# INDEPENDENT EXPERT ADVISORY PANEL FOR MINING

**ADVICE RE:**

**REPORT TITLED:**

***Metropolitan Coal Mine:***

***Independent review of environmental performance to 2022***

**(Dupen, 2023)**

**September 2023**

**Report No: IEAPM 202309-2**

## EXECUTIVE SUMMARY

In March 2023, a report titled *'Metropolitan Coal Mine – independent review of environmental performance to 2022'* was prepared by consulting company H2onestly Pty Ltd on behalf of the Nature Conservation Council of NSW (NCC), a community-based organisation. The author of the report is Mr Peter Dupen and it is referred to as the 'Dupen Report' in this Executive Summary.

The Dupen Report is founded on the hypothesis by its author that higher than expected flows measured during 2020 in the Eastern Tributary, which feeds Woronora Reservoir, can be attributed to surface flows and shallow groundwater being widely diverted and drained as a result of mining-induced fracturing on each side of and beneath the valley hosting the Eastern Tributary. This fracturing is hypothesised to comprise an interconnected network of sub-vertical surface fractures and sub-horizontal bedding plane shears that Dupen refers to as a *new subsidence mechanism.* He associates this mechanism, which he has termed *'ridge fracture drainage'*, with the *unexpected and unpredicted formation of large-scale shear planes opening up* at the base of aquifers. This forms the basis for Dupen's conclusions that:

- *The aquifers which sit above and feed the incised valley streams are draining at rates measurably higher than pre-mining, in places rapidly and completely, due to unexpected and unpredicted formation of large-scale shear planes opening up at their base.*

- *If this new subsidence mechanism is indeed widespread, a likely outcome is that a range of protected Special Area ecosystems overlying the mine will dry and change. The other major risk from widespread basal shear formation is that it will cause the water quality in the Woronora drinking water reservoir to become increasingly degraded by metal-laden discharges from unmeasured shear plane vents.*

In May 2023, the NSW Department of Planning and Environment (DPE) requested the following advice from the Independent Expert Advisory Panel for Mining (IEAPM) in relation to the Dupen Report.

- *Identify and comment on the elements of the Report that are relevant to the operation and environmental performance of Metropolitan Coal;*
- *Provide advice as to what actions or further investigations would be required to test or confirm the hypothesis put forward in the Report; and*
- *Any other significant advice that the Panel may wish to provide concerning this issue.*

The Panel overlapped with another IEAPM Panel established to provide DPE with a range of advice relating to water quality performance measures for Woronora Reservoir specified in Consent Conditions for Metropolitan Coal Mine. Matters of significance raised in the Dupen Report in relation to potential mining impacts on water quality fall within the brief of the other Panel and the reader is referred to the advice of that Panel (IEAPM**,** 2023).

The nature of the structure and content of the Dupen Report results in a range of conclusions and recommendations being developed progressively throughout the Panel's advice report. The reader is referred to these for further insight into the following summary advice:

*Identify and comment on the elements of the Report that are relevant to the operation and environmental performance of Metropolitan Coal*

**Subsidence Focussed**

1. The two basic mining-induced elements that constitute Dupen's hypothesised *ridge fracture drainage* model are sub-vertical surface fractures and sub-horizontal bedding plane shears. Both elements are well established in subsidence engineering and, individually and collectively, have been the subject of a number of detailed subsidence and hydrogeological studies in the Southern Coalfield over recent decades for the purpose of detecting and monitoring their formation, including at the Eastern Tributary. Hence, ridge fracture drainage cannot be considered a *new subsidence mechanism.*
2. If the Dupen hypothesis concerning surface flows and shallow groundwater being widely diverted and drained as a result of mining-induced fracturing is validated then ridge fracture drainage could, arguably, be considered to be a *new subsidence consequence*. This depends on the spatial scale and the magnitude and distribution of shear displacement on what Dupen refers to as *large scale shear planes opening up at their base,* in comparison to documented past experience. The term *large scale* is not defined in the Dupen Report.
3. The Dupen Report does not provide sufficient evidence to cause the Panel to believe that the scale of bedding plane shears in the vicinity of the Eastern Tributary might be materially different to that of other shear planes detected and studied in the Southern Coalfield.
4. Due to the low values of predicted incremental valley closures during the 300 series of longwalls, it is unlikely that ground movements were significant enough to increase the hydraulic conductivity of shear planes in the Eastern Tributary during the period of flow anomalies.

**Groundwater Focussed**

5. Perched water in swamp colluvium and very shallow weathered Hawkesbury Sandstone is hydraulically disconnected from the deeper regional groundwater systems and will not drain unless near surface fracturing intersects these features. There is no clear evidence of drainage of these shallow groundwater systems in the available monitoring records.
6. There is no evidence from Metropolitan Coal's groundwater monitoring network (except at the transect bore locations overlying LW305 and LW306) that water levels in the Hawkesbury Sandstone aquifers across the Eastern Tributary catchment have fallen and desaturated the ridgelines. In fact, most monitored regional water table levels have stabilised or risen in recent years.
7. Alternative explanations of the increased surface flows at the Eastern Tributary gauging station observed since August 2020 (which corresponds with the commencement of an above average rainfall period) include:
    i. underflow that previously discharged to Woronora Reservoir downstream of the Eastern Tributary gauging station is now reporting as surface water flow upstream of the gauging station; and

ii. larger volumes of (natural) interflow and regional groundwater are discharging and contributing to surface water flows across the whole catchment.

8. Increased groundwater discharge is potentially consistent with the Dupen hypothesis of sub-vertical fractures and shears with enhanced hydraulic connection connecting regional groundwater to the Eastern Tributary. However, there is no widespread evidence of a reduction in water levels or groundwater storage volumes across the catchment in the Hawkesbury Sandstone aquifer, which is contrary to the Dupen hypothesis.

9. Beneath ridgelines and hillslopes, the absence of permanent springs and any obvious perched groundwater (apart from in the vicinity of swamps) suggests most rainfall recharge (apart from that portion that is lost to evapo-transpiration and via interflow after rain) drains vertically to the regional water table and then moves laterally to emerge in the base of the valleys as baseflow.

10. The shallow perched water table in colluvium and underlying/adjacent weathered sandstone supports upland swamps. The upland swamps will not drain and will not be impacted unless near surface fracturing intersects and drains these features.

11. The regional water table occurs at depth beneath the ridgelines, and naturally discharges to permanent streams. Regional groundwater does not discharge at elevated sites and does not support ridgeline and hillside terrestrial ecosystems, however it may contribute to some riparian communities.

**Surface Water Focussed**

12. Metropolitan Coal (through consultants) has undertaken a detailed analysis of potential reasons for the Eastern Tributary flow anomalies that Dupen uses to support the ridge fracture drainage hypothesis. The Panel agrees with main conclusions and recommendations from that analysis, being:

    i. There are serious errors in the flow data used by Dupen but this is not the reason for the anomalies. To address these errors the rating curve for the Eastern Tributary should be extended to improve high flow measurement accuracy.

    ii. The flow anomalies are unlikely to be due to subsidence movements of the flume.

    iii. The controlled burn conducted from September 2021 to March 2022 in the Eastern Tributary catchment has likely contributed but, by itself, is unlikely to fully explain the flow anomalies.

    iv. The flow anomalies may be related to mining-induced increases in the hydraulic conductivity of the creek bed.

13. Additional to the considerations in the consultant's analysis, the Panel concludes that:

    i. While blockage of the flume by debris is another potential reason for the flow anomalies, regular inspection and clearance of the flume makes this unlikely.

    ii. Errors in the rainfall-runoff modelling may also contribute to flow anomalies, including non-linearity in the groundwater storage-discharge relation and non-stationarity in hydrological processes related to drought. This has not been assessed by Metropolitan Coal.

14. Contrary to the observation by Dupen that "*Since 2017, the previously permanent Pools ETAG to ETAR have been dry except for short periods following major rainfall events*", these pools were generally flowing during 2017-2022 except during prolonged dry weather.

15. The reason for the Eastern Tributary flow anomalies remains unknown, and the Dupen hypothesis cannot be discounted based on the flow data.
16. The status of the pools and whether remediation improves the status of the pools, while important for assessing the environmental performance of the mine, will not be a decisive factor regarding the Dupen hypothesis.

**Overarching Conclusions**

17. Previous studies and investigations have been undertaken of basal shears and the magnitude of associated impacts on the groundwater system and these do not provide evidence supporting major impacts of the style and magnitude suggested in the Dupen Report.
18. The evidence that Dupen has used for the development of his hypothesis is limited (as acknowledged by Dupen) and incomplete and additional evidence sourced by the Panel confirms that this data contained errors, in some cases of a serious nature.
19. A wider assessment of the groundwater data, including more recent data than that available to Dupen, has not provided evidence of the widespread dewatering of the regional groundwater system predicted by Dupen's hypothesis.
20. Dupen's interpretation of the impacts of changing groundwater baseflow contributions to Woronora Reservoir arising from his hypothesis is also not consistent with enhanced basal shears and the dewatering of the Hawkesbury Sandstone aquifer beneath the ridgelines.
21. Consideration by the Panel of a wider set of data indicates that the inferences made by Dupen about the scale of impacts unfolding on the regional ecology and the Woronora reservoir are likely overstated. For this reason, the Panel does not support the Dupen Report's primary recommendation *"that further undermining of the Woronora Reservoir should be halted until the implications of these unexpected changes now unfolding in Woronora Reservoir Catchment can be urgently evaluated"*.
22. Even though the scale of impacts suggested by Dupen are not expected by the Panel to be as large as Dupen predicts, the Panel accepts that components of Dupen's hypothesis should be evaluated through new data collection and further interpretation to build confidence in Metropolitan Coal's assessment of the long-term impacts of mining under the catchment.
23. If the drainage mechanism hypothesised by Dupen has merit, it should be able to be validated by field experience at other sites above mine workings at Metropolitan Coal Mine and at other mines operating in similar topography in the Southern and Western Coalfields of NSW.

*Provide advice as to what actions or further investigations would be required to test or confirm the hypothesis put forward in the Report*

The Panel recommends (from a groundwater perspective) that:

1. Additional bores (standpipes) be established at the T5 monitoring location to monitor the vertical piezometry in the Hawkesbury Sandstone and to establish whether extensive basal shears occur at depth below this eastern ridgeline area.
2. Additional bores (standpipes) be established at the T6 monitoring location and at other accessible locations overlying the proposed LW311 to LW316 panels as soon as

practicable to monitor the natural vertical piezometry in the Hawkesbury Sandstone below this western ridgeline area.

The Panel recommends (from a surface water perspective):

3. Extension of the Eastern Tributary flow gauge rating curve as recommended by Metropolitan Coal's consultant (HEC, 2022); also spot measurements of flow covering flow rates as high as safely practicable; and urgent repair of the weir. Revised rating curves and the spot measurements of flow should be published in annual reports.
4. Re-analysis of the flow data including the most recent data. This analysis should be of the nature of HEC (2022) but also consider the possibility of increased flows being related to high groundwater or reservoir levels or errors in the modified AWBM model (Australian Water Balance Model).
5. Further reporting of the modelling in annual report appendices should contain details of the modified AWBM model and parameter values needed to allow independent assessment.
6. If it is concluded after review and extension of the rating curve and analysis using the most recent flow data that baseflows may have substantially increased due to subsidence effects, further investigation should be undertaken regarding the source of the increased baseflow and its significance for aquatic ecology and water quality entering the Woronora Reservoir.
7. Metropolitan Coal's 2023 Annual Report should provide information on the success of the Eastern Tributary remediation program.

*Any other significant advice that the Panel may wish to provide concerning this issue*

1. The Panel recommends for the purpose of developing a better understanding of valley closure impacts to inform mine design that, if it has not already done so, Metropolitan Coal undertakes and makes available to the Department, an investigation of mining impacts on the Eastern Tributary that includes an evaluation of:
    i. How predicted valley closure developed incrementally along the Eastern Tributary.
    ii. How well incremental and total predicted valley closure correlated with measured incremental and total measured closure.
    iii. The nature and extent of natural and mining-induced fracturing to a depth of at least 20 m along the Eastern Tributary downstream from the maingate of LW26 to the Full Supply Level (FSL) of Woronora Reservoir (noting that some of these investigations may have already been undertaken).
    iv. How well mining-induced environmental impacts along the Eastern Tributary correlate to both predicted valley closure and to measured valley closure.
    v. The hydraulic characterisation of the fracture system and the underflows that are taking place along that portion of the Eastern Tributary between the maingate of LW26 and the Eastern Tributary gauging station. This could include establishing new shallow groundwater bores in a longitudinal section to assist in better assessing long term water level and water quality behaviour.

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## 1.0 INTRODUCTION

In March 2023, a report titled *'Metropolitan Coal Mine – independent review of environmental performance to 2022'* was prepared by consulting company H2onestly Pty Ltd on behalf of the Nature Conservation Council of NSW (NCC), a community-based organisation. The author of the report was Mr Peter Dupen and, henceforth, that report is referred to as the 'Dupen Report' and referenced as Dupen (2023).

The Dupen Report is founded on the hypothesis by its author that higher than expected flows recently measured during 2020 in the Eastern Tributary, which feeds Woronora Reservoir, may be attributed to surface flows and shallow groundwater being widely diverted and drained through shear zones and fractures at the base of valleys because of a previously unidentified subsidence mechanism. Dupen refers to this new mechanism as *'ridge fracture drainage'.* Dupen is of the view that:

- *The aquifers which sit above and feed the incised valley streams are draining at rates measurably higher than pre-mining, in places rapidly and completely, due to unexpected and unpredicted formation of large-scale shear planes opening up at their base.*

- *If this new subsidence mechanism is indeed widespread, a likely outcome is that a range of protected Special Area ecosystems overlying the mine will dry and change. The other major risk from widespread basal shear formation is that it will cause the water quality in the Woronora drinking water reservoir to become increasingly degraded by metal-laden discharges from unmeasured shear plane vents.*

On 16 May 2023, the NSW Department of Planning and Environment (DPE) requested the following advice from the Independent Expert Advisory Panel for Mining (IEAPM) in relation to the Dupen Report.

- *Identify and comment on the elements of the Report that are relevant to the operation and environmental performance of Metropolitan Coal;*
- *Provide advice as to what actions or further investigations would be required to test or confirm the hypothesis put forward in the Report; and*
- *Any other significant advice that the Panel may wish to provide concerning this issue.*

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

- Em. Professor Jim Galvin – Chair – Subsidence and Mining
- Professor Neil McIntyre – Surface Water
- Mr John Ross – Groundwater
- Em. Professor Rae Mackay – Groundwater

All four Panel members have experience in the Southern Coalfield that is relevant to addressing DPE's brief.

The Panel overlapped with another IEAPM Panel established to provide DPE with a range of advice relating to water quality performance measures for Woronora Reservoir specified in Consent Conditions for Metropolitan Coal Mine. Matters of significance raised in the Dupen Report in relation to potential mining impacts on water quality fall within the brief of this other Panel and the reader is referred to the advice of that Panel (IEAPM**,** 2023).

The topics of mining subsidence and associated impacts and consequences for water resources in the Southern Coalfield are complex and have been the subject of many studies over the last 50 years. To assist the non-technical specialist in understanding the hypotheses and propositions put forward in the Dupen Report and the Panel's assessment of them, this current advice report is structured around first providing a summary of Dupen's hypotheses and associated concerns (Section 3.0), followed by a summary of the evolution of the local knowledge base and some relevant foundation principles relating to mining impacts on groundwater and surface water at Metropolitan Coal Mine (Section 4.0). A detailed critique of the Dupen Report is then presented in Section 5.0, which forms the basis of the Panel's advice in Section 6.0.

## 2.0 METHOD OF OPERATION

The Panel convened by videoconference during the preparation of its advice and was administratively supported by Secretariat staff provided by the DPE's Major Projects and Resource Assessments teams.

A wide range of documents was provided through DPE to support the Panel in preparing this advice. The principal documents are summarised in Table 1.

**Table 1:** Key documents reviewed by the Panel

| Document Reference | Document Name |
|---|---|
| Documents provided by DPE | • DPE Request for Advice – Water Quality Performance Measures for Metropolitan Coal Mine – 6 April 2023<br>• Metropolitan Coal Consolidated Project Approval 08_0149<br>• Metropolitan Coal Mine – Independent review of environmental performance to 2022, Peter Dupen, March 2023 |
| Additional documents provided by Metropolitan Coal | • Metropolitan Coal Review of Recorded Streamflow – Eastern Tributary, Hydro Engineering & Consulting, November 2022 |

### 2.1.1.Site Visit

On 10 May 2023, the Panel undertook a site inspection in the Woronora Catchment under the guidance of WaterNSW and in the company of DPE officers. It inspected the valley sides and valley floor area of the Eastern Tributary between Fire Trail 9J crossing and the Eastern Tributary Gauging Station (at the end of Fire Trail 9G), and the Flat Rock Crossing area of Waratah Rivulet.

### 2.1.2.Meetings

The Panel convened multiple times over the course of preparing its advice. The Department's Resource Assessments team was invited to several of these meetings on an as-needed basis. to provide technical briefings and updates to the Panel. Table 2 summarises in chronological order the schedule of formal meetings that involved the Panel. A number of meetings restricted to Panel members also took place.

**Table 2:** Schedule of formal meetings involving the Panel.

| Meeting Date | Meeting Information |
|---|---|
| 14 April 2023 | Panel - DPE Briefing |
| 10 May 2023 | Site Visit |
| 11 May 2023 | Site Visit Debrief and meeting at DPE Offices |

| | |
|---|---|
| 31 May 2023 | Panel Meeting Discussion |
| 14 June 2023 | Panel Meeting Discussion |
| 30 June 2023 | Panel Meeting Discussion |
| 18 August 2023 | Panel Meeting Discussion |
| 24 August 2023 | Panel Meeting Discussion |
| 1 September 2023 | Panel Meeting Discussion |

## 3.0 DUPEN HYPOTHESIS AND CONCERNS

### 3.1. LOCATION MAPS

Figure 1 is reproduced from the Dupen Report and shows the near east-west layout of longwall panels LW20 to LW27 (the '20 Series') in the lower section of the figure and the near north-south layout of LW301 to LW316 (the '300 Series') in the upper section of the figure. The 20 Series longwall panels are separated from the 300 Series by main development roadways. Extraction of LW309 commenced shortly before finalising this advice report. The Panel has added the blue text boxes in Figure 1 to identify Waratah Rivulet, Woronora Reservoir, and the point (X) marking the start of the downstream section of the Eastern Tributary that is the subject of a Performance Measure of particular relevance in this matter.

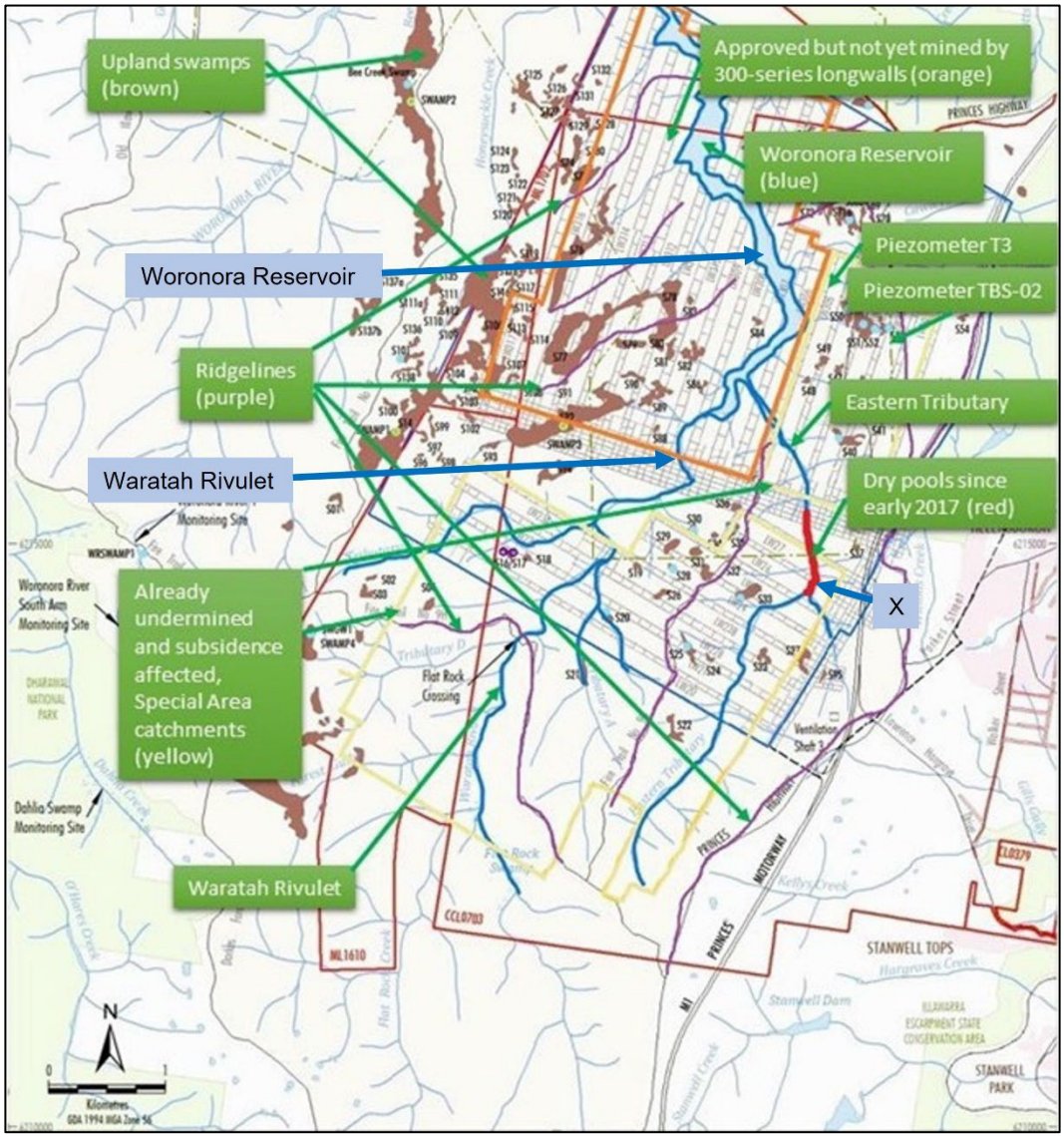


Figure 1: Reproduction of Figure 1 of the Dupen Report in which it is captioned as *Key features discussed in this report, annotated in green over base figure reproduced from Metropolitan Coal 2021 Annual Report,* with the blue text boxes being added by the Panel.

Figure 2 shows the naming and location of pools on Waratah Rivulet and the Eastern Tributary and surface water monitoring sites over Metropolitan Coal Mine. Note that rock bars WRS1 and WRS3 referred to in this Panel advice report control, respectively, Pools E and F on Waratah Rivulet.

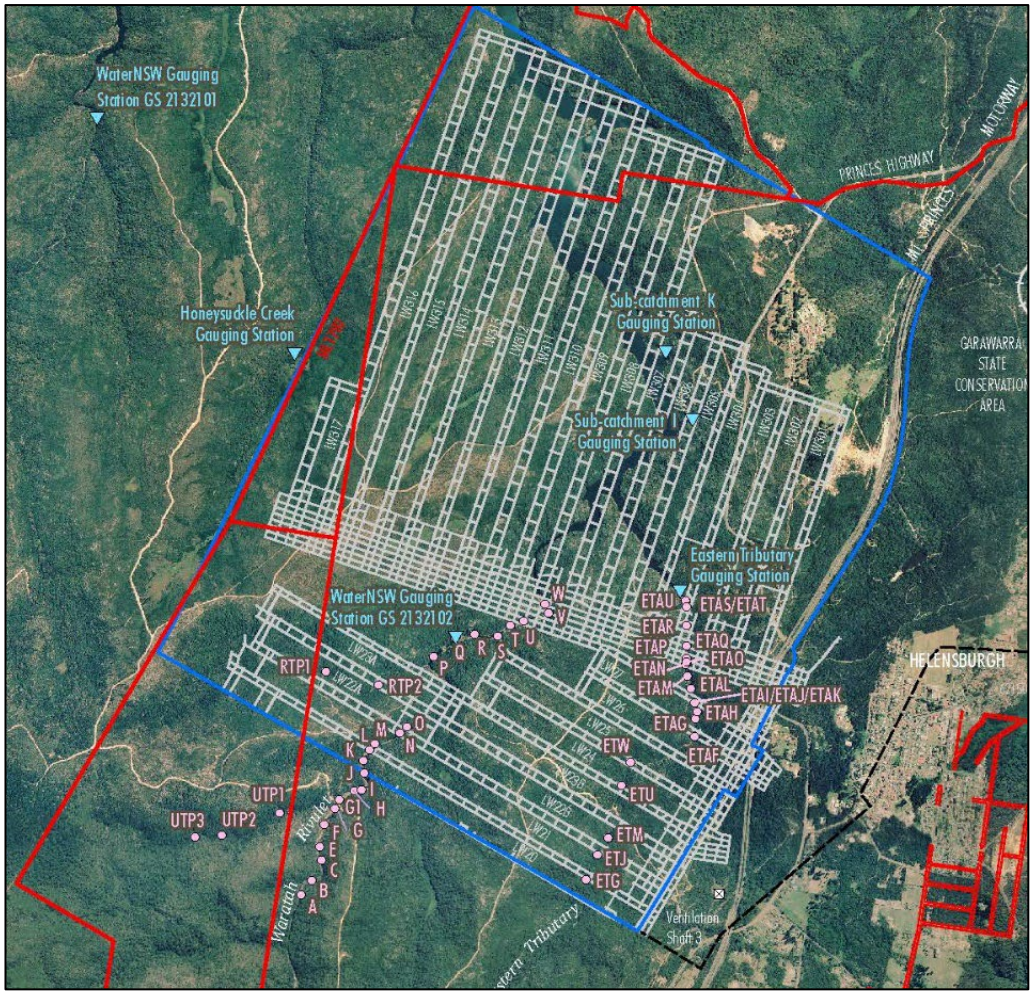


Figure 2: Plan showing the naming and location of rock pools on Waratah Rivulet and Eastern Tributary and surface water monitoring sites over Metropolitan Coal Mine. Note that rock bars WRS1 and WRS3 referred to in this Panel advice control, respectively, Pools E and F on Waratah Rivulet (extract from Figure 7 of Peabody, 2022b)

### 3.2. THE DUPEN HYPOTHESIS

The Dupen Hypothesis[1] has its primary basis in Figure 3, which is Chart 3 of the Metropolitan Coal 2021 Annual Review (Peabody, 2022b). Dupen has concluded on the basis of this chart that during the reporting period (1/1/21 to 31/12/21), flow in Eastern Tributary has been increasingly higher than model predictions [2].

[1] Dupen invokes the term 'hypotheses' for addressing the evidence he believes supports his central hypothesis noted in Section 1.0 of this Panel Advice report. The Panel's use of the term 'hypothesis' refers to Dupen's central hypothesis.
[2] p19 of Dupen, 2023a

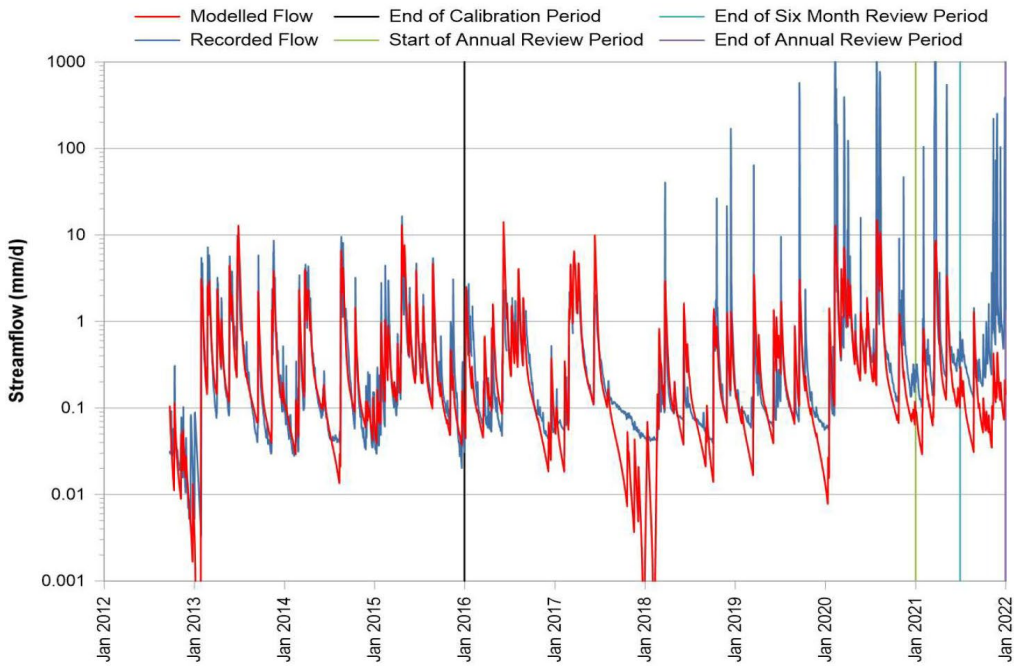


Figure 3: Reproduction of Figure 12 of Dupen Report where it is described as *monitored and model-predicted flows – Eastern Tributary upstream of Woronora Reservoir.* The figure is originally Chart 3 from Peabody (2022b). The y-axis scale (mm/day) is the flow volume rate in $mm^3$/day divided by the catchment area in $mm^2$. 1 mm/day = 67 L/s, equating to almost 5.8 ML/d.)

Dupen introduces other lines of evidence for his hypothesis. Of particular significance are the changes in piezometry observed in the transect boreholes T1 – T6, shown in Figure 4. The location of the transect can be identified from Figure 1 by the positioning of piezometer T3.

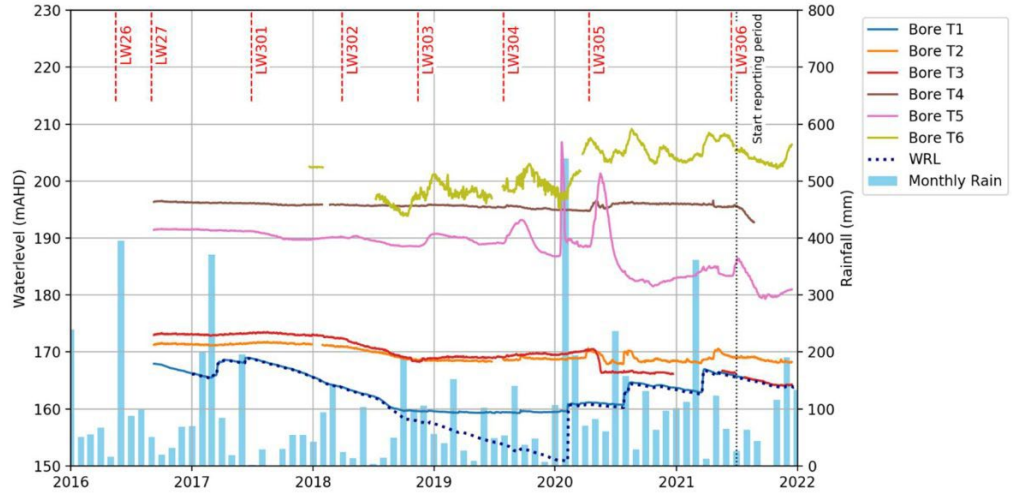


**Chart 52 Groundwater Level in Bores T1 to T6**

Figure 4: Piezometric data for Boreholes T1 to T6 extending from the reservoir along a transect approximately at right angles to the reservoir. (Reproduction of Figure 9 in the Dupen Report)[3]

A cross section showing the elevations of the Boreholes T1-T5 is shown in Figure 5 (Figure 2 in SLR**,** 2023a which is an updated version of Figure 8 in the Dupen Report)

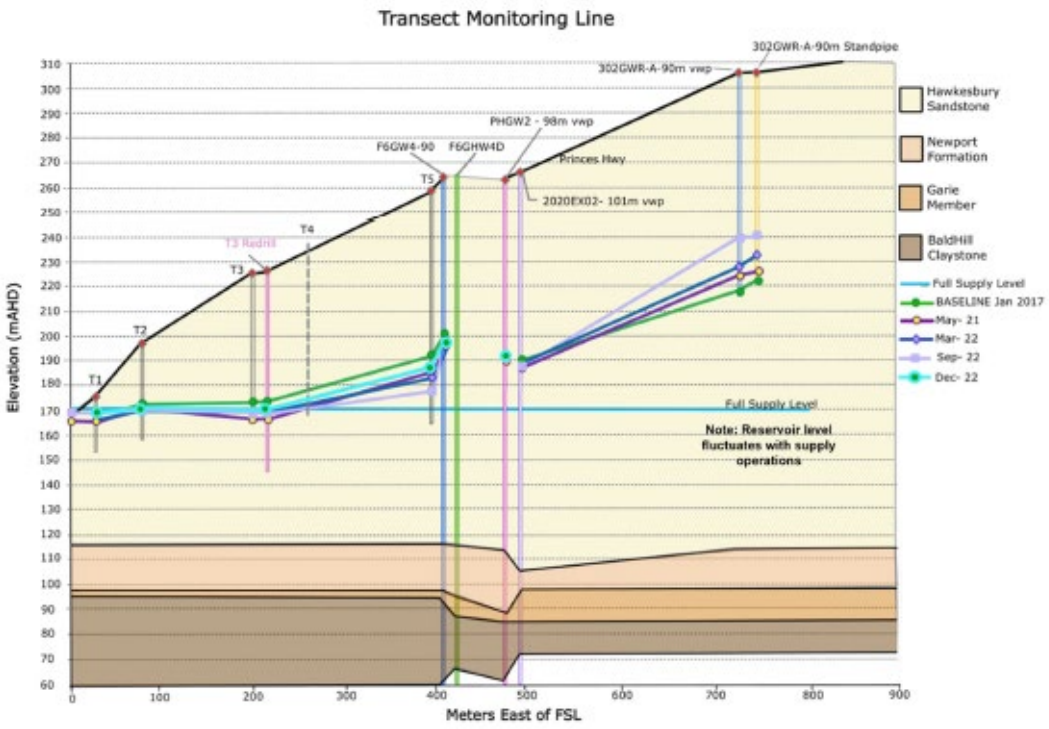


Figure 5: Cross section along the line of Boreholes T1 to T5 showing the elevation of the monitoring bores and the observed water levels at the end of 2022 (reproduction of Figure 2 in SLR**,** 2023a).

Based on the author's interpretation of the data, the Dupen Report states:

> *There are numerous concerning aspects of the post-mining groundwater conditions revealed by the transect piezometers. These include the long-term anomalously low water table in T5 (Figure 8 and Figure 9) and recent drops in T4 and T5 levels. Another surprising feature are the three large (+10 m) observed level surges in T5 between mid-2019 and mid-2020 (Figure 9), which are reasonably attributed by Peabody's consultants to pressure waves affecting the aquifer as the longwalls progress beneath. If present however, any pressure waves felt at T5 should intuitively have been observed at all of the nearby wells, especially the adjacent T4 piezometer (Figure 3). The reason for this contrast in pressure wave response through the*

[3] The actual water level in T1 during 2018 and 2019 when reservoir levels are low is not known. It would drop and not flatline as shown in this hydrograph

*transect is not clear, but suggests a high degree of structural heterogeneity in the aquifer.*

*The most disturbing trend however, is that the levels in T3 dropped below its base 17 days after the commencement of Longwall 305 (Figure 3), and then sheared in December 2020 (Figure 9). The piezometer was replaced in 2021 by a deeper one at the same location (T3-R). As can be observed by the red trace in Figure 9, groundwater responses in T3/T3-R appeared sensible for its ridge position prior to mining but now the water table closely mimics the reservoir level.*

Dupen is also of the view that a number of unpredicted mining-induced environmental consequences have appeared in the catchments, including:

*The perennial Eastern Tributary has unexpectedly gone dry for a 500 m length since the end of 2016 as a result of undermining.*[4]

This 500 m section of the Eastern Tributary is the section that has been marked in 'red' by Dupen in Figure 1.

Dupen offers what he describes as being *the only two hydrogeologically plausible hypotheses that I can think of which could account for the …behaviours in streamflow affected by subsidence.* The first of these, stated below, is reported by Dupen to be difficult to comprehend.

1. *The bedrock base of Eastern Tributary has been crushed by "non-conventional" subsidence effects (particularly the subsidence-induced valley closure mechanism) resulting in a relatively small (say 50-100 m in cross-section) "tunnel" of shallow fractures induced along and below the valley axis between Pools ETAG to ETAR. This conceptual model (summarised in Section 5.3.2) was the same one employed to explain the sub-surface diversion of flows in Waratah Rivulet, as well as WC21 and some other streams over the Dendrobium Mine nearby.*

   *It is difficult to comprehend using this conceptual model however, how sub-surface flows through a 500 m long, poorly interconnected "crush zone" of compressive fractures can have mimicked above-ground catchment flow responses as closely as shown in Figure 12*[5] *since the desiccation event in 2016/2017. I also struggle to identify a plausible mechanism for the increasing flows observed since about October 2021 using this conceptual model.*

The second conceptual model is Dupen's preferred explanation for the increased flow and is stated as:

2. *Whilst some non-conventional valley closure effects may well have contributed, the primary cause of flow diversion is the impositions of a mechanism termed here as "ridge fracture drainage" (Figure 4)*[6]*; the opening of widespread and interconnected basal shear planes beneath the base of the valley between Pools ETAG to ETAR*[7]*, combined with sub-vertical drainage along and below the ridge surfaces. If these subsidence effects are indeed substantial, ridge fracture*

[4] ES1
[5] Reproduced in this advice report as Figure 3
[6] Reproduced in this advice report as Figure 6
[7] See Figure 2 of this advice report

*drainage presents a risk to the catchments that has not previously been recognised, and the implications for future longwalls should be urgently re-considered.*

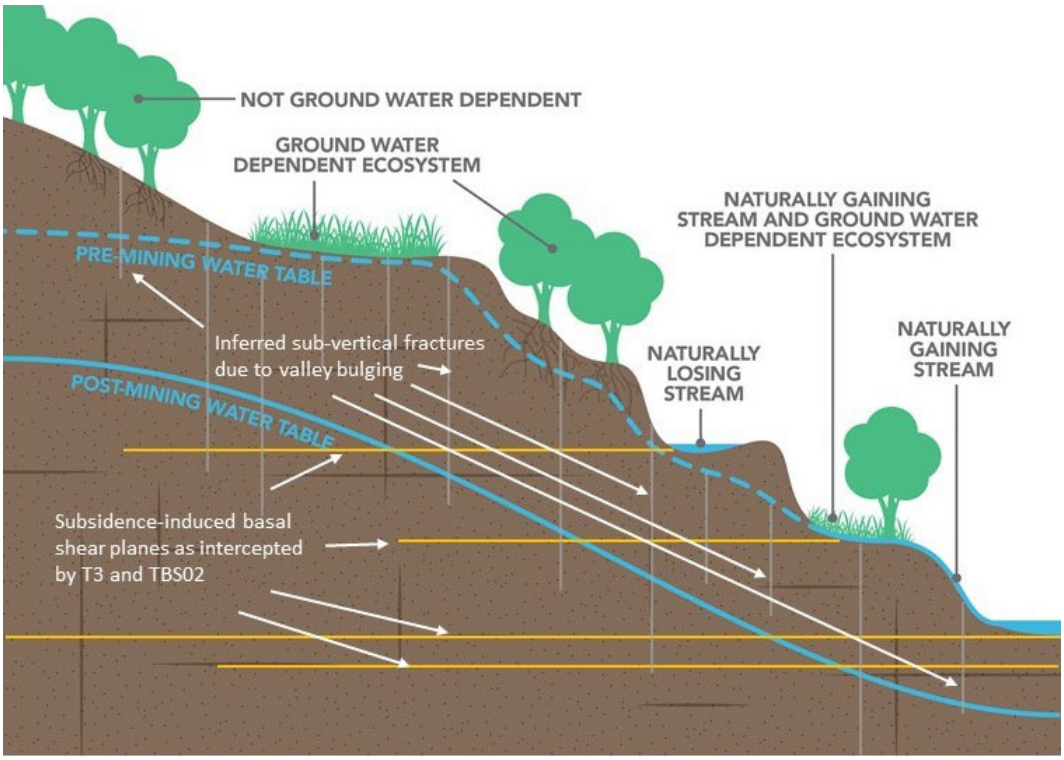


Figure 6. Reproduction of Figure 4 of the Dupen Report where it is described as *Schematic showing the hypothesised causes of "ridge fracture drainage", annotated here as basal shear planes (yellow) and sub-vertical stress relief fractures (grey). Base figure reproduced from Advisian, 2016*

In view of the ridge fracture drainage hypothesis, the Dupen Report goes on to state in the conclusions and recommendations that:

- *There is considerable evidence….that shear planes developed beneath the stream and reservoir base are leading to unpredicted and substantial subsidence impacts and environmental consequences. If the hypotheses presented in Section 5 are correct, surface flows and shallow groundwater are being widely diverted and drained by expanding shear and fracture systems in a mechanism termed here as ridge fracture drainage (Figure 1)*[8]*. If this new subsidence mechanism is indeed widespread, a likely outcome is that a range of protected Special Area ecosystems overlying the mine will dry and change. The other major risk from widespread basal shear formation is that it will cause the water quality in the Woronora drinking water reservoir to become increasingly degraded by metal-laden discharges from unmeasured shear plane vents.*[9]

[8] This Figure number appears to be incorrect and, presumably, should read *Figure 4*, being Figure 6 of this Panel advice report
[9] p32

with the primary recommendation arising from Dupen's report being:

- *…that further undermining of the Woronora Reservoir should be halted until the implications of these unexpected changes now unfolding in Woronora Reservoir catchment can be urgently evaluated.*

The Dupen Report acknowledges that the concerns raised in it are based on hypotheses and inferences, stating:

- *….this report has not followed a causally sound epistemology because I am not enumerating all hypotheses for all dimensions of the catchments nor impacts, nor rigorously falsifying any of the hypotheses against evidence - unfortunately there has not been an opportunity to use causal science directly in the time and budget allocated for this report.*[10]

[10] p24 – last paragraph

## 4.0 HISTORICAL BACKGROUND AND CONTEXT

### 4.1. SUBSIDENCE KNOWLEDGE BASE

Over the past 50 years, a range of public inquiries, studies and independent assessments have been undertaken into mining in the Southern Coalfield. A number of these are particularly relevant to the mining operations of Metropolitan Coal Mine and to reviewing aspects of the Dupen Report.

In the mid-1970s, the NSW Government commissioned Mr Justice Reynolds to conduct an inquiry into coal mining under stored waters in the Southern Coalfield, including beneath Woronora Reservoir. The Reynolds Inquiry (Reynolds, 1976) made a number of recommendations relating to the design of underground mine workings in the vicinity of stored waters. Subsequently, the guidelines have been the subject of theoretical and applied research and field investigations (for example, Byrnes, 1999; Singh & Jakeman, 1999, 2001) that have informed the design of longwall panels beneath Cataract Reservoir at South Bulli Colliery and beneath Woronora Reservoir at Metropolitan Coal Mine.

During the early 1990's, it began to be recognised that surface subsidence behaviour in the Southern Coalfield of NSW was more complex than predicted by conventional methodologies. Large areas of both the Southern Coalfield and the Western Coalfield in NSW are characterised by steep, incised topography with valleys and gorges that align with natural joint systems in the host rock. The incised topography naturally interrupts the transmission of horizontal tectonic stresses and causes them to be re-directed from the hills and into the floor of valleys and gorges. This process can lead to overstressing of valley floors, causing the rock mass to shear on bedding planes at or just below the floors of valleys. This movement, in turn, can result in the near surface rock strata bending and buckling upwards. This natural process is known as *'valley bulging'* and is sustained over time by weathering, leading to a progressive deepening of valleys. The planes on which the shear displacement occurs progressively daylight in the sides of a valley as it deepens.

Field investigations dating back well before the assessment of the Metropolitan Coal Project in 2009 confirmed that valley bulging can result in the creation of voids beneath watercourses, often in the form of open bedding planes which can act as underground flow paths for groundwater and stream water (Patton & Hendren, 1972; Fell et al., 1992; Everett et al., 1998; and Waddington & Kay, 2002a). Subsurface stream flow, commonly referred to as *'underflow',* can occur independently of the surface flow or the two flow paths may intermittently connect.

During the late 1990s the unpredicted severity of mining-induced subsidence impacts on natural and man-made surface features associated with valleys in the Southern Coalfield and the Western Coalfield became of increasing concern and prompted a range of investigations. These established that underground mining has the potential to grossly increase both the rate and magnitude of valley bulging. Underground mining layouts involving the formation of excavations, or panels, of sufficient width to induced fracturing, caving and subsidence of the overlying strata can cause significant changes on a regional scale in the pre-mining stress field. These changes to the stress field can significantly accelerate the rate and magnitude of valley bulging and result in significant uplift of valley floors and lateral movement of valley sides. This lateral movement is referred to as *'valley closure'*.

The mining-induced component of valley closure develops incrementally as panels are extracted, can extend well beyond the mining footprint and can be up to the order of 800 mm in the Southern Coalfield. The mining-induced subsidence effects on valley floors are due to a combination of conventional subsidence involving bending and sag of the bedded strata above excavations and non-conventional subsidence involving valley closure, with both

behaviours inducing (basal) shearing along bedding planes[11]. The subsidence effects are variable because they are a function of the location and direction of mining panels relative to that of the valleys. Depending on the relative locations of these two sources of mining-induced surface strain, surface strains associated with strata sag over each longwall panel may increase or reduce surface strains associated with valley closure. This is one reason why the prediction of mining-induced valley closure effects and impacts is an imprecise process.

One of the earliest and more detailed investigations into mining-induced valley closure involved monitoring the development of ground deformation along Waratah Rivulet at Metropolitan Coal Mine. This watercourse runs approximately parallel to and about 1400 m west of the Eastern Tributary, as shown in Figure 1. Mining-induced impacts on the Waratah Rivulet were a significant catalyst for establishing the *Strategic Review – Impacts of Underground Mining on Natural Features in the Southern Coalfield* (often referred to as the Southern Coalfield Inquiry) (DoP**,** 2008). Publications relating to valley closure which informed that Inquiry included Waddington and Kay (2002b), Mills and Huuskes (2004), Galvin (2005) and Mills (2007).

The PAC Panel for the Metropolitan Coal Project was required to have regard to the findings of the Southern Coalfield Inquiry. The PAC's report included the following Figure 7, sourced from Mills**,** 2007. The figure summarises its author's understanding of subsidence and valley closure impacts on watercourses based on the investigations conducted at Waratah Rivulet and shows the activation of bedding plane shears both in the sides and floors of a valley. Since 2009, additional detailed field investigations into the development and permeability of basal shear planes have been undertaken at a number of other sites in the Southern Coalfield, in particular at Dendrobium Mine in similar topography to that at Metropolitan Colliery.

Notable studies at Dendrobium Mine relate to setback distance of the finishing ends of LW6 to LW8 from Sandy Creek Waterfall (Walsh et al.**,** 2014) and setback distance of the starting ends of longwalls LW12 to LW18 from Avon Reservoir (SCT**,** 2015, 2016, 2017; HGEO**,** 2020). Basal shear plane locations and mining-induced displacements were determined from borehole monitoring at both sites. HGEO (2020) reported that at Sandy Creek Waterfall, packer testing indicated these bedding plane shear horizons have a hydraulic conductivity within the normal range of naturally jointed rock at shallow depth. It reported that a comprehensive program of groundwater monitoring between Avon Reservoir and the western end of longwalls LW12 to LW18 indicated that the measured hydraulic conductivity on a bedding plane shear increases two to three orders of magnitude to $1x10^{-6}$ m/s because of mining-induced initiation and/or remobilisation of shear plane displacement. This change in hydraulic conductivity was observed in five boreholes. The report concluded that the two to three orders of magnitude change in hydraulic conductivity had the effect of bringing the hydraulic conductivity of the bedding plane shear to a hydraulic conductivity similar to that of the surrounding strata.

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[11] This Advice report is premised on the following definitions as recommended by the Southern Coalfield Inquiry:

- Subsidence Effects: the deformation of the ground mass surrounding a mine due to the mining activity. The term is a broad one and includes all mining-induced movements, including both vertical and horizontal displacement, tilt, strain and curvature.
- Subsidence Impacts: the physical changes to the ground and its surface caused by subsidence effects. These impacts are principally tensile and shear cracking of the rock mass and localised buckling of strata caused by valley closure and upsidence but also include subsidence depressions or troughs.
- Environmental Consequences: the environmental consequences of subsidence impacts, including: damage to built features; loss of surface flows to the subsurface; loss of standing pools; adverse water quality impacts; development of iron bacterial mats; cliff falls; rock falls; damage to Aboriginal heritage sites; impacts to aquatic ecology; ponding.

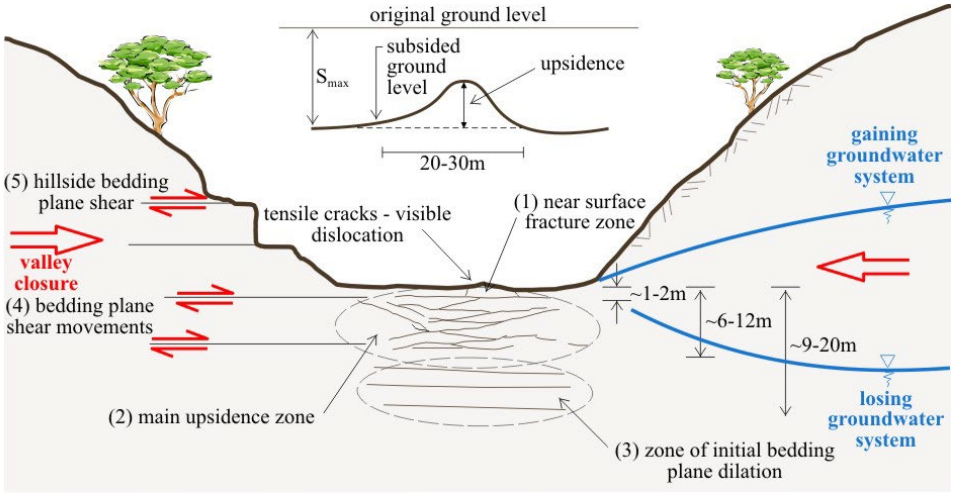


Figure 7: Cross section showing nature of rock fracturing observed due to valley closure in river channels in the Southern Coalfields (Mills, 2007)[12].

In 2017, DPE placed a condition of approval on Metropolitan Coal Mine that required it to engage independent experts endorsed by DPE to prepare a Woronora Reservoir Impact Strategy (WRIS). The WRIS Panel comprised three experts covering the discipline areas of mining and subsidence, groundwater and surface water[13]. The issues that DPE requested the WRIS Panel to address included *probable leakage rates* and *characterization of fractures (pre and post mining) including shear planes* (WRIS**,** 2017) The first report of the WRIS concluded that since 2009 water make into mine workings had averaged 0.09 ML/day and the 20-day average make had been below 0.5 ML/d. It also concluded that the then current debate around whether mining-activated shear planes would extend to the base of the Woronora Reservoir when the 300 Series of longwall panels were extracted needed to be informed by more detailed monitoring and review. The WRIS's recommendations included the drilling of additional boreholes for the purpose of monitoring the development of shear planes and groundwater pressures in response to mining.

The second report of the WRIS concluded that bedding plane shear monitoring had been very successful and clearly identified multiple planes of shear that initiated at a distance of less than 400 m from the approaching longwall face (WRIS**,** 2019). The report concluded that not all shear planes demonstrate increased conductivity, even though they have exhibited significant shear displacement (20 mm – 50 mm).[14]

In 2018, the NSW Department of Planning commissioned the Office of the Chief Scientist and Engineer to convene an *Independent Expert Panel for Mining in the Catchment* (IEPMC) to undertake a Scope of Works that included a specific focus on past and future mining activities at Metropolitan Coal Mine. The IEPMC concluded in its first report (OCSE**,** 2018) that losses of water from the catchment into the mine workings were negligible and that, going forward, the potential for water to be diverted out of Woronora Reservoir and into other catchments through valley closure shear planes and geological structures including

[12] Gaining groundwater system means groundwater baseflow to a gaining stream; Losing groundwater system means surface water loss from a losing stream
[13] The Chair of the WRIS Panel was Professor Bruce Hebblewhite, who is Deputy Chair of the IEAPM and not involved in the preparation of this advice report.
[14] p92, WRIS**,** 2019

lineaments would require careful assessment because the remaining longwall panels in the approved area passed beneath the reservoir[15],[16].

The IEPMC also produced three advice reports for DPE regarding the Extraction Plans for LW303, LW304 and LW305 to LW307, respectively. These reports were concerned with limiting further impacts of valley closure on the lower reaches of the Eastern Tributary, including part of the area of particular concern to Dupen shown in red in Figure 1.

## 4.2. GROUNDWATER AND SURFACE WATER

### 4.2.1. Groundwater Characteristics

The geological unit of primary interest, with respect to the impacts of mining on groundwater systems and baseflows to surface water and the Woronora Reservoir, is the Hawkesbury Sandstone, shown in Figure 8.

The shallow groundwater system in this sandstone unit comprises:

- Localised perched groundwater associated with swamp colluvium and shallow sandstone (predominantly in the weathered zone); and
- Regional groundwater comprising saturated porous and fractured sandstone below the regional water table.

Rainfall infiltration over the catchment area and surface water losses from losing stream sections are the only groundwater recharge characteristics. Evapo-transpiration, baseflow discharges and leakage to deeper aquifers in the Narrabeen Group rocks are the primary discharge characteristics.

The Panel's site inspection on the 10 May 2023 (after an extended dry period) did not identify any other groundwater discharge features in the landscape apart from one seepage area in a depression towards the northern end of Fire Trail 9G. There were no obvious spring discharge areas and no evidence of basal shear zones (above stream level) that were discharging mineralised groundwater. There was no evidence of any terrestrial GDEs tapping shallow groundwater. However, the Panel recognises that during and just after rain, ephemeral springs and seeps could occur through interflow where cross bedded sandstone and bedding plane partings daylight in the valley sides.

Perched groundwater derived from rainfall occurs in colluvium beneath ridgelines and valley sides, and also in the weathered Hawkesbury Sandstone underlying swamp sites (Figure 8). Perched groundwater sits above the regional groundwater leading to different water tables at different depths. Typically, perched groundwater occurs within 10 m of surface with the water table potentially ranging from at surface during wet periods to being absent during severe droughts. The absence of permanent springs and any obvious perched groundwater in the upper Hawkesbury Sandstone (apart from in the vicinity of swamps) suggests most rainfall recharge (apart from that portion that is lost to evapo-transpiration and via interflow after rain) drains vertically to the regional water table and then moves laterally to emerge in the base of the valleys as baseflow.

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[15] piii, OCSE (2018)

[16] The Panel notes that the Dupen Report also states that there is no concrete evidence that there is a substantial net loss of water volumes from the Woronora Reservoir catchment into underlying workings.

Groundwater flow in the Hawkesbury Sandstone in areas unaffected by mining occurs mainly through natural fractures and to a lesser extent through porous layers. The natural fracture system is complex and flow paths are tortuous from recharge zones to discharge zones. The depth to the regional water table (based on limited data) varies between 70 m below ground level (mbgl) below the major ridgelines to less than 3 mbgl near the permanent streams and Woronora Reservoir (see Figure 5). From the ridgelines, there is both lateral flow to permanent streams and vertical flow to deeper aquifers. A downward hydraulic gradient typically exists, even to the deeper strata in the Narrabeen Group and Illawarra Coal Measures underlying the Hawkesbury Sandstone. This is the case before and after mining, although downward flows are small due to the limited hydraulic conductivity of the low permeability siltstone and claystone formations.

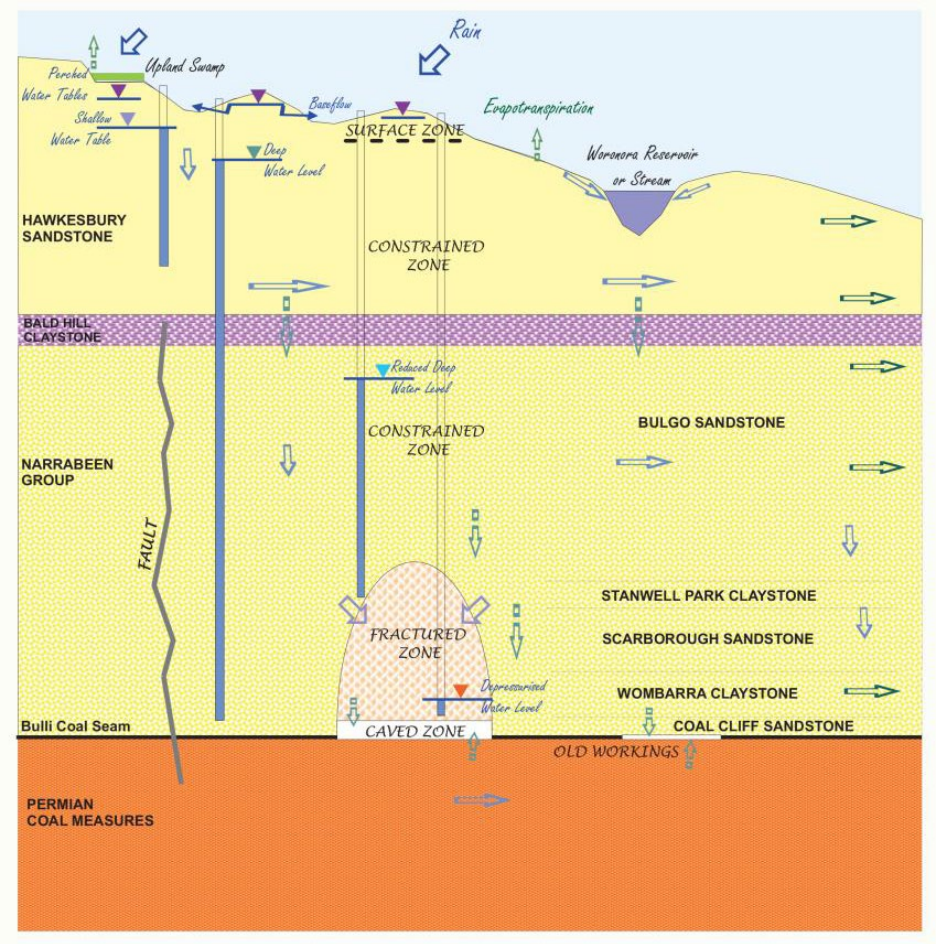


Figure 8: Conceptual groundwater system proposed by the WRIS for Metropolitan Coal Mine (Figure 3-1 from WRIS, 2017).

Longwall mining changes the groundwater flow geometry within the regional groundwater system in the Hawkesbury Sandstone above longwall panels as groundwater depressurisation occurs in deeper formations and as enhanced fracturing propagates through portions of the upper formations including the sandstone. These changes generally result in lowering of the regional water table due to:

- release of pressurised groundwater into dilated fractures;
- increased flow of groundwater to surface water due to enhanced fracturing and dilated bedding planes; and

- increased flow into the mine void.

Due to the significant depth (435 to 550 m) and relatively conservative geometry of the workings at Metropolitan Coal Mine and the hydrogeological conditions, the latter contribution is recognised as not presently significant.

Where subsidence-induced fracture systems increase the hydraulic connection of groundwater to surface watercourses, mining can result in increased surface water flows. Conversely, the possibility of surface flows being diverted to underflow due to subsidence effects, means that surface water flows may be seen to reduce over some lengths of creeks. The Dupen report refers to these potential changes as "changed baseflow patterns". Currently the magnitude and location of net baseflow gains or losses to Waratah Rivulet, Eastern Tributary and other Woronora tributaries are uncertain.

Measurement of groundwater levels is generally undertaken using piezometers. A piezometer measures a groundwater level or pressure at a specific areal location and depth. Because fractures dominate flow paths in the Hawkesbury Sandstone, and installed piezometers in this formation may or may not coincide with fracture locations, measurements cannot be interpreted as measuring the precise response of the regional groundwater system to natural recharge, flow, and any mining induced subsidence. It is not uncommon that groundwater levels and their responses to mining vary between nearby piezometers.

Care is required in attributing the cause of piezometric changes above longwall panels. Strata relaxation associated with overburden strata sagging and subsiding above a longwall excavation can result in delamination and the creation of partings (voids) between stratum, which a piezometer can report as depressurisation. Water pressure may be recovered once sufficient time has elapsed for groundwater to fill this new void space. This behaviour can be largely site specific because the sag component of total vertical displacement is site specific and has minimal interaction with sag over adjacent panels.

### 4.2.2. Surface Water Characteristics

The Eastern Tributary consists of a series of pools, rock bars and boulder fields, which are mapped and photographed in detail in Peabody**,** 2022a). The Metropolitan Coal 2021 Annual Report (Peabody**,** 2022b) acknowledges subsidence effects and consequences on pool drainage behaviour over a ~ 2 km length of the creek overlying LW20 to LW27 and further downstream towards the Woronora Reservoir (Pools ETAG, ETAH, ETAI, ETAJ, ETAK, ETAL, ETAM, ETAN, ETAO, ETAQ and ETAR). This has led to an ongoing program of grouting in an attempt to seal surface and near-surface fractures and recover pool water levels and continuity of surface flows. Subsidence has not visibly affected pool drainage behaviour further downstream at Pools ETAS, ETAT and ETAU (Peabody**,** 2022b).

The Eastern Tributary hydrology is consistent with 2$^{nd}$ and 3$^{rd}$ order creeks generally in the Southern Coalfield, with sources dominated by surface runoff, interflow, discharge from shallow aquifers, and exchanges of flow between surface and subsurface zones of the creek. The potentially significant sources of water are:

- Surface water discharges. During rainfall, the rainfall in some areas of the catchment will exceed the infiltration capacity of the soil, and overland flow will be generated. This flows into the creek within a few minutes to hours, creating rapid increases in flows and being the main contributor to flood flows. A proportion of this overland flow will infiltrate as it moves over the soil surface and then migrate as interflow or evaporate or recharge the perched or regional groundwater. Disturbances to vegetation and soil such as fire can change the

balance of overland flow, interflow, recharge and evaporation, although any change should recover quickly in the case of controlled burns.

- Interflow. During and after high rainfall events, interflow occurs where water infiltrates the unsaturated zone and moves laterally to then return to the surface as an ephemeral spring or enter a nearby stream. Interflow is fast flow that occurs in the subsurface after a few hours and can last for days and weeks depending on the nature of the rainfall event and the available storage in the unsaturated zone.
- Perched groundwater discharges. Perched groundwater is recharged by rainfall and interflow and remains in the subsurface for long periods. This groundwater is localised and sits on shallow impermeable layers above the regional groundwater system (not shown in Figure 7). It can discharge slowly laterally (potentially as interflow) depending on the geometry of the impermeable layer but otherwise will remain as a localised pocket of shallow groundwater in the landscape subject to evapo-transpiration.
- Regional groundwater discharges. This discharge occurs in creek lengths where the regional water table sits above the creek level; i.e. a gaining system shown in Figure 7. This source of flow can be sustained for weeks to months over prolonged periods of dry weather and is commonly considered to be the major component of "baseflow". The low flows during prolonged dry weather (Figure 3) reflect a limited sustained contribution of regional groundwater in the Eastern Tributary catchment, although what lengths of creek this applies to is not well understood.

  The baseflow rate depends on the hydraulic connectivity between the regional groundwater system and the creek, among other factors. In principle, mining can decrease baseflow rates due to lowering of the groundwater levels or increase baseflow rates if subsidence leads to an increase in the hydraulic connectivity[17]. Either can be a temporary or permanent effect.

The main potential mechanisms for loss of water from the Eastern Tributary are:

- Loss of water to the regional groundwater system (the losing system in Figure 7). The available groundwater data does not indicate this mechanism is widespread along the lower portion of the Eastern Tributary.
- Diversion of water through fractures to the shallow subsurface (underflow), where it flows downstream in the near-surface fracture zone (Figure 7). This water generally re-appears further downstream in the creek, where the near surface fracture flow paths reconnect with the surface. The surface and near-surface fracture zone may be natural or mining-enhanced. Exchanges between the visible surface flows and the near-surface fracture zone mean that flow may appear absent from considerable lengths of the creek during dry weather.

Measuring and modelling creek flow rates is a common approach to measuring the consequences of mining for water resources. For example, the comparison of modelled flow (representing pre-mining conditions) and measured flow (representing mining conditions) near the Waratah Rivulet inlet to the Woronora Reservoir is the basis for a flow performance indicator for Metropolitan Coal Mine. A comparison of modelled and measured flows is also reported in Peabody (2021, 2022) at the Eastern Tributary flow gauge location (Figure 3). The flow gauge consists of a prefabricated flume set into a concrete wall, the latter acting as a weir when overflow occurs. Measurements and modelling of the Eastern Tributary flows

[17] Flow gauging in the Eastern Tributary (Figure 3) began in 2012 while longwall mining in the area dates back to 1995, including the LW20 series from 2010, so there is no pre-mining baseline data for this catchment that would allow an assessment of long-term cumulative consequences on baseflows.

are prone to errors especially at high flows: the flume is designed to accurately measure flows up to approximately 235 L/s (3.5 mm/day in Figure 3) (HEC, 2022). Any flows above this value are estimated using a rating curve (a curve showing the relationship between water level and stream flow rate), which has been approximately estimated and lacks validation (HEC, 2022). The Panel's field inspection on 10 May 2023 noted that the concrete weir stops short of the bank, which may contribute to errors at low to medium flow rates due to water escaping around the flume and weir.

The Eastern Tributary surface flow model employs the industry-standard AWBM model, which has been adjusted specifically for the Woronora catchments and peer-reviewed (Gilbert & Associates, 2015). The Panel has not undertaken an in-depth technical review of the model. The Panel's review of the model is based on the figures and commentary in Peabody (2022b) and HEC (2022). The model does not (and was not designed to) estimate high flows accurately for a number of reasons, including the reliance on daily rather than peak rainfall data, and absence of accurate high flow calibration data. The model also has some errors at medium to low flows (as can be seen in the calibration period in Figure 3). These types of errors are generally considered acceptable for this type of model application. The assessment looks for changes in errors between the calibration and the mining period and considers whether they should be attributed to mining or other effects. Further review of Figure 3 and its interpretation by the Dupen Report is in Section 5 of this advice report.

### 4.3. PERFORMANCE MEASURES AND INDICATORS

Performance measures are set as part of the Project Approval conditions (DoP, 2009b). The performance measures most relevant for the scope of this advice report are:

- *Catchment yield to the Woronora Reservoir:*
    - *Negligible reduction in the quality or quantity of water resources reaching the Woronora Reservoir*
    - *No connective cracking between the surface and the mine*
- *Woronora Reservoir:*
    - *Negligible leakage from the Woronora Reservoir*
    - *Negligible reduction in the water quality of Woronora Reservoir*
- *Eastern Tributary between the full supply level of the Woronora Reservoir and the maingate of Longwall 26*[18]*:*
    - *Negligible environmental consequences over at least 70% of the stream length (that is no diversion of flows, no change in the natural drainage behaviour of pools, minimal iron staining and minimal gas releases)*
- *Upland swamps, riparian vegetation and aquatic biota:*
    - *Negligible impact on Threatened Species, Populations, or Ecological Communities*

The performance measures related to water flow are relevant to this current advice report in light of the potential significance of matters raised in the Dupen Report and arising out of the Panel's review of the Dupen Report. Specific areas of relevance for the current advice report

[18] The location of the maingate of Longwall 26 is approximated by the blue cross in Figure 1.

relate to potential changes over time to flows into the Woronora Reservoir and to changes to the environmental conditions along the Eastern Tributary due to diversion of flows. The performance measures related to upland swamps, riparian vegetation and aquatic biota are relevant to the comments in the Dupen report that ecosystems will inevitably degrade due to the diversion of surface and near-surface flows.

As previously noted, matters of significance raised in the Dupen Report in relation to potential mining impacts on water quality fall within the brief of another IEAPM Panel and the reader is referred to IEAPM (2023).

## 5.0 DUPEN REPORT ASSESSMENT

### 5.1. APPROACH

This section first focusses on overviewing the primary hypothesis of the Dupen Report and key supporting statements, then identifies other key statements made in the report related to the implications of the hypothesis. The Panel has not assessed Section 3.8 (Volumetric loss calculations) of the report as it is considered to be outside of the scope of the Department's request for advice from the IEAPM.

### 5.2. PRIMARY HYPOTHESIS AND STATEMENTS – OVERVIEW AND EVALUATION

#### 5.2.1. Prediction and appearance of impacts on Eastern Tributary

Dupen states that:

> *Such widespread fracturing and surface flow water diversions* [on the Eastern Tributary] *were not anticipated in the planning application documents (Helensburgh Coal, 2008; 2009), and their implications are not acknowledged by the mining company nor the regulators and their expert committees, based on the documentation reviewed.*

It is correct that the planning application documents lodged by Helensburgh Coal for assessment by the Planning Assessment Commission (PAC) made no provision for limiting subsidence impacts on the Eastern Tributary. However, the PAC and subsequent expert panels (IEPMC and the IEAPM) did anticipate and/or acknowledge the potential for widespread subsurface fracturing.

The Eastern Tributary was designated as a significant natural feature by the PAC after it conducted a field inspection. The draft Preferred Project Report (PPR) lodged by Helensburgh Coal in the final stages of the PAC's assessment included a revised mine layout that was based on preventing fracturing and drainage of any more rock bars on Waratah Rivulet, downstream of pool L shown on Figure 2. Helensburgh Coal proposed to achieve this with a revised mine layout designed to limit predicted valley closure to no more than 200 mm downstream of pool L.

This criterion was based on minimising the potential for draining of pools due to cracking of rockbars, which had not been recorded on watercourses up to that time at sites for which predicted total closure was less than 200 mm[19],[20]. The PAC concluded that:

> "*Because the 200 mm closure limit is an outcome of a prediction methodology that is under development, it is subject to change as the prediction methodology evolves* (DoP**,** 2009a).

The PAC questioned whether closure and upsidence behaviour in the Project Area could be presumed to conform to past Southern Coalfield experience, given that conventional subsidence effects were greater in the Project Area than recorded elsewhere in the Southern Coalfield. It was advised by Helensburgh Coal that:

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[19] Note, as explained in Part 1 of the IEPMC's report (OCSE**,** 2018) that mine design criterion was (and still is) based, unusually so, on predicted values of valley closure and not on measured values (because measured values did not correlate as well with subsidence impacts)

[20] Reference MSEC**,** 2007

"*There is some probability, regardless of the approach, that potential impacts could occur at predicted closure values less than the minimum predicted total closure of 200 mm that has been identified to date".*[8]

The revised mine layout was based on limiting predicted valley closure along Waratah Rivulet to less than 200 mm. However, this in turn did result in a reduction in predicted valley closure along the Eastern Tributary, as shown in Figure 9.

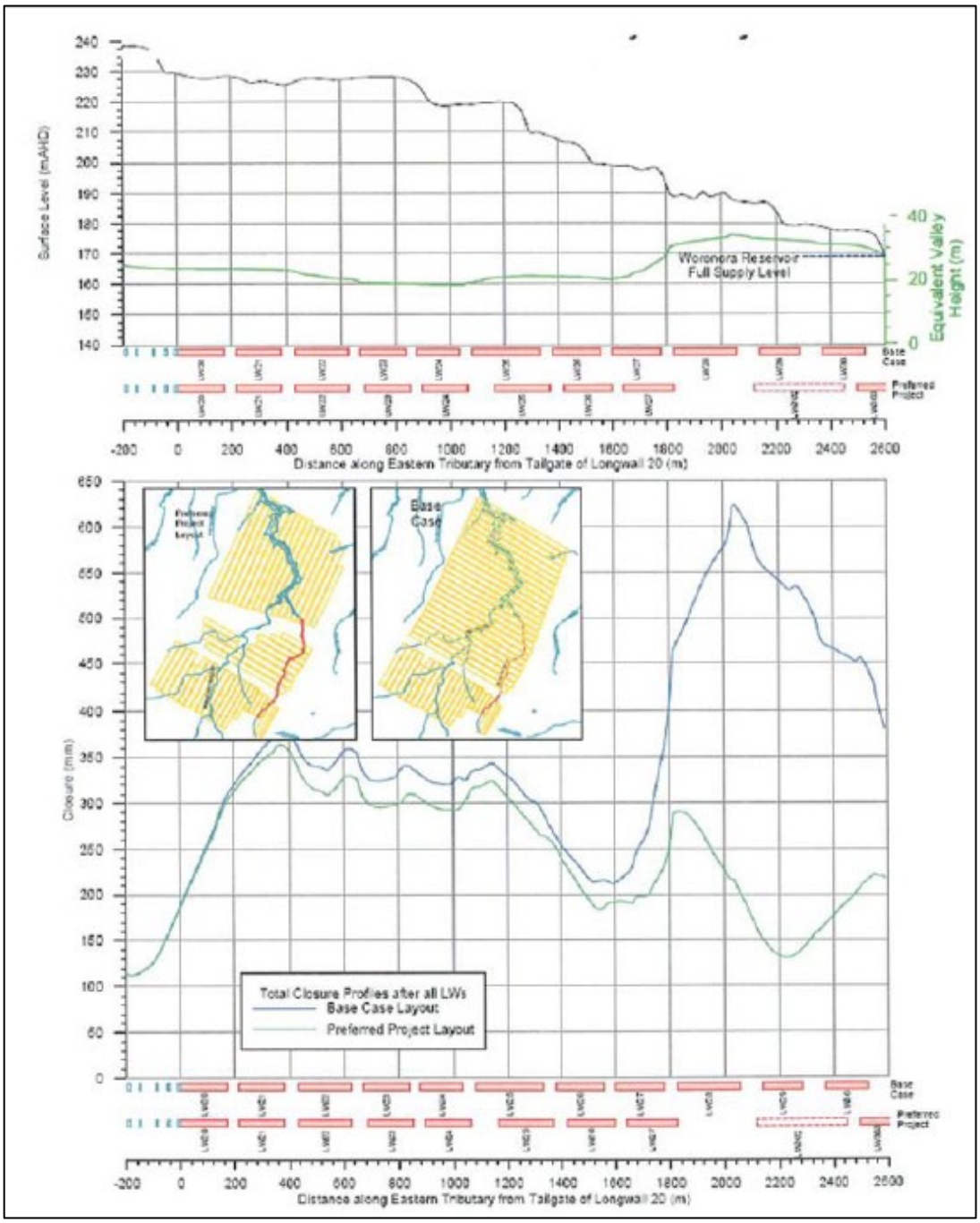


Figure 9: Profiles of predicted valley closure along the Eastern Tributary associated with both the mine layout proposed in the EIS for the Metropolitan Coal Project and the modified layout presented to the PAC during its assessment process (Peabody, 2009).

The PAC foresaw that the levels of valley closure predicted in the draft PPR were still sufficient to result in significant impacts to Eastern Tributary. Accordingly, the PAC recommended that the environmental *outcome for the reach of the Eastern Tributary between the junction of the two tributaries at approximately 6214600N and 312200E and the full storage level be set at negligible consequences (i.e. no diversion of flows, no change in the natural drainage behaviour of pools, and minimal iron staining)*. These coordinates correspond closely to the position of the maingate of LW26 at the eastern (outbye) end of this longwall panel, marked by 'X' in Figure 1. Notwithstanding the changes to the original mine plan, the PAC did not endorse the modified mine plan nor was it required to. In fact, the PAC concluded that[21]:

> *The main problems* [with the revised mine plan] *appear to be:*
>
> - *The predicted impacts associated with the southern ends of Longwalls 30 and 31* [since renumbered LW301 and LW302]*; and*
> - *The predicted impact associated with Longwall 27.*

An expanded version of the PPR was submitted to the Department of Planning (DoP) after the PAC had concluded its review (as reported in the Department's 'Reasons for Approval'). However, the mine plan and predictions of valley closure were basically unchanged from that shown in Figure 9. DoP stated in its assessment of the PPR that:

> *It is generally accepted that the figure* [of 200 mm of predicted valley closure] *is far from established. It must be seen as indicative, rather than determinate. There remains a possibility, particularly for fragile rock types, that significant buckling and shearing of stream beds will eventually be observed where predicted valley closure is less than 200 mm.*[22]

Subsequently, DoP relaxed the PAC's recommended Performance Measure for the lower end of the Eastern Tributary, stating:

> 1. *HCPL has made a convincing case that reducing valley closure to 200 mm over this stretch of the Tributary* [midway across Longwall 26 to the Reservoir] *would cause it to be unable to extract Longwall 27*[23]*;* and
>
> 2. *The Department has therefore recommended a condition that the environmental outcome for the lower length of the Eastern Tributary be set at "negligible consequences" for at least 70% of the stream downstream of the maingate of Longwall 26 to full storage level.*[24]

The Panel is unaware of the basis for determining a figure of 70% and what sections of the Eastern Tributary downstream of the maingate of LW26 were expected make up this accumulated proportion of unimpacted stream length.

Within 12 months of the PAC's assessment, it was established that some 10% of those rock bars that had been monitored in the Southern Coalfield had been impacted at predicted valley closure levels of less than 200 mm to the extent that '*pool water levels were observed to drop more than was expected after considering the rainfall and groundwater flow conditions*'. This level of impact was classified as a 'Type 3' impact. On that basis, based on the mine layout as approved, the full extent of the Eastern Tributary between the maingate of LW26 and the

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[21] P126 of DoP, 2009a
[22] p21 of DoP, 2009b
[23] p25 of DoP, 2009b
[24] p 26 of DoP, 2009b

full supply level of Woronora Reservoir was vulnerable to environmental impacts that exceeded a performance measure of *negligible.* This always included that section of the Eastern Tributary located over the 'pillar' zone since predicted valley closure over this area still ranged up to almost 300 mm.

LW27 was completed in March 2017 and mining of LW301 commenced in June 2017. This panel was shortened for operational reasons and, as shown in Figure 10, stopped over 350 m short of its planned finish point. Hence, the contribution of this panel to cumulative valley closure along the Eastern Tributary could be expected to be minimal. LW302 was extracted to its originally planned and finished in February 2018. Soon after, it was recognised that the Performance Measure of negligible for 70% of the length of Eastern Tributary downstream of Point X had been exceeded, resulting in LW303 to LW305 being setback from Eastern Tributary substantially greater distances than planned at the time of project approval. The modified layout, shown in Figure 10, resulted in moderate to very large decreases in predicted valley closure downstream of about pool ETAM[25], as evidenced by comparing predictions plotted (in green) in Figure 9 with those tabulated in Figure 10.

Nevertheless, although the actual mine layout was predicted to result in valley closure of only 125 mm at rockbar ETAO, it appears that subsidence effects were sufficient to cause subsurface flow at this rockbar. Figure 11 shows the appearance of 10 m of core recovered to one side of Rockbar ETAO. This photograph was taken during the Panel's site inspection on 20 May 2023. Drilling was in progress and the core had still to be geotechnically logged. However, the photograph clearly shows a high density of iron-stained fractures, especially in the upper 5 m of the core. No information was available at the time on the in-situ aperture of these fracture planes and how fracture density and aperture compared with that towards the centre of the watercourse. Grouting was also in progress to remediate the fracture network at the rock bar. Field observations and discussions with operators made a compelling case that subsurface flow is occurring at this location.

[25] This is an informed estimate by the Panel and should be confirmed by more detailed information and analysis by Metropolitan Coal

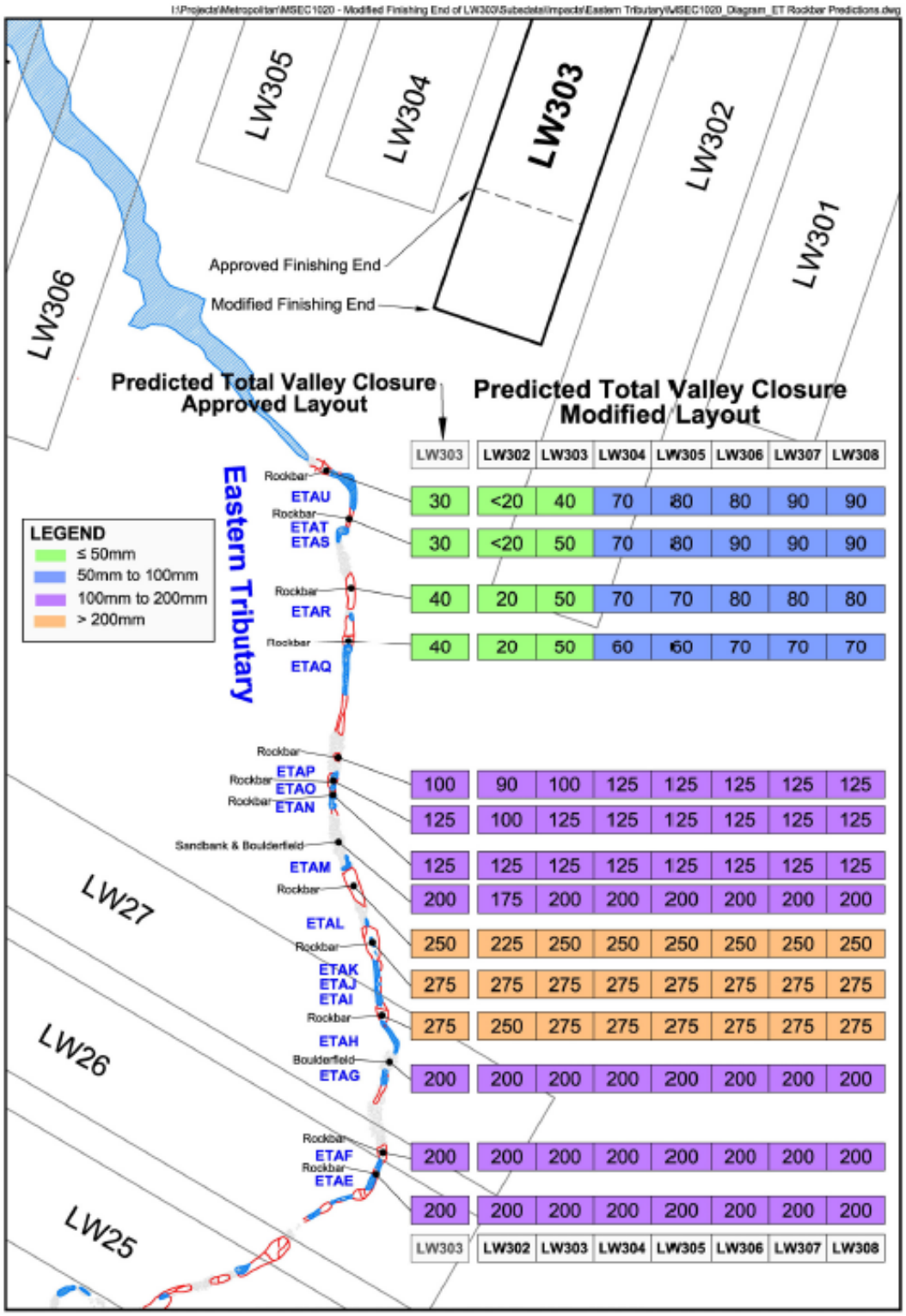


Figure 3 Predicted total valley closure after LW303 to 308 at Eastern Tributary rock bars

Figure 10: Predicted cumulative valley closure at the Eastern Tributary for LW302 to LW308 (Peabody, 2019).


Figure 11: Core observed during the Panel's site visit on 10/5/23, the core having been recovered to a depth of 10 m from one side of Rockbar ETAO on the Eastern Tributary and showing a series of iron-stained partings indicative of subsurface flowpaths.

Other subsidence related statements in Dupen (2023) relevant to the Panel's advice are:

- *Again unlike the Waratah Rivulet impacts (and WC21 over Dendrobium Mine), the desiccation event occurred not gradually and progressively following undermining, but over a relatively short time period after most of the 20 series longwalls had already been mined. The wholly unpredicted drying event was first reported in November 2016 and by February 2017, over 500 m of the previously permanently flowing creek was frequently or permanently dry.*

  The Panel notes that the Eastern Tributary was undermined by LW27 in November and December 2017 and remained within the area of influence of active mining until the panel was completed in March 2017. The tabulations of predicted valley closure presented in Figure 10 show that after the completion of LW302, predicted valley closure plateaued at 200 mm on the southern flank and at the centre of LW27 and at 275 mm on the northern flank of LW27 and downstream to rockbar ETAL. It then progressively reduced and plateaued at 200 mm at ETAM and 125 mm at ETAN, ETAO and ETAP.

Based on the predictions of valley closure for both the original approved mine layout and the actual mine layout, it appears likely that the extraction of subsequent longwalls after LW27 would have resulted in minimal additional (incremental) predicted valley closure at rockbars upstream from ETAP; that is, the values of predicted valley closure tabulated for these rockbars in Figure 10 are likely to be close to those at the time that the Eastern Tributary was being undermined by LW27. This being the case and given the magnitudes of the predicted cumulative valley closures at that stage, it is quite plausible that the incremental increase in valley closure over not only LW27 but also over previously extracted longwalls in its vicinity was a trigger for a significant mining-induced ground deformation event beneath the Eastern Tributary, at least downstream to ETAP.

Buckling is a form of structural failure due to deflection initiated by load acting through the long axis of a structure (as opposed to bending initiated by load acting at right angles to the structure). Step increases in deflection can be initiated by very small increases in load or, in this case, valley closure. Once a threshold value is exceeded, deflection can develop rapidly. In the case of valley closure, one is dealing with high stresses on a regional basis that act on natural material that is of variable composition and contains defects. Hence, it is quite conceivable that sometime around or just after the completion of LW27 a large area that had appeared relatively benign could deform quickly as a result of incremental increases in valley closure over LW27 and earlier panels. The total valley closure at that point in the mining process had been predicted to reach a level known to result in fracturing of rock bars.

The Panel recommends for the purpose of developing a better understanding of valley closure impacts to inform mine design that, if it has not already done so, Metropolitan Coal undertake an investigation of mining impacts on the Eastern Tributary that includes an evaluation of:

1. How predicted valley closure developed incrementally along the Eastern Tributary.
2. How well incremental and total predicted valley closure correlated with measured incremental and total measured closure.
3. The nature and extent of natural and mining-induced fracturing to a depth of at least 20 m along the Eastern Tributary downstream from the maingate of LW26 (point ‘X’) to the FSL of Woronora Reservoir (noting that some of these investigations may have already been undertaken).
4. How well mining-induced environmental impacts along the Eastern Tributary correlate to both predicted valley closure and to measured valley closure.

- *Another unexpected feature of the Eastern Tributary pool drying event is that much of it has occurred over areas in which very little subsidence occurred as they lie over unsubsided “first workings” or unmined rock (Figure 11).*

  Valley closure is not confined to above mine workings. It can develop at considerable distances beyond the mining footprint.

- *There is little evidence that the Eastern Tributary pool drying event may be attributed to “rock-bar throughflow”, as envisaged by Peabody’s consultants (Figure 14). …This mechanism, in which water in an upstream pool is able to seep through the fractured fabric of the intervening rock bar ……. It is worth noting*

*that, if shear planes have indeed been widely developed beneath the valley axis as hypothesised in Section 3.2, the remedial design that was used with considerable success at Waratah Rivulet may not be successful in restoring surface flows to Eastern Tributary.*

As noted earlier, drilling being undertaken at the time of the Panel's site visit in May 2023 provides evidence that subsurface flow had occurred at Rockbar ETAO, well downstream of the footprint of LW27.

- *Subsidence monitoring showed that valley closure effects in the area of the dried pools were mostly within the "conservative" valley closure threshold hypothesised by subsidence consultants MSEC (2008). MSEC's subsidence impact predictions suggest that no more than 10% of stream beds should be cracked as long as valley closure is less than 200 mm, measured across the axis of a valley). On this basis, the widespread flow diversions experienced in Waratah Rivulet were not expected to be repeated in Eastern Tributary (Metropolitan Coal, 2022b)*.

  The mine design procedures and subsidence impact assessments were based on predicted valley closure, not measured valley closure, because measured valley closure did not produce as good a correlation with impact outcomes as did predicted valley closures (see OCSE**,** 2018 for a more detailed discussion on this matter). As reflected in Figure 9 and Figure 10, valley closure for Rockbar ETAI to ETAM was always predicted to be greater than 200 mm.

### 5.2.2. Flow measurements

Dupen suggests that the anomalously high flows recently measured at the Eastern Tributary gauge (see Figure 3) may be explained by the Dupen Report's main hypothesis, being:

> *My interpretation of the reported trends (Section 3.5) is that flows in Eastern Tributary and probably other undermined streams are currently being affected by increased draining of the undermined ridges through basal shear planes. Once a new equilibrium is established, quicker and smaller baseflows may reduce overall flows to the Reservoir.*[26]

For high flows, from January 2019, Figure 3 includes several incidences of the flow rate measured at the Eastern Tributary weir being well above the rainfall rate at the nearby Darkes Forest gauge, Figure 12, which is implausible.[27] Following Metropolitan Coal's investigation into the flow anomalies (HEC**,** 2022), the rating curve (i.e. the calibration of the flow-depth relation at the flow measurement flume and weir) was updated to give the data in Peabody (2022b) reproduced as Figure 13 in this advice report. Figure 14 (Figure 8 from HEC**,** 2022) is the same plot, zooming in on the period 1-Jan-2020 to 1-Sept-2022.

[26] p28 of Dupen**,** 2023a.

[27] Groundwater contributions to the flow hydrograph, derived from prior rainfall events, would not be sufficient to allow the peaks in measured surface flows to exceed the rainfall rate for these incidences.

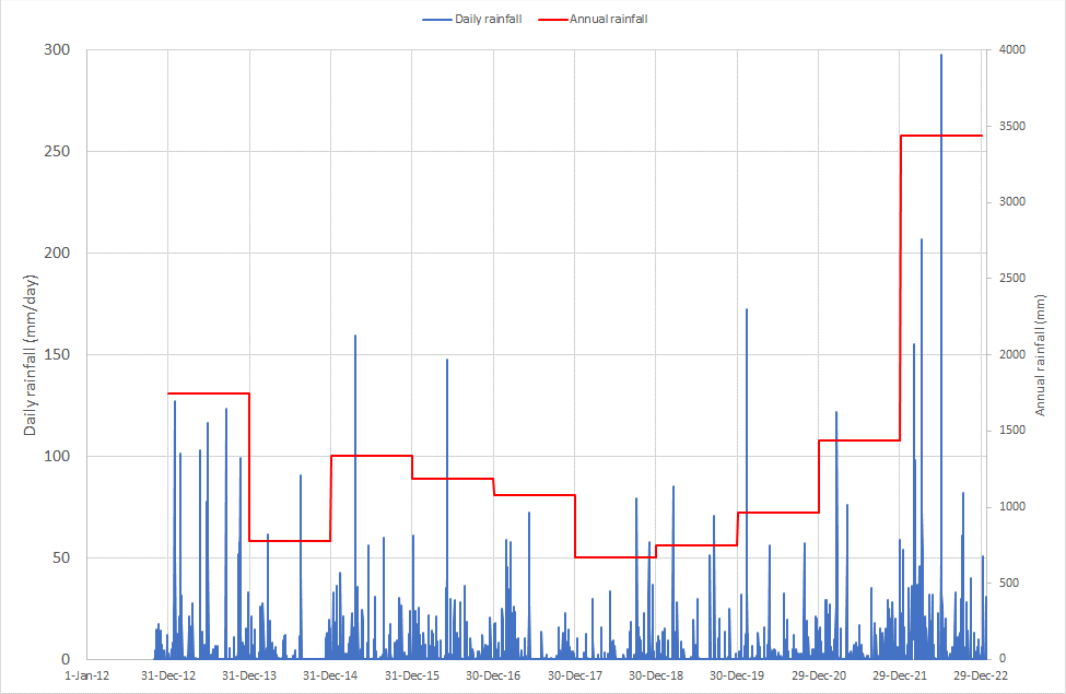


Figure 12: Daily and annual rainfall at the Darkes Forest gauge (approximately 5 km south-west of the Eastern Tributary flow gauge). Data sourced from https://www.longpaddock.qld.gov.au/silo/ .

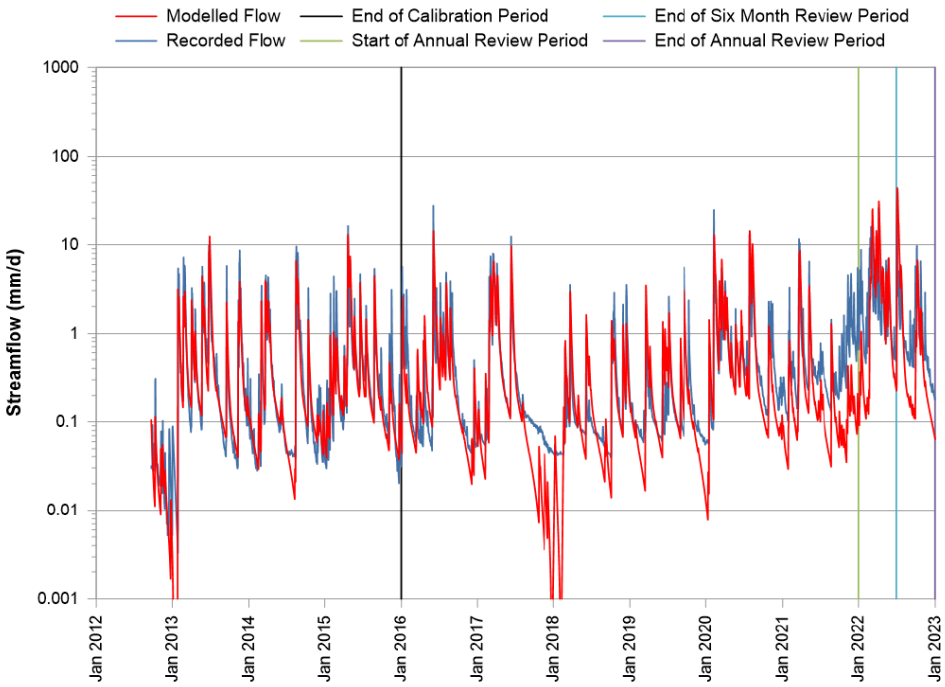


Figure 13: Flow data from the Eastern Tributary gauge. Originally Chart 4 in Peabody (2023). (The y-axis scale (mm/day) is the flow volume rate in $mm^3$/day divided by the catchment area in $mm^2$. 1 mm/day = 67 L/s.)

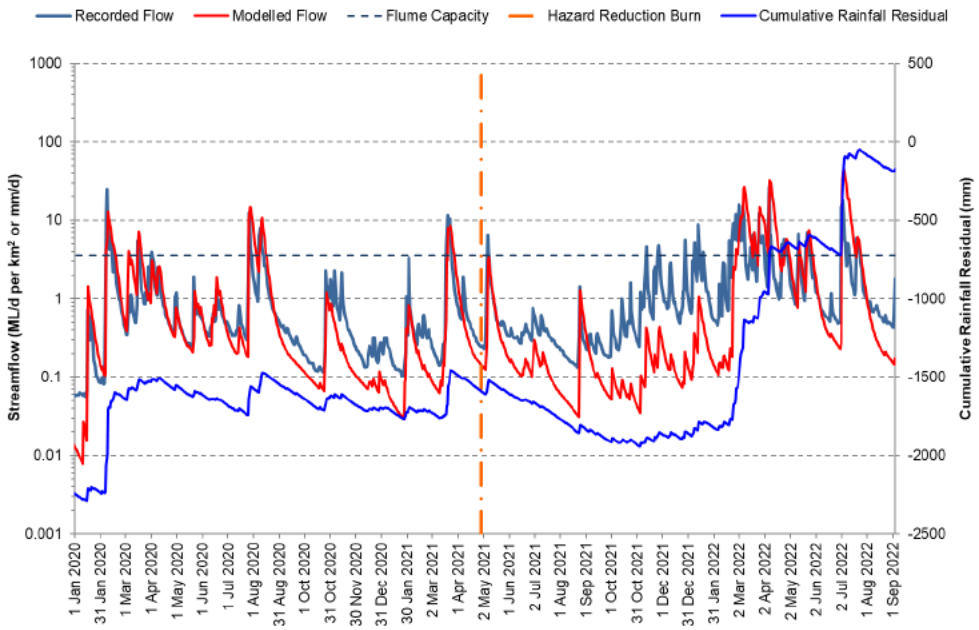


Figure 14: Flow data from the Eastern Tributary gauge between 1 January 2020 and 1 September 2022. Originally Figure 8 from HEC (2022).

HEC (2022) explores the following potential reasons for the higher-than-predicted flows during the period early 2017 to late 2022:

1. Flow measurement errors due to subsidence effects on the flume and weir.
2. Changes in catchment hydrology due to a controlled burn in the catchment on 29 April 2021.
3. Increased baseflow due to subsidence-induced stream bed fracturing.

The relevant conclusions and recommendations of HEC (2022) are:

1. *It is apparent that flume movement could not conceivably lead to significant changes in monitored flow rates.*
2. *A controlled hazard reduction burn was conducted within the Metropolitan Special Area and the catchment of GS 300078 on 29 April 2021. For a period of approximately 10 months following, the divergence between the hydrographs increases and this behaviour is considered related to the effects of the burn, which likely increased the rate of catchment runoff. However, this behaviour appears to have diminished since the onset of higher rainfall in approximately March 2022.*

   and

   *the hazard reduction burn alone could not have resulted in the significant divergence between modelled and recorded streamflow*
3. *During periods of flow recession dating back to spring 2017, the modified streamflow record somewhat exceeds modelled flow. It is considered that this may be related to increased baseflow occurring due to subsidence-induced stream bed fracturing upstream of GS 300078 leading to flow diversion through the fracture network which increases flow routing.*
4. *It is recommended that Metropolitan Coal conduct high resolution survey of the stream bed and banks (including the concrete weir either side of the flume) for a*

*distance upstream and downstream of the flume and that this data be used as input to a numerical hydraulic model of the stream at GS 300078. The model should then be used to extend the gauging station rating relationship beyond the capacity of the flume. In the interim, streamflow in excess of flume capacity should be estimated using the quadratic extrapolation of the flume rating curve.*

The Panel's comments on each of these are:

1. The first conclusion was based on a field survey of the flume to estimate possible movements since installation, and then testing sensitivity of the flow estimates to a revision of the flume rating curve that accounts for these movements (HEC**,** 2022). The level of detail provided in HEC (2022) about the nature of the movements of the flume and the rating curve revision approach is not sufficient to critically review this conclusion; nevertheless, from the information provided, the Panel considers that movement of the flume is unlikely to have caused the observed flow anomalies.

   The HEC (2022) investigation did not consider the possibility of measurement errors due to the presence of flood debris behind the flume, which could create the types of flow anomaly observed. However, if the flume is regularly inspected and cleared, which is normal good practice, and is implemented in this case according to Peabody staff[28], this could not be a reason for the prolonged flow anomalies.

2. Regarding the second conclusion, the increased flow rates from April 2021 are consistent with what might be expected due to partial clearance of vegetation due to the hazard control burn combined with the relatively persistent rainfall that occurred from September 2021 to March 2022. The modelling conducted in HEC (2022) is simplistic regarding the potential effects of fire (e.g. see Bren**,** 2023) and it is possible that it significantly underestimates the effect of the fire. Nevertheless, considering the presence of anomalous flows even before the burn, the Panel agrees with conclusion that the burn has likely had an effect but, by itself, is unlikely to fully explain the flow anomaly.

3. The substantially increased flows since August 2020, which is before the burn event, suggest larger volumes of groundwater release following rainfall events. Higher infiltration rates would be reflected in increased interflow volumes and potentially increased regional groundwater levels and discharges. While the AWBM model used to produce the red lines in Figure 13 and Figure 14 will translate high rainfall to groundwater storage and flows, it is possible there are non-linear responses to high rainfall that the model does not account for, which could create the flow anomalies in Figure 13 and Figure 14.

   Drought conditions such as those experienced from early 2017 to early 2020 are capable in some situations of changing the nature of flow responses in a way that simple models, such as the AWBM model used in Peabody (2022) and HEC (2022), cannot replicate. The hydrological modelling literature has examples of higher than predicted flows following dry years (for example, Deb & Kiem**,** 2020). However, the magnitude of flows observed from August 2020 relative to the rainfall are probably too high to be explained by the limitations of the model.

   Increased groundwater discharge is potentially consistent with the hypothesis in the Dupen report of sub-vertical fractures connecting the surface with groundwater stores combined with enhanced hydraulic connection of these stores to the creek. However, as suggested in the conclusion of HEC (2022) "*It is considered that this may be related to increased baseflow occurring due to subsidence-induced stream bed*

[28] As indicated to Professor McIntyre during a field visit on 19/07/2023.

*fracturing",* this may be related to increased connectivity between the creek and regional groundwater due to creek bed fracturing and does not necessarily mean enhanced flow through basal shear planes as proposed in the Dupen Report. The clear divergence in model and recorded flows commences in August 2020 during the extraction of LW305 (the closest longwall to the Eastern Tributary gauging station).

Another possible explanation for increased surface flows is the recent rise in reservoir levels. There has likely been underflow beneath the flow gauge that has not been recorded via the flume while the reservoir levels are low. As the reservoir level began to rise in early 2020, the piezometric head of the underflow and regional groundwater may have risen forcing the underflow to become surface flow captured by the flume.

4. Regarding the recommendation under HEC (2022) point 4 above, the Panel agrees. The Panel also recommends that:
    i. Spot flow measurements are taken and used to validate the rating curve for the flume, to further check whether subsidence of the flume or damage to the weir has caused flow estimation errors.
    ii. Repairs to the weir are carried out.

In summary, the Panel concludes that HEC (2022) has undertaken a detailed analysis of potential reasons for the apparent flow anomalies. While there remain questions about the sufficiency of both the flow measurements and the model used for that analysis, the Panel agrees with the main conclusions and recommendations of that report, including that the flow anomalies observed may be partially due to enhanced release of groundwater due to subsidence effects. However, there are additional hypotheses for the flow anomalies that should be explored.

Regarding the timing of the flow anomaly in relation to mining, the clear flow anomaly in Figure 13 and Figure 14 begins in August 2020, whereas mining of LW27 ceased in early 2017, so it seems unlikely that this change in flow response is associated with basal shear plane movement as a result of mining, unless this happened during the 300 longwall series. Predicted valley closure due to cumulative effects of LW302 to LW308 are shown in Figure 10. This shows a small increase in predicted closure from rockbars ETAU to ETAM due to the extraction of LW302 and LW303, being a maximum 25 mm in the vicinity of ETAM. Subsequent longwalls do not result in any increases in predicted valley closure. Where there are closure increments due to LW302 and LW303, it is only in the vicinity of ETAM that the predicted cumulative closure reaches above 125 mm. The Panel concludes it is conceivable but unlikely that ground movements upstream of the Eastern Tributary flow gauge since 2017 were significant enough to increase hydraulic conductivity of shear planes. The Panel recommends that available measurements and predictions of ground movements due to the 300 series of longwalls, including measured valley closures, are reviewed to determine if ground deformation might be responsible for changes in flow responses observed since August 2020.

In summary, the Panel recommends:

1. Extension of the Eastern Tributary flow gauge rating curve as recommended in HEC (2022); also spot measurements of flow covering flow rates as high as safely practicable; and urgent repair of the weir. Revised rating curves and the spot measurements of flow should be published in annual reports.
2. Re-analysis of the flow data including the most recent data. This analysis should be of the nature of HEC (2022) but also consider the possibility of increased flows being related to high groundwater or reservoir levels or errors in the modified AWBM model.

3. Further reporting of the modelling in annual report appendices should contain details of the modified AWBM model and parameter values needed to allow independent assessment.
4. If it is concluded after review and extension of the rating curve and analysis using the most recent flow data that baseflows may have substantially increased due to subsidence effects, further investigation should be undertaken regarding the source of the increased baseflow and its significance for aquatic ecology and water quality entering the Woronora Reservoir.
5. The Metropolitan Coal 2023 Annual Report should provide information on the success of the Eastern Tributary remediation program.

### 5.2.3. Pool levels

The Dupen Report proposes that the drying of pools over a 500 m length of the Eastern Tributary (Figure 1) supports the ridge fracture drainage hypothesis [29]. This is based on the concept in Figure 6 that water is diverted from the ridges and hillsides through vertical fractures and shear planes into the fractured zone below the creek. The Report includes the statements *'This evidence includes the unpredicted drying of all pools along a partly undermined section of Eastern Tributary'*[30] and '*Since 2017, the previously permanent Pools ETAG to ETAR (Figure 11) have been dry except for short periods following major rainfall events'*[31].

The latter statement does not accurately reflect the data, which shows that outside the period of unusually dry weather from 2017-2019 (see Figure 12), the pools were generally flowing in the reported period (2017-2022). This is illustrated in Figure 15 for pool ETAI, which is generally representative of the data for other pools from ETAG to ETAR (as shown in Peabody (2023), Charts 5-12) although pools ETAM to ETAR are less frequently dry during the dry weather of 2017-2019. This shows that weather is the dominant control on pool levels. Nevertheless, mining subsidence consequences on pool levels and drainage at pools ETAG-ETAR have been acknowledged (Peabody, 2023)

In order to support the hypothesis that ridge fracture drainage and pool drying in the Eastern Tributary during 2017-2019 are connected, the Dupen Report proposes that loss of pool water due to fracturing of rock-bars, which has been widely observed in the Waratah Rivulet, is an unlikely reason for dry pools in the Eastern Tributary. The Panel does not accept the reasons behind this argument, as explained in Section 5.2.1 of this advice report.

The Dupen report states[32]:

> *"It is worth noting that, if shear planes have indeed been widely developed beneath the valley axis as hypothesised in Section 3.2, the remedial design that was used with considerable success at Waratah Rivulet may not be successful in restoring surface flows to Eastern Tributary".*

This is yet to be tested: the remediation, which started in the Eastern Tributary in 2020-2021, was not assessed by Peabody in the Metropolitan Coal 2022 Annual Report. The Panel assumes this lack of assessment was due to lack of pool level data during 2022 and anticipates

[29] p22 of Dupen, 2023b
[30] pES1 of Dupen, 2023b
[31] p18 of Dupen, 2023b
[32] p21 of Dupen, 2023b

an assessment in the 2023 Annual Report. However, this is unlikely to provide definitive further evidence regarding the hypothesis. If assessments of pool levels show that remediation has not been successful, this indicates that flow is being diverted downstream by fractures deeper or wider than the influence of the remediation, possibly but not necessarily including shear planes. Therefore, while the assessment of the outcome of the remediation of the Eastern Tributary is essential, it is not critical to testing the hypothesis.

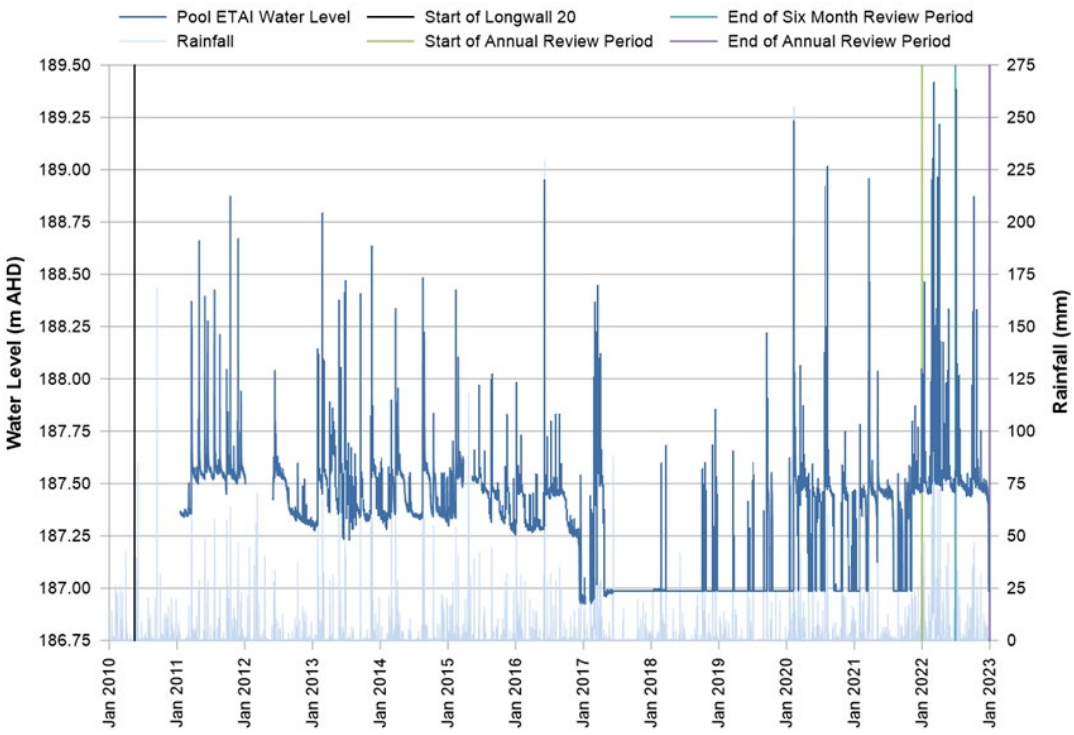


Figure 15: Chart 7 from Peabody (2022) showing recorded water levels at Pool ETAI

### 5.2.4. Bedding planes shears

The Dupen hypothesis lacks clarity as to the criteria used by Dupen to define shear planes as *'large-scale'*. The Panel considers that these criteria should at least include the regional extent of a shear plane and the magnitude of shear displacement that it has undergone. The magnitude of shear displacement is not considered in the Dupen Report.

Figure 4 of the Dupen Report (reproduced as Figure 6 of this advice report) is a schematic that represents most of the perched and regional groundwater flow and discharge processes that occur in the Hawkesbury Sandstone landscape across the Southern Coalfields. However, the schematic is not representative of the specific groundwater processes that are occurring in the Eastern Tributary catchment. The schematic shows:

- bedding shear planes daylighting on the valley side and labelled *'Subsidence-induced basal shear planes as intercepted by T3 and TBS02*.

  These are shown as both linear and extensive beneath both the valley sides and valley floor. The Panel believes that the nature of the valley side shears is exaggerated in this schematic. The Panel's visit to the Eastern Tributary area on the

10 May 2023 did not locate any valley side shears that were actively discharging regional groundwater.[33]

TBS02 is located over the centreline of LW302 and TBS03 is located over the centreline of LW303, both adjacent to the Eastern Tributary. WRIS (2019) reported that bedding plane shear movement occurred at depths of 105 m, 114 m, 162 m and 202 m below surface, with the deeper bedding plane being at approximately the top interface of the Bald Hill Claystone. The WRIS Panel reported that the extent of shear movement at each horizon differed slightly but was in the range of at least 20 mm – 50 mm and that there were only very small differences in hydraulic conductivity for the 105 m, 114 m and 162 m horizons, but a dramatic increase in hydraulic conductivity for the 202 m shear horizon at the top of the Bald Hill Claystone (shown in Figure 5 to be some 70 m below the Eastern Tributary). It concluded that the results confirm the view that whilst shears can occur on multiple horizons, not all horizons represent increased flow paths.

- *'inferred sub-vertical fractures due to valley bulging'.*

  The caption to Figure 4 of Dupen (2023) refers to the inferred sub-vertical fractures as being *stress relief fractures.* As the valley sides are not subjected to lateral stress, stress relief is not a plausible mechanism for inducing vertical cracking. However, sub-vertical fracturing can be associated with conventional subsidence (subsidence troughs) and with unravelling of slope material caused by subsidence movement, although these fractures tend to close. This is because surface alluvium and rock displace downhill under the effect of gravity, resulting in tensile strains accumulating towards ridge tops and being expressed as wide, open cracks. For example, Galvin (2005) reported the presence of a +200 mm wide crack on a fire trail at the top of the ridge above Waratah Rivulet.

Against this background, subsidence can be expected to increase the capacity of the surface to absorb rainfall, however, the distributions and depth of the inferred subvertical fracturing shown in Figure 4 of the Dupen Report (Figure 6 of this Panel Advice report) is considered highly conceptual and very unlikely to represent the situation in the field.

The Panel concludes that the subsidence environment and ground response to subsidence is not unique to Eastern Tributary and, therefore, if the drainage mechanism hypothesised by Dupen has merit, it should be able to be validated by field evidence at other sites above mine workings at Metropolitan Coal Mine and at other mines operating in similar topography in the Southern and Western Coalfields of NSW. The Panel is unaware of any other such evidence.

[33] The Panel does not consider the photo of the bedding plane shear shown in Figure 6 of the Dupen report to be representative of the process being hypothesised by Dupen. The photograph has appeared in multiple publications, including as Figure 10B in the first report of the IEPMC (OCSE, 2018) where it was captioned:

> *"Photographs taken in a railway cutting undermined by approximately 150 m wide longwall panels at an approximate depth of 300 m (W/H ~0.5) in the Southern Coalfield showing the development of vertical fractures and shear displacement on bedding planes in response to mining-induced subsidence*."

### 5.2.5. Hydrogeological behaviour

Figure 4 in the Dupen Report, reproduced as Figure 6 of this advice report, and associated explanations in Sections 3.2 and 3.3 of the Dupen Report are an over-simplification of the groundwater flow processes in the Waratah Rivulet and Eastern Tributary catchments.

It is important to recognise that for these two catchments:

- There are localised shallow perched water tables in upland swamp colluvium and underlying/adjacent weathered sandstones;
- The regional water table occurs at depth beneath the ridgelines, and naturally discharges to permanent streams. Regional groundwater does not present or discharge at elevated sites on the valley sides;
- The regional water table is a subdued reflection of the topography and in these catchments does not support the upland swamps or terrestrial vegetation on ridgelines and steep hillslopes; and
- The post mining water table does not always occur at depth below previously gaining streams – the current conceptualisation suggests there are most likely connected gaining and losing sections along Waratah Rivulet and the Eastern Tributary (Peabody**,** 2022a) but that overall regional groundwater continues to flow to these streams.

Dupen argues that the transect boreholes T1 - T6 (located above the northern portion of LW305 and LW306 adjacent to Woronora Reservoir) provide a good profile of aquifer levels through the upper aquifer (Hawkesbury Sandstone) within the ridge immediately east and west of the reservoir.

While the Panel agrees that these monitoring bores are useful to assess the regional water table elevation and level variations between the ridgeline and the reservoir, these locations do not provide any vertical piezometry data to better understand lateral and vertical flows, and the potential for deep drainage. Ideally, to better understand groundwater flow in the fracture network, a more appropriate design would have included multiple (3 or 4 elevation) level monitoring in separate monitoring bores with the lower two intervals occurring below the minimum reservoir level.

Two of the five transect boreholes (T3R and T1) confirm the intersection of a fracture zone that is hydraulically connected to the Woronora Reservoir. Water levels at these two sites rise and fall with reservoir levels. The latest published trends for all six transect bores are shown in Figure 16.

Dupen states:

> *The aquifers which sit above and feed the incised valley streams are draining at rates measurably higher than pre-mining, in places rapidly and completely, due to unexpected and unpredicted formation of large-scale shear planes opening up at their base. These shear zones are inferred to be 500 m long in one location and over 250 m wide at another. Where they are developed they appear to be acting as drains centred on the undermined valley centers which now accommodate creeks and Sydney's stored drinking water (Figure 4)* [Figure 6 of this advice report].

Dupen does not provide corroborating evidence of substantial aquifer drainage. The groundwater data provided by Metropolitan (SLR**,** 2023b) show no large scale groundwater drainage in the near surface environment. Only one borehole over the 300 series longwalls

shows any near surface impact from mining, namely: Swamp 50 10m Piezometer where the perched water level fell by 6.5 m (SLR, 2023b). The sharp decline occurred during the passage of LW304 followed by stabilisation and some recovery.

For the Hawkesbury Sandstone aquifer, there are many monitoring sites at ridgeline locations with multiple depth sensors that show no evidence of aquifer depressurisation or drainage (SLR, 2023b). Many sites show subtle increases in water table levels during recent years as a result of increased rainfall recharge and/or an increase in the Woronora reservoir level. However, the borehole T1 to T5 transect does show some evidence of mining-induced water level declines (Figure 14 in this report taken from SLR, 2023a):

- Water level in Borehole T5 has declined by 10-12 m since the commencement of LW305;
- Water level in Borehole T4 (inoperable since August 2021) declined by approx. 5 m at the commencement of LW306; and
- Water level in the original Borehole T3 declined by approx. 5 m at the commencement of LW305 but has since risen in the deeper replacement bore T3-R with the increase in the reservoir storage levels.

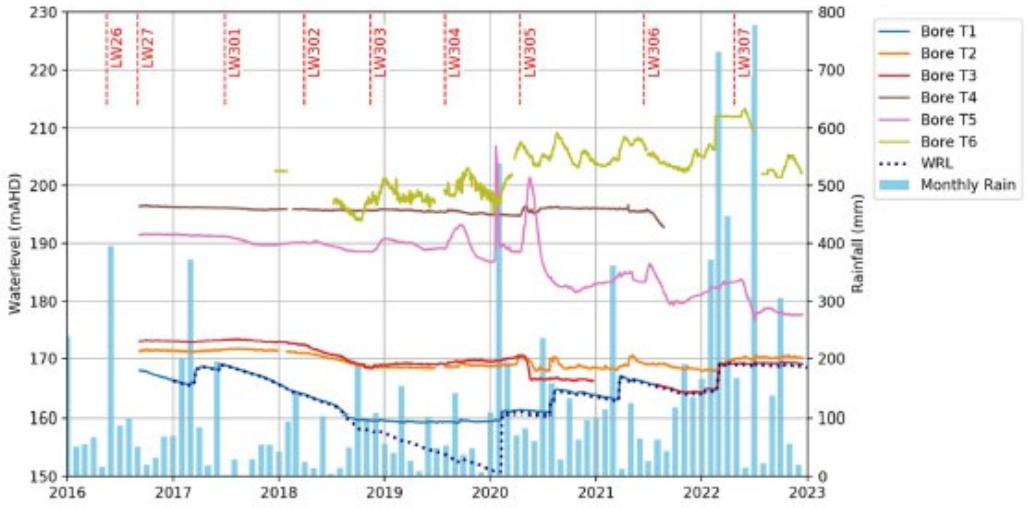


**Figure 3** Groundwater hydrographs for bores T1 to T6 compared with reservoir water level and rainfall


**Figure 4** Groundwater hydrographs for bores T1 to T3 compared with reservoir water level and rainfall

Figure 16: Groundwater hydrographs for transect boreholes T1 to T6. (Figures 3 and 4 from SLR, 2023a)

Gradients are still towards the reservoir and the observed declines at just one transect cannot be considered sufficient evidence of substantial aquifer drainage to creek lines and the reservoir through the ridge fracture drainage mechanism without a better understanding of the vertical piezometry and spatial/temporal variations in the Hawkesbury Sandstone groundwater system.

The inferred sizes of the basal shear with increased transmissivity due to mining associated with the Eastern Tributary seems to be solely inferred from the length of the 'dry' section of Eastern Tributary and the position of Borehole T3 lower in the catchment. As noted in Sections 5.2.1 and 5.2.3, there is evidence that the 500 m dry section identified by Dupen is not completely dry and surface flows do occur. Underflow is apparent for the section but the connection to a large-scale basal shear extending along the full length of the 'dry' tributary cannot be confirmed by the available observations. It is clear that the groundwater at Borehole

location T3 has a strong connection to the reservoir and while this indicates how far away from the reservoir a high conductivity connection can extend, it also cannot define the length of tributary or reservoir section that it connects to. Without further observations these data do not provide strong support to the ridge fracture drainage hypothesis.

There are several hypotheses that can explain the drop in water level at Borehole T3 including by fracturing connecting the borehole to an existing basal shear that has already been identified in Borehole T1. The Panel is of the view that the change in conditions in May 2020 at Borehole T3 is most likely due to local ground movements forming a connection between the local groundwater at the measurement depth in Borehole T3 with an existing underlying fracture or basal shear that is also identified in Borehole T1. The fracture permeability is sufficiently high to bring the hydraulic head at location T3 close to the reservoir water level.

As noted in Section 3.0, Dupen states that there are only two hydrogeologically plausible hypotheses that he can think of which could account for behaviours in streamflow affected by subsidence, the first of which is related to crushing of bedrock due to non-conventional subsidence impacts to create a 'tunnel' of shallow fractures. He states that *'it is difficult to comprehend using this conceptual model, how sub-surface flows through a 500 m long, poorly interconnected "crush zone" of compressive fractures can have mimicked above-ground catchment flow responses as closely as shown in Figure 12 since the desiccation event in 2016/2017'.*

The Panel does not agree with the reasoning presented by Dupen because the comparisons of catchment flow responses in his Figure 12, reproduced as Figure 3 of this advice report, are based on observed and modelled daily flows. The modelled flows are derived using the Australian Water Balance Model (AWBM), which is a spatially lumped catchment model. Neither this model nor the use of daily flows are designed to simulate local (500 m scale) effects on flow travel times, and so Figure 12 in the Dupen Report should not be used to support or challenge the "tunnel" concept. The Report goes on to state "*I also struggle to identify a plausible mechanism for the increasing flows observed since about October 2021 using this conceptual model*". While other mechanisms can be identified to explain the increasing flows, no mechanism has been validated to explain the increased flows at this stage. The increased flows need to be better understood, as has been partly addressed by HEC (2022) and commented on by the Panel in Section 5.2.2.

### 5.2.6. Evaluation summary

The Panel's findings from its evaluation of the primary Dupen hypothesis and statements can be summarised as follows.

An important initial observation is that the subsidence mechanism underpinning Dupen's hypothesis is not new. However, Dupen has placed new emphasis on the significance of this mechanism for the long-term behaviour of the regional groundwater system and the resulting downstream impacts on the quantity and quality of water entering Woronora Reservoir and upstream impacts on the hydrology and ecology of ridge line ecosystems. Previous studies and investigations have addressed ground movements on basal shears and have assessed the magnitude of associated impacts on the groundwater system. These studies do not provide evidence supporting major impacts of the style and magnitude suggested in the Dupen report.

Dupen's hypothesis was developed through assessment of several features of the data collected from monitoring of surface and groundwater conditions in and around the Eastern Tributary. The data relied upon by Dupen has been reviewed by the Panel as well as that derived from additional studies undertaken by Metropolitan Coal's consultants. While corrections to the stream flow data have been made by the consultants, these have not

removed the anomalies used by Dupen to build his hypothesis. Nevertheless, the further review has offered up viable alternative explanations for the anomalies. Neither Dupen's hypothesis nor the alternative explanations can be validated at this time based on the available evidence. For this reason, a range of additional work is recommended to provide the necessary field evidence to support or reject each of these explanations for the mining-induced impacts on both groundwater and surface water.

A wider assessment of the groundwater data, including more recent data than that available to Dupen, has not provided evidence of the widespread dewatering of the regional groundwater system predicted by Dupen's hypothesis. Dupen's interpretation of the impacts of changing groundwater baseflow contributions to Woronora Reservoir arising from his hypothesis is also not consistent with enhanced basal shears and the dewatering of the Hawkesbury Sandstone aquifer beneath the ridgelines.

The Dupen Report recommends stopping mining until the validity of the Dupen hypothesis has been adequately tested and the long-term implications of groundwater dewatering are fully assessed. As noted above, consideration by the Panel of a wider set of data, notably of groundwater responses to mining, indicates that the inferences made by Dupen about the scale of impacts unfolding on the regional ecology and the Woronora Reservoir are likely overstated. For this reason, the Panel does not agree with this recommendation.

Even though the scale of impacts suggested by Dupen are not expected by the Panel to be as large as Dupen predicts, the Panel accepts that components of Dupen's hypothesis should be evaluated through new data collection and further interpretation to build confidence in Metropolitan Coal's assessment of the long-term impacts of mining under the catchment.

If the drainage mechanism hypothesised by Dupen has merit, it should be able to be validated by field experience at other sites above mine workings at Metropolitan Coal Mine and at other mines operating in similar topography in the Southern and Western Coalfields of NSW.

## 5.3. EVALUATION OF OTHER DUPEN STATEMENTS

### 5.3.1. Implications for aquifer storage and baseflows

> *The aquifers which sit above and feed the incised valley streams are draining at rates measurably higher than pre-mining, in places rapidly and completely, due to unexpected and unpredicted formation of large-scale shear planes opening up at their base.*
>
> *The desaturation of the undermined ridges hypothesised in Section 3 is likely to continue for some years or decades to come even if mining is stopped at this point.*
>
> *My interpretation of the reported trends (Section 3.5) is that flows in Eastern Tributary and probably other undermined streams are currently being affected by increased draining of the undermined ridges through basal shear planes. Once a new equilibrium is established, quicker and smaller baseflows may reduce overall flows to the Reservoir.*

The Panel is of the opinion that apart from the water level declines observed at three bores along the T1-T5 transect, there is no evidence of widespread desaturation of the ridges around the reservoir from monitoring groundwater levels in the shallow Hawkesbury Sandstone aquifers at any other locations across the catchment. If the Dupen hypothesis is correct, then there should be evidence of regional groundwater depletion within days to weeks based on the apparent increased flows in the Eastern Tributary. The observed localised declines at the

transect bores cannot be considered sufficient evidence of substantial aquifer drainage beneath the catchment ridgelines.

If ridge fracture drainage were occurring, it is unlikely that "*Once a new equilibrium is established, quicker and smaller baseflows may reduce overall flows to the Reservoir."* Indeed, any lowering of groundwater levels would likely increase overall flows due to accelerated drainage and reduced evapotranspiration. Overall flows could reduce if the changes in hydraulic conductivity of the shear planes meant that water was being diverted to outside the Woronora catchment, but there is no evidence to suggest that inter-catchment diversions of flow is happening. In summary, the Panel is of the view that the ridge fracture drainage hypothesis has no bearing on overall flow volumes into the reservoir.

> *The mining-induced shear planes and fractures are causing the drainage of the sandstone aquifers within the ridges that lie above the undermined creeks and stored waters. The desaturation of the aquifers through the newly imposed fracture system would permanently change the hydrological ecological and geochemical nature of the drinking water catchment.*

The current 300 series longwall designs have been adopted to minimise the risk of hydrological impacts to the Woronora Reservoir by minimising the likelihood of vertical leakage. The available field observations are consistent with the adopted design aims. The historical and current longwall design also appear to have limited impact on the regional groundwater system based on the available evidence, however additional monitoring of the piezometry within the Hawkesbury Sandstone aquifer for the remaining longwalls in the current 300 series is required to confirm any long-term drainage impacts.

The ecological and geochemical implications are reviewed below.

### 5.3.2. Implications for water quality

> *Formation of rapid subsurface flowpaths through fractures are expected to add a substantial but as yet unquantified addition of metal and salt (drinking water contaminants) discharged into this drinking water via subsurface springs created by basal shear planes*
>
> *The discharges of water diverted through these new fracture systems are emerging with high concentrations of iron, manganese, aluminium and other metals and salts. The sampled discharges to the reservoir from Eastern Tributary already appear to be breaching performance measures, and these effects can be expected to worsen significantly as unmeasurable discharges from aquifer drainage emerge at or below the axis of the valley. The long-term fate of these additional contaminants in the reservoir is currently unknown, but so far the dissolved metal concentrations have not been greatly elevated at the drinking water off-take at the northern end of the reservoir near the Woronora Dam wall.*

The quantity of natural contaminants that will enter the reservoir will be directly related to the size and density of fracture/shear zone that has occurred. If the fracture zone due to valley closure is restricted to the tributary floor and neighbouring rock then the total contaminant mass may be quite limited. However, it is not immediately possible to determine the size or density.

The question of water quality is out of scope of the current Panel and the reader is referred to IEAPM (2023).

### 5.3.3. Implications for ecosystems/swamps

> *A likely result of these changed baseflow patterns is that a large proportion (potentially all) of the riparian, swamp and forest ecosystems on the undermined ridges will become drier and presumably less capable of filtering surface flows entering the reservoir (ES2)*

The regional groundwater table under the ridgelines (between 50 and 70mbgl based on available piezometric data) is well below the limit of groundwater extraction by terrestrial ecosystems. There is no evidence to suggest that these terrestrial ecosystems on the ridgelines and steep slopes will become drier.

The riparian, swamp and forest ecosystems all rely on the moisture in the shallow soils and any perched groundwater at shallow depth. The upland swamps in these catchments are maintained by perched groundwater that is not in hydraulic connection with the regional water table. Provided there is no fracturing of the base of swamps that causes accelerated drainage of perched groundwater, then these terrestrial ecosystems should continue to survive. They are maintained by rainfall, interflow and runoff from adjacent sideslope areas and should continue to filter runoff that enters the permanent streams and the reservoir.

All available borehole data indicate that there has yet to be any significant impact to the shallow perched groundwater systems other than the weathered sandstone underlying Swamp 50 and here the impact of the groundwater decline is not likely to be sufficient to impact the near surface hydrology or ecological functioning of the swamp.

> *Extensive fracturing in the Hawkesbury Sandstone aquifer is leading to desaturation of the ridges around the reservoir, as well as the possibly permanent loss of ecologically important surface flows*

The lack of evidence for desaturation of shallow groundwater beneath the ridgelines is discussed in Section 5.3.1.

There is no evidence for the permanent loss of baseflows that help to sustain surface flows. In fact, stream flow data primarily since August 2020, suggest an increase in flows compared to model predictions (Section 5.2.2)

### 5.3.4. Implications for performance measures and indicators

> *Contrary to Peabody's interpretation, my conclusion from the review reported herein is that a diversion of around 500 m of virtually all surface water flows via subsurface channels (Figure 1) constitutes more than a negligible environmental consequence, and therefore an exceedance of the Performance Measure*
>
> *The Performance Indicators now used to enable evaluation of Performance Measure success in respect to Eastern Tributary are unfortunately not useful for evaluating the environmental consequences of basal shear planes developing beneath the stream surface, a mechanism which was not predicted nor yet publicly recognised. The Environmental Indicators provided in the 2021 Annual Review are focused instead entirely on the important role of protecting the integrity of the flow gauge at Rockbar ETAU*

Diversion of nearly all surface water into the subsurface is not correct based on observations of flow and pooling in the tributary.

It is acknowledged by Peabody (2022a) that mining has resulted in environmental consequences in regards to the drainage behaviour of the rock pools ETAG, ETAH, ETAI, ETAJ, ETAK, ETAL, ETAM, ETAN, ETAO, ETAQ and ETAR along the tributary (although the performance indicator relates only to pools ETAS, ETAT and ETAU, which are not reported to be impacted and the Panel has no reason to suggest that they have been). Current understanding is that these exceedances are due to surface fractures in the creek, and remedial measures are being employed with the aim of restoring the affected pools and surface water flows (see comments in Sections 5.2.1 and 5.2.2). The observations in the Dupen Report regarding diversions of flow from the ~500 m length of Eastern Tributary has no new implications for whether the performance measures are being met.

The unexpected increase in flows that is seen in Figure 13 does not breach the quantity component of the performance measure "*negligible reduction in the quantity and quality of water resources reaching the Woronora Reservoir*" as the flows to the reservoir are higher than expected. The Dupen Report considers long term changes to the flows by suggesting that *"Once a new equilibrium is established, quicker and smaller baseflows may reduce overall flows to the Reservoir"*[34] but does not present the basis for this suggestion. The Panel agrees that the pattern of baseflows to Woronora Reservoir would change if the Dupen hypothesis is correct. This is because of the more rapid transit of water through the groundwater system leading to quicker rises and falls in the baseflow component of the reservoir inflows. However, the Panel does not agree with the suggestion that the baseflows would be smaller. The total volume of baseflow would only reduce if groundwater recharge is reduced or if groundwater is diverted out of the reservoir catchment. The Dupen Report identifies higher groundwater recharge conditions as *"stress relief fractures are expected to result in increased infiltration of rainfall runoff from undermined ridge surfaces and soil-rock interfaces"*[35]. No mechanism is presented in the report that indicates that groundwater is likely to be diverted away from the reservoir catchment. In these circumstances, inflows to the reservoir are not expected to reduce unless the climate changes. This is contrary to Dupen's assertion.

Of greater significance for catchment yield to the Woronora reservoir is the potential impact of subsidence on the quality of flows reaching the reservoir. This is an issue associated with mining subsidence impacts whether or not the Dupen hypothesis is accepted. The monitoring and assessment of water quality in the Eastern Tributary has been considered by a separate IEAPM panel (IEAPM**,** 2023).

As covered in Section 5.3.3 the Panel considers that the Dupen Report has no implications for performance measure *Negligible impact on Threatened Species, Populations, or Ecological Communities* in relation to riparian and swamp ecosystems. If long-term changes to baseflow regimes are confirmed by the further analysis, the potential implications for that performance measure in relation to aquatic biota will need to be considered.

### 5.3.5. Dupen Report recommendations

> *Consideration should be given to applying causal science to the analysis of volumetric and water quality changes discussed in this report, in order to truly understand the*

[34] p28 Dupen (2023)
[35] p26 Dupen (2023)

*impacts of what is now unfolding in the catchments of Sydney's water supply due to Metropolitan's proposed progress towards the deepest parts of the catchment.*

Data collection to date at the mine has not been focussed on developing statistical models to examine the linkages between cause and effect. Consequently, new data plans would be needed to underpin a causal science assessment based on statistical approaches. New statistical techniques would be required to accompany the new data that would be difficult to explain and demonstrate to both mine owners and the regulators. This would take considerable time given the complexity of the natural environment applicable to hydrology and hydrogeology and the limitations of modern data collection methods. It would not be guaranteed to add new knowledge in time to be effective.

At this point in time, the Panel considers that stage assessing causal relationships through traditional modelling using deterministic flow models combined with careful sensitivity studies that are implemented by experts and rigorously peer reviewed represents the most effective means of eliciting the necessary knowledge about the system responses given current practices. It will also be the most easily understood by the operators, regulators and the wider community.

As the Dupen Report demonstrates, inferences about hydrogeological processes based on sparse data sets with unrecognised errors are fraught with difficulties. These difficulties are not likely to be reduced by adopting a new paradigm for their analysis.

## 6.0 SUMMARY PANEL ADVICE

The nature of the structure and content of the Dupen Report results in a range of conclusions and recommendations being developed progressively throughout the Panel's advice report. The reader is referred to these for further insight into the following summary advice:

*Identify and comment on the elements of the Report that are relevant to the operation and environmental performance of Metropolitan Coal*

**Subsidence Focussed**

1. The two basic mining-induced elements that constitute Dupen's hypothesised *ridge fracture drainage* model are sub-vertical surface fractures and sub-horizontal bedding plane shears. Both elements are well established in subsidence engineering and, individually and collectively, have been the subject of a number of detailed subsidence and hydrogeological studies in the Southern Coalfield over recent decades for the purpose of detecting and monitoring their formation, including at the Eastern Tributary. Hence, ridge fracture drainage cannot be considered a *new subsidence mechanism.*
2. If the Dupen hypothesis concerning surface flows and shallow groundwater being widely diverted and drained as a result of mining-induced fracturing is validated then ridge fracture drainage could, arguably, be considered to be a *new subsidence consequence*. This depends on the spatial scale and the magnitude and distribution of shear displacement on what Dupen refers to as *large scale shear planes opening up at their base,* in comparison to documented past experience. The term *large scale* is not defined in the Dupen Report.
3. The Dupen Report does not provide sufficient evidence to cause the Panel to believe that the scale of bedding plane shears in the vicinity of the Eastern Tributary might be materially different to that of other shear planes detected and studied in the Southern Coalfield.
4. Due to the low values of predicted incremental valley closures during the 300 series of longwalls, it is unlikely that ground movements were significant enough to increase the hydraulic conductivity of shear planes in the Eastern Tributary during the period of flow anomalies.

**Groundwater Focussed**

5. Perched water in swamp colluvium and very shallow weathered Hawkesbury Sandstone is hydraulically disconnected from the deeper regional groundwater systems and will not drain unless near surface fracturing intersects these features. There is no clear evidence of drainage of these shallow groundwater systems in the available monitoring records.
6. There is no evidence from Metropolitan Coal's groundwater monitoring network (except at the transect bore locations overlying LW305 and LW306) that water levels in the Hawkesbury Sandstone aquifers across the Eastern Tributary catchment have fallen and desaturated the ridgelines. In fact, most monitored regional water table levels have stabilised or risen in recent years.
7. Alternative explanations of the increased surface flows at the Eastern Tributary gauging station observed since August 2020 (which corresponds with the commencement of an above average rainfall period) include:
    i. underflow that previously discharged to Woronora Reservoir downstream of the Eastern Tributary gauging station is now reporting as surface water flow upstream of the gauging station; and

ii. larger volumes of (natural) interflow and regional groundwater are discharging and contributing to surface water flows across the whole catchment.

8. Increased groundwater discharge is potentially consistent with the Dupen hypothesis of sub-vertical fractures and shears with enhanced hydraulic connection connecting regional groundwater to the Eastern Tributary. However, there is no widespread evidence of a reduction in water levels or groundwater storage volumes across the catchment in the Hawkesbury Sandstone aquifer, which is contrary to the Dupen hypothesis.

9. Beneath ridgelines and hillslopes, the absence of permanent springs and any obvious perched groundwater (apart from in the vicinity of swamps) suggests most rainfall recharge (apart from that portion that is lost to evapo-transpiration and via interflow after rain) drains vertically to the regional water table and then moves laterally to emerge in the base of the valleys as baseflow.

10. The shallow perched water table in colluvium and underlying/adjacent weathered sandstone supports upland swamps. The upland swamps will not drain and will not be impacted unless near surface fracturing intersects and drains these features.

11. The regional water table occurs at depth beneath the ridgelines, and naturally discharges to permanent streams. Regional groundwater does not discharge at elevated sites and does not support ridgeline and hillside terrestrial ecosystems, however it may contribute to some riparian communities.

**Surface Water Focussed**

12. Metropolitan Coal (through consultants) has undertaken a detailed analysis of potential reasons for the Eastern Tributary flow anomalies that Dupen uses to support the ridge fracture drainage hypothesis. The Panel agrees with main conclusions and recommendations from that analysis, being:

    i. There are serious errors in the flow data used by Dupen but this is not the reason for the anomalies. To address these errors the rating curve for the Eastern Tributary should be extended to improve high flow measurement accuracy.

    ii. The flow anomalies are unlikely to be due to subsidence movements of the flume.

    iii. The controlled burn conducted from September 2021 to March 2022 in the Eastern Tributary catchment has likely contributed but, by itself, is unlikely to fully explain the flow anomalies.

    iv. The flow anomalies may be related to mining-induced increases in the hydraulic conductivity of the creek bed.

13. Additional to the considerations in the consultant's analysis, the Panel concludes that:

    i. While blockage of the flume by debris is another potential reason for the flow anomalies, regular inspection and clearance of the flume makes this unlikely.

    ii. Errors in the rainfall-runoff modelling may also contribute to flow anomalies, including non-linearity in the groundwater storage-discharge relation and non-stationarity in hydrological processes related to drought. This has not been assessed by Metropolitan Coal.

14. Contrary to the observation by Dupen that "*Since 2017, the previously permanent Pools ETAG to ETAR have been dry except for short periods following major*

*rainfall events*", these pools were generally flowing during 2017-2022 except during prolonged dry weather.

15. The reason for the Eastern Tributary flow anomalies remains unknown, and the Dupen hypothesis cannot be discounted based on the flow data.
16. The status of the pools and whether remediation improves the status of the pools, while important for assessing the environmental performance of the mine, will not be a decisive factor regarding the Dupen hypothesis.

**Overarching Conclusions**

17. Previous studies and investigations have been undertaken of basal shears and the magnitude of associated impacts on the groundwater system and these do not provide evidence supporting major impacts of the style and magnitude suggested in the Dupen Report.
18. The evidence that Dupen has used for the development of his hypothesis is limited (as acknowledged by Dupen) and incomplete and additional evidence sourced by the Panel confirms that this data contained errors, in some cases of a serious nature.
19. A wider assessment of the groundwater data, including more recent data than that available to Dupen, has not provided evidence of the widespread dewatering of the regional groundwater system predicted by Dupen's hypothesis.
20. Dupen's interpretation of the impacts of changing groundwater baseflow contributions to Woronora Reservoir arising from his hypothesis is also not consistent with enhanced basal shears and the dewatering of the Hawkesbury Sandstone aquifer beneath the ridgelines.
21. Consideration by the Panel of a wider set of data indicates that the inferences made by Dupen about the scale of impacts unfolding on the regional ecology and the Woronora reservoir are likely overstated. For this reason, the Panel does not support the Dupen Report's primary recommendation *"that further undermining of the Woronora Reservoir should be halted until the implications of these unexpected changes now unfolding in Woronora Reservoir Catchment can be urgently evaluated"*.
22. Even though the scale of impacts suggested by Dupen are not expected by the Panel to be as large as Dupen predicts, the Panel accepts that components of Dupen's hypothesis should be evaluated through new data collection and further interpretation to build confidence in Metropolitan Coal's assessment of the long-term impacts of mining under the catchment.
23. If the drainage mechanism hypothesised by Dupen has merit, it should be able to be validated by field experience at other sites above mine workings at Metropolitan Coal Mine and at other mines operating in similar topography in the Southern and Western Coalfields of NSW.

*Provide advice as to what actions or further investigations would be required to test or confirm the hypothesis put forward in the Report*

The Panel recommends (from a groundwater perspective) that:

1. Additional bores (standpipes) be established at the T5 monitoring location to monitor the vertical piezometry in the Hawkesbury Sandstone and to establish whether extensive basal shears occur at depth below this eastern ridgeline area.

2. Additional bores (standpipes) be established at the T6 monitoring location and at other accessible locations overlying the proposed LW311 to LW316 panels as soon as practicable to monitor the natural vertical piezometry in the Hawkesbury Sandstone below this western ridgeline area.

The Panel recommends (from a surface water perspective):

3. Extension of the Eastern Tributary flow gauge rating curve as recommended by Metropolitan Coal's consultant (HEC, 2022); also spot measurements of flow covering flow rates as high as safely practicable; and urgent repair of the weir. Revised rating curves and the spot measurements of flow should be published in annual reports.
4. Re-analysis of the flow data including the most recent data. This analysis should be of the nature of HEC (2022) but also consider the possibility of increased flows being related to high groundwater or reservoir levels or errors in the modified AWBM model (Australian Water Balance Model).
5. Further reporting of the modelling in annual report appendices should contain details of the modified AWBM model and parameter values needed to allow independent assessment.
6. If it is concluded after review and extension of the rating curve and analysis using the most recent flow data that baseflows may have substantially increased due to subsidence effects, further investigation should be undertaken regarding the source of the increased baseflow and its significance for aquatic ecology and water quality entering the Woronora Reservoir.
7. Metropolitan Coal's 2023 Annual Report should provide information on the success of the Eastern Tributary remediation program.

*Any other significant advice that the Panel may wish to provide concerning this issue*

8. The Panel recommends for the purpose of developing a better understanding of valley closure impacts to inform mine design that, if it has not already done so, Metropolitan Coal undertakes and makes available to the Department, an investigation of mining impacts on the Eastern Tributary that includes an evaluation of:
    i. How predicted valley closure developed incrementally along the Eastern Tributary.
    ii. How well incremental and total predicted valley closure correlated with measured incremental and total measured closure.
    iii. The nature and extent of natural and mining-induced fracturing to a depth of at least 20 m along the Eastern Tributary downstream from the maingate of LW26 to the Full Supply Level (FSL) of Woronora Reservoir (noting that some of these investigations may have already been undertaken).
    iv. How well mining-induced environmental impacts along the Eastern Tributary correlate to both predicted valley closure and to measured valley closure.
    v. The hydraulic characterisation of the fracture system and the underflows that are taking place along that portion of the Eastern Tributary between the maingate of LW26 and the Eastern Tributary gauging station. This could include establishing new shallow groundwater bores in a longitudinal section to assist in better assessing long term water level and water quality behaviour.

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