## ATTACHMENT A: ADDITIONAL INFORMATION REQUESTED BY DPE

***Height of Connective Cracking***

> *The Department notes that it has previously advised Illawarra Coal that the most critical information required by the Department relates to the currently predicted and/or measured height of cracking, across the Area 3B domain, based on subsidence and groundwater modelling which takes into account the actual extraction heights of longwalls mined to date and both predicted and potential maximum extraction heights for all longwalls in the domain, going forward. This has been provided in the report prepared by HydroSimulations, dated October 2015.*

In 2015 HydroSimulations' completed an assessment of the estimated height of connected fracturing at Dendrobium. The assessment included:

- The effects of longwall mining and subsidence on overburden strata;
- A summary of previous research in relation to estimating the extent of the deformed strata above longwall mining, both in general and at Dendrobium;
- Revised estimates of the height of connected fracturing for Dendrobium longwalls using the Ditton 'Geology Model' (Ditton and Merrick, 2014) and the Tammetta (2013) method.

The assessment concluded that the Ditton 'Geology model', as outlined in Ditton and Merrick (2014), is the most appropriate method for estimating the vertical extent of connected fracturing above longwalls at Dendrobium. This is supported by the research above Longwall 9 by Parsons Brinkerhoff (2015) and earlier studies by GHD (2007) and Heritage Computing (2011).

There are numerous models for the height of fracturing and height of desaturation. A review of these matters was conducted for the Bulli Seam Operations Project Response to PAC deliberations (Hebblewhite 2010).

Water fingerprinting is used to determine the source of water pumped out of the underground workings and this provides strong evidence on the height of connective fracturing. The results of water analysis from the surface, the strata and the mine workings and the interpretation of the height of connective fracturing from water fingerprinting at Dendrobium Mine was peer reviewed by Parson Brinckerhoff (2012). The peer review states 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". Although the report acknowledged limitations of the available data, this review is based on one of the most comprehensive datasets available in the Southern Coalfield.

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 surface water bodies.

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 (2016) 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 (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 Dendrobium Mine to identify the height of "significant depressurisation" above mined panels.

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 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 Dendrobium 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 (3H) 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 2016 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 water inflow at Dendrobium Mine 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 (and the above water fingerprinting) 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 company shall undertake a program of sampling and assessment of the properties of water entering the workings, water in adjacent workings, water near any mine portal, groundwater in overlying strata and surface water overlying the workings, in accordance with a plan endorsed by the DSC".*

As part of the approval to mine within the Avon and Cordeaux Notification Areas the Dams Safety Committee (DSC) requires extensive water sampling and analysis.

Dendrobium Mine has DSC Endorsement for Longwall 11 and 12 extraction and development workings for Longwall 13. This approval includes the Avon and Cordeaux Reservoirs DSC Notification Area Management Plan.

The Dendrobium Water Management Procedure (DENP0048) supports the Plan details the routine periodic sampling of water sources with fingerprinting analysis against known reference sources and this analysis is reported monthly to the DSC and other stakeholders. The characteristics of underground waters are compared to reference surface water samples (Cordeaux Reservoir, Sandy Creek, Kembla Creek and the Upper Cordeaux No.2 Reservoir), rainwater and groundwater in overburden strata (Scarborough, Hawkesbury and Bulgo sandstones). Fingerprinting of discrete water sources using hydrogeochemistry, isotopes, and algae allows for identification and quantification of any surface water or groundwater water reporting to underground workings.

The procedure applies to all underground waters that are sampled and analysed for the purposes of identifying their type, and likely origin or sources. It includes sampling protocols, analytical suites, post-sampling treatment, quality assurance/quality control protocols and reporting requirements.

A number of potential sources exist that may contribute to water in underground workings at the Dendrobium Mine:

- Roof / wall seepage: Water assumed to have seeped into the mine from the coal seam or from immediately surrounding formations (roof seepages and in seam boreholes).
- Stored water pumped from Nebo Colliery old workings used for general (nonhydraulic) uses within Dendrobium Mine.

- Town water pumped from Dendrobium Pit Top for use in hydraulic oil makeup for the longwall chocks. The original source of town water is known to be Lake Avon (Avon Dam Reservoir).
- Stored water from Kemira Colliery old workings adjacent to Dendrobium Mine that can flow through the surrounding strata including coal seams, geological structures and boreholes.
- Stored water from Mt Kembla Colliery old workings lying partly above Dendrobium Mine workings that can flow through the surrounding strata including coal seams, geological structures and boreholes.
- Groundwater in overlying strata (Scarborough, Hawkesbury and Bulgo sandstones).
- Surface water including lakes, creeks and dams that may flow over and partly through strata or faults and fissures that might extend from the Dendrobium Mine workings to the surface.

Samples from some sites are a mixture of water derived from more than one source.

Sampling is focused on analytes that are useful for fingerprinting discrete water sources and identifying potential ingress of low salinity surface waters (rainfall, storage water from Lake Cordeaux or Lake Avon, or creeks) into underground workings. The monitoring results and findings are reported to the DSC and other stakeholders on a monthly basis (Attachment H).

More than 2,700 water samples have been collected and analysed at Dendrobium Mine since 2004, providing an extensive database with which to assess mine water chemistry against baseline surface water chemistry. The data have allowed water sources to be uniquely characterised or "fingerprinted" and characteristic trends to be identified.

In general, the chemistry of mine seepage has been shown to be consistent with water sourced from the Wongawilli Coal Seam and adjacent shales. In contrast, ingress of water from surface water sources would be identified by temporal and/or spatial trends towards lower salinity waters.

Tritium is a short-lived isotope of hydrogen with a half-life of 12.43 years. It is directly incorporated into the water molecule (1H3HO or 1HTO) and so is the only radioisotope that directly dates groundwater (rather than a dissolved constituent). It is commonly used to identify the presence of modern recharge. Tritium is produced naturally in small amounts from the interaction of cosmic radiation with atmospheric oxygen and nitrogen in the troposphere.

However, tritium was also produced by thermonuclear bomb testing in the 1950s and 1960s. The concentration of tritium in Australian precipitation reached a maximum level of 160 TU in 1960, during one of the most intense periods of nuclear testing, but has declined to around 1.5 to 3 TU since that time.

Rain and surface water tritium data provide background values with which to identify any ingress of modern water into underground. Tritium concentrations in mine water are typically low (<0.3 TU), consistent with a negligible proportion of modern water entering the mine workings. Samples that are identified as direct mine seepage tend to have lower tritium concentrations than general goaf water samples which can contain water from a mixture of sources including surface water supplies.

Water quality monitoring carried out to date has shown a number of dissolved constituents that are useful in discriminating or “fingerprinting” waters derived from different sources. The most characteristic are:

- Tritium (indicating the average time elapsed since the water fell as rain)
- Electrical Conductivity (EC, an indicator of salinity or total dissolved salts)
- Na/Cl ratio (an indicator of sodium enrichment as a function of aquifer processes)
- Si (dissolved silica derived from weathering of silicate minerals)
- Li, Ba, Sr (Minor ions liberated during silicate weathering)

Of these, tritium, EC and Na/Cl are identified as the most useful indicators for routine monitoring and reporting. Tritium specifically identifies waters derived from rain within the last ~50 to 70 years (or mixing with a young source). However, groundwater samples from Bulgo Sandstone and Hawkesbury Sandstone can contain elevated tritium levels indicative of relatively recent recharge, and therefore elevated tritium levels in mine inflow cannot be uniquely attributed to a direct surface water source.

EC and Na/Cl are analysed routinely for many sites and each shows a significant difference in composition between surface waters and mine waters (one to two orders of magnitude), making them sensitive indicators.

The type of algal species present within mine waters can also be used to determine the source of the water. Algal species detected in Dendrobium goaf waters (Areas 1 to 3B) have typically belonged to Cyanophyceae or Cyanophytes (Blue-green) algae division. The most commonly occurring species in goaf water, the small-celled marine species Synechoccus. Synechoccus is rare in Lake Cordeaux (maximum levels at a few hundred cells/mL) and has not been detected in Lake Avon.

Freshwater blue-green algae species which frequently appear in Lake Cordeaux or Avon have only been detected sporadically at low levels in goaf waters: Pseudanabaena, Merismopedia, Aphanocapsa. The most common algae in both Lake Cordeaux and Lake Avon is Cyanogranis libera.

In addition to identifying algae species, stable isotope analysis of δ13C of dissolved inorganic carbon (DIC) and the equivalent Seston (particulate organic matter (POM)) (principally bluegreen algae) of δ13C, δ15N, carbon/nitrogen mole ratio, and net carbon isotope fractionation (Δ δ13C) were analysed by ANSTO for samples collected from lakes Cordeaux and Avon, and underground waters (Area 2 and Area 3B). Data to date has shown there is a statistically significant difference in the Seston (POM) δ15N between samples of mine inflow water and samples from the reservoirs. These results indicate that mine water is unlikely to contain modern lake water which could have been contributed via short timescales (that is via a fast flow path) commensurate with the timescales over which adaptation of algal metabolism typically occurs (i.e. less than several days up to about 1 week).

> *However, there is some uncertainty regarding the accuracy of the predicted height of connective cracking given the below concerns regarding subsidence modelling and groundwater modelling, both of which have implications for the height of connective cracking.*

The height of connected fracturing is calculated independently of any groundwater model, and of any subsidence model. The height of fracturing is used to populate subsequent groundwater models.

The Dendrobium Area 3B Subsidence Report (Section 4.8) addresses the estimated height of the fracture zone. MSEC459 states that the heights of the collapsed and fractured zones above extracted longwalls are affected by a number of factors, which include:

- widths of extraction,
- heights of extraction,
- depths of cover,
- types of previous workings, if any, above the current extractions,
- interburden thicknesses to previous workings,
- presence of pre-existing natural joints within each strata layer,
- thickness, geology, geomechanical properties and permeability of each strata layer,
- angle of break of each strata layer,
- spanning capacity of each strata layer, particularly those layers immediately above the collapsed and fractured zones,
- bulking ratios of each of strata layer within the collapsed zone, and the presence of aquiclude or aquitard zones.

Although some of these aspects also relate to the predicated level of subsidence at the surface, the predicted level of subsidence does not directly relate to the height of connected fracturing.

Estimates of the heights of the collapsed and fractured zones are typically based on the extracted seam height and/or widths of extraction, whilst equations based on the width-to-depth ratios of the extractions are also used. Estimates of the heights of the collapsed and fractured zones require thorough analysis and should include mining parameters and other properties, such as geology and permeability, of the overburden strata.

In light of revised subsidence predictions for Area 3B (Attachment M: MSEC792), Ditton Geotechnical Services has been engaged to review relevant field data from Dendrobium Mine to confirm the calibration of the model used to estimate the height of connected fracturing.

> *DSC has raised concerns with the accuracy of the predicted height of connective cracking and has recommended a 300 metre set back from the Full Supply Level. The Department is strongly considering this recommendation.*

Dendrobium Mine has previously extracted Longwalls 1 and 2 in Area 1, Longwalls 3 to 5 in Area 2 and Longwalls 6 to 8 in Area 3A. Area 3B is located to the east of Lake Avon, between the Native Dog Creek arm of the Lake and Wongawilli Creek, and is partly located within the DSC Notification Area for Avon Reservoir. Dendrobium has DSC Endorsement for the extraction of Longwalls 11 and 12 and the development of roadways for Longwall 13.

Longwalls 12 to 18 are set back from the Avon Reservoir Full Storage Level (FSL) by 301m, 242m, 275m, 353m, 214m, 228m and 250m respectively (Attachment K).

In order to gain and maintain approval for mining within the DSC Notification Area, Dendrobium Mine is required to implement the Avon and Cordeaux Reservoir DSC Notification Area Management Plans. This Plan has been updated to incorporate learning's from the extraction of Longwalls 9 to 11 in Area 3B and has been endorsed by the DSC for Longwalls 11 and 12 extraction and roadway development for Longwall 13.

The Plan describes the monitoring, contingency and closure requirements for the Avon and Cordeaux Reservoirs Notification Areas and has been developed in accordance with the relevant provisions of the Dams Safety Act 1978, to minimise the loss of reservoir water as a result of mining within the Notification Areas.

The potential for loss of Stored Water from the Avon Reservoir whilst mining Area 3B was considered in a risk assessment held in February 2014 which was conducted by AXYS Consulting. The objective of the assessment was to assist Dendrobium Mine control identified risks associated with the mining of Longwalls 12 to 18 which may cause the loss of stored water. The following hazards were identified as potential causes for such losses:

- Loss of stored water through porous flow outside the influence of mining or fracture flow within the mining induced fracture zone.
- Loss of stored water through porous flow outside the influence of mining or fracture flow within the mining induced fracture zone.
- Known or unknown geological features such as faults and dykes act as a conduit between the Avon Reservoir and the mine workings (development or longwall) resulting in loss of stored water.
- Unsealed borehole within the DSC Notification Area acts as a conduit between the Avon Reservoir and the mine workings (development or longwall) resulting in a loss of stored water.

The DSC wrote to Dendrobium Mine 15 July 2014 to indicate their requirements for mining within the Avon Notification Area. The following requirements have been addressed in the DSC Plan:

- Water chemistry data has been reviewed by an independent expert.
- Boreholes have been established between the mine workings and the Avon Reservoir to monitor the pressure heads in strata and to sample formation waters.
- Water sampling and analytical programme as well as interpretation will continue while mining progresses in Area 3B.
- A comprehensive review/analysis of water chemistry and piezometer data for Areas 2, 3A and 3B has been completed.

The DSC wrote to Dendrobium Mine 29 June 2015 outlining requirements for mining Longwall 12:

- That it would not be recommending any longwalls within the Notification Area that mine through a geological structure unless it can be clearly demonstrated there will be no risk to dam water.
- That it would not be recommending any longwalls within 35 deg plus half depth of cover unless it can be clearly demonstrated there will be no risk to dam water due to the presence of shear planes below the Native Dog Creek valley.

Dendrobium Mine undertook additional studies and assessments and presented the finding to the DSC Mining Subcommittee 14 October 2015.

Assessments undertaken for the report Estimated Height of Connected Fracturing above Dendrobium Longwalls (Attachment I) were discussed with the DSC. The assessment addressed the effects of longwall mining, specifically the estimated height of connected fracturing, including:

- Discussion on the effects of longwall mining and subsidence on overburden strata.
- A summary of previous research in relation to estimating the extent of the deformed strata above longwall mining, both in general and at Dendrobium.
- Revised estimates of the height of connected fracturing for Dendrobium longwalls using the Ditton 'Geology Model' (Ditton and Merrick, 2014).
- A comparison with previous estimates made using the Tammetta (2013) method.

The assessment was reviewed by Ditton Geotechnical Services.

Attachment I presents analysis of the distances between the nearest arm of either Lake Cordeaux and Avon to each of the Dendrobium Mine areas. The lateral distance from Lake Avon and the nearest estimated (predicted) connected fracture zones of the proposed Area 3B longwalls is further than the lateral distance between the connected fracture zone above the previously mined longwalls in Areas 1 and 2 from Lake Cordeaux and there is a greater (vertical) thickness of rock between Area 3B and Lake Avon.

Based on distances, the risk from mining near Lake Avon appears less than for the historical mining of Areas 1 and 2 near Lake Cordeaux.

The Dendrobium Regional Groundwater Model uses the revised estimates of the height of connected fracturing and incorporates the vertical and horizontal distances from the dams. The model also accounts for the variation in bulk permeability expected between the Bulgo Sandstone and Hawkesbury Sandstone, which are the geological units that are critical to controlling groundwater flow around Lake Avon.

Recent field investigation, calculations and modelling has led Hydrosimulations to the conclusion that the Ditton 'Geology Model', as outlined in Ditton and Merrick (2014), is the most appropriate method for estimating the vertical extent of connected fracturing above longwalls at Dendrobium. The research above Longwall 9 by Parsons Brinkerhoff (2015) supports this selection. The results of earlier reports such as GHD (2007) and Heritage Computing (2011), in which bore data was analysed in order to assess the height of the fractured zone, also correlate well with the mean fracture height predicted by the Ditton 'Geology Model'.

In the letter of 29 June 2015 the DSC expressed concern about geological structures that could form a flow path between the Avon Reservoir and Dendrobium Mine. Geological structures have been assessed as a potential risk to stored water since mining operations at Dendrobium began. This risk has been successfully managed since the first approval for mining within the Cordeaux Reservoir Notification Area. The existing controls that minimise the risk of water inflow along hydraulically charged geological structures were discussed with the DSC 14 October 2015.

Dendrobium is a modern retreat longwall mine and this mining technique requires large areas of geologically undisturbed ground as it is inherently an inflexible mining system. The technique requires the extent of the extraction to be fully developed by roadways prior to any secondary extraction.

In order to provide certainty for mine planning Dendrobium Mine has undertaken extensive surface based exploration, including boreholes, 2D seismic surveys and aerial magnetic surveys. The surface based exploration identifies faults, dykes and sills as a basis for mine planning. The results of the surface exploration for Area 3B have been reported to the DSC and other Government Agencies. The exploration techniques define areas of relatively undisturbed ground suitable for longwall mining. The surface based exploration techniques define the location of major structures which define the mining domains but do not identify if the structures are hydraulically charged.

In addition to surface based exploration Dendrobium Mine relies on in-seam exploration. In-seam drilling is undertaken between development roadways and reservoirs within the DSC Notification Area and exploration is used to define:

- The location (margin and extent) of geological feature that could not be detected by the surface exploration techniques e.g. sills or dykes with no magnetic signature or faults smaller than the resolution of the surface techniques,
- If the area in advance of the development is hydraulically charged due to any known or unknown geological feature. In-seam drilling is undertaken through standpipes that enable flow from the hole to be measured and controlled.

Dendrobium Mine has drilled numerous in-seam boreholes in Areas 1, 2, 3A and 3B and not detected any hydraulically charged geological features despite several of these being directly under a reservoir. The results of the in-seam drilling enable the mine plan to be modified prior to development and hence avoid geological features including hydraulically charged features. The in-seam drilling results have been used to refine the mine plan and avoid geological features in Area 1, 2 and 3.

After in-seam drilling the development roadways are mined. The roadways are mapped for geological and geotechnical features as well as water inflow. The mapping enables the extent of the longwall to be refined even further by adding additional detail such as minor faulting or geotechnical instability due to associated jointing. By the time the longwall block is fully defined the area of extraction is comprehensively defined from a geological and hydrogeological basis. The results of mapping of development roadways have been used to refine the size of longwalls e.g. the start position of Longwall 9, 10, 11 and 12.

There are proven drilling and grouting techniques available to manage water inflow into development roadways. The details of suitable contractors have previously been provided to the DSC. If the drilling and grouting techniques were not successful, a series of temporary and final seals could be utilised. The grouting and sealing process is described in the Contingency and Closure Plan, developed to the satisfaction of the DSC.

Historically there have been very few inflows in the Southern Coalfield. Doyle 2007 and Tonkin and Timms 2015 reviewed the relationship between geological structures and water inflow in the Southern

Coalfield. The details of the Kemira inflow (Whittall 1990) due to longwall extraction below the overlying flooded Mt Kembla workings has previously been provided to the DSC as reported by Tonkin and Timms. The Kemira inflow is not applicable to Dendrobium Area 3B as there are no overlying flooded workings. The Wongawilli and Gilmore Shunt inflow events were associated with pillar extraction at shallow depth (<100m cover) directly under the reservoir. The lessons from the Wongawilli and Gilmore Shunt flows is also not applicable to Area 3B as the extraction is >350m deep and is offset from the reservoir.

Dendrobium Mine proposes that any risk from hydraulically charged geological units can be well managed using the existing risk mitigation measures of surface and in-seam geological investigations, drilling between the mining and the reservoirs, fully developing roadways that outline the longwall prior to any secondary extraction and contingent measures in the unlikely event hydraulically charged structures be encountered.

In the letter of 29 June 2015 the DSC expressed concern about basal shear that could form a flow path between the Avon Reservoir and Dendrobium Mine. This is a risk which has existed at previous mining areas at Dendrobium Mine and has been successfully managed using appropriate setbacks from the reservoirs. The existence of basal shear and proposed setbacks to minimise the risk of water inflow along these features was discussed with the DSC 14 October 2015.

Although the presence of basal shear planes has been recognised relatively recently and this recognition may help to explain some of the previous experience of mine inflows at shallow depths, basal shear planes have always been present around valleys in the Southern Coalfield both naturally and as a result of mining. The strategy of developing an appropriate barrier between the goaf and the full supply of the reservoir has been an effective strategy to control inflows from the reservoir to low levels provided the barrier has been sufficiently large. Attachment J Mills (2015) compares barrier sizes and discusses them in terms of their relative effectiveness to reduce the risk of inflows to the mine.

In Areas 1 and 2 at Dendrobium Mine the barrier between the FSL of Cordeaux Reservoir and the mining was 262m. Longwalls 12 to 18 are set back from the FSL by 301m, 242m, 275m, 353m, 214m, 228m and 250m respectively (Attachment K).

Notwithstanding the challenges of differentiating sources of inflow to an underground mine, previous mining at Dendrobium has not indicated unacceptably high inflows from Cordeaux Reservoir through the barriers provided and these barriers would therefore appear to be of more than adequate size (Attachment J). The experience of these barriers being adequate is also consistent with the historic experience of mining adjacent to reservoirs.

The two recognised examples of significant inflow from previous mining in the Southern Coalfield at Blue Panel and Gilmore Shunt were both associated with shallow depths of cover. The consequence of shallow depth is that the offset based on the concept of an angle of draw is also reduced. Inflow rates across the barrier are related to the length of the flow path and not necessarily overburden depth to the mining horizon. By basing the barrier size on angle of draw, the flow path at shallow depth was reduced and the inflows observed increased.

The barrier provided to Longwall 12 in the design of Area 3B is greater than the barrier provided previously to Cordeaux Reservoir and so a greater level of protection would be expected. The barriers proposed for Longwalls 13-18 are less by up to about 40 m and, although they would need to be increased to provide the same size offsets as previously, there does not appear to be a compelling reason to do so (Attachment J). Additional monitoring has been installed to measure basal shear between the Avon Reservoir and the mine to determine if greater setbacks are required (Attachment U).

The DSC Plan has been updated to incorporate the DSC approval conditions for mining Longwalls 11 and 12 as well as the additional work that has been conducted on geological features and basal shear.

The successful mining within Dendrobium Area 1, Area 2 and Area 3A with no significant inflow of water from the Cordeaux Reservoir should provide the DSC with confidence that mining within Area 3B has an acceptable risk.

Area 3B is a relatively simple sequence of sedimentary stratigraphy and there are no complications associated with overlying workings. The longwall domain is between geological features that have negligible risk of providing a conduit from the reservoir to the workings. Dendrobium Mine has developed the most extensive mine and groundwater monitoring system in the Southern Coalfield and believes in the importance of making decisions based on facts. Longwall mining over a period of 10 years has not resulted in any measurable reservoir water reporting to the mine.

Dendrobium has installed and is currently monitoring an extensive array of piezometers in the area. In addition, the underground water balance and chemistry sampling provides data that can be used to trigger actions within the DSC Plan. Dendrobium Mine proposes that the proposed mining in Area 3B presents a tolerable risk to Avon Reservoir.

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; and
- a 300 m offset between the proposed longwalls from the Avon Reservoir (based on the FSL).

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.

Avon Dam is a prescribed dam which is surrounded by the Avon Notification Area. Mining within Notification Area is regulated by the DSC using its powers under the Dams Safety Act 1978 and the Mining Act 1992. The proposed mining within the Notification Area requires endorsement of the DSC.

The interests of the DSC are specific to the safety of the Dam and its stored waters. The DSC has expressed concerns with extraction within the Notification Area which is based on assessment of information to date. A comprehensive monitoring program is in place to provide additional data to the DSC to assess the proposed longwall extraction and specifically an appropriate horizontal distance from the FSL of Lake Avon.

The DSC has endorsed a series of applications by Dendrobium Mine since 2005 to conduct first workings and secondary extraction within the Cordeaux and Avon Notification Areas. The DSC is currently considering conditions to be placed on extraction of Longwalls 13 to 18, within the Avon Notification Area.

The DSC has stated it will be applying the precautionary principle and restricting extraction within the Notification Area unless it is proved that the extraction will not adversely affect the safety of the stored waters.

From the DSC's understanding and perspective, 'intolerable' losses from the Reservoir have been denoted previously as losses of 1ML/day from the Reservoir to the mine. In the ongoing development of methods of risk analysis (both qualitative and quantitative) for dams and their storages undertaken by the DSC, interception of structure is one of the most difficult risks to predict.

To ensure that structures are not inadvertently intercepted the DSC requires mines to conduct in-seam drilling a minimum of 30m ahead (and frequently hundreds of metres ahead) of their first workings. This ensures that the mines are aware of the presence of major structures months in advance of mining within the area delineated for extraction. By the time secondary extraction of a longwall is endorsed by the DSC, the first workings have already been conducted and mapped for structures. The consequences of using this approach is that mines establish an excellent understanding of the actual structure present prior to extraction of a longwall.

The DSC uses the precautionary principle when recommending applications for mining within Notification Areas. If there is any doubt the Mine must change its mine plan appropriately or develop effective contingency measures ahead of mining. As neither the in-seam drilling nor the delineation of Longwall 14 is complete, any decision on the risks to stored waters from geological structure cannot be made at this time. An acceptable set-back distance from the FSL should only be determined once sufficient data is available.

The Cordeaux and Avon Reservoirs DSC Management Plan (Attachment T) includes:

- Water sampling and analysis of algae, trace element analyses and Tritium isotopes.
- Sampling boreholes between the mine workings and the Reservoir to monitor groundwater pressure in the Hawkesbury Sandstone below the level of the thalweg of the Reservoir.
- Analysis and assessment of monitoring data, including a review team with the authority to commission further studies and to approve changes to the mine plan if necessary.
- Reporting to interested government departments and WaterNSW.
- A contingency Plan which addresses the implementation of hydraulic barriers.
- Results from the monitoring are compared to the groundwater model and the model is updated as required (Attachment G).
- The DSC Management Plan is subject to an Independent Environmental Audit every 3 years in accordance with Condition 6, Schedule 8, of the Dendrobium Development Consent.

***Subsidence Modelling***

> *As outlined previously, one critical decision for the Department is whether to confirm the existing width of the Area B longwalls (i.e. 300 metres) or whether to impose a requirement to narrow the width of future longwalls to limit the height of cracking and/or surface impacts. To assist in this matter, the Department requests subsidence modelling for varying longwall panel and pillar widths. This would assist the Department in determining whether there would be any environmental benefit in reducing panel width or increasing pillar width when compared to the current proposed layout.*

A detailed assessment has been carried out to determine if it is feasible to reduce impacts to the surface by reducing the area mined and/or altering the mining parameters. The focus of this assessment was upland swamps and the conclusions are outlined in Section 5.3 of the Swamp Impact Monitoring Management and Contingency Plan (SIMMCP). The SIMMCP is provided as Attachment L.

This analysis demonstrated that the reduction in resource recovery necessary to reduce impacts to upland swamps was approximately 45% of the total resource available within Area 3B. This analysis was conducted with a 150m setback from the swamps, which is the furthest distance from mining where a groundwater response has been identified.

The longwalls proposed for Area 3B are 300m wide and the Environmental Assessment (EA) undertaken to support the Subsidence Management Plan (SMP) was undertaken on that basis. The EA and SMP are based on extensive empirical data collected during the mining in Areas 1, 2 and 3A, including Longwall 8 which was successfully extracted with a width of 300m. The SIMMCP has been revised to take into account a revised subsidence model for Dendrobium MSEC792 (Attachment M) based on measured subsidence resulting from the extraction of Longwalls 9 and 10.

Detailed analysis was conducted into options for reducing impacts to swamps, including reducing the widths of the longwalls to a maximum of 180m. This analysis demonstrated that the reduction in subsidence movements achieved through reducing the longwall width to 180m would not significantly reduce the potential for impacts to the swamps. The analysis included an assessment of the reduced subsidence movements against the Draft Office of Environment and Heritage (OEH) criteria for assessing impacts to swamps that may be at risk of negative environmental outcomes:

- Systematic tensile strains >0.5mm/m;
- Systematic compressive strains >2mm/m;
- Depth of cover less than 1.5 times longwall panel width;
- Transient or final tilt >4mm/m;
- Valley closure >200mm; and
- Maximum closure strain >7.0mm/m.

A summary of the analysis is provided in Table 5.1 of the SIMMCP. It was found that between six and three of the above criteria from OEH would be breached even if the longwall width was reduced to 180m.

The predicted subsidence parameters in Dendrobium Area 3B have been reviewed based on varying longwall widths and chain pillar widths (Attachment N). The analysis compared maximum predicted vertical subsidence, maximum predicted tilt and maximum predicted curvature.

Based on a 45 metre chain pillar, the maximum predicted vertical subsidence is approximately 3 metres based on 250 metre wide longwalls, 2 metres based on 200 metre wide longwalls and 1 metre based on 150 metre wide longwalls.

The maximum observed ground movements due to mining in the Bulli Seam in the Southern Coalfield at depths of cover ranging between 500 and 600 metres are typically 1 to 1.3 metres for vertical subsidence, 7 to 10 mm/m for tilt and 0.15 to 0.25 km-1 for curvature. In order to achieve similar levels of ground movements as those observed due to Bulli Seam mining, the longwalls void widths at Dendrobium Area 3B would need to be reduced to around 150 metres based on vertical subsidence and to around 100 metres based on tilt and curvature.

MSEC reviewed the observed movements in valleys elsewhere in the Southern Coalfield (Attachment N). Ground movements have been monitored at many sites where stream valleys are located directly above mining in the Bulli Seam within the Southern Coalfield.

Compressive strains up to 17.2 mm/m have been measured within stream valleys due to Bulli Seam mining in the Southern Coalfield. The valley related movements resulted in compressive strains much greater than 2 mm/m which are sufficient to result in fracturing of the topmost bedrock. The maximum observed vertical subsidence for these cases varied between 0.3 and 1.35 metres.

The analysis indicates that significant reductions in subsidence movements would be required to limit surface impacts to levels seen in Bulli Seam mining, which include fracturing and flow diversion. There would be very little environmental benefit in reducing panel width or increasing pillar width to achieve levels of subsidence movements in Bulli Seam mining i.e. 100 to 150 metre wide longwalls.

The relationship between the observed maximum measured soil crack and rock fracture widths versus the maximum predicted vertical subsidence and maximum predicted curvature at Dendrobium Mine was assessed by MSEC (Attachment N).

Soil crack and rock fracture widths (i.e. greater than 100 mm) occurred across the full ranges of the predicted vertical subsidence and curvature. Large surface crack and rock fracture widths occurred even where the predicted vertical subsidence was less than 1 metre.

The site data indicates that larger cracking and fracturing (i.e. greater than 100 mm widths) can occur over the full ranges of the predicted vertical subsidence and curvature. More significant impacts typically occur due to steeply sloping terrain that results in increased horizontal movements in the downslope direction. These downslope movements result in localised and elevated tensile strains at the tops and sides of the slopes and localised and elevated compressive strains at the bases of the slopes. The natural surface slopes become less incised from Dendrobium Area 1 to Area 2, with Dendrobium Area 3 having a more gentle landscape and as a result decreased likelihood of wide soil cracking and rock fracturing due to down slope movements.

Surface water impact sites (i.e. flow diversions and/or pool water loss) were compared to the maximum predicted total closure and vertical subsidence by MSEC. The shallow groundwater impact sites (i.e. piezometers) were compared to maximum predicted total closure and vertical subsidence (Attachment N).

The surface water impact sites occurred in locations having a wide range of predicted vertical subsidence and closure movements. There are three surface water impact sites (two along stream SC10C and one along Donalds Castle Creek) that have low levels of predicted ground movements (i.e. less than 100 mm vertical subsidence). These sites are located above solid coal immediately downstream of the extracted longwalls.

The shallow groundwater impact sites occurred in locations having a wide range of predicted vertical subsidence and closure movements. There is one shallow groundwater impact site that has low levels of predicted ground movements (i.e. less than 100 mm vertical subsidence). This site is located above solid coal immediately downstream of the maingate of Longwall 11.

The results suggest that impacts to shallow groundwater occur directly above or immediately adjacent to the extracted longwalls. These impact sites occurred over a wide range of predicted vertical subsidence, between 1 and 2.2 metres for the piezometers located directly above the extracted longwalls, and less than 50 mm for the one site located outside and immediately adjacent to the mining area.

The above analysis demonstrates that a requirement to narrow the width of future longwalls to limit surface impacts will be ineffective unless widths are substantially reduced. There would be very little environmental benefit in reducing panel width or increasing pillar width.

> *MSEC has reported conventional subsidence parameters significantly greater than those based on the earlier model, ie. 30% for vertical subsidence, 25% for tilt and 40% for curvature. Similar increases for upsidence and valley closure have not been reported. The Department seeks clarification on and reasons why increases are not predicted for these parameters.*

Horizontal movements that develop due to mining comprise a number of components. The horizontal movements that develop when mining beneath relatively flat terrain are often referred to as the 'conventional movements'. Additional or greater horizontal movements also develop when mining beneath steep topography or valleys due to the downslope movements and valley related effects.

The horizontal movements that are measured within stream valleys therefore include both the conventional component and the valley related component. Report No. MSEC792 (Attachment M) provides separate predictions for the conventional closure and the valley related closure. The reason that these components are reported separately is that the strains can manifest differently from these two components. The conventional component generally results in tensile strains developing near the longwall edges and compressive strains developing near the longwall centre. Whereas the valley related component generally results in localised and elevated compressive strains developing close to the base of the valley and elevated tensile strains developing towards the top of the valley.

The horizontal movements that develop due to the conventional component are directly related to the magnitude of the vertical subsidence. A 30% increase in the vertical subsidence therefore results in a similar increase in the conventional horizontal movements and, hence, the conventional closure. The predicted conventional closures for the streams that are provided in MSEC792 have been increased based on the higher levels of predicted vertical subsidence.

The horizontal movements that develop due to the valley related component are also affected by vertical subsidence. The valley related movements were predicted using the method outlined in ACARP Research Project C8005 and C9067 (the 2002 ACARP method). No reduction factors have been used. The influence of vertical subsidence on the valley related component reduces as the magnitude increases based on the 2002 ACARP method. As the vertical subsidence increases the valley related component also increases, but at a reducing rate. The prediction curve based on the empirical data tapers and, when the vertical subsidence is greater than around 1 metre, only small additional valley related movements are predicted with increasing vertical subsidence.

One limitation of the 2002 ACARP method is that the prediction curves were developed where there was limited monitoring data for cases where the vertical subsidence was greater than 1 metre. Hence, there is greater uncertainty in the 2002 ACARP method at the magnitudes of subsidence that occur at Dendrobium Mine. Nevertheless, the predicted conventional component of closure increases proportionally to the vertical subsidence and, therefore, it is considered that this would account for the greater potential for closure movements across the valleys at Dendrobium Mine.

A comparison between the observed and predicted closure for the monitoring lines in Dendrobium Area 3B was provided in MSEC792. The predicted closures include both the conventional and valley related components. The comparisons showed that the observed movements were less than predicted in all but two cases. It is considered therefore that the methodology provides adequate predictions of the overall closure within the valleys based on the available ground monitoring data.

***Groundwater Modelling***

> *In its previous letter, the Department noted that it would give close consideration to the revised groundwater modelling and the outcomes of the height of connective fracturing research. I note that the most recent groundwater modelling is that dated March 2014.*
>
> *The Department understands from its discussions with Illawarra Coal that there has been a significant amount of work undertaken on upgrading the groundwater model at Dendrobium, including integration with a surface water model and incorporation of monitoring data. This upgrade is important and the Department requests an update on its progress.*

A regional-scale numerical groundwater model was developed in support of the approval process for mining of Area 3B at Dendrobium Mine (Coffey Geotechnics (Coffey), 2012). The Area 3B SMP approval conditions stipulated further development of the numerical model. HydroSimulations (2013) addressed these conditions, however the model used to support this work was based on the conservative model developed by Coffey. HydroSimulations (2014) updated the fracture simulation using the Ditton (2012) method and time-varying material properties to simulate fracturing height.

HydroSimulations has prepared an assessment of potential impacts of extraction of Area 3B Longwalls 14 to 18 and Area 3A Longwall 19 on groundwater and connected surface water systems around the Dendrobium Mine (Attachment G). This assessment forms part of this application to DoPE to satisfy Condition 5 of the SMP Approval.

Since the Dendrobium Regional Groundwater numerical models were completed in 2012 and 2014, there have been improvements in the functionality of finite-difference modelling software that allow more realistic simulation of fracture networks. At the same time our understanding of the nature and extent of fracturing above longwall mines, specifically at the Dendrobium Mine, has continued to evolve through the collection of high quality geotechnical and hydrological data. The improvements to the Dendrobium Regional Groundwater Model (Attachment G) take advantage of the following recent advances:

- Conversion of the existing groundwater model from MODFLOW-SURFACT to MODFLOW-USG including the amalgamation of existing “time-slice” models into one single run and re-calibration using the latest groundwater monitoring data including shallow groundwater systems (within the Hawkesbury Sandstone and upland swamp substrates);
- Integration of more robust estimates of recharge from rainfall-runoff-recharge modelling for predictive modelling stream flow and swamp interactions with mining, with particular importance placed on replicating field measurements;

- Revised estimates of height of fracturing on the basis of recent research, groundwater monitoring data and subsidence predictions;
- Incorporating recent investigations into the potential for hydraulic connection between the Avon Reservoir and mine workings at Area 3B Longwalls 14 to 18; and
- Sensitivity analysis on the effect of fracture height, panel length and width, and connectivity between streams/swamps and aquifers on impact prediction.

Previous versions of the Dendrobium models created by HydroSimulations (2014) and Coffey Geotechnics (2012) were run using MODFLOW-SURFACT (HydroGeoLogic). MODFLOW-SURFACT has been considered the industry standard for modelling coal mines due to its capability to simulate both saturated and unsaturated flow conditions, allowing appropriate handling of dry cells that commonly cause difficulty in mining models. MODFLOW-SURFACT additionally allows variable hydraulic properties with time (due to subsidence related fracturing and placement of backfill) using the Time-Varying Material Properties (TMP) package.

However, due to the high complexity in the model associated with the numerous mining operations, and the potential to remove superfluous model cells that require inclusion but are in areas where layers are absent (eroded away), Hydrosimulations considered the use of MODFLOW-USG ('Unstructured Grid)', which is the most recent addition to the United States Geological Survey's (USGS) family of software. Following consultation with geotechnical consultants, who favoured the use of some functionality available in MODFLOW-USG, HydroSimulations re-built the most recent model into the new MODFLOW-USG platform (Attachment G).

MODFLOW-USG uses a different underlying numerical scheme to earlier version of MODFLOW: control volume finite difference (CVFD), rather than traditional MODFLOW's finite difference (FD) scheme. MODFLOW-USG allows discontinuous layers (pinch outs), removing the need for dummy layers, reducing the cell count and increasing the conceptual correctness of the model. Similar to SURFACT, MODFLOW-USG is able to simulate variably saturated flow and can handle desaturation and re-saturation of multiple hydrogeological layers. When run using the USG-Beta version through Groundwater Vistas, MODFLOW-USG is also able to simulate changing hydraulic properties with time using the Time-Variant-Materials (TVM) package developed by HydroAlgorithmics Pty Ltd.

Due to the conversion from MODFLOW-SURFACT to MODFLOW-USG, differences between the functionality are unavoidable, and differences between the results of previous modelling and the updated model are expected.

MODFLOW-USG also contains a new package, Connected Linear Networks (CLN), which are a new feature in MODFLOW unique to MODFLOW-USG (Panday et al., 2012). They allow representation of a one-dimensional structure with a cross-sectional dimension much smaller than that of the cell in which it is contained, and so allows simulation of flow through 'conduits' (e.g. wells or bores, fractures). CLN segments can be singular or connected to each other, with multiple CLNs in one model cell.

This allows for the host rock to retain its original hydraulic properties, while simulating fracturing at variable intensity above the goaf. Flow calculations are done in two parts; within the CLN domain and between the CLN domain and surrounding groundwater flow cells. The current version of the CLN package assumes laminar flow conditions through a circular conduit. CLN segments can be singular or connected to each other to represent variable intensity of fracturing, with the amount of flow through a single CLN controlled by its radius, and limited in the connected network by the segment with the smallest radius.

CLNs are used within this model to represent vertical connectivity of strata due to mining, and are applied in the model as a single CLN segment per cell, stacked in a vertical profile with decreasing radius away from the goaf.

The MODFLOW-USG model mesh or grid is identical to that of Coffey (2012) i.e. resolution varying between 50 m and 215 m (finest resolution in Longwalls 13-18 and nearest Lake Avon). There are 239 rows and 225 columns in the mesh, giving a total of 53,775 cells per layer.

There are 16 model layers, which is identical to that of HydroSimulations (2014). There are a total of 860,400 cells, of which 525,213 are active.

The temporal discretisation has been modified from the 2014 model, which previously ran in three time slices based on the original Coffey (2012) set-up. The updated model now runs as a single simulation to cover calibration, prediction and recovery modelling. The calibration period includes a single steady state stress period to initialise the heads leading into the transient run.

Following this, a series of transient stress periods are used to simulate the historical mining at adjacent and nearby mines before the beginning of Dendrobium Mine in 2004 (first longwall in 2005).

Effort to simulate the detail of historical and proposed mining at nearby mines has been limited to focus on the broad activities at those sites that are deemed likely to affect groundwater levels at Dendrobium or contribute to any cumulative effect on surface and groundwater.

The model has been set up to write the results of the modelled mass balance multiple times per stress period. The times for which output is written is somewhat dependent on the length of each stress period, but follow a geometric progression, in line with Mackie (2013), mainly from the point of view of accurately capturing the simulated mine inflow.

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.<br>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.<br><br>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.<br><br>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.<br><br>This is considered low priority compared to potential improvements in the model representation of geology/geometry. | Sections 5, 5.2, 5.3. |

***Surface Water Modelling and Monitoring***

> *Modelling at Dendrobium is currently unable to provide DPI-Water with estimates of water take therefore limiting its ability to licence the mine. This is a serious concern and should be addressed immediately in consultation with DPI-Water.*

The Water Management Act provides for a number of zones and in the Dendrobium area these 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.

Hydrosimulation used the ZoneBudget mass balance software (Harbaugh, 1990) on the MODFLOW budget files to extract the simulated stream leakage and baseflow for each zone and for each predictive run (Attachment G). The results were than aggregated into 'water years'. This includes the net loss of baseflow in watercourses entering the reservoirs (as distinct from the induced leakage from the storages).

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

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).

> *Direct measurements of flow in WC21 above and below the undermined parts of the creek should be undertaken immediately to assist in understanding what proportion of diverted stream waters are returning to the stream below the impacted zone.*

Monitoring along tributary WC21 includes pool water levels and surface flow. Monitoring is carried out in accordance with the approved Dendrobium Area 3B Watercourse Impact, Monitoring, Management and Contingency Plan (WIMMCP). The WIMMCP is included as Attachment O.

Flow monitoring is located at site WC21S1, approximately 470m downstream from Area 3B mining (Attachment O). Monitoring is semi-automated, using logged pool depths which are converted to daily flow rates using a rating curve. Daily flow rates at the site have been recorded since June 2012.

At the request of DoPE an additional flow monitoring location has been selected, upstream of Longwall 11 (Attachment P). The location was chosen as the most hydrometrically suitable site in this section of WC21 not yet influenced by subsidence movements. The site captures the surface outflow of a small pool before continuing through a small channel and over a downstream step.

The location is approximately 115m upstream from Longwall 11. Manual flow monitoring will be carried out in-situ at the site using a Pigmy flow meter. Automated monitoring is not appropriate at the site due to geomorphological conditions. Frequency of flow gaugings will be in line with WIMMCP requirements of nearby monitoring i.e. undertaken on a weekly or monthly basis, depending on the location of the longwall. This will provide approximately 12 months of baseline data, prior to any influence of Longwall 12.

The Secretary wrote to Dendrobium Mine 28 August 2015 to request; under Condition 4 of Schedule 3 of the Dendrobium Consent that Dendrobium Mine prepare a remediation program for the impacts to WC21. The Plan (Attachment Q) was provided to DoPE and other Government Departments in December 2015.

The aims of the Plan include:

- Characterising the impacts at WC21.
- Avoiding additional impacts during rehabilitation where possible.
- Implementing the WIMMCP.
- Carrying out mitigation and remediation works.
- Achieving the Performance Measures outlined in the Area 3B SMP Approval.

- Monitoring and reporting effectiveness.

Flow monitoring sites are 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.

These sites are not installed directly over the longwalls as mining induced surface fracture networks typically result in receding flows being entirely diverted below the surface, which is the case for WC21. 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.

Prior to remediation works within WC21 the depth and characteristics of the fracturing will be assessed by 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.

A drill site is proposed directly adjacent to Rockbar 24 on WC21 (Attachment Q). This is for the purpose of downhole investigations including packer testing, visual analysis using a downhole camera and installation of piezometers. These investigations aim at building a better understanding of the impacted strata and ways of targeting remediation works.

This monitoring will continue during and following implementation of the rehabilitation program and will be used as one of the indicators of the rehabilitation success.

***Biodiversity***

> *The Department is of the understanding that summer is an appropriate time for conducting surveys of Giant Dragonfly. The Departments agrees with OEH's recommendation that a targeted survey for this species in all swamps within Area 3B is undertaken as a matter of priority.*

Targeted surveys for the Giant Dragonfly were undertaken between 20 and 27 January 2016 (Attachment R). Surveys were undertaken when weather parameters were favourable for flying adults i.e. days above 20$^{o}$c, wind speeds lower than 15 km/h and no precipitation.

The 13 swamps within Dendrobium Area 3B were surveyed for the presence of both exuviae and adults, including Swamps 01a, 01b, 03, 04, 05, 08, 10, 11, 13, 14, 23, 35a and 35b.

Surveys were undertaken by two zoologists experienced in the identification of the species, with the aim of covering all, or the majority of each swamp. Cyperoid Heath and Tea-Tree Thicket were prioritised as these sub-communities have been found to provide the most suitable Giant Dragonfly breeding habitat in swamps of the Cordeaux and Cataract catchment areas. Foraging habitat for adult Giant Dragonfly was also surveyed throughout all swamps and within adjacent woodlands.

When an exuviae was observed, its location was noted along with its sex and where it was perched. Surveys for adults, included scanning for flying individuals and searching for perched individuals in all sub-community types visited within swamps and adjacent woodlands. When an adult was observed, its location was noted along with its sex and its behaviour at the time (i.e. perched, flying, copulation).

Giant Dragonfly were recorded at Swamp 01a, Swamp 11 and Swamp 14. A total of 11 adults and one exuviae were recorded during the surveys. The exuviae recorded was a female found at Swamp 01a, in an area of Cyperoid Heath.

A total of three adults were recorded within Swamp 11, including a solitary female and two males engaging in a territorial dispute. A total of eight adults were recorded within Swamp 14, including three males attempting copulation with a female, several solitary males flying and a solitary male observed actively foraging.

All records of exuviae and adults were located in areas recognised as suitable habitat for the species, within either Cyperoid Heath or Tee-tree Thicket.