INDEPENDENT EXPERT ADVISORY PANEL FOR MINING

ADVICE RE:

Water Quality Performance Measures for Metropolitan Coal Mine

September 2023

Report No: IEAPM 202309-1

EXECUTIVE SUMMARY

Overview

On 4 April 2023 the Department of Planning and Environment wrote to the Chair of the Independent Advisory Panel for Underground Mining (IAPUM), which is now the Independent Expert Advisory Panel for Mining (IEAPM, referred to as "the Panel" here on), requesting advice on Water Quality Performance Measures for Metropolitan Coal Mine.

The Metropolitan Coal Project Approval (08_0149) requires Metropolitan Coal to ensure that its mining activities do not cause any exceedance of subsidence impact performance measures that include "*negligible reduction to the quality or quantity of water resources reaching the Woronora Reservoir*" and "*negligible reduction in the water quality of Woronora Reservoir*". While there has been a succession of triggers in recent years indicating a degradation of water quality reaching the reservoir and water quality in the reservoir, Peabody has consistently concluded that the impacts of the Metropolitan Mine have been negligible.

In this context, advice was requested on:

1. *The Assessments Against Water Quality Performance Measures, and whether the justifications and conclusion that the water quality performance measure for Woronora Reservoir have not been exceeded are reasonable.*

2. *Whether the performance indicator for negligible reduction to the quality of water resources reaching the Woronora Reservoir defined in WMPs is appropriate.*

3. *Whether additional water quality monitoring, analysis and/or assessment is required to further determine compliance with the water quality performance measure for Woronora Reservoir.*

4. *Whether any further reasonable and feasible actions to mitigate and manage water quality impacts are considered necessary, beyond the existing requirements to continue implementing monitoring and management programs.*

5. *Whether a cumulative impact assessment study is considered necessary to review water quality trends and potential impacts on drinking water supply from increased metals loads from the catchments impacted by mine subsidence at Metropolitan Mine.*

The Department also noted that it would welcome any other significant advice that the Panel may wish to provide concerning this issue.

This is the first advice provided by the Panel or IAPUM that focusses on water quality, which the Panel views as a topic relevant not only for the Woronora Reservoir but also for the other water bodies subject to mining impacts in the Special Areas. Understanding the advice requires background knowledge of the relations between subsidence, tributary water quality, reservoir water quality and the operational targets of the reservoir. This report provides this basic knowledge, prior to addressing the five items of advice listed above.

Conclusions

The quality of the Woronora Reservoir has been poor during 2022-2023 (and during other periods historically) and has led to significant complications for water treatment and water supply. Although there are natural influences on water quality that might explain the observed variations in water quality, the Panel cannot rule out the possibility that the Metropolitan Mine has had a significant adverse impact.

While dissolved forms of iron, manganese and aluminium (Fe, Mn and Al) are of primary relevance to raw water quality, there is potential for particulate forms to be transported from the catchment into the reservoir and thereafter, in the case of Fe and Mn, be transformed into dissolved forms. Hence, total (dissolved plus particulate) Fe, Mn and Al concentrations are relevant and the reliance on dissolved Fe, Mn and Al concentrations in the Metropolitan Mine performance indicators for water quality reaching the reservoir is unsatisfactory.

The assessments of the quality of water reaching the Woronora Reservoir presented by Peabody in response to level 3 triggers are not based on sufficient data and analysis and therefore do not provide sufficient justification and reasonable conclusions. The assessments do not adequately consider the potential significance of the impaired water quality for the WaterNSW Raw Water Supply Agreement and Water Quality Incident Management trigger levels.

The assessments of the quality of water in the Woronora Reservoir are not based on sufficient data and analysis and therefore do not provide sufficient justification and reasonable conclusions. The Panel considers that the depth of analysis provided in the annual and six-monthly reports, while significant, is incommensurate with the uncertainty regarding mining's potential contribution to the degraded water quality and incommensurate with the consequences of the degradation in terms of the ability of WaterNSW to meet the Raw Water Supply Agreement and in terms of the disruption to operation of the Water Filtration Plant (WFP).

Aside from the need to transition to the use of total metals, the existing descriptions of the performance indicators and trigger levels for the Eastern Tributary and Waratah Rivulet are satisfactory. They will need to be reviewed when and where performance indicators are changed to the use of total metals concentrations.

The performance indicators and trigger levels for the reservoir (which use total Fe, Mn and Al concentrations) are appropriate, although should be subject to annual review.

The significance of the impaired water quality reaching the reservoir can only be fully determined using contaminant loads (concentration x flow rate) as well as concentrations because high loads can coincide with low concentrations and vice-versa. Improved high flow data and flow event water quality is required to understand water quality impacts and to estimate contaminant loads.

Due to data constraints and monitoring practicalities, analysis of contaminant loads will have limited applicability to determining cumulative impacts of mining in the Eastern Tributary and Waratah Rivulets and other catchments that are being undermined as part of the 300 longwall series. Nevertheless, approximate estimates of loads from these catchments will support scenario analysis to assess whether water quality risks from mining are potentially significant for the operation of the reservoir and WFP. Application of contaminant load estimates to future mining areas including baseline periods and control sites will allow a complete Before-After-Control-Impact (BACI) analysis based on loads as well as concentrations.

An appropriate hydrodynamic and contaminant transport model can support determination of whether a measured or estimated increase in metal loads due to mining affects the current or future ability of WaterNSW to meet raw water supply agreements. It can also allow testing of hypotheses that measured changes in water quality in the reservoir are attributable partially to mining. WaterNSW is planning to implement such a model for the Woronora Reservoir in the 2023-2024 financial year. Due to the catchment and reservoir data sets required, and knowledge of reservoir operations required, it is unlikely to be sensible for Peabody to undertake an independent hydrodynamic and contaminant transport analysis.

Temperature and water quality data obtained at various depths through the water column in the upper reservoir would capture both the temperature stratification behaviour and the water quality at this point. As well as supporting assessments of whether changes in the water quality reaching the reservoir due to mining have been non-negligible, these data will be of value in calibrating and validating a hydrodynamic and contaminant transport model of the reservoir.

There would be value in improved understanding of the extent of any increase in iron and manganese concentrations in reservoir sediments. Sediment cores can provide a historical record of changes to inputs to the reservoir though it should be recognised that increased inputs are likely to be associated with both high rainfall events and, possibly, increased loads of iron and manganese as a result of mining.

The program of remediation (grouting of fractures) in the Waratah Rivulet and Eastern Tributary has contributed and continues to contribute to the sealing of fractures and reducing subsidence-induced contamination. The Panel expects this program to continue to have positive impacts on contaminant loads to the reservoir. However, because the grouting cannot and does not aim to seal all fractures that interact with the surface flows, the Panel does not expect the remediation to return contaminant concentrations or loads to pre-mining values.

At this time, the Panel does not advise additional mitigation and management measures (aside from the monitoring and analysis recommended above) beyond the ongoing grouting program.

Long-term risks to water quality in the Special Areas arise from:

- The potential for cumulative consequences of historical, current and future mining areas on reservoir water and sediment composition and quality.

- The potential for widespread mobilisation of contaminants from subsidence fractures if regional groundwater levels and pressures rebound.

The current advice partially addresses these concerns for the Woronora reservoir by recommending monitoring and analysis that supports a better understanding of the contaminant loads from longwall mining areas of the catchment, improved capability to predict the consequences for water quality supplied to the WFP and better baseline data and modelling capability for assessing future mining proposals.

If the unexpectedly high flow rates that have been measured at the Eastern Tributary from early 2020 to late 2022, which are assessed in detail in IEAPM (2023), are due to increased groundwater discharge through subsidence fractures or shear planes, they may be associated with highly elevated contaminant loads. This illustrates the need for reporting of contaminant loads wherever possible with available data. Furthermore, measurement of water chemistry can assist in determining the source of these unexpectedly high flows.

Recommendations

Performance indicators and associated trigger levels for water reaching the Woronora Reservoir should be assessed using total Fe, Mn and Al where sufficient baseline data exist. Both total and dissolved Fe, Mn and Al concentrations should be reported in six-month and annual reports.

Contaminant loads as well as concentrations should be considered in performance measure assessments and six-monthly and annual reporting as far as data allow. Current data limitations mean that reliance on concentrations for monthly assessment of performance indicators is appropriate for the current series of longwalls.

Flow event water quality (including dissolved and total Fe, Mn and Al concentrations) using automatic samplers at ETWQ AU, WQWQ9 and WOWO2 should be obtained to support analysis of contaminant loads. At the same sites, continuous measurements of electrical conductivity, pH, redox potential, and turbidity should also be obtained.

After a database of flow and concentration measurements has been built up, analysis should be conducted towards generalisation of flow-concentration relationships, and approximation of loads, and whether these have changed as mining has progressed. Initial results including total Fe, Al and Mn loads at ETWQ AU, WQWQ9 and WOWO2 should be reported in the 2024 Annual Report and updates provided in subsequent annual reports.

For future mining areas, flow and contaminant concentrations should be measured and loads estimated at least two years in advance of mining at impact and control sites to allow BACI analysis.

Suitable methods for improving the extension of the Eastern Tributary rating curves to improve high flow measurement accuracy should be undertaken by Peabody. WaterNSW should review whether the extension of the rating curve at the Waratah Rivulet could be improved. Selected watercourses in future mining areas should have flow gauges installed with validated rating curves. Where it is impractical to extend rating curves to high flows, alternative methods of high flow estimation should be considered.

Temperature and water quality data should be obtained at various depths through the water column in the upper reservoir (at a location such as WDFS1 that is downstream of the entry of both the Waratah Rivulet and Eastern Tributary) to capture both the temperature stratification behaviour and the water quality at this point. Frequency of data collection should increase following significant flow events and following level 3 triggers for water quality reaching the reservoir.

It is recommended that an agreement be reached whereby a hydrodynamic and contaminant transport model set-up is designed to support assessments of potential mining impacts. Consideration should be given as to how the responsibility for the modelling is shared between WaterNSW and Peabody.

Peabody should procure sediment cores at selected locations downstream of the confluence of Waratah Rivulet and Eastern Tributary with the reservoir and at control sites in the reservoir in order to assess the possible impacts of mining on alterations to sediment composition (with implications to possible mobilisation of Fe and Mn should these sediments become anoxic).

When quality of water reaching the reservoir at performance indicator sites surpasses a level 3 trigger, analysis should be extended to:

- once installed, water quality data collected at various depths at WDFS1 or similar site representing the confluence of the Eastern Tributary and Waratah Rivulet arms of the reservoir,
- if available, contaminant load estimates,
- if available, reference to results of a lake hydrodynamic and contaminant transport model run using relevant scenarios of increased contaminant loads.

In any future mining areas, performance indicators and triggers should be based on loads as well as concentrations.

When reservoir water quality passes a level 3 trigger, more detailed analysis of the reservoir water quality should be undertaken including:

- data collected at various depths at DW01 (i.e., at the vertical profiler),
- data collected at various depths at Woronora Reservoir at DWO_THMD (Honeysuckle Creek Junction),
- once installed, data collected at various depths at WDFS1 (Figure 3) (or similar site representing the confluence of the Eastern Tributary and Waratah Rivulet arms of the reservoir),

- once available, iron and manganese concentrations in reservoir sediments.

Irrespective of these recommendations for further analysis in response to triggers, the Panel recommends that a more detailed analysis be undertaken of historical reservoir water quality and sediment cores in order to analyse potential trends and relations with mining development. This should be included in the 2023 Annual Review and updated in subsequent annual reviews.

Following the conclusions in IEPMC (2019), it is recommended that a broader study of potential long-term cumulative impacts of mining on water quality in the Special Areas is needed.

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1.0 SCOPE OF WORKS

On 4 April 2023, the Department of Planning and Environment wrote to the Chair of the Independent Advisory Panel for Underground Mining (now the Independent Expert Advisory Panel for Mining, referred to as "the Panel" here on) requesting advice on Water Quality Performance Measures for Metropolitan Coal Mine. Specifically, advice was requested on:

1. *The Assessments Against Water Quality Performance Measures[1], and whether the justifications and conclusion that the water quality performance measure for Woronora Reservoir have not been exceeded are reasonable.*

2. *Whether the performance indicator for negligible reduction to the quality of water resources reaching the Woronora Reservoir defined in WMPs is appropriate.*

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5. *Whether a cumulative impact assessment study is considered necessary to review water quality trends and potential impacts on drinking water supply from increased metals loads from the catchments impacted by mine subsidence at Metropolitan Mine.*

The Department also noted that it would welcome any other significant advice that the Panel may wish to provide concerning this issue.

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

- Professor Neil McIntyre – Surface water (and Chair of the Panel for this advice)
- Mr John Ross – Groundwater
- Professor David Waite – Water quality

2.0 METHOD OF OPERATION

As part of developing its advice, the Panel undertook the following activities:

- Online meeting with WaterNSW on 12 July

- Field visit on 19 July to Eastern Tributary, Waratah Rivulet and Woronora dam attended by Neil McIntyre and David Waite of the Panel and representatives of DPE, WaterNSW and Peabody.

- Online meeting with Sydney Water and WaterNSW on 26 July

[1] The Assessments Against Water Quality Performance Measures are primarily a series of assessments from 2018 to 2022 conducted for Peabody by Associate Professor Barry Noller of The University of Queensland that followed exceedances of performance indicators for water quality reaching the Woronora Reservoir.

- Online meetings of Panel members on 5 July, 7 August and 28 August.

The following primary documentation was referred to by the Panel:

- HEC (2023) Metropolitan Coal - Surface Water Review 1 July to 31 December 2022 (App B2 of Metropolitan Coal Annual Review 2022)

- Peabody (2022) Metropolitan Coal Water Management Plan for Longwalls 308-310

- The University of Queensland (2018-2022), Assessments Against Water Quality Performances. A series of 25 letters from Associate Professor Barry Noller of The University of Queensland to Peabody between November 2018 to December 2022.

- Peabody (2023) Assessment Against The Water Resources Subsidence Impact Performance Measure, Letter of 10 January 2023 to NSW Department of Planning and Environment

- Metropolitan Coal Project Approval (08_0149)

- WaterNSW letter to Peabody in response to Annual Review Report 2021 (dated 31 August 2022)

- WaterNSW letter to Peabody in response to Assessment against Water Quality Performance Measure - April 2022 (dated 26 September 2022)

- WaterNSW letter to Peabody in response to Assessment against Water Quality Performance Measure - April, May and June 2022 (dated 15 February 2023)

- WaterNSW Annual Water Quality Monitoring Reports 2020-2021, 2021-2022

- WaterNSW Greater Sydney Destratification Systems Operating Considerations, March 2023

- WaterNSW Water Quality Incident Response Protocol, June 2021

- Independent Expert Panel for Mining in the Catchment (IEPMC), 2018, Initial report on specific mining activities at the Metropolitan and Dendrobium coal mines, Prepared for the NSW Department of Planning and Environment

- Independent Expert Panel for Mining in the Catchment (IEPMC), 2019, Independent Expert Panel for Mining in the Catchment Report: Part 2. Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment, Prepared for the NSW Department of Planning, Industry and Environment

- Responses to Panel's request for information provided by WaterNSW on 14 July, 1 August and 1 September (emails).

- Responses to Panel's request for information provided by Sydney Water on 4 September (email).

3.0 BACKGROUND

3.1. WORONORA RESERVOIR AND MINING IN THE CATCHMENT

Woronora Reservoir (Figure 1) is one of the raw water storages that serves the Sydney area. Its capacity is 71.79 GL with catchment area 74.1 km^2 and surface area 3.996 km^2 when at capacity. The average total inflow over 2012-2017 was estimated to be approximately 28,000 ML/year or 900 L/s (WRIS 2019). The Eastern Tributary and Waratah Rivulet, which are the main tributaries affected by mining (Figure 1 and Figure 2), enter the reservoir approximately 10 km upstream of the dam. The catchment areas of these tributaries are 6.7 km^2 and 20.2 km^2 respectively (at flow gauge station numbers GS2132102 and GS300078).

Metropolitan Coal has undertaken longwall mining within the Woronora Reservoir catchment boundaries since mining of Longwall 1 in 1995 (Figure 2). Mining of longwalls 1-27 was complete in 2017 and, following mining of longwalls 301-308 from 2017 to 2023, mining of longwall 309 (immediately to the west of the reservoir in Figure 2) commenced in August 2023 (Peabody 2023).

The presence of mining subsidence-induced fractures and dilated bedding planes at locations in the Eastern Tributary and Waratah Rivulet and changes in pool drainage behaviour have been the subject of previous assessments (IEPMC 2018) and are summarised in Peabody's annual reports (e.g. Tables 7-9 of Peabody 2023). Further assessment of the subsidence effects, impacts and environmental consequences[2] for the Eastern Tributary catchment is provided in concurrent Panel advice (IEAPM 2023) whereas the current advice focusses on the potential consequences for water quality.

3.2. WORONORA RESERVOIR – WATER QUALITY CRITERIA

The Woronora Reservoir supplies raw water to the Woronora Water Filtration Plant (WFP), situated at Woronora Dam and operated for Sydney Water by Veolia. The design capacity of the WFP is approximately 160 ML/day and its minimum output in order to prevent shut-down and to maintain a minimum supply is approximately 40 ML/day.

WaterNSW also has a Water Quality Incident Management protocol based on trigger levels and associated responses. The responses include notifying WFP operators when delivered raw water quality exceeds specified trigger levels (Table 1). The WFP operation, including its output rate, are adjusted when the input water quality reduces below specified limits. These limits are aligned with the trigger levels in Table 1.

The raw water supply agreement (RWSA) standards for Woronora Reservoir for total iron, total manganese and total aluminium (WaterNSW 2022a, Table 4.2) correspond to the major incident levels

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[2] The advice 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

in Table 1. The significance of the RWSA standards is described by WaterNSW (2022a) as "*WaterNSW has established terms and conditions of supply with wholesale customers to ensure treated water is not harmful to consumers' health. … These standards are based on the treatment capabilities of the plants and the natural characteristics of the catchment. This ensures that raw water can be treated to meet ADWG requirements*". WaterNSW (2021a, p19) further explains "*These RWSAs include site specific water quality standards applicable for each Water Filtration Plant (WFP) based on typical historical raw water quality and plant capabilities".*

The ADWG requirements referred to above and also referred to in the Peabody assessments (e.g., The University of Queensland 2022) are the Australian Drinking Water Guidelines published by the National Health and Medical Research Council and National Resource Management Ministerial Council (NHMRC & NRMMC, 2011). The ADWG requirements include maximum concentrations of metals in drinking water following treatment in a WFP. While the ADWG requirement for total manganese is 0.5 mg/L, the ADWG also indicate that some nuisance microorganisms can concentrate manganese and give rise to taste, odour and turbidity problems in distribution systems. A discretionary target of 0.01 mg/L is suggested by the ADWG for waters leaving a WFP. High filterable manganese concentrations in raw waters necessitate use of permanganate dosing to ensure treated waters contain less than 0.02 mg/L, above which manganese will form a coating on pipes that can slough off as a black ooze.

Another water quality guideline, which is referred to in the Peabody assessments (e.g., The University of Queensland 2022), is the Australian and New Zealand Guidelines for fresh and marine water quality (ANZG 2018), which includes guidelines for protection of aquatic species.

Figure 1. The Woronora Reservoir and its catchment (Figure 5.3 from WaterNSW 2021b, with the Eastern Tributary and Waratah Rivulet labels added to indicate their locations). HWOP1 is the picnic ground drinking water tap (and is not referred to again in this advice); DW01, HW01-A, E677 and E6131 are other WaterNSW monitoring points referred to in Section 3.3 below.

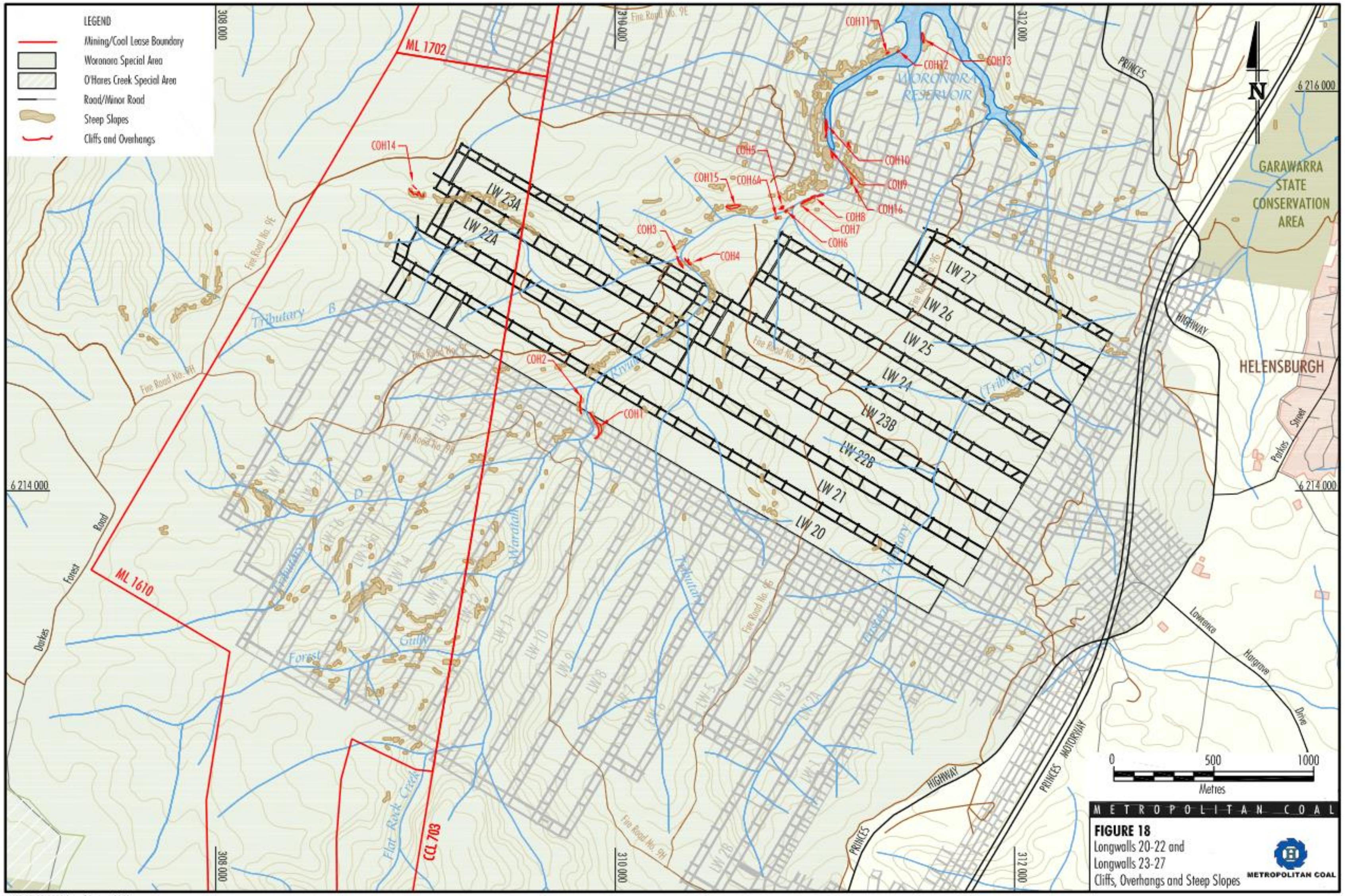

Figure 2. Longwalls 1-27 overlying the Waratah Rivulet and Eastern Tributary catchments (Figure 18 from Peabody, 2016)

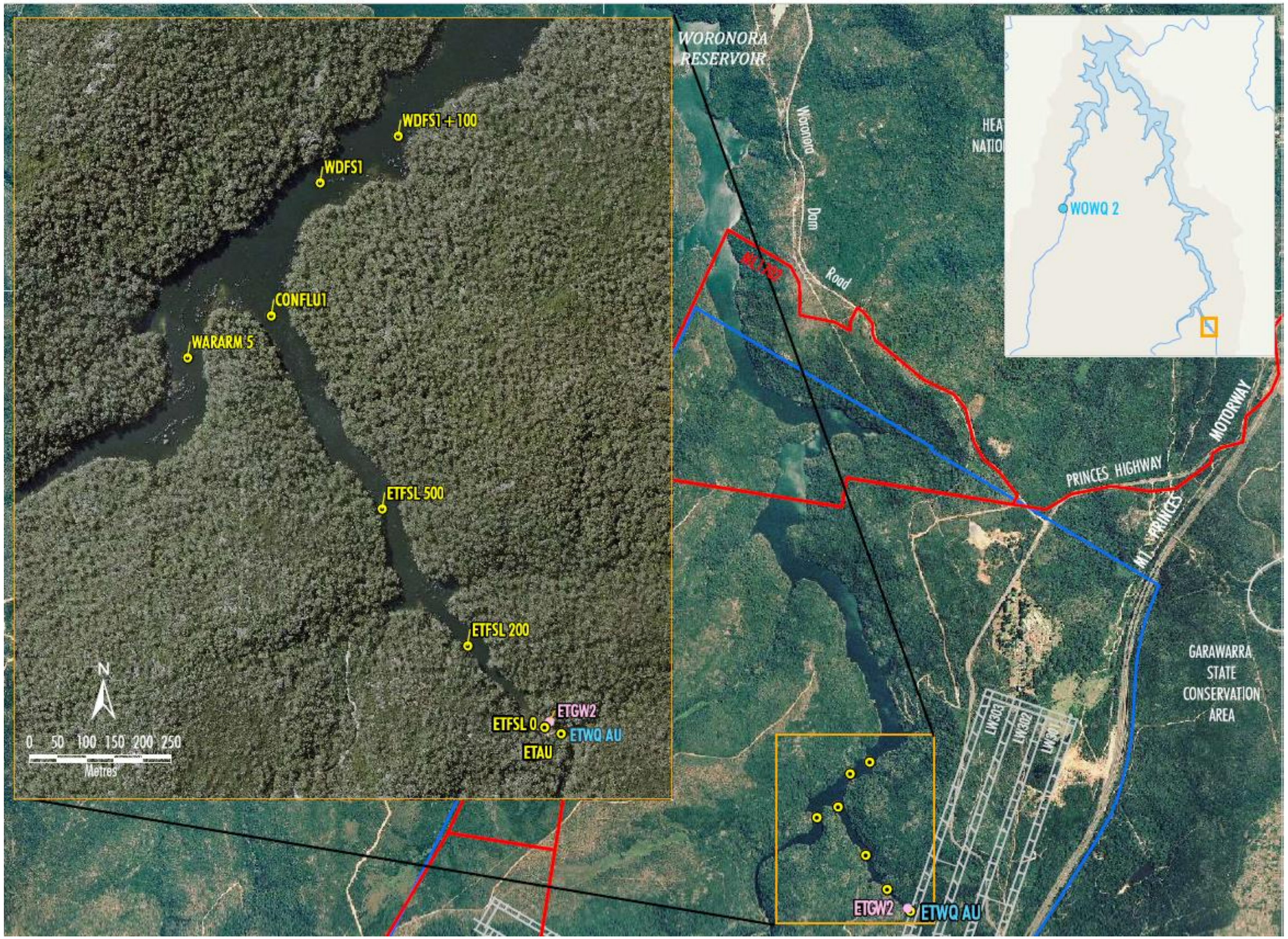

Figure 3. Peabody's monitoring locations at ETWQ AU and below the Full Supply Level of the Woronora Reservoir (copied from Figure 1 of The University of Queensland 2022)

Table 1 Water Quality Incident Management trigger levels for selected parameters at point of supply to Woronora Water Filtration Plant (from Table 7 of WaterNSW 2021)

Parameter	**Alert level**	**Minor incident level**	**Major incident level[1]**
Turbidity (NTU)	>3-11	>11-20	>20
True Colour @ 400 nm (CU)	>6 – 52.5	>52.5-70	>70
Filterable Iron (mg/L)	>0.1		
Total Iron (mg/L)	>0.5-0.75	>0.75-1.0	>1.0
Filterable Manganese (mg/L)	>0.02		
Total Manganese (mg/L)	>0.03-0.07	>0.07-0.1	>0.1
Total Aluminium (mg/L)		>0.3-0.4	>0.4
Total Organic Carbon (mg/L)	>4		

[1] The major incident level corresponds to the Raw Water Supply Agreement (RWSA) for Total Iron, Total Manganese and Total Aluminium (Table 4.2 of WaterNSW 2022a)

3.3. RAW WATER QUALITY MONITORING

As well as at the point of supply to the water filtration plant (HW01-A in Figure 1), raw (i.e., untreated) water quality is regularly monitored by WaterNSW near to the dam wall (DWO1) and at the junction of the reservoir and Honeysuckle Creek (DWO_THMD) (Figure 1). DW01 has long-term data (e.g., total iron since 1953, total manganese since 1986 and total aluminium since 1990) while water quality monitoring at DWO_THMD began in 2012. The frequency of monitoring varies, typically 1 to 2 weeks at DWO1. DWO1 and DWO_THMD samples are taken over a range of depths from the surface down to near the bed of the reservoir (at up to 59.5 m depth). Water quality has been sampled by WaterNSW at six other sites in the reservoir over the decades. Three reservoir sites are currently operational: DWO1, DWO_THMD and a new site downstream of Bee Creek that was added in 2023[3]. WaterNSW routinely monitor the Waratah Rivulet and Woronora River (E6131 and E677 in Figure 1). The WaterNSW monitoring results are reported in WaterNSW annual reports and, for DWO1, in Metropolitan Mine annual and six-month reviews.

Peabody monitors water quality at many locations in the Metropolitan mining areas and control sites to inform performance assessments and to contribute to six-monthly and annual reporting (e.g., see locations of sites in Figure 7 of Peabody 2022). For performance assessments, the key sites are ETWQ AU, WRWQ9 and WOWQ2 (ETWQ AU is shown in Figure 3, while WRWQ9 and WOWQ2 are co-located with E6131 and E677 in Figure 1). ETWQ AU is co-located with the Eastern Tributary Gauging station immediately upstream of the reservoir at its Full Supply Level, WRWQ9 is co-located with the WaterNSW flow gauge on the Waratah Rivulet, approximately 700 m upstream of the Full Supply Level, and WOWQ2 is the Woronora River control site, unaffected by mining. Measurement of water quality at site ETWQ AU commenced in 2010, while at WQWQ9 it commenced in 2006 though measurements elsewhere in the Waratah Rivulet date back to 2001 (Parsons Brinckerhoff 2010). Additionally, monitoring has been undertaken by Peabody at sites in the reservoir downstream of the Full Supply Level at the Eastern Tributary and Waratah Rivulet (ETFSL (x3), WDFS (x2), CONFLU1

[3] This summary of water quality monitoring is based on a spreadsheet provided to the Panel by WaterNSW

and WARARM 5 sites in Figure 2), which allow sampling from the "mixing zone" (The University of Queensland 2022) where the incoming contaminants are mixed with the upper reservoir water.

3.4. WATER QUALITY INCIDENTS AND TRENDS

Historically and most recently in July 2022, the Woronora reservoir water quality reduces during and after floods. This is illustrated here in Figure 4 and Figure 5 replicated from HEC (2022), showing that iron (Fe), aluminium (Al) and manganese (Mn) concentrations were unusually high during 2022 at DWO1[4] (i.e., all consistently above the 10 year Average Recurrence Interval curves and often above the 20 year Average Recurrence Interval curves). Sediment (turbidity) and Natural Organic Matter (NOM) concentrations were also elevated. Twelve months after the July 2022 flood event, the Woronora reservoir water quality had not recovered to average historical concentrations.

High sediment and Natural Organic Matter (NOM) concentrations necessitate the use of high coagulant dosages and frequent filter backwash with resultant high sludge loads and thus greater difficulty and increased cost in treating these waters compared to waters of lower turbidity and NOM content. For this reason, the WFP is currently operating at its minimum operational flow of 40 ML/day. This has financial implications for Sydney Water related to the contractual arrangements with the water treatment provider and the need to provide alternative drinking water sources including running the Kurnell desalination plant. While the principal operational challenges with the WFP are due to increased organic matter concentrations and increased turbidity associated with flood events (which result in the need for increased addition of coagulants, increased sludge loads and decreased filter run times), the challenges due to elevated metal concentrations cannot be ignored with high total iron concentrations contributing to high turbidity and high manganese concentrations requiring treatment to meet the 0.01 mg/L discretionary guideline referred to previously.

The quality of feed waters to the Woronora WFP is monitored by WaterNSW. WaterNSW has provided details of exceedances of the alert and incident levels (Table 1) since 2013 with a tabulation of numbers of exceedances (and severity of the exceedance) per year for particular parameters provided in Table 2 below.

Woronora Reservoir is artificially mixed by aerators deployed at the base of the reservoir near the dam wall with the injection of air preventing stratification and potential subsequent development of anoxic (low oxygen) conditions at depth. This aims to avoid the development of poor water quality at depth, including preventing the release of iron and manganese and associated nutrients (particularly phosphorus) from the sediments that can occur in anoxic conditions. The aerators are operated when temperature differences between deep and shallow water indicates the potential for stratification. The aerators destratify the reservoir in the vicinity of the dam wall but are unlikely to prevent stratification in the upper reaches of the reservoir, meaning that any redox-active metals (particularly iron and manganese) accumulated in the sediments of the upper reaches due to mining may be prone to release during anoxic conditions and potentially transported downstream towards the dam.

[4] Trends and variations in reservoir water quality are assessed only at DWO1 due to relatively short lengths of record at all other monitoring stations

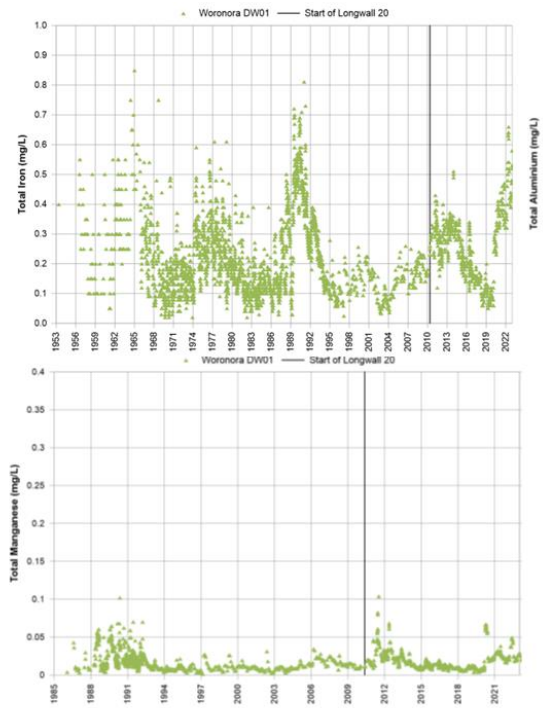

Figure 4. Time-series of total iron, aluminium and manganese at set DWO1 (Charts 42-44 of Peabody 2023). The far right-hand side of each plot shows the spike in July 2022.

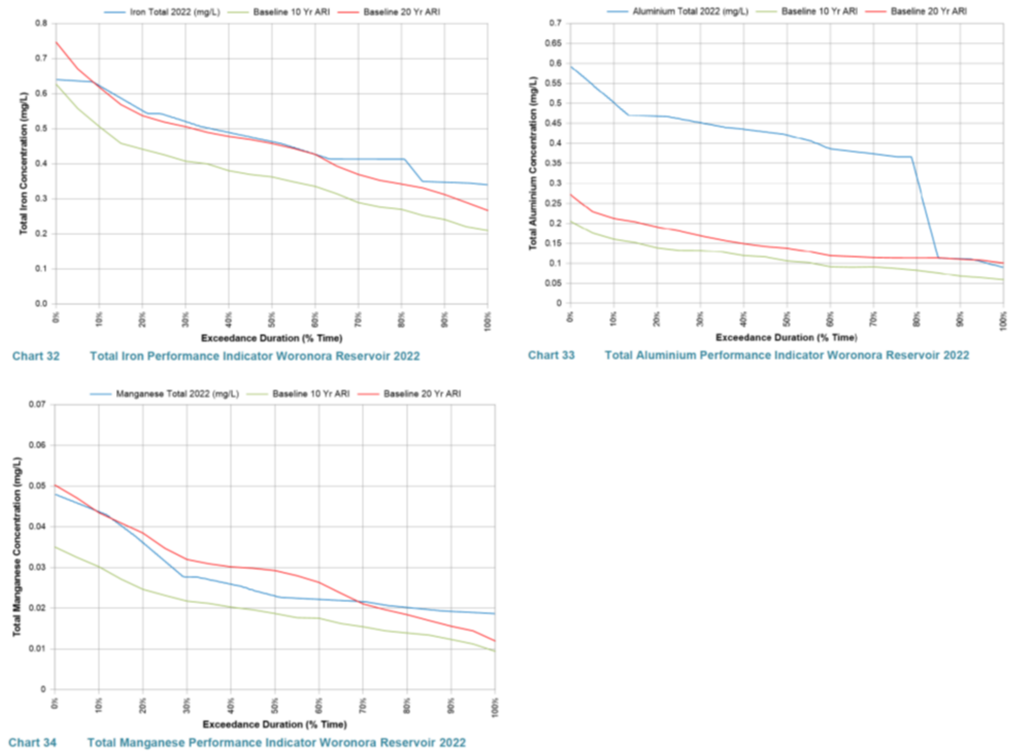

Figure 5. Exceedance durations of concentrations of total iron, aluminium and manganese at DWO1 during 2022, compared with exceedance durations in two historical years with poor quality water (10 Yr and 20 Yr ARI years) (Charts 45-47 of Peabody 2023).

Table 2 Number of exceedances at alert, minor and major levels per year for water quality parameters listed in Table 1. Data provided to Panel by WaterNSW based on monitoring data from HW01-A (location in Figure 1).

Year	Turbidity	Colour	TOC	Al tot	Fe tot	Fe filt	Mn filt
2023 (to end June)	0	6	6	2 (minor)	4 (alert)	0	6 (alert)
2022	36 (alert)	40 (alert)	41 (alert)	5 (minor) 33 (major)	26 (alert)	41 (alert)	27 (alert)
2021	2 (alert)	23 (alert)	23 (alert)	1 (minor)	2 (alert)	23 (alert)	10 (alert)
2020	6 (alert)	11 (alert)	22 (alert)	6 (minor) 1 (major)	0	22 (alert)	5 (alert)
2019	1 (alert)	0	2 (alert)	0	0	0	0
2018	0	0	0	0	0	0	0
2017	0	0	12 (alert)	0	0	0	0
2016	11 (alert)	0	26 (alert)	2 (minor) 6 (major)	0	0	0
2015	6 (alert)	0	20 (alert)	0	0	0	0
2014	1 (alert)	0	9 (alert)	0	0	0	0
2013	0	0	6 (alert)	0	0	0	0

3.5. SUBSIDENCE IMPACTS ON WATER QUALITY – MECHANISMS

The mechanisms of mining subsidence impacts and effects as relevant to the watercourses in the Metropolitan mining area are described in IEPMC (2018), WRIS (2017, 2019) and IEAPM (2023). Previous studies by and for the Sydney Catchment Authority have investigated in detail the mechanisms and evidence of the consequences of subsidence for water quality in the Waratah Rivulet, and reviewed water quality consequences of mining in other watercourses of the Southern Coalfield (Parsons Brinckerhoff 2007, 2010, Jankowsi 2010, Jankowsi and Knights 2010). Here, a summary of the mechanisms is given.

Of primary relevance here is the diversion of surface water and groundwater through mining-induced rock fractures and subsequent discharge of contaminated water into creeks and then into the reservoir. A variety of physicochemical processes influence the particular forms of iron, aluminium and manganese likely to be present. Under anoxic conditions, as is typical in subsurface environments, iron and manganese will be present predominantly in their soluble ferrous (Fe(II)) and manganous (Mn(II)) forms. On exposure to oxygen-containing water, the reduced forms of these redox-active elements should, thermodynamically, be transformed to their oxidised ferric (Fe(III)) and manganic (Mn(IV)) forms. Given the tendency of these oxidised forms to hydrolyse and precipitate, these elements will eventually be present, under oxic conditions, principally as particulate iron and manganese oxyhydroxides (typically represented as FeOOH(s) and MnOOH(s)). The rates of Fe(II) and Mn(II) oxidation by oxygen however differ markedly and are strongly pH dependent with Fe(II) expected to transform to particulate FeOOH(s) within minutes at circumneutral pH while Mn(II) transformation may take many days or even weeks to reach its preferred MnOOH(s) form. The oxidised forms of these elements will initially form nanosized particulates that may aggregate to micron-sized assemblages that will be trapped on the 0.45 μm membrane filters used to separate the “dissolved” (filterable) fraction from the total metal oxyhydroxide present though a portion of the particulates may remain in fine colloidal form and pass through the membrane filters (and appear in the "dissolved" fraction)[5].

The presence of natural organic matter (NOM) in oxic waters may inhibit the aggregation process (as a result of adsorption of this organic matter to particulates and imposition of negative surface charge) with resultant increase in proportion of the metal oxyhydroxide present in colloidal form. Unlike redox active iron and manganese, aluminium occurs only in the trivalent (Al(III)) form and will be present either as aluminium oxyhydroxides (AlOOH(s)) or, more likely, as aluminosilicate clays. Like FeOOH(s), these particulate forms of aluminium may be retained by the 0.45 μm membrane filters or, if sufficient NOM is present, a portion of the particulate aluminium may remain in colloidal form and pass through the filters into the filterable fraction. High concentrations of total aluminium are often observed together with high turbidity as suspended aluminosilicate clays are typically the cause of high turbidity.

In summary,

- The mass of iron, aluminium and manganese transported from rock fractures to the reservoir depends on the degree and location of fracturing, properties of the rock, chemistry of the water, and flow pathways, flow rates, and the interactions of all these.

- If baseflow discharges from regional groundwater increase after a high rainfall event, or if regional water table levels recover post mining, then increased loads of iron, aluminium and manganese transported from rock fractures could be expected.

- The physicochemical processes influencing the forms of iron, aluminium and manganese result in iron and aluminium being present in streams flowing into Woronora Reservoir predominantly in particulate form and manganese being present predominantly in filterable ("dissolved") form.

- Iron, aluminium and any particulate manganese present in streams flowing into Woronora Reservoir would be expected to deposit, for the most part, to the sediments in solid oxyhydroxide form though a portion may remain in suspension if stabilised in colloidal form by adsorbed natural organic matter.

- Dissolved manganous (Mn(II)) manganese, the predominant form of manganese in streams flowing into Woronora Reservoir, is likely to remain in this form for some time (days-weeks) though would be expected to eventually oxidise to manganic (Mn(III)) form and deposit to the sediments as particulate oxyhydroxide (MnOOH(s)).

The eventual fate of the redox active elements iron and manganese that are deposited to benthic Woronora Reservoir sediments will be dependent on the oxidation state of the sediments. In winter, the reservoir will typically be well-mixed with sufficient oxygen through the water column to maintain iron and manganese in their oxidised particulate forms within the benthic sediments. In summer, when the reservoir naturally thermally stratifies (i.e., separates into a higher temperature well-mixed oxic surface layer (the epilimnion) and a lower temperature anoxic deeper layer (the hypolimnion)), the particulate forms of iron and manganese are likely to be transformed, to some extent, to filterable ("dissolved")

[5] While the word "dissolved" has been consistently used in the Metropolitan Water Management Plan, it should be recognised that "dissolved" concentrations may also include colloidal materials that may have passed through the 0.45 μm filter used in field sampling. In this advice, "filterable" is used to include both dissolved and colloidal forms.

forms that, subsequently, may be transported through the reservoir and, potentially, to the raw water offtake near the dam wall.

As noted above, the reservoir is artificially destratified (by injection of air) near the dam wall during summer to reduce the extent of release of iron and manganese from the sediments and to minimise the likelihood of high concentrations of iron and manganese being present in raw waters supplied to the WFP. This destratification process is effective in preventing formation of an anoxic zone in the vicinity of the aerator but is unlikely to break the stratification that will occur in summer in the upper reservoir. It is possible that natural convective forces and/or the aeration process could result in the transport of high iron and manganese content waters from the upper reaches of the reservoir toward the dam wall though hydrodynamic and contaminant transport modelling of the reservoir would be required to assess the likelihood of this occurring.

While the diversion of surface water and groundwater through mining-induced rock fractures and subsequent discharge of contaminated water into creeks and then into the reservoir is evident, the extent to which the increased loads of iron, aluminium and manganese transported to reservoir benthic sediments as a result of mining subsequently impacts reservoir water quality is uncertain given that these elements occur naturally in the runoff from non-mined catchments and in the benthic sediments. It should be noted however that freshly deposited particulate oxyhydroxides of these elements are likely to be more reactive and more readily mobilised on onset of low oxygen conditions than the more crystalline (and thus less reactive) forms of these elements that are intrinsically present naturally in the sediments.

Aside from metals leaching from rock fractures, potential consequences of mine subsidence on water quality include:

- Physical drying of affected swamps and subsequent increase risk of erosion of swamp organic material, and reduced capacity of the swamp to moderate contaminant export.
- Changes to slopes of watercourses and associated soil erosion.
- Accidental spills of contaminants from surface operations within the catchment.

These mechanisms, if and when they exist in this catchment, could affect reservoir water quality, particularly during and after flood events. However, these mechanisms are relatively localised and the diversion of surface water and groundwater through mining-induced rock fractures is considered to be the more relevant mechanism for the purpose of this advice.

3.6. SUBSIDENCE IMPACTS MANAGEMENT AND PERFORMANCE MEASURES

The Metropolitan Coal Project Approval (08_0149) requires Metropolitan Coal to ensure that its mining activities do not cause any exceedance of subsidence impact performance measures outlined in Table 1 of Condition 1, Schedule 3 of the Approval, which includes:

- *Negligible reduction to the quality or quantity of water resources reaching the Woronora Reservoir*
- *Negligible reduction in the water quality of Woronora Reservoir*

The associated Performance Indicators (Peabody's proposed measure of whether the performance measure in being met) are:

- *Changes in the quality of water entering Woronora Reservoir are not significantly different post-mining compared to pre-mining concentrations that are not also occurring at control site WOWQ2*

- *Changes in the quality of water in the Woronora Reservoir are not significantly different post-mining compared to pre-mining concentrations.*

The first of these is based on comparing pre-mining baseline with post-mining measurements of water quality on the Eastern Tributary (site ETWQ AU) and Waratah Rivulet (WRWQ9), taking into account variations at the control site on the Woronora River (WOWQ2). The parameters considered for the creek water quality performance indicators are filterable (field filtered using 0.45 µm filter) iron, filterable manganese and filterable aluminium.

The second of these performance indicators – that focusses on Woronora Reservoir water quality - is based on comparing pre-mining baseline and post-mining measurements of water quality at site DWO1 in the reservoir without use of a control site (although variations in water quality in other reservoirs have been considered in the analysis of results). In this case the parameters are total iron, total manganese and total aluminium.

A series of three water quality triggers (defined in Table 24-a, 24-b and 26 of Peabody 2022, copied as Tables 3, 4 and 5 below) are used to escalate management actions based on the degree of difference between pre-mining and post-mining water quality. If trigger level 3 for creek sites ETWQ AU or WRWQ9 is surpassed for any of the three parameters this is treated by Peabody as requiring an investigation to determine if it should be regarded as a non-negligible impact that would constitute an exceedance of the performance measure related to the quality of water resources entering the Woronora Reservoir. This investigation has been provided by Associate Professor Barry Noller of The University of Queensland resulting in a series of reports from November 2018 to December 2022 (and earlier assessments are referred to in Peabody 2022), which concluded that the performance measure has not been exceeded. The rationale of that conclusion is reviewed as part of Section 4 of this advice. If the trigger level 3 for reservoir water quality at site DWO1 (Table 5 below) is triggered, then an investigation is also required. The Panel has not seen specific reports associated with the reservoir water quality triggers except those in the 6-month and annual reports, which have concluded that the level 3 triggers during 2022 were not associated with mining. This conclusion is also reviewed in Section 4 of this advice.

Table 24-A

Trigger Action Response Plan – Negligible Reduction to the Quality of Water Resources Reaching the Woronora Reservoir

Performance Measure	Performance Indicator	Monitoring Site(s)	Parameters	Frequency/ Sample Size	Analysis Methodology	Error Types	Baseline	Significance Levels/Triggers		Action/Response
Negligible reduction to the quality of water resources reaching the Woronora Reservoir.	*Changes in the quality of water entering Woronora Reservoir are not significantly different post-mining compared to pre-mining concentrations that are not also occurring at control site WOWQ2.*	Site WRWQ9 on the Waratah Rivulet. Site ETWQ AU on the Eastern Tributary. Control site WOWQ2 on the Woronora River.	Iron (Fe). Manganese (Mn). Aluminium (Al). [Field filtered].	Monthly.	Water quality data analysed quarterly, following the receipt of laboratory data[1]: • Adjusted baseline mean plus two standard deviations[2, 3] have been calculated for each water quality parameter and are provided in Table 24-B. • Adjusted baseline mean plus one standard deviation[4, 5] has been calculated for each water quality parameter and are provided in Table 24-B. The six month mean metal concentration will also be calculated at the end of each six month review period.	Potential for sampling, laboratory and data management errors.	<u>WRWQ9</u> • Fe (0.03 to 0.39 mg/L). • Mn (0.01[6] to 0.069 mg/L). • Al (0.001[6] to 0.15 mg/L). <u>ETWQ AU</u> • Fe (0.1 to 0.5 mg/L). • Mn (0.005[6] to 0.033 mg/L). • Al (0.03 to 0.11 mg/L). <u>WOWQ2</u> • Fe (0.05[6] to 1.3 mg/L). • Mn (0.01[6] to 0.1 mg/L). • Al (0.0005[6] to 0.11 mg/L).	Level 1	Data analysis indicates no water quality parameter exceeds the adjusted baseline mean plus two standard deviations.	Continue monitoring. Six monthly reporting.
								Level 2	Data analysis indicates any water quality parameter exceeds the adjusted baseline mean plus two standard deviations for one month.	Increase the frequency of data analysis to monthly (until such time that data analysis indicates a return to Level 1). Six monthly reporting.
								Level 3	Data analysis indicates: • any water quality parameter exceeds the adjusted baseline mean plus two standard deviations for two consecutive months; or • over a three month period the water quality parameter exceeds the adjusted mean plus two standard deviations in the first month, the adjusted mean plus one standard deviation in the next month and the adjusted mean plus two standard deviations in the third month; or • the six month mean exceeds the adjusted baseline mean plus one standard deviation for two consecutive assessment periods (i.e. over two six monthly reports); and • there was not a similar exceedance of the trigger at the control site.	Increase the frequency of data analysis to monthly (until such time that data analysis indicates a return to Level 1). If the water quality parameter is greater than the historical maximum, then undertake an investigation and assess against the performance measure. If the water quality parameter is less than the historical maximum, then undertake an investigation and assess against the performance measure at the end of the quarter[7]. Report to DPE, WaterNSW, DPE – Water and BCS within one month of assessment completion. Consider the need for management measures, in accordance with Sections 8 and 9.

Table 3 Trigger Action Response Plan for water quality entering the Woronora Reservoir (Table 24-A of Peabody 2022).

Table 24-B
Adjusted Baseline Mean plus Standard Deviations for Sites WRWQ9, ETWQ AU and WOWQ2

Assessment	Site	Water Quality Indicator	Baseline Mean Plus Two Standard Deviations (mg/L)	Adjusted Baseline Mean Plus Two Standard Deviations (mg/L)	Baseline Mean Plus One Standard Deviation (mg/L)	Adjusted Baseline Mean Plus One Standard Deviation (mg/L)
Waratah Rivulet water quality post-mining versus baseline, and compared to control site WOWQ2	**WRWQ9**	Dissolved Iron	0.544	0.706	0.284	0.337
		Dissolved Aluminium	0.097	0.100	0.041	0.047
		Dissolved Manganese	0.092	0.117	0.055	0.066
	WOWQ2 (using same baseline period as WRWQ9 to allow comparison)	Dissolved Iron	0.741	0.961	0.324	0.385
		Dissolved Aluminium	0.244	0.250	0.094	0.109
		Dissolved Manganese	0.064	0.082	0.042	0.051
Eastern Tributary water quality post-mining versus baseline, and compared to control site WOWQ2	**ETWQ AU**	Dissolved Iron	0.543	0.543	0.336	0.336
		Dissolved Aluminium	0.094	0.188	0.065	0.106
		Dissolved Manganese	0.029	0.030	0.017	0.020
	WOWQ2 (using same baseline period as ETWQ AU to allow comparison)	Dissolved Iron	1.657	1.657	0.555	0.555
		Dissolved Aluminium	0.075	0.151	0.061	0.100
		Dissolved Manganese	0.090	0.094	0.052	0.058

Table 4 Water quality criteria that define the water quality trigger levels referred to in Table 3 (Table 24-B of Peabody 2022).

Table 26

Trigger Action Response Plan – Negligible Reduction to the Quality of Water Resources in the Woronora Reservoir

Performance Measure	Performance Indicator	Monitoring Site(s)	Parameters	Frequency/ Sample Size	Analysis Methodology	Error Types	Baseline	Significance Levels/ Triggers		Action/Response
Negligible reduction in the water quality of Woronora Reservoir.	*Changes in the quality of water in the Woronora Reservoir are not significantly different post-mining compared to pre-mining concentrations.*	Woronora Reservoir (site DW01) (subject to data availability from WaterNSW) Nepean Reservoir (subject to data availability from WaterNSW) Cataract Reservoir (subject to data availability from WaterNSW)	Total Iron (Fe). Total Manganese (Mn). Total Aluminium (Al).	Sampling frequency is variable.	Water quality data analysed annually, following the receipt of data from WaterNSW. Water quality parameters, measured in the same location on the same day will be geometrically averaged. The parameter records will be interpolated to provide daily records. Concentration exceedance duration curves will be calculated for each parameter by determining the concentration exceeded at each location by percentages of days of the year covering the full range from 0% to 100%, at 5% intervals. Baseline data[1] will be analysed in an annual format to determine concentration exceeded with an estimated average recurrence interval (ARI[2]) curve of 20 years by percentages of days in the year from 0% to 100%. For each percentage of time selected from this range, an ARI curve will be calculated by fitting a log Generalised Extreme Value distribution to the concentration exceeded each year of the baseline record by that percentage of days. For each water quality parameter, the concentration exceedance curve for the current year of monitoring and the 20 year ARI exceedance curve calculated from the baseline records will be plotted on a graph.	Potential for sampling, laboratory and data management errors.	Baseline 10 and 20 year ARI exceedance curve	Level 1	The current year's duration exceedance curve for a water quality parameter in Woronora Reservoir (total iron, total manganese and total aluminium) is below the baseline 10 year ARI exceedance curve for any range of the duration percentages from 0% to 75%.	Continue monitoring. Annual reporting.
								Level 2	The current year's duration exceedance curve for a water quality parameter in Woronora Reservoir (total iron, total manganese and total aluminium) is above the baseline 10 year ARI but below the baseline 20 year ARI exceedance curve for any range of the duration percentages from 0% to 75%.	Plot and qualitatively assess the Woronora Reservoir, Nepean Reservoir and Cataract Reservoir water quality data every six months (until such time that data analysis indicates a return to Level 1). Annual reporting.
								Level 3	The current year's duration exceedance curve for a water quality parameter in Woronora Reservoir (total iron, total manganese and total aluminium) is above the baseline 20 year ARI exceedance curve for any range of the duration percentages from 0% to 75%.	Plot and qualitatively assess the data from the Nepean Reservoir and Cataract Reservoir. Undertake investigation and assess against the performance measure. Report to DPE, WaterNSW, DPE – Water and BCS within one month of assessment completion. Consider the need for management measures, in accordance with Sections 8 and 9.

[1] Baseline data includes data prior to 19 May 2010 (i.e. prior to the commencement of Longwall 20).

[2] Average Recurrence Interval. This term has been used here for consistency with previous Annual Reviews and Water Management Plans. Based on recommendations by the Institution of Engineers Australia, the preferred terminology now involves the term Annual Exceedance Probability (AEP) expressed as a percentage probability. This is to avoid confusion that the term ARI has caused within the industry, community and other stakeholders. A 20 year ARI is equivalent to a 5% AEP.

Table 5 Trigger Action Response Plan for Woronora Reservoir water quality (Table 26 of Peabody 2022).

3.7. PREVIOUS INVESTIGATIONS AND ADVICE RELATING TO MINING IMPACTS ON THE WATER QUALITY OF THE WORONORA RESERVOIR

Parsons Brinckerhoff (2010) conducted a study for the Sydney Catchment Authority that included understanding the consequences of subsidence for water quality of the Waratah Rivulet. Relevant conclusions were:

- *The effects of longwall mining induced subsidence on surface water quality were most apparent under low flow conditions. During low flow conditions EC, major ion concentrations, dissolved manganese, barium and strontium concentrations were elevated. In addition, dissolved iron readily oxidised to form orange/brown precipitates of iron oxides and hydroxides on the creek bed and thick bacterial mats flourished under the low flow conditions.*

- *The long term impacts on surface water in Waratah Rivulet are difficult to assess due to lack of baseline (pre-mining) data. During the study period [2006-2009], there was no significant increase in major ion or metal concentrations over time. However a comparison of the current data with the only available historical water quality data (from 2001) does show an increase in salinity, and some major ions and metals in Waratah Rivulet at Flat Rock Crossing.*

Although assessing in some detail the water quality of the Waratah Rivulet, which accounts for 29% of the Woronora Reservoir catchment, Parsons Brinckerhoff (2010) did not quantify or comment in any detail on the implications of modifications to the Waratah Rivulet water quality for the Woronora Reservoir. The WaterNSW annual reviews include a data summary and brief commentary on water quality at a site on Waratah Rivulet (downstream of Flat Rock Crossing, near where Fire Road 9H crosses the Waratah Rivulet on Figure 1), with WaterNSW (2022) stating "*Aluminium and indices reflecting increases in organic loading (pH and dissolved oxygen) showed increased exceedances mainly due to increased inflows*". Trends are assessed biannually by WaterNSW, with the last assessment in WaterNSW (2021) (Table 9.3 of that document) showing statistically significant negative trends (reducing concentrations) at DW01 during 2011-2021 for total and filterable manganese, total aluminium, and total and filterable iron.

Considering the implications of impaired water quality due to mining in the Special Areas, IEMPC (2019) cited a literature review prepared for WaterNSW (Advisian 2016):

> *"In summary, although some consequences on water quality within the watercourses in the study are documented in the literature, these consequences are likely to be short term, sporadic and localised… Any consequences on water quality at the reservoirs would be treatable by the existing Sydney Water treatment plants."*

The adequacy of relying on water treatment capacity in context of the relevant performance measures is considered in Section 4 of this advice.

IEMPC (2019) continued:

> *However, the literature review did not consider potential consequences of groundwater outflows from spill points following mine closure and groundwater repressurisation. This needs careful consideration because of the potential for the outflow to leach metals as it travels through the overburden fracture network. The total surface area of fractures in this network is orders of magnitude greater than that of local fracture networks that affect water quality in watercourses impacted by valley closure. This could have serious potential implications for both the volume of metals reporting to the Sydney water supply in the future and for the unknown but likely extremely long duration of these elevated metal loads, unless appropriately managed. As management options may be limited where spill points occur inside Special Areas, considerations arise as to whether it is feasible to restore water table in the long term.*

> *Better understanding of the potential long-term contaminant loads to reservoirs and other water supply works is essential. This should include integrating monitoring of contaminant concentrations with flow monitoring at operational mines so that contaminant loads*[6] *can be calculated and modelled at key locations. Relevant contaminants should be agreed between primary stakeholders.*

The Independent Advisory Panel for Underground Mining (IAPUM 2021) echoed that advice in the context of the Dendrobium mine:

> *The Panel regards contamination as a potential strategic concern if mining in the Special Areas is to continue long-term or if groundwater levels might recover and lead to increased discharge of contaminated water following the cessation of mining. If either scenario is possible, further consideration by stakeholders of the value and feasibility of estimating contaminant loads and their incorporation in TARPs is recommended.*

Where creeks enter a large reservoir such as the Woronora Reservoir, the creek's contaminant load over periods of days, weeks or months (depending on the flows and hydrodynamics) significantly influences the contaminant concentrations. Basing assessments only on concentrations has limited value, since high loads often coincide with low concentrations and vice versa.

The Woronora Reservoir Impact Strategy (WRIS) expert group was initiated in 2017 for "*Engagement of independent experts to prepare a Woronora Reservoir Impact Strategy, which provides a staged plan of action for further investigations and a report into the impacts of mining near the Reservoir*". Potential impacts on water quality were not considered in the WRIS reports (WRIS 2017, 2019).

3.8. WATERNSW COMMENTS

The Panel was provided by the Department with two documents (WaterNSW 2022b, 2023) in which WaterNSW comment on the water quality performance assessments undertaken by Associate Professor Barry Noller and one document (WaterNSW 2022c) that includes comments on the water quality results in the Metropolitan Coal 2021 Annual Review.

WaterNSW concerns of particular relevance to this advice are:

- Ongoing exceedances of filterable manganese performance indicators (Level 3) for water reaching the reservoir

- 2021 exceedances (Level 3) of water quality indicators for total aluminium, manganese and iron in the Woronora Reservoir (following the WaterNSW letter of 31 Aug 2021 these exceedances have been repeated during 2022)

- Lack of assessment of water quality trends and the impacts of mining on loads

- The potential for more frequent impacts from extreme events as mining footprint increases

- Monitoring and assessment is not rigorous enough to evaluate cumulative impacts on water quality in Woronora Reservoir

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[6] Load rate = concentration x flow. This needs to be calculated continuously over time in order to determine loads, which requires methods of measuring or estimating flow and water quality continuously over time. Lack of measurement or estimation of flows and concentrations at high flows currently precludes the estimation of loads in the mine-impacted areas of the Woronora Reservoir catchment (and other mining-impacted catchments in the Special Areas).

- The inadequacy of performance indicators based on filterable metals
- The potential for water quality impacts beyond the upper reservoir due to reservoir flood hydrodynamics.

3.9. CUMULATIVE IMPACTS ASSESSMENT USING NUMERICAL MODELS

In the current context, cumulative impact assessment can include: 1) analysis of historical trends in water quality to assess whether there is a relation with the development of mining, 2) numerical modelling of historical and future impacts of mining on water quality at the reservoir dam wall, and 3) examination of sediment cores to assess the change in nature of benthic sediments. The need for and applicability of these assessments is addressed in Section 4 of this advice. Some introduction to numerical modelling is given here as background.

Modelling potential impacts of mining on water quality at the reservoir dam wall would require a hydrodynamic and contaminant transport numerical model of the Woronora Reservoir. Such models are widely used to support understanding of water quality variability over time and space, to predict risks from environmental changes, and to help identify sediment and water quality management options. A hydrodynamic model simulates the details of how flow moves through the reservoir over time, including the effects of incoming surface and groundwater flows, wind effects and vertical stratification. A contaminant transport model simulates how the relevant contaminants are carried with the flow and their physical and chemical transformations, including transformations between dissolved and particulate states and exchanges between the water and the sediments. The validation of such a model, which is essential to have good confidence in its results, generally requires specific monitoring of reservoir flows, temperature and water chemistry in addition to the routine monitoring that has been undertaken historically. The modelling would also require estimates of flow and contaminant loads at all inflow points.

A hydrodynamic and contaminant transport model does not exist for Woronora although WaterNSW advised that such models exist or are under development for a number of the water supply reservoirs and one is planned for Woronora, with its development underway in the current financial year (2023-2024). WaterNSW has the capacity to employ these models for operational and strategic purposes, including predicting spatial and temporal variations of contaminants in response to loading events, with a recent example in Rumman et al. (2023). These models, if developed considering the relevant physical and chemical processes (including storage and release of metals from sediments under anoxic conditions), have the capacity to estimate how loads of metals associated with mining are translated to the concentrations of metals and other contaminants at the drinking water off-take. They do not have the capacity to estimate the input loads, which must be based on measurements and scenarios.

4.0 PANEL ADVICE

4.1. ASSESSMENTS AGAINST WATER QUALITY PERFORMANCE MEASURES

The Assessments Against Water Quality Performance Measures, and whether the justifications and conclusion that the water quality performance measure for Woronora Reservoir have not been exceeded are reasonable

There are two relevant water quality performance measures to consider: 1) *Negligible reduction to the quality or quantity of water resources reaching the Woronora Reservoir*; 2) *Negligible reduction in the water quality of Woronora Reservoir*. The associated performance indicators are listed in Section 3.6 of this advice.

Assessment against the performance measure for water reaching the reservoir

To assess whether *the justifications and conclusion that the water quality performance measures for Woronora Reservoir have not been exceeded are reasonable* requires careful consideration of both the performance indicators used and the criteria used to assess whether *reduction to the quality of water resources reaching the Woronora Reservoir* is "negligible". The definition of "negligible" in the Project Approval is "*Small and unimportant, such as not to be worth considering*".

The parameters considered for the creek water quality performance indicators are filterable (field filtered using 0.45 μm filter) iron, manganese and aluminium.

The case of manganese is considered first. While the Panel has not re-analysed the extensive water quality data set that is now available for sites ETWQ AU, WRWQ9 and control site WOWQ2, HEC (2022) and previous assessments concluded that exceedances in filterable manganese concentrations at site ETWQ AU and the lack of exceedances at the control site equated to a Level 3 trigger. This triggered the assessment against the performance measure conducted by Associate Professor Barry Noller of The University of Queensland.

In his reports regarding manganese (e.g. The University of Queensland 2022), Associate Professor Noller notes that low levels of filterable manganese, e.g. <0.1 mg/L, exist in the natural creek water but comments that, while increases in manganese concentrations in the Eastern Tributary have been observed as a result of the transfer of soluble manganese from groundwater to surface water through mine-induced subsidence and cracking, values at ETWQ AU and at the various monitoring sites in the mixing zone[7] have been below the ADWG health limit of 0.5 mg/L except for occasional observations above this ADWG value. In drier years prior to 2022, in particular 2018, manganese concentrations at ETWQ AU were considerably higher, up to approximately 2.8 mg/L (Figure 6 below); nevertheless, manganese concentrations in the mixing zone have been, with some exceptions, below 0.5 mg/L. The dilution of high concentrations as the flow moves from the Eastern Tributary at ETWQ AU to the mixing zone at ETFSL 100 and ETFSL 200 is illustrated in Figure 7 below.

The series of assessments from 2018 to 2022 (e.g. The University of Queensland 2018, 2022) consistently conclude that "*Manganese concentrations are easily diluted by freshwater flow to low levels when higher creek flows occur*" and "*The watercourse performance measure, Negligible reduction to the quality of water resources reaching the Woronora Reservoir, is not considered to have been exceeded*".

Regarding whether or not the justifications and conclusions presented in the performance assessments are reasonable for manganese, the Panel has considered the following issues.

[7] The mixing zone is where the creek water is mixed with the upper reservoir water represented by Peabody monitoring sites ETFSL 0, ETFSL 200, ETFSL 500, WDFS1, WDFS1 +100, CONFLU1 and WARARM5 in Figure 2

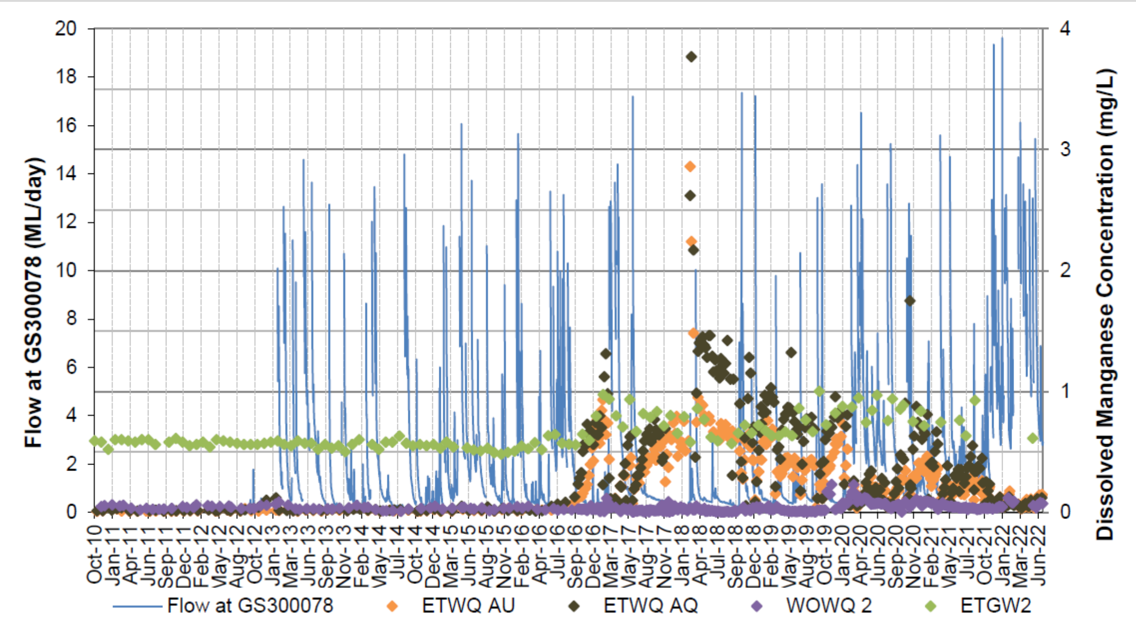

Figure 6. Chart 2 from The University of Queensland (2022): Dissolved Manganese Concentrations at Surface Water Quality Sites ETWQ AU, ETWQ AQ and WOWQ 2 and Groundwater Quality Site ETGW2, and Stream Flow at ETWQ AU (to 30 June 2022)

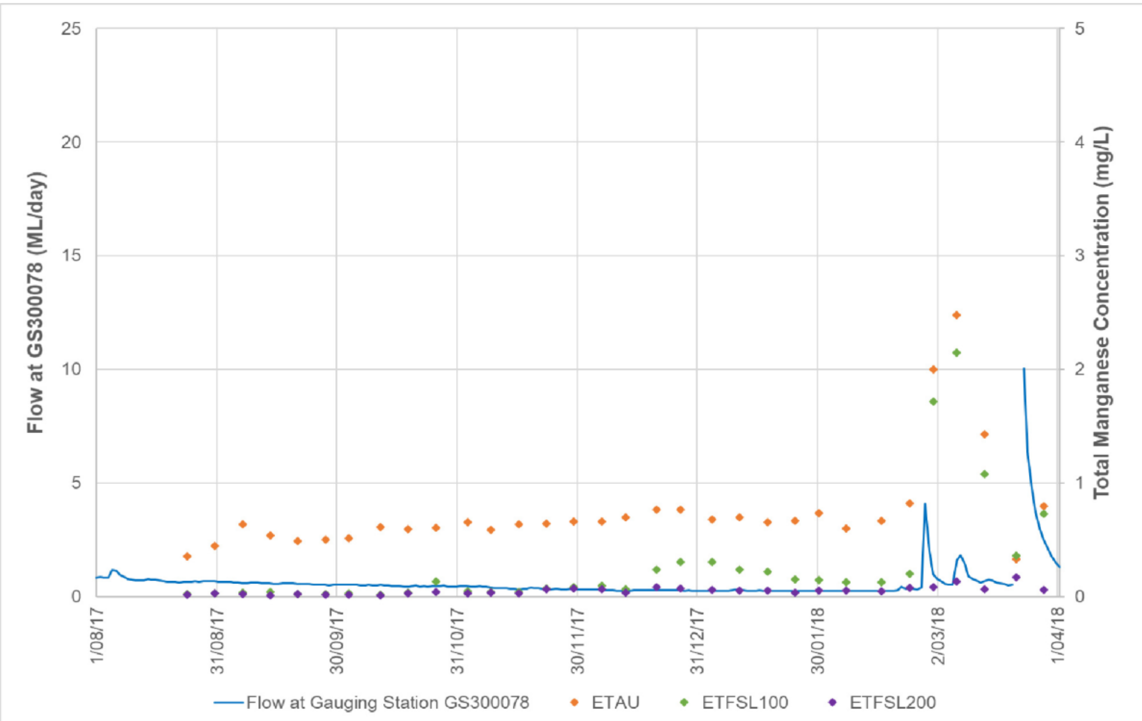

Figure 7. Chart 4 of The University of Queensland (2018): Total Manganese Concentrations at Surface Water Quality Sites ETWQ AU, ETFSL 100 and ETFSL 200 and Stream Flow at ETWQ AU (August 2017 to 31 March 2018)

1. The Water Quality Incident Management protocols and RWSA that define the operational targets and trigger levels of WaterNSW are relevant to the operation of the WFP, and therefore the Panel considers them to be relevant to determining the significance of mining impacts. In particular, the Panel considers that any impact that contributes to concentrations at the off-take point (i.e., at the dam) rising above the alert levels should be treated as a non-negligible impact. The main criterion used in the assessment reports (e.g. The University of Queensland 2022) for manganese is the ADWG limit of 0.5 mg/L, which is considerably higher than the alert level of 0.02 mg/L for filterable manganese.

2. It is unknown how a concentration measured near the entrance to the reservoir (i.e., ETWQ AU, WRWQ9 and the sites in the mixing zone), and the potential accumulation of contaminants in the reservoir sediments, can translate to raw water supply quality at the Woronora dam off-take point some 10 km further downstream. The ADWG criterion applied in the assessment reports for determining a negligible impact might be conservative due to the large potential for dispersion and dilution of manganese between the mixing zone and the dam; on the other hand, it does not consider the potential for manganese to accumulate in the reservoir sediments and subsequently to be released from the sediments and contribute to disruptive events such as that beginning in July 2022.

3. The significance of the impaired water quality reaching the reservoir can only be fully determined using loads as well as concentrations, together with an appropriate hydrodynamic and contaminant transport model to calculate how loads propagate to concentrations at the off-take point, including consideration of cumulative impacts.

4. The persistence of elevated manganese concentrations entering the Woronora Reservoir since, at least, 2017 raises concerns about cumulative impacts, which requires improvement of the assessment approach as addressed in Sections 4.2-4.5 of this advice.

The Panel concludes that the assessment reports presented by Peabody from 2018-2022 and the Peabody Annual Reviews are not based on sufficient data and analysis and therefore do not provide sufficient justification and reasonable conclusions. The assessments do not adequately consider the significance of the impaired water quality (including cumulative impacts) to the ability of WaterNSW to meet the RWSA and Water Quality Incident Management trigger levels. The Panel recognises the significant additional monitoring and modelling that would be required for a fuller assessment and there are associated challenges and uncertainties, which are addressed in Sections 4.2-4.5.

Each of the four points and the conclusion above also apply, in general terms, to aluminium and iron. For these two parameters, there have been occasional level 3 triggers at either ETWQ AU or WRWQ9 during the period 2018-2022 (e.g. HEC 2022, The University of Queensland 2018). These triggers have been based on measurements of filterable iron and filterable manganese although the subsequent assessments of concentrations in the mixing zone sites have included total as well as filterable iron (e.g. The University of Queensland 2018). The Panel emphasises the need for measurement and assessment of both total and filterable concentrations of these elements at all water quality sites (as addressed further in Section 4.2 below). This is particularly the case for iron in view of the possibility that particulate iron oxyhydroxides, the major form of iron present in waters reaching the reservoir, may subsequently undergo reductive dissolution if/when reservoir sediments experience low oxygen conditions (as is likely under thermally stratified conditions in summer) and contribute to an increase in iron concentrations within the reservoir. As emphasised in Section 4.2 below, the measurement of total concentrations of iron, aluminium and manganese will also be critical to obtaining a reliable estimate of total loads of these elements transported to the reservoir.

Assessment against performance measure for the reservoir

The water quality performance measure for Woronora Reservoir is that *changes in the quality of water in the Woronora Reservoir are not significantly different post-mining compared to pre-mining concentrations*. As prescribed in Table 26 of Peabody (2022) (reproduced in Table 5 above), the water quality performance measure for Woronora Reservoir is quantified by determination of the percentage of time that total concentrations of iron, aluminium and manganese for any particular year are above the 10 and 20 year average recurrence interval (ARI) exceedance curves with increasing incidence of exceedances defining the Levels 1, 2 and 3 triggers. Exceedances of these triggers results in the requirement for particular actions by Peabody as described in Table 26 of Peabody (2022). Assessment against this water quality performance measure for Woronora Reservoir is presented in the six-monthly and annual surface water review reports (e.g. HEC 2022). HEC (2022) states that "*Total iron exceeded the baseline 10 Year exceedance curve for 100% of the review period and marginally exceeded the baseline 20 Year ARI exceedance curve for approximately 92% of the review period (refer Chart 32). Total aluminium exceeded the baseline 10 Year and 20 Year ARI exceedance curves for 100% and 85% of the review period respectively (Chart 33). Total manganese exceeded the baseline 10 Year exceedance curve for 100% of the review period and marginally exceeded the baseline 20 Year ARI exceedance curve for approximately 31% of the review period (Chart 34). The results for total iron, total aluminium and total manganese equate to a Level 3 significance*."

Implementing the Level 3 exceedance actions (listed in Table 5 above), HEC (2022) concluded that reasonably similar trends in total iron, aluminium and manganese concentrations were observed in Woronora, Nepean and Cataract Reservoirs through 2022. HEC also compared total aluminium, iron and manganese concentrations with the Water Quality Incident Management trigger levels (Table 1 above) and concluded that:

- The water quality standard applicable for (total) aluminium of 0.4 mg/L was slightly exceeded from March to October 2022
- The water quality standard applicable for (total) iron of 1.0 mg/L was not exceeded during 2022
- The water quality standard applicable for (total) manganese of 0.1 mg/L was not exceeded during 2022.

On the basis of these analyses, HEC advised that the Performance Measure of "*Negligible reduction in the water quality of Woronora Reservoir*" had not been exceeded.

In providing advice on compliance with this Performance Measure, the Panel has taken into account the advice from Sydney Water Corporation that operators of the Woronora Filtration Plant have experienced difficulty in operating the plant at outputs above the minimum of 40 ML/day since mid-2022 with this difficulty associated with the high sediment and natural organic matter (NOM) content of incoming raw water from Woronora Reservoir.

In assessing the extent of potential challenges associated with maintenance of water of good quality in Woronora Reservoir, the Panel has considered WaterNSW's Water Quality Incident Response Protocol (WaterNSW 2021a) (a partial list of incident trigger levels is provided in Table 1). Increased incidence of exceedances of the alert, minor or major response levels provides a clear indication of deterioration of reservoir water quality as a result of either natural or man-made phenomena or both.

While it is likely that high rainfall in the Woronora Reservoir catchment and resultant increase in transport of sediment and dissolved materials (such as natural organic matter and manganese) has contributed to the increase in number of water quality exceedances in recent years, the Panel is unable to rule out the possibility, on the basis of the information provided, that mining-related activity may have also been a contributing factor.

In summary, the assessment of HEC (2022) is not sufficient in that water quality during 2022-2023 (and during other periods historically) has been poor and caused significant water treatment and water supply operational complications, and the contribution of mining to this is yet to be determined. The Panel considers that the depth of analysis provided in the annual and six-monthly reports (e.g. HEC 2022), while significant, is incommensurate with the impacts and the uncertainty regarding mining's potential contribution to these impacts and their consequences. Advice on further assessment is provided in Section 4.3.

4.2. PERFORMANCE INDICATORS

Whether the performance indicator for negligible reduction to the quality of water resources reaching the Woronora Reservoir defined in WMPs is appropriate

Due to the potential for particulate forms of Fe, Mn and Al to be transported into the reservoir and thereafter be transformed into filterable forms (see the description of mechanisms in Section 3.5 of this advice) and due to the relevance of total Fe, Mn and Al for the WaterNSW Water Quality Incident Response Protocol, the performance indicators and associated trigger levels should be assessed using total Fe, Mn and Al where sufficient baseline data exist. Sufficient baseline data should be ensured for future mining areas. Both total and filterable metals concentrations should be reported in six-month and annual reports.

The descriptions of the performance indicators and trigger levels for ETWQ AU and WRWQ9 in Table 24-A of Peabody (2022) (Table 3 above) are satisfactory, although will need to be reviewed where performance indicators are changed to use of total metals concentrations. The Panel emphasises the importance of also considering loads for impacts assessment and six-monthly and annual reporting when supporting data sets become available (see advice in 4.3); however, data limitations mean that the reliance on concentrations for monthly assessment of performance indicators and associated trigger levels is appropriate for the current series of longwalls.

The performance indicator for the reservoir (comparison of ARI curves for total Fe, Mn and Al) and associated trigger levels are appropriate. As noted above, the assessment of the performance indicators against the performance measures has not been sufficient.

4.3. MONITORING, ANALYSIS AND ASSESSMENT

Whether additional water quality monitoring, analysis and/or assessment is required to further determine compliance with the water quality performance measure for Woronora Reservoir

Additional water quality monitoring

Flow event water quality (including filterable and total Fe, Mn and Al) using automatic samplers at ETWQ AU, WQWQ9 and WOWO2 should be obtained to support analysis of loads. At the same sites, continuous measurements of electrical conductivity, pH, redox potential, and turbidity should be obtained. This is required to understand water quality impacts at high flows and to estimated metal loads. It is recommended that Peabody develop a monitoring plan in consultation with WaterNSW. The plan should include additional sites that will allow BACI (Before-After-Control-Impact) analysis of concentrations and loads to be applied to creek sites in potential future mining areas.

It is recommended that temperature and water quality data be obtained at various depths through the water column in the upper reservoir (at a location such as WDFS1 that is downstream of the entry of both the Waratah Rivulet and Eastern Tributary as shown in Figure 3) to capture both the temperature stratification behaviour and the water quality at this point. Time series analysis of this information should be used in assessing the possible impact of increased loads of metals resulting from mining on reservoir water quality at this location. These data will also be of value in calibrating and validating a hydrodynamic and contaminant transport model of the reservoir that would assist in assessing whether increased concentrations of filterable and particulate metals, that may arise as a result of mining, impact the quality of feed waters to the Woronora Filtration Plant (see Section 4.5).

Reservoir sediment sampling

Diversion of surface water and groundwater through mining-induced rock fractures and subsequent discharge of contaminated water containing elevated concentrations of iron and manganese into creeks and then into the reservoir would be expected to result in an accumulation of freshly deposited iron and manganese oxyhydroxides in benthic sediments in Woronora Reservoir. As noted earlier, freshly deposited particulate oxyhydroxides of iron and manganese are likely to be more reactive and more readily mobilised on onset of low oxygen conditions than the more crystalline (and thus less reactive) forms of these elements that are intrinsically present naturally in the sediments. While the iron and manganese minerals deposited to the sediments in the upper reaches of the reservoir may not necessarily lead to increased exceedances of alert levels for these elements at the offtake point to the WFP, the Panel is of the view that there would be value in improved understanding of the extent of any increase in iron and manganese concentrations in reservoir sediments as a result of mining through the procurement and subsequent analysis of sediment cores at selected locations downstream of the confluence of Waratah Rivulet and Eastern Tributary with the reservoir. An advantage of analysis of sediment cores is that it can provide a historical record of changes to inputs to the reservoir though it should be recognised that increased inputs are likely to be associated with both high rainfall events and, possibly, increased loads of iron and manganese as a result of mining.

Improved high flow estimation

A constraint in estimating loads is the uncertainty in high flow rates measured at the Eastern Tributary and Waratah Rivulet flow gauges. For example, the rating curve for the Waratah Rivulet indicates that maximum accurately measured flow (approximately 17,000 L/s) is less that the maximum estimated flow (230,000 L/s)[8]. The Eastern Tributary flow gauge is accurate up to a flow rate of 235 L/s, while flows have been estimated up to approximately 2,000 L/s (see IEAPM 2023).

Suitable methods for improving the extension of the Eastern Tributary rating curves should be undertaken by Peabody. WaterNSW should review whether the extension of the rating curve at the Waratah Rivulet could be improved. Selected watercourses in future mining areas should have flow gauges installed with, as far as practicable, validated rating curves. For flow gauges in the small tributaries, it may be impractical to extend rating curves to high flows, and alternative methods of high flow estimation may be required (rainfall-runoff modelling).

Additional analysis and assessment

When reservoir water quality passes a level 3 trigger, more detailed analysis of the reservoir water quality should be undertaken to help determine whether the consequences of subsidence impacts have been negligible. This more detailed analysis should include:

i) data collected at various depths at DW01 (i.e., at the vertical profiler),

ii) data collected at various depths at Woronora Reservoir at DWO_THMD (Honeysuckle Creek Junction),

iii) once installed, data collected at various depths at WDFS1 (Figure 3) (or similar site representing the confluence of the Eastern Tributary and Waratah Rivulet arms of the reservoir),

iv) iron and manganese concentrations in reservoir sediments.

Similarly, when water quality reaching the reservoir at performance indicator sites surpasses a level 3 trigger, analysis should be extended to:

i) once installed, data collected at various depths at WDFS1 (Figure 3) (or similar site representing the confluence of the Eastern Tributary and Waratah Rivulet arms of the reservoir),

[8] Rating curve and maximum flow estimate is from the Waratah Rivulet entry on https://realtimedata.waternsw.com.au/

ii) if available, metal load estimates (see below).

iii) if available, reference to results of a lake hydrodynamic and contaminant transport model (see Section 4.5).

After a database of flow and concentration measurements has been built up, analysis should be conducted towards generalisation of flow-(total metal) concentration relationships, and approximation of loads, and whether these have changed as mining has progressed. Initial results including total Fe, Al and Mn loads at ETWQ AU, WQWQ9 and WOWO2 should be reported in the 2024 Annual Report, and updates provided in subsequent annual reports. The same reports should be provided for water quality performance indicator sites in future mining areas. BACI analysis should be undertaken as far as permitted by data.

For both flow and load estimation, the Panel acknowledges that high accuracy is not achievable for high flows; furthermore, there is a lack of baseline data covering historical longwall mining in the catchment, which started in 1995 (measurement of water quality at site ETWQ AU commenced in 2010, while at WQWQ9 it commenced in 2006 though measurements elsewhere in the Waratah Rivulet date back to 2001). For these reasons a BACI analysis will have limited applicability to determining cumulative impacts of mining in the Eastern Tributary and Waratah Rivulets, and smaller catchments being undermined as part of the 300 longwall series. Furthermore, estimation of loads from current mining areas will be limited by difficulty of monitoring flows and water quality in the smaller and less accessible tributaries of the reservoir. Nevertheless, approximate estimates of loads and mining impacts on loads from these catchments will support scenario analysis to assess whether water quality risks from mining are potentially significant for the operation of the reservoir and WFP. Application of load estimates to future mining areas including baseline periods and control sites will allow a complete BACI analysis based on loads as well as concentrations.

4.4. MITIGATION AND MANAGEMENT OF WATER QUALITY IMPACTS

Whether any further reasonable and feasible actions to mitigate and manage water quality impacts are considered necessary, beyond the existing requirements to continue implementing monitoring and management programs

A significant program of remediation (grouting of fractures) in the Waratah Rivulet and Eastern Tributary has contributed and continues to contribute to the sealing of fractures and reducing subsidence-induced contamination. The Panel expects this program to continue to have positive impacts on contaminant loads to the reservoir. However, because the grouting cannot and does not aim to seal all fractures that interact with the surface flows, the Panel does not expect the remediation to return concentrations or loads of metals to pre-mining values. Some fractures may self-seal due to accumulation of oxidised contaminants and other particles.

At this time, the Panel does not advise additional mitigation and management measures (aside from the monitoring and analysis recommended above) beyond the ongoing grouting plan. Depending on future water quality trends, there may be a need for mitigation and management measures by WaterNSW and Sydney Water, which might include expansion of reservoir de-stratification and adjustments to the WFP operation. Depending on future water quality trends and the degree of attribution to mining, there may also be a need for mitigation and management measures by Peabody in forms of changing the nature of water quality trigger levels, expansion of the remediation program, and changes to mine plans.

4.5. CUMULATIVE IMPACT ASSESSMENT

Whether a cumulative impact assessment study is considered necessary to review water quality trends and potential impacts on drinking water supply from increased metals loads from the catchments impacted by mine subsidence at Metropolitan Mine.

As previously noted, although there are natural influences on water quality that might explain the observed variations in water quality including the extreme event in July 2022, the Panel cannot rule out the possibility that the Metropolitan Mine has had a significant adverse impact based on the existing analyses in Annual Reports. The Panel recommends that a more detailed analysis be undertaken of historical reservoir water quality (including control sites in reservoirs not affected by mining) in order to analyse potential trends and relations with mining development**.** This should be included in the 2023 Annual Review and updated in subsequent annual reviews.

As noted earlier, analysis of cores of reservoir benthic sediments can provide a historical record of changes to inputs to the reservoir and represents one of the few ways of assessing cumulative changes. It should be recognised however that increased inputs are likely to be associated with both high rainfall events and, possibly, increased loads of iron and manganese as a result of mining. Also, it should be emphasised that any increase in the extent of iron and manganese minerals deposited to the sediments in the upper reaches of the reservoir may not necessarily lead to increased exceedances of alert levels for these elements at the offtake point to the WFP. Despite this, the Panel is of the view that such information would add to general understanding of potential impacts of mining on reservoir water quality.

Development and application of a hydrodynamic and contaminant transport model may be useful to inform assessments required by level 3 trigger exceedances (either those for water entering the reservoir, or those for water in the reservoir). The model results could support determination of whether a measured or estimated increase in metal loads due to mining affects the current or future ability of WaterNSW to meet raw water supply agreements. It would also allow testing of hypotheses that measured changes in water quality in the reservoir are attributable partially to mining. The Panel understands that WaterNSW is commissioning a hydrodynamic and contaminant transport model for the Woronora Reservoir in the 2023-2024 financial year. Due to the catchment and reservoir data sets required, and knowledge of catchment and reservoir operations required, it is unlikely to be sensible for Peabody to undertake an independent hydrodynamic and contaminant transport analysis. It is recommended that a model set-up is designed to support assessments of potential mining impacts with consideration of how the responsibility for the modelling is shared between stakeholders. For example, the model may be run over a long time-frame to capture potential effects of historical, current and future mining, updated every year to allow for advances in data (in particular load estimates). Peabody could refer to the model results when assessments against performance measures are required.

4.6. OTHER MATTERS

Strategic water quality risks

As noted by the IEPMC (2019), there are strategic risks to water quality in the Special Areas related to the cumulative and long-term consequences of mining subsidence. These arise from:

- The potential for cumulative consequences of historical, current and future mining areas on reservoir water and sediment quality.

- The potential for widespread mobilisation of contaminants from subsidence-induced fractures if regional groundwater levels and pressures increase. This could occur if voids (such as roadways and adits) are sealed following mining, or due to wet weather increasing groundwater levels and pressures beyond those seen during the mining period. Increasing groundwater pressure has the potential to drive groundwater to surface water through fractures that have not previously been flushed of contaminants.

The current advice partially addresses these concerns for the Woronora reservoir by recommending monitoring and analysis that supports a better understanding of the contaminant loads from longwall mining areas of the catchment, improved capability to predict the consequences for water quality supplied to the WFP and better baseline data and modelling capability for assessing future mining proposals. The Panel emphasises the recommendation of the IEPMC (2019) that a broad study is needed of long-term cumulative impacts of mining on water quality in the Special Areas. While some elements of this are addressed in this advice, there are other considerations that may affect long-term water quality management that need considered for Metropolitan mine (including post-mining monitoring design, closure and post-closure planning, and groundwater and hydrogeochemical modelling).

The Dupen (2023) report

The Dupen (2023) report raises concerns that unforeseen impact mechanisms are having adverse consequences for hydrology, ecology and water quality in the Woronora catchment. In the IEAPM's advice to the Department on the Dupen (2023) report (IEAPM 2023), matters related specifically to water quality were deferred to this advice.

Dupen (2023) put forward the views 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.*

As discussed elsewhere in this advice, the Panel advises that there is a risk that mining-induced fracturing has and will continue to have adverse consequences for the Woronora Reservoir water quality. Further, the Panel considers that, if the increased flow rates associated with the Dupen hypothesis are due to the formation of large-scale shear planes then this is expected to result in an increased load of contaminants entering the Woronora reservoir. Indeed, the unexplained high flows from April 2020 to late 2022 (the latter being the end of the data period presented in Dupen 2023) combined with the elevated Mn concentrations in Figure 6 above raise concern and illustrate the need in future for loads to be assessed as well as concentrations. However, if contaminant load estimation at site ETAU WQ indicates an increased load of Mn, Fe or Al, this could be caused by increased flow though fractures underlying the creek or an increased discharge of regional groundwater by natural pathways and would not by itself confirm the Dupen hypothesis. If further investigation of the source of the increased flows is required (the reader is referred to the IEAPM (2023) for recommendations on this), the use of chemical and physical tracers of regional groundwater discharge should be considered as an element of that analysis.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The quality of the Woronora Reservoir (and during other periods historically) has been poor during 2022-2023 and has led to significant complications for water treatment and water supply. Although there are natural influences on water quality that might explain the observed variations in water quality, the Panel cannot rule out the possibility that the Metropolitan Mine has had an adverse impact.

While dissolved forms of iron, manganese and aluminium (Fe, Mn and Al) are of primary relevance to raw water quality, there is potential for particulate forms to be transported from the catchment into the reservoir and thereafter, in the case of Fe and Mn, be transformed into dissolved forms. Hence, total (dissolved plus particulate) Fe, Mn and Al concentrations are relevant and the reliance on dissolved Fe, Mn and Al concentrations in the Metropolitan Mine performance indicators is unsatisfactory.

The assessments of the quality of water reaching the Woronora Reservoir presented by Peabody in response to level 3 triggers are not based on sufficient data and analysis and therefore do not provide sufficient justification and reasonable conclusions. The assessments do not adequately consider the potential significance of the impaired water quality for the WaterNSW Raw Water Supply Agreement and Water Quality Incident Management trigger levels.

The assessments of the quality of water in the Woronora Reservoir are not based on sufficient data and analysis and therefore do not provide sufficient justification and reasonable conclusions. The Panel considers that the depth of analysis provided in the annual and six-monthly reports, while significant, is incommensurate with the uncertainty regarding mining's potential contribution to the degraded water quality and incommensurate with the consequences of the degradation in terms of the ability of WaterNSW to meet the Raw Water Supply Agreement and in terms of the disruption to operation of the Water Filtration Plant (WFP).

Aside from the need to transition to the use of total metals, the existing descriptions of the performance indicators and trigger levels for the Eastern Tributary and Waratah Rivulet are satisfactory. They will need to be reviewed when and where performance indicators are changed to the use of total metals concentrations.

The performance indicators and trigger levels for the reservoir (which use total Fe, Mn and Al concentrations) are appropriate, although should be subject to annual review.

The significance of the impaired water quality reaching the reservoir can only be fully determined using contaminant loads (concentration x flow rate) as well as concentrations because high loads can coincide with low concentrations and vice-versa. Improved high flow data and flow event water quality is required to understand water quality impacts and to estimate contaminant loads.

Due to data constraints and monitoring practicalities, analysis of contaminant loads will have limited applicability to determining cumulative impacts of mining in the Eastern Tributary and Waratah Rivulets and other catchments that are being undermined as part of the 300 longwall series. Nevertheless, approximate estimates of loads from these catchments will support scenario analysis to assess whether water quality risks from mining are potentially significant for the operation of the reservoir and WFP. Application of contaminant load estimates to future mining areas including baseline periods and control sites will allow a complete Before-After-Control-Impact (BACI) analysis based on loads as well as concentrations.

An appropriate hydrodynamic and contaminant transport model will support determination of whether a measured or estimated increase in metal loads due to mining affects the current or future ability of WaterNSW to meet raw water supply agreements. It would also allow testing of hypotheses that measured changes in water quality in the reservoir are attributable partially to mining. WaterNSW is planning to implement such a model for the Woronora Reservoir in the 2023-2024 financial year. Due to the catchment and reservoir data sets required, and knowledge of reservoir operations required, it is unlikely to be sensible for Peabody to undertake an independent hydrodynamic and contaminant transport analysis.

Temperature and water quality data obtained at various depths through the water column in the upper reservoir would capture both the temperature stratification behaviour and the water quality at this point. As well as supporting assessments of whether changes in the water quality reaching the reservoir have been non-negligible, these data will be of value in calibrating and validating a hydrodynamic and contaminant transport model of the reservoir.

There would be value in improved understanding of the extent of any increase in iron and manganese concentrations in reservoir sediments. Sediment cores can provide a historical record of changes to inputs to the reservoir though it should be recognised that increased inputs are likely to be associated with both high rainfall events and, possibly, increased loads of iron and manganese as a result of mining.

The program of remediation (grouting of fractures) in the Waratah Rivulet and Eastern Tributary has contributed and continues to contribute to the sealing of fractures and reducing subsidence-induced contamination. The Panel expects this program to continue to have positive impacts on contaminant loads to the reservoir. However, because the grouting cannot and does not aim to seal all fractures that interact with the surface flows, the Panel does not expect the remediation to return contaminant concentrations or loads to pre-mining values.

At this time, the Panel does not advise additional mitigation and management measures (aside from the monitoring and analysis recommended above) beyond the ongoing grouting program.

Long-term risks to water quality in the Special Areas arise from:

- The potential for cumulative consequences of historical, current and future mining areas on reservoir water and sediment composition and quality.

- The potential for widespread mobilisation of contaminants from subsidence fractures if regional groundwater levels and pressures rebound.

The current advice partially addresses these concerns for the Woronora reservoir by recommending monitoring and analysis that supports a better understanding of the contaminant loads from longwall mining areas of the catchment, improved capability to predict the consequences for water quality supplied to the WFP and better baseline data and modelling capability for assessing future mining proposals.

If the unexpectedly high flow rates that have been measured at the Eastern Tributary from early 2020 to late 2022 (which are assessed in detail in a separate report by the IEAPM) are due to increased groundwater discharge through subsidence fractures or shear planes, they may be associated with highly elevated contaminant loads. This illustrates the need for reporting of contaminant loads wherever possible with available data. Furthermore, measurement of the water chemistry of these streams can assist in determining the source of these unexpectedly high flows.

5.2 RECOMMENDATIONS

Performance indicators and associated trigger levels for water reaching the Woronora Reservoir should be assessed using total Fe, Mn and Al where sufficient baseline data exist. Both total and dissolved Fe, Mn and Al concentrations should be reported in six-month and annual reports.

Contaminant loads as well as concentrations should be considered in performance measure assessments and six-monthly and annual reporting as far as data allow. Current data limitations mean that reliance on concentrations for monthly assessment of performance indicators is appropriate for the current series of longwalls.

Flow event water quality (including dissolved and total Fe, Mn and Al concentrations) using automatic samplers at ETWQ AU, WQWQ9 and WOWO2 should be obtained to support analysis of contaminant loads. At the same sites, continuous measurements of electrical conductivity, pH, redox potential, and turbidity should also be obtained.

After a database of flow and concentration measurements has been built up, analysis should be conducted towards generalisation of flow-concentration relationships, and approximation of loads, and whether these have changed as mining has progressed. Initial results including total Fe, Al and Mn loads at ETWQ AU, WQWQ9 and WOWO2 should be reported in the 2024 Annual Report and updates provided in subsequent annual reports. Load estimates should be provided in future Annual Reports for performance indicator sites in future mining areas.

For future mining areas, flow and contaminant concentrations should be measured at least two years in advance of mining at impact and control sites to allow BACI analysis.

Suitable methods for improving the extension of the Eastern Tributary rating curves to improve high flow measurement accuracy should be undertaken by Peabody. WaterNSW should review whether the extension of the rating curve at the Waratah Rivulet could be improved. Selected watercourses in future mining areas should have flow gauges installed with validated rating curves. Where it is impractical to extend rating curves to high flows, alternative methods of high flow estimation should be considered.

Temperature and water quality data should be obtained at various depths through the water column in the upper reservoir (at a location such as WDFS1 that is downstream of the entry of both the Waratah Rivulet and Eastern Tributary) to capture both the temperature stratification behaviour and the water quality at this point. Frequency of data collection should increase following significant flow events and following level 3 triggers for water quality reaching the reservoir.

It is recommended that an agreement be reached whereby a hydrodynamic and contaminant transport model set-up is designed to support assessments of potential mining impacts. Consideration should be given as to how the responsibility for the modelling is shared between WaterNSW and Peabody.

Peabody should procure sediment cores at selected locations downstream of the confluence of Waratah Rivulet and Eastern Tributary within the reservoir and at control sites in the reservoir in order to assess the possible impacts of mining on alterations to sediment composition (with implications to possible mobilisation of Fe and Mn should these sediments become anoxic).

When quality of water reaching the reservoir at performance indicator sites surpasses a level 3 trigger, analysis should be extended to:

- once installed, water quality data collected at various depths at WDFS1 or similar site representing the confluence of the Eastern Tributary and Waratah Rivulet arms of the reservoir,
- if available, contaminant load estimates,
- if available, reference to results of a lake hydrodynamic and contaminant transport model run using relevant scenarios of increased contaminant loads.

In any future mining areas, performance indicators and triggers should be based on loads as well as concentrations.

When reservoir water quality passes a level 3 trigger, more detailed analysis of the reservoir water quality should be undertaken including:

- data collected at various depths at DW01 (i.e., at the vertical profiler),
- data collected at various depths at Woronora Reservoir at DWO_THMD (Honeysuckle Creek Junction),
- once installed, data collected at various depths at WDFS1 (Figure 3) (or similar site representing the confluence of the Eastern Tributary and Waratah Rivulet arms of the reservoir),
- iron and manganese concentrations in reservoir sediments.

Irrespective of these recommendations for further analysis in response to triggers, the Panel recommends that a more detailed analysis be undertaken of historical reservoir water quality and sediment cores in order to analyse potential trends and relations with mining development. This should be included in the 2023 Annual Review and updated in subsequent annual reviews.

Following IEPMC (2019), it is recommended that a broader study of potential long-term cumulative impacts of mining on water quality in the Special Areas is needed.

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