.

> *After reviewing the Hydro Simulations Memo (13/10/15), DPI Water suggests that the estimate of H (height of fracture drainage) by Ditton method does not allow sufficient margin of error for proposed mining. The H values above the Longwall may get very close to significant water assets. In the event if the actual fracturing is about 20% more than that was predicted, there is a possibility that fracture may reach the bottom of a water asset above.*
>
> *Of note the current mining area 3b has shown a number of impacts with some rivers beds having cracked and lost surface flow and shallow groundwater associated with wetlands drying up. The impacts on the rivers and baseflow should be minimised as much as possible in the vicinity of two nearby water storages of the Avon and Cordeaux. Therefore, DPI Water recommends detailed sensitivity analysis of H, using the numerical model to assess potential risks, prior to further mining of longwall panels 14-19.*

Hydrosimulation used the Dendrobium Area 3B Regional Groundwater Model (Attachment G) to undertake predictive modelling of the mine plan for Area 3B. In order to assess the effects of the proposed Longwalls 14-19 a number of predictive scenarios have been applied, including different estimates of the height of connected fracturing, i.e. the Ditton and the Tammetta models.

The predictive runs had overall mass balance errors of ~0.3% which is acceptable based on the recommended threshold of 1-2% of Barnett et al (2012).

The predictive runs simulated leakage from the reservoirs to groundwater, including leakage due to all mining activities, the simulated leakage from Longwalls 14-19 and the simulated leakage from all mining assuming connected fracturing to the Tammetta (2012) H height.

The maximum cumulative leakage from Lake Avon ranges from 0.55 ML/d (Ditton method) to 0.63 ML/d (Tammetta method). The maximum leakage due to Dendrobium only is about 0.39 ML/d (Ditton) to 0.47 ML/d (Tammetta). The maximum leakage due to Longwalls 14-19 is approximately 0.2 ML/d (Ditton) and 0.3 ML/d (Tammetta). All of these predicted rates of loss are less than 1 ML/d, which is the prescribed tolerable limit.

The model over-estimates the degree and speed of drawdown due to mining in the Hawkesbury and Bulgo Sandstones in this area and this means that the model is likely conservative in estimating the amount of leakage from the reservoir.

The simulated maximum cumulative leakage from Lake Cordeaux was predicted to be 0.32 ML/d. Of this, about 0.12-0.16 ML/d is from Dendrobium Mine (assuming Ditton or Tammetta method height of fracturing). The leakage due to Longwalls 14-19 is minimal, at about 0.01 ML/d. This is due to the distance between those longwalls and the Cordeaux Reservoir.

The model over-estimates the degree and speed of drawdown due to mining in the Bulgo Sandstone in this area and this means that the model is likely conservative in estimating the amount of leakage from the reservoir.

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> *Any future approval that might be granted for longwalls 14-18 (Area 3B) and longwall 19 (Area 3A) should include a requirement for the revision of the existing Groundwater Management Plans for both Areas 3A and 3B in the first instance to recognise the provisions of the NSW Aquifer Interference Policy and the Groundwater Monitoring and Modelling Plans – Information for prospective mining and petroleum activities.*
>
> *The proponent should be required to undertake ongoing regular review of relevant Groundwater Management Plans to encourage adaptive management by the operator, and improve monitoring and reporting arrangements. Such a requirement should include the following considerations:*
>
> *Reporting of all groundwater-related data quarterly to a dedicated website (to be maintained by the operator) in downloadable spreadsheet format or otherwise in accordance with the Integrated Mining Policy Web-based Reporting Guideline.*
>
> *Measurement of all surface water diversions from affected creeks to shallow groundwater systems and measurement of any return discharge to watercourses.*

Annual reporting of the groundwater take volumes and surface water diversion volumes to a dedicated website (to be maintained by the operator) in downloadable spreadsheet format or otherwise in accordance with the Integrated Mining Policy Web-based Reporting Guideline.

Amendments to the Groundwater Management Plans for both Areas 3A and 3B to reflect the requirements of the NSW Aquifer Interference Policy.

Amendments to the Groundwater Management Plans for both Areas 3A and 3B to align with the guidance provided by Groundwater Monitoring and Modelling Plans – Information for prospective mining and petroleum activities.

Ongoing formal review of the Groundwater Management Plans for both Areas 3A and 3B in consultation with DPI Water on an annual basis.

Additional specific requirements as advised by DPI Water in alignment with the recommendations of the independent expert review of the numerical modelling approaches and databases used in the prediction of mining-related impacts.

The Dendrobium Area 3B SMP was submitted to DoPE 4 October 2012 in accordance with Schedule 3, Conditions 7 and 8 of the Dendrobium Mine Development Consent. The SMP included a Groundwater Management Plan prepared in accordance with the Dendrobium Consent and in consultation with relevant stakeholders. The aims of the program are to:

- Monitor groundwater levels and quality.
- Identify hydraulic characteristics of overlying and intercepted groundwater systems, and determine changes to groundwater systems due to coal extraction and dewatering operations.
- Report any pumping tests and groundwater/surface water simulation studies.

The monitoring requirements of the Groundwater Management Plan are generally consistent with the SCA's 'The Design of a Hydrological and Hydrogeological Monitoring Program to Assess the Impacts of Longwall Mining in SCA Catchment'.

Reporting of the updated Dendrobium Regional Groundwater Model (Attachment G) recognises the provisions of the NSW Aquifer Interference Policy and the Groundwater Monitoring and Modelling Plans – Information for prospective mining and petroleum activities.

The Dendrobium Area 3B SMP submitted to DoPE 4 October 2012 included a WIMMCP prepared in accordance with the Dendrobium Consent and in consultation with relevant stakeholders.

The WIMMCP (Attachment O) includes flow monitoring sites installed downstream of the mining area to assess any changes in surface flow from a catchment resulting from the mining. Due to the general requirement to not install V notch weirs or other large artificial flow controls within the catchment areas, the sites are predominately installed using natural flow control features such as rockbars.

For this reason, the monitoring program focuses largely on recessional, baseflow and small storm periods where the flow data is of sufficient quality i.e. lies below the upper limit of validity of the rating curve. The downstream monitoring sites are specifically designed to answer the question: do diverted flows within the surface fracture network return to the surface downstream of the mining area.

In accordance with Condition 11, Schedule 8 of the Development Consent, approved Groundwater Management Plans, Regional Groundwater Model and WIMMCP are publicly available on its website: http://www.south32.net/home.

Annual reporting of groundwater and surface water monitoring results will be through established mechanisms required by the Development Consent, including the Dendrobium Annual Environmental Management Report (AEMR) required under Condition 5, Schedule 8, which is available on the South32 website. Groundwater and surface water data can be shared subject to an agreed data sharing arrangement.

The Dendrobium Mine Environmental Management Strategies, Plans and Programs, including the Groundwater Management Plan and WIMMCP are developed to comply with legislative, corporate and ISO14001 Certification standards. The Groundwater Management Plan and WIMMCP are subject to regular auditing and review.

Auditing and review includes the use of internal and accredited external auditors. In addition, regular audits are undertaken to maintain certification under the ISO14001 standard. The Dendrobium Groundwater Management Plan and WIMMCP are included within the scope of the audit program and ISO14001 Certification.

The Dendrobium Groundwater Management Plan and WIMMCP are subject to an Independent Environmental Audit every 3 years, in accordance with Condition 6, Schedule 8, of the Dendrobium Development Consent.

In accordance with Condition 8, Schedule 8, of the Dendrobium Development Consent, within three months of submitting the audit report to the Director-General, the review (and if necessary, revision) of the strategies/plans/programs required under the consent is to be undertaken.

Outstanding issues not addressed by the mine

> *The following recommendations are made.*
>
> *Expansion of the shallow groundwater monitoring network into specific locations and at particular depths is required to further inform the impacts of mining and to meet the specific requirements of the Groundwater Monitoring and Modelling Plans – Information for prospective mining and petroleum activities. Purpose built (cased and screened) monitoring bores should be installed to target the disturbance zone between 10 and 20 m below the base of creeks and swamps at locations selected in consultation with DPI Water and Water NSW as well as intermediate and deep strata. For the shallow systems, the expanded monitoring should also include additional soil moisture, water level and hydrochemical sampling of shallow groundwater systems underlying and adjacent to swamps as well as those in the upper Hawkesbury Sandstone.*

Monitoring of shallow groundwater levels allows for the indirect measurement of water storage and transmission parameters within the saturated part of hill-slope/upland swamp complexes. Shallow groundwater piezometers have been installed in a number of swamps within and around Area 3 (Attachment L). This data is used to compare differences in shallow groundwater levels within swamps and hill-slope aquifers before and after mining. Sites that will not be mined under are monitored to provide a comparison of sites mined under and not mined under during different climatic conditions.

The piezometric monitoring directed at shallow groundwater levels is supplemented with monitoring of soil moisture profiles. The soil moisture probes monitor to a depth of 1.5m and key monitoring sites have been installed with loggers to provide a continuous soil moisture record.

The shallow groundwater piezometers and soil moisture probe data is compared with the Cumulative Monthly Rainfall Residuals (a key parameter for interpreting temporal soil and shallow groundwater data).

The Dendrobium Regional Groundwater Model (Attachment G) includes a thin (nominally 2 m thick) superficial layer to represent swamp deposits where they exist, and regolith otherwise. This allows inclusion of swamp and other 'shallow' groundwater level data for calibration.

The model was calibrated using the 96 shallow groundwater monitoring sites which possess recorded groundwater levels for the model calibration period. The groundwater model will be subject of ongoing development and calibration.

Dendrobium Mine monitors in excess of 100 boreholes and has analysed many thousands of samples for field parameters, laboratory analysis, algae and isotopes.

The results and interpretation of water analysis has been routinely reported to the DSC (Attachment H), Impact Assessment Reports, End of Panel (EoP) Reporting and the Dendrobium Annual Environmental Management Report (AEMR). Parson Brinckerhoff (2012) stated in a peer review of this work that "the use of standard hydrogeochemical tools clearly demonstrated the geochemical difference between water from the Wongawilli Coal Seam and goaf, and the overlying sandstone formations and surface water from Lake Cordeaux".

In January 2015 SRK Consulting conducted a detailed independent review of the Dendrobium water chemistry data, to:

- Assess the level of detail, quality of science, depth and technical appropriateness of the water chemistry data.
- Evaluate associated interpretations in relation to underground operations of Dendrobium Mine, with specific focus on how these address the question of hydraulic connectivity between the mined areas and the reservoirs.

Based on the review SRK concluded that the observed geochemical trends are not consistent with a high degree of hydraulic connectivity between the underground workings and the surface water bodies.

The WC21 Rehabilitation Plan (Attachment Q) proposes to undertake additional studies to determine the depth and characteristics of subsidence fracturing using standard techniques such as drilling, coring, geophysical logging, establishment of piezometers, down-hole cameras and calliper measurements. The hydraulic conductance of these fracture networks will also be assessed. Tracer tests will be used to determine likely flow paths for the diverted water.

The WC21 Rehabilitation Plan proposes locations for these investigations. The Plan was provided to WaterNSW 11 December 2015 for consultation, as required by the letter from DoPE 28 August 2015. The Plan will be made available to DPI Water and other stakeholders for consultation as part of the further approval for Longwalls 14 – 19.

> *For the deeper systems, the monitoring bores should intersect; (1) upper, middle and deep systems in the Hawkesbury Sandstone, (2) Bald Hill Claystone, and (3) upper and lower Bulgo Sandstone, at a minimum. These bores should be cased and screened (not grouted vibrating wire piezometers) to allow access for both water level (pressure) measurement and water quality sampling. This monitoring would enhance the knowledge of the near-surface impact of subsidence. Additional shallow substrate monitoring should be established in as-yet undisturbed upland swamp locations likely to be impacted by potential future longwall extraction in consultation with DPI Water, and other relevant agencies.*

A Groundwater Management Plan has been prepared for Dendrobium Area 3B to comply with Schedule 3(13) of the Dendrobium Consent.

There is substantial exploration drill-hole and hydro-geological information available in the area to define the groundwater regime. Monitoring holes have been monitored for some years. A number of detailed studies have been undertaken of the near surface and deeper aquifers in the mining areas.

The Groundwater Monitoring Program is generally consistent with the WaterNSW standard *The Design of a Hydrological and Hydrogeological Monitoring Program to Access the Impacts of Longwall Mining in SCA Catchment*.

Hydraulic characteristics of overlying and intercepted groundwater systems are being determined by a number of shallow and deeper groundwater investigations. The data from these investigations is used to identify changes to groundwater systems due to coal extraction and dewatering operations.

A series of piezometers are installed and completed to varying depths to monitor groundwater. This includes overburden sequences that would be subsided by mining, including those that may influence ecosystems and/or dam safety.

Groundwater bores have been established with accurate absolute datum levels. Groundwater level is recorded at each of these additional stations with water quality analysis conducted at selected sites within the catchment. A large number (~100) of bores have been installed to adequately define the slope of the groundwater and any potential impacts of subsidence. Groundwater is monitored for levels and water quality using down-hole water level and conductivity temperature and depth (CTD) sensors or low volume displacement pumps at key horizons to enable water sampling for selected strata.

Due to the size of Area 3B, instrumentation is installed progressively, focussing on the earlier longwalls.

Dendrobium uses groundwater monitoring to understand the groundwater regime in the stratigraphic units between the mining horizon, in the Wongawilli Seam, and the outcrop stratigraphy in Avon and Cordeaux Reservoirs. Dendrobium uses borehole packer tests, piezometers and pumps to establish strata permeability, groundwater levels and water quality in conjunction with in-mine monitoring of water quantity and quality data. The monitoring data is used to:

- identify the pre-mining groundwater regime,
- model the groundwater and prepare impact assessments,
- monitor the mining impacts on groundwater, provide a basis for Triggered Action Response Plans; and
- determine if the mining impacts are within prediction and acceptable.

The groundwater monitoring for Area 3B is based on a regional approach to support the development and calibration of the Dendrobium Mine Regional Groundwater Model (Attachment G).

Multi-level piezometers target the Hawkesbury, Bulgo and Scarborough Sandstones as well as the Bulli and Wongawilli Seams.

Where groundwater is sampled from multiple strata units the issue of drawing water from above and below the target stratigraphic unit is increased. Monitoring holes typically have VWPs installed to measure groundwater pressure. In these circumstances it is not appropriate to have a water column open between the stratigraphic units as the pressure would equalise between them, rendering the pressure data unusable.

In these circumstances holes are instrumented with micro-purge pumps with plugs (most recently using bentonite) separating the target stratigraphic units. The advantage of the micro-purge pumps was in housing multiple pumps in different stratigraphic horizons.

Groundwater monitoring has been installed into the Hawkesbury Sandstone adjacent to and within Swamp 11 in Area 3B. The program will investigate shallow and deep groundwater interaction below the swamp before, during and after mining.

S2306 was drilled adjacent to the swamp to a depth of 70m, and S2307 was drilled within the swamp to a depth of 50m (Attachment U).

The holes were monitored for flow and geophysics and piezometer monitoring equipment installed. Samples were also collected by a geologist for permeability testing.

> *The proponent should be required to install additional monitoring as and where deemed necessary by the NSW Government to improve coverage (both within the SMP domain and vertically) or to replace damaged installations. DPI Water may request the installation of cased and screened monitoring bores at specific locations or to intersect specific lithologies in order to facilitate the measurement of water levels or for water quality sampling in the event that such additional monitoring is considered necessary for the identification of mining impacts on water resources.*

Dendrobium Mine would consider any additional monitoring proposed by the NSW Government.

The numerical modelling undertaken for the project should be revised based on the outcomes of the independent expert review proposed in the report to the Minister for Planning. If not recommended by that review, DPI Water would seek to include sensitivity analysis of reduced longwall heights and panel widths to understand the potential for such modifications to mitigate or minimise impacts on upland swamps, water courses and shallow groundwater systems. In that regard, DPI Water recommends that panel dimensions are not prematurely fixed due to first workings being constructed in advance of full consideration and approval by the NSW Government.

In 2016 Hydrosimulations conducted an assessment of the height of connected fracturing above the seam at Dendrobium (Attachment G).

The extents of mining-induced fracture zones are dependent on a number of factors including the thickness and geology of the overburden material and the dimensions of the longwall.

Tammetta (2013) refers to a zone of ‘Complete Groundwater Drainage’ or ‘Collapsed Zone’, taken to be where the pressure head falls to zero (corresponding to the Ditton AA and A Zones), and a saturated Disturbed Zone (corresponding conceptually to Ditton’s B Zone). Both models have a continuous fracture zone that is arched in cross-section.

Both authors have found a relation between the height of some representation of the "fracture zone" and three key attributes of the mining system:

- mining height [T (Ditton) or t (Tammetta)];
- cover depth [H (Ditton) or h (Tammetta)]; and
- longwall panel width [W (both authors)].

Ditton (2012 and then Ditton and Merrick, 2014) presents two semi-empirical formulas. The first “geometry” model uses only the parameters described above. The second, “geology” model includes a term to account for the integrity of a spanning roof block (effective spanning thickness, t’).

The Ditton formulas for fractured zone height (A) for single-seam mining (Ditton and Merrick, 2014) are:

- Geometry Model: A = 2.215 W’0.357 H0.271 T0.372 +/- [0.16 - 0.1 W’] (metres)
- Geology Model: A = 1.52 W’0.4 H0.535 T0.464 t’-0.4 +/- [0.15 - 0.1 W’] (metres)

where W' is the minimum of the panel width (W) and the critical panel width (1.4H).

The 95th percentile A-Zone heights are estimated by adding aW' to A, where a varies from 0.1 for supercritical panels to 0.16 (geometry model) or 0.15 (geology model) for subcritical panels.

The Ditton models have been validated to 35 measured Australian case-studies (including Tahmoor, Dendrobium, Metropolitan, West Wallsend, Newstan, Mandalong, Springvale, Able, Ashton, Austar, Berrima, and Wollemi/North Wambo Mines) with a broad range of mining geometries and geological conditions included.

Several studies have been undertaken at Dendrobium to assess the existing fracture height above mined longwalls in order to identify and calibrate the predictive height of fracturing model used. These studies present evidence in support of assumptions regarding the height of fracturing above longwalls at Dendrobium.

In order to constrain estimates for heights of connective fracturing and the mechanisms for inflow to the mine, Hydrosimulations looked at the following sets of monitoring data:

- Groundwater pressure drawdown in response to mining;
- The Dendrobium Mine water balance, which provides an estimate of groundwater flow into each of the mining areas (1, 2, 3A and 3B).
- Chemical fingerprinting of various water sources which provide information on the origin of mine inflow waters.
- Available research, including the Longwall 9 height of connective fracturing research.

Together, these various lines of evidence support a model in which mine-related fracturing and depressurisation do not propagate to the surface and there is no evidence for rapid surface-to-seam water pathways. Significant depressurisation is apparent above longwall panels, extending to about the mid to upper part of the Bulgo Sandstone (in Area 3A), and locally to the lower part of the Hawkesbury Sandstone in Area 3B (Attachment G).

The groundwater pore pressure in deep formations is monitored using vibrating wire piezometers. The Tammetta's (2013) study on the height of fracturing above longwall mines used this approach to identify the height above the longwall goaf at which the pressure effectively dropped to zero (atmospheric pressure), indicating free drainage within a vertically connected fracture zone (analogous to the 'A' zone).

Hydrosimulations reviewed the pressure responses in the vicinity of the mine to identify the height of "significant depressurisation" above mined panels at Dendrobium.

The main conclusions from this assessment are:

- There are numerous 'little or no depressurisation' points below the calculated Tammetta H level, which is conceptualised as the height of complete groundwater drainage. This suggests that the Tammetta (2013) method overestimates the height of complete drainage at Dendrobium.
- The majority of points that indicate either "some" or "significant" depressurisation plot below the Ditton A 95th percentile line. However, some points plot above this line, particularly for panels 6 and beyond.

Possible reasons why the Tammetta (2013) H heights consistently over-estimate the heights of groundwater depressurisation at Dendrobium are:

- The database used by Tammetta (2013) did not cover the area for which we now have data (particularly Area 3B);
- There may be differences in interpretation of data in respect of what constitutes depressurisation. In the Hydrosimulations study "significant depressurisation" refers to a decline in pressure equivalent to 25 m head or more over a period of a year (including decline

of pressure head to zero). It is therefore conservative with respect to “complete depressurisation”.

Groundwater inflow to the underground mine cannot be measured directly, but is inferred via a detailed daily water balance for each of the four Dendrobium Mine areas.

Analysis of the inflow to each mine area shows:

- Area 1: a mild correlation with the rainfall trend but not with individual rainfall events.
- Area 2: a clear correlation with high rainfall events (>200 mm across 1-2 days).
- Area 3A: During active mining, groundwater inflow increases linearly with time and the cumulative area mined. Following the completion of Longwall 8, the rate of inflow has an apparent correlation with rainfall trends, but not clearly with individual rainfall events.
- Area 3B: There is no apparent correlation between residual or daily rainfall and mine inflow. As with the active mining phase in Area 3A, the mine inflow rate in Area 3B is most strongly correlated with the cumulative area mined, and to a lesser extent, the rate of mining.

Hydrosimulations conducted an assessment of water fingerprinting and provenance at Dendrobium Mine (Attachment G). Water quality results and interpretation from surface waters, shallow and deep groundwater and from the underground mine workings and goaf are reported monthly to Government.

Na/Cl ratio (as an indicator of major ion water chemistry) and tritium from each water source has a distinct character. Mine seepage has a composition that is consistently distinct from surface water (having an elevated Na/Cl ratio and low tritium), but is most similar to deep groundwater from the Bulli Coal Seam. Additionally, mine inflow water typically has an electrical conductivity of 800-3000 µS/cm (brackish), whereas surface water is typically fresh (<100 µS/cm).

The mine water chemistry provides a powerful natural tracer for water samples. The Hydrosimulation study concluded the following:

- Mine water is predominantly, if not entirely, comprised of groundwater from the coal seams and deep sandstone formations.
- Mine water and surface waters have distinct characteristics and mine waters do not display intermediate compositions that would indicate mixing of groundwater with a significant component of surface water.
- Due to the natural variability in tritium levels in surface and groundwater, it is not possible to rule out a small component of surface water ingress.
- There is no significant correlation between inflow rate and chemical parameters such as EC, Na/Cl and tritium content. Peaks mine inflow at Area 2 can therefore not simply be attributed to surface water inflow.

Estimates of mine inflow clearly show some correlation with rainfall trends. The correlation is distinctly related to high rainfall events for Area 2, whereas other areas show a weaker and broader correlation with cumulative residual rainfall trends. These correlations suggest a mechanism whereby mine inflows that are higher than a nominal baseline are driven by elevated piezometric heads, which in turn are caused by high net recharge compared with long term discharge from the aquifer systems.

The data do not imply a direct link between the surface and the mine. The consistency of water chemistry parameters in mine waters such as tritium, EC and Na/Cl indicates that mine inflows do not contain a significant surface water component, and high inflows cannot simply be explained by a proportional increase in surface water ingress. The data do not allow us to rule out any surface water contribution because very small fractions of surface water (<10%) may not be apparent given the limits of precision and the natural range in source compositions. However, it can be concluded that there is apparently no direct and rapid pathway between the surface and the goaf. Otherwise the changes in tritium and EC would be noticeably greater. The same conclusion was reached by Parsons Brinckerhoff (2015) in a study that showed that potassium salt and dye tracers injected into the Hawkesbury and Bulgo Sandstones directly above longwall 9 were not detected in goaf waters, even up to six months after the test.

> *The review of the existing Trigger-Action-Response Plans (TARPs) by DP&E, as recommended in the report to the Minister for Planning, should include provisions for the monitoring of groundwater levels in and underlying upland swamps as well as considerations for the maintenance of existing species and species diversity. The outcomes of the proposed independent expert assessment of threatened species should be used to inform the revised TARPs, as well as advice from DPI Water (for shallow groundwater systems) and OEH (for flora and fauna other than threatened species).*

The SIMMCP and WIMMCP (Rev 1.4) were approved by the Secretary 10 August 2015. The approved Plans have been revised on eight occasions during extensive consultation with Government, the latest being October 2015. The TARP in the approved SIMMCP (Attachment L) was accepted as drafted by DoPE.

The existing TARPs include provisions for the monitoring of groundwater levels in and underlying upland swamps. The "groundwater" TARP is defined as *falls in surface or near-surface groundwater levels in swamps.* The following TARP levels are included:

- Level 1:
  - Groundwater level lower than baseline level at any monitoring site within a swamp (in comparison to reference swamps); and/or
  - Rate of groundwater level reduction exceeds rate of groundwater level reduction during baseline period at any monitoring site (measured as average mm/day during the recession curve).
- Level 2:
  - Groundwater level lower than baseline level at 50% of monitoring sites (within 400 m of mining) within a swamp (in comparison to reference swamps); and/or
  - Rate of groundwater level reduction exceeds rate of groundwater level reduction during baseline period at a 50% of monitoring sites (within 400m of mining) within the swamp.

- Level 3:
    - Groundwater level lower than baseline level at >80% of monitoring sites (within 400m of mining) within a swamp (in comparison to reference swamps); and/or
    - Rate of groundwater level reduction exceeds rate of groundwater level reduction during baseline period at >80% of monitoring sites (within 400 m of mining) within the swamp.

Soil moisture levels are also included in the existing TARP:

- Level 1: Soil moisture level lower than baseline level at any monitoring sites (within 400 m of mining) within a swamp (in comparison to reference swamps).
- Level 2: Soil moisture level lower than baseline level at 50% of monitoring sites (within 400m of mining) within a swamp (in comparison to reference swamps).
- Level 3: Soil moisture level lower than baseline level at >80% of monitoring sites (within 400m of mining) within a swamp (in comparison to reference swamps).

Species diversity is also included in the existing TARP:

- Level 1: A 2% (or otherwise statistically significant) decline in species richness or diversity during a period of stability or increase in species richness/diversity in reference swamps for two consecutive years; and/or
- Level 2: A 5% (or otherwise statistically significant) decline in species richness or diversity during a period of stability or increase in species richness/diversity in reference swamps for three consecutive years.
- Level 3: An 8% (or otherwise statistically significant) decline in species richness or diversity during a period of stability or increase in species richness/diversity in reference swamps for four consecutive years.

    The recommendations for technical investigations made previously by the operator's latest hydrogeological consultant (HS) should be implemented in the short-term. Work to address the following recommendations, in particular, should be programmed by the operator as soon as possible: the development of a recharge-runoff model; investigation of the significance and effect of fracturing mechanisms and the induced changes to hydraulic properties; a salt balance analysis of water source origins and mine inflows; sensitivity analysis of the numerical predictive model (as well as the comprehensive model rebuild) to improve fracture zone parameterisation; sensitivity analysis of the coarseness of model layering for swamp water table calibration and for the simulation of swamp water table impacts; and sensitivity analysis of the introduction of spatial aquifer parameter variability to the model.

A summary and review of the work to date on the recommendations of Hydrosimulations 2014 is provided in the table below.

RECOMMENDATIONS FROM HYDROSIMULATION 2014	ACTION TO DATE	LOCATION IN HYDROSIMULATION 2016
Development of a recharge-runoff model for the area.	Developed a lumped catchment model of Wongawilli Creek and of Swamp 13. This work will be extended in the forthcoming Surface Water EOP report for Longwall 11.	Section 4.6.3.
Independent estimates of baseflow to gauged streams should be developed.	Carried out chloride-constrained baseflow separation on Wongawilli Creek.	Section 3.6.1.
The height of the fractured zone to be adopted in the next model revision should be informed by a research project currently being undertaken (in 2014-15)	The findings of PB (2015) were considered, and further analysis has been undertaken here. Additional geotechnical advice by Steve Ditton is also in preparation.	Section 3.3, plus PB, 2015, HydroSimulations, 2015c.
The significance and effect of fracturing mechanisms (particularly surface cracking) and hydraulic properties should be explored.	The effect of surface cracking on swamp piezometry has been assessed in this report. Surface cracking has been simulated in the current model. New methods for representing the fracture flow have been employed in the current model.	Sections 3.5.1 and 4.7.2.
A salt balance, as recommended by the federal Independent Expert Scientific Committee (IESC), should be undertaken.	This has not yet been undertaken, although consideration of mine inflow chemistry has been presented here, and also in other reporting to agencies.	
Conduct sensitivity analysis of any predictive models to a variety of assumptions with regard to the representation of the fractured zone.	This has been completed in the current study.	Section 4.7.1, plus consideration was given to hydraulic conductivities estimated by PB (2015) and Tammetta (2014).
Sensitivity analysis of the implications of finer versus coarser model layering (i.e. vertical discretisation) for simulating swamp water tables.	This has not been conducted. Some improvement in simulation of swamp water tables was achieved in this study by modifying the method for using LiDAR data to parameterise the groundwater model. This is considered low priority, but maybe best assessed through use of 'unstructured' groundwater modelling techniques.	Sections 3.3.4, 3.6.
Consideration should be given to introducing spatial aquifer parameter variability to the model.	Some variable properties have been introduced for representing broad facies changes within the Narrabeen Group. This is considered low priority compared to potential improvements in the model representation of geology/geometry.	Sections 5, 5.2, 5.3.

> *In addition, further enhancement of the model should be undertaken to calibrate against shallow groundwater systems (within the Hawkesbury Sandstone and upland swamp substrates) to improve the prediction of mining-related impacts on the upland swamp ecosystems.*

In 2016 Hydrosimulations revised the Dendrobium Regional Groundwater Model (Attachment G).

Manual calibration methods were used to alter the hydraulic conductivity (horizontal and vertical), specific yield of modelled layers representing he Hawkesbury Sandstone and upland swamp substrates, as well as the parameters of the connected fractured zone and CLNs. Calibration has focussed on replicating observed groundwater levels and mine inflow.

While most of the monitoring locations that form the calibration dataset are the same as in HydroSimulations (2014), some additional sites have been added for the 2016 study. This includes the two new ‘Avon monitoring bores’ (S2313 and S2314), and a few other multi-level monitoring sites around Area 3B and one near Elouera.

The groundwater level from 348 piezometers were used in the calibration (219 were used in earlier rounds of modelling). The SRMS error of 9.4% is within the typically used criterion of 10% (MDBC, 2001; Barnett et al, 2012). The mean head error (17.9 m) is within the range of accuracy of vibrating wire piezometers when used in groundwater models with simplified stratigraphy, as outlined by Coffey (2012a), who provide an example accuracy for Dendrobium of around +/-20 m.

Hydrographs which include Hawkesbury Sandstone monitoring include:

Avon monitoring bores. These hydrographs show that the model does a reasonable job of matching the shallowest Hawkesbury Sandstone (HBSS) water levels, provides a good match for the deeper HBSS series, and overestimates the amount of drawdown (or the speed at which drawdown occurs) associated with Longwall 9.

S1925 is located in the centre of Area 3B, between Longwalls 11 and 12. The model does a good job of simulating drawdown throughout the sequence in Area 3B, except in the uppermost piezometer, where the model shows too much drawdown (the observed record shows no perceptible drawdown).

S1879 is located just south of Area 3A Longwall 8, and just west of Wongawilli Creek and Area 3B Longwall 13. The model replicates the timing of drawdown as well as the relative lack of drawdown in the shallow HBSS units.

These hydrographs show that the model does a reasonable job of simulating drawdown in the HBSS.

The revised model now simulates the groundwater levels in the swamps more accurately than previous, due to changes to the way topography is modelled. Generally, the modelled swamp water levels are now within 2-3 metres of the observed water level, which is considered a good result given the cell size of the model (50 x 50m, if not greater).

Calibrated model aquifer parameters remained unchanged aside from those for the regolith / swamps, and the Upper Hawkesbury Sandstone, which were altered to achieve an acceptable level of calibration to the new shallow groundwater data.

Model parameters are all within expected ranges and do not represent a marked departure from previous modelling. The specific yield of the swamp deposits has been increased from HydroSimulations (2014) to values considered more appropriate for the mix of sand, silt, clay and organics identified in bore logs.