

## **ATTACHMENT E: ADDITIONAL INFORMATION REQUESTED BY DSC**

*The Dams Safety Committee (DSC) has reviewed the available documents pertaining to Dendrobium Mine's Extraction Plan - SMP for Longwalls 14-18. These longwalls lie partly within the Avon Notification Area.*

*Avon Dam is a major water supply dam which is prescribed by the Dams Safety Committee. It is a 72m, concrete gravity rock filled dam. The Dam is owned by WaterNSW (formerly SCA) and forms a significant part of the integrated asset base, supplying the population of the Illawarra region with drinking water.*

*The DSC is currently regulating mining within the Avon Notification Area (NA) which surrounds the Avon Dam, using its powers under the Dams Safety Act (1978) and the Mining Act (1992). The proposed mining within the NA requires an application to the DSC to mine within the NA.*

Dendrobium Mine recognises the importance of the Avon Dam and is implementing an adaptive approach with the DSC to reduce any risk from the mining of Area 3B to a tolerable level, as defined by the DSC.

Dendrobium Mine 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 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 (Attachment T). This Plan has been updated to incorporate learning's from the extraction of Longwalls 9 to 11 in Area 3B.

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 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. The purpose of the boreholes is to monitor the pressure heads in strata and to sample formation waters.
- A 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 findings to the DSC Mining Subcommittee 14 October 2015. The DSC endorsed the extraction of Longwall 12 within the Avon Notification Area 29 October 2015 and T&I approved the extraction 13 November 2015. A number of conditions were attached to the approval which are designed to collect additional data to inform the assessment and approval of future longwalls in Area 3B.

Annexure D Condition 8.1 requires monitoring of the underground workings; including identification of any time that:

- Water monitoring indicates that total outflow is significantly greater than total inflow;
- A significant groundwater flow is observed;
- Significantly increasing water flows are encountered at any time during the development of workings; or
- Any visible flow is discoloured by the presence of clay, sand or silt.

Annexure D Condition 9.1 requires a subsidence monitoring program for subsidence movements at the following mining stages:

- Prior to the extraction of coal in each panel;
- When coal extraction in each panel has been completed, and thereafter as specified in the approval.

Annexure D1 Condition 2.1 requires the monitoring of groundwater including analysis and interpretation of the results.

Annexure D1 Condition 3.1: requires the installation of boreholes, enabling groundwater samples to be taken directly from the Hawkesbury, Bulgo and Scarborough Sandstone Units in Area 3B. The groundwater samples are measured and assessed and compared with the properties of water entering the longwall mining area, water in adjacent workings, groundwater in the overlying strata and surface water in Area 3B.

Annexure D Condition 7.1: requires a detailed site water budget, including daily measurements of all water entering and leaving sections of the mine.

Annexure D Condition 5.1: requires the monitoring of geological conditions during the first workings. Features to be reported include faults, dykes, slickensided joints, and areas of cinder.

Annexure D1 Condition 4.1: requires the installation of fixed monitoring prisms and 3D GPS stations across the Native Dog Creek arm of Lake Avon. Surveys shall be undertaken prior to the start of

longwall extraction, and monthly for the first 1000m of extraction and again at the end of Longwall 12 extraction.

Annexure D1 Condition 5.1: requires the installation of two additional monitoring bores, one close to DSC Avon Dam Hole 1 (S2313) and the other close to DSC Avon Dam Hole 2 (S2314), in order to measure the permeability of strata and potential shear zones down the holes post-mining.

Annexure D Condition 18.1: requires contingency planning arrangements including any such things as the DSC considers necessary to ensure the long-term safety of the dam and/or stored waters.

Annexure D Condition 18.2: requires the preparation of a closure plan, designed to permanently seal the workings, to the satisfaction of the DSC.

With the following monitoring, management and contingencies in place Dendrobium Mine contends that the proposed mining in Area 3B presents a tolerable risk to Avon Reservoir.

*It should be understood that the interests of the DSC are specific to the safety of the Dam and its stored waters. The DSC's views on the proposed longwall extraction at Dendrobium Mine are as follows:*

*The DSC has concerns with the extraction of 300m wide longwalls within the Notification Area and the resulting height of connective fracturing above the longwall panel. Based on assessment of information to date, the DSC's recommendation is that longwall extraction not be approved within a minimum horizontal distance from the Full Supply Level (FSL) of 300m.*

Assessments undertaken for the report Estimated Height of Connected Fracturing above Dendrobium Longwalls (Attachment I) have been 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 mine areas. Vertical elevations have been converted to a height above the seam in each area. Distances are based on mine plans, lake shorelines, lake stage and geological mapping.

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 (Attachment G) 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 Mine. 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'.

The DSC Plan (Attachment T) 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 the 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.

It is appropriate that assessments of risk and tolerability of mining within the Avon Notification Area are made by the statutory body within NSW that regulate these aspects and that this is done at a time when appropriate data is available. This is the preferable situation when compared to DoPE making determinations on these aspects under Condition 5 of the Area 3B SMP Approval prior to having a full data set available.

*Given the uncertainty that exists concerning the presence of geological structures connecting the mine to the reservoir, the DSC is not in a position to recommend any longwall extraction through geological structures intercepted by first workings. Request that longwalls be set back*

*from geological structures that are projected to intercept the reservoir, leaving a hydraulic barrier of solid coal against the structure for protection against water ingress.*

In the letter 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; the longwall technique requires large areas of geologically undisturbed ground as the technique is inherently an inflexible mining system. The technique requires the extent of the extraction to be fully developed 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 controlled.

Dendrobium 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 Areas 1, 2 and 3B.

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 Longwalls 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 block prior to any secondary extraction and contingent measures in the unlikely event hydraulically charged structures are encountered.

*The Dams Safety Committee (DSC) has endorsed a series of applications by Dendrobium Mine since 2005 to conduct first workings and secondary extraction within the Cordeaux Dam Notification Area. Most recently the DSC endorsed the extraction of LW12 within the Avon Notification Area. The Committee is currently considering conditions to be placed on extraction of LWs 13 to 18, within the Avon Notification Area.*

*Given the importance of the Avon Reservoir as the primary supplier of potable water to the Illawarra (a population of over 500,000) the Committee will be applying the precautionary principle and restricting extraction within the NA unless it is proved that the extraction will not adversely affect the safety of the stored waters.*

The DSC endorsed the extraction of Longwall 12 within the Avon Notification Area 29 October 2015 and T&I approved the extraction 13 November 2015. A number of conditions were attached to the approval which are designed to collect additional data to inform the assessment and approval of future longwalls in Area 3B. The following data will be collected during the extraction of Longwall 12 and will be a critical input to any decision on further longwall extraction within the Avon Notification Area:

- Monitoring of the underground workings.
- Subsidence monitoring.

- Monitoring of groundwater including analysis and interpretation of the results.
- Installation of boreholes, enabling groundwater samples to be taken directly from the Hawkesbury, Bulgo and Scarbrough Sandstone units in Area 3B.
- A detailed site water budget, including daily measurements of all water entering and leaving sections of the mine.
- Monitoring of geological conditions during the first workings.
- Installation of fixed monitoring prisms and 3D GPS stations across the Native Dog Creek arm of Lake Avon.
- Installation of two additional monitoring bores, one close to DSC Avon Dam Hole 1 (S2313) and the other close to DSC Avon Dam Hole 2 (S2314), in order to measure the permeability of strata and potential shear zones down the holes post-mining (Attachment U).

Any decision on the appropriate setback of Longwalls 14 to 18 from the Avon Reservoir FSL without the above information is premature. The DSC has specific and appropriate processes of review and assessment to endorse an appropriate setback to the Minister for Mines.

Given that the DSC will be applying the precautionary principle and restricting extraction within the Avon Notification Area unless it is proved that the extraction will not adversely affect the safety of the stored waters there is no reason for DoPE to prematurely restrict mining of Longwalls 14 to 18 prior to gathering and interpreting the critical monitoring data from the approved Longwall 12 extraction.

*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, e.g. Reid (2007) and Hilyard et al (2012), interception of structure is one of the most difficult risks to predict. Indeed the potential impact of intercepting geological structures such as dykes and faults beneath the full supply level (FSL) of a major water supply reservoir has been identified by the DSC as being one of the major sources of risk to the storage and the most difficult of which to be certain.*

*To ensure that structures are not inadvertently intercepted, even when mines are only conducting development workings under or near to a water storage, the DSC requires mines to conduct within 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 more 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 (rather than statistically likely) structure present prior to extraction of a longwall. If anything significant is in doubt the Mine is required to get an independent review of the situation undertaken by a consultant and if doubt still remains the mining does not proceed. The DSC uses the precautionary principle when recommending applications for mining within Notification Areas around WaterNSW storages to be approved. So that if there is any doubt at all the Mine must*

*either change its mine plan appropriately or develop effective contingency measures ahead of mining.*

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.

Dendrobium Mine undertakes extensive surface based exploration, including boreholes, 2D seismic surveys and aerial magnetic surveys. The surface based exploration identifies faults, dykes and sills.

In addition to surface based exploration Dendrobium 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 controlled.

Dendrobium 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 Areas 1, 2 and 3B.

Roadways are mapped for geological and geotechnical features as well as any 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.

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.

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 block prior to any secondary extraction and contingent measures in the unlikely event hydraulically charged structures are encountered.



### **Loss of water from Avon Reservoir**

*Avon Reservoir is the primary source of potable water to the Illawarra (pop. >500,000). FSL for Avon is 320.18mAHD. Thalweg of the Native Dog Creek Arm of the reservoir (adjoins the commencement ends of LWs 12 to 18) is approximately 290mAHD. Lowest water intake for supply to the Illawarra is 301mAHD. So a connection from the reservoir to the mine has the potential to impact the supply of potable water to the Illawarra.*

Dendrobium Mine recognises the importance of the Avon Dam and is implementing an adaptive approach with the DSC to reduce any risk from the mining of Area 3B to a tolerable level, as defined by the DSC.

Dendrobium Mine has DSC Endorsement for the extraction of Longwalls 11 and 12 and the development of roadways for Longwall 13.

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 (Attachment T). This Plan has been updated to incorporate learning's from the extraction of Longwalls 9 to 11 in Area 3B.

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 Plan will be updated to incorporate learning's from the extraction of Longwall 12 and other longwalls within Area 3B.

### **In General – Possible Causes for Waterloss**

*1) Creation of a Zone Of Hydraulic Connection to the mine opening (ZOHC). Generally, when a mine opening is formed, a ZOHC occurs in the strata surrounding the mine opening. Within this zone there is a direct hydraulic connection to the workings via connected fractures or openings, with an increase in permeability over the pre-mining case of at least two orders of magnitude.*

*2) Creation of a Zone Of Surface Mining Induced Hydraulic Connectivity (ZOSMIHC). This zone includes any areas near the surface which have increased permeability as a result of mining. For purposes of risk assessment of loss of storage, the ZOSMIHC does not extend above the FSL, and affected areas must be connected to the Reservoir.*

*While there may be zones of increased permeability at the surface prior to mining the ZOSMIHC does not necessarily include these, only areas where the permeability has increased. Pre-existing permeable zones should be captured as "sources".*

*3) Other impacts outside of the ZOHC/ZOSMIHC which might increase the permeability of an element: shearing on bedding planes, dilation of bedding planes, movement on a geological "defect" which may lead to an increase in permeability.*

*The possible means for water loss as a result of mining are best explained by the general pictorial diagrams above. Causes of loss of stored waters can be summarised as;*

- flow along a geological structure or*
- flow in a permeable strata to the connected fracture zone above the longwalls.*

### **Geological Structure**

*The Mine in its risk assessment has identified through going geological structures as a risk to the safety of the stored waters. At Elouera Colliery, which adjoins the southern boundary of Dendrobium Area 3B, there is a known high stress faulted zone which transverses Elouera LWs 1 - 8 and extends below Native Dog Creek and the reservoir. This structure is shown as DF12 and NNW-1 in Dendrobium documentation.*

*It is generally known that Elouera longwalls experienced high water make and while the source of the inflows has not been identified, the possibility exists that the structure across the longwalls may have been the cause.*

*Given the proximity of the Elouera longwalls to Dendrobium Area 3B, it is probable that a geological structure when mined through by longwalls would become a conduit for surface waters.*

*Therefore through-going structure that connects the reservoir to the mine workings should be avoided.*

The Dendrobium Mine Avon Dam Notification Area risk assessment identified through going geological structures as a risk to the safety of the stored waters. Elouera Colliery adjoins the southern boundary of Dendrobium Area 3B and there is a faulted zone which transverses the Elouera longwalls. The structure shown as DF12 and NNW-1 in Dendrobium DSC Avon and Cordeaux Reservoirs DSC Management Plan (Attachment T) will be avoided by mining to ensure that the geological structure would not be mined through by longwalls and become a conduit for surface waters.

Through-going structure that connects the reservoir to the mine workings will be avoided.

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.

### ***Permeable strata connects to fracture zone above longwalls***

*Dendrobium has also identified a pathway via permeable strata to the fracture zone above the longwalls. This pathway is dependent on the height of connective fracturing extending to the Hawkesbury Sandstone (HBSS). The DSC has formed the view that the height of connective fracturing extends to the Hawkesbury Sandstone.*

*For the situation where connective fracturing extends to the HBSS and the reservoir sits in the HBSS, it is recommended that management controls include:*

- *no extraction within a 300m horizontal distance from the FSL*

*Other management controls for consideration in reducing impacts at the surface would include:*

- *reduced width of longwall panels and/or*
- *reduced height of coal extraction, to decrease the height of connective fracturing.*

*A paper by K. Mills of SCT on movement on a shear plane below the Sandy Creek Arm of Cordeaux Reservoir documents the existence of shear planes below valleys as naturally occurring. The permeability of these horizons could increase after longwall mining.*

*The possibility of shear planes being present below Lake Avon and the potential for flow along these planes was not addressed by Dendrobium in their documentation. Consequently the DSC requested the mine address the possibility. The Mine contracted K. Mills of SCT to assess the concerns of the DSC. It was determined that although the possibility for flow along a shear plane exists the quantity of water reporting to the mine would be well within the DSC tolerable limit. Provided the longwalls are separated horizontally from the lake by a minimum distance of 300m.*

In the letter 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. 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 at Blue Panel and Gilmore Shunt were both associated with shallow depth. 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. Additional monitoring has been installed to measure basal shear between the Avon Reservoir and the mine to determine if greater setbacks are required.

Any decision on the appropriate setback of Longwalls 14 to 18 from the Avon Reservoir FSL without the above information is premature. The DSC has specific and appropriate processes of review and assessment to endorse an appropriate setback to the Minister for Mines.

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:  $A = 2.215 W^{0.357} H^{0.271} T^{0.372} \pm [0.16 - 0.1 W']$  (metres)
- Geology Model:  $A = 1.52 W^{0.4} H^{0.535} T^{0.464} t'^{-0.4} \pm [0.15 - 0.1 W']$  (metres)

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

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

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

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

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

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

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

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

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

The main conclusions from this assessment are:

- There are numerous 'little or no depressurisation' points below the calculated Tammetta H level, which is conceptualised as the height of complete groundwater drainage. This suggests that the Tammetta (2013) method overestimates the height of complete drainage at Dendrobium.
- 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 Mine are:

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

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

Analysis of the inflow to each mine area shows:

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

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

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

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

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

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

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

### **Conclusions**

*Significant risks to the safety of the stored waters may include permeable geological units, permeable geological structures, non-structure non-strata permeable zones (shear planes), topographic low points adjacent to the lake, and mining impacts on permeability.*

*Given the consequence of a connection from the reservoir to the mine, it is recommended:*

- *that extraction is not allowed within a minimum horizontal distance to the FSL equal to 300m.*
- *Also extractions through geological structures projected to intersect the Reservoir are avoided.*

The DSC endorsed the extraction of Longwall 12 within the Avon Notification Area 29 October 2015 and T&I approved the extraction 13 November 2015. A number of conditions were attached to the approval which are designed to collect additional data to inform the assessment and approval of future longwalls in Area 3B.

Any decision on the appropriate setback of Longwalls 14 to 18 from the Avon Reservoir FSL without the above information is premature. The DSC has specific and appropriate processes of review and assessment to endorse an appropriate setback to the Minister for Mines.

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.

Dendrobium Mine undertakes extensive surface based exploration, including boreholes, 2D seismic surveys and aerial magnetic surveys. The surface based exploration identifies faults, dykes and sills. In addition to surface based exploration Dendrobium relies on in-seam exploration. In-seam drilling is

undertaken between development roadways and reservoirs to identify and define any geological features.

Dendrobium 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 Areas 1, 2 and 3B.

Roadways are mapped for geological and geotechnical features as well as any 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.

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.

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 block prior to any secondary extraction and contingent measures in the unlikely event hydraulically charged structures are encountered.

Given that the DSC will be applying the precautionary principle and restricting extraction within the Avon Notification Area unless it is proved that the extraction will not adversely affect the safety of the stored waters there is no reason for DoPE to prematurely restrict mining of Longwalls 14 to 18 prior to gathering and interpreting the critical monitoring data from the approved Longwall 12 extraction.

*Adaptive management steps to reduce the height of connective fracturing could be undertaken including:*

- *Reduce the width of the longwalls*
- *Reduce the height of extraction*

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

Attachment I presents analysis of the distances between the nearest arm of either Lake Cordeaux and Avon to each of the mine areas. Vertical elevations have been converted to a height above the seam in each area.



The Dendrobium Regional Groundwater Model (Attachment G) uses the revised estimates of the height of connected fracturing. 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 Mine (Attachment G). 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'.

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 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 Mine water chemistry data, to:

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

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

In 2016 Hydrosimulations conducted an assessment of the height of connected fracturing above the seam at Dendrobium (Attachment G). In order to constrain estimates for heights of connective fracturing and the mechanisms for inflow to the mine, Hydrosimulations looked at the following sets of monitoring data:

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

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

The 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 the confidence that mining within Area 3B has an acceptable risk.

### **Approval Conditions**

*A program to collect and analyse data and report on the water chemistry of the overlying strata, the water entering the mine and the Reservoir waters.*

- *At a minimum, water should be sampled on a monthly basis and analysed for algae, trace element analyses and Tritium isotopes.*
- *Sampling borehole sites between the mine workings and the Reservoir should be established, and as much background data as possible be obtained prior to extraction.*
- *A means of analysing and assessing the implications of the results from the monitoring needs to be established. This would involve a review team with the authority to commission further studies if needed and to approve changes to the mine plan if it were thought necessary.*
- *Results of programs should be made available to interested government departments and WaterNSW*

*Hydraulic barriers need to be established against identified structures.*

*The establishment of boreholes between the Reservoir and mine workings, to monitor groundwater pressure in the Hawkesbury Sandstone below the level of the thalweg of the Reservoir.*

- *Results from the monitoring should be compared to those predicted by the Groundwater Model and the model updated as required*
- *The results should be assessed by an independent team whose purpose it is to ensure that the approved mining is occurring as predicted.*

The DSC endorsed the extraction of Longwall 12 within the Avon Notification Area 29 October 2015 and T&I approved the extraction 13 November 2015. A number of conditions were attached to the approval which are designed to collect additional data to inform the assessment and approval of future longwalls in Area 3B. These conditions have been implemented.

Annexure D Condition 8.1 requires monitoring of the underground workings; including identification of any time that:

- Water monitoring indicates that total outflow is significantly greater than total inflow;
- A significant groundwater flow is observed;

- Significantly increasing water flows are encountered at any time during the development of workings; or
- Any visible flow is discoloured by the presence of clay, sand or silt.

Annexure D Condition 9.1 requires a subsidence monitoring program for subsidence movements at the following mining stages:

- prior to the extraction of coal in each panel;
- when coal extraction in each panel has been completed, and thereafter as specified in the approval.

Annexure D1 Condition 2.1: requires the monitoring of groundwater including analysis and interpretation of the results.

Annexure D1 Condition 3.1: requires the installation of boreholes, enabling groundwater samples to be taken directly from the Hawkesbury, Bulgo and Scarborough Sandstone units in Area 3B. The groundwater samples are measured and assessed and compared with the properties of water entering the longwall mining area, water in adjacent workings, groundwater in the overlying strata and surface water in Area 3B.

Annexure D Condition 7.1: requires a detailed site water budget, including daily measurements of all water entering and leaving sections of the mine.

Annexure D Condition 5.1: requires the monitoring of geological conditions during the first workings. Features to be reported include faults, dykes, slickensided joints, and areas of cinder.

Annexure D1 Condition 4.1: requires the installation of fixed monitoring prisms and 3D GPS stations across the Native Dog Creek arm of Lake Avon. Surveys shall be undertaken prior to the start of longwall extraction, and monthly for the first 1000m of extraction and again at the end of Longwall 12 extraction.

Annexure D1 Condition 5.1: requires the installation of two additional monitoring bores, one close to DSC Avon Dam Hole 1 (S2313) and the other close to DSC Avon Dam Hole 2 (S2314), in order to measure the permeability of strata and potential shear zones down the holes post-mining.

Annexure D Condition 18.1: requires contingency planning arrangements including any such things as the DSC considers necessary to ensure the long-term safety of the dam and/or stored waters.

Annexure D Condition 18.2: requires the preparation of a closure plan, designed to permanently seal the workings, to the satisfaction of the DSC.

With the following monitoring, management and contingencies in place Dendrobium Mine contends that the proposed mining in Area 3B presents a tolerable risk to Avon Reservoir.

These approval conditions have been included in an updated DSC Avon and Cordeaux Notification Area Management Plan (Attachment T) and will ensure data is collected, analysed and reported as required by the DSC. As requested by DSC data is being collected on the water chemistry of the overlying strata, the water entering the mine and the Reservoir waters. Water is sampled as described

in the DSC Plan which includes sampling for algae, trace element analyses and Tritium isotopes at a monthly or more frequent basis.

Sampling boreholes have been established between the mine workings and the Reservoir to provide sufficient background data prior to extraction. Avon Dam Hole 1 (S2313) and Avon Dam Hole 2 (S2314) were drilled in Dendrobium Area 3B during the period June-August 2015 (Attachment U).

Monitoring data is analysed and assessed as described in the DSC Management Plan. A review team meets on a monthly basis or more frequently if needed and provides reports to the DSC and other interested agencies. The DSC is able to approve changes to the mine plan if it were thought necessary. The results of programs are made available to interested government departments and WaterNSW. Results from the monitoring will be compared to the Dendrobium Regional Groundwater Model. The Dendrobium Regional Groundwater Model was updated March 2016 (Attachment G) and will be further updated as required. Monitoring results and interpretation is regularly presented and discussed with the DSC whose purpose is to ensure that the approved mining is occurring as predicted.

Annual reporting of matters related to the DSC are via established mechanisms required by the Development Consent, including the AEMR (required under Condition 5, Schedule 8), which is available on the South32 website.