ATTACHMENT B: ADDITIONAL INFORMATION REQUESTED BY WATERNSW

Additional Information & Assessment

> *WaterNSW notes that the updated Subsidence Prediction Report (MSEC, 2015) states that some of the maximum predicted "conventional" subsidence parameters are significantly greater than those based on the earlier model (reported in the MSEC report with the Area 3B SMP application in October 2012), by 30% for vertical subsidence, 25% for tilt and 40% for curvature. The increases in predicted subsidence for each longwall are readily apparent by comparing Figure 14 of each MSEC report.*
>
> *Despite these significant increases in predicted subsidence, the predictions of environmental effects (i.e. upsidence and valley closure) have not increased - the reason for this is not explained in the MSEC report.*
>
> *As advised at the meeting (9 December 2015), WaterNSW believes that appropriate consideration of the SMP for Longwalls 14 to 18 will necessitate:*
>
> *1. Clarification and further justification of the subsidence modelling which:*
>
> *a) Explains the reason for the increased predictions of conventional subsidence*

A review of predicted and observed subsidence for Areas 2, 3A and 3B is provided in Section 3.6 of MSEC792 (Attachment M).

It is considered that the subsidence prediction model has provided reasonable predictions in Area 2, i.e. Longwalls 3 to 5, based on the Airborne Laser Surveys. This is not unexpected, as the subsidence prediction method was calibrated using the monitoring data from Longwalls 3 to 5 in Area 2 and Longwall 6 in Area 3B, which was described in Section 3.6 of MSEC459.

It appears that for Longwalls 7 and 8 in Area 3A and Longwalls 9 and 10 in Area 3B, that the maximum observed vertical subsidence exceeded the predictions, in many locations, with these exceedances being typically up to 1.3 times predicted. The observed subsidence directly above the tailgate chain pillars for Longwalls 7 and 8 in Areas 3A and Longwall 10 in Area 3B were also greater than predicted.

It is likely that the observed vertical subsidence exceeded that predicted in Areas 3A and 3B due to the higher depths of cover and wider longwall void widths, as compared with those in Area 2, which resulted in pillar compression greater than that predicted by the subsidence model.

It is also possible that higher subsidence has developed in Area 3B as the Coal Cliff Sandstone is not present in this area, with higher compression of the overburden occurring within the thicker Wombarra Formation above the chain pillars.

The subsidence prediction model for Area 3B, therefore, has been further refined based on the latest monitoring data as follows:

- the maximum predicted incremental subsidence has been increased by 30%; and

- the vertical subsidence above the chain pillar (i.e. pillar compression component) has been increased based on the observed profiles.

The latest calibration of the subsidence prediction model (Attachment M) has been referred to as the ‘MSEC792 subsidence profiles’. The observed subsidence movements in Area 3B more closely match those predicted based on the MSEC792 subsidence profiles.

The depths of cover to the Wongawilli Seam reduce towards the south within Area 3B. The additional vertical subsidence due to pillar compression is likely to reduce for the future Longwalls 12 to 18 as the depths of cover progressively reduce. The pillar compression component of vertical subsidence in the calibrated model has considered the local depth of cover for each longwall.

> *b) Explains how it is possible that such increases have not resulted in consequent increases in predictions in upsidence and valley closure. If this has been achieved by a reduction in the "factor of safety" for the prediction, the basis for this reduction needs to be justified.*

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. MSEC792 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 Projects 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 prediction methodology provides adequate predictions of the overall closure within the valleys based on the available ground monitoring data.

> *c) Provides greater detail of how the updated predictions for non-conventional subsidence parameters have been achieved and clarifies whether these are consistent with findings presented in the recent ACARP Research Project No. C'18015 report (Effects of Mine Subsidence, Geology and Surface Topography on Observed Valley Closure Movements, and development of an updated Valley Closure Prediction Method, July 2014).*

The predicted valley related movements for the SMP Application and MSEC459 were determined using the methods outlines in ACARP Research Projects C8005 and C9067 (the 2002 ACARP method). The revised methodology presented in ACARP Research Project C18015 (the 2014 ACARP method) was published in November 2014, i.e. after the completion of MSEC459. MSEC792 also adopted the 2002 ACARP method to remain consistent with the SMP Application and MSEC459.

The 2014 ACARP method provides seven additional factors that could be used to refine the predicted valley related movements. These factors are based on: whether the valley had been previously undermined; the geology of the valley floor and valley sides; angle of the longwall to the valley; consideration of headland features; thickness of the valley floor strata; survey mark spacing; and the location of the valley top.

These additional factors adopted in the 2014 ACARP method allow the predicted valley related movements to be reduced based on site specific conditions. It was not considered appropriate to consider these reduction factors until sufficient ground monitoring data was gathered at Dendrobium Mine to support their application. The comparisons between observed and predicted closures for the monitoring lines at Dendrobium Mine suggest that the 2002 ACARP method provides adequate predictions without introducing the additional factors presented in the 2014 ACARP report.

In any case, the predicted closures obtained using the 2014 ACARP method are similar to those obtained using the 2002 ACARP method (C18015).

> *2. Further information on changes to the predicted environmental consequences as result of the significantly increased predictions of subsidence. WaterNSW notes that MSEC states that*

> *there is predicted to be a greater number of fractures with increased widths in the exposed bedrock.*
>
> *Information is required to quantify these predictions and to describe in more detail the environmental consequences.*

Subsidence impacts and environmental consequences for Area 3B have been assessed against Condition 9 Table 1 of the SMP Approval (Attachment S). This assessment considers the Performance Measure, how the impacts are measured, the performance from longwall mining to date and references where detailed information on the impacts have been reported to Government.

The relationship between maximum predicted subsidence parameters, subsidence impacts and environmental consequences (e.g. flow diversion and pool water loss) was assessed by MSEC (Attachment M).

Soil crack and rock fracture widths (i.e. greater than 100 mm) occurred across the full ranges of the predicted vertical subsidence and predicted 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 and there is no increasing trend in crack or fracture width with increasing vertical subsidence or 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 M).

The surface water impact sites and shallow groundwater impact sites also occurred in locations having a wide range of predicted vertical subsidence and closure movements. Due to the relatively small flows and water store within the first and second order streams being mined beneath in Area 3B relatively small fracture networks can result in a loss of pool water level and shallow groundwater.

> *3. Provision of an updated groundwater modelling report by IC's consultants. It is understood that significant upgrades have been made to the groundwater model since the 2014 report was prepared, including integration with a surface water model and incorporation of monitoring data collected during mining of Longwalls 9 and 10. A revised modelling report has been expected for several months (e.g. report was expected to be ready prior to DSC's consideration of Longwall 12 mining within the Avon Dam Notification Area), and is considered essential to WaterNSW's review of this SMP application for the following reasons:*

> *a) The modelling should enable a greatly improved understanding of likely losses from streams and swamps, and of the surface water contributions to mine inflows.*

A regional-scale numerical groundwater model was developed in support of the approval process for mining of Area 3B at Dendrobium Mine (Coffey 2012). The Area 3B SMP approval conditions stipulated further development of the numerical model. HydroSimulations (2014) updated the fracture simulation using the Ditton (2012) method and time-varying material properties to simulate fracturing height.

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 following improvements to the Dendrobium Regional Groundwater Model 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 (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), 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.

Simulation of mining-induced changes to the hydraulic properties of rock strata within and above the mined zone was modified from the approach taken in HydroSimulations (2014). The conceptual model of the zones is presented in (Attachment G).

Changes in the hydraulic properties as a result of mining subsidence were simulated in three ways:

- The Connected Linear Network (CLN) boundary conditions were used to model the increased vertical hydraulic conductivity due to fracturing. This is the key difference between this study and the previous study (HydroSimulations, 2014), which adopted changes to the bulk or average vertical hydraulic conductivity of the overburden in the caved and fractured zones.
- The time-varying material properties (TVM) package is used to simulate the zones of fracturing and deformation within mine workings and the caved zone immediately above

longwall panels. Specifically, this package is used to increase horizontal hydraulic conductivity (Kh) as well as storage properties (Sy) due to mining. No changes were made to specific storage (Ss).

- Surface cracking above longwalls was simulated by changing hydraulic conductivity and specific yield to a depth of 4 m. This depth is likely to be the minimum depth of such cracking, which could occur to 10-20 m in places, however model stability proved an issue, so this zone was set to 4 m for practicality.

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.

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.

The percentage area of swamps that potentially will be affected by depressurisation was estimated by counting the number of model cells designated as swamps that dry out in any given time step.

The surface cracking mechanism was included in the 2016 Dendrobium Groundwater Model and this represents a key difference between this model and previous rounds of modelling.

The assessment suggests that at any point in time, up to 35% of the swamp sediments, by area, in the mine footprint will be desaturated. This is in line with the analysis in Appendix G that about 50% of all undermined swamps are affected by mining-related drawdown. The similarity in the two sets of results supports the concept that surface cracking is the primary mechanism controlling impacts upon swamps.

This assessment suggests that swamps above Longwalls 12, 14, 15, 16, 17, and a small area near Longwall 19, would be affected. This covers Swamps 11, 13, 14, 23 (Area 3B) and 15(a2) (Area 3A). The model suggests that eventually the swamps will recover, except where the swamp hydrology is permanently altered by surface impacts.

> *b) WaterNSW needs to be confident that surface water behaviour is consistent with a calibrated integrated model. This is of particular importance with regard to understanding impacts on upland swamps and WC21, where surface water diversions appear to be above predictions following mining of Longwalls 9 and 10.*

WC21 is a first and second order stream and the impacts to WC21 are consistent with Section 4.3.4 of the approved WIMMCP (Attachment O) predictions: "Based on previous experience at the mine it is expected that fracturing and surface water flow diversion would occur along Donalds Castle Creek and the drainage lines which are directly mined beneath".

A review of the impacts to WC21 from Longwalls 9 and 10 identified:

- There are 37 pools mapped pools in WC21 within the 3B mining area (within 400m of mining).
- Ten mapped pools have been impacted (Level 1 change in water appearance). The percentage of pools impacted by change in water appearance in WC21 in the mining area is 27%.
- Three mapped pools have been impacted (Level 2 fracturing and flow diversion). The percentage of pools impacted by fracturing and flow diversion in WC21 in the mining area is 8%.
- Six mapped rockbars in WC21 have experienced fracturing with flow diversion (Level 2).

The area of impacts at WC21 is not large in terms of the total catchment. The overall area directly affected is less than 1 ha, which is a very small proportion of the Metropolitan Special Area's overall total of 90,000 ha (DoPE 2016).

A number of studies have been carried out to determine whether surface water systems that overlie mine workings have lost water and whether the loss is permanent or temporary. These fall into two main categories:

- Dye and salt tracer studies. These studies inject a tracer up-stream and measure the concentration of the tracer down-stream. Mass balance is used to determine if there has been a net loss along various reaches.
- Catchment water balance. These studies calibrate a rainfall-runoff model for specific gauged catchment. After the catchment has been undermined, the model is re-run. Significant losses

from the catchment or changes to the runoff coefficients will be apparent by comparing the pre- and post-mining model parameters.

Two salt and dye tracer studies were carried out by Parsons Brinckerhoff at Waratah Rivulet which had been affected by mining. The 2010 study concluded that the permeability of the substrate to the rivulet was enhanced relative to areas not affected by subsidence. The study detected losses from some reaches of the Rivulet, but those flows were returned downstream resulting in no detectable net loss. The 2013 study identified a possible loss of 25% of tracer in Waratah Rivulet and loses from Woronora River, however due to technical and logistic issues, the study was not conclusive.

Routine hydrological analysis of catchments is carried out in the vicinity of Dendrobium at the end of each longwall panel and results are reported to Government and other stakeholders. The most recent catchment water balance was carried out following the completion of Longwall 10 by EcoEngineers in February 2015. The study found that the mining of Longwall 10 produced negligible hydrologic impact on the overall catchment recessional and baseflow behaviour and associated water balances of Wongawilli Creek, Donalds Castle Creek and the non-mined under Lake Avon sub-catchment denoted LA4.

Notwithstanding the limited precision of these methods, there is no conclusive evidence to date that mine related subsidence has resulted in a net loss of yield in overlying catchments at Dendrobium. Additional hydrological analysis is currently being completed and will be reported in the Longwall 11 End of Panel Report.

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.

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.

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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.

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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.

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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.

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.

The percentage area of swamps that potentially will be affected by depressurisation was estimated by counting the number of model cells designated as swamps that dry out in any given time step.

The surface cracking mechanism was included in the 2016 Dendrobium Model and this represents a key difference between this model and previous rounds of modelling.

The assessment suggests that at any point in time, up to 35% of the swamp sediments, by area, in the mine footprint will be desaturated. This is in line with the analysis in Appendix G that about 50% of all undermined swamps are affected by mining-related drawdown. The similarity in the two sets of results supports the concept that surface cracking is the primary mechanism controlling impacts upon swamps.

This assessment suggests that swamps above Longwalls 12, 14, 15, 16, 17, and a small area near Longwall 19, would be affected. This covers Swamps 11, 13, 14, 23 (Area 3B) and 15(a2) (Area 3A). The model suggests that eventually the swamps will recover, except where the swamp hydrology is permanently altered by surface impacts.

> *c) The updated report is expected to include the results of sensitivity analysis to a variety of assumptions incorporated in the model. In particular, WaterNSW needs to understand the sensitivity of the model to assumptions about the height of the fractured zone, the height of full desaturation, postmining permeabilities in particular strata and swamp aquifer interactions with bedrock aquifers.*

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, including different estimates of the height of connected fracturing, i.e. the Ditton and the Tammetta models.

Simulation of mining-induced changes to the hydraulic properties of rock strata within and above the mined zone was modified from the approach taken in HydroSimulations (2014). The conceptual model of the zones is presented in (Attachment G).

Changes in the hydraulic properties as a result of mining subsidence were simulated in three ways:

- The Connected Linear Network (CLN) boundary conditions were used to model the increased vertical hydraulic conductivity due to fracturing. This is the key difference between this study and the previous study (HydroSimulations, 2014), which adopted changes to the bulk or average vertical hydraulic conductivity of the overburden in the caved and fractured zones.
- The time-varying material properties (TVM) package is used to simulate the zones of fracturing and deformation within mine workings and the caved zone immediately above longwall panels. Specifically, this package is used to increase horizontal hydraulic conductivity (Kh) as well as storage properties (Sy) due to mining. No changes were made to specific storage (Ss).
- Surface cracking above longwalls was simulated by changing hydraulic conductivity and specific yield to a depth of 4 m. This depth is likely to be the minimum depth of such cracking, which could occur to 10-20 m in places, however model stability proved an issue, so this zone was set to 4 m for practicality.

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).

> *d) The implications of increased predicted subsidence discussed in MSEC (2015) on predicted surface water and groundwater behaviour needs to be clarified.*

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.

Section 4.8 of the Dendrobium Area 3B Subsidence report (MSEC459) 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 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.

The relationship between surface water behaviour and the maximum predicted vertical subsidence and maximum predicted curvature was assessed by MSEC (Attachment N).

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 nature of the impacts described above and the resulting environmental consequences are the same or similar over a wide variety of predicted subsidence movements. This is because most of the impacts of subsidence relate to exceeding a threshold level of movement i.e. sufficient movement to fracture rockbars and result in pool water loss. Whilst it would be expected that the rates of potential impacts would increase, given greater predicted subsidence, the nature of these impacts are unlikely to change. Greater numbers of fractures, increased widths and increased potential for surface water flow diversions is more likely a result of steeper terrain than increased subsidence. The impacts resulting from Longwalls 12 to 18 are likely to be similar in nature to the impacts observed due to Longwalls 10 and 11.

> *The lack of an updated groundwater modelling report places very real restrictions on WaterNSW's ability to assess and understand the likely impacts and environmental consequences on the Special Area catchment, and WaterNSW considers it would be*

> *inappropriate to attempt the assessment without the updated modelling report. This is not dissimilar to the situation which we were confronted with during the initial review of the SMP application in 2012, and all efforts should be taken to avoid its repetition.*

A regional-scale numerical groundwater model was developed in support of the approval process for mining of Area 3B at Dendrobium Mine (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 report 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 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 Mine models created by HydroSimulations (2014) and Coffey (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.

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), Connected Linear Networks 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 as per Table 8. 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.

HydroSimulations (2016) includes the use of a new and conceptually more realistic representation of flow into and through connected fracturing that occurs above longwall panels. The following results were obtained from the revised groundwater model:

- The new model configuration uses Connected Linear Networks (CLNs) to represent fracture flow. This novel approach has the benefit of simulating flow within two domains: the unfractured host rock as well as in the fractures themselves (although the model aggregates the many small real-world fractures into a number of large fractures).
- The model matches historical inflow to the Dendrobium Mine with reasonable accuracy, although slightly overestimates the flow due to a number of excessive peaks in the hydrograph.
- Dendrobium Mine inflows or groundwater make is predicted to be less than predicted previously, but still peaking at about 10 ML/d (3650 ML/a).
- Dendrobium mine inflows or groundwater make are not especially sensitive to the assumptions made regarding the height of the fractured zone above longwalls. These estimates, and the subsequent estimates of leakage from the reservoirs, are based on the two primary models for estimating the height of connected fracturing or depressurisation (Ditton and Merrick, 2014; Tammetta, 2012).
- In the case of the Avon Reservoir, the simulated maximum leakage from the reservoir storage as a result of mining Longwalls 14-19 is 0.2 to 0.3 ML/d, and is up to 0.6 ML/d based on the cumulative effect of all mining activities in this area.
- In the case of the Cordeaux Reservoir, the simulated maximum leakage from the reservoir storage as a result of mining Longwalls 14-19 is very small at 0.01 ML/d. The cumulative leakage from all simulated mining activities is about 0.32 ML/d.
- The estimated effects on groundwater discharge to and leakage from Lake Avon are slightly higher than those of HydroSimulations (2014). These differences are due to the minor changes in the simulated height of connected fracturing and due to significant differences in the way in which the fractured zone was simulated. Regardless, the simulated impacts are considered negligible, as they were by HydroSimulations (2014) and Coffey (2012a).

- The analysis of field data indicates that, based on probability, half of all undermined swamps (i.e. those within about 100 m of a longwall) will show some degree of water table drawdown following undermining. Few of the piezometers that were analysed showed any significant recovery over time. These effects are considered to be due to cracking in the shallow subsurface, rather than intersection by fractures connected to the goaf. The model results support these findings. The swamps to be undermined by the proposed longwalls, and therefore at risk of groundwater level change, are Swamps 11, 13, 14, 23 (Area 3B) and 15 (Area 3A).

  WaterNSW supports DPI-Water's suggestion that direct measurement of flows in WC21 above and below the undermined parts of the creek would assist in better understanding what proportion of diverted streamwaters are returning to the stream below the impacted zone. These measurements can be readily and rapidly undertaken by suitably qualified hydrographers, and can be compared to the two measurements previously undertaken by Manly Hydraulics Laboratory (as referenced in DPE's Dendrobium Report to Government, details available on request).

Monitoring along tributary WC21 includes pool water levels and surface flow. Monitoring is carried out in accordance with the approved WIMMCP (Attachment O).

Flow monitoring is located at site WC21S1, approximately 470m downstream from mining operations (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.

> *In addition to the above, careful examination and revision where appropriate of the Performance Measures and associated TARPs for Longwalls 14-'18 is also required. The need for this examination is acknowledged in DPE's Dendrobium Report to Government. A review of the Performance Measures is a priority (excluding those in the development consent). A review of the proposed environmental monitoring required to support and enforce revised TARP triggers, potentially including increased ecological and hydrological monitoring in key swamps and streams, will also be required. It is acknowledged however, that provision of this information and consideration of appropriate TARPs and other information will take some months.*

The performance measures and environmental monitoring are provided in the approved WIMMCP (Attachment L) and SIMMCP (Attachment O). There was extensive consultation with Government during the development of these plans, including T&I; DoPE; OEH; NoW; and Water NSW.

A number of submissions were made in relation to the WIMMCP and the SIMMCP, including detailed submissions from OEH (26 October, an undated submission and 13 December 2012) and Water NSW (December 2012 undated). Illawarra Coal provided a detailed response to submissions 20 December 2012.

The Secretary of the DoPE approved the Dendrobium Area 3B SMP (including the WIMMCP and SIMMCP) 6 February 2013. Condition 12 of this approval requires the Plans be reviewed to the satisfaction of the Secretary by 31 May 2013.

The Plans were redrafted to take into account feedback during the SMP consultation period as well as the conditions and performance measures included in the Area 3B SMP Approval. The revised Plans were provided to DoPE, OEH, NoW, Water NSW and T&I 10 May 2013.

The Wollongong Office of T&I hosted a joint Agency workshop to discuss the Plans (27 May 2013) with the following agencies attending DoPE, OEH, Water NSW and T&I. Following the workshop the Agencies provided submissions. The Plans were revised on the basis of the agreed outcomes from this workshop and taking the submissions into account.

The Wollongong Office of T&I hosted a second joint Agency workshop with IC to discuss the Plans (16 December 2013) with the following agencies attending DoPE, OEH, Water NSW and T&I. Following the workshop the Agencies provided submissions. The Plans were revised on the basis of the agreed outcomes from the workshop and taking the submissions into account.

The SIMMCP and WIMMCP (Rev 1.4) were approved by the Secretary 10 August 2015.

The Plans were revised in October 2015 to account for the revised Dendrobium Mine subsidence model MSEC792 (Attachment M).

The approved Plans have been revised on eight occasions during extensive consultation with Government, the latest being October 2015. Critical components of the Plans e.g. the Swamp Plan performance measures were accepted as drafted by DoPE. The Plans provide for comprehensive and appropriate environmental monitoring and performance measures for Dendrobium Area 3B.

Appropriate Dimensions of the Longwalls

> *WaterNSW is not in a position to confirm whether the proposed longwall dimensions are appropriate. Our view is that the company needs to demonstrate that they will achieve the performance measures set out in the Planning and SMP Approvals with longwalls with the proposed dimensions.*

Achievement of the performance measures is addressed in Sections 3.6 and 3.7 of the SIMMCP (Attachment L) and WIMMCP (Attachment O) respectively. Longwall mining can result in surface cracking, heaving, buckling and stepping at the surface. Surface deformations can also develop as the result of downslope movements where longwalls are extracted beneath steep slopes. In these cases, the downslope movements can result in the development of tension cracks at the tops of the steep slopes and compression ridges at the bottoms of the steep slopes. Fracturing of bedrock can also occur in the bases of stream valleys due to the compressive strains associated with valley closure movements. The extent and severity of these mining induced ground deformations are dependent on a number of factors, including the mine geometry, depth of cover, overburden geology, geomorphology, locations of natural jointing in the bedrock and the presence of near surface geological structures.

A number of large surface cracks were observed at the commencing end of Longwall 3 in Area 2 at Dendrobium Mine. The depth of cover at the commencing end of Longwall 3 was as shallow as 145m, which is less than that above Longwalls 9 to 18 in Area 3B, which varies between 310m and 450m. The widths of surface cracking resulting from the extraction in Area 3B is less than that observed above the commencing end of Longwall 3.

The experience gained from mining in Dendrobium Areas 1, 2 and 3A indicate that mining induced fracturing in bedrock and rockbars are commonly found in sections of streams that are located directly above extracted longwalls. However, minor fracturing has also been observed in some locations beyond extracted longwall goaf edges, the majority of which have been within the limit of conventional subsidence or associated with valley closure.

The maximum predicted total conventional tensile and compressive strains for Wongawilli Creek, based on applying a factor of 15 to the maximum predicted conventional curvatures, are in the order of survey tolerance (i.e. less than 0.3mm/m). The creek is likely to also experience elevated compressive strains, resulting from the valley related movements, which could be in the order of 5mm/m based on observations at valleys with similar heights at similar distances from extracted longwalls.

An empirical database has been developed of pool and rockbar sites in the Southern Coalfield that have experienced mining induced valley related movements. The upsidence and closure movements at these sites have been predicted, using the ACARP Method of predicting valley closure, at the time when the first pool impact occurred, or after this time, when pool water loss was first recorded.

An analysis of impact rates has been undertaken using the currently available database of pools and rockbar case studies. This database is being continually developed and, to date, research has mainly concentrated on collating knowledge on the known pool and rockbar impact sites, whilst less data has been included for sites that had no impacts as a result of mining. The current reference to the 200mm predicted total closure value should therefore be viewed as an indication of low probability of impact (i.e. around 10%).

It has been assessed, therefore, that it is unlikely that significant fracturing or surface water flow diversions would occur along Wongawilli Creek as a result of the extraction. This assessment has been based on limiting the predicted closure at the mapped rockbars and riffles to 200mm and, as a result, the proposed longwalls have been setback more than 150m from the majority of the mapped rockbars and more than 150m from all of the mapped riffles.

It should be noted, however, that minor fracturing has occurred and is expected in the bed of Wongawilli Creek as a result of the extraction of the proposed longwalls. Fracturing that does occur in the bed of the creek would be isolated and of a minor nature and not result in any significant surface water flow diversions.

After the extraction of Longwalls 6 to 8 in Area 3A to the east of Wongawilli Creek and the extraction of Longwall 9 in Area 3B to the west of Wongawilli Creek a fracture was identified in Wongawilli Creek. The rock fracture is in the base of WC_Pool 43a and has a length of approximately 2m and a width of up to 0.02m. There was no observed flow diversion associated with the fracture and the pool remains full and flowing. This fracturing is consistent with the impact model described above and the performance measures for Wongawilli Creek.

The Waterfall WC-WF54 is located 75m east of the finishing end of Longwall 18. The waterfall is predicted to experience less than 20mm subsidence as a result of the extraction of the longwalls. While it is possible that the waterfall could experience subsidence slightly greater than 20mm, it would not be expected to experience any significant conventional tilts, curvatures or strains.

The maximum predicted valley related movements at the waterfall are 100mm upsidence and 150mm closure. Fracturing resulting in surface water flow diversions has not occurred and the likelihood of this occurring is considered low. The method of assessment for surface water flow diversions has been predominately based on the previous experience of mining near to and beneath relatively flat streams in the Southern Coalfield. The impact assessments for the pools immediately upstream of the waterfall, therefore, need to take into account the steep gradient (i.e. the waterfall) immediately downstream.

A comprehensive monitoring and management plan will be developed for WC-WF54, including the implementation of suitable management strategies such as a Trigger Actions Response Plan (TARP) similar to that which was successfully implemented for Sandy Creek Waterfall.

The upper reaches of Donalds Castle Creek have been mined beneath by Longwalls 9 to 12. The total length of the creek located directly above the longwalls is around 1.5 kilometres. The length of the creek within the predicted limits of 20mm total upsidence and 20mm total closure is approximately 2.4 kilometres.

There are no predicted or observed reversals of grade along Donalds Castle Creek resulting from the extraction of the longwalls.

The maximum predicted valley related upsidence and closure movements for Donalds Castle Creek are 370mm and 280mm, respectively. Elevated compressive strains across the alignment of the creek are also likely to result from the valley related movements.

The rockbars which were identified along Donalds Castle Creek are all located outside the extents of the proposed longwalls. The closest rockbar, being DC-RB35, is located 25m north of Longwall 9.

Fracturing and diversion of surface water flows has occurred at DC-RB33. On the basis that there is no connective fracturing to any deeper storage it is likely that any diverted surface water will reemerge at the surface. This would occur at the limit of subsidence induced fracturing downstream within Donalds Castle Creek.

In times of heavy rainfall, the majority of the runoff flows over the fractured bedrock and would not be diverted into the dilated strata below. In times of low flow, however, surface water flows are diverted into the dilated strata.

Remedial measures targeting the surface fracturing at DC-RB33 have been proposed as part of the Swamp Rehabilitation Research Plan. The proposed remediation includes grouting the bedrock, similar to the methods which have been previously undertaken in the Georges River.

The western ends of Longwalls 11 to 18 lie within the Avon Notification Area. As was the case for Areas 1, 2 and 3A, none of the current and proposed Area 3B longwall extraction is undertaken below stored waters. Longwalls 9 and 10 are outside the Avon DSC Notification Area and Longwall 11 is just inside the Area. Longwalls 12 to 18 are set back from the FSL by 301m, 242m, 275m, 353m, 214m, 228m and 250m respectively (Attachment K).

The depth of cover to the Wongawilli Seam directly above the proposed longwalls varies between a minimum of 310m, above the eastern end of Longwall 9, and a maximum of 450m, above the eastern ends of Longwalls 17 and 18.

The potential for loss of stored water from 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 Illawarra Coal control identified risks associated with the mining of Area 3B longwalls which may cause loss of stored water.

Dendrobium Mine has DSC Endorsement for Longwall 11 and 12 extraction and development workings for Longwall 13. An application for the extraction of Longwalls 12 to 18 within the DSC Avon Notification Area has been made. The application was supported by the following documents and data:

- Avon and Cordeaux Reservoirs DSC Notification Area Management Plan;
- Geology report for Area 3B;
- Geochemical review of connectivity between Lake Cordeaux and Dendrobium Area 2 and 3A and implications for monitoring Lake Avon and Area 3B;
- Dendrobium Area 3B Regional Groundwater Model;
- Hydrogeoleogical analysis regarding DSC’s requirements for mining within the Avon Notification Area;
- Qualitative risk assessment for loss of stored water from Avon Reservoir from the mining of Longwalls 12-18; and
- Plans.

HydroSimulations (2016) includes the use of a new and conceptually more realistic representation of flow into and through connected fracturing that occurs above longwall panels. The following results were obtained from the revised groundwater model:

- The new model configuration uses Connected Linear Networks (CLNs) to represent fracture flow. This novel approach has the benefit of simulating flow within two domains: the unfractured host rock as well as in the fractures themselves (although the model aggregates the many small real-world fractures into a number of large fractures).
- The model matches historical inflow to the Dendrobium Mine with reasonable accuracy, although slightly overestimates the flow due to a number of excessive peaks in the hydrograph.
- Dendrobium Mine inflows or groundwater make is predicted to be less than predicted previously, but still peaking at about 10 ML/d (3650 ML/a).
- Dendrobium mine inflows or groundwater make are not especially sensitive to the assumptions made regarding the height of the fractured zone above longwalls. These estimates, and the subsequent estimates of leakage from the reservoirs, are based on the two primary models for estimating the height of connected fracturing or depressurisation (Ditton and Merrick, 2014; Tammetta, 2012).
- In the case of the Avon Reservoir, the simulated maximum leakage from the reservoir storage as a result of mining Longwalls 14-19 is 0.2 to 0.3 ML/d, and is up to 0.6 ML/d based on the cumulative effect of all mining activities in this area.
- In the case of the Cordeaux Reservoir, the simulated maximum leakage from the reservoir storage as a result of mining Longwalls 14-19 is very small at 0.01 ML/d. The cumulative leakage from all simulated mining activities is about 0.32 ML/d.
- The estimated effects on groundwater discharge to and leakage from Lake Avon are slightly higher than those of HydroSimulations (2014). These differences are due to the minor changes in the simulated height of connected fracturing and due to significant differences in the way in which the fractured zone was simulated. Regardless, the simulated impacts are considered negligible, as they were by HydroSimulations (2014) and Coffey (2012a).
- The analysis of field data indicates that, based on probability, half of all undermined swamps (i.e. those within about 100 m of a longwall) will show some degree of water table drawdown following undermining. Few of the piezometers that were analysed showed any significant recovery over time. These effects are considered to be due to cracking in the shallow subsurface, rather than intersection by fractures connected to the goaf. The model results support these findings. The swamps to be undermined by the proposed longwalls, and therefore at risk of groundwater level change, are Swamps 11, 13, 14, 23 (Area 3B) and 15 (Area 3A).

The successful mining within Dendrobium Area 1, Area 2 and Area 3A with no significant inflow of water from the Cordeaux Reservoir provides confidence that mining adjacent to the Avon Reservoir 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. 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 Avon and Cordeaux Reservoir Notification Area Contingency Plan. The proposed mining in Area 3B presents a tolerable risk to Avon Reservoir and the Area 3B SMP performance measures for Lake Avon will be met.

Due to the relatively recent inclusion of ‘Before After Control Impact’ designed monitoring programmes related to long-term monitoring parameters there is some uncertainty related to the achievement of long-term performance measures for swamps. However, mining has been occurring for a number of years beneath swamps and this allows an opportunity to do some relatively simple back analysis of impacts to these features over the long-term. This approach has the disadvantage of a relatively simple experimental design whereby only obvious changes as a result of the mining are likely to be identified.

Subsidence predictions for swamps in historic mining areas were reviewed as part of the Bulli Seam Operations Project Environmental Assessment (Resource Strategies 2009). Field investigations were carried out in these swamps to assess impacts and consequences from various levels of back-predicted subsidence movement. This data was used to inform the assessment of risk of impacts and environmental consequences for the Bulli Seam Operation Project. A summary of the review findings is provided below.

Back predictions have been undertaken for 34 swamps previously subject to subsidence in the Southern Coalfield. The back predictions indicate that six of these swamps would have been subject to closure values of greater than 200mm, namely:

- Swamp STC-S4 (221mm predicted closure) at West Cliff;
- Swamp STC-S1c (276mm predicted closure) at West Cliff;
- Swamp STC-S1a (278mm predicted closure) at West Cliff;
- Swamp 12 (335mm predicted closure) at Dendrobium;
- Swamp STC-S1b (461mm predicted closure) at West Cliff; and
- Swamp STC-S2 (542mm predicted closure) at West Cliff.

Site inspections have been conducted of the swamps listed above. An additional ten swamps predicted to have been previously subject to less than 200mm valley closure were also inspected.

The inspection methods included walking the length of the swamp and recording observations of any significant environmental impacts or consequences, for example:

- Significant subsidence-induced buckling or cracking.
- Any significant erosion or scour.
- Significant vegetation dieback on a broad scale.
- Significant desiccation of vegetation or peat materials on a broad scale.

Evidence of cracking and minor erosion was observed during the site inspections, however no evidence of significant environmental consequences was observed.

A review of the impacts resulting from previous mining similar to the proposed longwall dimensions demonstrate that the performance measures set out in the Dendrobium Mine Development Consent and SMP Approvals can be met with implementation of the SIMMCP (Attachment L) and WIMMCP (Attachment O).