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13 October 2015

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Dear Gary

ASSESSMENT OF POTENTIAL INFLOWS FROM AVON RESERVOIR INTO AREA 3B VIA BASAL SHEAR PLANES ASSOCIATED WITH VALLEY CLOSURE

Please find herein a summary of our initial review of available data in relation to the potential for inflow from Avon Reservoir into Area 3B via the horizontal shear planes that exist naturally and others that are likely to form as a result of downslope movements associated with mining subsidence.

1. SUMMARY

Dendrobium Mine owned by South32 Pty Ltd (South32) proposes to mine Longwall 12 and subsequent longwall panels in Area 3B in close proximity to Avon Reservoir, some 18 km west of Wollongong. The Dams Safety Committee (DSC) has identified, in a screening risk assessment for the proposal, two pathways for loss of water from Avon Reservoir along basal shear planes extending from the reservoir, one into the fracture network above each panel and the other into Wongawilli Creek. The DSC has requested that these pathways be investigated and the potential inflows quantified. South32 commissioned SCT Operations Pty Ltd (SCT) to review the data from the extensive piezometer monitoring and the exploration programs available in the area to address the DSC requirements. This report presents the results of our initial review of the available data as well as recommendations for additional quantitative measurements to better define the hydraulic conductivity of potential basal shear planes identified at the site through packer testing.

Our initial assessment indicates that the first of the pathways identified by the DSC – the flow pathway along basal shear planes into the connected fracture network above each of the proposed longwall panels – is likely to exist at this site at the completion of mining if it does not exist already as a result of natural processes. As the flow path may not be fully developed yet, because Longwall 12 has yet to be mined, it is difficult to quantify the hydraulic conductivity of the fully developed fractures from the data that is currently available.

Hydraulic conductivity measurements in one or more fully developed bedding plane shears at equivalent sites are recommended to determine if the inflows are tolerable or not. An extended injection fall off test is recommended because of the larger fracture volume that is able to be tested using this method compared to packer testing.

High conductivity zones observed in packer testing of the two holes drilled close to Avon Reservoir indicate that, assuming these high conductivity zones are basal shear planes and the hydraulic conductivity does not increase significantly as a result of mining Longwall 12, this flow path may be capable of delivering up to about 0.04 Ml/day for the geometry that would exist at the completion of Longwall 12. The flow would then be expected to increase incrementally with each additional longwall panel by about 0.03 Ml/day (again assuming no further increase in hydraulic conductivity). A natural reduction in hydraulic conductivity over time would be expected as fines move into the fracture and reduce its hydraulic conductivity. As such flows along this pathway are considered likely to be within the tolerable range based on the DSC assessment criteria described in Hilyard et al (2011).

In previous mining areas at Dendrobium, the barrier between the Full Supply Level (FSL) of the reservoir (Cordeaux Reservoir) was 262 m in Areas 1 and 2, and 410 m in Area 3A. The larger barrier size in Area 3A was a result of the protection barrier associated with Sandy Creek Waterfall which coincidentally provided the larger barrier to the reservoir. The proposed barrier size between the FSL of Avon Reservoir and the nearest goaf edge have been estimated from available drawing files as being 302 m for Longwall 12 and 236 m, 251 m, 232 m, 224 m, 223 m, and 226 m respectively for Longwalls 13-18.

Notwithstanding the challenges of differentiating sources of inflow to an underground mine, previous mining at Dendrobium Mine 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 barrier provided to Longwall 12 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. It is noted that overburden depth to the mining horizon is unlikely to play a significant role in the effectiveness of barriers to prevent inflows associated with basal shears given the mining geometries at Dendrobium Mine.

There is considered to be no potential for the other pathway identified by the DSC, i.e. flow from Avon Reservoir to Wongawilli Creek, to be a credible source of loss from Avon Reservoir. The general downward hydraulic gradient between Avon Reservoir and Wongawilli Creek precludes this pathway. The downward gradient existed prior to mining in Area 3B and has continued to develop with additional longwall mining in the area.

2. INTRODUCTION

Dendrobium Mine owned by South32 proposes to mine Longwall 12 and subsequent longwall panels in Area 3B in close proximity to Avon Reservoir. The DSC has identified, in a screening risk assessment for the proposal, two pathways for loss of water from Avon Reservoir along basal shear planes extending from the reservoir, one into the fracture network above each panel and the other into Wongawilli Creek. The DSC has requested that these pathways be investigated and the potential inflows quantified. South32 commissioned SCT to review the data from the extensive piezometer monitoring and the exploration programs available in the area to address the DSC requirements. This report presents the results of our initial review of the available data as well as recommendations for additional quantitative measurements to better define the hydraulic conductivity of basal shear planes identified at the site through packer testing.

South32 has a comprehensive program of monitoring in place across Area 3B including background monitoring for an extended period prior to mining as well as monitoring in areas that have been mined. This monitoring provides insight into how the groundwater systems have been influenced by mining. A review of the piezometer monitoring, interference testing, and packer testing have provided a strong basis from which to assess the influence of mining on the groundwater systems. The focus of the assessment presented in this report has been directed towards the potential for basal shear planes developed by mining subsidence movements at about the level of the base of the reservoir to create a flow path between the reservoir and the fracture network developed above each of the longwall panels.

3. SITE DESCRIPTION

Figure 1 shows a plan of the proposed mining in Area 3B in the vicinity of Avon Reservoir, overburden depth contours to the Wongawilli Seam mining horizon, and the location of two boreholes, S2313 and S2314, drilled in the area between the reservoir and the proposed longwall panels.

Figure 2 shows a stylised section showing the relative distances from through the boreholes to the reservoir and to the goaf edge of Longwall 11. The corner of Longwall 11 is approximately 680 m from the FSL of Avon Reservoir.

The FSL of Avon Reservoir is at RL320.2 m AHD. In this area, the bottom of the reservoir is estimated to be at between RL285 m and RL290 m.

S2313 is located approximately 340 m from the FSL of Avon Reservoir, the reduced level of the collar is RL415.28 m, and the hole was drilled to 194.75 m. The Bald Hill Claystone was intersected in this hole between 162.43 m and 178.32 m. The reduced level of the top of the Bald Hill Claystone is at approximately RL253 m.

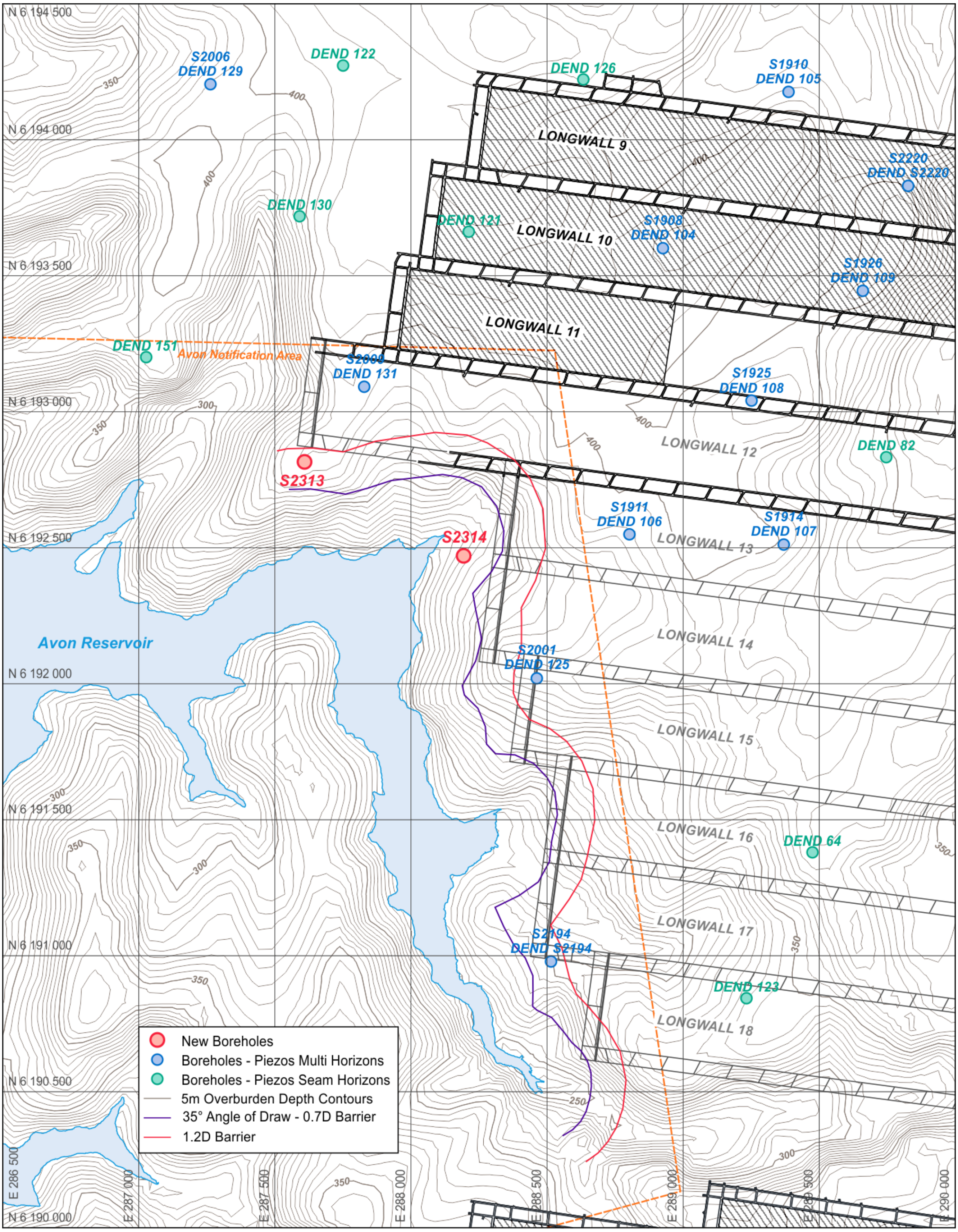


Figure 1: Site plan showing the overburden depth contours and location of current and proposed longwall panels in Area 3B relative to Avon Reservoir.

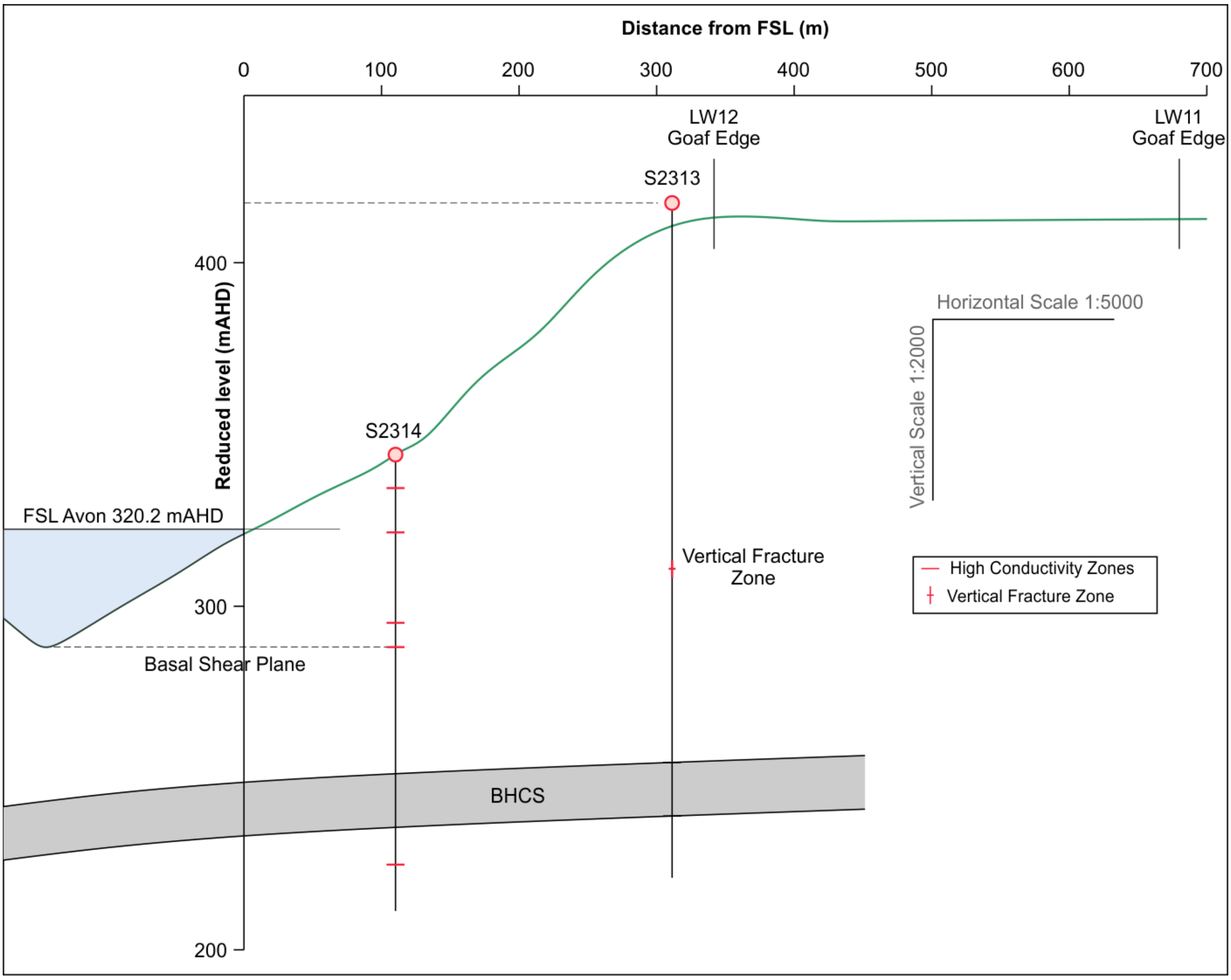


Figure 2: Stylised Cross Section between Longwall 12 and Avon Reservoir.

S2314 is located approximately 110 m from the FSL of Avon Reservoir, the reduced level of the collar is RL342.36 m, and the hole was drilled to 131.78 m. The Bald Hill Claystone was intersected in this hole between 95.08 m and 110.45 m. The reduced level of the top of the Bald Hill Claystone is at approximately RL247 m.

The Wongawilli Seam mining horizon is located at an elevation of between RL0 m AHD and RL30 m AHD through the area between Longwall 12 and the FSL of Avon Reservoir.

4. Basal Shear Planes

The term "basal shear plane" is used to refer to the deepest of the horizontal shear planes that accommodate differential horizontal shear movements associated with the phenomenon of horizontal movement in a downslope direction, also known as valley closure. The basal shear plane is the interface between the ground that moves laterally toward the valley and the ground below the base of the valley that is buttressed by the rock on the other side of the valley.

Figure 3 illustrates the mechanism envisaged to cause mining induced basal shear planes. When strata subsides incrementally such as above a longwall panel, there is a tendency for it to fracture and dilate. Dilation, effectively an increase in volume, occurs because fractures are created and these fractures occupy some volume. Dilation occurs in all directions but, consistent with taking conservation of energy principles, dilation movements tend to occur in the direction of the path of least resistance. In circumstances where horizontal dilation associated with mining subsidence is constrained by the adjacent intact rock strata on either side of the panel there is a tendency for dilation to occur predominantly in a vertical direction or in a direction along the panel. In sloping terrain however, strata that forms the flanks of a valley is least constrained in a downslope direction directly toward the valley. Dilation movements drive the valley sides horizontally in this downslope direction because it is the direction of least resistance. The interface between the deeper constrained strata and the upper less constrained strata located above the base of the valley develops as a basal shear horizon.

Basal shear planes have been inferred to exist for several decades; indeed since horizontal movements in a downslope direction were first recognised. However, there have been relatively few direct observations. A profile of horizontal closure in a steep gorge presented in Hebblewhite et al (2000) shows that most of the horizontal movement occurs at the level at or close to the base of the valley. When longwall panels were mined in Area 4 at Appin, a basal shear plane was observed to develop at the level of the Cataract Tunnel and was able to be observed visually for some distance along the tunnel alignment. This basal shear plane was inferred to have developed suddenly during a seismic event in the area.

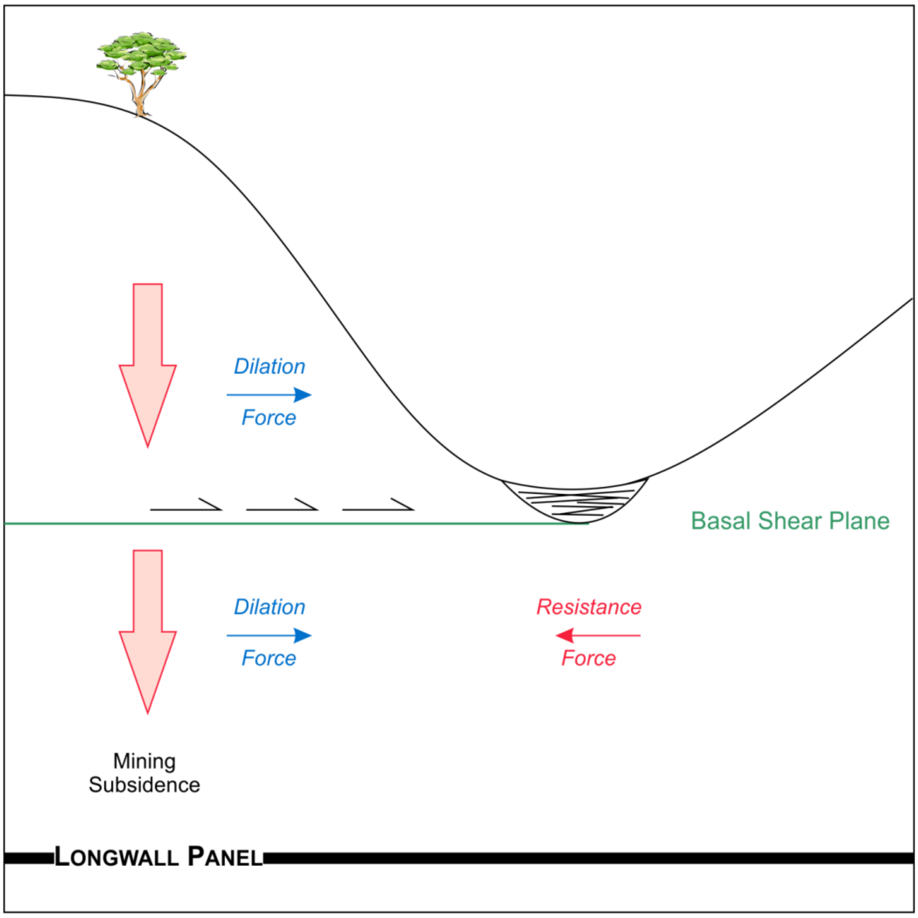


Figure 3: Mechanism leading to the formation of mining induced basal shear planes.

Mills (2007) reports the presence of a basal shear plane during a characterisation study in a river valley west of Helensburgh. Walsh et al (2014) report inclinometer measurements that identified mobilisation of shear movements at two horizons that correspond with the base of river channels upstream and downstream of a 20 m high waterfall at Sandy Creek in New South Wales. The shear movements developed gradually with mining and appeared to be remobilised by high intensity rainfall events once mining was complete. Mills (2014) presents an analysis of the stability of the slopes above Sandy Creek Waterfall showing that basal shear planes adjacent to valleys are likely to be at close to limiting equilibrium in shear in their natural condition and that mining has the capacity to remobilise them.

There are no known studies aimed directly at measuring the hydraulic conductivity of basal shear planes. There have undoubtedly been some measurements conducted as part of packer testing campaigns without potentially higher conductivity horizons necessarily being recognised as basal shear planes.

Further work is recommended to study the hydraulic characteristics of basal shear planes. Mining induced basal shear planes are likely to be initially more conductive than shear surfaces that may have developed gradually over geological time and subsequently healed through natural weathering processes. It is considered likely that mining induced basal shear planes will also infill over extended periods through fines migration and gradual infilling so that they become less hydraulically conductive with time. However, the speed at which these infilling processes may occur is unknown.

Figure 4 shows some photographs of shear planes that have been mobilised by mining subsidence in rock outcrop. The relative offsets of vertical features can be seen across the shear plane. Significant vertical fractures are also evident. These vertical flow paths are typically observed to be restricted at horizontal shear planes so that the overall vertical inflow rates through the strata is effectively controlled by the hydraulic conductivity of the horizontal shear plane.

It is noted that vertical holes are more likely to intersect horizontal bedding planes and basal shear planes than they are to intersect steeply dipping fractures such as those shown in Figure 4. These steeply dipping fractures may be more hydraulically conductive than horizontal shear planes but they are also less likely to be intersected by vertical boreholes.

5. HYDRAULIC CONDUCTIVITY INDICATED BY PACKER TESTING

Packer testing in S2313 and S2314 shows several zones of elevated hydraulic conductivity.

Figures 5 and 6 show the packer testing results summarised as a function of depth below surface.

The one higher conductivity zone in S2313 at a depth of about 107 m appears to be associated with a vertical fracture. This zone does not align with the base of the valley and appears unlikely to be associated with a basal shear plane. S2313 is some 340 m from the reservoir and 540 m from the nearest longwall goaf, so it is possible that a basal shear plane associated with the valley in which Avon Reservoir is located has yet to develop through this area.

Multiple zones in S2314 include two that are approximately at the same level as the base of the reservoir. These are likely to have formed naturally because the area is remote from active mining, but the elevations of these zones is consistent with their being associated with basal shear planes.

Mining induced horizontal movements are recognised as likely to cause remobilisation of existing naturally formed basal shear planes or create new ones if none exist. However, the relationship between hydraulic conductivity of these shear horizons and the magnitude of shear movements remains unknown.

Figure 4: Examples of mining induced shear movements causing offsets and associated vertical fracturing.

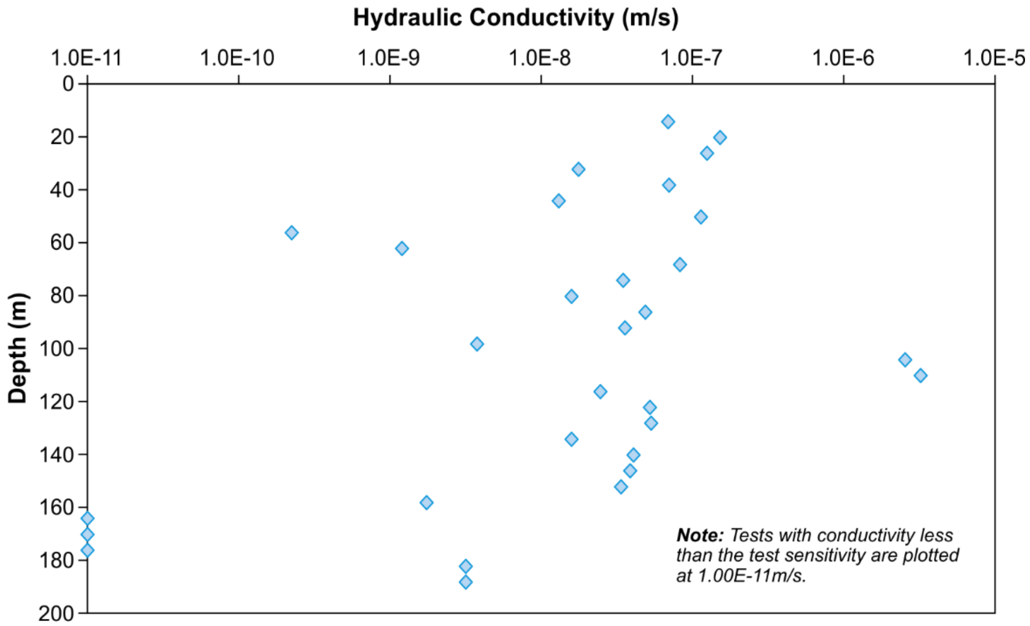


Figure 5: S2313 hydraulic conductivity profile based on packer testing results.

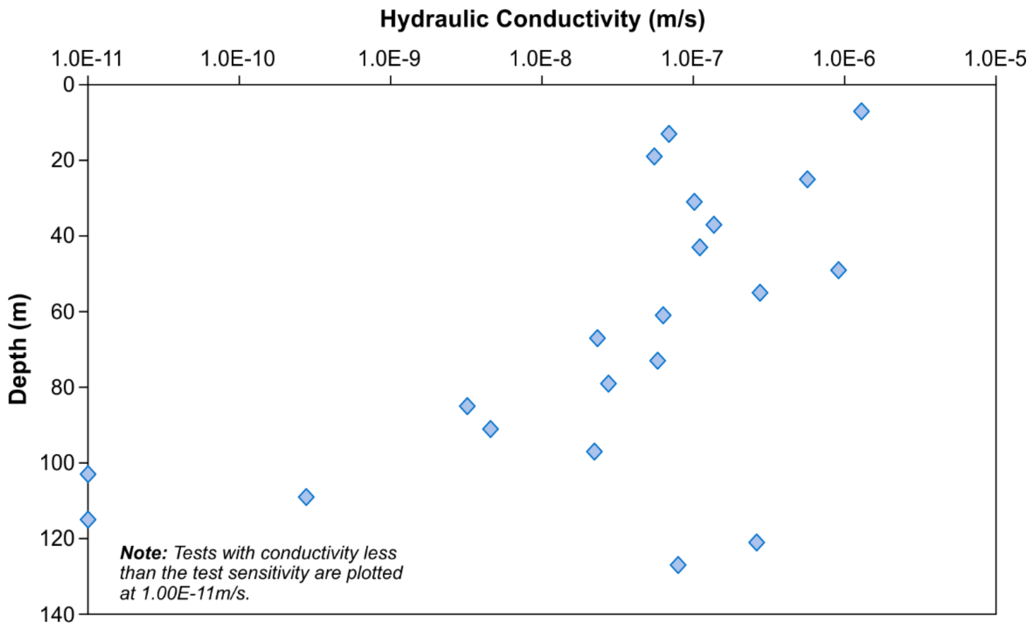


Figure 6: S2314 hydraulic conductivity profile based on packer testing results.

Assuming the two high conductivity zones observed in the packer testing in S2314 are associated with basal shear horizons and their hydraulic conductivity does not increase significantly as a result of mining Longwall 12 which will remain beyond 300 m from the edge of the reservoir, a flow path with these hydraulic conductivities may be capable of delivering up to about 0.04 Ml/day for the geometry that would exist at the completion of Longwall 12. This calculation is based on Darcy's Law assuming a horizontal flow path length of 420 m (300 m to the edge of Longwall 12 and a further 120 m over the goaf edge of Longwall 12 to intersect the fracture network above the panel), a hydraulic head equal to 35 m (the depth of the reservoir to the shear plane), an area based on a representative length along the reservoir of 500 m and a packer test interval of 6 m (giving 3000 m^2), and a hydraulic conductivity of 2 x 10^{-6} m/s as measured in the packer testing.

Using a similar methodology to calculate flow, the flow would be expected to increase incrementally with each additional longwall panel by about 0.03 Ml/day (again assuming no further increase in hydraulic conductivity due to mining). A natural reduction in hydraulic conductivity over time would be expected as fines move into the fracture and reduce its hydraulic conductivity. As such flows along this pathway are considered likely to be within the tolerable range based on the DSC assessment criteria described in Hilyard et al (2011).

These estimates of inflow are strongly dependent on the assumed representative hydraulic conductivity of the basal shear planes. Further testing to confirm the hydraulic conductivity of basal shear planes at a range of equivalent post mining sites is recommended. Ideally both short term and long term measurements would be made. A program of injection fall-off tests are recommended as likely to provide a more quantitative measure of the hydraulic conductivity of basal shear planes because of their capacity to test a larger volume of the fracture.

6. Discussion of Previous Experience and Barrier Size

Although the presence of basal shear planes has only 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 Coalfields 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. In this section, the barrier sizes are compared and discussed in terms of their relative effectiveness.

In previous mining areas at Dendrobium, the barrier between the Full Supply Level (FSL) of the reservoir (Cordeaux Reservoir) was 262 m in Areas 1 and 2, and 410 m in Area 3A. The larger barrier size in Area 3A was a result of the protection barrier associated with Sandy Creek Waterfall which coincidentally provided the larger barrier to the reservoir.

In the area of interest in Area 3B, the proposed barrier size between the FSL of Avon Reservoir and the nearest goaf edge have been estimated from available drawing files as being 302 m for Longwall 12 and 236 m, 251 m, 232 m, 224 m, 223 m, and 226 m respectively for Longwalls 13-18.

Notwithstanding the challenges of differentiating sources of inflow to an underground mine, previous mining at Dendrobium Mine 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 presence of geological structure is also likely to have had an effect and it is recognised that inflow through geological structure needs to be assessed on a case by case basis.

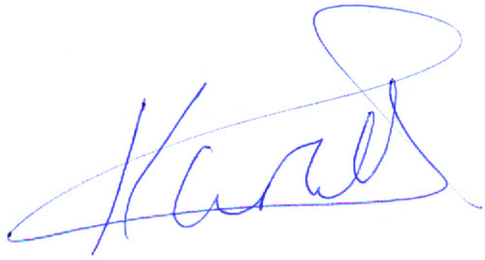
The barrier provided to Longwall 12 in the design of Area 3B is greater than the barrier provided previously to Cordeaux Reservoir and so a greater level of protection would be expected. The barriers proposed for Longwalls 13-18 are less by up to about 40 m and, although they would need to be increased to provide the same size offsets as previously, there does not appear to be a compelling reason to do so. Overburden depth to the mining horizon is unlikely to play a significant role in the effectiveness of barriers to prevent inflows associated with basal shears given the mining geometries at Dendrobium Mine.

7. Loss to Wongawilli Creek

A second flow pathway was identified by the DSC from Avon Reservoir to Wongawilli Creek. Such a pathway is considered credible, albeit with low potential for significant flow, if the longwall panels were narrow and deep so that the basal shear plane did not intersect the mining induced fracture network above each individual longwall panel. However, there is evidence of a general downward hydraulic gradient between Avon Reservoir and Wongawilli Creek toward the mining horizon that precludes this pathway. The downward gradient existed prior to mining in Area 3B and piezometer monitoring indicates that this downward gradient has continued to develop with additional longwall mining in the area. Loss from Avon Reservoir into Wongawilli Creek is not considered a credible in this circumstance.

If you have any queries or require further clarification of any of these issues, please don't hesitate to contact me directly.

Regards



Ken Mills
Principal Geotechnical Engineer

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