INDEPENDENT ADVISORY PANEL FOR UNDERGROUND MINING

ADVICE RE:

DENDROBIUM COAL MINE

LONGWALL 18

SUBSIDENCE MANAGEMENT PLAN

November 2020

EXECUTIVE SUMMARY

Overview

The Executive Director of Energy, Industry and Compliance, NSW Department of Planning, Industry and Environment requested the Independent Advisory Panel for Underground Mining (the Panel) to provide advice in relation to the Subsidence Management Plan (SMP) for Longwall 18 (LW18) in Area 3B at the Dendrobium Coal Mine. Specifically:

> *The Department requests advice from the Panel as to the adequacy of the investigations completed for the SMP on the potential leakage from Avon Dam associated with these geological structures, and whether an increased offset distance from the full supply level of Avon Dam would be warranted to reduce risks of increased leakage from the reservoir into either Area 3B or the Elouera colliery workings.*
>
> *The Panel should also feel free to provide any other advice it considers would assist the Department in reviewing the Extraction Plan.*

LW18 is the southern-most longwall panel planned in Area 3B and is bounded to the south by the defunct workings of Elouera Colliery, to the west by Lake Avon and to the east by Wongawilli Creek. The area is impacted by a range of different geological features that include the Elouera Fault system and a number of lineaments. It is also susceptible to mining-induced impacts that include the generation of basal shear planes and the relaxation of confinement across the Elouera Fault. The potential for these to impact on water quantity and quality in the catchment if LW18 is extracted has been identified for some years as a matter requiring careful consideration.

The SMP is based on LW18 having been shortened by some 800 m from originally planned and set back about 70 m from the fault zone. Subsidence predictions for the new layout have been updated and the SMP has been subjected to a peer reviewed risk assessment. The Panel is satisfied with these documents and does not consider that a critique of them is warranted to address the Department's Scope of Works.

Hence, this advice is focused on the Groundwater and on the Surface Water sections of the SMP. The Groundwater section is directly relevant to the Department's request for the Panel to advise on the adequacy of investigations and setback distance from Lake Avon. The Surface Water section is also relevant to aspects of this request and to responding to the Department's invitation to provide any other advice it considers would assist the Department in reviewing the Extraction Plan.

Conclusions

Groundwater

1. The Panel acknowledges the genuine and significant investigations undertaken to specifically consider the potential effects of mining LW18 on lineaments, the Elouera Fault Zone and leakage from Lake Avon. The additional field data and focus on characterizing the Elouera Fault and subsequent specific modelling of predicted potential changes following mining of LW18 are noted in particular.
2. Based on the information provided and reviewed by the Panel, the Panel considers the following predictions of the groundwater impacts associated with the mining of LW18 to be reasonable:
    i. Increased leakage from Lake Avon ranges between of 0.01 and 0.13 ML/day (Watershed HydroGeo, 2020);
    ii. Increased leakage from overlying water courses (not including Lake Avon) estimated at a maximum of 0.46 ML/day (Watershed HydroGeo, 2020);

iii. Increased inflow to the mine workings is estimated to be between 0.5 and 1.5 ML/day, (Watershed HydroGeo, 2020).

Surface Water

1. The surface water report supporting the SMP (Attachment D) is of a high technical standard with clear and generally appropriate interpretations of the data. A constructive effort has been made to address the recommendations of the IEPMC (2019).
2. The Panel has no concerns about incremental subsidence impacts on Wongawilli Creek due to LW18; and considers that the total incremental increase in surface water loss from Lake Avon and its tributaries due to LW18 is likely to be very low compared to existing losses due to Dendrobium mine.
3. The nature and degree of water quality impacts is likely to be similar to those previous experienced in Area 3B.
4. There is a sufficient number of surface water monitoring (flow, pool and water quality) sites and they are at suitable locations.
5. Good progress has been made in improved use of control stations in the estimation of surface flow losses and in improved TARPs. However, further assessment and peer review of the new accounting methods and TARPs are required prior to regarding them as suitable for use.
6. While the water quality TARPs are acceptable for management of LW18 impacts, the water quality TARPs are not sufficient indicators of medium to long-term trends in water quality.

Generally

1. Overall, the SMP reflects a genuine effort to undertake sound field studies, numerical modelling and risk assessment.
2. The Panel concludes that it largely responds to and satisfies the recommendations of the Part 1 report of the IEPMC (Part 2 only being published while the SMP was in the process of being prepared) and a number of other past reviews and advices prepared for the Department in relation to Dendrobium Mine.
3. The Panel concludes that the investigations undertaken into assessing the potential for additional leakage from Lake Avon due to the extraction of LW18 are adequate and that based on the outcomes of those investigations, there is no need to increase the setback distance of 300 m from Lake Avon.

Recommendations

Groundwater

1. The Panel supports the recommendation of DPIE Water for additional standpipe monitoring bores to be constructed adjacent to vibrating wire piezometers (VWP) to provide validation of VWP sensor data.
2. It is recommended that one or two additional nested groundwater monitoring sites are established to the south west of LW18: either between LW18 and Lake Avon and/or between LW18 and the Elouera Mine workings, in order to consider groundwater pressures and water quality in the shallow/mid and deeper Hawkesbury Sandstone.
3. Ongoing monitoring of groundwater levels within the fault should continue at site 3 (S2490).
4. The Panel supports the recommendation to construct either VWPs or open holes at the vertical holes at Sites 1 and 2. Ongoing monitoring of pressures should occur at these two sites. Ideally, if future drilling is to occur in this area, consideration should be given as to whether an open standpipe bore into the fault zone could be constructed to provide both verification of water level and also to provide for monitoring of water quality changes within the fault over time.

5. The Panel recommends additional stress investigations at end of mining LW18 to confirm unloading changes.
6. Monitoring the groundwater (both pressures at depth and the water table) overlying Elouera Mine is recommended. This information will contribute to the conceptual understanding of groundwater recovery processes post mining in this area.
7. Any observed reversal in the Hawkesbury Sandstone groundwater level gradients between Lake Avon and the Elouera fault monitoring bores to the south-west of LW18 should result in a review by an independent expert to ascertain the water loss rate (as committed to in the South32 Response to Agency advice).
8. For future mining areas groundwater TARPS and performance measures should be considered.

Surface Water

1. The previous (pre-LW15) surface water flow TARPs should be employed in parallel with the new surface water flow TARPs, and the most conservative outcome taken, until the new trigger metrics have undergone further assessment and peer review for fitness for purpose.
2. A method of quantifying and reporting trends in key water quality indicators (both concentrations and loads) should be trialled in addition to applying the proposed water quality TARPs.

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1. INTRODUCTION AND SCOPE OF WORKS

On 28 October 2020, the Executive Director of Energy, Industry and Compliance, NSW Department of Planning, Industry and Environment (Mr Mike Young) requested the Independent Advisory Panel for Underground Mining (the Panel) to provide advice in relation to the Subsidence Management Plan (SMP) for Longwall 18 (LW18) in Area 3B at the Dendrobium Coal Mine. Specifically:

> *The Department requests advice from the Panel as to the adequacy of the investigations completed for the SMP on the potential leakage from Avon Dam associated with these geological structures, and whether an increased offset distance from the full supply level of Avon Dam would be warranted to reduce risks of increased leakage from the reservoir into either Area 3B or the Elouera colliery workings.*
>
> *The Panel should also feel free to provide any other advice it considers would assist the Department in reviewing the Extraction Plan.*

The Chair of the Panel (Em. Professor Jim Galvin) nominated the following members of the Panel to prepare the advice:

- Em. Professor Jim Galvin – Chair – Subsidence and Mining
- Dr Neil McIntyre – Surface Water
- Liz Webb – Groundwater

2. METHOD OF OPERATION

COVID19 constraints prevented the Panel from meeting in person and from undertaking a site inspection, with the Panel convening by videoconference. It sourced additional reports from the Department and submitted two sets of questions for the Proponent that were addressed by way of written responses and additional reports.

A wide range of documents were reviewed by the Panel in preparing this review, the principal ones being:

1) Longwall 18 Area 3B - Subsidence Management Plan, August 2020
2) Longwall 18 Area 3B - Subsidence Management Plan, August 2020- Attachments A to G
3) Agency advice on LW18:
    a) WaterNSW, 21 Sep 2020 and 9 November 2020
    b) Dams Safety NSW, 18 Sep 2020
    c) Environment Energy and Science, 31 August 2020
    d) Heritage NSW, 10 Sep 2020
    e) Mining. Energy and Geoscience, 11 Sep 2020
    f) Resources Regulator, 17 Sep 2020
    g) Subsidence Advisory, 8 Sep 2020
4) South32 response to Agency Advice, 29 September 2020
5) Agency advice on South32 response, 15 October 2020
6) Additional background information
    a) Development consent conditions
    b) SMP LW17 approval conditions
    c) End of Panel Report LW 15 (Summary Report)
    d) Annual Review 2020

7) Responses, dated 11/11/2020 and 16/11/2020 to Panel questions directed to South32 through DPIE on 10/11/2020 and 16/11/2020
8) Additional reports supplied by the Department or Proponent:

    a) 2019 – *Review of HGEO Report D19341: Investigation into the height of fracturing above extracted longwalls in Area 3, Dendrobium*. Ken Mills (Mills, 2019).
    b) *Assessment of strata permeability adjacent to Avon Dam following Extraction of Longwall 16, Area 3B,* September 2020, Report number D20370 HGEO Pty Ltd 2020
    c) 2020 – *Dendrobium Mine – Longwalls 14-18 Independent Review – Height of Depressurisation (Stage 3)*. Bruce K Hebblewhite (Hebblewhite, 2020).
    d) 2020 – *Dendrobium Mine – Longwalls 14-18 Independent Review – Height of Depressurisation (Stage 4: Review of Longwall 16 data)*. Bruce K Hebblewhite (Hebblewhite, 2020).
    e) 2020 – *Effects of Longwall 16 extraction on overlying strata and groundwater conditions, Dendrobium Area 3A*. Dr Stuart Brown HGEO (Brown, 2020).
    f) 2020 – *Geological Structures Comparison Review*. SRK Consulting (SRK, 2020).
    g) 2020 - *Investigation into the height of fracturing above extracted longwalls in Area 3, Dendrobium*. HGEO (Brown, 2020).
    h) 2020 – *Structure and hydrogeology of the Elouera Fault*. HGEO (Brown, 2020).
    i) 2020 – *Updated review of overcore measurements adjacent to Elouera Fault*. (Mills, 2019).

3. BACKGROUND AND CURRENT STATUS

LW18 is the southern-most longwall panel planned in Area 3B and is bounded to the south by the defunct workings of Elouera Colliery, to the west by Lake Avon and to the east by Wongawilli Creek. The area is impacted by a range of different geological features that include the Elouera Fault system and a number of lineaments, shown in Figure 1. It is also susceptible to mining-induced impacts that include the generation of basal shear planes and the relaxation of confinement across the Elouera Fault. The potential for these to impact on water quantity and quality in the catchment if LW18 is extracted has been a concern for some years. This is reflected in the Part 1 report of the Independent Expert Panel for Mining in the Catchment (IEPMC) which noted (IEPMC, 2019a) that:

> *"faulting, basal shear planes and lineaments need to be very carefully considered and risk assessed going forward, especially when planning for further longwall panels to the south of Longwall 16"*

and

> *"the Panel advises that the potential impacts associated with interaction between the existing workings of Elouera Mine and the future workings in the southern end of Area 3B also need to be carefully assessed, especially given the current upper-end dimensions of the Dendrobium Mine layout. Assessment should include the potential for Dendrobium Mine workings to cause enhanced conductivity between Lake Avon and the Elouera Mine workings.*
>
> *It is anticipated that decision making for LW 17 and LW18 will be guided and better informed than in the past by the outcomes of investigations, monitoring and independent reviews that the Department has incorporated into conditions of approval in recent SMPs. Nevertheless, additional information commensurate with the risk of impacting water quantity, may still be required, especially into establishing the local behaviour of lineaments, the influence of panel span, extraction height and subsidence magnitude on lineament behaviour, the potential for relaxation of the faulted zone between Elouera Mine and Dendrobium Mine and the implications these matters may have for hydraulic connections from both Elouera and Dendrobium mines to Lake Avon."* [1]

The IEPMC also recommended that:

> *Subsidence Management Plans for future longwall panels in Area 3B at Dendrobium Mine must:*
>
> *i. give very careful consideration to the risk to water quantity in the catchment presented by basal shear planes, lineaments, faults and mining-induced changes in permeability around the flanks of Avon Reservoir*
>
> *ii. give very careful consideration to the potential for further mining in the southern end of Area 3B to reduce confinement of fault planes and the implication of this for enhanced conductivity between Lake Avon and both the Elouera and Dendrobium mine workings*
>
> *iii. be supported by robust independent peer review, risk assessment and risk mitigation controls.* [2]

and

[1] IEPMC (2019a), p.40.
[2] IEPMC (2019a), p.49.

- *"mine design methodologies and procedures that underpin critical aspects of future mining proposals should be supported by robust, independent peer review and/or a demonstrated history of reliability when applications are submitted for approval*

- *all future applications to extract coal within Special Areas should be supported by independently facilitated and robust risk assessments that conform to ISO 31000 (the international standard for risk management subscribed to by Australia)"*[3]

The Panel concludes that the Subsidence Management Plan (SMP) for LW18 largely satisfies these recommendations, while also responding to some findings and recommendations of a number of other past reviews, such as the PSM report on the height of cracking (PSM, 2017).

The SMP is based on LW18 having been shortened by some 800 m from originally planned (see Figure 1) and set back about 70 m from the fault zone. [4] Subsidence predictions for the new layout have been updated in MSEC (2020) and the SMP has been subjected to a peer reviewed risk assessment (AXYS, 2020). The Panel is satisfied with these documents and does not consider that a critique of them is warranted to address the Department's Scope of Works.

Hence, this advice is focused on the Groundwater and on the Surface Water sections of the SMP. The Groundwater section is directly relevant to the Department's request for the Panel to advise on the adequacy of investigations and setback distance from Lake Avon. The Surface Water section is also relevant to aspects of this request and to responding to the Department's invitation to provide any other advice it considers would assist the Department in reviewing the Extraction Plan.

[3] IEPMC (2019a), p.iii
[4] Watershed HydroGeo (2020) p.20

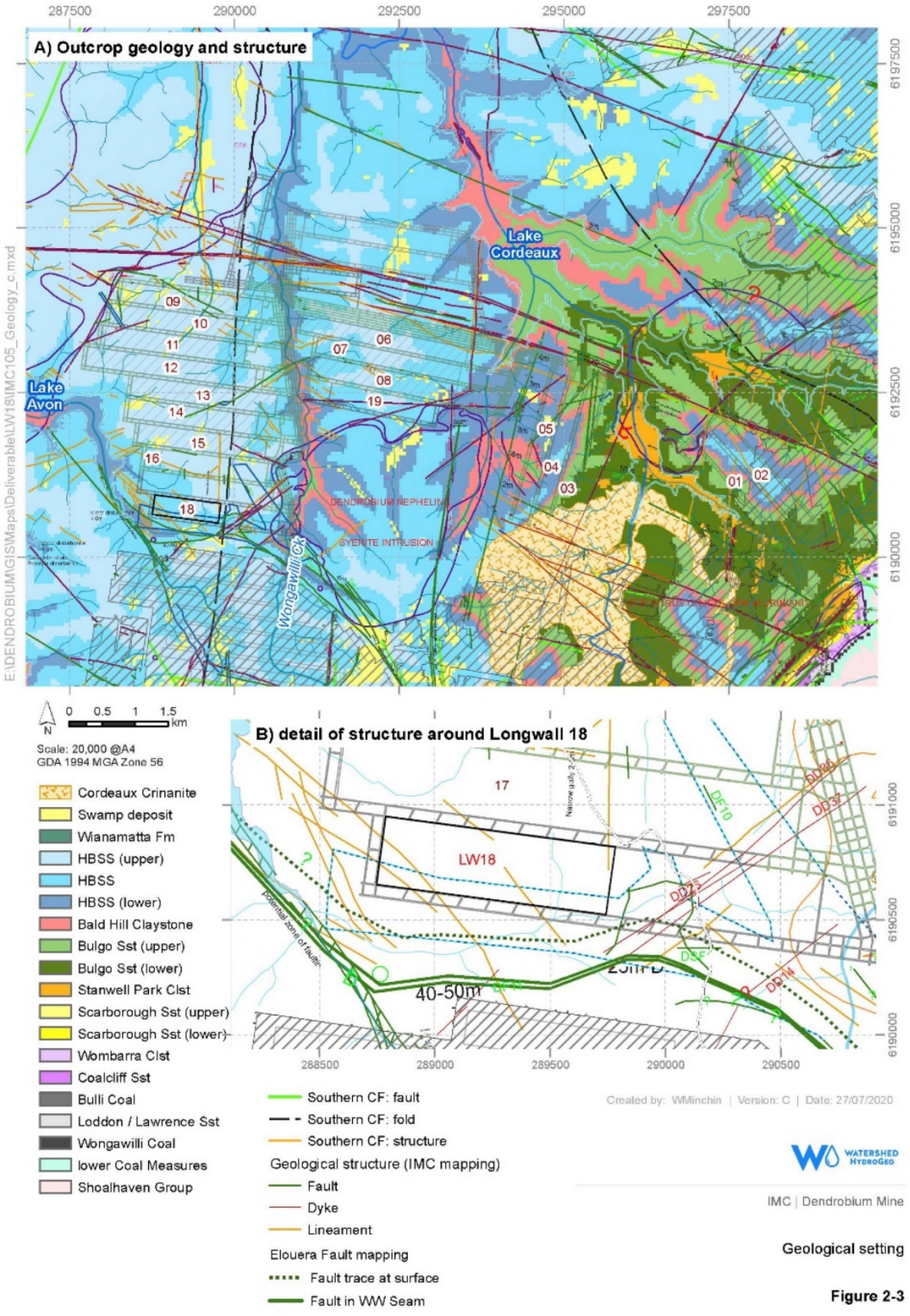

Figure 1: Plan showing past and proposed mining at Dendrobium Mine, the defunct workings of Elouera Colliery and Lake Avon and the geological setting in and around the vicinity area of LW18

4. GROUNDWATER

4.1. SCOPE

This section provides commentary and recommendations concerned primarily with the potential for enhanced leakage from Avon Reservoir due to connected fracturing between the mine workings and Lake Avon associated with the Elouera Fault zone. Concerns in this regard have been raised by a number of parties including WaterNSW, Dams Safety NSW and the IEPMC and have been referred to the Panel for consideration. Additional general comments and observations on the overall groundwater assessment are also provided.

This advice is focused on reviewing and commenting on the adequacy of the technical investigations undertaken into the conductivity of the Elouera Fault. The SMP and reports that have been relied upon in formulating this advice consider the general understanding of the overall geological and groundwater regime, geotechnical investigations into the fault specifically, and groundwater modelling scenarios that address potential increases in the permeability of the Elouera Fault.

LW18 extends into the Dams Safety NSW Avon Notification Area, but is proposed to be 300 m from the Full Supply Level (FSL) of Lake Avon (Watershed HydroGeo, 2020). There are no overlying workings but Elouera Mine workings are located to the south in the same Wongawilli Seam. Maximum extraction height (3.9 m) and panel width (305 m) are the same as for recent panels as per the Conditions of Approval for Area 3B (Watershed HydroGeo, 2020).

4.2. KEY TECHNICAL CONSIDERATIONS

4.2.1. Regional Water Summary and Licence Context

The water balance components for the Lake Avon catchment are taken from the technical reports to provide overall context for this advice.

The surface water resources for Dendrobium Area 3B lie within the Upper Nepean and Upstream Warragamba Water Source, within Upper Nepean Tributaries Headwaters Management Zone. Some general surface water statistics are:

- Rainfall – average between 1961 and 1990 is 1,200 – 1,400 mm/yr with the average of 1,100 mm/yr for the period 2003-2017 (HydroSimulations, 2019);
- Catchment Area of Avon Dam is approximately 142 km^2 (WaterNSW, 2020);
- Inflows to Lake Avon are highly variable depending on climate and range between 6,005 and 279,000 ML/yr with a long term average of 68,875 ML/yr for the period from 1909 to 2015 (Hydrosimulations 2019). The average inflow for the decade preceding 2019 is 30% lower than the long term average (HydroSimulations, 2019);
- Evaporation from Lake Avon is estimated at 8,410 ML/yr (HydroSimulations, 2019)

LW18 is in Dendrobium Area 3B, which lies within the Sydney Basin Nepean Groundwater Source (Management Zone 2). The Sydney Basin Nepean Groundwater Source extends over a larger area than the Lake Avon Catchment area, and the statistics for this water source are:

- The estimated long-term average annual recharge into the Sydney Basin Nepean Groundwater Source is 244,483 ML/yr (NSW Government, 2011).
- The Long Term Average Annual Extraction Limit (LTAAEL) for the Sydney Basin Nepean Groundwater Source is 99,568 ML/yr (NSW Government, 2011).

- The current level of entitlement in this water source is 31,359.4 shares (1 share = 1 ML in 2020/21).

It is noted that under the NSW Government Aquifer Interference Policy (AIP) (DPI, 2012), proponents are required to hold licences for both the direct and indirect take of water as a result of mining activities. These licences are to account for water intercepted by mining activities **and** induced flow from adjacent and overlying water sources. This is considered in the groundwater modelling for the project (HydroSimulations, 2019) which predicts water intercepted by the mine is sourced from the Sydney Basin Nepean Groundwater Source, and indirect impacts of induced flow from adjacent and overlying water sources also occurs. These are Sydney Basin South Groundwater Source, Upper Nepean and Upstream Warragamba Water Source and the Illawarra Rivers Water Source.

4.2.2. Conceptual Groundwater Understanding during Mining

The Sydney Basin geology comprises a Permo Triassic sedimentary rock sequence underlain by Carboniferous and Devonian age rocks. The Illawarra Coal Measures are the primary economic sequence of interest in the Sydney Basin and are overlain by Triassic Sandstones, siltstones and claystones of the Narrabeen Group and the Hawkesbury Sandstone. The Hawkesbury Sandstone is the dominant surface geology (HydroSimulations, 2019) and also forms the primary groundwater source in the area.

The hydraulic parameters of the rock strata vary with both depth and lithological control. Depth is assumed as the primary control of vertical conductivity and lithology is the primary driver influencer for horizontal conductivity (HydroSimulations, 2019). The Panel notes that the depth below ground is an assumed primary driver for hydraulic conductivity in both the conceptual and numerical modelling for the Project and that ongoing investigations into this key assumption are recommended to continue.

The Hawkesbury Sandstone, has both high and low permeability zones of variable connections including perched zones (HydroSimulations, 2019). Recharge is dominated via rainfall with additional sources via surface water systems (HydroSimulations, 2019). Discharge is via the surface water systems (rivers and lakes) and evapotranspiration from shallow water tables with very little groundwater extraction via bores.

There is a long history of mining in the Southern Coalfield and the baseline groundwater systems in many areas are already influenced by mining (HydroSimulations, 2019). During mining, dewatering of the mined coal seam occurs followed by dewatering of surrounding strata (HydroSimulations, 2019). Following mining, the overlying strata immediately above the roof collapses (HydroSimulations, 2019)) and investigations into the height of fracturing above longwalls (SCT (2019), SCT (2020), HGEO (2020b), HGEO (2020c)) conclude:

- rock defects occur throughout most of the strata following mining (HGEO, 2020b) and mine induced fracturing extends to the surface above longwall panels (SCT, 2019));
- there is a gradual reduction in mining induced fracturing with height above the mined seam all the way to surface (SCT, 2019);
- mining related changes in the central part of the panel increase hydraulic conductivity by an order of magnitude of 2 to 3 (SCT, 2019);
- fracturing style changes with height above the goaf with a higher ratio of high angle faults within 100 m of the goaf and a higher ratio of low angle fractures in the shallower zones (HGEO, 2020b);
- the high permeability of the coal seams relative to the overlying and underlying strata means that depressurization of the Wongawilli Seam due to mining is observed at greater distance from the mining area relative to the lower permeability overlying and underlying strata and so depressurization in the coal seam is observed at a location well in advance (up to several years (HGEO, 2020b) of mining reaching that location;

- complete depressurisation of the strata is apparent in vibrating wire piezometers immediately overlying the mined longwalls (SCT (2019) and HGEO (2020e));
- groundwater depressurisation directly overlying LW18 and immediately following the mining of LW18 is predicted in the model to be significant in the Wongawilli Seam (with a decline in pressure head of 270 m from baseline) and a 10 m decline in the water table.
- at a location 1 km northwest of Area 3B, depressurisation within the Wongawilli Seam at the end of mining LW18 is predicted to have declined by 120 m and in the lower Hawkesbury Sandstone the pressure head decline is predicted to be 30 m (Watershed HydroGeo, 2020).
- at a location 3 km northwest of Area 3B, depressurisation of the Wongawilli Seam at the end of mining LW18 is predicted to have declined by 25 m and in the lower Hawkesbury Sandstone the pressure head decline is predicted to be 1 m (Watershed HydroGeo, 2020)).
- the long term (175 years post mining) model prediction of the piezometric levels in the area of LW18 is that the groundwater table will remain depressed by 5-10 m, the lower Hawkesbury Sandstone will recover to almost pre mining conditions, and the Wongawilli Seam will remain depressurised by 10- to 20 m from pre mining conditions (Watershed HydroGeo, 2020).
- following mining, groundwater levels begin to recover. Enhanced recharge (due to surface cracking) is likely and the hydraulic gradient of the rocks overlying the workings remains downward while recovery occurs.
- groundwater drains vertically towards the goaf but VWP data (i.e. recovery) suggests some perched areas exist and are likely (locally) retarding groundwater flow down through the goaf directly over mined longwall panels (HGEO, 2020c).

The Panel notes that the recovery level and timeframes as reported (HydroSimulations, 2019) and (Watershed HydroGeo, 2020)) cannot be relied upon (IAPUM, 2020) as the model is not based on a clear technically feasible description of mine sealing, and the post mining roadway conductivities remain the same as during mining (IAPUM, 2020).

4.2.3. Connection with Lake

The main thalweg (deepest channel) of Lake Avon is incised through the Hawkesbury Sandstone and into the underlying Bald Hill Claystone and Bulgo Sandstone layers. However, mining in Area 3B is not adjacent to the main Lake Avon thalweg, but is adjacent to the less incised Native Dog Creek arm of Lake Avon. The Lake Avon incision remains within the Hawkesbury Sandstone in this area, and does not intersect the deeper geological layers (see Figure 3.10 of HydroSimulations (2019)).

4.2.4. Faults in the Southern Coalfield

An investigation into the hydraulic character of faults and structures within the Southern Coalfield, with particular reference to mining within close proximity to the major lakes (reservoirs), has previously been undertaken within the Sydney Catchment area. The study by Tonkin & Timms investigated faults and concluded that there '*was a lack of evidence for direct vertical flow paths via geological structures from the ground surface, through overburden strata to coal seams in the Southern Coalfield and no significant mine inflow events have occurred in the past 25 years'*.

The study found that at Dendrobium Mine, 95% of geological structures were not associated with any inflow. Inflows on the 5% of faults that recorded inflow were all less than 0.001ML/day with the exception of two, which were 0.01 ML/day.

In a separate investigation (SRK, 2020), the effects of mining on faults and reactivation of faults were considered in two locations, one in the Western Coalfield and the other in the Southern Coalfield.

Fundamental geological differences between the Western and Southern Coalfield areas lead to the conclusion that the occurrence of reactivation of faults and lineaments in the Southern Coalfield is low, which is different to the Western Coalfield.

The overall thickness of the Permo Triassic Basin is much thicker in the Southern Coalfield, where there is more than 1,500 m of Permian sequence below the mining horizon and up to 409 m of Triassic units above. This compares to the Western Coalfield where there is less than 100 m of Permian sequence below the mined horizon and up to 340 m above. There is a greater presence of intrusions in the Southern Coalfield and they contain few and discontinuous aquitards. This compares to the Western Coalfield which has notably less intrusions and several laterally continuous aquitards present in overlying the mined seams. The Western Coalfield has a noticeable structural network of major lineaments that clearly extends from basement to surface, whereas in the Southern Coalfield the link between basement structure and surface features is variable (SRK, 2020).

The SRK report concludes that '*Longwall mining activities to date at Dendrobium appear to have had little or no effect in the reactivation of surface lineaments'* in the Southern Coalfield. The conclusions regarding limited evidence for reactivation of lineaments in the Southern Coalfield (SRK (2020) and Tonkin & Timms (2015)) suggest the fundamental conceptualisation is that in the Southern Coalfields lineaments and faults have a low risk of being reactivated as a direct result of longwall mining.

4.2.5.Elouera Fault

The Elouera Fault is located between Dendrobium Mining Area 3B (LW18) to the north, and the existing, flooded, Elouera Mine workings to the south. Figure 2 has been derived from a combination of two figures in existing reports, being: Figure 2 from HGEO (2020d), with annotations added to define the three key fault zones referenced as Figure 4 of HGEO (2020d).

The fault is a complex fault zone with three connected fault zones:

1. **Main Elouera Fault** – main fault zone displacement of 20 m and a number of small faults and defined by the boundary of the Dendrobium Nepheline Syenite;
2. **En echelon NW Fault Zone** –intercepted in Elouera Colliery workings in LW 7, with a 2 m displacement and aligns with the Native Dog Creek arm of Lake Avon; and
3. **Second order oblique-slip Fault** splay connecting the two NW oriented faults and potentially a reactivation fault with up to 40 m displacement and a disturbed zone of 450 m.

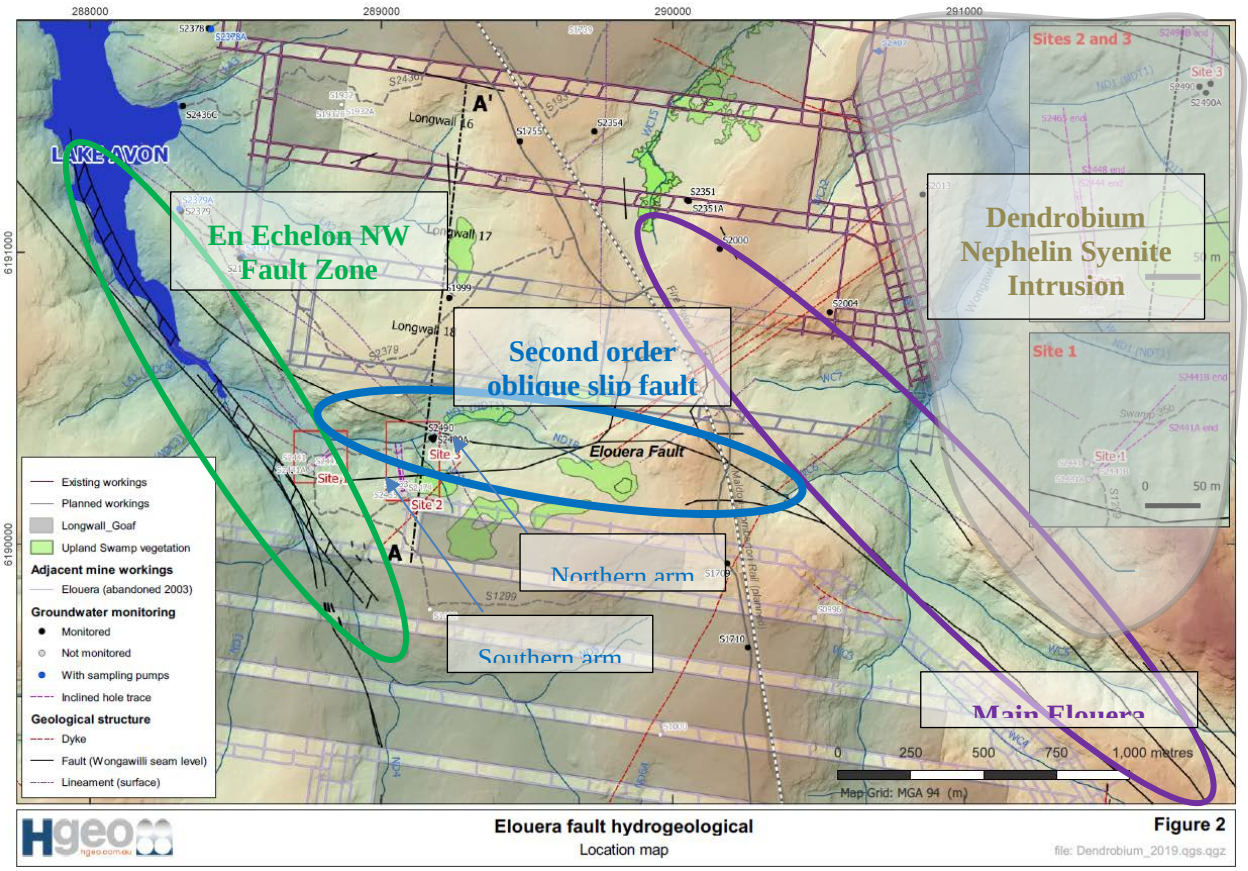

Figure 2: Elouera fault location

Of note is the 'box' structure in the mid/eastern section of the original footprint of LW18, which is associated with a geologically complex zone. LW 18 has now been shortened to avoid this structurally complex zone.

HGEO (2020d) documents the desktop and field investigations into the assessment of the Elouera Fault complex. The investigations focused on the southern fault within the second order oblique-slip fault as it is recognized as having the greatest vertical displacement (39 m at the Wongawilli Seam). The northern branch which is much closer to LW18 and the en echelon NW Fault Zone have been previously investigated and known to be minor features with small displacements of less than 1 m in most locations (Kaag, 2017)

The Tonkin & Timms (2015) study referenced five key factors for reduction of potential inflows to mines via geological structured in the Southern Coalfield. A comparison between the findings of the Elouera fault investigation and these five key factors is presented in Table 1.

Table 1: Features of the Elouera Fault related to factors that reduce potential for mine inflow via geological structures in Tonkin & Timms (2015).

Factors from Tonkin & Timms (2015)	**Relevant references to Elouera Fault in South 32 documentation**
Geological structures are generally discontinuous and there is a lack of surface expression	Surface expression of structures mapped underground is indistinct (HGEO, 2020d) and field mapping undertaken over Area 3B by BHP (Billiton, 2013) and John Doyle (in HGEO 2020c) did not identify specific expression of the Elouera Fault. During recent field investigations (HGEO, 2020d) the Elouera Fault was projected to surface and investigated further. It appeared to be aligned to a break in slope at one site and lineaments (vegetated gullies). Although no clear evidence of the fault trace was found in outcrop, HGEO (2020d) concluded that it 'probably' extends to the surface. Elouera Fault is not obviously recognisable at the surface.
Infill of faults with low permeability clayey material	The Elouera Fault consists of multiple fault cores within a broader damage zone (of elevated fracture frequency). The damage zone ranges in thickness between 8 and 31 m. The individual fault cores range between a few cm to tens of cm thick and are infilled with clay or pulverized rock (HGEO, 2020b). Infill of low permeability material is present in fault cores which are variable in thickness and location.
Depth of cover resulting in increased vertical stress and reduced permeability of strata	Depth of cover over LW18 ranges from 248 to 375 m, with a mean of 332 m (HydroSimulations, 2019)
High horizontal stress generally oriented perpendicular to mine scale faults reducing the aperture of joints and fractures	Consideration of existing and predicted future stress states and resulting changes in permeability is addressed, with SCT concluding a slight reduction in horizontal stress likely as a result of mining LW18 (SCT 2020).
Improved mine design and subsidence practices	Reduction of LW18 to approximately half its length to avoid known complex geological structures and dyke intrusions in the eastern half of the original proposed LW18 area.

4.2.6.Fault Zone Permeability

It is noted that in the assessment area, the Elouera Fault Zone displays a highly variable longitudinal permeability (HGEO, 2020d). Of the eight tests undertaken (HGEO, 2020d), three are greater than the P90 (i.e. three of the eight have permeability greater than 90% of the host rock permeabilities -

indicating increased permeability compared to the host rock). Five of the tests are within the P10 to P90 range for the host rock. HGEO concluded that fracturing within the faulted zone does lead to localized elevated permeability but that these elevated zones are not continuous over scales of greater than 10 m (HGEO, 2020d).

The Panel concurs that the fault complex has localised zones of variable permeability and that based on information provided (HGEO, 2020d), these areas of increased permeability appear non-continuous. Therefore, no obvious continuous conduit to groundwater flow is apparent.

Transverse permeability has been assessed by HGEO (2020d) using an approach that considers both 1) the displacement of the geological formation, and 2) the potential for clay/shale smear. The displacement analysis concluded that the fault is likely to represent a weak barrier to flow based on offsetting of strata by an order of magnitude of between 0.3 to 0.5 (HGEO, 2020d). The potential for clay smear in sandstone units is unlikely be a barrier to transverse flow, but some minor smearing may occur in deeper Wombarra Formation and the coal seams (HGEO, 2020d). Overall the conclusion (HGEO, 2020d) was that the fault provides a minor barrier from displacement and no obvious barrier from clay/shale smear. Therefore, the Panel concludes that there is no clear or obvious transverse barrier to flow, although a potential weak transverse barrier due to displacement may exist.

Consideration of groundwater pressures indicate that the Elouera Fault zone is currently not a conduit for groundwater flow. Groundwater heads overlying the Elouera workings are noted to be approximately 125 mAHD (HGEO, 2020d), compared to much shallower levels within the fault itself (340 mAHD). However, the horizontal distance between these two measurements is not reported as it is not stated whether the measurement of the groundwater level overlying Elouera Mine is the central part of Elouera Mine workings or whether it relates directly to the groundwater pressure immediately overlying LW8.

4.2.7.Predicted Changes from Mining of Longwall 18

Overview

The mining of LW18 is predicted to cause additional low level stress releases and relief on the Elouera Fault (SCT, 2020). However, based on information presented and assessed it appears likely that this relief will be minor in comparison to the existing stress relief already experienced from mining in Elouera Mine (HGEO, 2020d).

Measurements of in situ stress in boreholes either side of the fault show that the stresses on the northern side of the Elouera Fault (Dendrobium side) are similar to background levels, with some rotation apparent (SCT, 2020). In situ stress measurements on the southern side of the fault (that is, on the Elouera Mine working side), indicate that the mining on that side of the fault has already caused the fault to be unloaded. It is somewhat unclear in the reports (SCT, 2020 and HGEO (2020d)) as to why the reduction of horizontal stress on the southern side of the fault is not directly carried across to the northern side of the fault.

SCT concluded that the future mining of longwalls on the northern side of the fault at Dendrobium Mine concluded that mining of LW18 will cause additional low level stress relief in the horizontal direction across the Elouera Fault (SCT, 2020). The additional stress relief from mining of LW18 is expected to be small in comparison with the stress relief already experienced from the initial longwall mining at Elouera Mine (SCT, 2020).

The Elouera Fault currently does have zones of slightly elevated localized permeability, but this permeability does not appear continuous (HGEO, 2020d). The conceptual understanding of the fault in its current form as it pertains to groundwater flow is that it is most likely a transverse barrier to flow with longitudinal permeability similar to the host rock background levels (HGEO, 2020b, 2020d) .

The predicted minor reduction in horizontal stress across the Elouera Fault will potentially lead to a slight increase in permeability but the specifics of this increase are difficult to predict and may be localized and are not likely to be uniform. To consider potential changes in groundwater flow, it was recommended that numerical models apply an increase in permeability of by an order of magnitude of 0.5 (HGEO, 2020d) and 0.63 (K Mills pers. comms. reference within Watershed 2020).

The groundwater model has since been updated to include scenarios for the specific effects of mining of LW18 and also potential changes to the Elouera Fault permeability with scenarios of enhanced hydraulic conductivity by an order of magnitude of 0.5 (Scenario D) and an order of magnitude of 1.0 (Scenario E which represents a 10 times increase from current) (Watershed HydroGeo (2020).

4.2.8. Groundwater model predictions

The Panel concludes that the groundwater conceptual model and numerical model prepared to evaluate the potential effects of mining LW18 are well considered. The greater Dendrobium model has a long history of development, continuous improvement and peer review by Kalf (2019) that concludes it to be fit for the purpose of predicting impacts of mining. The Panel considers that the recent scenarios modelled in consideration of the potential effects of LW18 on the Elouera Fault are appropriate given the recent field investigations and characterization of the Elouera Fault and are well structured and logical.

Mine water inflow information, trends and the quality of the water have been considered in various studies by HGEO (2020e) and Mackie (2016) and analysis of this information is considered and included to further refine the conceptual groundwater model and numerical groundwater model for Dendrobium. There have been obvious attempts to correlate high rainfall events to all facets of the water balance (HGEO, 2020e). This continuous improvement of both the conceptualization, numerical modelling and the ongoing peer reviews of the mine is noted by the Panel and aligns to best practice modelling as per the Australian Groundwater Modelling Guidelines (Barnett et al., 2012)

Increased inflow to the mine workings is estimated to be between 0.5 and 1.5 ML/day (Watershed HydroGeo, 2020). There is also an increase of inflow predicted to the Elouera mine from mining of LW18, of 0.01- 0.05 ML/day (Watershed HydroGeo, 2020)).

The potential increase in inflow to Dendrobium Mine as a result of mining LW18 is considered reasonable given that the mining of LW18 will increase the overall mined area in Dendrobium Area 3B. It is understood that groundwater licences are held to account for groundwater inflow. However, the Panel questions how the mine can comply with the requirements of the AIP with regard to holding sufficient surface water licences to account for leakage from overlying surface water sources.

It is somewhat confusing that as a result of mining LW18 an increase volume of inflow is predicted into Elouera Mine workings of 0.01 to 0.05 ML/day (Watershed HydroGeo, 2020)) Elouera Mine is currently flooded, with a measured pressure head of 60 m above the mined seam (Watershed HydroGeo, 2020). It is assumed that the '*increase to the Elouera Mine*' is referring to the recovery of the groundwater levels in the goaf area directly overlying the mine workings. Additional information on the mechanism for this increased inflow to Elouera Mine has not been provided and clarification/commentary would be beneficial to explain whether this increased inflow to Elouera Mine is a result of: an increase in vertical hydraulic over the workings; connection across workings; and/or increase of flow via the Elouera Fault.

The leakage from Lake Avon as a result of mining at Dendrobium has been estimated and considered in various groundwater assessments, models and reports since 2012. Figure 3 is reproduced from Watershed HydroGeo (2020), to illustrate both the duration and number of studies that consider the leakage component from Lake Avon.

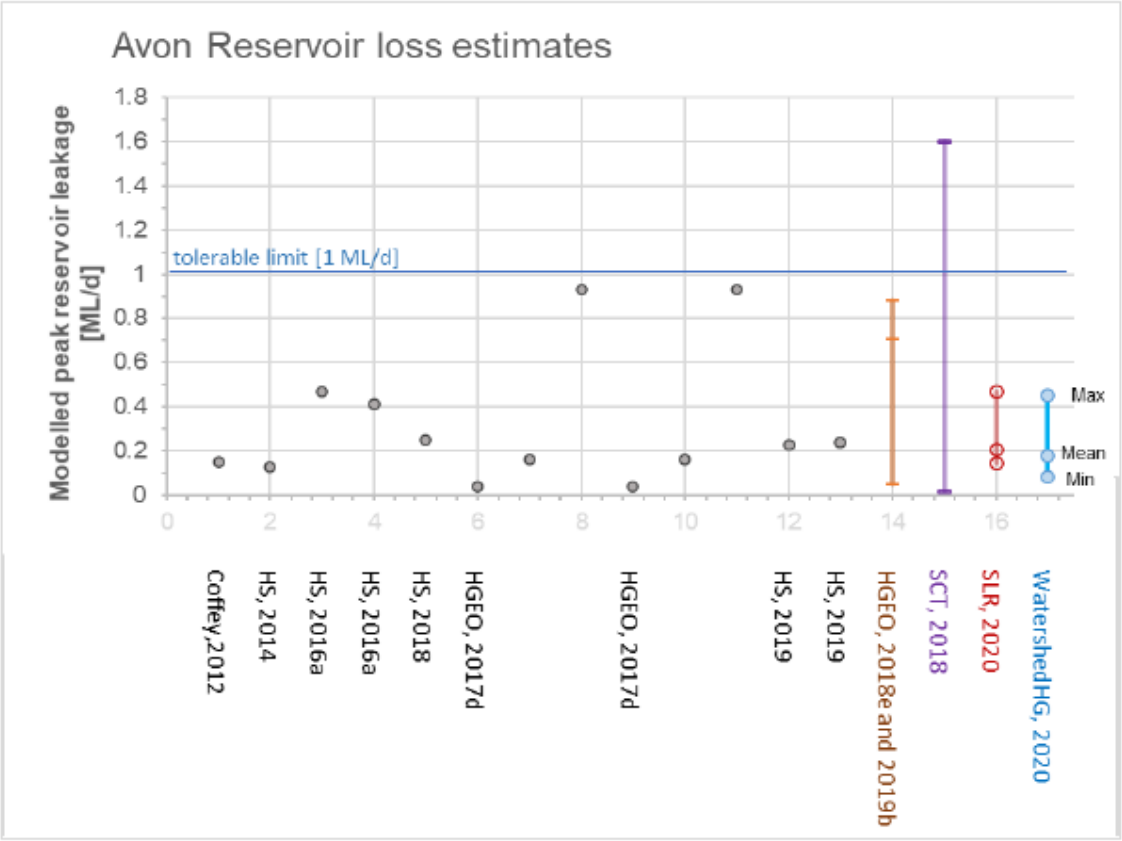

Figure 3: Avon Reservoir loss estimates (Watershed 2020 (Watershed HydroGeo, 2020).

The current modelled leakage from Lake Avon as a result of all mining at Dendrobium Mine is estimated to be between 0.09 and 0.45 ML/day (Watershed HydroGeo, 2020) depending on which scenario is modelled. All scenarios fall within the prescribed tolerable limit as established by Dam Safety NSW of 1 ML/d with one exception being the range provided by (SCT, 2020). The higher end of this modelled range occurs for the higher 'off goaf' permeability scenario and not from scenarios that increase the permeability in the Elouera Fault (Watershed HydroGeo, 2020), suggesting the model results are not overly sensitive to fault permeability. The increase in leakage from Lake Avon due to LW18 is estimated to range between 0.01 and 0.13 ML/day.

It is noted that there is no increase in inflow predicted to Lake Cordeaux from mining of LW18 (Watershed HydroGeo, 2020).

The predicted change in incidental take from surface watercourses is estimated in Watershed HydroGeo (2020) as a result of all mining at Dendrobium as well specifically for mining of LW18. The incremental increase in water take from overlying water courses is estimated to be a maximum of 0.46 ML/day Watershed HydroGeo (2020).

4.3. CONCLUDING COMMENTS

1. One of the key impact predictions required from the groundwater model is details of connectivity with overlying surface water systems. The Panel notes that there are various limitations to the accuracy of the groundwater model with regard to its resolution at a local scale near the surface. The level of accuracy of this is difficult to verify given measurement of these changes at the scale required is difficult to achieve. Consideration of how to best gain additional water table information, ongoing baseflow and leakage studies and an overall understanding of the connectivity of streams

based on data would be advisable over the longer term. The Panel is satisfied that these model uncertainties have been managed appropriately for the purpose of LW18 SMP through the scenario modelling, monitoring and management plans.

2. The AIP requires that both the direct and indirect take of groundwater as a result of mining be estimated and accounted for via licences from the respective sources of that water. Therefore, consideration of specifics for how licences can be held to account for both the maximum predicted groundwater 'take' from the respective water source as well as the increased 'leakage' from overlying surface water sources as a result of mining is required. The surface water licence estimated (Watershed HydroGeo, 2020), for the overall Dendrobium project are:
    a. 500 ML/yr (ranging from 330-1,100 ML/yr) from the water supply catchment (ie induced leakage from both the reservoirs and the upstream catchments (Watershed HydroGeo, 2020) and
    b. 430 ML/yr (ranging from 285 – 1,000 ML/yr) from Wongawilli Creek and Donalds Castle Creek (Watershed HydroGeo, 2020).
3. Additional detail on the predicted overall recovery of the groundwater regime following mining at Dendrobium Mine was a focus of previous Panel advice (IAPUM, 2020) particularly with regard to ongoing leakage/take of groundwater following mining within the longwall roadways and the ongoing take of groundwater over time.

4.4. CONCLUSIONS

1. The Panel acknowledges the genuine and significant investigations undertaken to specifically consider the potential effects of mining LW18. In particular, the additional field data and focus on characterizing the Elouera Fault and subsequent specific modelling of predicted potential changes following mining of LW18 is acknowledged.
2. Based on the information provided and reviewed by the Panel, the groundwater impacts for mining of LW18 are predicted to be:
    i. Increased leakage from Lake Avon ranges between of 0.01 and 0.13 ML/day (Watershed HydroGeo, 2020);
    ii. Increased leakage from overlying water courses (not including Lake Avon) estimated at a maximum of 0.46 ML/day (Watershed HydroGeo, 2020);
    iii. Increased inflow to the mine workings is estimated to be between 0.5 and 1.5 ML/day (Watershed HydroGeo, 2020).
3. These predictions are considered reasonable by the Panel.

4.5. RECOMMENDATIONS

1. The Panel supports the recommendation of DPIE Water for additional standpipe monitoring bores to be constructed adjacent to vibrating wire piezometers (VWP) to provide validation of VWP sensor data.
2. It is recommended that one or two additional nested groundwater monitoring sites are established to the south west of LW18: either between LW18 and Lake Avon and/or between LW18 and the Elouera Mine workings, in order to consider groundwater pressures and water quality in the shallow/mid and deeper Hawkesbury Sandstone.
3. Ongoing monitoring of groundwater levels within the fault should continue at site 3 (S2490).
4. The Panel supports the recommendation to construct either VWP's or open holes at the vertical holes at Sites 1 and 2. Ongoing monitoring of pressures should occur at these two sites. Ideally, if future drilling is to occur in this area, consideration should be given as to whether an open standpipe bore into the fault zone could be constructed to provide both verification of water level and also to provide for monitoring of water quality changes within the fault over time.
5. The Panel recommends additional stress investigations at end of mining LW18 to confirm unloading changes.

6. Opportunities to more conclusively monitor recovery of waterlevels above Elouera Mine are welcomed to assist with ongoing conceptualization of the regional hydrogeology regime and to gain additional understanding of the recovery above nearby longwall mines over the longer term.
7. Any observed reversal in the Hawkesbury Sandstone groundwater level gradients between Lake Avon and the Elouera fault monitoring bores to the south-west of LW18 should result in a review by an independent expert to ascertain the water loss rate (as committed to in the South32 Response to Agency advice).
8. For future mining areas groundwater TARPS and performance measures should be considered.

5. SURFACE WATER

5.1. SCOPE

This section comments on the potential impacts to surface water resources, the adequacy of the assessments undertaken, and the monitoring and management plans as relevant to LW18. Additionally, comment is made on water quality TARPs, which is more relevant for future mining areas.

The main surface water risks that arise specifically for LW18 are those related to the Elouera Fault and the degree of connectivity of LW18 to the surface water system, in particular Lake Avon. These issues of connectivity are addressed mainly under the Groundwater section of this report.

5.2. SURFACE WATER CONTEXT FOR LW18

The surface water context of the proposed LW18 is described fully in Section 2 of Attachment E of the Subsidence Management Plan (SMP). A summary is provided here.

The Elouera Fault system includes branches to the south of LW18 as shown in Figure 4. The DF11 fault branch is considered by South32 to be most significant in terms of potential connectivity between Lake Avon and LW18. DF11 is 150 m from the LW18 footprint at its closest projected surface point (Table 2-3 of Watershed HydroGeo (2020)). Surface expressions of the fault have not been observed. The fault investigations conclude that, although the data show that in places the permeability of the fault zone is higher than in the surrounding hydrogeological units, the data indicate that the DF11 fault does not provide a conduit to groundwater flow.

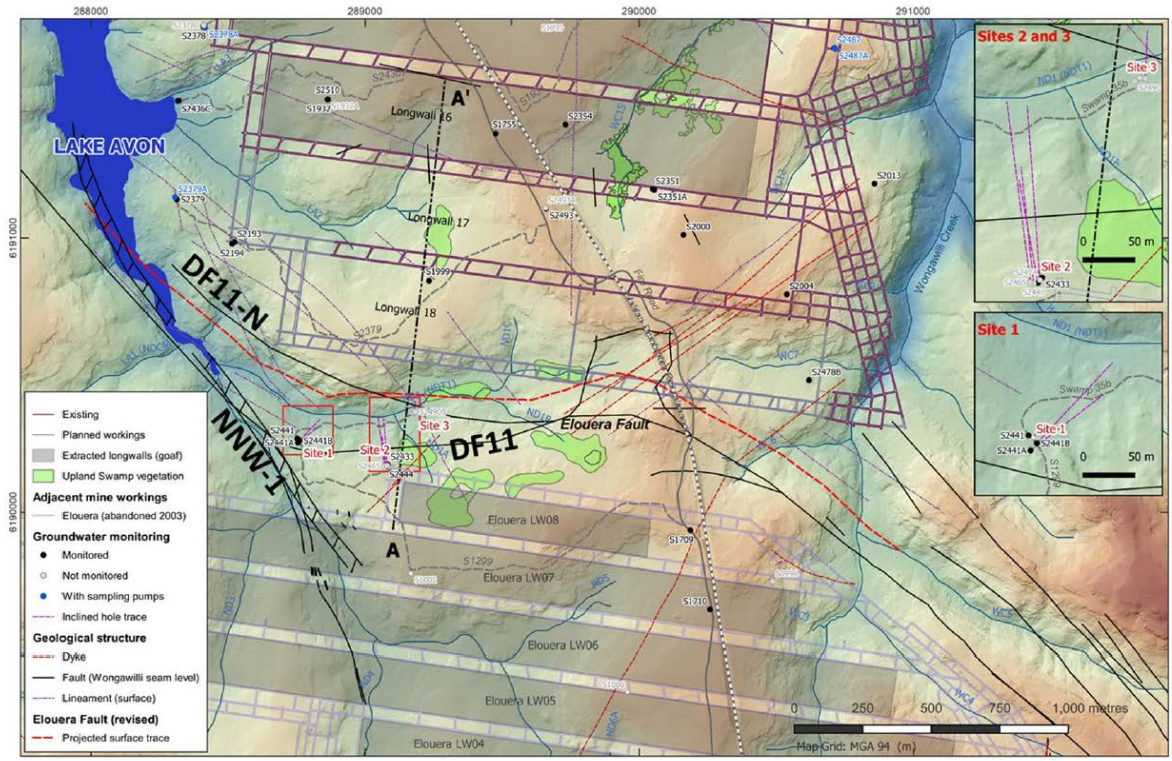

Figure 4: Figure provided by S32 on 16/11/2020 in response to Panel query regarding the northern fault branch (DF11-N)

Figures 3-36 and 3-37 from the Watercourse Impact Monitoring, Management and Contingency Plan (WIMMCP), reproduced in this advice as Figure 5 and Figure 6, show the watercourses and catchments undermined by the proposed LW18 and those within its Study Area defined by the 600 m boundary. The LW18 eastern end is approximately 1050 m from Wongawilli Creek. LW18 will overlap the LA2 and ND1 subcatchments of Lake Avon (13% and 18% of the total areas of these subcatchments), which includes undermining almost the full length of the first order watercourse ND1C. Within the Study Area also lie WC7, WC12 and WC15 subcatchments of Wongawilli Creek and subcatchments to the south of Native Dog Creek. 290 m of the third order Native Dog Creek is within 400 m of LW18.

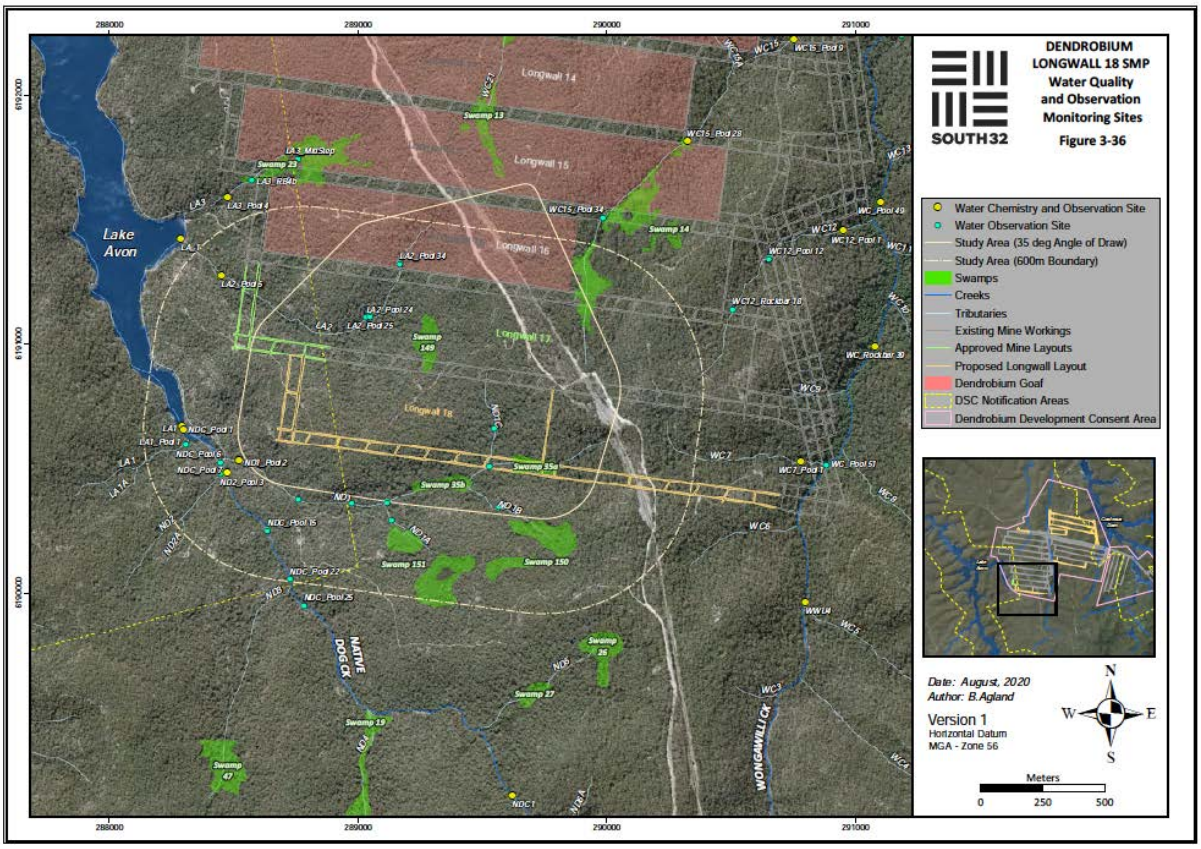

Figure 5: Figure 3-36 from the WIMMCP

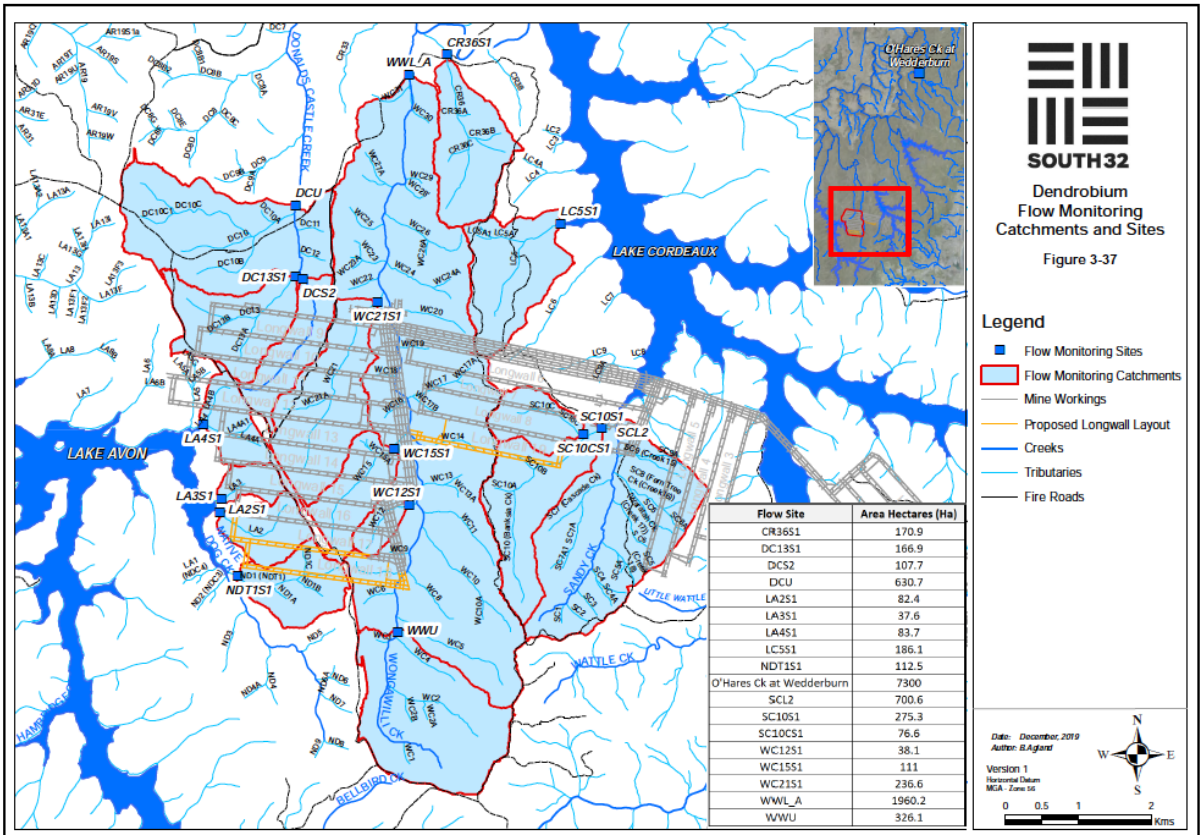

Figure 6: Figure 3-37 from the WIMMCP

There are existing surface impacts from Elouera Colliery in the upper reaches of Native Dog Creek and its tributaries within the Study Area, both affecting water quantity and potentially also quality. Any observed impacts of LW18 on Native Dog Creek will be the cumulative impacts of the Elouera Colliery as well as previous Dendrobium longwalls.

Data from seven monitoring boreholes between Lake Avon and previous longwalls, following completion of LW16, show enhanced off-goaf horizontal permeability in the HBSS of up to 1.5 orders of magnitude (i.e. up to 32 times as high post-mining compared to pre-mining).

5.3. PREDICTED SURFACE WATER LOSSES DUE TO LW18

Surface water losses due to LW18 are predicted using the regional groundwater model (Watershed HydroGeo, 2020). This modelling is supplemented by a local-scale groundwater model for the purpose of estimating losses from Lake Avon (HGEO, 2020e).

It is concluded in the SMP documents that, even when using a conservatively enhanced hydraulic conductivity, the estimates of leakage from Lake Avon remain within the assumed acceptable limit of 1 ML/day, with peak leakage due to Dendrobium mine of 0.45 ML/day and peak increment in leakage due to LW18 of 0.13 ML/day (both these values result from the most conservative (high-loss) modelled scenario).. It is noted that South32 plan to re-assess loss rates if the groundwater pressure gradient from the fault monitoring bores to Lake Avon is observed to reverse (South32 response to Dam Safety NSW advice).

The peak loss of surface water flowing into Lake Avon due to the Dendrobium mine is predicted to be 1.49 ML/day, with approximately 0.24 ML/day of this due to LW18, under the most conservative scenario. The peak loss of surface flow from gauge WWL is predicted to be 2.23 ML/day, of which

0.074 ML/day is due to LW18, again under the most conservative scenario. Losses using the baseline scenario, which is based on the modellers' best estimates of hydrogeological parameters, are considerably less than these conservative estimates. All these values are taken from T7.4 to T7.6 of Attachment B of the SMP (Watershed HydroGeo, 2020).

The proposed LW18, although predicted to have small impacts on the more distant flow sites (in particular DCU and WWL), is predicted to lengthen the time taken for flow to recover at these sites (Appendix H of Attachment B of the SMP, Watershed HydroGeo (2020)). All surface water flow sites are predicted to experience long-term impacts based on results shown up to 2060 (Appendix H ofWatershed HydroGeo (2020)).

5.4. OTHER WATERCOURSE IMPACTS DUE TO LW18

The large distance of the proposed LW18 from Wongawilli Creek (approximately 1050 m) means that potential impacts on it are predicted to be very low (Table 7 of Attachment E of the SMP, Watershed HydroGeo (2020)). As experienced in previous Dendrobium longwalls, the full range of subsidence movements is expected within the LW18 mining footprint, with associated fracturing, flow losses and flow diversions from the overlying subcatchments and tributary ND1C.

Maximum predicted valley closures are 650 mm, 420 mm and 350 mm in LA2, ND1 and ND1C respectively (Appendix C, Attachment C of SMP, MSEC (2020)). These are cumulative values including longwalls LW9 to LW18. LA2 is predicted to be heavily impacted by LW17, with a maximum increment of 150 mm due to LW18. Native Dog Creek is predicted to have experienced up to 700 mm closure due to the Elouera mine, with a maximum increment of 30 mm due to LW18. Minor fracturing is considered possible for the 290 m length of Native Dog Creek that is within 400 m of LW18. Minor fracturing and localised flow diversion is considered likely in ND1 due to LW18 (Section 4.4.1 in HGEO (2020a)).

There are six swamps (14, 35a, 35b, 149, 150, 151) with potential subsidence impacts (5.11.5 of MSEC (2020)). Hydrological impacts due to LW18 are considered likely at 35a and 149, with the latter likely to be already impacted by LW17 (T11 of Watershed HydroGeo (2020)).

The SMP concludes that, although local impacts on water quality are likely consistent with those observed at previous longwalls, these are expected to have negligible and undetectable impacts on the water quality of Lake Avon (Section 4.6 of Watershed HydroGeo (2020)).

5.5. MONITORING SURFACE WATER IMPACTS OF LW18

Surface water flow monitoring stations have recently been established at ND1, LA2 and WC12S1. Assessment of flow gauging accuracy is underway. This will be supplemented with observations of flow conditions at other locations (as listed in Table 3 of Watershed HydroGeo (2020)).

There is no flow gauging station proposed for Native Dog Creek. This is in the context that 0.22 ML/day peak loss (the conservatively high estimate) is predicted from ND1 (which is gauged) compared to 0.13 ML/day from the rest of the Native Dog Creek catchment (T7-5 of Watershed HydroGeo (2020)).

Each of the six swamps potentially impacted by LW18 are being or will be monitored with at least one piezometer and soil moisture sensor (Figure 3-89 of the SIMMCP), along with monthly or more frequent observation of pools that exist within swamp 14. Section 3.2 of the SIMMCP notes that the required two years monitoring baseline will not be achieved at 149, 150 and 151 due to the recognition of their existence only during the biodiversity surveys in 2020; their monitoring is reported to start in September 2020.

5.6. PANEL'S OBSERVATIONS RELATED TO PREDICTED WATERCOURSE IMPACTS

The assessments of surface water losses are generally high quality, sufficient in scope and easy to follow.

The statement in Watershed HydroGeo (2020)(Section 6.6) that *"With respect to the downstream gauging sites DCU and WWL, the modelling is clearly conservative compared to the results derived from field data"* should be viewed with caution. The EOP reports for LWs 12, 13 and 14, reported observed losses at WWL of 3%, 3% and 4%, as opposed to the gain in flow at WWL obtained using the new accounting method. At least until the new method of estimating surface flow losses from gauged data undergoes further assessment and peer review, the Panel does not consider the predicted losses at WWL to necessarily be conservative. This is discussed further below in context of TARPs. However, due to the relatively large distance of LW18 from Wongawilli Creek and the relatively low proportion of its catchment being undermined, the Panel has no concerns about incremental impacts on Wongawilli Creek due to LW18.

The Panel welcomes the improved presentation of the predicted incremental and total surface flow losses in Appendix H of Watershed HydroGeo (2020), including comparison with estimates based on gauged flows, and the uncertainty analysis. Concerns about the comparison of estimated median daily losses with volumetric loss projections are discussed below in context of TARPs. The Panel also welcomes the comparison of predictions to the history of predictions, including uncertainty bounds in Figure 7 of Watershed HydroGeo (2020).

The accuracy of estimates of losses from Lake Avon depends primarily on the accuracy of hydraulic parameters used in the groundwater model and the validity of the assumptions regarding mine sealing in the long-term (see also the Groundwater section of this report).

The required two years baseline will not be achieved at swamps 149, 150 and 151 due to the delayed recognition of their existence. Since the basic impacts on swamp drainage have been evident even from a low number of wetting-drying cycles (e.g. End of Panel (EOP) report for LW15, Figs 43-48), this is not preclusive to effective identification of potential impacts, assuming that the baseline period is neither exceptionally dry nor exceptionally wet.

On water quality, the Panel agrees that the nature of water quality impacts is most likely to be similar to previous experience in Area 3B. Looking forward, the Panel has reservations about the ability of the water quality TARPs to signal long-term deterioration in quality of water, as explained below.

5.7. OBSERVATIONS RELATED TO SURFACE WATER MONITORING

The Panel considers there to be a sufficient number of flow gauges, which are at suitable locations. Various improvements to surface water monitoring and assessment approach have been made or are underway in response to IEPMC (2019b) recommendations.

The Panel agrees that there is no major advantage in installing a gauge on Native Dog Creek due to its relatively low overlap with the Study Area and relatively large impact of the Elouera mine.

5.8. OBSERVATIONS RELATED TO WATER QUANTITY TARPS

The surface water TARPs relating to impacts on flows have been substantially changed since the March 2019 version of the WIMMCP following consultation with agencies (as reported in the EOP report for LW15, Section 2.3). These new TARPs have also been employed in the EOP report for LW15, Appendix B following previous trials (Watershed HydroGeo, 2020).

The previous (2019 WIMMCP) TARPs related to the performance measure of *"negligible reduction in the quantity of surface water inflow to Cordeaux River at its confluence with Wongawilli Creek"* and *"negligible reduction in the quantity of surface water inflows to Lake Avon"* were assessed using a rainfall-runoff model to estimate post-mining flow losses relative to a pre-mining reference period. In some cases, flows at control gauges were also used to interpret the rainfall-runoff modelling results. The IEPMC concluded (IEPMC, 2019a): *"The surface flow modelling outputs are analysed using appropriate methods… However, complementary analysis using suitable reference (control) sites should be used more consistently."* Although the value of continued use of a rainfall-runoff model is recognised by the IEPMC and also by the discussion in Watershed HydroGeo (2020), the new TARP assessment method relies solely on comparisons with control (reference) gauged sites. The new TARP assessment method also changes the metrics used, from volumetric measures of flow loss, to three statistical metrics – changes in the median flow (Q50), changes in the number of zero-flow days, and changes in the time-series of flow percentiles.

In principle, the reliance on control sites, if their flows or relevant flow statistics are well correlated with the pre-mining flows/flow statistics at the TARP site, removes the complicating influence of rainfall-runoff model errors. Therefore, the Panel welcomes the new approach being trialled. The Panel agrees that the three statistics used in the new TARPs are relevant. The advantages and limitations of replacing a volumetric measure of flow loss (e.g. mean daily flow) by the Q50 are discussed in Watershed Hydrogeo (2019) with the conclusion that Q50 is more robust for the purpose of TARPs. The Panel agrees; however changes in the Q50 cannot reasonably be used for flow loss accounting, at least not until a good relation between the Q50 and volumetric flow loss is established. This is important since it relates to ability to assess performance against the consent condition. The same issue also arises in Appendix H of Attachment B of the LW18 SMP, where the estimates of changes in Q50 from the EOP are compared with 5-year average flow losses predicted by the groundwater model.

The basic requirement of the reliance on control sites – that there is a good correlation between the control and target site flows (or at least the relevant flow statistics) – has not been demonstrated. The correlation of the log-transformed daily flows between two sites in Watershed HydroGeo (2020) appears to be poor. Validation tests should include assessment of the inferred impacts when comparing one control to another control.

In addition to flow TARPS related to surface flow loss performance measures, the TARPs relevant to the performance measure *"Wongawilli Creek – minor environmental consequences"* have also been modified in the WIMMCP for LW18. The modified TARP introduces an additional baseflow loss assessment in the case that a Level 2 trigger is recorded. This method also needs validation, since it assumes relations in baseflow between upstream and downstream sites that may not exist.

The Panel is not aware of an independent peer review of these new TARPs.

In conclusion, the Panel welcomes the exploration of improved TARPs related to surface flow losses and watercourse impacts and considers that good progress has been made. However, further assessment and peer review of the new TARPs are required prior to regarding them as suitable for use. For LW18, the Panel recommends that the previous TARPs are employed in parallel with further assessment of the new TARPs.

5.9. OBSERVATIONS RELATED TO WATER QUALITY TARPS

The water quality TARPs remain as in previous (2019) version of the WIMMCP. For the purpose of the LW18 SMP, the Panel has no objections to the TARPs or associated monitoring. However, going forward, the TARPs by themselves are not sufficient indicators of medium to long term trends in water quality. The TARPs are designed to identify and manage short-term anomalous extremes in water quality indicators (values greater than the 99.7 percentile). However, it is trends over periods of years

that pose the greatest risk to the water quality of the reservoirs. The issue with trends is illustrated in Figure 7, which shows the long-term (since 2013) increase in electrical conductivity at WC21 Pool5. In that case, and in general, the EOP reports include discussion of the trends and their potential significance, but there is no metric that allows trends to be easily analysed and recorded. A reporting requirement should be adopted that reports changes in trends in concentrations and also loads (flow x concentration). Consideration should also be given to the IEPMC (2019b) and IAPUM (2020) conclusions and recommendations regarding long-term, post-closure water quality risks.

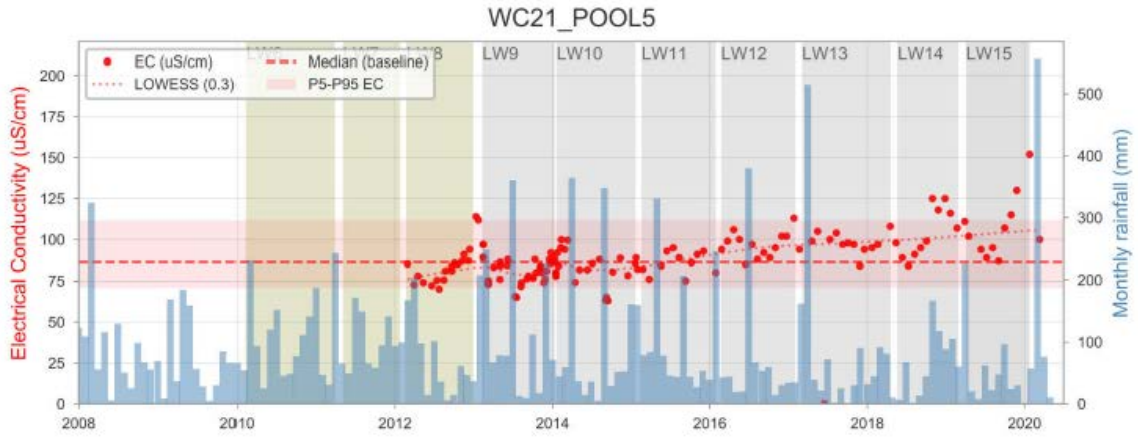

Figure 7: Long-term (since 2013) increase in electrical conductivity at WC21 Pool.

5.10. MINOR COMMENTS ON TARPS

- The new proposed surface flow loss metrics should be more precisely defined (equations) in the WIMMCP or surface water attachment to the SMP.
- Table 1-2 of the WIMMCP, Surface Water Flow: first line under Level 1 is *"Lower flow than expected (additional 10-15% of days where Q% lower than Reference Q)"* The meaning of *"additional"* here is ambiguous. The same also applies to level 2 and 3.
- Table 1-2 of the WIMMCP, Water Quality - Lake Avon. This should be updated to include other monitored tributaries entering Lake Avon.
- Table 1-2 of the WIMMCP, Surface Water Flow: Footnote includes ND2, but the WIMMCP contains no other reference to a flow site there. Also, there is some inconsistency over whether NDCS1 will be a flow site.

5.11. CONCLUSIONS

1. The surface water report supporting the SMP (Attachment D) is of a high technical standard with clear and generally appropriate interpretations of the data. A constructive effort has been made to address the recommendations of the IEPMC (2019).
2. The Panel has no concerns about incremental subsidence impacts on Wongawilli Creek due to LW18; and considers that the total incremental increase in surface water loss from Lake Avon and its tributaries due to LW18 is likely to be very low compared to existing losses due to Dendrobium mine.
3. The nature and degree of water quality impacts is likely to be similar to those previous experienced in Area 3B.
4. There is a sufficient number of surface water monitoring (flow, pool and water quality) sites and they are at suitable locations.
5. Good progress has been made in improved use of control stations in the estimation of surface flow losses and in improved TARPs. However, further assessment and peer review of the new accounting methods and TARPs are required prior to regarding them as suitable for use.
6. While the water quality TARPs are acceptable for management of LW18 impacts, the water quality TARPs are not sufficient indicators of medium to long-term trends in water quality.

5.12. RECOMMENDATIONS

1. The previous (pre-LW15) surface water flow TARPs should be employed in parallel with the new surface water flow TARPs, and the most conservative outcome taken, until the new trigger metrics have undergone further assessment and peer review for fitness for purpose.
2. A method of quantifying and reporting trends in key water quality indicators (both concentrations and loads) should be trialled in addition to applying the proposed water quality TARPs.

6. CONCLUSIONS

Groundwater

1. The Panel acknowledges the genuine and significant investigations undertaken to specifically consider the potential effects of mining LW18 on lineaments, the Elouera Fault Zone and leakage from Lake Avon. The additional field data and focus on characterizing the Elouera Fault and subsequent specific modelling of predicted potential changes following mining of LW18 are noted in particular.
2. Based on the information provided and reviewed by the Panel, the Panel considers the following predictions of the groundwater impacts associated with the mining of LW18 to be reasonable:
    i. Increased leakage from Lake Avon ranges between of 0.01 and 0.13 ML/day (Watershed HydroGeo, 2020);
    ii. Increased leakage from overlying water courses (not including Lake Avon) estimated at a maximum of 0.46 ML/day (Watershed HydroGeo, 2020);
    iii. Increased inflow to the mine workings is estimated to be between 0.5 and 1.5 ML/day (Watershed HydroGeo, 2020).

Surface Water

1. The surface water report supporting the SMP (Attachment D) is of a high technical standard with clear and generally appropriate interpretations of the data. A constructive effort has been made to address the recommendations of the IEPMC (2019).
2. The Panel has no concerns about incremental subsidence impacts on Wongawilli Creek due to LW18; and considers that the total incremental increase in surface water loss from Lake Avon and its tributaries due to LW18 is likely to be very low compared to existing losses due to Dendrobium mine.
3. The nature and degree of water quality impacts is likely to be similar to those previous experienced in Area 3B.
4. There is a sufficient number of surface water monitoring (flow, pool and water quality) sites and they are at suitable locations.
5. Good progress has been made in improved use of control stations in the estimation of surface flow losses and in improved TARPs. However, further assessment and peer review of the new accounting methods and TARPs are required prior to regarding them as suitable for use.
6. While the water quality TARPs are acceptable for management of LW18 impacts, the water quality TARPs are not sufficient indicators of medium to long-term trends in water quality.

Generally

1. Overall, the SMP reflects a genuine effort to undertake sound field studies, numerical modelling and risk assessment.
2. The Panel concludes that it largely responds to and satisfies the recommendations of the Part 1 report of the IEPMC (Part 2 only being published while the SMP was in the process of being prepared) and a number of other past reviews and advices prepared for the Department in relation to Dendrobium Mine.
3. The Panel concludes that the investigations undertaken into assessing the potential for additional leakage from Lake Avon due to the extraction of LW18 are adequate and that based on the outcomes of those investigations, there is no need to increase the setback distance of 300 m from Lake Avon.

7. RECOMMENDATIONS

Groundwater

1. The Panel supports the recommendation of DPIE Water for additional standpipe monitoring bores to be constructed adjacent to vibrating wire piezometers (VWP) to provide validation of VWP sensor data.
2. It is recommended that one or two additional nested groundwater monitoring sites are established to the south west of LW18: either between LW18 and Lake Avon and/or between LW18 and the Elouera Mine workings, in order to consider groundwater pressures and water quality in the shallow/mid and deeper Hawkesbury Sandstone.
3. Ongoing monitoring of groundwater levels within the fault should continue at site 3 (S2490).
4. The Panel supports the recommendation to construct either VWP's or open holes at the vertical holes at Sites 1 and 2. Ongoing monitoring of pressures should occur at these two sites. Ideally, if future drilling is to occur in this area, consideration should be given as to whether an open standpipe bore into the fault zone could be constructed to provide both verification of water level and also to provide for monitoring of water quality changes within the fault over time.
5. The Panel recommends additional stress investigations at end of mining LW18 to confirm unloading changes.
6. Monitoring the groundwater (both pressures at depth and the water table) overlying Elouera Mine is recommended. This information will contribute to the conceptual understanding of groundwater recovery processes post mining in this area.
7. Any observed reversal in the Hawkesbury Sandstone groundwater level gradients between Lake Avon and the Elouera fault monitoring bores to the south-west of LW18 should result in a review by an independent expert to ascertain the water loss rate (as committed to in the South32 Response to Agency advice).
8. For future mining areas groundwater TARPS and performance measures should be considered.

Surface Water

1. The previous (pre-LW15) surface water flow TARPs should be employed in parallel with the new surface water flow TARPs, and the most conservative outcome taken, until the new trigger metrics have undergone further assessment and peer review for fitness for purpose.
2. A method of quantifying and reporting trends in key water quality indicators (both concentrations and loads) should be trialled in addition to applying the proposed water quality TARPs.

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