Independent Expert Panel for Mining in the Catchment

Initial report on specific mining activities at the Metropolitan and Dendrobium coal mines

12 November 2018

Mr Marcus Ray
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Planning Services
NSW Department of Planning and Environment
320 Pitt Street
SYDNEY NSW 2000

Dear Mr Ray

Initial report from the Independent Expert Panel for Mining in the Catchment

In November 2017 the NSW Government established the Independent Expert Panel for Mining in the Catchment to provide expert advice to the Department of Planning and Environment on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a particular focus on risks to the quantity of water in the catchment.

This initial report from the Panel addresses the first Term of Reference, drawing on a review of previous reports and inquiries, site visits and a limited number of presentations provided to gain an understanding of current activities as well as the history of the two mines that are the subject of this report, the Dendrobium Mine and the Metropolitan Mine. The Panel has also had regard to submissions made to date.

It is worth emphasising that this is an initial report focusing on the two mines noted above, with the final report addressing Term of Reference 2 to cover mining activities and effects across the Catchment as a whole.

A limited number of recommendations are made, particularly dealing with technical considerations that would inform longwall and mine design and approvals, monitoring and performance. For the most part, the Panel thought it appropriate to first consult and seek submissions on observations made in this report before reaching final conclusions. This will be a major focus for the next period of work and reflected in the Final report.

Yours sincerely

Emeritus Professor Jim Galvin
Chair, Independent Expert Panel for Mining in the Catchment
12 November 2018

EXECUTIVE SUMMARY

The Independent Expert Panel for Mining in the Catchment was established in late February 2018 to provide informed expert advice to the NSW Department of Planning and Environment on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a focus on risks to the quantity of water.

The Panel's first Term of Reference required it to undertake an initial review and provide advice to government focused on the mining activities of Dendrobium Mine and Metropolitan Mine in the Special Areas, having regard to other relevant studies and reports including the 2016 Audit of the Sydney Drinking Water Catchment and the PSM Height of Cracking – Dendrobium Area 3B study. This report constitutes that initial response, although some issues originally envisaged to fall under Term of Reference 2 have also needed to be considered in order to properly inform the Panel and the reader and to contextualise the Panel's observations and findings.

The report is intended to prompt submissions to assist the Panel in addressing Terms of Reference 2 and 3, which require it to assess environmental consequences for swamps and cumulative impacts, update the findings of the 2008 Southern Coalfield Inquiry and provide advice to the Department of Planning and Environment as required on mining activities in the Catchment Special Areas.

There is universal agreement that the issues are complex. Some require high level technical understanding and, for this reason, this report is founded on providing an explanation of core concepts related to mining-induced effects on ground deformation and the nature and monitoring of their impacts on groundwater and surface water systems. Only high level findings are presented in this Executive Summary. A complete reading of the detail contained in chapters is needed to understand the full range of the Panel's conclusions and recommendations.

The existing development consent for Dendrobium Mine was granted almost two decades ago and expressly allows mining in Areas 1, 2, 3A, 3B and 3C. The Wongawilli Seam is currently being extracted by longwall mining to a height of 3.7 to 3.95 m at an average depth of around 360 m in Area 3B in the Catchment Special Areas, adjacent to Avon Reservoir. The Panel concludes that performance measures for Dendrobium Mine complemented by a provision to offset impacts to swamps provide considerable scope for maximising mining dimensions. This is reflected in 305 m wide longwall panels, 87% areal extraction, vertical surface subsidence of typically 2.5 to 3 m and a total mine water of about 7.5 ML/day that responds to rainfall.

Metropolitan Mine is currently longwall mining the Bulli Seam to a typical height of 3 m at an average depth of around 460 m in the Special Areas adjacent to Woronora Reservoir, with future longwalls planned to pass under Woronora Reservoir. The performance measures for this mine were approved nine years ago. The mine plan is based on 163 m wide longwall panels on the flanks of Woronora Reservoir, reducing to 145 m beneath the Reservoir but with potential to increase this width. The influence of the greater depth of mining, the narrower longwall panels and the lower extraction height compared to Dendrobium Mine are reflected currently in 78% areal extraction, around 1.1 to 1.2 m of vertical surface subsidence and a total mine water inflow of about 0.5 ML/day that does not respond to rainfall.

There have been major efforts over the last decade by both Dendrobium Mine and Metropolitan Mine to employ up-to-date 3-dimensional groundwater models and best practice modelling methods undertaken by specialists, with expert peer review. The models have continued to improve in accuracy and predictive capacity. However, as with any modelling, limits remain and the assumptions must be scrutinised carefully.

The height of complete groundwater drainage is an important consideration in groundwater modelling and the Tammetta equation and the Ditton equations were developed in Australia for this purpose some 5 years ago. Considerable controversy and confusion surround their predictive capacities in the Catchment Special Areas. The Panel has given detailed consideration to the equations and, notwithstanding that uncertainty is associated with all, recommends erring on the side of caution and deferring to the Tammetta equation until:

i. field investigations quantify the height of complete drainage at the Dendrobium Mine and Metropolitan Mine, and/or

ii. alternative geomechanical modelling of rock fracturing and fluid flow is utilised to inform the calibration of groundwater models.

Since the approval of both mines, advances have been made in the knowledge bases underpinning subsidence, groundwater and surface water. However, some deficiencies and gaps in these knowledge bases have also emerged that are relevant to mines operating in Catchment Special Areas, particularly regarding the impacts on groundwater and surface water of valley closure and the behaviour of lineaments. Valley closure has the potential to cause diversion of drinking water from watercourses and reservoirs, while it still needs to be established if lineaments in the Southern Coalfield could impact on subsidence, groundwater and surface water in similar manners to those identified recently in the adjacent Western Coalfield.

Although a large amount of investigations, modelling and monitoring have been undertaken at Dendrobium Mine, the Panel concurs with the PSM study that, in relation to groundwater, these have been insufficient for the scale and complexity of the technical issues in relation to groundwater. Similarly, it concurs with the 2016 Audit of the Catchment regarding the inadequate availability and quantity of data and monitoring in relation to surface water in general in the Special Areas.

Knowledge of the consequences of mining on surface water quantity in the Catchment Special Areas has progressed substantially over the last 10 or so years but limitations in monitoring and modelling mean that it is still difficult to verify conclusions by some stakeholders that mining has had negligible consequences on surface water supplies. There is considerable scope for mine operators to improve Trigger Action Response Plans to better inform this matter.

The insufficiency, variability and limitations of information restrict the scope and accuracy of calculations of groundwater and surface water diversion from the catchment into mine workings and other storages. The water balance data for the Dendrobium and Metropolitan mines currently rely on rainfall-runoff models (catchment water balance) and groundwater models (groundwater balance), with a minimal amount of work undertaken to date on reservoir water balances. A limitation of these models is that they do not necessarily correspond to the space or time scales relevant for quantifying water losses to the Sydney water supply.

Knowledge of the contribution of swamps to water supplies is also particularly undeveloped due to lack of integrated monitoring targeting swamp water balances.

This initial report draws a wide range of other conclusions and makes a number of recommendations in relation to future investigations and monitoring to better inform groundwater modelling and surface water modelling to quantify mining impacts on water quantity in the Catchment Special Areas.

Supported by its own analysis, the Panel concludes that in the case of Dendrobium Mine:

- water inflow into all four mining areas (Areas 1, 2, 3A & 3B) exhibits some correlation with rainfall, ranging from weak in Area 3B to strong and rapid for Area 2

- it is very likely that the high rate of influx is associated with a connected fracture regime that extends upwards to the surface
- it is plausible that an average of around 3 ML/day of surface water and seepage from reservoirs is currently being diverted into the mine workings
- faulting, basal shear planes and lineaments need to be very carefully considered and risk assessed going forward, especially when planning for further longwall panels to the south of Longwall 16.

In the case of Metropolitan Mine:

- the average daily water inflow of about 0.5 ML/day displays no evidence of a connected fracture regime to surface or correlation with rainfall
- the potential for water be diverted out of Woronora Reservoir and into other catchments through valley closure shear planes and geological structures including lineaments will require careful assessment in the future because it is planned that most of the remaining longwall panels in the approved mining area will pass beneath the reservoir.

Against this background, the Panel endorses the Department of Planning and Environment's approach for dealing with the legacy issues and evolving knowledge base whereby:

- the management plans for longwall panels at Dendrobium and Metropolitan mines are only being approved on an incremental basis that provides for considering existing and emerging information and knowledge gaps that have the potential to jeopardise compliance with performance measures
- conditions are attached to approved Subsidence Management Plans and Extraction Plans that require mine operators to undertake a range of investigations and monitoring and engage independent experts to review and prepare advice to address geotechnical and hydrogeological information and knowledge gaps
- some mining applications are being referred to independent experts and bodies, including the Panel, for advice.

These actions have already gone some way towards responding to the PSM study. Going forward, the Panel recommends that:

- mine design methodologies and procedures that underpin critical aspects of future mining proposals should be supported by robust, independent peer review and/or a demonstrated history of reliability when applications are submitted for approval
- all future applications to extract coal within Catchment Special Areas should be supported by independently facilitated and robust risk assessments that conform to ISO 31000 (the international standard for risk management subscribed to by Australia)
- field investigations and data collection, analysis and reporting need to be based on a standard agreed to by key stakeholders. This is an issue that the Panel is keen to see addressed in submissions.

A range of matters remain to be considered by the Panel, including the cumulative impacts of flow losses and the relative significance of these for water supplies as well as the practicalities associated with establishing a robust regional water balance model. Submissions will be important to providing informed advice on these matters and other issues arising out of this initial report.

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1 INTRODUCTION

In November 2017 the NSW Government established the Independent Expert Panel for Mining in the Catchment (the Panel) to provide expert advice to the Department of Planning and Environment (DPE) on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a particular focus on risks to the quantity of water in the catchment.

Advice is to include, but is not confined to, risks to the total water quantity and holding capacity of surface and groundwater systems, including swamps and reservoirs, and the types and reliabilities and methodologies used to predict, monitor, assess and report on mining effects, impacts and consequences. The full Terms of Reference are at Appendix 1.

Under Term of Reference 1, this initial report focuses particularly on activities at the Dendrobium and Metropolitan coal mines which have workings within the Metropolitan and Woronora Special Areas, respectively, in the Southern Coalfield of NSW.

This is an initial report, reflecting Panel observations arising from reports made available to it, site visits and initial submissions. In addition to a small set of recommendations, uncertainties are highlighted and questions posed. It is intended that stakeholders will consider and provide feedback on these matters, to inform further Panel deliberations and conclusions in its next report.

The Panel recognises the importance of water quality and appreciates some stakeholders will be seeking comment on this. It is important, therefore, to emphasise at the outset that the focus of the first Term of Reference and this initial report is on water quantity. To inform the reader and to contextualise Panel findings and observations, this report anticipates and reports on some matters originally intended for inclusion in the Term of Reference 2 report. These will be expanded upon in that report as appropriate. Regard to a range of reports including those specified in the Panel's Terms of Reference is embedded throughout this document.

The first section of this chapter provides an overview of the catchment and key trends relevant to long-term demand and supply. This is followed by an introduction to the regulatory framework in which mining-related decisions are made.

1.1 THE SYDNEY DRINKING WATER CATCHMENTS

1.1.1 Catchments and Special Areas

Sydney has an extensive drinking water catchment that includes the catchments of the Hawkesbury-Nepean, Shoalhaven and Woronora Rivers (Figure 1). There are five major water supply catchments (Upper Nepean, Shoalhaven, Warragamba, Blue Mountains and Woronora) which drain into a number of dams connected to a network of filtration plants from which drinking water is supplied (Table1).[1]

The major dams, reservoirs and canals used for drinking water supply are surrounded by Special Areas within which access and certain types of activities are restricted to protect water quality and maintain ecological integrity (Figure 1). The Special Areas cover approximately 364,000 hectares (3,640 km^2). The dams and catchment within the Upper Nepean and Woronora catchments are protected by the Metropolitan and Woronora Special Areas respectively. The Upper Nepean and Woronora Catchments overlie the coal measures of the Southern Coalfield.

[1] The Greater Sydney region water supply system includes 21 storage dams and reservoirs (11 major - Avon, Blue Mountains, Cataract, Cordeaux, Fitzroy Falls, Nepean, Prospect, Tallowa, Warragamba, Wingecarribee and Woronora) (WaterNSW, 2015b).

Figure 1: Greater Sydney's Drinking Water Catchment (WaterNSW, 2015a)

Table 1: The Upper Nepean and Woronora Catchment and details of associated dams

Catchment	River	Dam	Customers	Size (km^2)[1]	Storage Capacity (GL)[2]	Current Storage (%)[2]
Upper Nepean	Cataract	Cataract	Sydney, the Macarthur and Illawarra regions	130	97.19	32.8
	Cordeaux	Cordeaux		91	93.64	36.4
	Avon	Avon		142	146.7	59.9
	Nepean	Nepean		320	67.73	51.2
Woronora	Woronora	Woronora	Southern Sydney and northern Wollongong	75	71.79	55.0

[1] (WaterNSW, 2018b)
[2] As at 22 October 2018 (WaterNSW, 2018a)

These two catchments provide about 24% of the water supply for Sydney Water. This statutory body provides water, wastewater, recycled water and some stormwater services to people in Sydney, the Illawarra and Blue Mountains.[2] The Dendrobium Mine underlies the Avon and Cordeaux Catchments in the Metropolitan Special Area; some flow from above the mine also reports downstream at Pheasants Nest weir. The Metropolitan Mine underlies the Woronora Catchment and the Woronora Special Area. Details of the catchments and their associated dams are shown in Table 1.

Special Areas are designated and protected under the *Water NSW Regulation 2013*. The Regulation divides the Special Areas into Schedule 1 lands which includes the Special Areas and Controlled Areas where entry is not allowed and Schedule 2 lands that have restricted access. Approximately 33% of the Metropolitan Special Area and 0.08% of the Woronora Special Area are National Parks reserves (WaterNSW & NSW OEH, 2015) which also have activity restrictions.

'Dam Safety Notification Area' restrictions declared under Section 369 of the *Mining Act 1992* by the NSW Dam Safety Committee to apply to the surrounds of dam infrastructure and their storages due to the risks that dam failure can pose to life and property. The Committee advises on permissible mining activities near dams. There are completed, approved and planned mines in Dam Safety Notification Areas in the Metropolitan and Woronora Special Areas.

1.1.2 Factors relevant to long-term drinking water demand and supply

Long term drinking water demand and supply for Greater Sydney depends on a number of factors. Water in the catchment has many uses including supplying drinking water for Greater Sydney, agriculture, industry and the environment. Cumulative impacts on the catchment can affect the catchments integrity, with consequences for water supply, the associated infrastructure and the environment.

1.1.2.1 Population and Climate

The demand for water in Sydney is primarily (70%) for household purposes (70%, ~295 L/person/day) (Sydney Water, 2018). The population of Greater Sydney is expected to grow by 1.74 million people by 2036, which will increase demand for water from the catchment (Greater Sydney Commission, 2017).

Drinking water supply in Sydney is based on rainfall in the catchments and is captured in dams. Varying climatic conditions, affect inflows from rivers and streams to dams, evaporation levels from stored waters and evapotranspiration on the broader ecosystem. This balance of 'water-in' and 'water-out' influences the quantity of drinking water in the catchment.

[2] The majority of supplies for the Greater Sydney region are treated by Sydney Water, the balance by local Councils (WaterNSW, 2018c).

At the time of this report, 99.8% of NSW is in drought and the Upper Nepean and Woronora catchments have been assessed to be in 'intense drought' (DPI, 2018). This has impacted overall inflows to dams in the state. Dam levels as at 22 October 2018 are at Table 1.

Climate projections for the region surrounding the Upper Nepean and Woronora catchments suggest a long-term warming trend and an annual increase in rainfall (NSW Office of Environment & Heritage, 2018).[3]

The NSW Government is developing plans to meet the requirements of Sydney's growing population and to prepare for uncertainties such as climatic changes, varying demands and droughts, including strategies for water conservation (e.g. water recycling) and restrictions (such as during droughts).[4] During drought, when operational, the Sydney desalination plant can supplement the drinking water supply (~250 ML/day, approximately 17% of current drinking water demand).

1.1.2.2 Cumulative Impacts

Cumulative impacts are the combined effects of a development, such as mining, and other proximate land uses and activities on an environment. The cumulative impacts from past and continuing mining need to be considered as a potential factor impacting water supply from the Special Areas dealt with in this Report. Assessment of cumulative impacts is difficult, as ecological, hydrological and geomorphic processes can occur over long timescales, with significant lag, are interdependent, and can have different recovery potentials (Advisian, 2016).

Cumulative impacts are required to be considered in the planning and assessment process under the *Environmental Planning and Assessment Regulation 2000*, which requires that "*any cumulative environmental effect [of a proposed development] with other existing or likely future activities*" must be taken into consideration when assessing the environmental impact of that development.[5] Cumulative impacts are also considered under other state legislative instruments.[6]

In addition to environmental systems and temporal complexities, the assessment and management of cumulative impacts pose further challenges where multiple stakeholders conduct activities which impact an environment. Further complexities are posed by legacy approvals where future cumulative impacts were not contemplated at the time approval was granted.

1.2 REGULATORY FRAMEWORK

NSW and Commonwealth statutes and policies provide the regulatory framework in which the risks and impacts of developments, including mining, are assessed, having regard to environmental, social and economic considerations. This section describes the existing

[3] NSW and ACT Regional Climate Modelling (NARCliM): increase in average temperatures, increase in the number of hot days (maximum temperature >35°C), decrease in the number of cold nights (nights minimum temperature <2°C) seasonality of rainfall is predicted to change (both in the projections for 2020-2039 and 2060-2079), with projections indicating less rainfall in winter and more in autumn (NSW Office of Environment & Heritage, 2018).

[4] This includes the 2017 *Metropolitan Water Plan*, the Greater Sydney *Commission Opportunities for a Water Sensitive Greater Sydney*: *The importance of water in our city's future* and Sydney Water *Growth Servicing Plan 2017-2022*.

[5] *Environmental Planning and Assessment Regulation 2000* cl 228(2)(o). The proponent must address these cumulative impacts in an Environmental Impact Statement (EIS), requirements for the EIS set out in the DPE Secretary Environmental Assessment Requirements (DPE, 2015a).

[6] This includes the *Water Management Act 2000* principles, which include that "*the cumulative impacts of water management licences and approvals and other activities on water sources and their dependent ecosystems, should be considered and minimised.*" *Water Management Act 2000* s 5(2)(d). The *Protection of the Environment Operations Act 1997* directs that Protection of the Environment Policies (PEPs) "*may be made for the purpose of managing the cumulative impact on [the NSW] environment of existing and future human activities*", *Protection of the Environment Operations Act 1997* s 10(b). However, the *Environmental Protection and Biodiversity Conservation Act 1999* (Cth) s 136 does not require the Commonwealth Minister for the Environment to consider cumulative impacts from (other) present or anticipated projects, beyond the proponent's control, when considering whether or not to approve of a controlled action and what conditions to attach to that approval. See Tarkine National Coalition v Minister for the Environment [2015] FCAFC 89 ("Tarkine National Coalition v Minister for the Environment [2015] FCAFC 89," 2015).

legislative model and objects that underpin the exercise of powers by decision-makers in relation to mining activities and to contextualise the technical considerations of the Panel. An overview of the current approvals process is provided in Appendix 2.

NSW legislative reforms have established the Department of Planning and Environment (DPE) as the lead decision authority for State Significant Developments (SSDs), including mining, with the intent that legislative responsibilities and interests managed by other agencies are coordinated with and integrated into the planning process.[7] Other agencies with responsibilities for the oversight or regulation of mining-related activities or their impacts include the Environment Protection Authority (EPA), the NSW Office of Environment and Heritage (OEH), the Department of Industry (DOI) including DOI Water, the Natural Resources Access Regulator (NRAR), WaterNSW and the Dams Safety Committee (DSC).

International trends in regulation have evolved over time from *prescriptive regulation*, focused on inputs and defining how activities should be undertaken, to *outcomes-based regulation*, focused on the ends to be achieved.[8] This approach is intended to minimise regulatory burden and costs, to encourage efficiencies and innovation in how outcomes are achieved, and to better align regulatory and environmental protection goals. Common principles include adoption of a transparent and outcomes-based approach; evidence-based decision making supported by risk assessments, and a cascade of compliance and enforcement options available to regulatory authorities to ensure interventions are proportionate and effective, with net benefits outweighing costs. An inherent challenge is to provide sufficient detail and stringency to promote transparency and accountability for meeting objectives while providing sufficient flexibility for managing specific circumstances; enabling productivity and innovation (Natural Resources Canada, 2013).

Consistent with international trends, mining applications in NSW have been subject to an outcomes-based and iterative development approval process as part of broader legislative and planning policy reforms.[9] This has resulted in some complexity as approvals have been granted at different points in time under different regulatory regimes. This is the case in relation to the Dendrobium and Metropolitan mines. Information about these changes is included in Appendix 2.

Development approvals (or 'consent') set out conditions under which mining activities can be undertaken. Conditions typically include outcomes-based targets (performance measures), specifying the acceptable levels of adverse impacts of the development and requiring the proponent to develop management plans specifying how outcomes will be met and performance monitored with respect to both anticipated and unanticipated impacts.[10]

[7] *State Environmental Planning Policy (State and Regional Development) 2011* cl 8A(1). The Independent Planning Commission (IPC) is the consent authority for SSD applications (and modifications) where there have been 25 or more public objections to the application, or the local council has objected, or a reportable political donation has been made.

[8] Organisation for Economic Co-operation and Development (2016);Department of the Prime Minister and Cabinet (2014);Natural Resources Canada (2013); Department of the Environment (2014);Australian Centre for Sustainable Mining Practices (2011); Asia-Pacific Economic Cooperation Mining Task Force (2010).

[9] From the early 2000's these include changes to the way state significant projects are assessed and consolidation of planning instruments and approval processes. The effect of changes included removal of previous exemptions held by many existing coal mines from the requirement to obtain development consent; transitional provisions giving underground coal mines until 2010 to obtain approval. Subsequent introduction of the *Environmental Planning and Assessment Amendment (Part 3A Repeal) Act 2011* repealed the old Part 3A 'major projects' approval system and included a new assessment pathway under Part 4 of the EP&A Act for State Significant Developments (SSDs); delegated more determination functions to the (then) Planning Assessment Commission; narrowed the definition of developments considered state significant, and included local environmental plans in SSD assessments. Other reforms include the introduction of the *Biodiversity Conservation Act 2016*, which includes a statutory-based method to offset adverse environmental impacts; establishment of WaterNSW through the *Water NSW Act 2014* (a merger of the Sydney Catchment Authority and State Water Corporation) and establishment of the Natural Resource Access Regulator under the *Natural Resource Access Regulator Act 2017.*

[10] Conditions under the regulatory framework have evolved over time, the most recent mining examples including general conditions requiring details of the proposed development, risk assessments and management plans and a justification for the proposed development having regard to the impacts on interests outlined above; specific conditions relating to factors such as subsidence, water, air quality, noise, biodiversity and rehabilitation of the final land-form post-mining; and consultation requirements. See, for example, requirements for the Dendrobium mine extension project (DPE, 2017e).

1.3 MINE ACTIVITIES AND HISTORY

Mining operations in the Southern Coalfield began in the 1800s on the Illawarra escarpment behind Wollongong. The Metropolitan Special Area was declared in 1923 and the Woronora Special Area in 1941. There are active, inactive and historic mines throughout these Special Areas (Table 2, Figure 2). The Dendrobium, Metropolitan and Wongawilli Mines are currently operating and the Russell Vale Mine is under care and maintenance in the Special Areas. As at 2013, mining has occurred beneath 25% of the Metropolitan and Woronora Special Areas (GHD, 2013).

Table 2: Current and historic mines located under the Metropolitan and Woronora Special Areas

Catchment	Current	Care and Maintenance	Proposed	Historic
Nepean	-	-	-	-
Avon	Dendrobium Area 3B, Wongawilli	-	Dendrobium Area 5	Avon, Avondale, Huntley, Wongawilli, Elouera
Cordeaux	Dendrobium Areas 2 & 3A	-	Dendrobium Area 6	Kemira/Mt Keira, Mt Kembla, Mt Pleasant, Nebo, Cordeaux
Cataract		Russell Vale	Russell Vale	Bulli, Cordeaux, Corrimal, Excelsior No. 1 & No. 2, North Bulli, South Bulli, South Clifton
Woronora	Metropolitan	-	-	Darkes Forest, Coalcliff

Modified from Advisian (2016) Literature Review of Underground Mining Beneath Catchments and Water Bodies

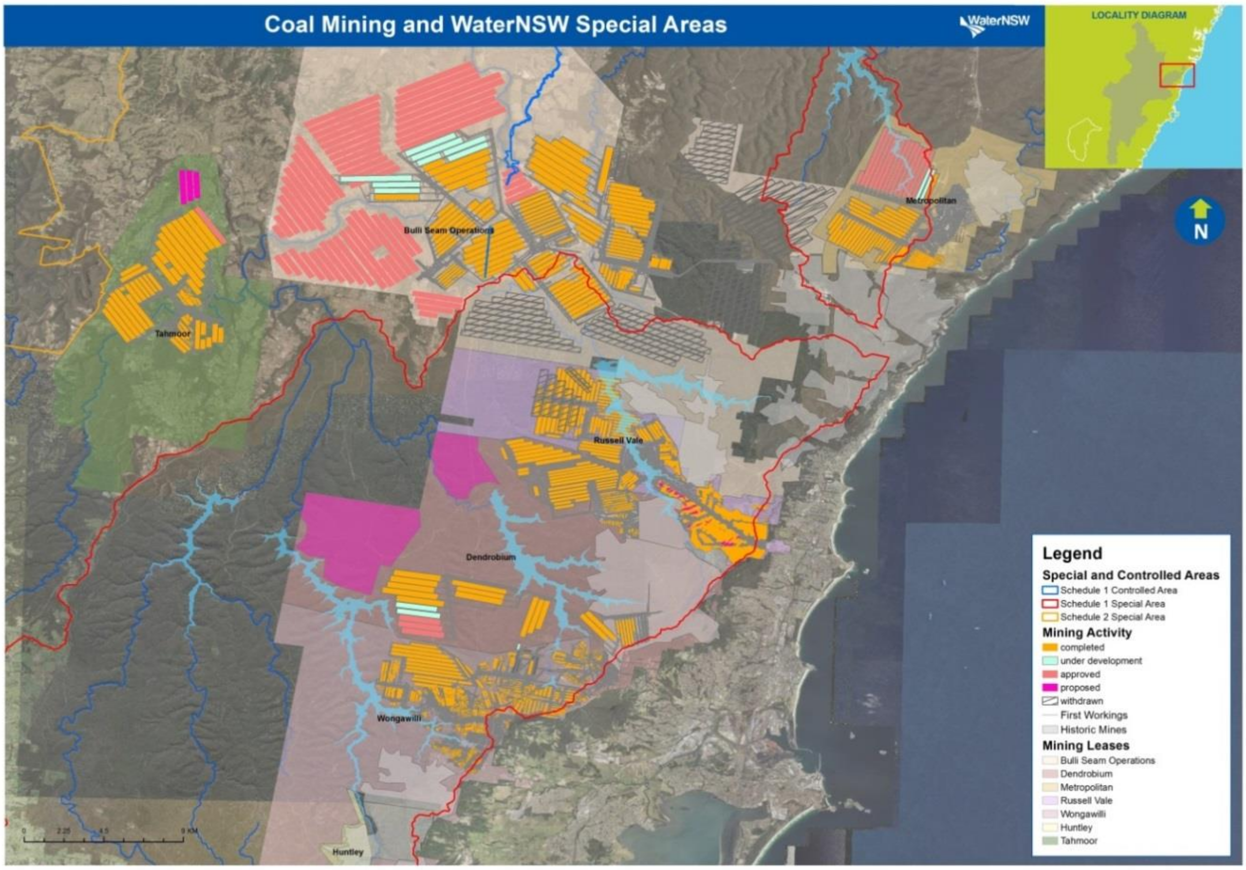

Figure 2: Current and historic coal mines in the Special Areas (WaterNSW, 2018d)

The Metropolitan and Dendrobium mines, the foci of this report, both currently use the longwall mining method in their operations. The dimensions of the longwall panels and a comparison of the respective mining activities are provided in Table 3.

Longwall mining involves delineating blocks or panels of coal that are typically 150 m to 400 m wide and between 1,500 m and 4,000 m long. A longwall panel is formed by driving tunnels (roadways) down its longitudinal boundaries and connecting them at the inbye extremity of the block. A continuous miner is used to cut roadways. The longwall mining equipment comprising a skin-to-skin bank of enclosed hydraulic supports, a conveyor and a coal cutting machine (shearer) is installed in this roadway. The longwall block is progressively extracted on the retreat; mining slices of coal about 1 m thick (deep) across the full width of the block. As the coal is removed, the hydraulic supports are lowered, advanced and reset in sequence and the roof caves in behind the supports to constitute the goaf. The extent of caving, fracturing and subsidence of the ground above the goaf is determined primarily by the mining dimensions and the nature of the geology.

The headings comprising the longitudinal roadways are referred to as gateroads. The driving of longwall gateroads is referred to as longwall development, with a set of gateroads constituting a longwall development panel. Hence, it takes two longwall development panels to delineate a longwall block. The pillars left between each longwall block are referred to as interpanel pillars or chain pillars.

Table 3: Comparison of Dendrobium Mine and Metropolitan Mine activities

		Dendrobium Mine	**Metropolitan Mine**
Current Coal Seam		Wongawilli	Bulli
Catchment		Avon, Cordeaux	Woronora
Special Area		Metropolitan	Woronora
Mining Leases		CCL 768 (18,560 ha) ML 1510 (44.03 ha) ML 1566 (5.26 ha)	CCL 703 (5,195 ha) ML 1610 (543.3 ha) CL 379 (59.82 ha) ML 1702 (386.4 ha)
Longwall dimensions (m)	Void Width	245 - 305	125 - 163
	Length	1,590 – 2,591	1,158 – 3,085[1]
	Max extraction height	3.4 - 4.5[2]	2.8 - 3.3[3]
	Depth of cover	138 - 409[4] (mean 364 for Area 3B)	390 – 540[5] (mean 459)[6]
Run-of-mine coal per year (million tonnes)	Approved	5.2[7]	3.2[8]
	Actual	4.57 (2017), 4.42 (2016)[9]	1.37 (2017), 2.24 (2016)[10]
Groundwater entitlements currently held by mines	Water Source Entitlement (ML/year)	Sydney Basin Nepean Groundwater Source: 3,962 Sydney Basin South Groundwater Source:75[11]	Sydney Basin Central Groundwater Source: 182.5[12]

1) (MSEC, 2012b, 2013, 2014, 2015, 2016b, 2017), 2) HydroSimulations (2015b), 3) Max Extraction Height LW 12-17: 3.3 m, 4) HydroSimulations (2015b), 5) Minimum 390 m for LW 10 and 11; Maximum 540 m for LW 23A and 302, 6) Peabody Energy (2018d), 7) Dendrobium development consent, 8) Metropolitan Mine development consent, 9) South32 (2017b), 10) Peabody Energy (2018a), 11) Water Access Licences WAL37465 and WAL36473, HydroSimulations (2016), 12) Water Access Licence WAL36475

1.3.1 Dendrobium Mine

The Dendrobium Mine is located adjacent to the township of Mt Kembla, approximately 8 km west of Wollongong. It is currently owned and operated by Dendrobium Coal Pty Ltd, a wholly owned subsidiary of South32.

The mine was approved in 2001 after a Commission of Inquiry, directed by the (then) Minister for Urban Affairs and Planning to enquire into "*all environmental aspects of the [project]*" (Cleland & Carleton, 2001). The Commission found approval for the project was not precluded, recommending amendments to the project. The approval process for the mine and a timeline of activities at the mine to date are at Appendix 2.

Approved mining domains include Areas 1, 2 and 3 (Figure 3 and Figure 4), with Area 3 divided into three zones (3A, 3B and 3C). Area 3B is north of the historic workings of Elouera mine. Mining in Areas 1, 2 and 3A has ceased (a further longwall (LW) has been proposed in

Area 3A, see Figure 4). Extraction of LW 14 in Area 3B is ongoing at October 2018. The original development consent has been modified eight times (Appendix 2, Table A2.1).

Hard coking coal is extracted from the Wongawilli Seam with coal transferred by conveyer to the surface facility at Kemira Valley, near the Mt Kembla pit top. The coal is then transported by train on a private line to the Dendrobium Coal Preparation Plant at the Port Kembla Steelworks. Here the coal is blended with coal from the Appin and West Cliff Mine operations (also owned by South32). Washery reject material is transported to and emplaced at the West Cliff facility near Appin, unless beneficial uses can be found.

South32 is now seeking development consent, under the SSD approvals process, to expand operations at Dendrobium Mine within mining lease CCL 768. In December 2016, South32 released a Preliminary Environmental Assessment (PEA) for the expansion and requested that DPE provide Secretary's Environmental Assessment Requirements (SEARs), which describe the required content of an Environmental Impact Statement (EIS) under the SSD approval process. The PEA proposes an expansion into Areas 5 and 6, with the Bulli Seam to be targeted in Area 5 (to a depth of 300-375 m) and the Wongawilli Seam in Area 6 (to a depth of 300 m - 400 m).

DPE sought input on the PEA and draft SEARs from relevant agencies including the DSC, DOI, EPA, OEH, Roads and Maritime Services (RMS), WaterNSW and the Wollongong City and Wollondilly Shire Councils. On 6 February 2017, the Department issued the SEARs specifying the requirements for the EIS.

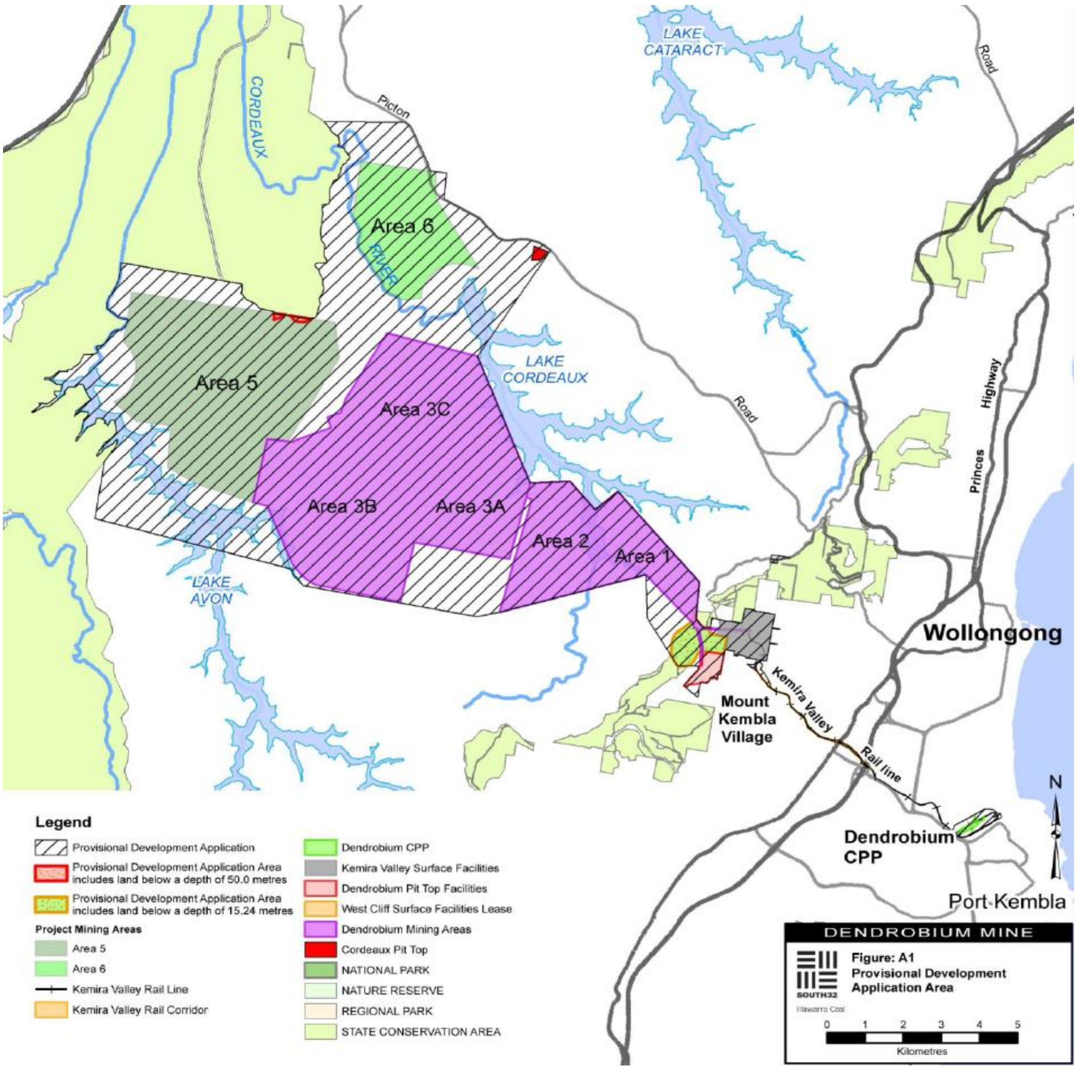

Figure 3: Dendrobium Mine Areas 1 – 5 (South32, 2016b)

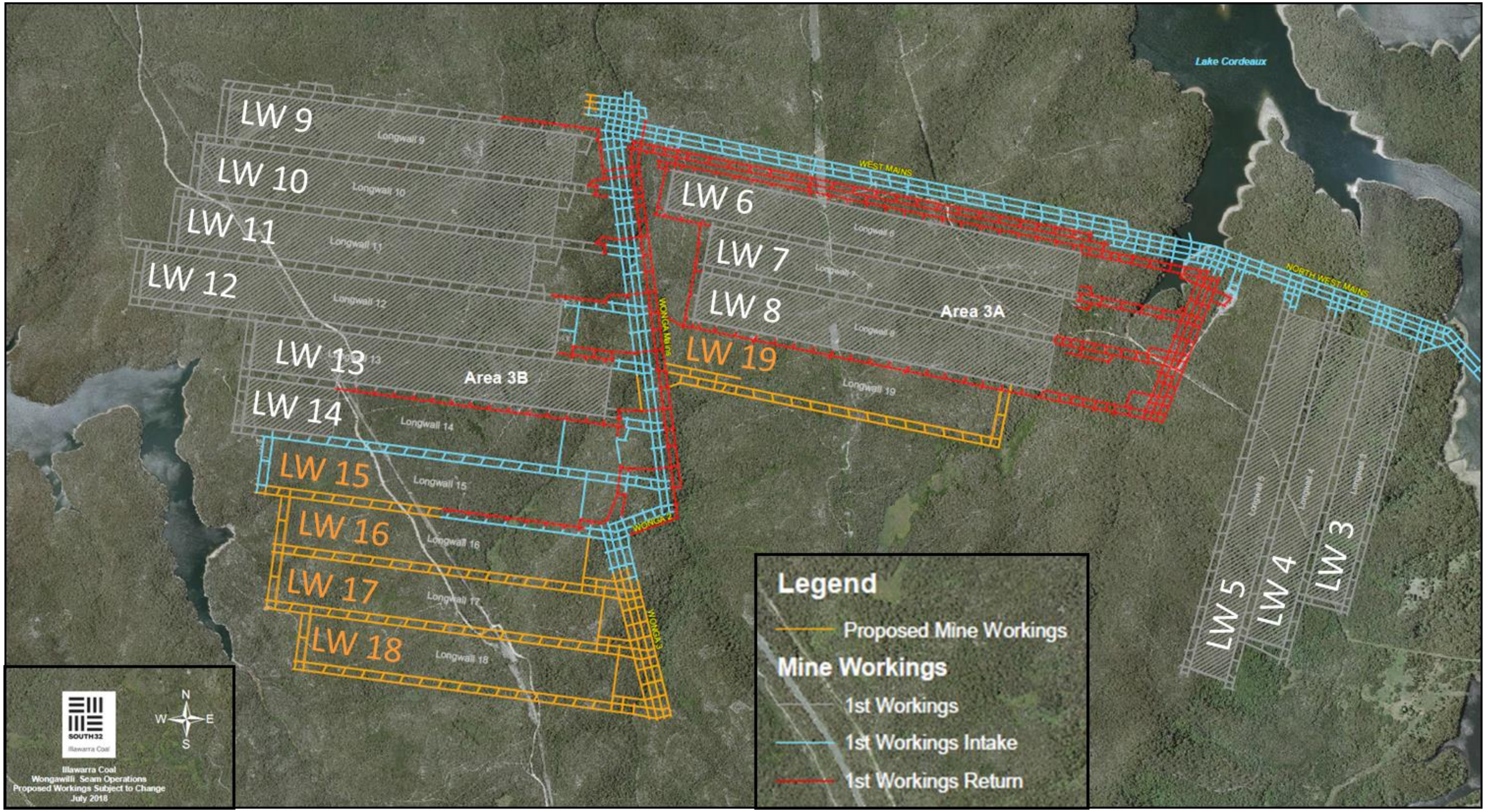

Figure 4: Location of mining domain, including longwall status as at end of FY 2017 (Modified from South32, 2018b)

1.3.2 Metropolitan Mine

The Metropolitan Mine is located near Helensburgh, approximately 30 km north of Wollongong, first beginning operations in 1888. The oldest operating coal mine in Australia, it is currently owned and operated by Metropolitan Collieries Pty Ltd, a subsidiary of Peabody Energy Australia Coal Pty Ltd.

In the early history of the mine, coal was extracted by hand working, with mechanised bord and pillar extraction introduced in 1951 and longwall mining techniques employed from 1995. Hard coking coal is extracted from the Bulli Seam and transferred from within the mine by conveyor to the surface facilities. Most of the coal is then transported by train to the Port Kembla Coal Terminal for domestic and international customers. Coal reject material is either emplaced underground or transported by road to the Glenlee Washery for emplacement.

On 14 November 2008, the mine submitted a development application under Part 3A of the *Environmental Planning and Assessment Act 1979* (EP&A Act) for the Metropolitan Coal Project, representing additional activities in the mine within the Woronora Special Area. The development application for the project was referred by the (then) Minister for Planning, to the Planning and Assessment Commission (PAC),[11] for review and advice on the acceptability of the potential impacts and any other significant issues raised in submissions or public hearings.[12] In May 2009, the PAC recommended the approval of the project, subject to a "*broad-ranging suite of strict conditions*" relating to environmental outcomes, data collection, monitoring and responding to exceedances (PAC, 2009). The development consent has been modified three times (Table A2.2).

Extraction of LWs 1 to 18 was conducted between 1995 and 2009 (part of a previous approval), and LWs 20 to 27 between 2010 and 2017. As at October 2018, LW 302 was being extracted (Figure 5). The mine has plans to extract coal from a further 15 longwall panels as part of the '300' series underneath the Woronora Reservoir (Figure 5).

[11] Now the Independent Planning Commission.
[12] The Metropolitan Coal project was the first mining proposal in the Southern Coalfield referred to the PAC to be assessed under Part 3A of the EP&A Act after the publication of the Southern Coalfield report (Hebblewhite, Galvin, Mackie, West, & Collins, 2008; PAC, 2009).

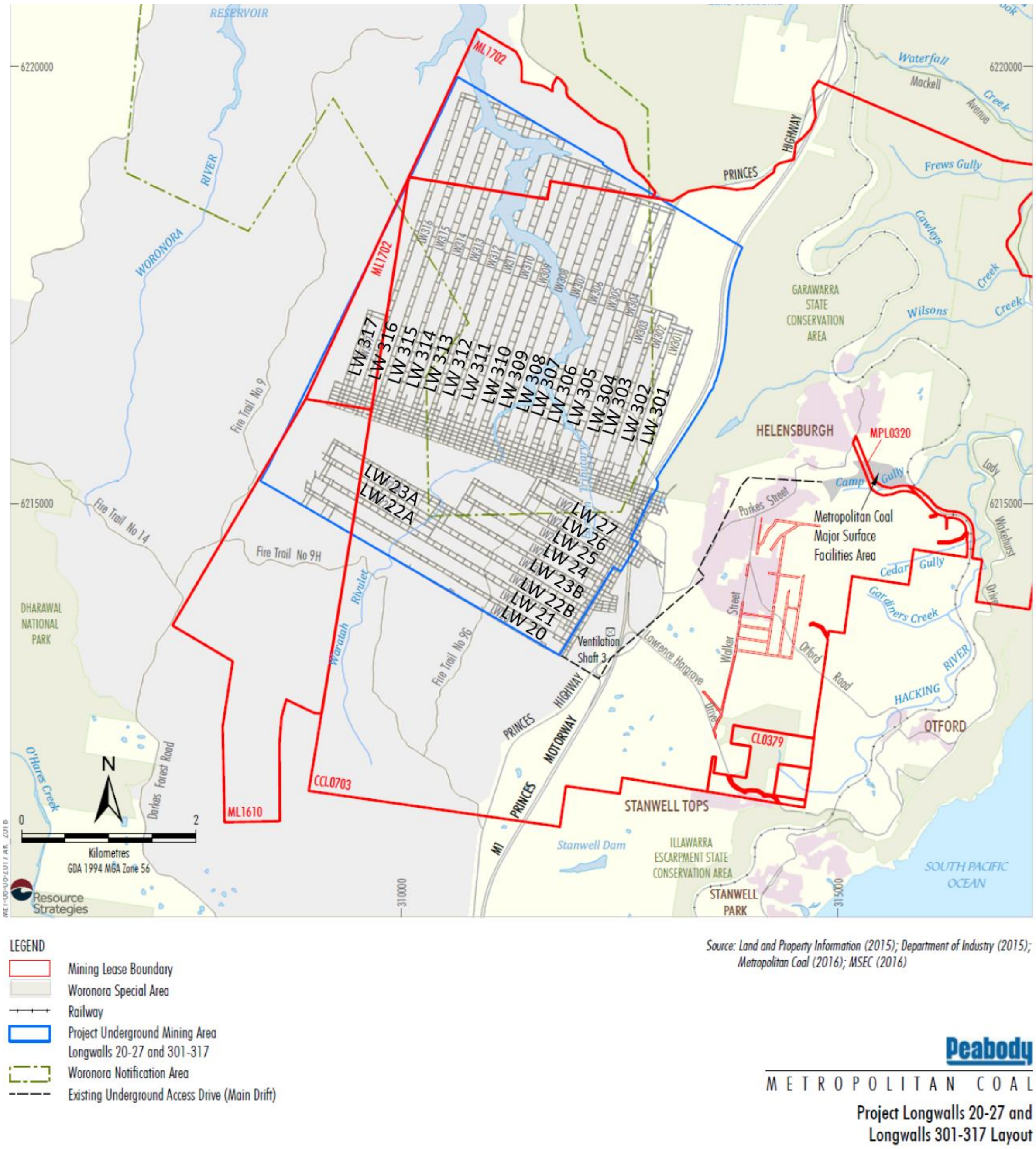

Figure 5: Metropolitan Mine Project LWs 20-27 and 301-317 layout (Peabody Energy, 2018a)

1.4 PROCESS FOR THE PANEL

The Panel is comprised of a Chair and technical experts in the areas of mining subsidence, groundwater, surface water and swamps. Members are Emeritus Professor Jim Galvin (Chair – mining and subsidence), Professor Neil McIntyre (surface water), Mr Robert Williams (groundwater), Dr Ann Young (swamp ecology) and Dr Christopher Armstrong (Office of the NSW Chief Scientist & Engineer).

The Office of the NSW Chief Scientist & Engineer provides secretariat support to the Panel.

1.4.1 Meetings and site visits

Minutes of meetings are available on the website of the NSW Chief Scientist & Engineer.

The Panel has conducted three site visits (Appendix 3). These initial site visits were to swamps and watercourses above past, current and proposed mine operations at the Dendrobium Mine and Metropolitan Mine. The Panel intends to undertake further site visits as its work progresses.

1.4.2 Briefings and presentations

The Panel has received presentations from the two companies that are the focus of this report, South32 (Dendrobium Mine) and Peabody Energy (Metropolitan Mine). These briefings were arranged to provide the Panel with information about current and historical mining activities and to inform the Panel about predictive models being used and their underlying assumptions. The Panel also received a presentation from WaterNSW to gain a current understanding of the catchment and WaterNSW management responsibilities.

There have been significant changes over time in NSW to legislation and agency roles relating to water. Initial meetings by the secretariat and select Panel members have been held with agencies to gain an understanding of historical and current regulatory arrangements and approvals. This includes meetings with DPE, EPA, OEH, NRAR and DOI Water.

Consultations will be undertaken with a broader array of stakeholders to obtain feedback on the findings from this initial period of work and as part of Term of Reference 2.

1.4.3 Public submissions

The Panel made a call for public submissions in relation to Term of Reference 2. To date, five submissions have been received as well as correspondence about the review (Appendix 3). Initial issues in the submissions received thus far include comment on longwall dimensions and impacts; monitoring and modelling methods, data interpretation, reporting and availability; Trigger Action Response Plans (TARPs) and management of exceedances of performance measures. The Panel also received 382 standard form emails as part of a campaign by Lock the Gate recommending an immediate moratorium on further coal mining in Sydney's drinking water catchment. Submissions will be more substantively dealt with in the Term of Reference 2 report. The timeline for submissions has been extended to enable submissions to be informed by this initial report.

Further details regarding making a submission to the Panel are available at www.chiefscientist.nsw.gov.au/reports/independent-expert-panel-for-mining-in-the-catchment.

1.4.4 Other reviews and reports

The level and impact of mining activities in the Sydney catchment has been subject of a number of reviews and reports with associated recommendations including: the nature and extent of permissible activities; approaches to monitoring, modelling and impact assessment; and the need for further research, data collection, oversight and reporting. In its deliberations, the Panel noted the findings of previous reviews and reports, as well as two

Commonwealth concurrent inquiries. Some of these key reviews and reports are described in Appendix 4.

1.4.5 Referrals under Term of Reference 3

To date the Panel has received three referrals under Term of Reference 3. These relate to:

- Dendrobium Mine Subsidence Management Plan for LW 16
- Metropolitan Mine LW 303 Extraction Plan
- Metropolitan Mine application to amend the first workings layout for LWs 304 to 306

At the time of preparing this report, the department had only finalised the first matter, with the decision available through the DPE planning portal

1.5 STRUCTURE OF THIS REPORT

- Chapter 2 provides an overview on mining induced subsidence effects
- Chapter 3, 4 and 5 examine ground subsidence effects, groundwater impacts and surface water impacts, respectively, at Dendrobium Mine and Metropolitan Mine
- Chapter 6 provides initial commentary on catchment, groundwater and reservoir water balances
- Chapter 7 concludes the report, providing a summary of major conclusions and recommendations made in this report

2 MINING-INDUCED GROUND SUBSIDENCE EFFECTS

In NSW today, subsidence engineering requires engagement with a wide range of disciplines, technical specialists and stakeholders. This has not always been the case, resulting in differences in focus, terminology and meaning arising between disciplines over the years that now gives rise to considerable ambiguity and confusion when assessing some mining projects.[13] This is particularly the case in regard to effects of mining on subsurface and surface deformation and groundwater. The situation is not unique to NSW.

This chapter presents a basic overview of mining-induced effects on ground deformation, subsidence and groundwater above underground coal mine workings. This provides a foundation for later considering the nature, magnitude and prediction of mining impacts on groundwater and surface water systems and clarifying and addressing some of the issues that the Panel has been asked to consider. One of the more contentious of these issues is the height of fracturing (or 'height of cracking') above mine workings.

2.1 DEFINITIONS

Ground subsidence is an expression of ground deformation. The term 'subsidence' has two meanings in underground coal mining. It is used generally to refer to all mining-induced movements of the overburden and the surface. It is also used specifically to refer to the vertical component of ground movement. The general meaning is adopted in this report.

The report *Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield: Strategic Review* (the Southern Coalfield Report) (Hebblewhite et al., 2008) drew a distinction between subsidence effects, subsidence impacts and subsidence consequences. The following definitions have been adopted in this report in light of refinements by the PAC (2009) and Galvin (2016):

- **Effect** - the nature of mining-induced deformation of the ground mass. This includes all mining-induced ground movements such as vertical and horizontal displacements and their expression as ground curvatures, strains and tilts.
- **Impact** - any physical change caused by subsidence effects to the fabric of the ground, the ground surface, or a structure. In the natural environment these impacts are principally tensile and shear cracking of the rock mass, localised buckling of the strata and changes in ground profile.
- **Consequence** - any change caused by a subsidence impact to the amenity, function or risk profile of a natural or constructed feature. Some consequences may give rise to secondary consequences. For example, the redirection of surface water to the subsurface through mining-induced fractures may be a primary consequence for water inflow to a reservoir and result in secondary consequences for surface ecology.

2.2 PRE-MINING CONDITIONS

Sedimentary rocks are deposited in layers that vary in thickness, composition and physical and mechanical properties. An individual rock layer is known as a 'stratum' (plural 'strata'). Some of these features are illustrated in Figure 6, which shows a geological cross-section through Areas 1, 2, 3A and 3B at Dendrobium Mine.

[13] For example, mining engineers, geotechnical engineers, hydrogeologists and ecologists.
[13] Geomechanics is concerned with the application of physics and mechanics to explain and predict the behaviour of geological materials.

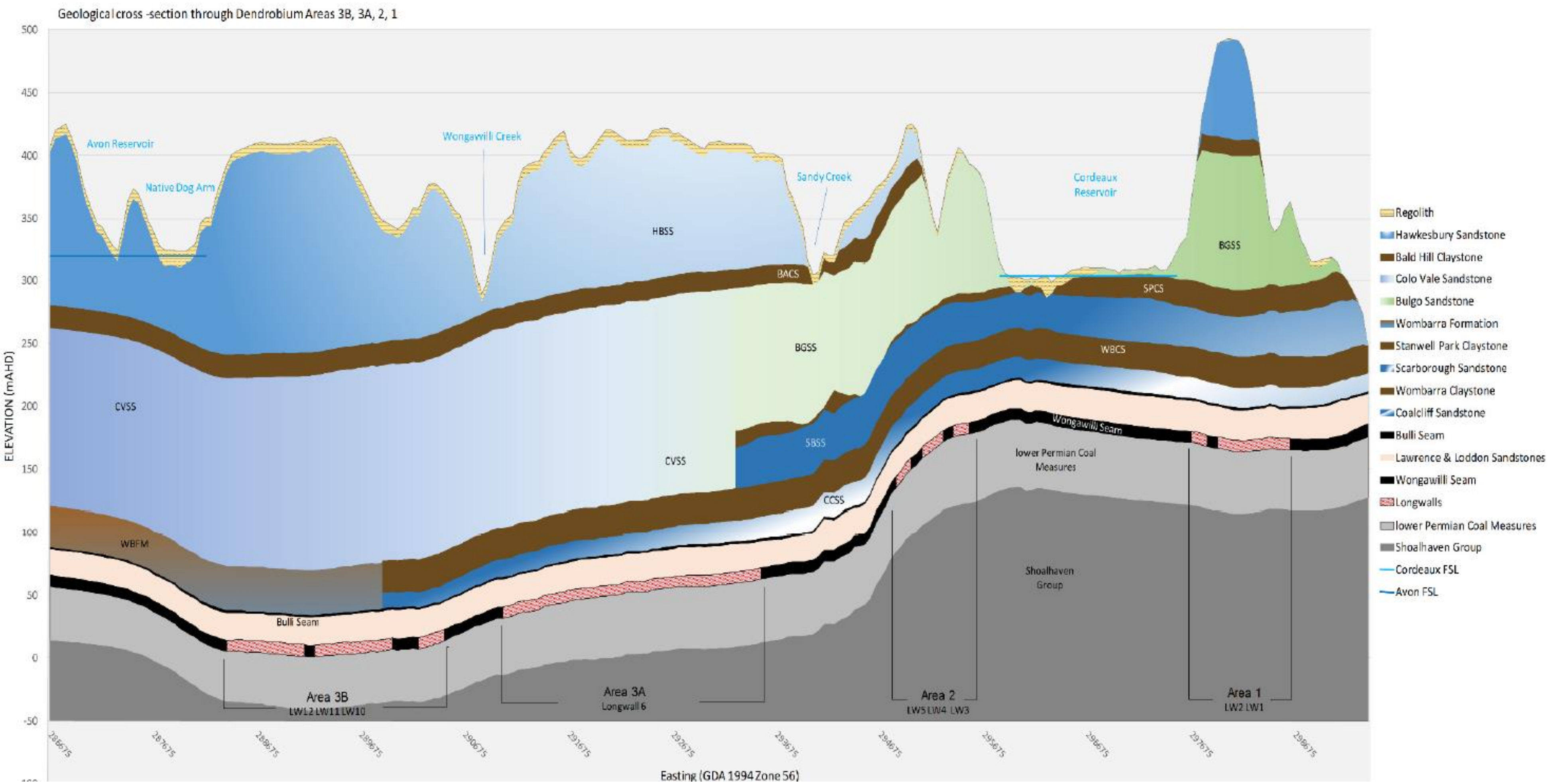

Figure 6: Vertically exaggerated cross-section through Dendrobium Areas 1, 2, 3A and 3B (HydroSimulations, 2016)

Figure 6 also illustrates how the Southern Coalfield is characterised by steep and deeply incised valleys. These tend to align with the direction of regional geological discontinuities such as joints and lineaments.[14] The valleys are subjected to valley bulging, which is a natural process in horizontally bedded sedimentary rock because gravity loading of the valley sides induces deformation of the rocks beneath the valley floors. Outcomes include sliding on bedding planes under the hillsides, buckling of the valley floors, redirection of stream flows to subsurface fracture pathways and closure of the valley sides. Because the valley sides are unconfined, there is a degree of freedom for joints and other fractures on the valley sides to open.

Sedimentary rocks usually contain 'pores' which can store fluids. Water may be stored in and drain from these pores (matrix storage) and also from natural partings such as fractures between blocks of rock and bedding planes (fractures storage). The connectivity of these pores is reflected in the term 'drainable porosity' which is a measure of the drainable pore volume within a rock mass. 'Permeability' or hydraulic conductivity[15] is a measure of the rate (or ease) with which fluids can flow through the pores. If the pores are fully occupied with a fluid, the rock is said to be in a 'saturated' state. If the pores are only partially occupied then the rock is considered to be 'variably unsaturated'.

A rock mass can also contain a network of natural 'fractures' or 'joints' which have the capacity to store and transmit fluids. These features may be confined to a particular rock layer or they may extend through a sequence of layers. They can exhibit a wide range of apertures from less than 10 microns to tens of millimetres in width depending on local conditions. Small apertures are commonly associated with confined conditions (at considerable depths) while large apertures are associated with surface joint exposures where destressed conditions prevail. Joint systems can impose significant structural control on the alignment of streams.

A 'fault' is a particular type of natural fracture where the rock on one side of the fracture has been displaced relative to the other side. Faults are laterally more extensive than joints and it is common for them to be continuous across and well beyond a mining lease. They can occur as a distinct feature or as a series of sub-parallel features. Often, the movement that has occurred on a fault plane results in the interface between each side of a fault being comprised of sheared and crushed rock (commonly referred to as gouge material). Fault planes can contain locked-in tectonic stresses and be in a quasi-state of stability.

Joints and faults are planes of weakness that are susceptible to intrusion by molten igneous rock under pressure. This results in the formation of 'dykes' (near-vertical intrusions) which can range in thickness from millimetres to tens of metres and act as feeders for sedimentary strata to be penetrated by igneous sills (near-horizontal intrusions). Joints, faults and dykes are referred to collectively by several terms including 'geological defects' and 'geological discontinuities'. These defects have a capacity to both store and transmit fluids or to act as hydraulic barriers depending upon the permeabilities of opposing and displaced face rocks.

An assemblage of rocks that exhibits relatively high permeabilities and high drainable porosities and can yield perceptible volumes of groundwater when left to freely drain is regarded as an 'aquifer'. Examples in the Southern Coalfield include the Hawkesbury and Bulgo Sandstones (Figure 6). In contrast, rocks that exhibit low permeabilities and low porosities are commonly termed 'aquitards'. Examples include the Bald Hill and Stanwell Park claystones. The definitions are more useful in a pre-mining context where strata have not been disturbed by mining related fracturing.

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[14] Lineament - A topographic alignment of features that appears to be structurally controlled; also referred to as a 'fracture trace' or 'photolineament'.

[15] Permeability (k) characterises the capacity for flow through a porous rock mass. It has the dimensions $(Length)^2$ and is not fluid specific. Hydraulic conductivity (K) is fluid specific e.g. it incorporates the viscosity of water. It has dimensions Length/time. Permeability and hydraulic conductivity are used interchangeably in this document with permeability generally taken to mean hydraulic conductivity.

'Water pressure' is generated within rock pores and geological defects due to the weight of the overlying water column. The top of this water column, where water pressure equals atmospheric pressure, is referred to as the 'water table' or phreatic surface. Depending on site-specific conditions such as the depth of the water table below the surface and the presence of one or more aquitards, water pressure at a point may or may not be directly proportional to the depth of that point below surface. The water pressure at a point is measured by a device known as a 'piezometer' that is installed down a borehole.

The creation of a mining excavation can affect groundwater in two fundamental ways. Firstly, it creates a low pressure region or sink towards which groundwater may seep or flow. If the rate of recharge from surface is less than the rate of seepage into the mining excavation, then pore pressures will decrease (referred to as 'depressurisation') and the depth to the water table below surface may increase. Secondly, if the excavation is sufficiently wide to cause natural fractures to open and to induce new fractures and caving of the overlying strata, groundwater inflow into the mine sink is enhanced, including from possible conduits to the surface.

2.3 GROUND DEFORMATION

2.3.1 Subsurface Effects

The minimum lateral dimension of a tabular excavation is the critical dimension that controls the response of the rock mass to the formation of an excavation. In coal mining, this is usually referred to as the 'width' (W) or 'span' (S). When the width of an excavation (or panel)[16] is small, the immediate roof strata will bridge across it and there is negligible disturbance of the surrounding strata. As excavation width is increased, a point is reached where the immediate roof begins to cave into the excavation. Further increases in excavation width, up to a maximum, cause mining-induced fracturing to extend higher into the roof but with a decrease in the density and continuity of the fractures.

Some of the first systematic investigations into mine subsidence were conducted in Belgium in the early 1820s as a result of widespread surface movements and damage to buildings above coal mine workings in the city of Liege (Shadbolt, 1977). Subsequently, because subsidence is concerned with ground movement and deformation, its theoretical understanding has been developed primarily by the geomechanics profession.[17] Significant advances were made between 1960 and 1990 in developing not only an understanding of mine subsidence but also of rock mass behaviour in general.[18] These advances led to subsidence above a tabular mining excavation being conceptualised from a geomechanics perspective as zones of characteristic deformation, such as the early example shown in Figure 7, reproduced from the textbook *Longwall Mining* by Peng and Chiang (1984).

[16] The terms 'excavation' and 'panel' are interchangeable when discussing W/H ratio.
[17] For example, mining engineers, geotechnical engineers, hydrogeologists and ecologists.
[18] Hood and Brown (1999) consider the period from 1960 to about 1983 to be the renaissance period for the discipline of rock mechanics, which is that branch of mechanics concerned with the response of rock and rock masses to the force fields of their physical environment (Brady & Brown, 2006).

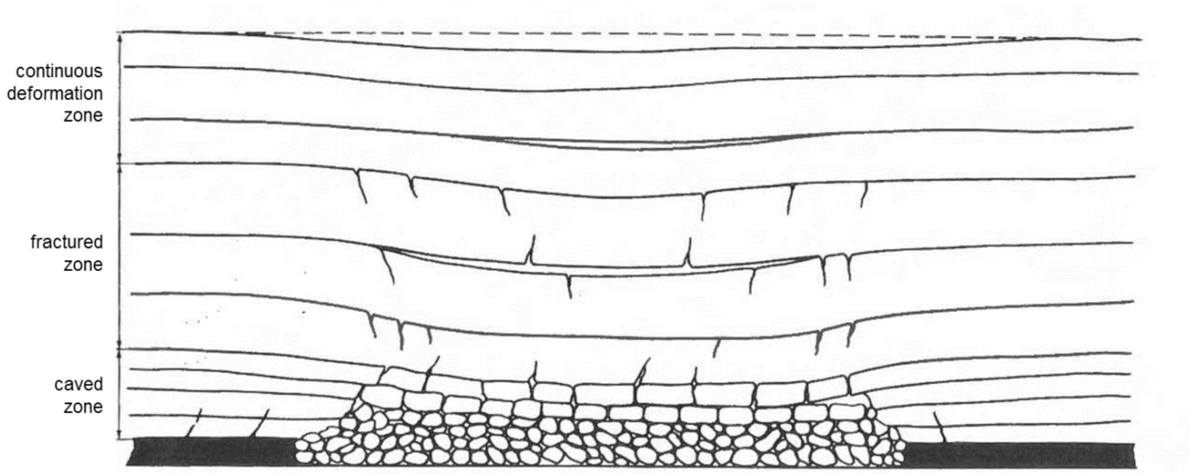

Figure 7: Characteristic zones of deformation above a longwall panel as conceptualised by Peng and Chiang (1984)

Although the number and naming of zones have subsequently been refined, the conceptualisation of strata disturbance above a longwall panel remains largely unchanged in principle from the 1984 model of Peng & Chiang. A surface zone has been added when considering surface subsidence to take account of 'skin' behaviour. In some models, the continuous deformation zone shown in Figure 7 has alternative names and is broken into two subzones. The model shows that subsidence of the overburden is associated with rock fracturing and caving and the formation of open tabular spaces between layers of rock.[19] It also shows how the roof strata do not break off vertically at the edge of an excavation but cantilever out over the mining void.

The four basic geotechnical zones, from deepest to shallowest, can be described in the following terms:

Caved Zone - as excavation width is increased, a point is reached where due to the combined effects of caving, bulking, lowering of the roof and uplift of the floor, the caved material comes into contact with the strata above and provides support to it. This defines the caving height (h_c), which is the upper limit of the caved zone. The caving height is directly proportional to extraction height (h) and a function of the geomechanical nature of the caved material.[20] The greater the extraction height, the higher the height of caving before bulking chokes off the fall.

Fractured Zone - the strata overlying the caved zone continue to sag as excavation width increases. They experience significant bedding separation, opening of natural joints and mining-induced fracturing, but the support and cushioning provided by the caved material prevents the strata from unravelling. As fracturing and bed separation extend up into this zone, they become less intense and continuous and the strata sag less, to the point where they remain self-supporting across the excavation and can transmit horizontal stress. This approximately marks the transition to the constrained zone but, importantly, not the upper limit of fracturing. In mining, the top of the zone is generally regarded as the limit of fracturing intensity that provides conduits for inrush and inundation of gas and/or water from overlying old workings, aquifers and surface water bodies.

Constrained Zone (corresponding to the *'continuous deformation zone'* in Figure 7) - If mining is taking place at a sufficient depth for the fractured zone not to extend right through

[19] Parting planes require careful consideration because the loss in groundwater pressure that occurs when they are first formed can be incorrectly attributed to complete drainage of groundwater due to fracturing when, in fact, it is due to the creation of additional groundwater storage that can fill with the passage of time and result in a recovery in groundwater pressure.

[20] For example, weak laminated strata tend to cave regularly at a steep angle (to the horizontal) and fall like a deck of cards so that caving has to extend a long way up into the roof before the fallen material bulks sufficiently to choke off the fall. On the other hand, stronger and more thickly bedded strata tend to cave at a flatter angle and to rotate and bulk more as they fall.

to the surface then further increases in excavation width result in additional sag, fracturing and shearing of the overburden but on a much reduced scale and level of severity. The zone is characterised as containing open horizontal partings (voids) between strata and sub-vertical fracturing that become increasingly sporadic with distance above the mining horizon.

Surface Zone - the surface is characterised by an absence of overburden load, meaning that it is in an unconfined state and so has additional degrees of freedom. The behaviour of this zone is of particular interest to mining, geotechnical and subsidence engineers as it determines how the surface responds to mining-induced subsidence.

It is important to appreciate these zones are not based on groundwater response to mining but rather on rock deformation inferred from instrumentation and from surface and underground observations.

Instrumentation and underground observations when mining over the top of extracted workings, supported by numerical modelling, confirm theoretical expectations that the profiles of zones of disturbance above a caved excavation can be approximated to that of arches with their apexes aligned close to the centreline of the excavation (for example, Mills and O'Grady (1998) and SCT Operations (2008)). Exceptions can occur in the presence of a very competent bed, such as a dolerite sill or a massive conglomerate stratum, due to deformation terminating at the base of the competent bed. The thickness, mechanical properties and height of a competent bed above the mine workings individually and collectively have a significant influence on the development of mining-induced fracturing and subsidence (see for example, Galvin (1982) and Ditton and Frith (2003)).

2.3.2 Surface Effects

Historically, surface subsidence behaviour in the Southern Coalfield was generally thought to conform to classical theory developed principally out of research in Britain and Europe. However, measurements and observations in the Southern Coalfield by Preston (1992), Holla (1997), Reid (1998) and others identified additional types of mining-induced ground movement, with some extending well beyond boundaries predicted from conventional theory. Subsequently, significant progress has been made in understanding the nature, causes and prediction of these additional subsidence effects. The two types of subsidence effects are referred to variously as ‘conventional’ and ‘non-conventional’, as in the Southern Coalfield Report (Hebblewhite et al., 2008); ‘systematic’ and ‘non-systematic’; ordered’ and ‘disordered’; and ‘classical’ and ‘site-centric’ (Galvin, 2016).

2.3.2.1 Conventional or classical subsidence

Other than in very shallow mining circumstances, the surface usually subsides in the shape of a trough, curving outwards near its perimeter and inwards towards its centre as shown in a grossly exaggerated manner in two-dimensions in Figure 8.

This surface expression is referred to as ‘curvature’. Curvature in an outwards direction is referred as ‘hogging’ and in an inwards direction as ‘sagging’. The surface stretches in zones of hogging and compresses and moves closer together in zones of sagging. Some parts of the surface may be subjected to a wave of extension followed by a wave of compression, while others towards the flanks of a subsidence trough may only experience extension. Implications of these behaviours include surface cracking caused by tensile strain, surface humps caused by compressive strain and changes in the slope of the surface and, therefore, in the tilt of surface features.

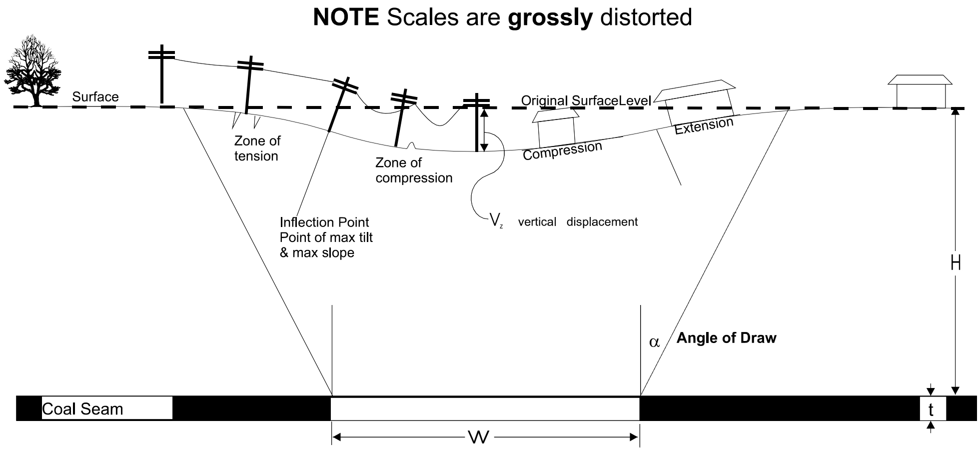

Figure 8: Exaggerated diagrammatic representation of the components of surface subsidence in a flat topography (adapted from Galvin (2004))

In reality, the near surface rocks over coal mine workings are usually comprised of laminated strata. In order for the strata to sag and subside, the individual strata have to slide past each other, as shown in Figure 9. This shear movement may or may not significantly enhance horizontal permeability. Figure 9 also shows how when one face of a stratum is subjected to tension, its opposite face is subjected to compression. Because rocks have very low tensile strength (rocks are typically 10 to 30 times weaker in tension than compression), surfaces in tension are susceptible to fracturing and to the opening of pre-mining fractures.

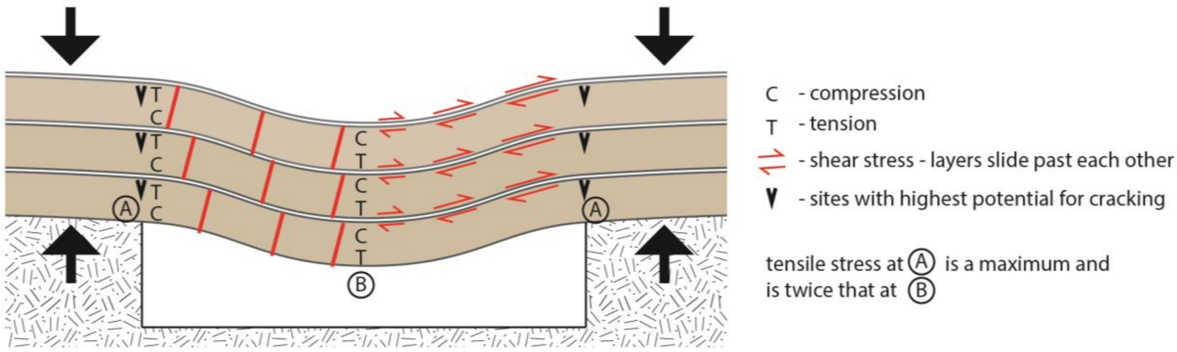

Figure 9: Diagrammatic representation of how individual stratum have to slide past each other in order for the surface to subside

Once a tensile fracture is initiated, it causes a reduction in the load carrying capacity of the beam which, in turn, can cause the fracture to self-propagate through the entire beam thickness. Hence, surface subsidence is conducive to the development and/or enhancement of horizontal and vertical fracture networks, as shown by the photographs in Figure 10. These were taken in a railway cutting undermined by approximately 150 m wide longwall panels at an approximate depth of 300 m (W/H ~ 0.5) not far from Dendrobium Mine.

As points on the surface subside into a subsidence trough, they experience varying degrees of both vertical and horizontal displacement. Vertical surface displacements are due to a combination of sagging of the overburden over each mining excavation and the compression of the adjacent coal pillars and their roof and floor strata under the additional weight of undermined overburden strata that does not fully subside.

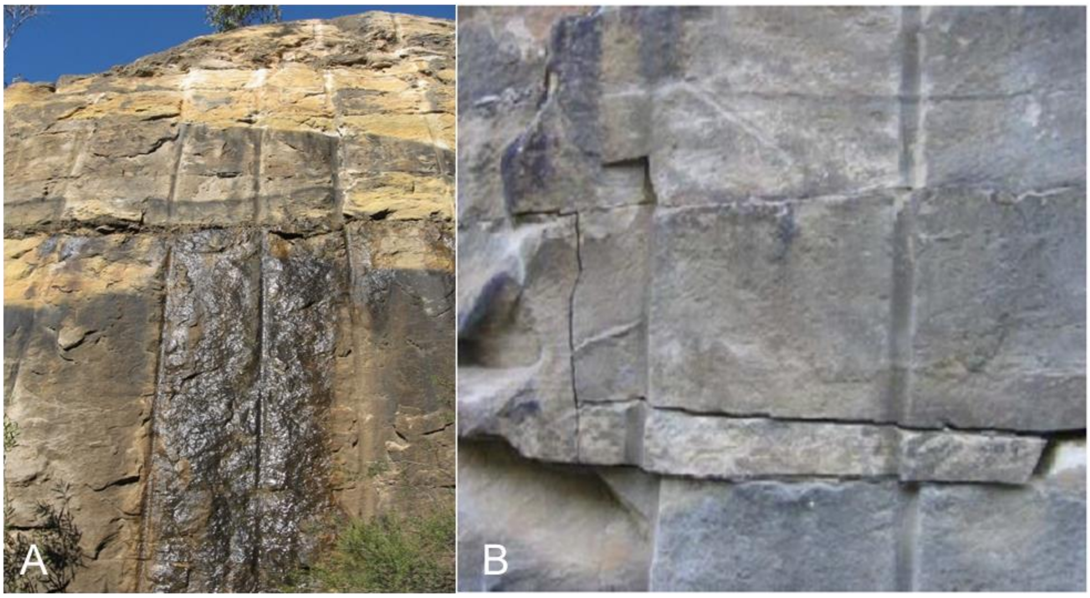

Figure 10: Photographs taken in a railway cutting undermined by approximately 150 m wide longwall panels at an approximate depth of 300 m (W/H ~0.5) in the Southern Coalfield showing the development of vertical fractures and shear displacement on bedding planes in response to mining-induced subsidence
Photograph A) courtesy of Dr Colin Mackie, Photograph B) MSEC (2007)

'Tilt' is the rate of change of vertical displacement and is calculated by differentiating the vertical displacement profile. Curvature is the rate of change of tilt and so it is calculated by differentiating the tilt profile. Curvature can then be converted into regions of tensile and compressive strain using a calibration factor. However, while strain profiles have a predictable form on a regional scale, local reversals from tensile to compressive strain and vice versa are not uncommon.

When a panel is wide compared to its depth (typically W/H >1.0 to 1.4), maximum subsidence will be almost fully developed by the time the panel is extracted. However, at lower panel width-to-depth ratios, subsidence may develop incrementally as subsequent panels are extracted and be due to a combination of strata sag over each panel and the compression of the interpanel pillar systems. These differences in behaviour are reflected to a considerable degree in the differences between the incremental and total surface subsidence profiles for Dendrobium Mine and Metropolitan Mine shown in Figure 11.

The limit of vertical displacement on the surface is defined by the angle of draw as shown in Figure 8. Theoretically, the angle of draw is the angle between two lines drawn from the edge of the mine workings, one a vertical line and the other a line to the point of zero mining-induced vertical displacement on the surface.

In practice, because changes in vertical elevation can also have natural causes such as seasonal variations and prolonged dry and wet periods, it can be difficult to identify the lateral extent of vertical displacements induced by mining. Therefore, it is standard practice in the Southern Coalfield to define the angle of draw on the basis of the 20 mm subsidence contour.

Historically, the angle of draw was considered to define the limit of all mining-induced ground movements on the surface. However, it is now known that horizontal surface movements in the Southern Coalfield can extend well beyond the angle of draw, giving rise to so-called 'far-field movements'.

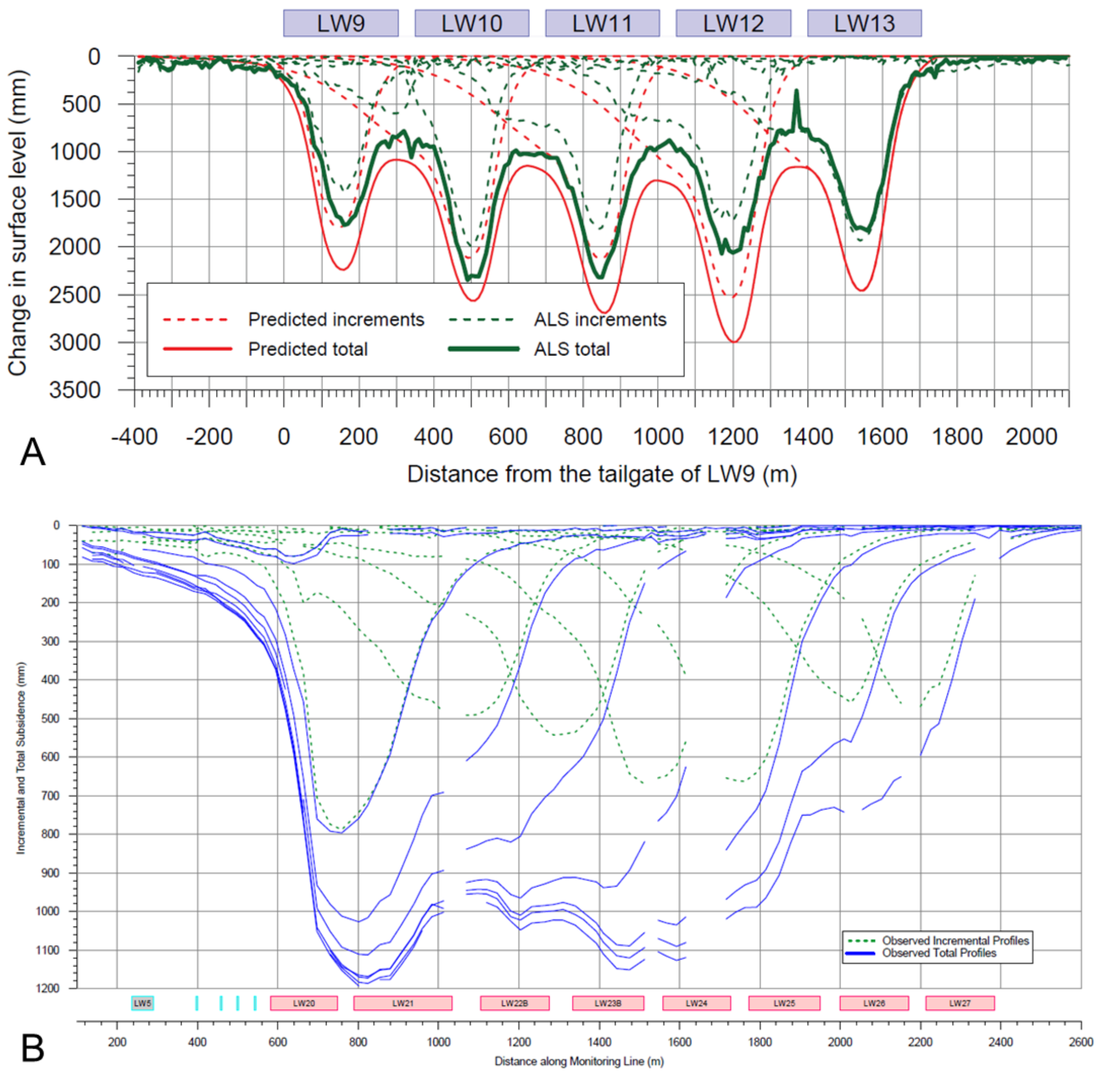

Figure 11: Difference between both incremental and total surface subsidence response to longwall mining at Dendrobium (A) and Metropolitan (B) mines due to differences in interpanel pillar width and panel width-to depth ratio

- **A) Incremental and total surface subsidence profile above Longwalls 9 to 13 at Dendrobium Mine where longwall panel width was 305 m, interpanel pillar width 45 m and mean W/H 0.8. Figure sourced from MSEC (2018)[21]**
- **B) Incremental and total surface subsidence profile above Longwalls 20 to 27 at Metropolitan Mine where longwall panel width was 163 m, interpanel pillar width was 45 m and mean W/H ~0.36. Figure sourced from: Peabody Energy (2018d)**

Depending on their location in the subsidence trough, some surface points may return to a state of near zero strain and near zero change in slope. Others may be left with a degree of extension or compression and change in slope. These states may or may not be permanent, depending on whether one or more adjacent panels are subsequently extracted and the extent of interaction between the panels. If the impact is permanent, the consequences can range from negligible to severe, being determined by the magnitude of the subsidence parameters, the nature and position of affected natural and constructed surface features, and the extent and effectiveness of mitigation and remediation measures.

Although ground strain and changes in slope are expressed in terms of millimetres per metre, differential ground movements are not always uniformly distributed in this manner in the field. In particular, tensile strain often accumulates at specific cracks or natural joints,

[21] ALS - Airbourne Laser Scan.

meaning that a predicted uniform tensile strain of, say, 5 mm/m could express itself as one 50 mm wide crack every 10 m.

It is a standard practice in subsidence engineering to express maximum vertical displacement (V_z), as a proportion of the mining height (h). This relationship (V_z/h) is known as the 'subsidence factor'. It is also a long-established practice to plot subsidence factor against excavation width-to-depth ratio (W/H) since this ratio has a very significant influence on the development of sub-surface and surface subsidence. This is illustrated in Figure 12, which also shows for future reference the approximate ranges associated with current and recent longwall panels at Dendrobium Mine, Metropolitan Mine and Springvale Mine calculated on the basis of mean depth of mining.

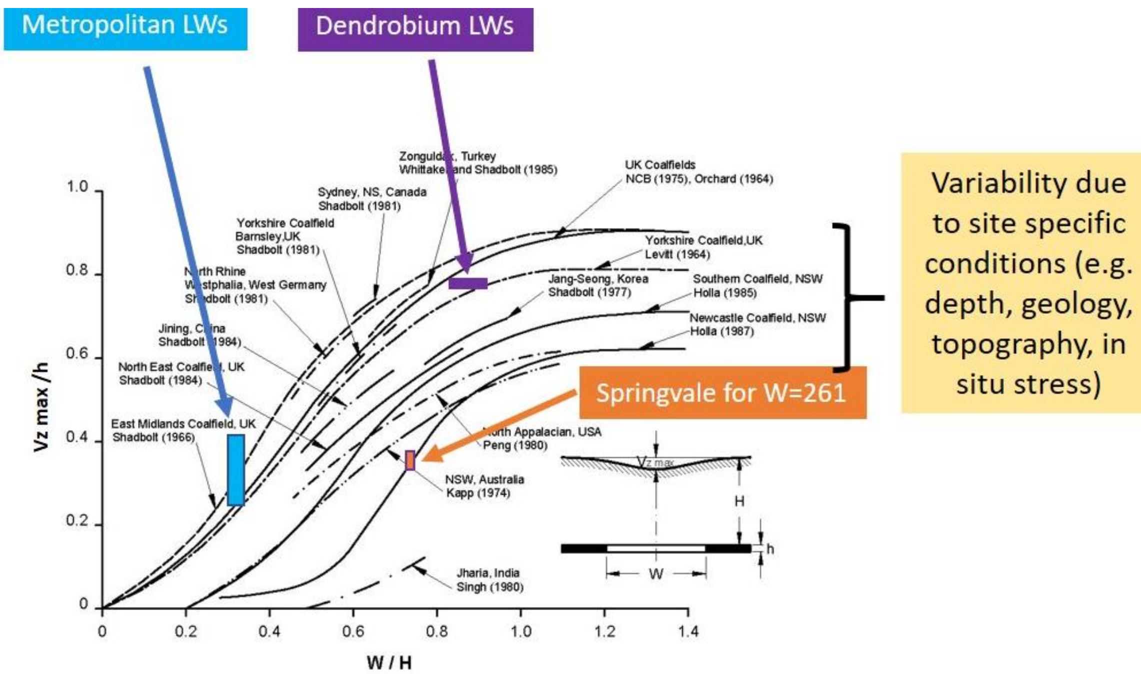

Figure 12: Plots of field data illustrating the influence of site specific conditions and extraction panel width-to-depth ratio on maximum vertical surface displacement expressed as a fraction of extraction height (adapted from Galvin (2016) based on Whittaker and Reddish (1989))

The different curves in Figure 12 reflect factors such as different geology, depth of mining, geomechanical properties and stress states in the various coalfields. The curves illustrate how excavation height (h) and panel width (W) can be manipulated to control vertical surface displacement (and subsidence impacts) for a given depth of mining (H). Interpanel pillar width can also be varied for this purpose in many situations.

It is standard practice to divide the development of surface subsidence into three stages as reflected by the curves in Figure 12. Initially, in the so-called 'sub-critical W/H range', surface subsidence develops slowly as panel width-to-depth ratio W/H increases. An accelerated and relatively steep increase in surface subsidence then occurs as the W/H ratio increases through the 'critical W/H range' before plateauing at the start of the 'supercritical W/H range'. The critical range is characterised by a small change in mine geometry or site-specific conditions inducing a significant change in ground deformation and, therefore, surface subsidence.

The curves labelled *'Southern Coalfield, NSW'* and *'Newcastle Coalfield, NSW'* are historical subsidence prediction curves that demonstrate these behaviours for single isolated extraction panels and for situations where the mining geometry and/or geology resulted in limited interaction between extraction panels. In the Newcastle Coalfield, for example, the sub-critical range is often taken to be W/H <0.7 and the critical range to be 0.7 ≤ W/H ≤ 1.4.

These circumstances may not be associated with regular layouts of longwall panels once depth of mining exceeds about 150 m to 200 m and care is required in utilising the historical curves in these circumstances as evidenced by where the Metropolitan and Dendrobium longwalls plot in Figure 12.

Figure 12 illustrates that once the panel width-to depth ratio exceeds 1.2, subsidence can generally be assumed to have plateaued in the supercritical range.

The figure also shows that maximum vertical surface displacement is less than the maximum mining height even in supercritical situations, typically being in the range of 60 to 90% of the extracted seam height. This is due to the surface subsidence trough extending beyond the footprint of the mine workings and to voids created in the overburden during the subsidence process. The rotation and bulking of fallen material in the caved zone, and the generation of vertical and horizontal fractures and parting planes in the fractured zone, account for much of the void space. This may decrease over time due to compaction under the weight of subsidising overburden. The remaining void space in the upper subsidence zones is associated with the opening of parting planes between strata. These voids may or may not close as subsequent longwall panels are extracted.

2.3.3 Non-conventional or site-centric subsidence

The primary non-conventional subsidence parameters relevant to Term of Reference 1 are valley closure (or valley bulging) and associated valley floor upsidence and basal bedding plane shear movements.

Dilation and closure of valley sides induces horizontal stress in a valley floor. This stress is relieved to some extent by a combination of:

- shearing and buckling of the valley floor, which results in uplift or 'upsidence'[22]
- shearing along beddings planes under the valley sides, with these sliding planes often referred to as 'basal shears'.

Mills and Huuskes (2004) and Mills (2007) established a relationship between these factors through extensive instrumentation and monitoring of Waratah Rivulet during longwall mining at the Metropolitan Mine. Some outcomes of this research are shown in Figure 13. Subsequent and ongoing field investigations have provided further insight into the phenomena of valley closure and basal shears planes in the Southern Coalfield.[23]

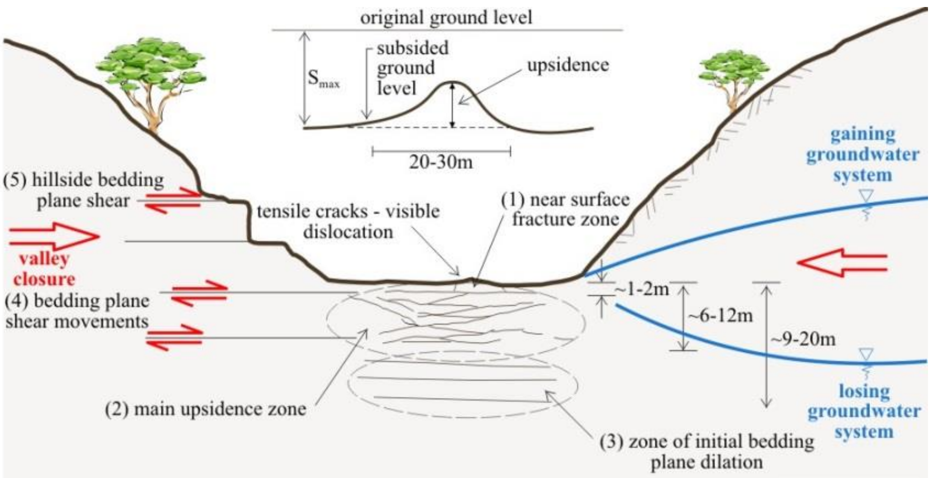

Figure 13: Upsidence fracture network and basal shear planes determined from surface and subsurface monitoring at Waratah Rivulet, Metropolitan Mine. (After Mills, 2007)

[22] Upsidence is the difference between measured vertical displacement and that which would have been predicted by classical subsidence theory if the surface had been flat.
[23] See for example Walsh, Hebblewhite, Li, Mills, Nicholson, Barbato, and Brannon (2014), Mills (2014) and SCT Operations (2015).

Valley closure and upsidence are natural phenomena. However, the rate, magnitude and extent of both are magnified in response to mining-induced subsidence. Fracturing within a valley floor can become more intense and develop to a greater depth in response to mining, as shown in Figure 13. This may be so severe as to result in a total loss of base flow in a surface drainage.

Shearing along bedding planes and partings due to strata bending and sagging over mine excavations occurs to varying degrees throughout the overburden above the caved zone horizon. When basal shear planes are associated with this behaviour, they are generally distinguished by occurring close to the surface of valley floors and extending for sufficient distances beyond the mining footprint to result in far-field movements.

Mining-induced displacements on basal shear planes can enhance their hydraulic conductivity. Careful consideration needs to be given to water transfer between catchments along these shear planes, in particular, from surface water storages to mine workings.

The prediction of non-conventional (or site-centric) surface subsidence effects is challenging due to the number and complexity of factors that can influence these effects. Prediction at Dendrobium Mine and Metropolitan Mine is based on an upper bound approach developed by Kay and Waddington (2014) from databases of predicted and measured valley closures and horizontal displacements. Examples are shown in Figure 14.

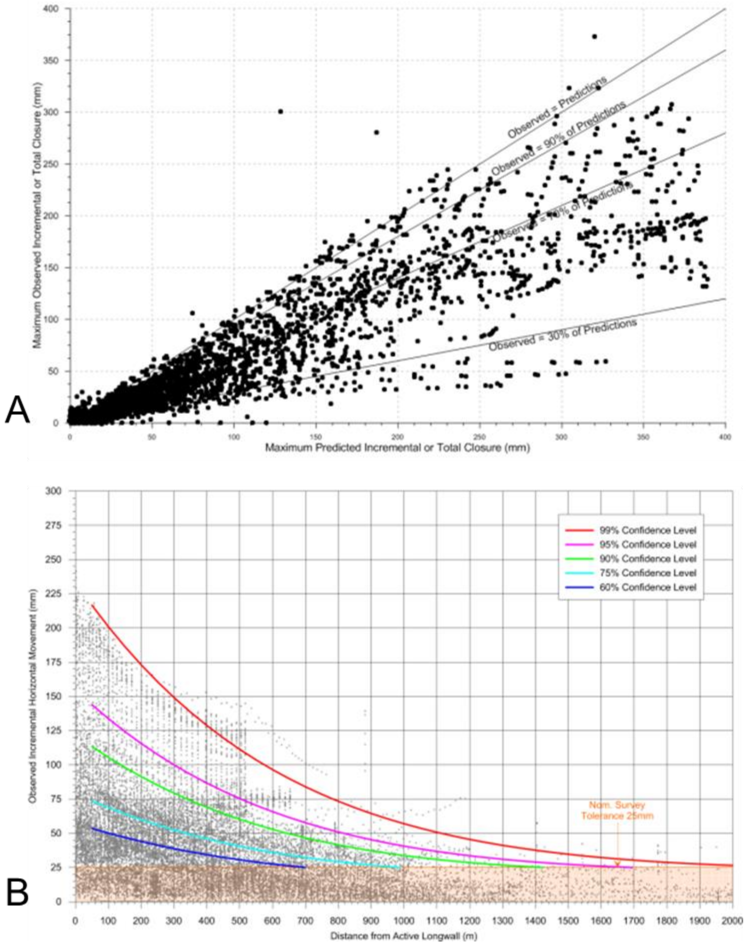

Figure 14: Illustration of upper bound approaches to predicting valley closure and far-field horizontal movements

A) **Comparison between predicted and measured closure (Waddington & Kay, 2002) (After Kay, DeBono, & Waddington, 2011)**

B) **Magnitude and rate of decay of incremental horizontal displacements with distance from longwall panels in the Southern Coalfield of NSW (After Barbato, 2015)**

In summary, features of valley closure and upsidence are:

- both behaviours can extend up to several hundred metres beyond the angle of draw
- the movements develop incrementally with each panel extracted
- the magnitudes of the movements increase with increasing vertical displacement
- both valley closure and upsidence are often greater in the presence of a headland (valley spur)
- the behaviours can also be associated with gentle valley systems and creek beds, albeit that the magnitudes of the closure and upsidence movements are less.
- effects and impacts are a function of the bedrock jointing and lithology (including composition, thickness, and the nature and dip direction of bedding) (Kay et al., 2011).

2.3.4 Geological structures

The presence of geological structures, such as joints, bedding planes, faults and igneous intrusions, adds complexity to the prediction and management of both conventional and unconventional subsidence. These discontinuities can disrupt the way ground displacements develop and are distributed and, therefore, modify how the subsurface and surface respond to the formation of excavations. If total extraction extends over a sufficiently large area about a fault plane, it can result in a significant reduction in confining stress across the fault plane. This unclamping effect can increase hydraulic conductivity along the fault plane and has been attributed with causing reactivation of movement on fault planes (Galvin, 2016).

In recent years, it has been identified in the Western Coalfield (which adjoins the Southern Coalfield of NSW) that surface subsidence, groundwater and surface water responses to longwall mining can be significantly modified in the vicinity of lineaments. A need was identified in 2009 to increase surface subsidence predictions by the order of 30% across lineament zones at Springvale Mine. Subsequently, significant drops in water level in watercourses and swamps hosted by major lineaments have been recorded when longwall mining was up to 700 m away (as the crow flies), well outside the range of conventional angles of draw (NSW OEH, 2014; Galvin, Timms, & Mactaggart, 2016; Galvin, 2017a). In the case of one swamp, water levels started to drop quickly very soon after the host lineament was intersected by a longwall goaf more than 1,200 m further upstream[24]. Dewatering impacts have apparently not been detected to date when lineaments have been intersected by only first workings. Investigations into this behaviour are ongoing and it is too early to know the extent, if any, of similar behaviour in the Southern Coalfield.

2.3.5 Rock Mass Response

Factors that influence how a rock mass responds to the extraction of a longwall panel include the prevailing geology, the geomechanical properties of the rock mass, the pre-mining stress field and the panel width-to-depth ratio (W/H). This ratio has a controlling influence on stress distribution and magnitude in the rock mass, the mode of strata failure and the extent of disturbance of the overlying strata. Important points of note are:

- **As extraction height (h) increases**, disturbance of the overburden due to caving and fracturing extends to a greater height above the excavation and surface subsidence increases
- **As the width (W) of an excavation at a fixed depth (H) is increased**, a point is reached where further increases in panel width do not increase the vertical extent of disturbance of the overburden

[24] See Figure 12: W=261 m, H ≈ 350 m, h ≈ 3.2 m, w_i = 58 m, $V_{z\ max}$ ≈ 1.1 m, W/H ≈ 0.75.

- **As the depth of an excavation of constant width is increased**, the relative influence of the surface on the mining-induced stress field becomes less and the extent of disturbance in the overlying strata approaches a limiting state
- **As depth of mining increases**, surface subsidence over panels of the same W/H ratio increases
- **As the depth of mining increases**, the maximum vertical and lateral extent of strata disturbance above an excavation may not be reached until after a number of adjacent panels have been extracted. In these situations, displacement of the overburden and surface occurs incrementally as each panel is extracted and is a function of the width of the pillars (w_i) between panels and the overall lateral extent of mining (W_o) as well as the width (W) of individual panels

2.4 HYDROGEOLOGICAL MODELS

Hydrogeologists have developed complementary models to those of geotechnical engineers to conceptualise how mining induced deformations impact on groundwater. Some of these models have been based on assigning hydrogeological properties to model shells developed for geotechnical purposes (Forster & Enever, 1991). These can range from two zones to as many as seven, with models of four or more zones generally being adaptions or extensions of the basic four zone geomechanical model.

An example developed by the CSIRO for a coal mine in the Western Coalfield of NSW is shown in Figure 15 (Guo, Adhikary, & Gaveva, 2007). The model defines the various zones in hydrogeological terms of changes in vertical and horizontal permeability.

Attributes of some rock deformation models and hydrogeological models are described by similar zones and/or terminology but the zones and terminology can have different meanings and significance to the respective professions. This is particularly apparent regarding the concept of 'height of fracturing' above mine workings and the nature and function of the constrained zone, about which there has been considerable discussion and confusion for some years when assessing mining impacts on groundwater in the Southern Coalfield.

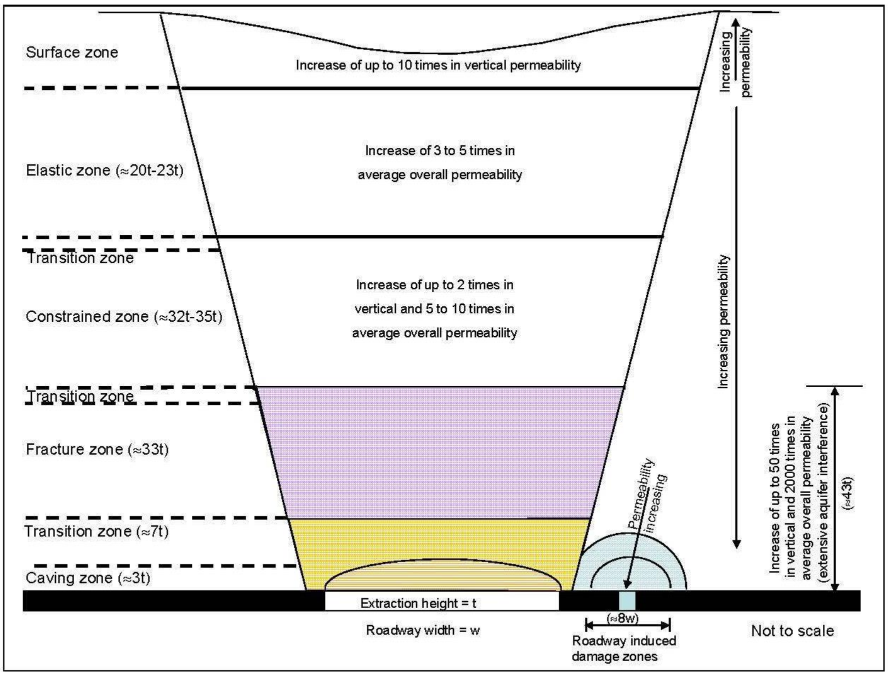

Figure 15: A schematic representation of the hydrogeological model developed for Springvale Colliery, Australia, by CSIRO (Guo et al., 2007)

This state of affairs is not new or unique to NSW. During the mid-1970s, the NSW Government instigated a judicial inquiry into coal mining under Sydney's drinking water dams in the Southern Coalfield. The 1976 report of the inquiry on coal mining under stored water, known as the 'Reynolds Inquiry' (see Appendix 4), dismissed a proposition that three zones are created in the overburden "*of which the central (zone) is tightly constrained and impervious"* (Reynolds, 1976). However, Reynolds went on to state that this did not destroy a view that:

> "*if the cover is sufficient in relation to the mining method employed, poorly permeable zones in a generally central zone will not be so affected by fracturing, joint opening, joint slippage, bed separation or bed slippage as to lose their retarding qualities"* (Reynolds, 1976)[25].

Kendorski, Khosla, and Singh (1979) proposed a four zone model as part of a study commissioned by the US Government into the criteria for determining when a body of surface water constitutes a hazard to mining. The model was generally consistent with the four zone geomechanical model described in Section 2.3.1 except in one very important aspect, this being that it referred to the 'constrained zone' as the 'aquiclude' zone.

This terminology is not inconsistent with the idea of a barrier zone to prevent uncontrolled inrush and inundation of mine workings. Singh & Kendorski (1981) defined the constrained zone as *the "aquiclude", which is a hydrogeological term meaning a leaky barrier to vertical movement of water.* They went on to calculate the minimum thickness of an aquiclude zone on the basis of an acceptable infiltration rate of almost 2 ML/d over an area measuring 200 m x 200 m.[26]

Forster and Enever (1991) also referred to the constrained zone as an 'aquiclude zone' when they developed a four zone hydrogeological model for mining areas on the Central Coast of NSW, with their model shell mirroring that of the four zone geotechnical model previously described. Singh and Jakeman (1999) also describe the Stanwell Park Claystone and Bald Hill Claystone shown in Figure 6 as 'aquicludes' when discussing longwall mining beneath Cataract Reservoir in the Southern Coalfield.

However, as Pells and Pells (2012), Galvin (2016) and others have noted, the constrained zone does not necessarily constitute an aquiclude[27] and the claystones overlying mine workings in the Southern Coalfield are, strictly speaking, 'aquitards'[28] rather than aquicludes.

The view that claystones have a very low permeability often ignores the fact that they can be highly fractured and affected by small faults, as in the case of the Bald Hill Claystone. Pells and Pells (2012) noted when discussing the impact of longwall mining on groundwater in the Southern Coalfield that:

> "*It is considered that the 'provenance' of hydrogeological language has hindered understanding........It is accepted that these terms [aquicludes, aquitards and aquifers] adopted in the hydrogeological fraternity are descriptors, not absolutes. The terms are useful tools to describe geology in some environments and, by differentiating different regions, have supported the conceptualisation and development of various equations of groundwater flow. However, in many situations, the terms are neither helpful nor accurate, particularly in the assessment of vertical flow. The arguments made in the Reynolds Inquiry [into mining beneath stored waters in the Southern Coalfield of NSW] are thus without scientific basis."*

Confusion between subsidence engineers and hydrogeologists as to the nature and extent of strata behaviour and its implications for each discipline resulted in Kendorski overseeing the consolidation of available field and modelling case histories in 1993 in an attempt to

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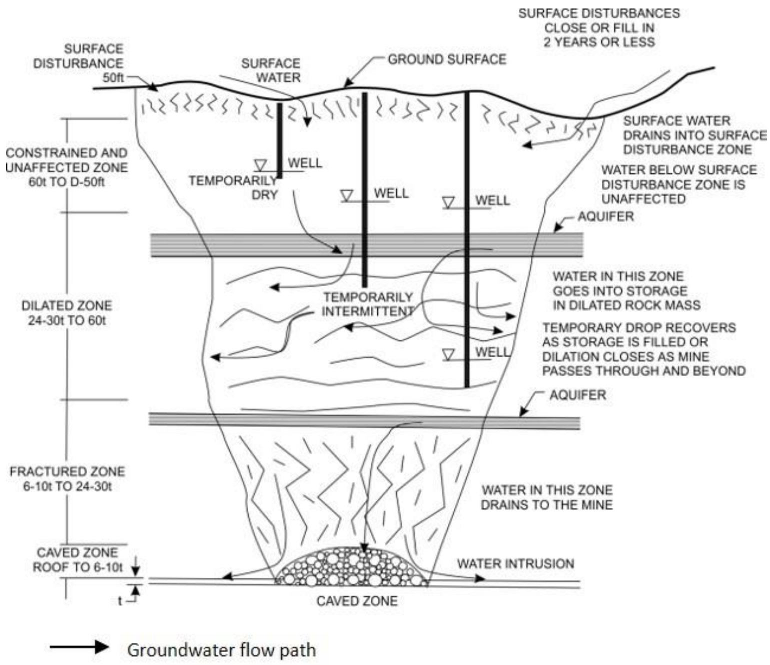
[25] p.67
[26] 10,000 US gallons per month over an area 600 feet x 600 feet.
[27] 'Aquiclude' is a body of rock that is effectively impermeable.
[28] 'Aquitards' is a body of rock that has a very low permeability, sufficient to significantly impede the transmission of water.

reconcile differences in observations (Kendorski, 1993). The study concluded that, as shown in Figure 16 aptly titled “*What we think miners and hydrogeologists both saw”,* the aquiclude zone needed to be broken into two zones, being:

1. “*a lower Dilated Zone of strata that ……… have dilated increasing their storativity potential …… but with no direct or effective hydraulic connection to lower strata or the mine”* and
2. *“an upper Constrained Zone that is unaffected by mining and subsidence deformations and has no change in permeability*.”

Models of sub-surface behaviour zones can be useful for conceptualising the impacts of mining on the surrounding rock mass and groundwater system but it is important to appreciate their limitations. In particular, while it is convenient to divide subsurface behaviour into a series of zones with distinct physical and/or hydrogeological characteristics, in reality changes in ground behaviour and fracturing, permeability and the lateral extent of affected areas occur gradationally rather than as step changes. The so-called ‘fractured zone’ is a misnomer. Fracturing still develops above this zone and may be connected.



WHAT WE THINK MINERS AND
HYROGEOLOGISTS BOTH SAW

Figure 16: A conceptual five zone model of caving and fracturing above an excavation (Kendorski, 1993)

2.5 CONCLUSIONS

a. Rock mass fracturing and surface subsidence reflect how the overburden responds to the formation of underground excavations. This response is governed by many variables that include:
   i. the physical and mechanical characteristics of the overburden. The more important factors include the presence or absence of particularly competent beds, their thickness and height above the working horizon, the angle at which roof strata cantilevers out over extraction panels and the bulking characteristics of caved material
   ii. mining layout dimensions, in particular, excavation widths, interpanel pillar widths and extraction heights

iii. depth of mining
iv. panel width-to-depth ratio
v. the in-situ stress field
vi. geological structures (discontinuities)
vii. topography.

b. Ground movements that occur around excavations in steep and incised topography are complex because they comprise both conventional and unconventional subsidence components. It is difficult to separate the individual contributions of these components. Some components may operate simultaneously in opposite senses. For example, an area could be subjected to downwards vertical displacement while also being subjected to upwards valley bulging.

c. A range of natural features and mining-induced deformations and their interactions need to be carefully considered when assessing subsidence impacts on groundwater and surface water systems. These include:

   i. rock mass fracturing associated with conventional subsidence working its way up from the mining horizon
   ii. creation of tabular void spaces, or partings, between strata as conventional subsidence works its way up from the mining horizon, with the potential for these partings to fill over time and result in partial or total recovery of groundwater pressures
   iii. generic surface fracturing associated with conventional subsidence working its way down from the surface, with the potential for this to result in temporary or permanent diversion of surface flow into subsurface fracture networks
   iv. valley floor fracturing associated with non-conventional subsidence working its way down from the surface, with the potential for this to also result in temporary or permanent diversion of surface flow into subsurface fracture networks
   v. intersection of mining-induced subsurface and surface fracture networks with geological features that have the potential to conduct water into or out of the system
   vi. the potential for mining to reactivate geological structures and/or enhance their conductivity and capacity to redirect fluid flow.

d. In attempting to reconcile rock mass deformation with impacts on groundwater and surface water, it is important to appreciate that:

   i. while it is convenient to divide subsurface behaviour into a series of zones with distinct physical and/or hydrogeological characteristics, in reality changes in ground behaviour and fracturing, permeability and the lateral extent of affected areas occur gradationally rather than as step changes
   ii. the so-called ‘fractured zone’ is a misnomer. Fracturing still develops above this zone and may be connected
   iii. due largely to the different interests and focus of geoscience and engineering disciplines, zones defining mining-induced rock deformation do not necessarily align with zones defining groundwater response to mining.

3 GROUND SUBSIDENCE EFFECTS AT DENDROBIUM MINE AND METROPOLITAN MINE

Dendrobium Mine was approved some 17 years ago and is currently extracting its 14th longwall panel while Metropolitan Mine is over 100 years old, was granted its most recent mining approval in 2009 and is currently extracting its 28th longwall panel. This chapter provides an overview of subsidence in recent times at each mine as a basis for considering mining impacts and consequences for groundwater and surface water going forward.

3.1 SUBSIDENCE PREDICTION

Mine Subsidence Engineering Consultants (MSEC) has been engaged for many years by both Dendrobium Mine and Metropolitan Mine to undertake subsidence predictions. MSEC utilises the Incremental Profile Method (IPM) for this purpose.

The IPM technique draws on a database of field performance to predict a profile of the incremental increase in vertical displacement resulting from the extraction of a mining panel. The incremental profiles are added to produce the overall profile of vertical surface displacement, as shown for each mine in Figure 11. The predictions of vertical surface displacement, in turn, inform the predictions of tilt, curvature and strain and some non-conventional subsidence effects.

MSEC employs a statistical approach to better quantify uncertainty associated with strain predictions. It follows that the reliability of predictions of subsidence impacts and consequences is particularly dependent on the reliability of vertical displacement predictions.

The approval process for each mine as well as the Southern Coalfield Report had regard to Figure 17 which presents the state of knowledge at that time regarding the correlation between predictions of valley closure and upsidence and their impacts on natural features.

The PAC for the Metropolitan Coal Project in 2009 was advised during its hearings that a target criterion of 200 mm maximum total predicted closure for avoiding significant impacts was developed based on reviews of previously observed impacts along Waratah Rivulet due to LW 1 to LW 14 at Metropolitan Mine and experience from other mines in the Southern Coalfield (PAC, 2009)[29]. The PAC report stated that because the 200 mm closure limit was an outcome of a prediction methodology that was under development, it was subject to change as the prediction methodology evolves (PAC, 2009)[30]. The PAC was also advised that there was some probability, *"regardless of the approach, that potential impacts could occur at predicted closure values less than the minimum predicted total closure of 200 mm"* that had been identified to that date.[31] The Panel notes that the criteria of restricting predicted valley closure to a maximum of 200 mm has continued to find application at Dendrobium Mine and Metropolitan Mine.

[29] p.33
[30] p.34
[31] Responses to Planning Assessment Commission Queries, Question 16, 24 February 2009 (PAC, 2009, p. 34).

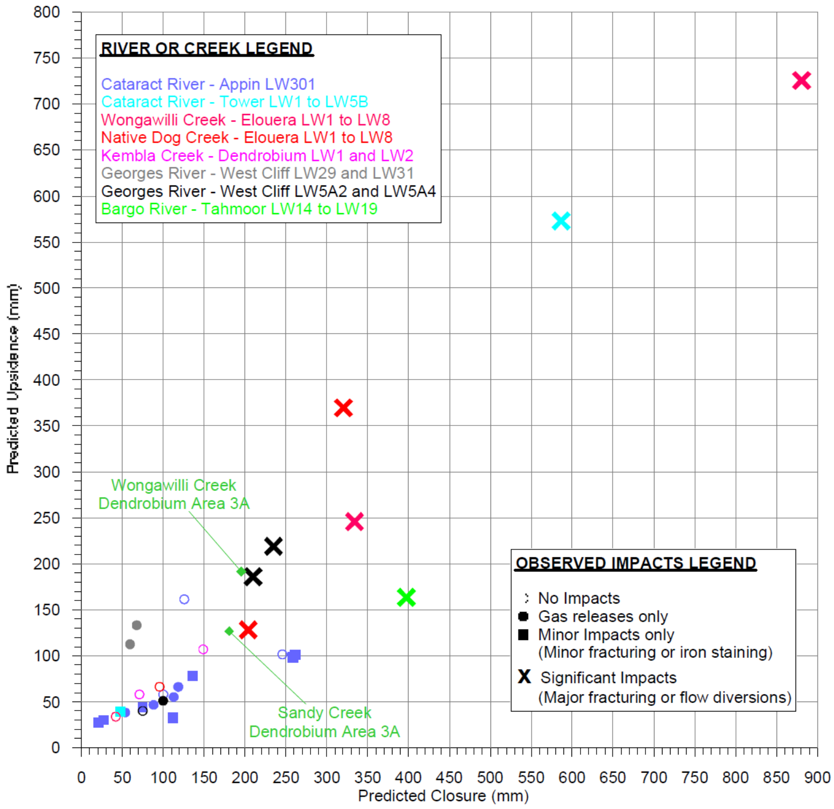


Figure 17: Back-predicted closure and upsidence and observed impacts for case studies (MSEC, 2007)

3.2 DENDROBIUM MINE

The existing development consent for the Dendrobium Mine expressly allows mining in Areas 1, 2, 3A, 3B and 3C, shown in Figure 3. With respect to Area 3B, the development consent conditions only place performance measures on three watercourses (Donalds Castle Creek, Wongawilli Creek and waterfall WC-WF54) and one reservoir (Lake Avon), as recorded in Table 4.

Offset provisions are in place to compensate for any exceedance of swamp performance measures. These mine approval conditions are embedded and provide significant scope for maximising mining dimensions and, therefore percentage extraction, which is 87% on an areal[32] basis. However, DPE also exercises its powers when approving Subsidence Management Plans for specific longwall panels. This had included requiring increased levels of monitoring of subsidence effects and impacts, the review and updating of groundwater models, the undertaking of detailed geotechnical and hydrogeological investigations of the height of connective fracturing, and the engagement of a suitably qualified, experienced and independent expert to prepare a report on a range of specified geotechnical and hydrogeological matters.

Area 3A was originally planned to be extracted from LW 5 to LW 10, with panel widths of 250 m, before commencing extraction in Area 3B with LW 11. Modification was sought after a greater-than-expected extent of the nepheline syenite intrusion to the south of Area 3A was identified during the mining of LW 6 in 2010. LW 8 was widened to 305m and an as-yet-unmined LW 19 was approved also.

As mining has progressed in Area 3B, modifications have been made to the mine layout including:

[32] Plan view

- the maingates under Wongawilli Creek are to be diverted at LW 16 to avoid the intrusion.
- several longwalls have been shortened because of poor roof or floor conditions, and/or ‘geological; and stress conditions
- the DSC has required shortening of several longwalls because of concerns about interaction with Lake Avon
- LW 14 is to be shortened to protect the bedrock reach of WC15 below Swamp 14.

Table 4: Subsidence Impact Performance Measures in the Consent Conditions for Dendrobium Mine

11. The Applicant must ensure that the development does not cause any exceedance of the performance measures in Table 1, to the satisfaction of the Secretary.

Table 1: Subsidence Impact Performance Measures

Swamps	
Swamps 1a, 1b, 5, 8, 11, 14 and 23	Minor environmental consequences including: • *negligible* erosion of the surface of the swamps; • *minor* changes in the size of the swamps; • *minor* changes in the ecosystem functionality of the swamp; • *no significant* change to the composition or distribution of species within the swamp; and • *maintenance or restoration* of the structural integrity of the bedrock base of any significant permanent pool or controlling rockbar within the swamp.
Swamps 3, 4, 10, 13, 35a and 35b	No significant environmental consequences beyond predictions in the Subsidence Management Plan (2012).
Watercourses	
Waterfall WC-WF54	Negligible environmental consequences including: • *no* rock fall occurs at the waterfall or from its overhang; • *no* impacts on the structural integrity of the waterfall, its overhang and its pool; • *negligible* cracking in Wongawilli Creek within 30 m of the waterfall; and • *negligible* diversion of water from the lip of the waterfall.
Wongawilli Creek Donalds Castle Creek	Minor environmental consequences including: • *minor* fracturing, gas release and iron staining; and • *minor* impacts on water flows, water levels and water quality.
Water storages	
Avon Reservoir	Negligible environmental consequences including: • *negligible* reduction in the quality or quantity of surface water inflows to the reservoir; • *negligible* reduction in the quality or quantity of groundwater inflows to the reservoir; and • *negligible* leakage from the reservoir to underground mine workings.

Notes: These performance measures apply to Longwalls 9 to 15. The Applicant may meet the requirements of this condition either by avoidance, mitigation or remediation. Most swamps and watercourse features are shown on the site and key natural features plan (see Appendix 1).

MSEC provided subsidence predictions for Area 3B in October 2007 on the basis of a panel width of 245 m and a mining height of 3.9 m (MSEC, 2007). The consultants advised that the maximum predicted conventional subsidence parameters for future longwalls in Areas 3B and 3C could be expected to be greater if mining height and/or panel width were to be increased in these areas, citing an example of approximately 20% increase in subsidence if panel width were to be increased to 300 m. Avoidance of significant impacts arising from valley closure was based on the earlier noted criteria of predicted closure to be less than 200 mm.

MSEC also undertook an assessment of the likely height of the fractured zone above the proposed longwalls based on a model that provided a relationship between the theoretical height of the fractured zone, as a fraction of the width of the extracted panel, and panel width-to-depth ratio. The model was tested against reported values in the literature. MSEC concluded from the model that:

- The predicted height of fracturing above 250 m wide longwall panels in Area 3A was 300 m
- "*It is probable that the fractured zones could extend to the surface where the depths of cover are less than 300 m, at the commencing ends and finishing ends of the proposed longwalls in Areas 3A and beneath Wongawilli Creek and its tributaries in Areas 3B and 3C"*
- "*This does not necessarily imply that there would be connectivity between the surface and the seam, however, since fractures caused by bed separation can increase horizontal permeability without necessarily increasing vertical permeability"* (MSEC, 2007).

Subsequently, LW 6 and LW 7 were extracted at a width of 250 m, followed by LW 8 at an increased width of 305 m. Operations then moved to Area 3B where mining has continued using 305 m wide longwall panels. The subsidence predictions and impact assessments for the SMP Application for LW 9 to LW 19 were produced by MSEC at the time that LW 8 was still being extracted (MSEC, 2012a). The IPM was recalibrated based on the available monitoring data from LW 1 and LW 2 in Area 1, LW 3 to LW 5 in Area 2 and LW 6 in Area 3A. MSEC employed a revised height of fracturing model and drew similar conclusions as in its 2007 report (MSEC, 2007).

DPE initially only granted approval to extract LW 9 to LW 13, with MSEC subsequently being commissioned to review and update the subsidence predictions and impact assessments for the proposed LW 14 to LW 19. The IPM was recalibrated on the basis of surface subsidence contours generated over Areas 2 and 3A and LW 9 and LW 10 in Area 3B using Airborne Laser Scan (ALS) / Light Detection and Ranging (LiDAR) surveys. MSEC's review of impact assessments was confined to physical impacts such as cracking and bedrock deformation, with the review of environmental consequences provided by other consultants in the Watercourse Impact Monitoring Management and Contingency Plan (WIMMCP) and the Swamp Impact Monitoring Management and Contingency Plan (SIMMCP). The assessment of the height of fracturing was also undertaken by another consultant (DGS, 2016).

MSEC concluded from the ALS survey data for LW 7 and LW 8 in Area 3A and LW 9 and LW 10 in Area 3B, that it appeared the maximum observed subsidence exceeded predictions in many locations, typically being up to 1.3 times predicted. The observed subsidence directly above the tailgate chain pillars for LW 7 and LW 8 in Areas 3A and LW 10 in Area 3B was also greater than predicted (MSEC, 2016a). It was considered that the exceedances were probably due to the greater depths of cover and wider longwall panels.

The Panel considers this to be a reasonable conclusion under normal circumstances but notes that the exceedance is the same magnitude (30%) to that experienced in lineament zones at Springvale Mine (see Section 2.3.4).

The IPM was recalibrated to take account of the field measurements over the wider longwall panels, resulting in the conclusion that the maximum predicted subsidence parameters based on the recalibrated technique were 30% greater for vertical displacement, 25% greater for tilt and 40% greater for curvature. Predictions of the maximum subsidence parameters for a number of drainage lines above the future LWs 12 to 18 were increased from those predicted for LW 9 and LW 10. These increases were 25% for vertical displacement, 32% for valley related upsidence, and 40% for valley related closure. Nevertheless, it was concluded that while the rates of impacts were likely to increase, the nature of these impacts was unlikely to change, i.e. a greater number of fractures with increased widths in the exposed bedrock resulting in a slightly increased potential for surface water flow diversions.

In the specific case of WC21, a notable tributary to Wongawilli Creek, vertical displacement was predicted to increase from 2.55 m to 3.50 m but closure and upsidence were predicted to remain unchanged because of the insensitivity of closure and upsidence predictions to displacements of this magnitude. An over-arching conclusion was that while the predicted subsidence parameters had increased, the impact assessments previously provided had catered for predictions being exceeded by two times.[33]

At a meeting between the Panel and South32 on 5 March 2018, the Panel was given a presentation on Dendrobium Mine that included the graphs shown in Figure 18 of predicted versus measured vertical surface displacements and valley closure over Area 3B. The Panel notes that the predictions of vertical subsidence are retrospective as they are based on the model that was recalibrated at the time LW 11 was being extracted.

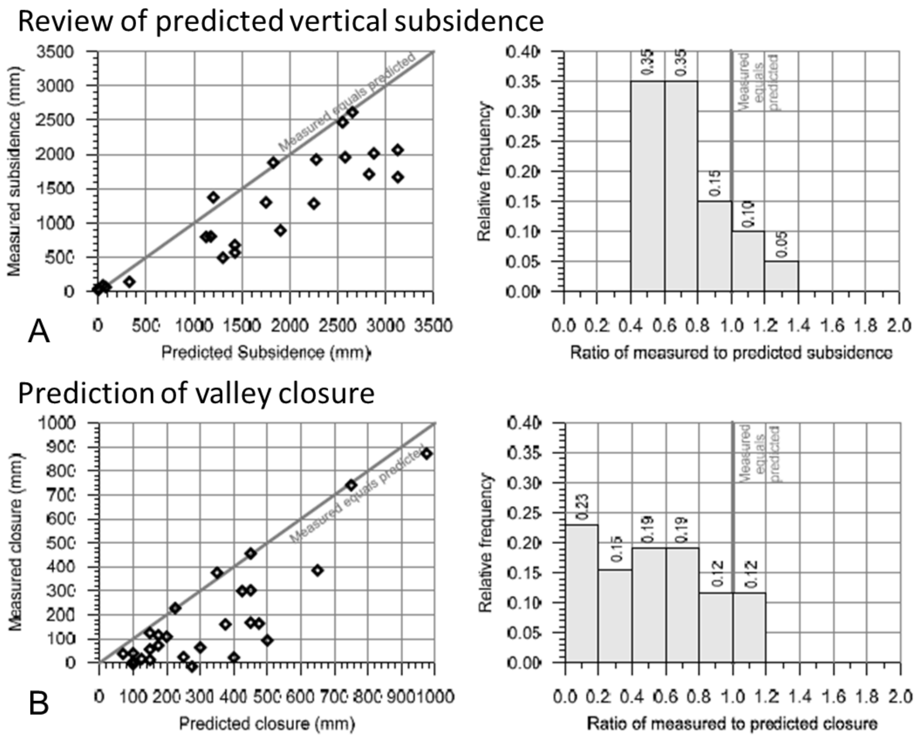


Figure 18: Extracts from presentation to the Panel by South32 showing predicted versus measured vertical surface displacement and closure in Area 3B based on the recalibrated prediction model (South32, 2018a)

- **A) Review of predicted vertical subsidence. Comparison of measured (ground monitoring) versus predicted vertical subsidence in Dendrobium Area 3B. Measured less than predicted in 18 of the 21 cases. Three exceedances range between +5% to +22%**
- **B) Prediction of valley closure. ACARP Research C9067 (Waddington, 2002): developed using ground monitoring data from the Southern Coalfield and reviewed using monitoring data from Dendrobium Area 3B. Measured less than predicted in 24 of the 27 cases (89%). Three exceedances range between +5% to +10%**

The minimum excavation width-to-depth ratio, W/H, for LW 1 to LW 11 ranged from 0.6 to 0.98 and the maximum ranged from 0.86 to 1.56. Based on Figure 12, it could be expected that there are areas above most of these longwall panels that fell within the supercritical range and, therefore, would have experienced maximum possible vertical displacement. Field measurements generally confirm that this was the case. Figure 12 shows that maximum vertical surface displacement was approximately 78% of the mining height, which is at the high end for Australian coal mines.

[33] It was a requirement of the regulator at the time that impact assessments had to include the case where actual vertical displacement was double predicted.

The End of Panel Report (EOP) for LW 13 records that the average daily water inflow to Area 3B during extraction of LW 13 (completed 19 April 2018) was 4.68 ML/day compared to 4.5 ML/day at the completion of LW 12 and represents 62% of total mine inflow. The LW 13 EOP also reports that the estimated net loss of water from Lake Avon, based on numerical model predictions, at the completion of LW 13 was less than 0.4 ML/day.

In the PSM *Height of Cracking Dendrobium Area 3B* report (the PSM study) noted that reported that the Dendrobium Mine region is affected by numerous structural lineaments made up of faults, dykes and sills and that the orientations of the regional scale north south trending Cordeaux River and Narellan Lineaments are possibly reflected in the orientation of major creeks and drainages in the area, including the arms of the Cordeaux and Avon Reservoirs. Further, in many cases, mapped mine scale structures do not appear to have an observed surface expression, which adds complexity to the estimation of mining effects and impacts (Sullivan & Swarbrick, 2017).

On 16 April 2018, and under Panel Term of Reference 3, DPE sought the advice of the Panel on the SMP lodged for LW 16. Matters considered by the Panel included the potential for water inflow into the Dendrobium Mine workings from Avon Reservoir via geological fault planes and basal shear planes identified from borehole investigations. Figure 19 shows projected faulting in the area and Figure 20 shows a basal shear plane intersecting what the consultant (SCT) refers to as the 'zone of large downward movement' above LW 13 at Dendrobium Mine. The numerous lineaments in the region referred to by PSM are reflected in Figure 19 and Figure 21. There is a significant amount of faulting projected in and around future longwall panels in Area 3B, with a major fault zone located within the barrier pillar between Dendrobium Mine and existing longwall panels in Elouera Mine, Figure 19. A splay of faults of similar orientation is projected to intersect LW 17 and encroach the edge of Avon Reservoir.

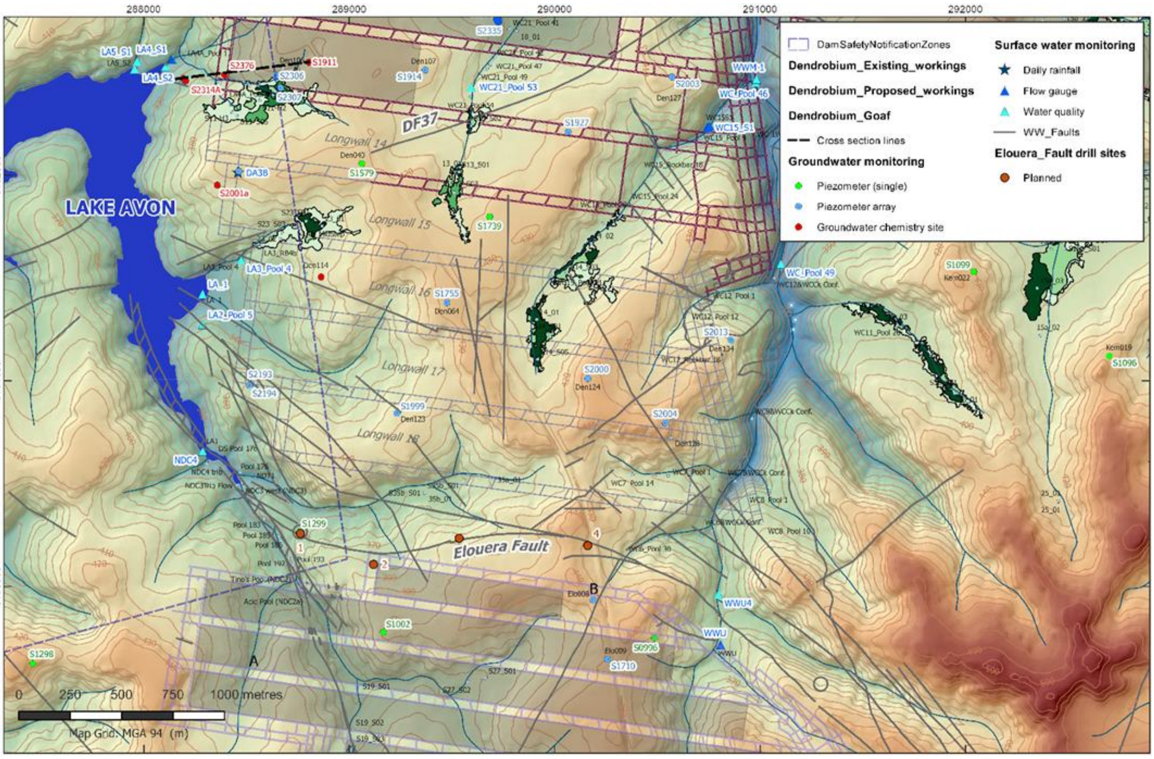


Figure 19: Map showing the location of Avon Reservoir, faulting in the vicinity of Dendrobium LW 15 to LW 18, and the Elouera Fault projected to run in the barrier pillar between Dendrobium Mine and extracted longwall panels in the Elouera Mine (HGEO, 2017d)

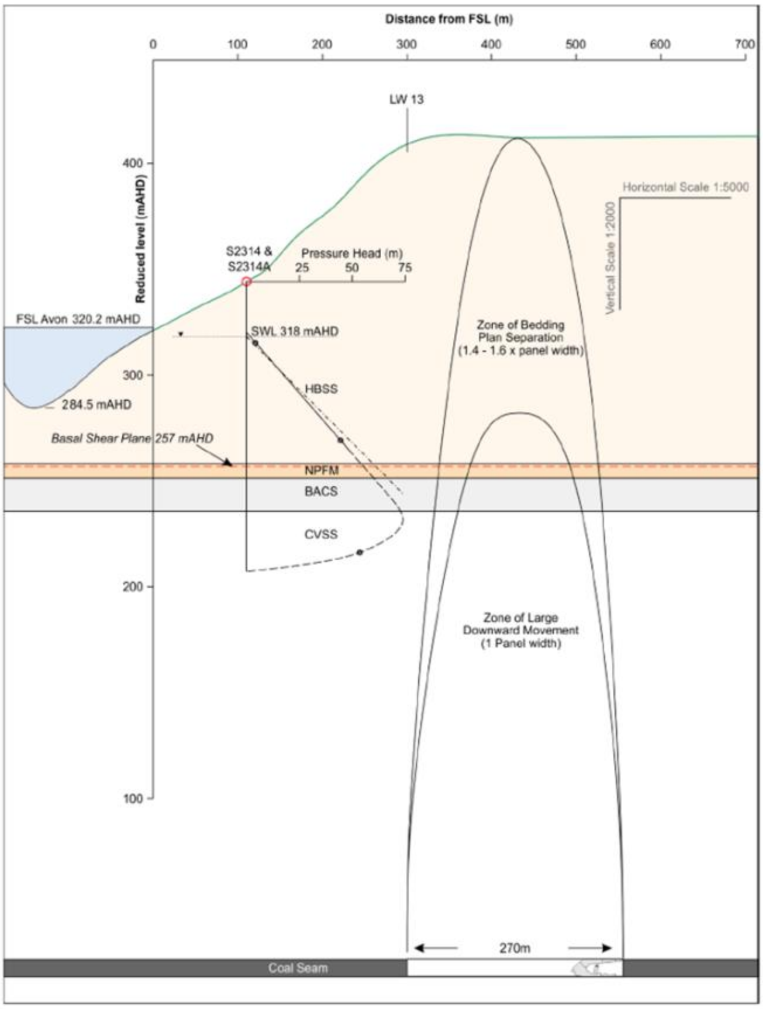


Figure 20: Stylised cross section between Avon Reservoir and Dendrobium LW 13 showing the location of the basal shear plane deduced from borehole investigations (SCT Operations, 2017)

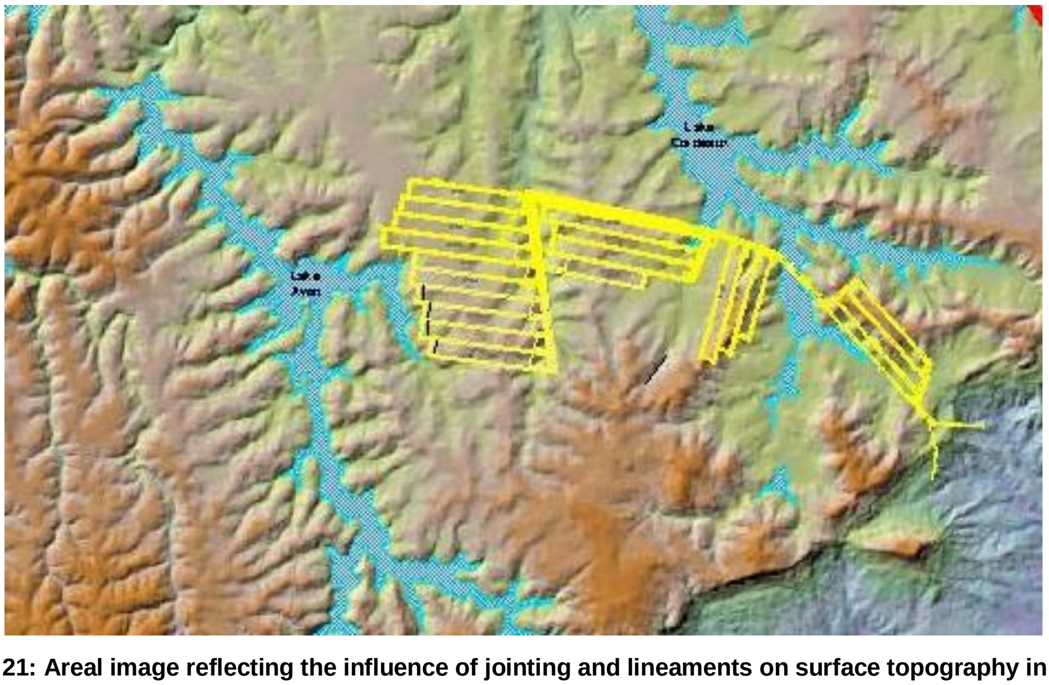


Figure 21: Areal image reflecting the influence of jointing and lineaments on surface topography in the vicinity of Dendrobium Mine

According to a report for South32 prepared by HGEO (2017d), numerical modelling has indicated that a transmissive fault in the vicinity of LW 16 is unlikely to have a significant influence on seepage loss from Lake Avon or inflow to the mine at the completion of LW 16. The report states that estimates of seepage from Lake Avon after the completion of LW 16 range between 0.04 ML/day to 0.93 ML/day (HGEO, 2017d).

Since Dendrobium Mine already has an approval to extract coal in Area 3B, the Panel was restricted to providing advice on whether it considered that the extraction of LW 16 would result in an exceedance of a Performance Measure. Accordingly, it advised that

> "*Based on the information available to it, the Panel does not have any evidence at this stage relating to loss of water that constitutes an exceedance of Condition 3 of Schedule 3 of the development consent; or exceedance of Condition 11 Performance Measures for Area 3B dated 16 December 2016 in relation to watercourses and water storages*" (IEPMC, 2018).

However, the Panel foresees that faulting, basal shear planes, lineaments and the potential to unclamp and reactivate fault planes will need to be very carefully considered and risk assessed prior to finalising the mine layout for LW 17 and LW 18. The PSM study had regard to investigations undertaken between Area 3B and Avon Reservoir (SCT Operations, 2015; South32, 2015; SCT Operations, 2016) that PSM understood were at the request of the Dam Safety Committee and formulated to test a number of hypotheses about potential losses from and connections with Avon Reservoir. The PSM study noted that based on these investigations, SCT Operations (2016) had concluded a two to three-fold increase in permeability post mining but that a review of the data by PSM indicated that an alternative interpretation would put this increase at a higher number. The PSM study did not disclose the alternative interpretation but the Panel agrees that there are alternative interpretations. The PSM study went on to conclude that:

> *"It is expected that the effects of shearing and valley bulging will be exacerbated with additional longwalls in Area 3B and therefore simple linear extrapolation of these findings as undertaken in SCT (2016) are likely to underestimate the impact."* (Sullivan & Swarbrick, 2017)[34]

The Panel concurs. Furthermore, the Panel advises that the potential impacts associated with interaction between the existing workings of Elouera Mine and the future workings in the southern end of Area 3B also need to be carefully assessed, especially given the current upper-end dimensions of the Dendrobium Mine layout. Assessment should include the potential for Dendrobium Mine workings to cause enhanced conductivity between Lake Avon and the Elouera Mine workings.

It is anticipated that decision making for LW 17 and LW 18 will be guided and better informed than in the past by the outcomes of investigations, monitoring and independent reviews that DPE has incorporated into conditions of approval in recent SMPs. Nevertheless, additional information commensurate with the risk of impacting water quantity, may still be required, especially into establishing the local behaviour of lineaments, the influence of panel span, extraction height and subsidence magnitude on lineament behaviour, the potential for relaxation of the faulted zone between Elouera Mine and Dendrobium Mine and the implications these matters may have for hydraulic connections from both Elouera and Dendrobium mines to Lake Avon.

3.3 METROPOLITAN MINE

The current mine plan for Metropolitan Mine, shown in Figure 22, is based on the Preferred Project Report assessed by the PAC (2009). In respect of water quantity and quality, the

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[34] Section 8.3

development consent conditions place performance measures on two watercourses and one reservoir, as recorded in Table 5.

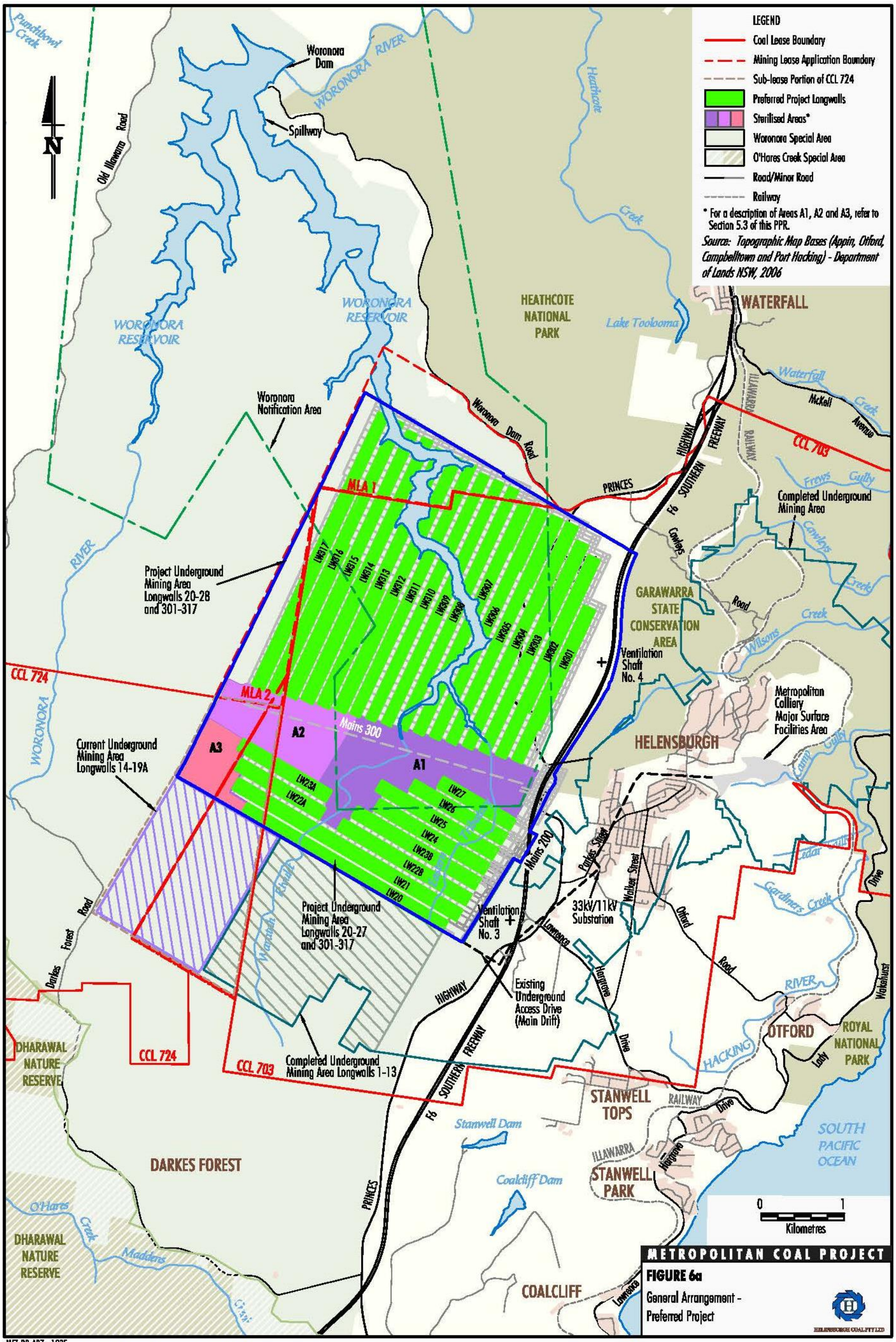

Figure 22: Metropolitan Mine plan on which mining approval was based (PAC, 2009)

Table 5: Subsidence impact Performance Measures for Metropolitan Mine

SCHEDULE 3
SPECIFIC ENVIRONMENTAL CONDITIONS – MINING

PERFORMANCE MEASURES

1. The Proponent shall ensure that the project does not cause any exceedances of the performance measures in Table 1.

Table 1: Subsidence Impact Performance Measures

Water Resources	
Catchment yield to the Woronora Reservoir	Negligible reduction to the quality or quantity of water resources reaching the Woronora Reservoir No connective cracking between the surface and the mine
Woronora Reservoir	Negligible leakage from the Woronora Reservoir Negligible reduction in the water quality of Woronora Reservoir
Watercourses	
Waratah Rivulet between the full supply level of the Woronora Reservoir and the maingate of Longwall 23 (upstream of Pool P).	Negligible environmental consequences (that is, no diversion of flows, no change in the natural drainage behaviour of pools, minimal iron staining, and minimal gas releases)
Eastern Tributary between the full supply level of the Woronora Reservoir and the maingate of Longwall 26	Negligible environmental consequences over at least 70% of the stream length (that is no diversion of flows, no change in the natural drainage behaviour of pools, minimal iron staining and minimal gas releases)
Biodiversity	
Threatened species, populations, or ecological communities	Negligible impact
Swamps 76, 77 and 92	Set through condition 4 below
Land	
Cliffs	Less than 3% of the total length of cliffs (and associated overhangs) within the mining area experience mining-induced rock fall
Heritage	
Aboriginal heritage sites	Less than 10% of Aboriginal heritage sites within the mining area are affected by subsidence impacts
Items of historical or heritage significance at the Garrawarra Centre	Negligible damage (that is fine or hairline cracks that do not require repair), unless the owner of the item and the appropriate heritage authority agree otherwise in writing
Built Features	
Built features	Safe, serviceable and repairable, unless the owner agrees otherwise in writing

Note: The Proponent will be required to define more detailed performance indicators for each of these performance measures in the various management plans that are required under this approval (see condition 6 below).

In November 2016, the company sought approval from DPE for its Extraction Plan for LW 301 to LW 303. Approval was granted in May 2017 for the extraction of LW 301 and LW 302. The Department considered that there remained a degree of uncertainty about the potential effects of LW 303, particularly on the Woronora Reservoir and the Eastern Tributary (DPE, 2017d). As at August 2018, the mine was in the process of extracting LW 302. LWs 301-303 have all been shortened at the northern end with respect to the layout shown in Figure 22 (see Hebblewhite, Kalf, & McMahon, 2017, Figure 2.1)

The mine plan is characterised by relatively narrow panels in comparison to most other Australian longwall operations. Mining is conducted at an average depth of around 460 m and a maximum depth of 540 m. Panel width was nominally 127 m for the first 7 longwalls, increasing to 139 m for LW 8 to LW 10, and then to 163 m for all subsequent longwalls. Interpanel pillar width was 35 m up until LW 20 and then increased to 40 m and subsequently 45 m. Mining height is currently 2.9 m but has ranged up to 3.3 m in early longwall panels. The current mining geometry (163 m panel / 45 m interpanel pillar) results in an areal extraction of 78%.

The combination of these dimensions results in subsidence at any point developing incrementally as shown in Figure 11 as up to four or more panels are subsequently extracted, and in restricted subsurface and surface subsidence as evident in Figure 12. Panel width-to-depth ratio is nominally 0.32 to 0.36, which puts it around the transition point from the sub-critical to critical subsidence range for deep longwall operations in the Southern

Coalfield. This results in a maximum vertical surface displacement of 1.2 m, which is around 40% of the extraction height and at the low end for Australian longwall mining operations.

Since 2009, the mine water make[35] has averaged 0.09 ML/day and, with the exception of May 2011, the 20 day average water make has been below 0.5 ML/day (Hebblewhite et al., 2017).

Condition 3, Schedule 3 of the Project Approval states:

> *"If the subsidence effects and subsidence impacts of the project exceed the relevant predictions by more than 15% at any time after mining has progressed beyond the halfway mark of Longwall 21, or if the profile of vertical displacement does not reflect predictions, then the Proponent shall use appropriate numerical modelling to supplement the subsequent predictions of subsidence effects and subsidence impacts for the project to the satisfaction of the Director-General."*

Figure 23, extracted from the Metropolitan Coal 2017 Annual Review (Peabody Energy, 2018a), shows that measured total vertical displacement over LW 3 to LW 26 has not exceeded predictions by more than 15%. EOP reports indicate that vertical surface displacement profiles are also generally in accordance with predictions. The Panel concludes that subsidence effects have been reasonably well predicted.

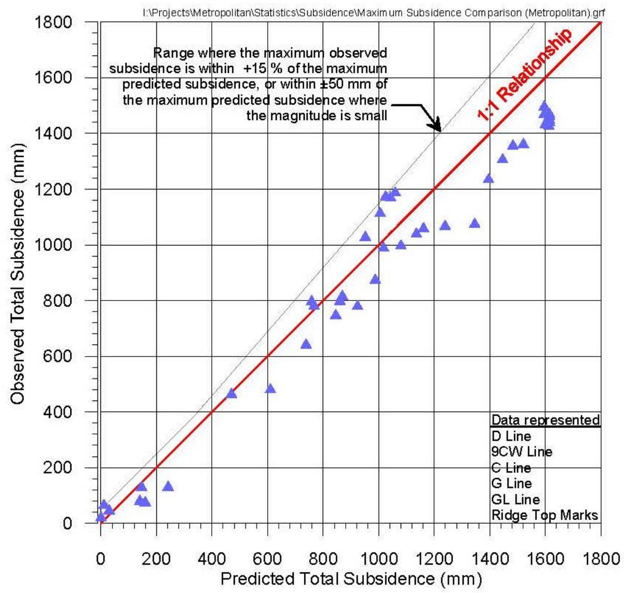

Figure 23: Comparison between the maximum observed and maximum predicted total subsidence for LWs 3 to 26 at Metropolitan Mine (Peabody Energy, 2018a)

Condition 1, Schedule 3 of the Project Approval sets out the performance measures for Eastern Tributary stating:

> *"Eastern Tributary between the full supply level of the Woronora Reservoir and the maingate of Longwall 26 - Negligible environmental consequences over at least 70% of the stream length (that is no diversion of flows, no change in the natural drainage behaviour of pools, minimal iron staining and minimal gas releases)."*

On 14 October 2016, Metropolitan Mine reported the exceedance of the Eastern Tributary performance measure in relation to iron staining. In January 2017, the natural drainage behaviour of additional pools on the Eastern Tributary was observed to be impacted by mine

35 Mine water make is the water that collects in the mine. This water is pumped out to enable mine activities to continue.

subsidence, resulting in the exceedance of the 'negligible' environmental consequences performance measure for the Eastern Tributary in relation to diversion of flows and drainage behaviour. Peabody Energy (2018c) reported that up until December 2016, water levels/drainage behaviour of pools on the Eastern Tributary between the maingate of LW 26 and the full supply level of Woronora Reservoir was consistent with predictions. However, in December 2016 and January 2017, a number of pools with predicted closure values of less than 200 mm experienced loss of pool water levels. The Panel notes that this is about the time that LW 27 undermined the Eastern Tributary.

The impacts are considered anomalous by the company because more than 15% of pools on the Eastern Tributary have experienced loss of pool water levels at predicted closure values of less than 200 mm. Metropolitan Mine reports that the combined data available to MSEC for the Southern Coalfield (including the Waratah Rivulet and the Eastern Tributary results) indicated that less than 10% of all pools have experienced the diversion of flow at predicted closure values of less than 200 mm, consistent with previous assessments of potential pool impacts (Peabody Energy, 2018a). The company considers that, on their own, the impacts for the Eastern Tributary are outside of the predictions of the empirical data base.

The Panel has had regard to the closure predictions shown in Figure 24 that were presented to the PAC and attached to the Conditions of Approval for the mine plan and to the performance measures set in the Conditions of Approval. Given the uncertainty associated with reliably predicting valley closure and its impacts, the Panel is of the view that the historic criteria of a maximum of 200 mm predicted closure for avoiding significant environmental consequences should be revised downwards, at least for watercourses.

On 31 August 2018, three Panel members inspected the Eastern Tributary from below the full supply level, upstream to the 9J crossing above LW 22B maingate and about 200 m further upstream. The entire length below 9J crossing displayed iron staining which extended well beyond the mining footprint.

It was apparent from this inspection that satisfying a performance standard of minimal iron staining over a specific portion of a watercourse might only be practically achievable if the same performance standard applies for a considerable distance upstream of the area to be protected.

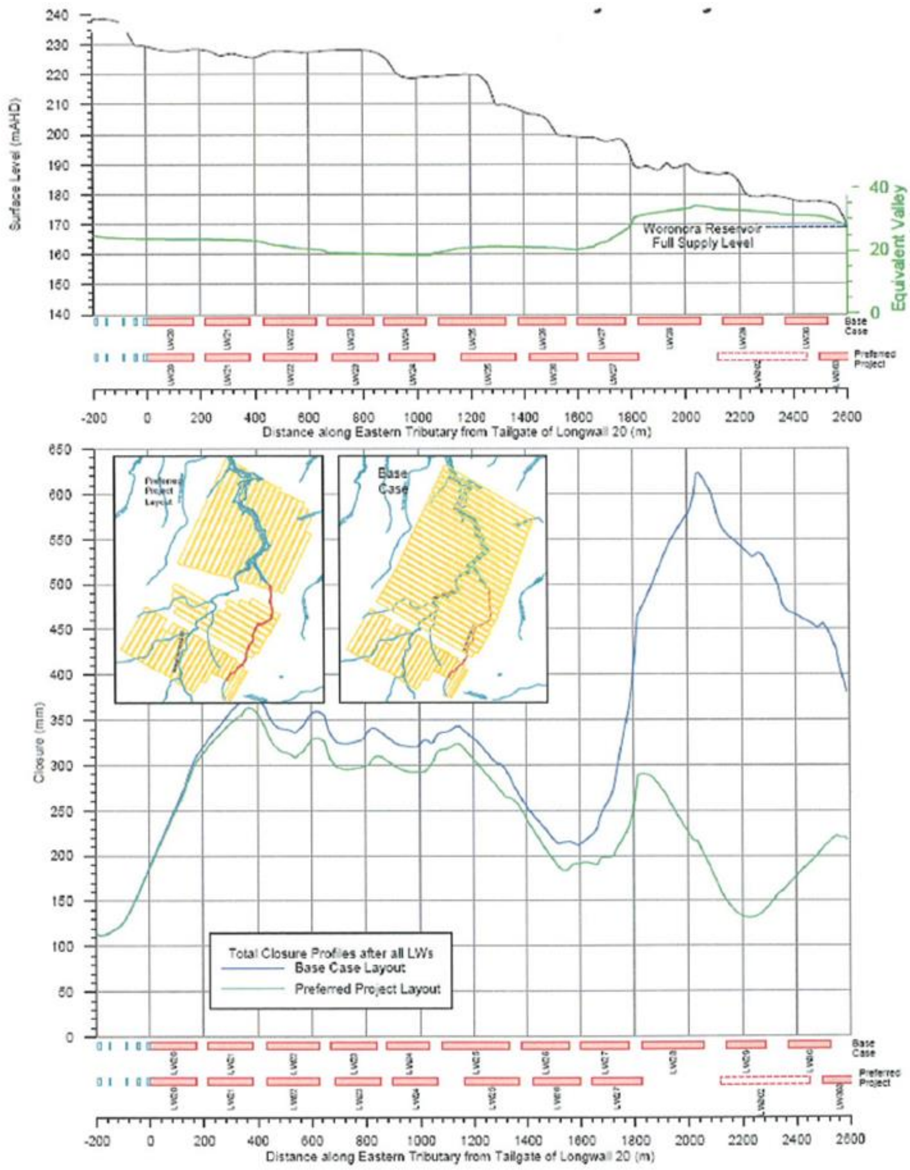

Figure 24: Predicted closure profiles along the Eastern Tributary for the Preferred Mine Plan at the time of PAC assessment in 2009 (DoP, 2009)

The PAC assessment of the Metropolitan Coal Project in 2009 (PAC, 2009) was based on proposed longwall panel widths of 163 m, reducing to 138 m[36] within the DSC's Notification Area for Woronora Reservoir. Metropolitan Mine has applied to DPE to increase the excavation width of LW 304 to LW 306 within the DSC Notification Area from 138 m to 163 m by reducing the width of the intervening chain pillars by a corresponding amount, from 70 m to 45 m. These changes (from a 138/70 to a 163/45 geometry) affect large areas of the three longwall panels.

DPE referred the application to the Panel in August for advice under Term of Reference 3. The Proponent pointed out that the 2009 PAC report noted that reducing longwall panel width beneath Woronora Reservoir was a very conservative approach to extraction under and adjacent to stored waters and was not necessary to prevent direct hydraulic connection between mine workings and surface water bodies.

The Panel notes that while the PAC did report that all stakeholders appeared to be in general agreement that the mine layout utilised at the Metropolitan Mine to (that) date still

[36] 133 m plus 5 m roadway width

resulted in a constrained zone between the mine workings and the surface, the PAC did not explicitly endorse the mining dimensions being proposed for LW 304 to LW 306 when working within the DSC Notification Area. Rather, the PAC Report included recommendations that:

> "*As the Dam Safety Committee (DSC) process lies outside Part 3A, the Panel makes no specific recommendations in relation to this for the Project except to recommend that the Proponent should apply to the DSC to increase the proposed level of extraction adjacent to or beneath stored waters of Woronora Reservoir, with a view to offsetting some of the resource constraints necessary to protect other significant features in the Project Area."*
>
> and
>
> *"On the more general issue of the Reynolds Inquiry, the Panel recommends that a review of the Reynolds Inquiry conclusions concerning mining under stored waters should be undertaken in view of the substantial advances in knowledge since 1977 and the likelihood that continued reliance on these conclusions may sterilize substantial reserves of coal unnecessarily"* (PAC, 2009)[37].

At the time the PAC made these recommendations, the height of connective fracturing was not the contentious issue that it is today and the potential for surface and subsurface drainage well outside the mining footprint along lineaments in the Lithgow region of the Western Coalfield had not been identified.[38] The matter is still under consideration.

A comparison between Figure 21 and Figure 25 suggests that lineament density is considerably less in future mining areas at Metropolitan Mine than at Dendrobium Mine. A number of surface expressions of lineaments were observed during the Panel's inspection of Eastern Tributary but no conclusions could be drawn as to their continuity through to seam level. The Panel currently relies on the Woronora Reservoir Strategy Report – Stage 1 (the Woronora Strategy report) which states that the area appears to be relatively clear of any high density or dominant fault structures and no dykes are known to be present in the area (Hebblewhite et al., 2017)[39],[40].

The Conditions of Approval for LW 301 and LW 302 include a requirement for characterisation of pre and post-mining fractures including shear planes. The Woronora Strategy report states that the current debate regarding the estimation of height and degree of connected fracturing above longwall panels, and whether the presence of shear planes extending towards the base of Woronora Reservoir within the 300 series of longwall panels is relevant, will require more detailed monitoring and review (Hebblewhite et al., 2017). The authors of the Woronora Strategy report consider that the primary focus regarding shear planes should be on major, mining-induced bedding plane shear detected in the upper sections of the overburden, in the region between the reservoir and the mining activity. Accordingly, the report recommends additional monitoring be undertaken at mid to shallow depth in a line extending from LW 301 and LW 302 towards the Woronora Reservoir and the installation of additional inclinometers in the upper sections of the overburden for detecting any significant shear plane movement extending towards the reservoir (Hebblewhite et al., 2017)[41].

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[37] p.137
[38] See Galvin et al. (2016) and Galvin (2017a).
[39] Noting however that the Geological Map for the Southern Coalfield (Moffit, R.S., 1999. Southern Coalfield Regional Geology 1:100 000, 1st Edition. Geological Survey of New South Wales) shows a dyke running down the Waratah Rivulet branch of the Woronora Reservoir.
[40] Just as this report was being finalised, the Panel was provided with an updated report on geological structures in the vicinity of Metropolitan Mine. The new information has no material bearing on the conclusions of this interim report and will be incorporated into the Panel's future reports.
[41] Section 5

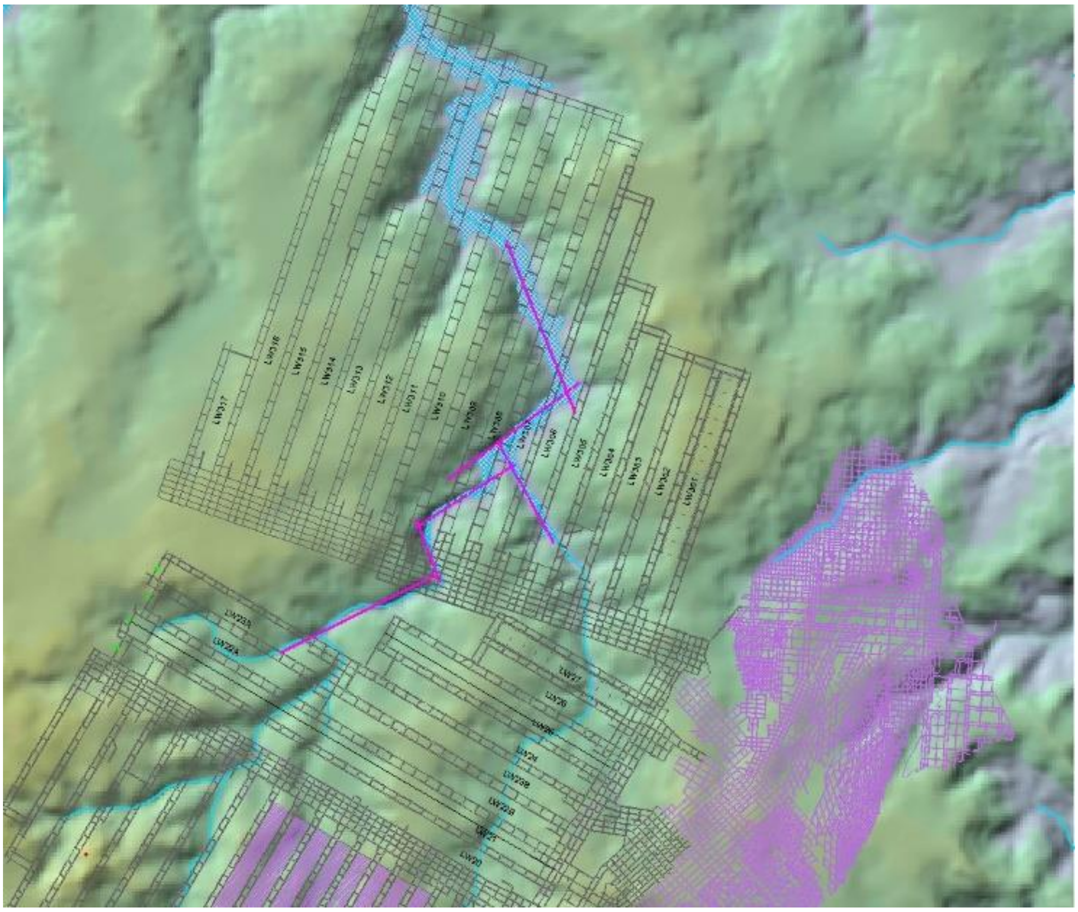


Figure 25: Topography in the vicinity of Metropolitan Mine

The Panel does not yet have a firm view on how relevant the behaviour of lineaments in the Western Coalfield is to the Southern Coalfield and on whether the security of water storage in Woronora Reservoir could be unacceptably impacted by basal shear planes. While history would suggest that due to the combination of relatively narrow panels, wide interpanel pillars and considerable depth of mining at Metropolitan Mine, the likelihood of unacceptable leakage into the mine is very low, the consequences of such an event also need to be carefully weighed up (risk being a combined measure of likelihood and consequence).

3.4 SUMMARY

Dendrobium Mine operates under an approval granted almost two decades ago to extract coal from the Wongawilli Seam using longwall mining in and around the Metropolitan Special Area but not under any reservoirs. Its performance measures complemented by a provision to offset impacts to swamps[42] have permitted it to extract coal up to a height of 4.5 m in longwall panels that are up to 305 m wide, resulting in a percentage areal extraction of approximately 87% and a maximum vertical surface displacement of approximately 78% of the extraction height. Based on the EOP for LW 13, the total daily water inflow into the mine workings is ~7.55 ML/day.

Metropolitan Mine operates under an approval granted almost 10 years ago to extract coal from the Bulli Seam using longwall mining in and around the Woronora Special Area, including under Woronora Reservoir. Its performance measures have permitted it to extract at a typical mining height of 3 m using restricted longwall panel widths of up to 163 m that result in a percentage areal extraction of approximately 78% and a maximum vertical

[42] Offsets for Swamps are discussed in Section 5.5 and the regulatory mechanisms for offsets are in Appendix 2.

displacement of approximately 40% of the extracted seam height. The 20 day average water make for the last decade has been below 0.5 ML/day.

The significant differences in panel width, interpanel pillar width and extraction height dimensions between the two operations are reflected in the significant differences in mining-induced subsidence effects and their corresponding impact on fracturing of the overburden and water inflow. Further investigations are required to determine if the density and behaviour of lineaments also account to some extent for mining-induced effects and their impacts, especially at Dendrobium Mine.

The PSM study concluded that the effects of valley bulging across the arms of Cordeaux Reservoir do not appear to be recognised or incorporated into modelling or the understanding of the effects or impacts of mining at Dendrobium Mine (Sullivan & Swarbrick, 2017, Section 7.5) and that this aspect needs to be evaluated in regard to future mining near Avon Reservoir (Sullivan & Swarbrick, 2017, Section 15). It identified a general need for additional monitoring between Area 3B and Avon Reservoir. The Panel is in general agreement with both conclusions.

The knowledge base regarding mining-induced subsidence and its impacts on groundwater and surface water continues to grow. In some cases, these advances have identified aspects not appreciated at the time of mine approval and may require the originally proposed mine layouts to be revised in order to comply with performance measures. While the PSM study was confined to Dendrobium Mine, many aspects of the study are relevant to Metropolitan Mine.

The conditions of approval for Dendrobium Mine require it to prepare a Subsidence Management Plan for each longwall panel layout and obtain DPE's endorsement of the plan prior to extracting a longwall panel. The conditions of approval for Metropolitan Mine have a similar requirement for a plan known as an Extraction Plan. In accordance with its regulatory powers, DPE can and has been attaching additional conditions of approval to these plans to address the evolving knowledge base and promote compliance with performance measures. This has already gone some way towards DPE responding to the PSM study.

3.5 CONCLUSIONS

a. The performance measures for Dendrobium Mine approved almost two decades ago and complemented by a provision to offset impacts to swamps provide considerable scope for maximising mining dimensions which, in turn, is reflected in the high percentage extraction of the coal resource, the high level of vertical surface displacement and the significantly higher daily water inflow than at Metropolitan Mine.

b. Faulting, basal shear planes and lineaments need to be very carefully considered and risk assessed at both Dendrobium and Metropolitan mines in light of the evolving knowledge base on these features.

c. The Panel endorses DPE's approach of:

    i. Approving longwall panels at Dendrobium and Metropolitan mines on an incremental basis in the light of existing and emerging information and knowledge gaps that have the potential to jeopardised compliance with performance measures.

    ii. Attaching conditions to the approval of Subsidence Management Plans and Extraction Plans that require mine operators to undertake a range of investigations and monitoring and engage independent experts to review and prepare advice to address geotechnical and hydrogeological information and knowledge gaps. This has already gone some way towards DPE responding to the PSM study.

3.6 RECOMMENDATIONS

1. Subsidence Management Plans for future longwall panels in Area 3B at Dendrobium Mine must:
    i. give very careful consideration to the risk to water quantity in the catchment presented by basal shear planes, lineaments, faults and mining-induced changes in permeability around the flanks of Avon Reservoir
    ii. give very careful consideration to the potential for further mining in the southern end of Area 3B to reduce confinement of fault planes and the implication of this for enhanced conductivity between Lake Avon and both the Elouera and Dendrobium mine workings
    iii. be supported by robust independent peer review, risk assessment and risk mitigation controls.
2. The conditions of approval for LW 301 and LW 302 at Metropolitan Mine in relation to additional groundwater monitoring (Section 7.1) and further investigations into potential impacts on Woronora Reservoir (Section 7.2) should be carried forward into future approvals and have explicit regard to the potential for mining-induced impacts on the hydraulic conductivity of lineaments, the possible development of basal shear zones and the risk that these impacts could present to water quantity in the catchment.
3. The concept of restricting predicted valley closure to a maximum of 200 mm to avoid significant environmental consequences should be revised for watercourses.

4 GROUNDWATER IMPACTS AT DENDROBIUM MINE AND METROPOLITAN MINE

This chapter presents an overview of mining related impacts on the groundwater systems at Dendrobium and Metropolitan mines. This is followed by a critique of equations that currently find application for predicting the height of complete drainage above longwall panels. It concludes with an explanation of and observations about the development and refinement of groundwater models that have been used by each of the mines to predict and account for groundwater responses to subsidence.

4.1 GROUNDWATER SYSTEMS

There are essentially two groundwater domains in the Southern Coalfield:

- the **surficial (and shallow) systems** associated with the unconsolidated regolith (soil and transported sediment), the weathered near-surface bedrock and swamps. These systems are often perched and tend to act as water stores and sources of surface water runoff following periods of high rainfall
- the **consolidated rock strata** comprising the deeper Hawkesbury Sandstone, the underlying Narrabeen Group and Illawarra Coal Measures.

Figure 26 illustrates the stratigraphic column for the Southern Coalfield. Shallow valleys on the Woronora Plateau lie in the Hawkesbury Sandstone while deeper and steep-sided valleys may cut through into the Narrabeen Group strata. The orientation and topographic profiles of these valleys are governed by structural elements including widespread vertical jointing, horizontal bedding shears and faults. The Hawkesbury Sandstone also commonly hosts the water table in many elevated areas. Above Metropolitan Mine, the Woronora River and its tributaries lie entirely in the Hawkesbury Sandstone; above Dendrobium Mine, some upstream reaches of the Cordeaux, Wongawilli and Avon streams are incised into the Bald Hill Claystone and Bulgo Sandstone of the upper Narrabeen Group (see Figure 5). Between Area 3A and Area 3B, the Bulgo Sandstone grades into the Colo Vale Sandstone.

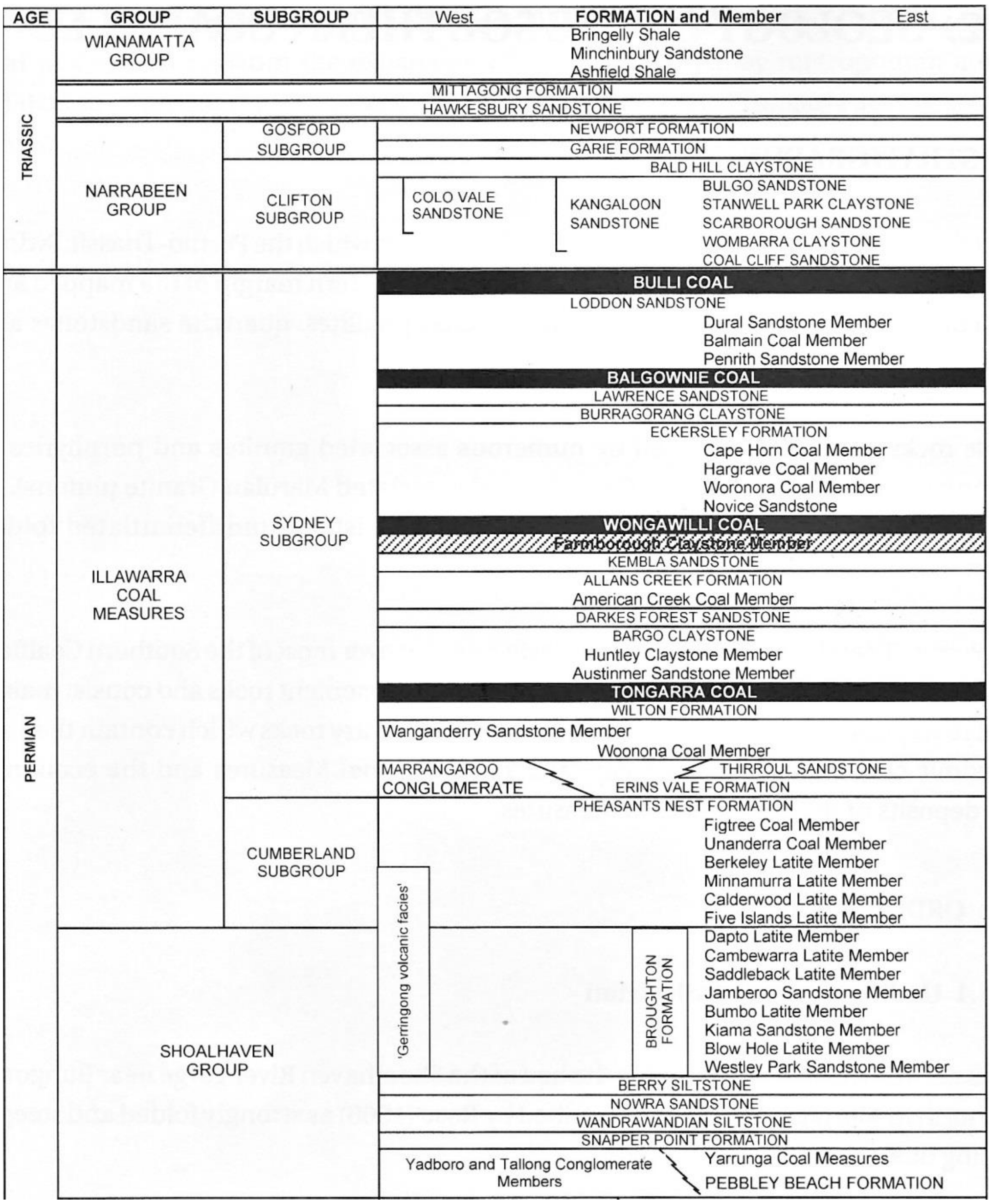


Figure 26: Stratigraphic column for the Southern Coalfield (Moffitt, 2000)

The Permian coal measures comprise interbeds of sandstones, siltstones, claystones and laminites together with the main coal seams being the Bulli, Balgownie and Wongawilli seams. Interburden strata generally exhibit low permeabilities and low drainable porosities while the coal seams often provide storage for low to moderate volumes of groundwater via coal cleats and joints. Figure 27 provides stratigraphic columns summarising the main lithologies in the two areas of interest – Dendrobium and Metropolitan mines. Currently Dendrobium Mine extracts the Wongawilli Seam and Metropolitan Mine extracts the Bulli Seam.

The water table is variously reported to reside at depths below the ground surface varying from zero in swamps and drainage channels, to more than 50 m in elevated terrain. In the elevated areas where mining has not occurred, the geometry of the water table typically reflects topography. This occurs as a result of rainfall infiltration and percolation combined with a resistance to vertically downwards flow which then elevates pore pressures and drives horizontal flow towards the valleys. Groundwater is discharged as baseflow to the creeks or as seepage faces above the creeks, usually exiting along bedding planes. Horizontal shears activated by subsidence also promote horizontal transmission and discharges as illustrated in Figure 10.

When undermined, there is a relatively rapid downwards displacement of the groundwater system. This displacement offsets the shallow water table and inevitably leads to a redirection of groundwater flow from unsubsided strata to subsided strata. The process is complicated by topography, geology, timing (rate of mining), crack propagation and numerous other factors but it invariably results in permanent change to swamp hydrology and potentially permanent re-direction of surface runoff.

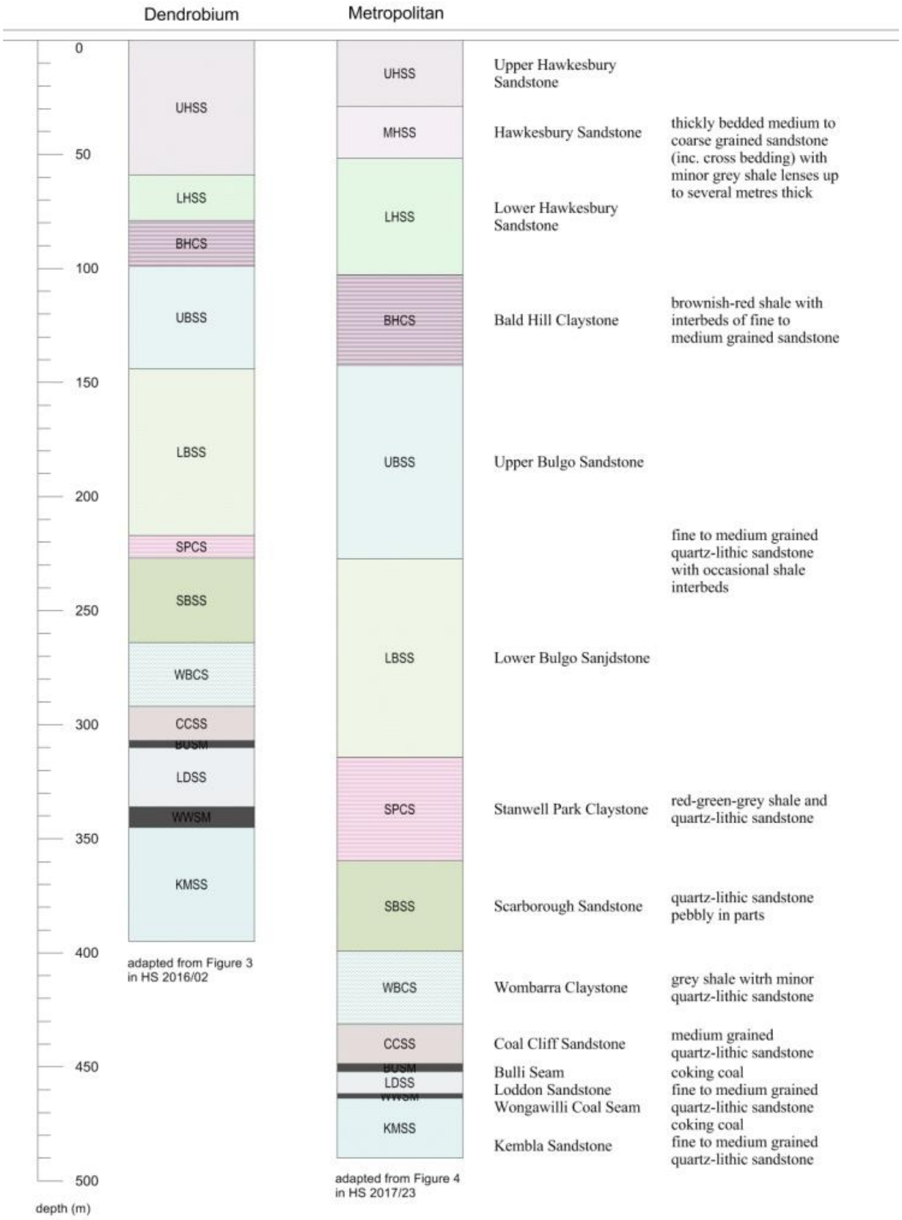


Figure 27: Typical stratigraphic successions for the Dendrobium and Metropolitan mines

More profound changes occur as a fracture regime evolves in the subsiding strata. These changes have been identified in Section 2.3.1 and in summary include:

- **development of a highly permeable caved zone or goaf** - this zone can be portrayed as a pile of rocks hosting relatively high permeability and drainable porosity. Since zero pore pressure (atmospheric pressure) is maintained at the coal cutting face, zero or near zero pore pressures can be expected to prevail in caved strata close to the cutting face (goaf)

- **evolution of a highly connected crack network above goaf**- flow pathways are generated through connection of vertical and sub-vertical cracks and bedding separations. Fracture connectivity is high in regions near the goaf but reduces with increasing height above a mined panel as dead-end fracture paths become more frequent. Intuitively this will result in increasingly tortuous flow paths
- **upwards migration of the phreatic surface** - occurs through the connected fracture zone until equilibrium is achieved between (surface) rainfall recharge percolating downwards, and drainage to goaf. Factors governing this process include the connectivity of fractures and/or the presence of aquitards. If recharge equilibrium is not achieved, then the zero pressure interface will eventually migrate to surface and the entire subsidence zone will become variably unsaturated

The transient nature and the regional extent of impacts associated with these processes are commonly observed through the installation of networks of piezometers.

The Panel notes that piezometers that monitor the water table or swamp systems are commonly constructed as standpipes with pipe slotting located over short vertical intervals. While these installations are generally acceptable for shallow depths, they are impractical for monitoring piezometric heads at depths beyond about 50 metres. A particular weakness relates to their physical dimensions - in order to provide an accurate piezometric elevation in low permeability strata, the standpipe needs to be of slim diameter, slotted over a relatively short section (less than 1 metre)[43], and isolated in the host borehole to the target depth using appropriate muds or grouts. These constraints provide significant challenges during construction.

The preferred method of monitoring pore pressures at depth utilises a piezo-electric device like a vibrating wire piezometer which is installed in a borehole and connected to the surface via a flexible signal cable. Cable connection also facilitates installation of multiple devices at different depths within the same borehole, thereby creating a vertical array which can be used for 3D mapping and analysis of the pore pressure regime. Pore pressures are routinely measured and stored on data logging devices for subsequent download and analysis.

Vertical arrays of piezometers installed along the centreline of longwall panels are especially important for providing the most reliable indication groundwater flows and the height of free drainage within the subsidence zone. Unfortunately, these centreline installations invariably fail when undermined due to stretching and shearing of the data cables. Consequently, it is necessary to drill a new borehole and install a new (vertical) array of piezometers if monitoring is to be continued. However, borehole construction post mining can also be extremely difficult due to the presence of subsidence related fracturing. Accordingly, piezometer installations (post mining) rarely attain depths equivalent to the mined seam. Further, the risk of failure remains until the effects of incremental subsidence have dissipated and the strata no longer exhibit movement. This period can be several years.

In contrast, piezometers installed over pillars and solid abutments are much less likely to fail. Data from these piezometers generally facilitates mapping of the regional water table and regional pore pressures, and an assessment of mining related impacts.

Given the above, the Panel confirms that there will always be a distinct knowledge gap within the subsidence footprint between the onset of subsidence (and failure of the devices), and installation of a replacement piezometer array. One way of addressing this issue is to conservatively assume atmospheric (zero) pressure prevails throughout the mined coal seam, including goaf. The pore pressures and pressure gradients prevailing in adjacent

[43] Long slotted sections can initiate groundwater flows between strata via the piezometer and host borehole resulting in imprecise assignment of piezometric elevation.

areas can then be interpolated through the use of a computer-based groundwater models combined with measured pressures to generate a reasonable estimate of pore pressure losses attributed to mining.

4.2 IMPACTS OF DENDROBIUM MINE AND METROPOLITAN MINE OPERATIONS

An overview of mining related impacts on the groundwater systems at Dendrobium and Metropolitan mines suggests the former has a significantly higher impact footprint based on the historically measured mine water ingress. Over the last five years, average daily ingress at Dendrobium Mine has increased from around 2.5 ML/day to more than 7.0 ML/day, with higher short term inflows after rainfall. In contrast, Metropolitan Mine has increased from about 0.4 ML/day to about 0.6 ML/day and does not react to rainfall events.

While both areas share a common stratigraphy (see Figure 27), obvious differences include the depth of mining, the seam being mined and the longwall panel dimensions. Dendrobium Mine operations target the Wongawilli Seam at depths ranging from about 140 m to 410 m (mean depth of ~364 m for Area 3B) while Metropolitan Mine operations target the Bulli Seam at depths of about 390 m to 540 m (mean depth of ~460 m). Panel widths at Dendrobium Mine have increased from 245 m to 305 m while panel width at Metropolitan Mine has been 163 m since LW 11.

Specific contributions to mine water ingress at Dendrobium and Metropolitan mines include:

- **depletion of porous strata storage** - this includes horizontal flow in strata adjacent to and within the subsidence zone, vertical leakage (downwards as porous matrix flow) and enhanced drainage via the crack network that evolves above goaves
- **rainfall runoff infiltration and percolation** - this contribution is associated with seam to surface cracking which intercepts surface drainage channels and provides flow paths to underlying mining operations
- **leakage from surface water storages (e.g. Avon Dam)** - the rate of leakage is governed by strata (matrix) permeabilities, subsidence induced cracking and bed separations, and the prevailing hydraulic gradient.

Each is discussed in the following sections.

4.2.1 Depletion of porous matrix storage

Porous matrix storage is defined by the drainable porosity which is fully depleted within the caved zone, partially or fully depleted within the overlying connected fracture zone and partially depleted in adjacent (and more regional) strata that are not undermined. Drainage of the porous matrix is significantly enhanced (and accelerated) by the crack network and crack connectivity within the subsidence zone. Since high matrix permeabilities are normally associated with high drainable porosities, strata exhibiting these characteristics can be expected to yield high volumes of groundwater when undermined. Conversely, low matrix permeabilities can be expected to yield low volumes of groundwater when undermined. Since mining is a continuous process, this contribution normally identifies with a steady increase in groundwater reporting to goaf and subsequently captured by the mine water management system.

The Panel notes that a particular feature of this flow system is a reduction in the horizontal flow rate towards the disturbed and subsided zone as the strata are dewatered. This results from the relationship between relative permeability and saturation within an aquifer layer; at zero saturation the permeability falls to zero and horizontal flow ceases or becomes restricted to a seepage face. This phenomenon tends to create steep hydraulic gradients around the perimeter of extracted longwall panels. The ‘steepness’ may be moderated if horizontal fracture (shear) planes or bed separations induce leakage from overlying strata and convey flow laterally to the connected vertical fracture network. These localised horizontal drainage features can sometimes be observed in shaft sinking operations.

At Dendrobium Mine, the contribution from porous storage has been identified from piezometric observations (showing reduced pore pressures towards longwalls) and from in the mine pumping data and separated from the total flows recorded in each of the four mining areas. The highest porous matrix inflow is associated with Area 3B which has risen from zero in mid-2013 to about 4.2 ML/day in January 2018. The Panel notes that this rate is much higher than rate of less than 0.6 ML/day recorded at Metropolitan Mine.

The Panel considers that it is very likely that the high rate of influx at Dendrobium Mine is associated with a connected fracture regime that extends upwards to the surface, with this network providing access to the high drainable porosities present within the Hawkesbury Sandstone.

4.2.2 Rainfall runoff infiltration

The potential magnitude of contributions at Dendrobium Mine from rainfall infiltration has been previously assessed by Mackie Environmental Research (MER, 2016). The methodology for separating rainfall runoff-percolation from the water balance data set[44] involves subtracting the low frequency rise (or fall) in mine water ingress from the full data set for each of the mining areas. The resulting subset exhibits short term (high frequency) fluctuations which have been compared to historical rainfall and potential percolation from surface to seam via crack pathways. Results demonstrate the following:

- **Area 1** (Cordeaux Dam catchment) exhibits a weak but discernible correlation with rainfall
- **Area 2** (Cordeaux Dam catchment) shows a strong correlation with rainfall events both during and post mining – most high rainfalls initiate reasonably rapid and generally large increases in water make with a number of inflows exceeding 3.5 ML/day. The scale and rapidity of response to rainfall suggests a direct fracture network connection to surface.
- **Area 3A** (part Cordeaux Dam, part Wongawilli Creek catchment) shows a strong correlation with rainfall; high rainfall events initiate substantial increases in water make with inflows generally between 0.5 and 1.5 ML/day. These contributions may be associated with reported loss of flow in sub-catchments of Wongawilli Creek [45]
- **Area 3B** (part Cordeaux Dam, part Donalds Castle Creek, part Wongawilli Creek catchment) shows a moderate correlation with rainfall events - some events initiate rapid increases in water make (above 1 ML/day) while others do not. This may be attributed to spatial variability in rainfall and surface cracking characteristics. These inflows may also be associated with reported loss of flow in sub-catchments of Wongawilli Creek noted above.

The Panel further notes that its rainfall event correlations are in general agreement with Dendrobium Mine assessments. However the mine reports that while large rainfall events (>150 mm/week) in Area 2 result in elevated mine inflows, "*small to moderate events generally do not"* (HGEO, 2017b).

This conclusion is questioned by the Panel and highlights the need to consider the runoff-infiltration component in a cumulative way since a number of small separate rainfall events occurring in close succession can, and do lead to recharge percolation and elevated mine inflows.

[44] Based on a water management data spreadsheet supplied by Dendrobium Mine.
[45] See South32 (2018c) Table 4.

In relation to surface water redirection, HydroSimulations (2016) determined from binary mixed modelling based on the presence of tritium[46] in surface waters, that the percentage of modern water entering Area 2 was 25%. The uncertainties associated with this and other hydrochemical markers in calculating percentage contributions, have previously been questioned (Mackie 2017). More recently, HGEO (2017b) derived an Area 2 estimate of 78% rainfall contributions. This inflow is more in line with the 90% contribution for some events derived by Mackie after independently assessing the mine water management data

In summary, total mine water ingress from January 2010 to March 2018 totals about 18 GL of which about 6 GL is attributed to rainfall percolation. This volume may be regarded as diverted surface runoff that would otherwise have reported to Wongawilli Creek or directly to either Cordeaux or Avon reservoirs.

4.2.3 Leakage from surface water stores

The potential for leakage from Avon Dam has been considered by South32 with a localised study being conducted in the area immediately west of longwall LW 13. The study relates to boreholes S2314 located approximately 175 m from LW 13 and drilled before mining of LW 13, and S2314A drilled adjacent to S2314 after subsidence associated with LW 13.

Key study findings reported by SCT Operations (2017) support an apparent increase in strata hydraulic conductivities from near surface to a depth of at least 85 m. Test results using a 6 m straddle packer interval, are represented in Figure 28 which shows an increase of one to two orders of magnitude in hydraulic conductivities after mining. The increases are attributed largely to joints and bed separations.

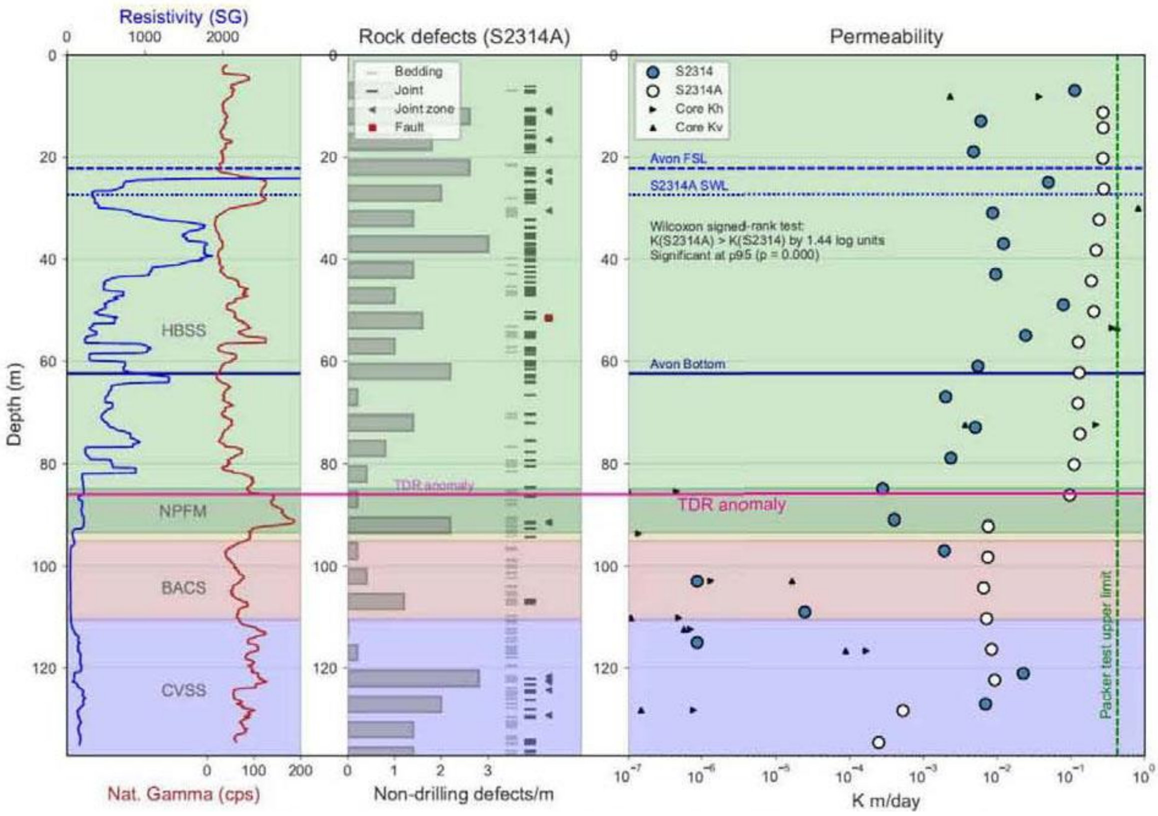


Figure 28: Hydraulic conductivity (permeability) profile in boreholes S2314 (before LW 13 subsidence) and S2314A after LW 13 subsidence from HGEO (2017a). An increase of one to two orders of magnitude is generally evident.

46 Tritium is a radioactive isotope of hydrogen that is used as a tracer (hydrochemical marker) to determine the transit times of groundwater and surface water.

Analyses by HGEO (2017a) suggest the upper limit of leakage along the shoreline reach adjacent to from LW 12 to 16 will be 0.73 ML/day. The Panel considers this upper limit estimate to be reasonable, provided that the area is not affected by geological structures (such as faults, dykes and diatremes).

4.3 ESTIMATION OF THE HEIGHT OF DRAINAGE ABOVE MINED LONGWALL PANELS

The development of a groundwater flow model to assess the impacts of longwall mining requires the inclusion of the fracture-enhanced domain to represent accelerated drainage of strata above mined panels. Chapter 2 discussed the characterisation of this sub-surface environment from a geomechanical perspective and introduced a hydrogeological perspective. Essentially this latter perspective acknowledges the evolution of a freely draining system whereby zero pore pressures that are present in underground roadways and at the coal cutting face, migrate upwards through the cracked and broken rock, to some definable height above the extracted coal seam. This height is synonymous with the so-called 'height of complete drainage (H_{cd})' above which, pore pressures are greater than zero.

Prediction of the height of complete drainage is not a simple task due to the high degree of uncertainty associated with the material properties (drainable porosities and hydraulic conductivities) of the different rock strata and the pre-existing and mining induced fracture regime. Ideally the behaviour of the strata could be simulated using a computer based geomechanical model to identify mining-induced strain in the rock mass and so establish the likelihood and locations of fractures.

Theoretically, coupled solutions which incorporate the outcomes of the geomechanical modelling into the groundwater models can then be adopted. Unfortunately such modelling requires significant computing power (and time) – especially three dimensional modelling. Accordingly, geomechanical modelling is generally restricted to two dimensions and the results translated into a three dimensional groundwater flow model for separate (uncoupled) predictive purposes. Gale (2008) presents examples of the geomechanical modelling approach for NSW mine sites, which was adopted in the EIS for the Wallarah 2 Coal Project assessed by the PAC (2010).

In recent years, an alternative approach involving empirical equations that attempt to define the height of complete drainage have gained variable degrees of acceptance with mine operators, consultants and regulators. Considerable controversy and confusion currently surrounds the predictive capacities of equations derived from three models that find application in Australia. These are the Tammetta model (Tammetta, 2013) and the two models of Ditton Geotechnical Services (DGS) referred to as the Geometry Model and the Geology Model (DGS, 2013; Ditton & Merrick, 2014). DGS recommends the Geology Model because it has a higher coefficient of determination when fitted to the underpinning database. (Note: The DGS models and DGS equations are generally referred to as the Ditton models and the Ditton equations, respectively).

4.3.1 Estimation Equations

The reliability of the respective databases for the Tammetta and the DGS equations has been the subject of considerable debate since the equations were first developed. DPE's Scope of Works for the PSM study included *"analysing the evidentiary databases and statistical methods used by Ditton (2013)[47] and Tammetta (2012 and 2015) and providing*" critical review of the reliability of the data points used and potential sources of uncertainty.[48]

[47] The Panel notes that this reference relates to the database that underpinned the first equation produced by DGS and that the database and the equations derived from it were updated by DGS in 2014 (DGS, 2014). The Panel has had regard to both databases.

[48] Sullivan and Swarbrick (2017) report that the PSM Scope of Works included: *"analysing the evidentiary databases and statistical methods used by Ditton (2013) and Tammetta (2012 and 2015) and providing: a summary of which data points have*

However, circumstances neither permitted the databases nor the mechanics of the models to be assessed in detail, although the consultants did make a number of negative findings about the models (Sullivan & Swarbrick, 2017). The peer reviewers of the PSM study report (Galvin, 2017b; MER, 2017) questioned some of these findings as have others subsequently (see for example, HydroSimulations (2017b) and Hebblewhite (2018)).

The current situation is that the matter remains as or more contentious than prior to the PSM study. Given the bearing that the equations have on the reliability of groundwater modelling and current and impending applications for approval from DPE for mine layouts at Dendrobium and Metropolitan mines, the Panel has given detailed consideration to them in addressing Term of Reference 1.

Figure 29 and Figure 30 highlight the nature of the problem, wherein the Tammetta equation (Tammetta, 2013) typically predicts a 40% to 60% greater height of complete drainage than the DGS geology equation (DGS, 2014; Ditton & Merrick, 2014). This has significant implications for Dendrobium Mine as illustrated by Figure 30A, because the Tammetta equation predicts complete drainage all the way to the surface over the centreline of longwall panels in Area 3B. In contrast, the mean height of complete drainage at Metropolitan Mine is predicted to remain about 300 m below the surface (Figure 30B).

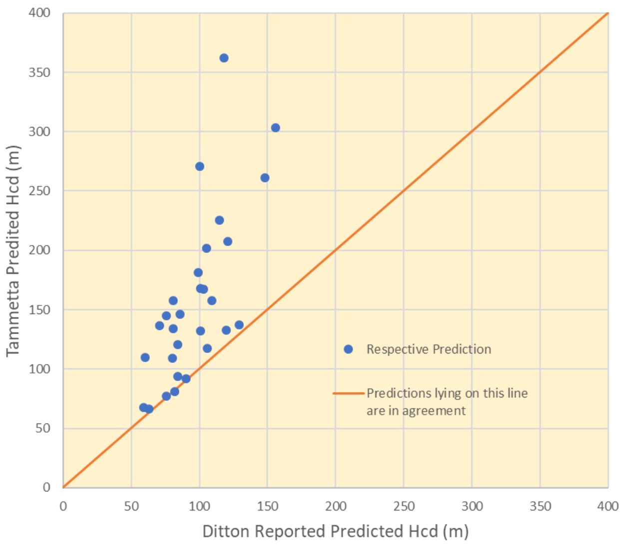


Figure 29: Comparison between the height of complete drainage as predicted by the Tammetta equation (Tammetta, 2013) and the DGS geology equation (Ditton & Merrick, 2014) when applied to the database of DGS (2014)[49]

been included in each model; a critical review of the reliability of the data points used and potential sources of uncertainty; and an analysis of the potential strengths and weaknesses of each model".

[49] Note: The X-axis is based on values reported in Table A6.5 of DGS (2014) and not on values calculated by the Panel by applying the DGS geology equation to the database recorded in Table A6.5. This is because the equation does not reproduce the values reported by DGS (2014) for Sites No. 21, 23, 24, 25, 29 and 30.

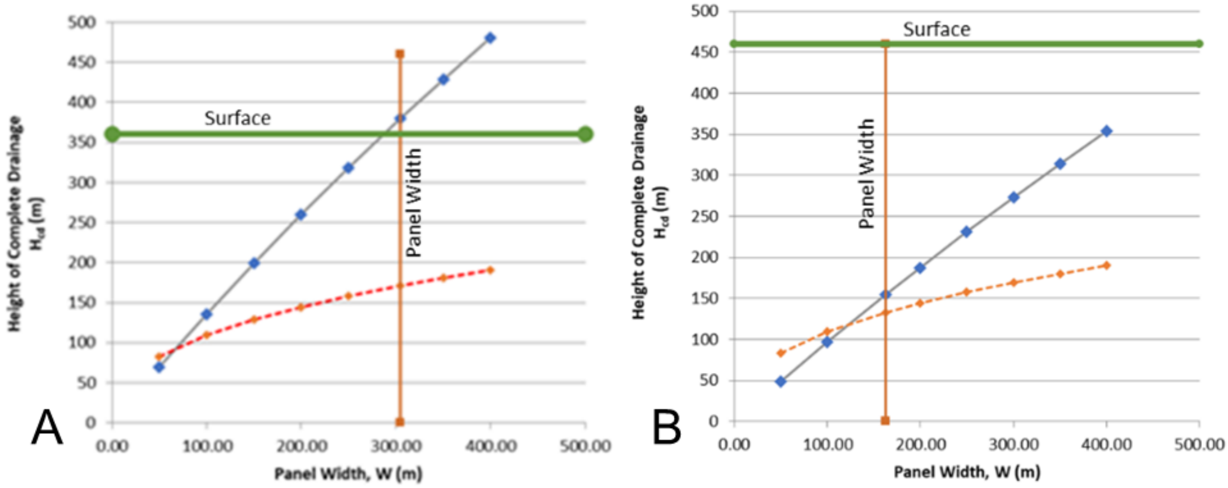


Figure 30: Comparison between the predictions of the Tammetta equation (blue squares) and the DGS geology equation (orange diamonds) based on typical extraction height and depth of mining at Dendrobium and Metropolitan mines

- **A) Dendrobium Mine Area 3B – Panel depth fixed at 360 m, Extraction height fixed at 4 m, Panel width increases left to right**
- **B) Metropolitan Mine LW 301 – LW 303 - Panel depth fixed at 460 m, Extraction height fixed at 3 m, Panel width increases left to right**

The Tammetta and DGS equations are generally referred to as empirical equations, although DGS has adopted an analytical approach based on simple beam theory in establishing the foundations for what it refers to as the 'geology' equation. It is important for the purpose of assessing reliability to recognise the criteria that an empirical model needs to satisfy for it to also be considered mechanistically sound. A purely empirical approach is one based on a series of controlled experiments in which the influence of each variable is examined in turn (Salamon, 1974). However, in underground geotechnical engineering it is rarely possible or practical to perform a sufficient number of experiments or to analyse a real engineering problem exhaustively in terms of all possible variables, in order to obtain quantitative general solutions. This is addressed by adopting a scientific approach to empirical research that is focussed on only investigating the effects of the most important or primary variables. Success is dependent on identifying all of the variables and having a database which contains sufficient relevant information to evaluate the influence of those variables (Salamon, 1992, 1993).

4.3.2 The Fracture Network Models and Their Underpinning Databases

4.3.2.1 Definitions of Data

Tammetta (2013) defined complete groundwater drainage as:

> *"the case where pressure head falls to zero or less, over a short time period following caving. The zone of complete drainage (the desaturated zone) provides minimal resistance to groundwater flow due to significant increases in hydraulic conductivity."*

This provides the foundation of the two zone model shown in Figure 31 which was adopted by Tammetta to conceptualise ground deformation on the basis of monitoring results from piezometers and extensometers.

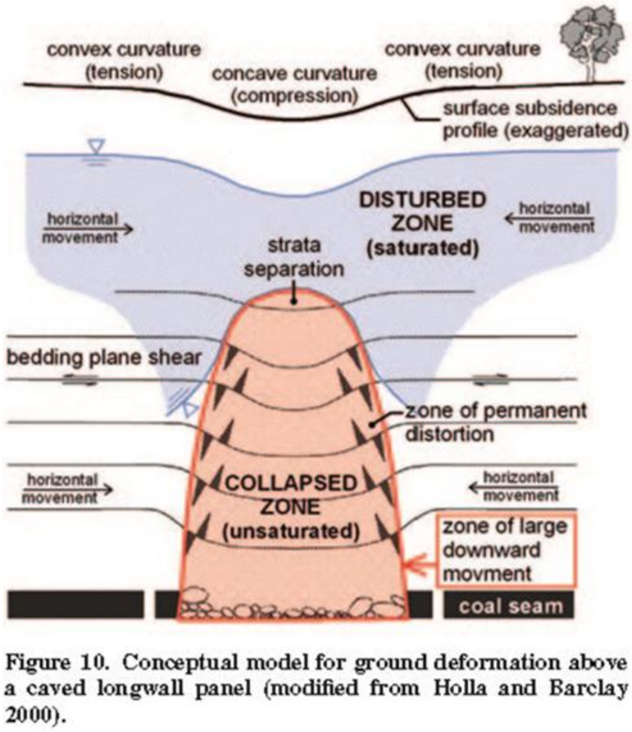


Figure 31: Conceptual ground deformation model associated with Tammetta's technique for predicting the height of complete groundwater drainage (Tammetta, 2013)

Pells (2014) expressed concern that the measured states of the Tammetta data points were assumed to be absolute, rather than snapshots in time. Seedsman Geotechnics (2014) expressed a similar concern, noting that a fundamental difficulty in using groundwater drainage as a measure of impact is that it is difficult to allow for the time factor associated with recovery of water pressure in the dilated zone and, recognising this, the best that the Tammetta model may be predicting is the top of the dilated zone.

DGS's models conceptualise groundwater response to mining using four zones which are mapped to the shell of the classical four zone geotechnical deformation model (See Figure 7). Examples are shown in Figure 32. The 'A Zone' is comprised of the combined caved zone and fracture zone. The 'B-Zone' is described as a subsurface fracturing zone that causes temporary groundwater system disturbance (DGS, 2014). DGS designates a typical vertical strain of 8 mm/m[50] as defining the transition point between the 'A Zone' and the 'B Zone'. Significantly, DGS also reports that its updated database on which the 2014 equations are based includes a greater number of cases "*where the A and B Zone fracture heights were determined from borehole and piezometric data collected over a reasonable period of time (i.e. >12 months after mining impacts)"*.

The 'A Zone' and the 'B Zone' in relation to Dendrobium Mine (DGS, 2016) are described as:

> ***A-Zone or Continuous Fracture Zone*** – *"VWPs[51] in this zone experience rapid head losses in the order of ten's to hundreds of metres due to the high level of fracturing and immediate roof collapse (goaf)……….Turbulent or non-linear flow occurs through the fractured ground in the A-Zone. After initial head losses, some pressure head recovery can and does occur due to resistance to flow that develops once the goaf starts to re-consolidate under load."*
>
> ***B-Zone or Discontinuous Fracture Zone*** – *"VWPs in this zone experience immediate but more gradual head losses as the overburden subsides, bends and shears to a lesser extent than strata in the underlying A-Zone. New voids are created*

[50] >8mm/m = A Zone
[51] VWP – Vibrating Wire Piezometer

but probably include the opening of existing bedding planes and joints with some fresh cracking. Overall, the deformation results in a discontinuous network of cracks that may be interconnected between several horizons but has minimal connectivity to the A-Zone crack network. This has been inferred by the reestablishment of hydrostatic pressure gradients once the new voids re-saturate".

Based on the descriptions of the respective developers, the two DGS models are distinguished from the Tammetta model in that DGS relates the height of full depressurisation specifically to the top of the geotechnically-defined fractured zone, and has regard to the recovery of groundwater pressures as mining-induced storages fill over time.

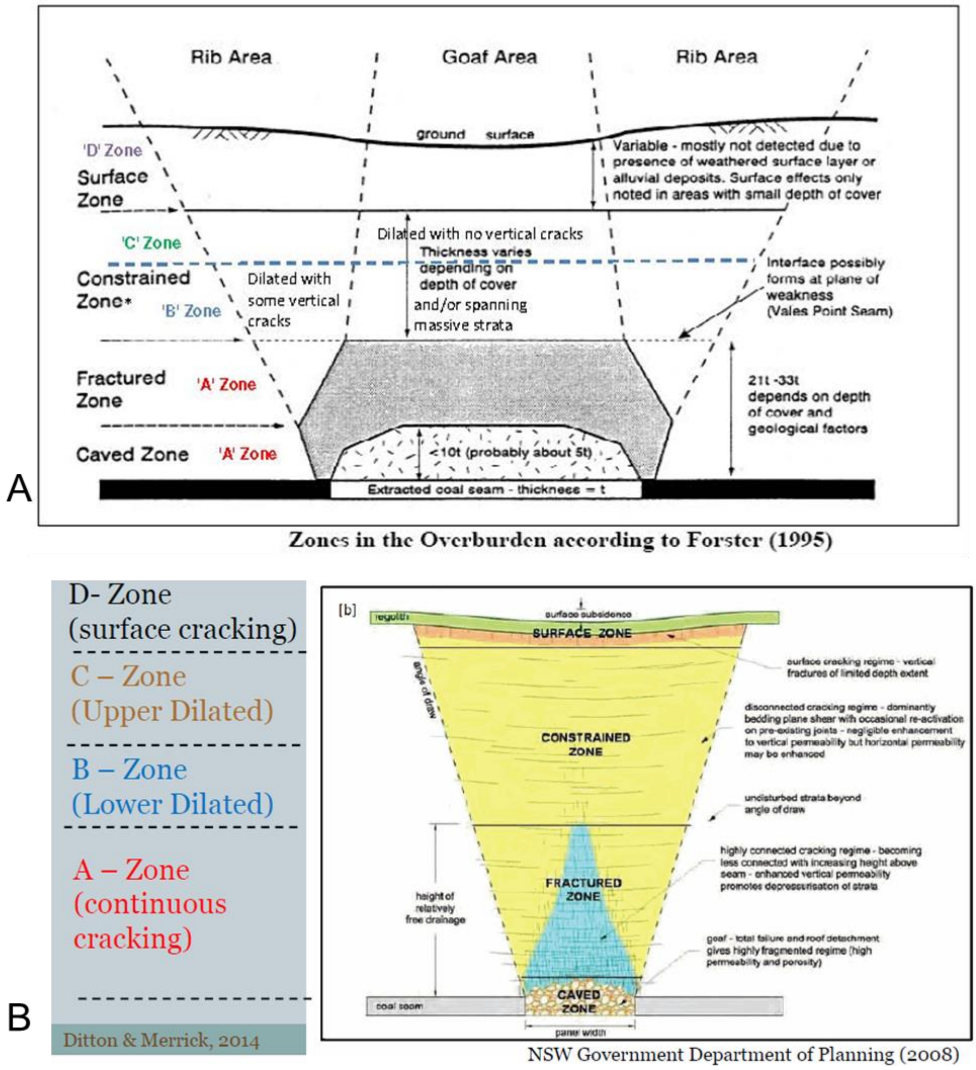


Figure 32: Sub-surface fracturing zones associated with the DGS model of complete groundwater drainage.(A) Zones of Overburden according to Foster 1995 (DGS, 2013), (B) Sub-surface Fracturing Zones (Ditton & Merrick, 2014)

In attempting to clarify this situation, the Panel has consulted with Dr Colin Mackie and had particular regard to what he has previously considered (MER, 2016) to be a consensus view of the changes to the groundwater flow system as a fracture regimes evolves (MER, 2017).

At the time, Dr Mackie introduced the concept of 'tortuous' flow which he has subsequently elaborated on (Galvin, 2017a), proposing that confusion between the various disciplines over the height of fracturing and conflicts between conceptual models and mathematical equations for predicting the height of fracturing can be resolved to some degree by:

1. considering the interval between the mining horizon and the top of the geotechnically defined ‘fracture’ zone (or zone of ‘connective fracturing’) to constitute the zone of ‘relatively free drainage’
2. considering the overlying geotechnically defined zones as constituting a zone of ‘tortuous drainage’ up to a height where mining induced fractures are truly isolated and unconnected.

Essentially, the geotechnically defined *zone of fracturing* is considered to align with a hydrogeologically defined *zone of relatively free drainage*.[52]

The Panel has also considered the following definitions adopted in the Woronora Strategy report (Hebblewhite et al., 2017) and does not find them to be inconsistent with Dr Mackie’s concepts:

> *“…the term “height of fracturing” is used herein to refer to the region of connected fracturing which results in significant depressurisation of the strata.*
>
> *The constrained zone tends to maintain the insitu (i.e. pre-mine) vertical permeability of the strata and therefore continues to restrict vertical flow but can display an increase in horizontal permeability within and above the parabolic fracture zone that has however little effect on vertical groundwater flow rate”.*

4.3.2.2 Data Source and Range

The Tammetta equation was derived from a data set comprising 18 “ordinary” observations of pore pressures in monitoring boreholes located centrally within the subsidence zone at 17 different longwall mine sites spread across four countries. Data from ‘special’ sites over longwall chain pillars, pillar extraction panels and over panels beneath significant water sources was specifically excluded after a significant contrast in measurements between the two groups became apparent.

Tammetta estimated the height of complete desaturation at each location by projecting measured pore pressures at different depths to a zero pressure state and determining the associated height of complete drainage (H_{cd}). A range from H_{min} to H_{max} around H_{cd} was also assessed in order to accommodate uncertainty arising from widely spaced pore pressure sensors typically located above and below the estimated height of complete drainage. This and other observational data along with the method of derivation have been published in the peer reviewed journal, *Groundwater* (see Tammetta (2013)). Subsequently, Seedsman Geotechnics (2014) has questioned the reliability of H_{cd} estimates at three of the locations.

The DGS database and methodology for deriving the geometry and geology equations have not been published but are included as attachments in DGS reports that have accompanied mine approval applications to DPE. An overview of the methodology is provided in a PowerPoint conference presentation that constitutes Ditton and Merrick (2014). The Panel is unaware of the methodology having previously been peer reviewed.

The 2014 DGS database was sourced from 32 mines in NSW and 2 mines in Queensland and includes seven pillar extraction panels. Only five data points are common to the Tammetta database. DGS reports that regard was had to both extensometer and piezometer measurements when compiling the database. The location of these installations relative to the mine workings has not been provided although at least some were above the centreline of extraction panels. It is also reported that when the original 2013 database was compiled “*it was necessary to apply engineering judgement in some cases where the boundaries between the fracture zones were inconclusive due to an incomplete data set caused by shearing of the boreholes above the piezometer unit” (DGS, 2013).*

[52] The Panel has confirmed this interpretation with Dr Mackie.

The PSM study concluded that the Tammetta model and the DGS models are limited by the coverage of their databases and that Dendrobium Mine geometries lay well outside the ranges of the models' databases. As extrapolation of empirical relationships beyond the range of data used in their derivation carries risk, the Panel prepared Figure 33 to help inform its advice. The Figure shows 'effective panel width' plotted against extraction height and against depth of mining for both the Tammetta and the DGS databases.

Effective panel width (W') is an established dimensional adjustment which accounts for ground disturbance not increasing indefinitely as panel width increases. Reference to Figure 12 illustrates that the limiting value (of longwall panel width) is typically in the range of 1.2 to 1.4 times depth of mining. The Panel has based its analysis on a limiting value of 1.4 H to be consistent with the values used to derive the DGS equations. That is:

Effective panel width (W') = W or 1.4 H, whichever is the lesser value.

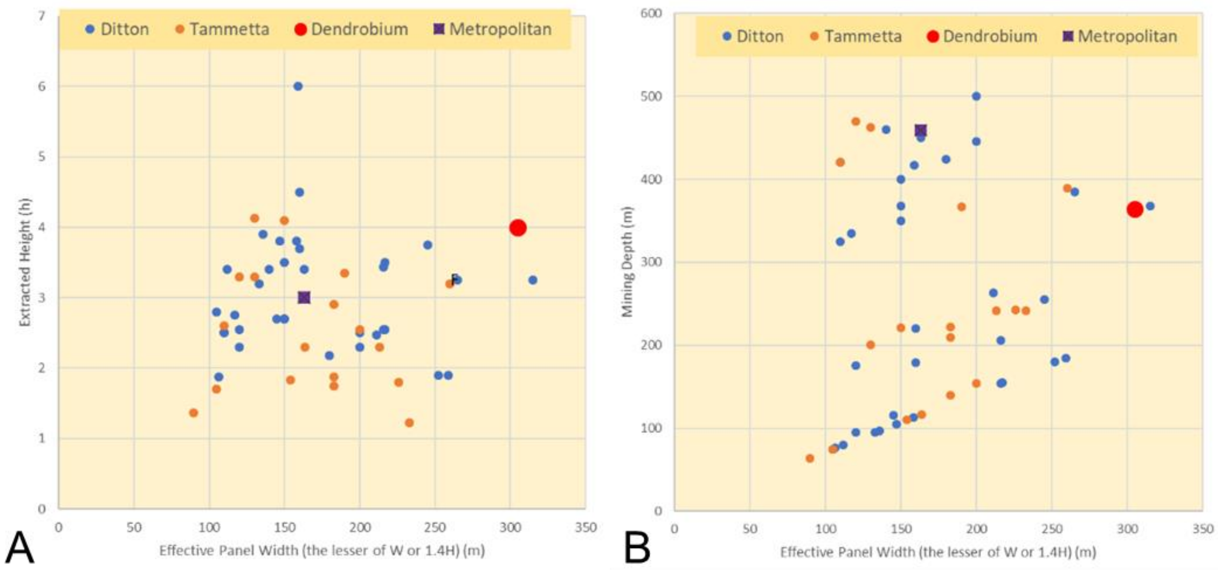


Figure 33: The Tammetta and DGS databases shown as A) extraction height plotted against effective panel width and B) as depth of mining plotted against effective panel width, with the corresponding information also shown for Dendrobium Mine and Metropolitan Mine

Figure 33 shows that the mining parameters associated with Metropolitan Mine are common to both databases (surrounding clusters). However, the parameters associated with Dendrobium Mine plot as an outlier with only one data point nearby which is Springvale Mine in the DGS database.[53] Significantly different subsidence outcomes are associated with these two data sets as illustrated in Figure 12.

4.3.2.3 Data Alignment

Figure 34 shows effective panel width plotted against height of free drainage normalised with respect to extraction height for each data point. The Tammetta data is characterised by the ratio of the height of complete drainage to extraction height exceeding 43 at 50 % (or 9) of the sites, compared to only at 3% (or 1) of the sites in the DGS database, and by a distinct increase in this ratio with increasing effective panel width, peaking at a value of 81. The DGS data is characterised by ratios in the range of 20 to 43 across a similar range of effective panel widths.

[53] Site 17 being Centennial Coal in the Western Coalfield near Lithgow.
This is not the complete picture as the equations are based on sets of data, with each set comprising three parameters. The Panel has assessed this factor and formed a view that conclusions drawn from presenting the data in Figure 33 as sets of two instead of three parameters are reasonable.

The values associated with the five sites common to both data sets have been plotted in Figure 35. Two sites are in agreement. In a review prepared for the owner of two[54] of the remaining three sites, Seedsman Geotechnics (2014) reported that it is not clear how Tammetta derived values from incomplete data sets at these sites.

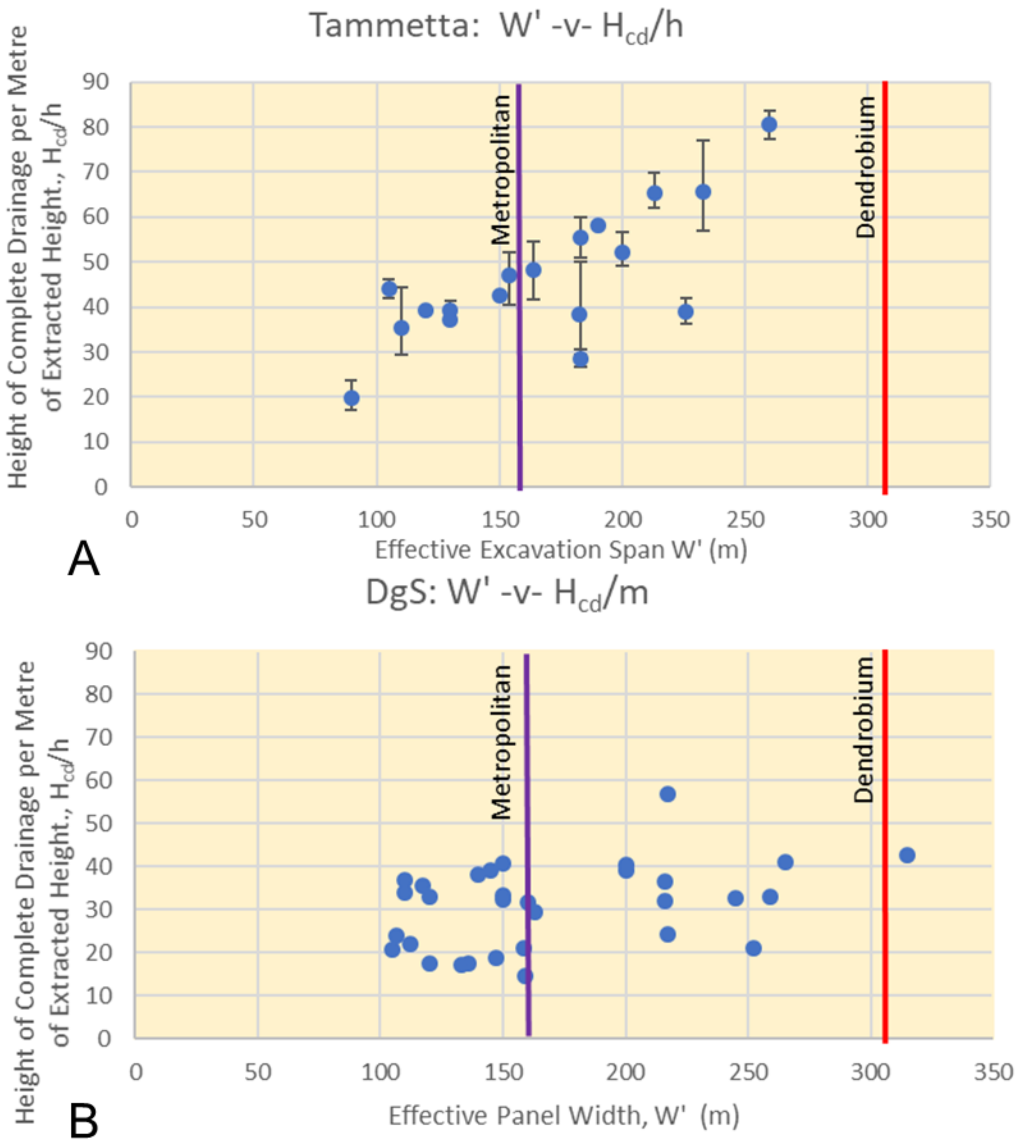


Figure 34: The 2013 Tammetta and 2014 DGS databases plotted in terms of A) effective panel width and B) height of complete drainage per metre of extraction height

54 Mandalong Mine and Springvale Mine

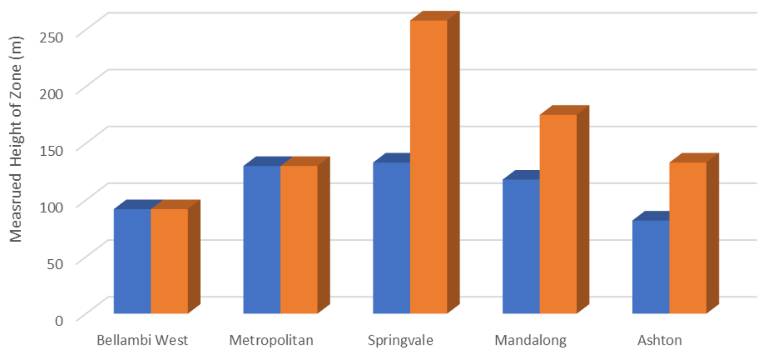


Figure 35: Comparison between measured height of free drainage for the same sites in the databases of Tammetta (2013) (orange), and DGS (2014) measured to top of 'A zone' (blue)

4.3.2.4 Discussion

The Tammetta data points are distinguished from the DGS data points by not being tied to any specific geotechnically based zone of ground deformation; by being based only on sites over the centreline of longwall panels; and on groundwater level measurements apparently made much sooner after the sites were undermined. It might be concluded as others have done (for example, Seedsman Geotechnics (2014)) that the Tammetta model assigns the top of the zone of complete groundwater drainage to an interval somewhere within the dilated zone of the Kendorski (1993) cross-discipline model shown in Figure 16. On the other hand, the DGS models associate the top of the 'A Zone' with the geotechnically defined zone of fracturing. It is not known how many sites in the DGS database were located above the centreline of longwall panels (where height of complete drainage is likely to be greatest) and how DGS derived the maximum height of complete drainage from sites not located over panel centrelines.

Put simply, the Tammetta and DGS databases are poorly aligned. This may be accounted for to some extent by the time dependent nature of the measured values, which Pells (2014), Seedsman Geotechnics (2014) and others have raised as concerns that are shared by the Panel. The Tammetta data is apparently based on measurements made very soon after mining and the Panel questions whether at least some of these data points may relate to parting planes where insufficient time had elapsed for groundwater levels and pressures to recover. The DGS database may not be as susceptible to this situation because the time delay between mining and data collection was longer and because the strain criteria incorporated into DGS data selection process might have accounted to some degree for partings that could recover groundwater pressure in the course of time.

From a geotechnical perspective, the increase in normalised height of complete drainage with increasing panel span (Figure 34A) displayed by the Tammetta database is to be expected but it is remarkably uniform by geotechnical standards. Conversely, the range in the normalised height of complete drainage about a given panel span in the DGS database is to be expected but the relative insensitivity of this range to increasing excavation span is surprising (Figure 34B). Data scatter about a given panel width is an expected consequence of the uncertainty associated with estimating the height of complete drainage and the range of factors noted in Chapter 2 that influence rock mass response to mining. [55] However, except for one data point (where it is known that the A Zone interacted with the surface), the range in height of complete drainage in the DGS database changes very little as panel width is increased, with the maximum height of complete drainage relatively fixed at approximately 40 m per metre of extraction height.

[55] These include the presence of particularly competent stratum, geological structures, the incremental development of subsidence, and changes in rock mass failure mode with increasing panel width-to-depth ratio.

More detailed information on the data selection process for both the Tammetta and DGS models is required to be able draw firm conclusions as to the reliability of each dataset.

4.3.3 The Tammetta Equation

Tammetta approached the prediction of the height of complete groundwater drainage from a groundwater perspective and assumed that this height was related to panel width, extraction height and depth of mining. This relationship was adjusted mathematically to produce the complex formula defined by Equation 1[56] that gave best agreement with Tammetta's estimates of the height of complete drainage.

$$H_{cd} = 1438 \ln(4.315\, x\, 10^{-5} * H^{0.2} * h^{1.4} * W + 0.9818) + 26 \quad (m)$$

Equation 1: Tammetta Model

Where:
H_{cd} = height of complete drainage (m)
H = depth of mining (m)
h = extraction (or mining) height (m)
W = overall panel width (m)[57]

The equation produces good agreement with the estimated values in the Tammetta database. However, due to the uncertainty associated with the determination of actual heights of complete drainage, there are an infinite number of alternative equations that can be generated between Tammetta's prescribed H_{min} and H_{max} bounds.[58] Tammetta addressed the uncertainty in each determination of H_{cd} using a statistical process that indicated a 5% probability bound at 31 m below the equation line and a 95% bound at 37 m above the line.

4.3.3.1 Panel observations

Some stakeholders place considerable weight on the Tammetta model having been published in a peer reviewed journal and conversely, the DGS equations having not been so published. However, the Panel notes that Tammetta's peer-reviewed paper did elicit comment. Notably, Pells (2014) was of the opinion that there was no physical basis for the equation and that it was mathematically inappropriate to define a single independent variable as a function of three independent variables. The lack of a physical basis is evident by the dimensions of the left hand side of the equation being (m) (metres) and the right hand side being ($m^{2.6}$). As such, the equation does not satisfy the principles of a purely empirical approach to deriving a mechanistically based equation.

Mackie (2014) showed that the Tammetta equation could be greatly simplified to a form involving only extraction height and panel span with a minimal reduction in the coefficient of determination.[59]

[56] The equation symbols have been changed in this report so that they more closely conform to established convention in geotechnical engineering.
[57] Note that the Tammetta Equation is based on overall extracted width, W, and not effective panel width, W'.
[58] For example, just assigning three possible drainage heights (say 0.5 m above $H_{cd\ min}$, H_{cd} as selected by Tammetta, and 0.5 m below $H_{cd\ max}$) for each of the 18 case studies in the Tammetta database gives rise to over 380 million possible combinations of input values.
[59] From r^2 = 0.93 to r^2 = 0.92.

Galvin and Mackie reprocessed the database without regard to maintaining dimensional accuracy and concluded that, for practical purposes, the height of complete drainage derived from it could be simplified further to:[60 61]

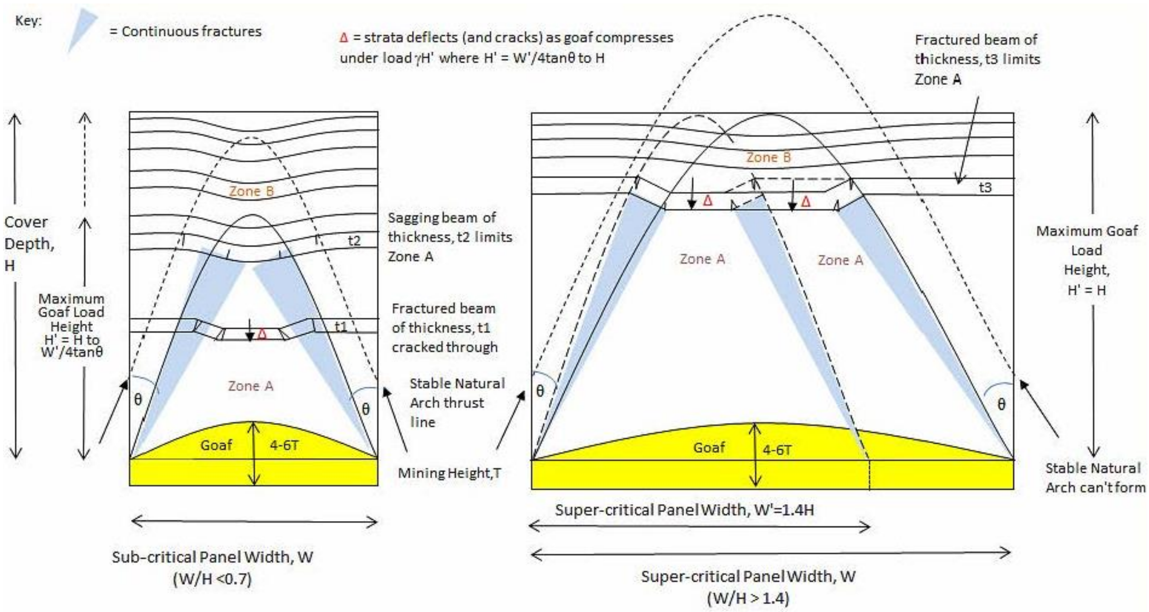
$$H_{cd} = 0.3 * h * W' \ (m)$$

Equation 2

4.3.4 The DGS Equation

4.3.4.1 Model Construction

The DGS geology equation is based on a geotechnical approach that proposes a conceptual model of how the height of the continuous fracturing zone (A Zone) develops for a range of longwall panel width-to-depth ratios, selects three analytical equations that describe key aspects of the model, condenses these into one equation and then calibrates this equation to the DGS database. It is a more complex model than the Tammetta model, both conceptually and mathematically. The model is shown in Figure 36.



Note: In this report, the symbol 'T' for mining (extraction) height in the figure is represented by the symbol 'h'.

Figure 36: DGS (2014) conceptual model for the development of the height of continuous fracturing zone for a range of longwall panel geometries

The DGS model assumes that when the width of an excavation is less than 0.7 times its depth, a natural arch will probably form and transfer the weight of the top 2/3rds of the overburden to the abutments. The strata below this arch will be subject to sagging and bending forces as a result of undermining. Once the W/H ratio exceeds 0.7, the geometry of the arch will be too shallow for it to develop and the rock mass will bend and crack. It is then proposed that provided the rock mass is capable of resisting shear and tensile stresses, a voussoir or 'cracked beam' will form across the excavation until the beam is no longer able to support the weight of the overburden. DGS notes that this is usually assumed to have occurred once W/H reaches 1.2 to 1.4, where after the weight of the overburden will be fully

[60] The total Tammetta database and select portions of it were fitted to a linear equation passing through zero, returning coefficients of determination ranging from r^2 =0.52 based on the complete Tammetta database (m= 0.27) to r^2 = 0.95 based only on those points where the estimated value of complete drainage was known to within an accuracy of 30 m (m = 0.30).

[61] It may per chance but the substitution of the average mining height of 3.25 m for Australian longwall sites based on the DGS database reduces this equation to $H_{cd} \approx W'$, which defines the 'zone of large downward movement' above longwall panels in the height of fracturing model of (Mills, 2012) and (SCT Operations, 2017). An example of this model is shown in Figure 20 relating to the basal shear plane between Lake Avon and longwall panels in Area 3B at Dendrobium Mine.

supported by the goaf. DGS then considers interaction between the goaf and the overlying strata.

DGS then presents an analytical model of overburden fracturing that it considers is consistent with the conceptual model. Three equations are presented by Ditton and Merrick (2014) to account for the fracture development process. The first equation (Equation 3) defines the tensile strength of a thin beam that is simply supported (it rests on stanchions).[62] The second (Equation 4) is a commonly employed equation that approximates the compressive strength of a cracked voussoir beam (there are alternative proposals). The third (Equation 5) has been derived by DGS to account for the interaction between the goaf and the overlying sagging strata (beams) and is based on defining failure in compression based on estimating beam curvature.

$$\text{For a spanning elastic beam, the tensile stress, } \sigma_t = \frac{3\rho g(H'-y)(W'-2ytan\theta)^2}{4t^2}$$

Equation 3

$$\text{For a spanning voussoir beam, compressive stress, } \sigma_c = \frac{\rho g(H'-y)(W'-2ytan\theta)^2}{4nt^2(1-0.667n)}$$

Equation 4

$$\text{For compressive stress in a goaf supported beam, } \sigma_c = \frac{16pgHTtE_{rockmass}}{E_{goaf}(W'-2ytan\theta+y)^2}$$

Equation 5

Where:

σ_t = tensile strength (kg/ms^2)
σ_c = compressive strength (kg/ms^2)
ρ = density (kg/m^3)
g = gravitational acceleration constant (m/s^2)
H = depth of mining (m)
W = excavation span (m)
W’ = effective span = the lesser of W and 1.4 H (m)
H’ = effective height above the mine floor of a parabolic arch of strata acting on the goaf (m)
y = distance above floor of mine workings (m)
n = a fraction representing the length over which load acts on the ends of a voussoir beam
T = excavation height = *h* in this report (m)
t = strata unit thickness (m)
$E_{rockmass}$ = elastic modulus of surrounding rock mass (kg/ms^2)
E_{goaf} = modulus of goaf material (kg/ms^2)
θ = angle (in degrees) of break or caving of the overburden subtended from the vertical for which DGS ascribes a range of values based on panel width-to depth ratio[63]

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[62] It appears that the symbols H and H’, which represent different parameters, are incorrectly presented on multiple occasions in the underpinning documentation and that H’ in Equation (1) of Ditton and Merrick (2014) should read H as in DGS (2013) that describes the original derivation of the DGS equation. Other places in which the error is repeated include the derivation of the B Zone equation in DGS (2014).

[63] θ = 12 for W/H<0.45,
θ = 9.63+4.42(W/H)+1.8(W/H)^2 for 0.45<W/H<1.4,
θ = 19.3 for W/H>1.4

A range of judgements, estimates and qualifiers are associated with the development of the conceptual model and the three supporting analytical equations. In developing the height of fracturing model, DGS acknowledged that

> *"the equations represent a very complex system with a significant number of variables that will influence the height of fracturing outcomes*. It was reported that *considering the complexity of the (above) equations and uncertainty in the assumptions made, the physical relationship between the variables may also be assessed practically with Dimensional Analysis, a commonly used tool in hydraulics* and that dimensional analysis *is a valuable means of determining physical relationships between variables in complex systems that defy analytical solutions and must be solved by empirical means (i.e. observation, intuition or experiment)"(DGS, 2013).*

DGS utilises the Buckingham Pi theorem to undertake dimensional analysis[64]. An important point to note is that the validity of applying the Buckingham Pi theorem is dependent on the height of fracturing under all circumstances being able to be defined by a single, physically meaningful equation.

The latest Buckingham Pi theorem dimensional analysis undertaken to refine models is reported in DGS (2014). This report provides a detailed description of the process that led to the reasoning that:

$$\text{The height of continuous fracturing } A = f(W', H, h, t, \rho, UCS, E, E_g, tan\theta)$$

Equation 6

The Buckingham Pi theorem was then invoked to transform this relationship into the shell of two distinct equations, referred to as the 'Geometry' and the 'Geology' equations. A statistical software package was used to interrogate the underpinning database to derive the relationships defined by Equation 7 and Equation 8.

$$Geometry\ Model: A = 2.215W'^{0.357}H^{0.271}h^{0.372}\ \mp\ 0.16 - 0.1W'\ (R^2 = 0.61)$$

Equation 7: DGS Geometry Equation

$$Geology\ Model: A = 1.52W'^{0.4}H^{0.535}h^{0.464}t'^{-0.4}\ \mp\ 0.15 - 0.1W'\ (R^2 = 0.81)$$

Equation 8: DGS Geology Equation

Effectively, the geometry model defines the height of fracturing in the same terms as Tammetta, being a product of panel width, mining depth and extraction height that are each raised to some power to produce an equation which best fits the database. However, fundamental differences between the two approaches are:

1. Panel width is constrained in the DGS approach to a maximum value of 1.4H. This addresses the limitation with the Tammetta equation which predicts that the height of complete drainage increases indefinitely with increasing panel width (W).
2. The sum of the powers for W', H and h in the DGS geometry equation always add up to one (1) so that the equation is dimensionally correct in accordance with the Buckingham Pi theorem.[65]

The derivation of the DGS geology equation is based on an additional term, t, which is described as:

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[64] The crux of the Buckingham Pi Theorem is that if a physically meaningful equation exists involving a certain number *n*, of physical variables (such as panel width and mining height) that involve *k* physical dimensions (such as distance, time, mass) then the equation can be derived by expressing the variables as a set of *p* dimensionless forms (referred to as π_1, π_2, π_3 …π_p) where $p = n - k$.

[65] That is, the units of the right hand side must be the same as the left hand side, being metres (m).

"The beam thickness, t, refers to the thickness likely to exist just above the fracture height location (t is the most difficult of the parameters to assess, as the strata units may 'break down' into thinner units during subsidence development. The assignment of the appropriate value therefore requires engineering judgement and analysis that includes a review of borehole logs and rock mass properties with extensometer and piezometer data (if available)".

and

"In order to calibrate the geological Pi-term model, it was necessary to use back-analysis techniques to estimate the likely strata unit thicknesses that existed immediately above the measured heights of continuous fracturing for a given mining geometry"

A process involving logistic regression analysis was developed and applied to define a probabilistic equation to indicate whether a strata unit was likely to span the goaf and limit the development of the height of fracturing at a given horizon above the workings. This height is incorporated into the geology equation as *t'*, the back-analysed effective strata unit thickness.

The derivation of the DGS geometry and geology equations is a complex process. A number of aspects need to be better understood for the process to be properly assessed, including the following:

- evidence of the reliability of the conceptual model on which the analysis is premised
- the rationale for Equation 3 being based on the tensile stress in a simply supported beam rather than in a beam with clamped ends, as shown in Figure 9.
- why tensile and shear failure modes for a voussoir beam and a goaf supported beam are not incorporated into the analysis given that rock is 10 to 30 times weaker in tension than in compression and that mining-induced tensile and shear fractures are more conductive to fluids than mining-induced compressive fractures
- the reliability of Equation 5 given that the interaction between the goaf and the overlying strata is statically indeterminate[66] and that the modulus of the goaf changes with displacement of the overlying strata
- how is it mechanistically feasible that a single and physically meaningful equation could exist that encapsulates both tensile and compressive failure regimes, especially when the equation also has to cater for more than one type of structure and loading situation
- given the parameter 't' does not feature in the geometry equation, how the derivation of this equation is related to and/or dependent on the underpinning conceptual model and analytical equations and the application of the Buckingham Pi theorem
- up until the panel width-to-depth ratio is sufficient to result in the height of continuous fracturing, or 'A Zone', reaching the surface, *H* and *H'* represent two different parameters, both of which appear to be primary variables and neither of which equate to depth of mining.[67,68]. If the Buckingham Pi theorem is valid for the circumstances and applied correctly, how it is feasible for both the geometry and the

[66] The behaviour of one causes a change in the behaviour of the other which cannot be resolved without making assumptions as to how load is shared between the two systems. This may require the use of numerical modelling.

[67] H' reflecting the effective load acting on the goaf within the 'A Zone' and H reflecting the load acting on a beam at the top of the 'A Zone'.

[68] The difference in the two parameters is reflected in the construct of Equation 7 and Equation 8 (noting that H and H' appear to have been incorrectly transposed in the equations presented in Ditton and Merrick (2014)).

geology equations to rely only on the total depth of mining, irrespective of the panel width-to-depth ratio

- given that mechanistically the stiffness and spanning capacity of a beam is inversely proportional to the square of its thickness (that is, $t'^{-2.0}$), whether the value of $t'^{0.4}$ is a true reflection of the influence of spanning strata.

The Panel needs to have an adequate understanding of these aspects before it can endorse the construct of the analytical model and the applicability of the Buckingham Pi theorem to the given circumstances. An independent expert peer review of the methodology would assist in this regard.

In 2016, DGS reviewed the performance of its geology equation in predicting sub-surface fracture height at Dendrobium Mine (DGS, 2016).[69] The review was based upon the inferences of fracture zone heights from data obtained from 212 vibrating wire piezometers installed in 29 boreholes. Only six of these boreholes were located over the goaves of longwall panels, with three of these being located close to panel centrelines. It appears that readings for one of these centreline piezometers were only available up until the longwall face was within 250 m of the borehole. The review concluded that:

> "*there was one measured exceedance out of 24 predicted U95%CL values (i.e. a 95% success rate) which demonstrates the calibrated Geology model has achieved the expected reliability of 95%. The predicted A-Zone horizon exceedance occurred above LW9 at Borehole S2192 where the inferred height of A-Zone extended to 245 m above the panel, compared to the U95CL values of 210m".*

The Panel notes that this was apparently the only centreline borehole fitted with an extensometer.

DGS reported that the back-analysed strata unit thickness for typical unit overburden lithologies in the Southern Coalfield is *t'* = 30 m. Some have suggested that this parameter represents a calibration factor rather than a physical identity.

The Panel has investigated this aspect based on the logic that if mechanistically sound, the DGS geology equation and the DGS geometry equation should give similar predictions when no thick strata units are present since both equations were calibrated to the same database. Accordingly, working backwards, the predictions of the geometry model were compared to the predictions of the geology model with *t'* set to 1 m[70] for the DGS database to produce (as is to be expected), the significant differences in outcomes shown in Figure 37.

[69] This report also appears to have transposed the parameters *H* and *H'* in presenting the geology equation for the height of fracturing in 'A Zone'.

[70] It cannot be set to zero as the equation would then deliver a prediction of zero (0 m) under all circumstances.

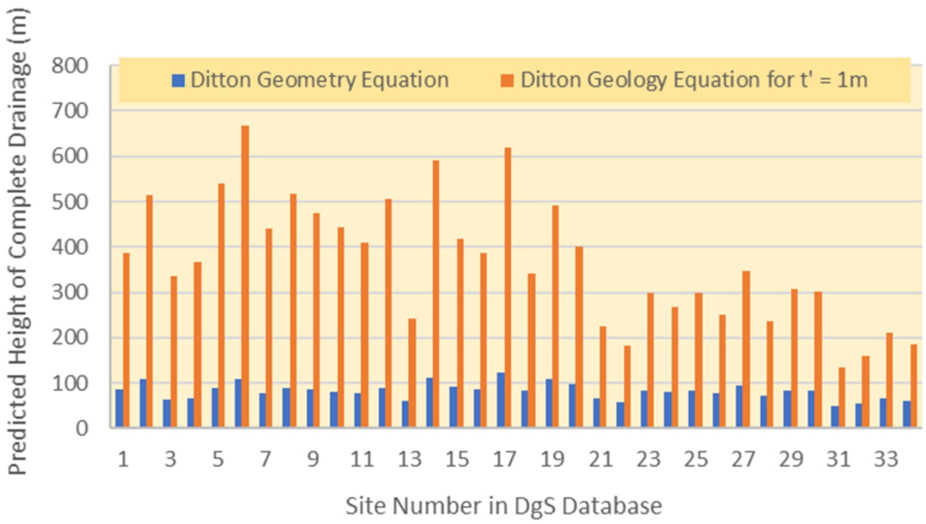

Figure 37: Comparison based on the DGS database between predictions of height of complete drainage calculated with the DGS geometry equation (blue) and the DGS geology model with t' set to 1 m (orange).

The application of an appropriate *t'* parameter in the geology model reduces this disparity so that the two equations predict similar outcomes. Therefore, the Panel next plotted the *t'* value assigned to each site in the DGS database against its panel width-to-depth ratio. The results, shown in Figure 38, reveal that except for one site, the selected *t'* values hover around 20 m for sites where the panel width-to-depth ratio is greater than 1. They vary from about 20 m to 35 m for sites in the range ≈0.6 ≤*W/H* ≤1, and from 30 m to more than 100 m for panels where *W/H* ≤ ≈0.6. The single exception is the only Dendrobium site in the database, where t' is significantly greater than all other sites with a width-to-height ratio *W/H* ≥ ≈0.6.[71]

This suggests to the Panel that the 't' factor, effectively, acts as a calibration factor to compensate for the geology model not fully accounting for the delayed onset of caving and fracturing at lower range panel width-to-depth ratios, rather than representing a parameter that realistically reflects strata behaviour.

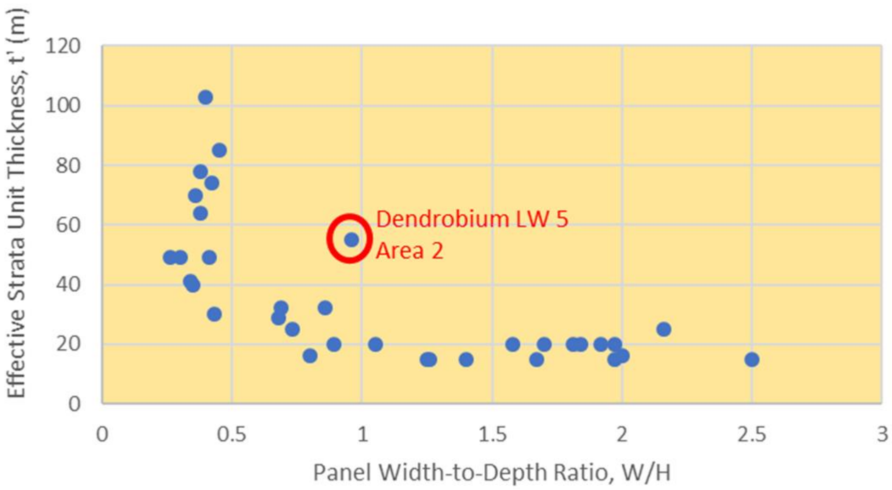

Figure 38: Effective strata unit thickness, *t'*, in the DGS database (DGS, 2014) plotted against the panel width-to-depth ratio of each site in the database

[71] The Panel notes that the non-conforming Dendrobium site was assigned a *t'* value of 55 m in both the original DGS database (DGS, 2013) and in the updated database (DGS, 2014). Nevertheless, a value of *t'*=32 m (rather then 55 m), which is not inconsistent with the blanket value of 30 m adopted by DGS in its 2016 review of the performance of the geology equation at Dendrobium Mine (DGS, 2016).

4.3.5 Panel observations

A basic consideration is whether it is mechanistically sensible and realistic for a single equation to be used to calculate the height of fracturing.

There are three distinct stages in the development of ground deformation above a mining void, as illustrated in Figure 12, each governed by a different set of conditions and failure criteria that define ground response to mining. Depending on mine geometry, the strata above a panel may be subjected to one, two or all three stages. This response and, in turn the start and finish of each stage can be modified significantly by the nature of the superincumbent strata, in particular, the thickness and mechanical properties of each stratum; and by the location of particularly stiff strata, massive strata or very weak strata relative to the mining horizon and to the surface. Different failure modes can operate within a stage and between stages of ground deformation.

The potential range in these behaviours is well established in subsidence engineering and in mining practice. DGS has considered many of these factors and endeavoured to incorporate them into the DGS geology equation. The scatter in the DGS database and in the upper 95% confidence level and lower 95% confidence level associated with the prediction methodology is likely to reflect the influence of these variable parameters to some extent, although the Panel is still perplexed by the consistency of the range and the effectively fixed maximum value of normalised height of complete drainage with increasing panel width in the DGS database (displayed in Figure 34).

Tammetta has excluded case studies associated with dolerite sills overlying mine workings in South Africa. Otherwise, he concluded that host geology appears to play a minor role. From a geotechnical perspective this is unexpected. However, it may well be a reasonable conclusion based on the Tammetta database because the database shows a notable degree of consistency. As the database is relatively small, it remains to be seen if this consistency persists as more data points are added. If it does not, then the concept of a single equation being able to define the height of fracturing under all circumstances is seriously in doubt unless high error bands are associated with predictions.

Assuming there is merit in deriving height of fracturing equations, a key consideration is what it is that Tammetta and DGS are measuring that results in such differences in values for some common points in their databases and in prediction outcomes.

The Panel believes this comes down to differences in the respective concepts of the height of complete drainage and to temporal and spatial aspects associated with collecting the data. Tammetta has adopted a groundwater approach and relies on hydrographs installed over the centreline of longwall panels, supported by extensometers measurements on occasions. DGS has adopted more of a geotechnical approach, and appears to place considerable reliance on ground displacements, supported by hydrographs where possible.

The Panel has questions relating to both databases and cannot determine at present which, if either, is appropriate for determining the height of complete drainage. As noted by Pells (2014), measurements can be snapshots in time. Both the Tammetta and the DGS databases may fall into this category, although it appears that DGS has had some regard to the issues when compiling its database.

The location of the data point relative to the centreline of excavations is another variable that can significantly influence groundwater response. Tammetta has taken care to only include points located on the centreline of longwall panels. It appears that both the DGS foundation database and the local database used to validate the DGS geology equation at Dendrobium Mine comprise sites spread over and around both pillar extraction and longwall mining panels (DGS, 2016). The Panel needs to better understand how DGS could infer the height of complete drainage from sites not located over the centreline of extraction panels.

In respect of the Tammetta and DGS equations, Figure 30A shows that the Tammetta equation predicts that the height of complete drainage extends through to the surface over Area 3B at Dendrobium Mine. However, the PSM study concluded that groundwater *response at Dendrobium has not exhibited full depressurisation at any height apart from the near-surface zone … pore pressure profiles exhibit a gradual change in depth and do not exhibit the discontinuities as suggested by Tammetta (2013) and Ditton and Merrick (2014)*

In his peer review of the (draft) PSM study, Mackie noted that:

> "*the reason why complete groundwater drainage is not demonstrated is quite simply because there are no piezometers located within any panel footprint that are able to provide a continuous monitoring history before, during and post mining. Piezometers located just beyond the goaves footprint do show very significant depressurisation at seam level".* (MER, 2017)

The PSM study also concluded that:

> *"If depressurisation occurs, a portion of the water that infiltrates below the ground surface will eventually report to the major permeable units at depth, the caved and fractured rock mass and the mine. This will occur as pressure pulses, driven by transient pore pressure rises from rainfall recharge events and or reservoir level increases. Hence, it is more beneficial to conceptualise the process as increased transient pressures due to rainfall runoff near the surface causing a pressure pulse through the system that increases inflows at the mine level"* (Sullivan & Swarbrick, 2017)

Hence, pre and post mining piezometer installations are required to verify which equation, if either, produces a reasonable prediction of the height of connective fracturing at Dendrobium Mine. It is possible that the DGS database reasonably reflects the height of complete drainage and that transient pressure pulses account for the infiltration of surface water into the mine. Alternatively, the Tammetta equation may be correctly predicting that the height of connective fracture can daylight over the centreline of longwall panels.

In support of its model, DGS (2016) has had regard to the Parsons Brinckerhoff (2015) study over LW 9, noting that it provides strong evidence that the pressure head losses due to mining (over the centre of the longwall panel) are unlikely to have been caused by significant vertical drainage to the lower strata. However, DGS acknowledges that some zones of de-saturation and vertical drainage have also occurred with the B Zone strata but contends that the re-establishment of piezometric pressure gradients suggests that deep aquifer connectivity to saturated surface strata is unlikely to have occurred.

There is general agreement that Area 2 at Dendrobium Mine responds relatively quickly to rainfall (see for example, HGEO (2017b) and Sullivan and Swarbrick (2017)). Therefore, the Panel has used this as a point of reference for assessing the predictive capacity of the respective height of fracturing equations. The outcomes are shown in Figure 39.[72] The Tammetta equation predicts that the height of complete drainage will have 'day-lighted' over the centreline of longwall panels in Area 2, while the DGS geology equation predicts the mean and upper 95% confidence limits for height of complete drainage to be 130 m and 105 m below the surface, respectively.

No definite conclusion can be drawn about the reliability of either equation until it is established whether Area 2 responds to rainfall as a result of surface water infiltration along connective fractures or as a result of rainfall generated pressure pulses. However, based on the response of Area 2 to rainfall events, it appears most likely that there is connective fracturing through to the surface.

[72] The figure also shows the predictions of the simplified formula derived from the Tammetta database by Galvin and Mackie.

The Panel notes that HydroSimulations is now calibrating its groundwater models on the basis of the Tammetta equation (HydroSimulations, 2017b).

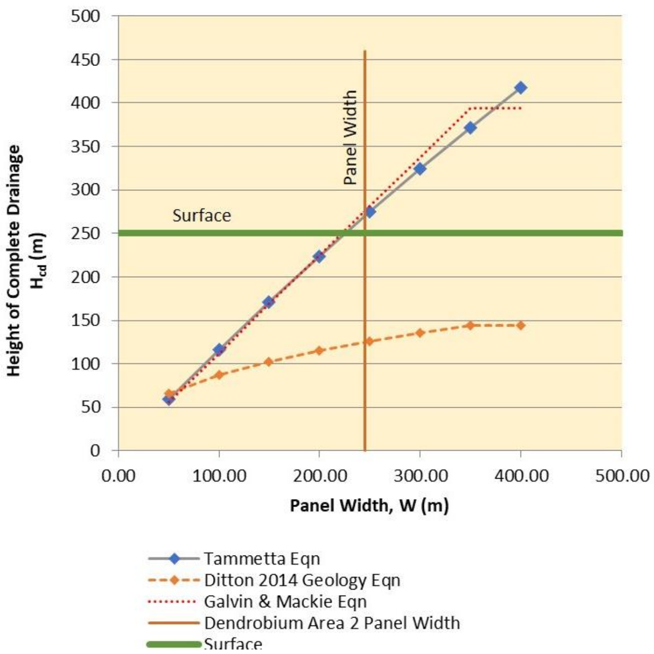

Figure 39: Height of complete drainage for Dendrobium Area 2 as predicted by the Tammetta equation, the DGS geology equation and the Galvin & Mackie simplified version of the Tammetta equation. Note: Panel depth fixed at 250 m, extraction height fixed at 3.75 m and panel width increases left to right

4.4 GROUNDWATER MODELS

Modern groundwater modelling has attained a level of sophistication which was not possible a few decades ago. Models now have the capacity to simulate groundwater systems at unprecedented resolution across multiple spatial and temporal scales. However, the suitability of a particular model to a specific task still depends on the capacity of the modeller to conceptualise and frame a problem into mathematical constructs of relevant hydrological processes, and on the available computing power.

Regional scale models are employed to predict the likely impacts arising from longwall mining operations but there are caveats. Overwhelmingly, the type of model currently employed to assess groundwater flow systems is based on three dimensional Darcian flow in porous media. The most popular codes employ finite difference or finite element schemes and include Modflow, Modflow-Surfact, Modflow-USG and Feflow. The models cannot directly represent the flow systems that evolve within the complex fracture networks associated with longwall mining, simply because to do so requires knowledge of the geometry and connectivity of each and every crack as well as the attributes of these same cracks (apertures, roughness, asperities etc.). While some offer 1 or 2 dimensional representation of discrete fractures and faults, the fundamental constraints on discretisation prohibit inclusion of larger fracture networks. Instead, a fracture regime is commonly represented by an ‘equivalent porous media’ or by a dual porosity system.

Nor can groundwater models unambiguously simulate shallow and perched systems like swamps and creek beds (pools and rock bars). This is simply because the material properties and flow balances of these systems are difficult to quantify and because the level of discretisation required to represent them (cell size and layer thickness) is not generally compatible with a regional scale groundwater flow model.

Impacts of mining on groundwater by the Dendrobium and Metropolitan mines have been assessed using models that have been progressively refined over the last decade, the latest updates being completed during 2018 for both operations. This section describes their development and compares the two.

4.4.1 The Dendrobium Mine groundwater model

At Dendrobium Mine, there have been numerous groundwater models developed over the last decade. Most are based on the Modflow-Surfact scheme, the earliest being a regional model assembled by Coffey Geotechnics in 2012 (Coffey Geotechnics, 2012a, 2012b). The model grid was comprised of 53,775 cells per layer with dimensions varying from 50m x 50m over longwalls LW 13 to LW 18, extended to 215 m x 215 m in outlying regional areas.

This finite difference code and the use of stacked drains to represent removal of groundwater from the subsidence zone was the broadly accepted approach for simulating underground mining until about 2010-2011. An inherent weakness of the use of stacked drains related to the possibility of shallower layers within the subsidence zone completely dewatering before the underlying layers had dewatered. The potential for this 'unnatural' response had to be carefully managed through drain conductance terms.

This model was modified and recalibrated by HydroSimulations (2014). Specific changes included utilising separate model simulations to represent progressive stages of mining in a stop-start manner. This resulted in a more natural representation of the subsidence zone. Increased efficiencies were subsequently achieved with the introduction of a specific routine (the TMP package) within the Modflow-Surfact code to facilitate time varying material properties in a single simulation.

HydroSimulations (2015a) prepared a Groundwater Monitoring and Modelling Plan (GWMMP) in accordance with the Exploration Licence conditions, providing "*for the future development of a calibrated computer model of regional groundwater behaviour, to enable the impacts of any proposed mining operations to be assessed*".[73] The GWMMP specifically stated that migration of the Modflow-Surfact model to the Modflow-USG code would be investigated in view of the benefits, including:

- a finer grid resolution, to be focused on areas deemed appropriate (longwall panels, drainage lines) without the redundancy of a rectilinear grid
- pinch-out of specific layers may be included without the need for cell deactivation
- unstructured grids allow model cells to be located precisely on rivers and creeks
- the potential to simulate faults and fractures as conduit flow using the connected linear network feature
- the orientation of the flow interfaces between cells can be varied.

The main benefits include increased precision and shorter model simulation times as a result of fewer model cells. The document also states that a reduced number of cells *"should permit development of a single model for the coal mines in the Southern Coalfield"*. An example model mesh was provided in the GWMMP[74].

The Modflow-Surfact model was migrated to a Modflow-USG regional model by HydroSimulations (2016). However, the 2016 model adopts the earlier Coffey Geotechnics (2012b) rectilinear model grid design[75] and could be more appropriately described as a 'structured grid' model offering little (if any) efficiency advantage associated with domain discretisation.

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[73] Exploration Licence (Authorisation 374), Condition 12 dated 28 August 2013. The Dendrobium Mine modification of consent for Area 3 (Mod 6) dated 8 December 2008 required a model under Sch 3 Condition 13(a). The model had to be revised under the SMP Approval dated 6 February 2013for Area 3B, Sch 3 Condition 13.

[74] HydroSimulations (2015a), Figure 9.

[75] HydroSimulations (2016) p.24

The model was again modified in 2017-2018 to address a number of weaknesses as well as the SMP requirements, including:

- detailed consideration of surficial aquifers, swamps and water courses
- inclusion of water table maps and sections illustrating pore pressure distributions
- commissioning a peer review of the modelling effort
- detailed geotechnical and hydrological investigations of the height of connective cracking in LW 6 to LW 12.

The revised model is reported in HydroSimulations (2018a), with the peer review conducted by Dr F. Kalf, reported in Kalf (2018). Updates to the model included:

- an additional model layer to accommodate swamps
- further inclusion of surface water aspects, notably estimation of surface cracking to 43 m - 45 m and 'deep valley' parameters to take account of valley closure estimates
- additional stress periods (to accommodate variable rainfall percolation events)
- seam to surface fracturing which has been applied (using stacked drain boundary conditions) as a conservative outcome of subsidence
- calibration against mine water ingress to each of the Areas 1, 2, 3A and 3B was attempted.

The 2018 model retains the same finite difference grid as the Coffey's 2012 model (Coffey Geotechnics, 2012b) despite previous reviews elucidating the benefits of Modflow-USG. The Panel notes that retaining the old grid geometry and perimeter 'no flow' boundaries, results in approximately 40% of the total grid area being inactivate

The Panel has reflected on the changes to the groundwater model and questions why the process of migration to Modflow-USG has stalled with no new model grid being incorporated in revisions in 2016, 2017 and 2018.

The GWMMP document also states that the fractured zone height and its uncertainty are best calculated by the DGS model as described by Ditton and Merrick (2014). The Panel notes that the current 2018 model does not incorporate the DGS height of fracturing model and, rather, the height of fracturing extends from seam to surface and is generally consistent with the Tammetta (2013) model. Hydrosimulations (2018b) comments that "*in order to provide an estimate of the effects of Area 3B longwalls height of connected fracturing, the groundwater model relies on the relatively conservative position that there is connection from the seam to the surface fracturing zone, as suggested by PSM (2017) for the strata above Longwall 9 and subsequent longwalls"*.

4.4.2 The Metropolitan Mine groundwater model

At Metropolitan Mine, the first groundwater model was assembled in 2008 (Merrick, 2009). This model adopted the basic Modflow code[76] but numerous issues were identified during the PAC review, including a very limited capability for the selected code to accurately simulate the water table (PAC, 2009).

The model was subsequently migrated to the Modflow-Surfact code in 2010, thereby circumventing the water table issue.[77] Two models were developed at that time, a 'high inflow' and a 'low inflow' version, the differences being change in material properties in the subsidence zone and the boundary conditions governing drainage of the coal seam and

[76] The Modflow code is a finite difference based code made available by the US Geological Survey (USGS).

[77] Modflow-Surfact (HydroGeoLogic, 2010) is based on the Modflow code. It has superior modules capable of addressing saturated and variably unsaturated conditions, changing material properties during a simulation, and powerful equation solver strategies.

subsided strata. The material properties beyond the longwall footprint were identical in both models. These were determined through a process of history matching of modelled and measured regional groundwater pressures in order to "s*imulate the propagation of depressurisation effects throughout the entire aquifer system*'" (Merrick & Alkhatib, 2011).

Several model revisions, which included an increase in the number of model layers, were undertaken in the period to 2018.[78] These revised models all utilised the Modflow-Surfact code.

The current model for the mine adopts the same regional extent as all previous models with two additional layers representing the Wongawilli Seam and the Lawrence Sandstone at the base of the model. The model grid or mesh is comprised of 28,560 cells per layer with cell dimensions of 100 m x 100 m. Presentation of output from the model has been enhanced when compared to earlier models with the inclusion of water table and piezometric elevation maps and vertical pore pressure sections through parts of the model.

The simulated height of connected fracturing and relatively free drainage within the subsidence zone was estimated using the Ditton and Merrick (2014) equation based upon calculations reported by HydroSimulations (2018c)[79]. Results support a freely draining fracture network extending from the Bulli seam up into the Bulgo Sandstone. Hydraulic conductivities within this zone are enhanced as model cells representing the progression of mining are triggered to act as 'drains' to remove water from the model.

Most recently, two regional faults, the Metropolitan Fault and the Pig Farm fault, have been included. The two faults transgress large parts of the model and extend vertically from layer 7 to the deeper layer 17. They are represented by high vertical and horizontal conductivities assigned to specific cells.[80] The faults appear to be important elements of the flow model since the regional pressure head contours are clearly influenced by their presence as shown in Figure 40.

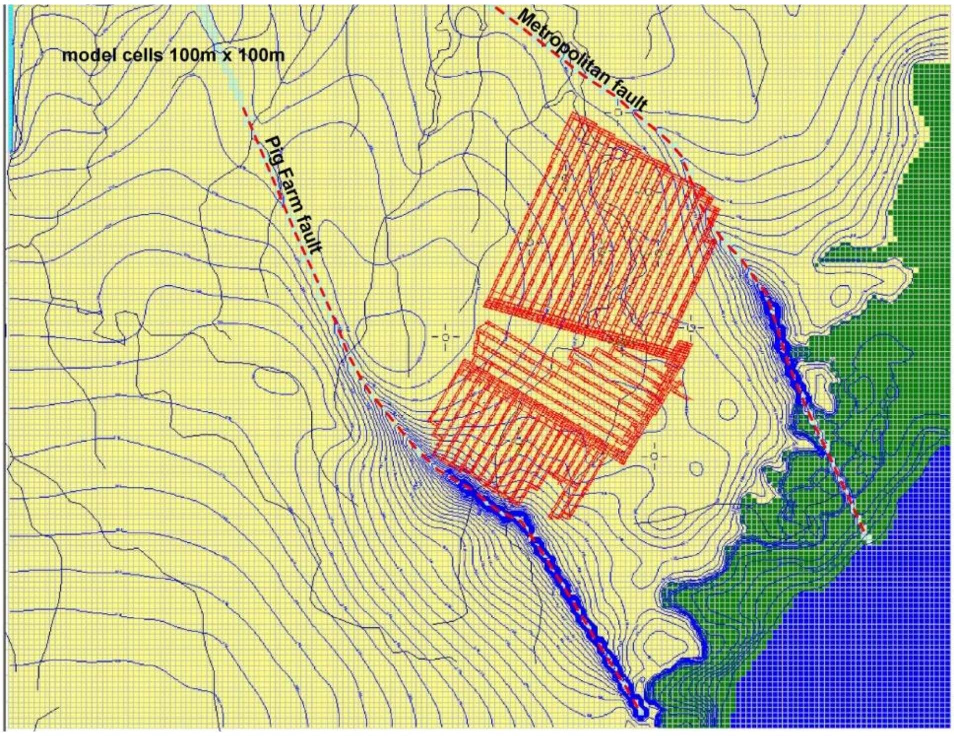

Figure 40: Metropolitan Mine model grid showing locations of the two introduced faults and their significant influence on groundwater systems (HydroSimulations, 2017a)

[78] A major change is previous models were steady state. The current (2018) model is transient.

[79] pp.11-12

[80] Modflow-Surfact does not include a capacity to simulate high hydraulic conductivity narrow flow conduits.

These features also serve to highlight drawbacks of discretisation. The cell dimensions are 100 m x 100 m and the faults are represented by one, and occasionally two, adjacent cells resulting in an unrealistic 100 m to 200 m width of faults. Similarly, representation of the longwall panels (width of 163 m) with this cell size means an individual panel will be either over- or under-represented when calculating groundwater ingress and drawdowns associated with panel extraction.

In the revised model by HydroSimulations (2018b) the River (RIV) boundary condition is used to represent watercourse flow losses, as opposed to the more complex Stream Flow Routing (SFR) boundary condition used in the previous version. This was done because the higher computation time when using the SFR compromises the ability to conduct model calibration and testing. This illustrates the underlying practical difficulty of using the Modflow model to achieve accurate surface flow loss estimation.

Due to deeper surface cracking and potentially also due to changes in the model, the 2018 model leads to larger surface water losses than predicted by the 2016 groundwater model. Both estimates should be considered highly uncertain due to the previously mentioned incompatibility with the groundwater model grid size and surface flow process.

4.4.2.1 Panel observations

While no specific peer review report of the 2018 model update has been provided to the Panel, the model update report notes that Dr F Kalf provided an external review. Dr Kalf also provided expert analysis for the Woronora Strategy report (Hebblewhite et al., 2017).

Based on the available reports, the groundwater model appears to exhibit an acceptable level of calibration from both a history matching of piezometric observations and a history matching of mine water ingress. Notably the rates of mine water ingress are quite low and are attributed to a relatively modest development of the connected and freely draining fracture regime when compared to Dendrobium Mine.

The Panel notes that the groundwater model for Dendrobium Mine employs variable cell sizes, including 50 m x 50 m cells above some longwalls. It may be that using similar finer cell sizes in the groundwater model for Metropolitan Mine could also be helpful in understanding groundwater flows at this mine, especially if the possible influence of major lineaments needs to be taken into account.

4.4.3 Material properties assigned to models

The Panel notes that while stratigraphic sections for the Metropolitan and Dendrobium mines are virtually identical (Figure 27), the material properties[81] associated with the different stratigraphic units and determined through respective model calibrations are not. Indeed, as shown in Table 6, the hydraulic conductivities for numerous units differ by one to two orders of magnitude (10 to 100 times difference). It is therefore unlikely that a ‘calibration’ would be maintained in each model if for example, the hydraulic conductivities of the same stratigraphic layers were simply swapped.

[81] Material properties include the hydraulic conductivities, specific (elastic) storage coefficients. and drainable porosities.

Table 6: Comparison of model hydraulic conductivities for Metropolitan and Dendrobium mines

Unit	Identifier	Horizontal K_h m/day		Vertical K_v m/day	
		Metropolitan	Dendrobium	Metropolitan	Dendrobium
Upper Hawkesbury Sandstone	UHSS	4.60E-02	2.50E-02	6.98E-04	1.20E-05
Lower Hawkesbury Sandstone	LHSS	2.49E-03	2.00E-02	1.00E-04	3.00E-05
Bald Hill Claystone	BHCL	7.45E-05	1.50E-03	2.07E-05	3.00E-06
Upper Bulgo Sandstone	UBSS	6.64E-04	6.00E-03	4.48E-05	2.00E-06
Lower Bulgo Sandstone	LBSS	1.10E-02	6.00E-03	4.92E-05	6.00E-06
Stanwell Park Claystone	SPCS	2.23E-04	6.00E-04	6.46E-08	4.00E-06
Scarborough Sandstone	SBSS	2.72E-03	4.00E-03	1.64E-07	5.00E-06
Wombarra Claystone	WBCS	2.30E-04	3.00E-04	6.44E-06	5.00E-06
Coalcliff Sandstone	CCSS	8.86E-05	4.00E-04	8.28E-06	7.00E-06
Bulli Seam	BUSM	2.46E-04	7.00E-04	3.41E-04	2.50E-05
Loddon Sandstone	LDSS	6.44E-06	3.00E-04	5.98E-07	9.00E-06
Wongawilli Seam	WWSM	6.02E-05	5.00E-03	3.49E-04	9.00E-06

Note: Shaded cells indicate substantial difference between the two modelled areas

This disparity is somewhat disconcerting considering the two models are separated by less than 3 km at their nearest point and both models were developed and/or overseen by the same modelling specialists (HydroSimulations).

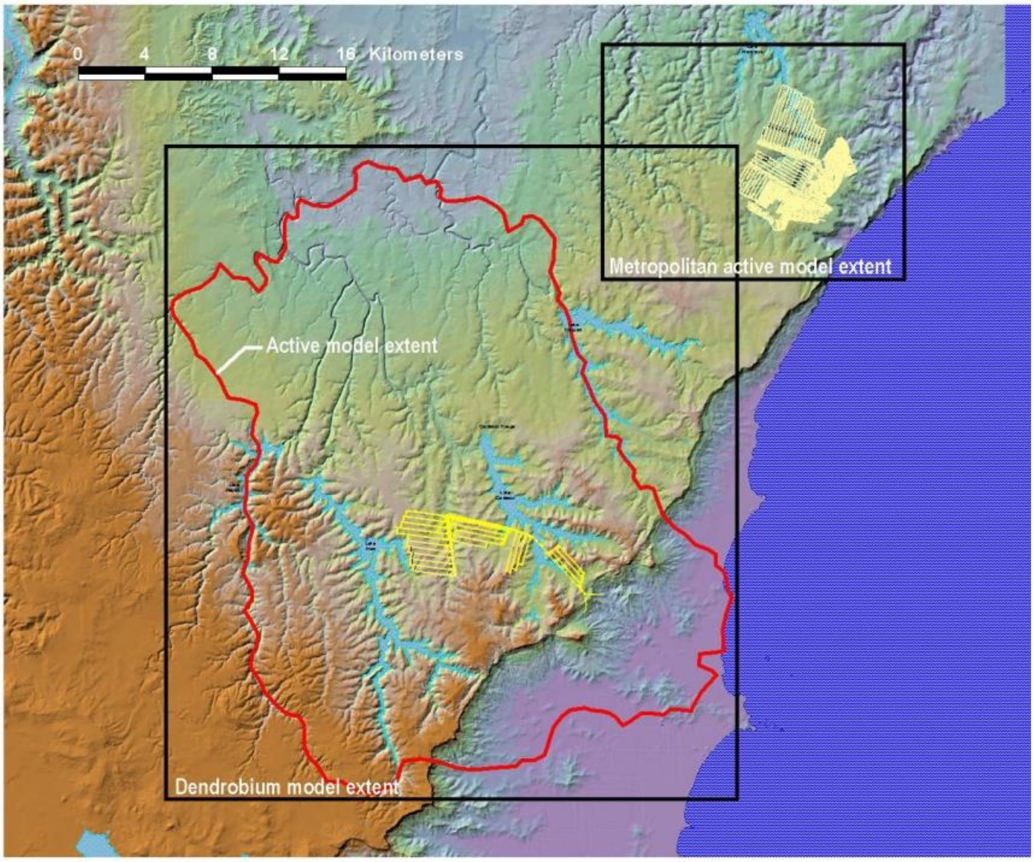

Figure 41: Extent of the Metropolitan Mine and Dendrobium Mine groundwater models
The black outlines show the extent of the groundwater models. The Metropolitan Mine model has active cells within the black outline (100% active). The Dendrobium Mine model only has active cells within the red polygon (60% active), with the remaining areas outside the polygon being inactive.

4.5 CONCLUSIONS

4.5.1 Groundwater Systems

a. Over the last five years, average daily water ingress at Dendrobium Mine has increased from around 2.5 ML/day to more than 7.0 ML/day, with higher short term inflows after rainfall.

b. In contrast, average daily water ingress at Metropolitan Mine has increased from about 0.4 ML/day to about 0.5 ML/day and does not react to rainfall events.

c. The highest porous matrix component of inflow is currently associated with Area 3B at Dendrobium Mine which has risen from zero in mid-2013 to about 4.2 ML/day in January 2018. This rate is much higher than the rate of less than 0.6 ML/day recorded at Metropolitan Mine.

d. The Panel considers that it is very likely that the high rate of influx at Dendrobium Mine is associated with a connected fracture regime that extends upwards to the surface, with this network providing access to the high drainable porosities present within the Hawkesbury Sandstone.

e. The Panel estimates that the total mine water ingress at Dendrobium Mine from January 2010 to March 2018 totals about 18 GL of which about 6 GL is attributed to rainfall percolation. This volume may be regarded as diverted surface runoff that would otherwise have reported to Wongawilli Creek or directly to either Cordeaux or Avon reservoirs.

f. This corresponds to an average annual diverted surface runoff over 8 years of about 2.1 ML/d.

g. As the mining footprint has increased during this 8 year period, the current annual diverted surface runoff is likely to be higher.

h. The Panel considers the upper limit estimate by consultants of leakage from Avon Reservoir to the subsidence zone of LW 12 to LW 16 of 0.73 ML/day to be reasonable, provided that the area is not affected by geological structures (such as faults, dykes and diatremes).

i. Further research, analysis and assessment are required before the Panel can conclude an opinion on the extent of any leakage from Cordeaux Reservoir into mine workings.

j. However, based on the information reviewed by the Panel to date, it is considered plausible that an average of around 3 ML/day of surface water could be currently diverted into the workings of Dendrobium Mine and that this could increase to the order of 3.5 ML/day after LW 16 is extracted.

k. Alternative interpretations of data and/or the influence of geological structures in future mining panels could produce larger estimates of leakage from water storages.

4.5.2 Height of Complete Drainage (Height of Fracturing) Equations

a. Based on the partial analysis of the Tammetta and DGS databases undertaken by the Panel, a full analysis of the evidentiary databases as originally requested of PSM by DPE would prove very challenging and may not yield useful outcomes.

b. More detailed information on the data selection process for both the Tammetta and DGS models is required before the two databases can be fully assessed.

c. There are significant and fundamental differences between the characteristics of the Tammetta and DGS databases which preordain that, irrespective of the methodologies adopted to process this data, the respective predictions of the height of complete drainage based on the data are likely to be very different.

d. The databases are significantly different even for some field sites common to both.
e. The significant and fundamental differences between databases are highlighted when estimated height of complete drainage per metre of extraction height is plotted against effective panel width for each data point.
f. Either or neither database may adequately reflect the height of complete drainage.
g. The ‘goodness-of-fit’ of predictive equations derived from each dataset should not be viewed as a measure of their respective reliability in predicting the height of complete drainage.
h. The uniformity of the database that underpins the Tammetta equation is unusual from a geotechnical perspective. It remains to be seen how the addition of more Australian data points could impact this.
i. The Tammetta equation is complex and can be substantially simplified to reflect the Tammetta database.
j. It is possible that the Tammetta database may prove to be more representative of the height of complete drainage in the short term and the DGS database more representative of the height of complete drainage in the longer term, although this only goes some way to accounting for the differences between the two databases.
k. The Tammetta equation is a good reflection of its underpinning database. It might be enhanced by being based on effective panel width rather than overall panel width.
l. Both the ‘goodness-of-fit’ of the Tammetta equation and the capacity to significantly simplify it derive from the uniformity of the underpinning database.
m. The Panel has a number of questions regarding the derivation of the DGS equations that need to be addressed before it can conclude a view on the validity of the equations.
n. Analysis and mechanistic considerations strongly suggest that the beam thickness parameter ‘t’ in the DGS geology model functions as a calibration factor to compensate for this model not properly accounting for the delayed onset of caving and fracturing at lower range panel width-to-depth ratios.
o. Effectively, the ‘t’ factor is back-calculated to cause the predictions of the DGS geology equation to better fit the database and, hence, to agree closely with the outcomes of the DGS geometry equation.
p. The DGS geometry equation is based on the same input parameters as the Tammetta model, with the differences in predicted outcomes being due to differences in the underpinning databases and mathematical processing technique.
q. Given a common database, the difference between the Tammetta and DGS geometry models would reduce to the curve fitting process used to achieve the best ‘goodness-of-fit’ with the data.
r. Field performance at Dendrobium Mine suggests that irrespective of whether the Tammetta equation is predicting the height of complete drainage reasonably accurately, its outputs can be useful as an indicator of the potential for water ingress from the surface.
s. Water ingress into mine workings could be an indication that the Tammetta predictions of the height of connective cracking are reasonable. However, if the driver for water ingress is transient pressure pulses, then the DGS equations could be providing a reasonable estimate of the height of complete drainage.
t. The accuracy of the Tammetta and the DGS prediction methodologies is currently not of concern in regard to Metropolitan Mine because its longwall layouts are associated with

low panel width-to-depth ratios and considerable depth, and both methodologies produce similar predictions for these circumstances.

u. The Panels considers that it would be quicker and more productive for Dendrobium Mine and Metropolitan Mine to develop their own site-specific databases.

v. The conditions attached by DPE to the Dendrobium Mine Subsidence Management Plans for LW 14 to 15 and for LW 16 and at Metropolitan Mine for LW 301 to LW 303 requiring site investigation and monitoring over past, current and proposed workings and for independent expert review and advice are appropriate and timely for informing mine design and risk management in the Special Areas of the Sydney Water Catchment, and go some way towards the mines developing their own site-specific databases.

w. The differences in databases of Tammetta and DGS partially reflect and reinforce the conclusions of the PSM study that investigations, modelling and monitoring to date at Dendrobium Mine have been insufficient for the scale and complexity of the technical issues.

x. However, the Panel concludes that this situation applies at all mines working in the vicinity of Special Areas.

4.5.3 Groundwater Models

a. There has been a major effort over the last decade by Metropolitan Mine and Dendrobium Mine to employ up-to-date 3-dimensional groundwater models and best practice modelling methods undertaken by suitable experts, with expert peer review.

b. The models have improved in accuracy and predictive capacity.

c. Peer reviews of the models and modelling have provided valuable direction without which the process may have been less focussed.

d. The modellers, peer reviewers and the Panel recognise the fundamental limitations of the groundwater models for predicting impacts and consequences of mine subsidence, including those related to grid scales, computation time, and hydrogeologic parameter estimation.

e. The migration of the models to using an unstructured grid (Modflow-USG) is recognised as having potential for addressing the current limitations. This migration was progressed for the Dendrobium Mine since 2016 but seems to have stalled. Continued migration to Modflow-USG should progress only if benefits can be demonstrated.

f. There is a need for groundwater modellers to address apparent inconsistency in the hydrogeologic parameters used to model Dendrobium and Metropolitan mines as it calls into question the robustness of current model predictions.

g. Due to the fundamental difficulty of accurately modelling groundwater – surface water interactions, the current groundwater model predictions of surface flow losses should be treated with caution and supplemented with other sources of evidence of likely surface flow losses.

4.6 RECOMMENDATIONS

4. In future, mines operating in the Catchment Special Areas need to develop, in consultation and with the agreement of regulators and key stakeholders, a standard for field investigations, data collection, analysis and reporting that provides for and integrates the interests of all stakeholders and facilitates the sharing of the information by being presented on a common platform.

5. This monitoring standard should include provision for:

   i. installation of multi-level piezometers on the centreline of panels at Dendrobium and Metropolitan mines in order to monitor pore pressure changes associated with subsidence. These should include at least five transducers per borehole with installation being completed at least two years in advance of being undermined
   ii. daily monitoring of local rainfall and of mine water ingress from overlying and surrounding strata; and separation of rainfall-correlated inflows for base flow volumetric analyses
   iii. Dendrobium Mine and Metropolitan Mine to develop site-specific databases in relation to the height of complete drainage in lieu of relying on height of drainage equations.

6. Notwithstanding that uncertainty is associated with both the Tammetta and the Ditton height of complete drainage equations, it is recommended to err on the side of caution and defer to the Tammetta equation until:
   i. field investigations quantify the height of complete drainage at the Dendrobium Mine and Metropolitan Mine, and/or
   ii. geomechanical modelling of rock fracturing and fluid flow is utilised to inform the calibration of groundwater models.
7. Research be progressed into the use of tritium for calculating ‘modern’ water contributions at Dendrobium Mine, including the potential for results to be affected (skewed) by adsorption.
8. Groundwater models should:
   i. continue to be updated
   ii. be migrated from Modflow-Surfact to Modflow-USG only if significant benefits can be demonstrated
   iii. be underpinned by unified material properties (for common stratigraphic layers) unless differences can be demonstrated to exist through measurements.
9. Government should verify that sufficient entitlements are retained by Dendrobium and Metropolitan mines to cover surface water losses resulting from mining-induced effects.
10. Mine owners be required to produce robust, independent peer reviews and/or a demonstrated history of the reliability of mine design procedures and methodologies that underpin important aspects of mining approvals.
11. Mine owners wishing to extract coal within Special Areas in the Sydney Water Catchment be required to support applications with robust, independently facilitated risk assessments that conform to ISO 31000 (2009a), the international standard for risk management to which Australia subscribes.
12. The Department of Planning and Environment should continue to exercise its powers to attach conditions of approval to Subsidence Management Plans for Dendrobium Mine and Extraction Plans for Metropolitan Mine to cause appropriate, timely and ongoing monitoring and responses to monitoring outcomes, consistent with the recommendations of the PSM study.
13. In the longer-term, arrangements should be made to ensure that government has access to appropriate and independent expert advice when assessing mining proposals and performance outcomes.

5 SURFACE WATER IMPACTS AT DENDROBIUM MINE AND METROPOLITAN MINE

The surface water resources in the Special Areas of Sydney's drinking water catchments, including the catchments, reservoirs and watercourses, are listed in Chapter 1. Longwall mining impacts on surface water resources may include reduced catchment runoff, diversions of surface water into underlying aquifers, and increased reservoir leakage rates from the beds of the reservoirs (Hebblewhite et al., 2017). This chapter focuses on watercourses, swamps and reservoirs overlying Dendrobium and Metropolitan Mines and the implications for surface water quantity.

This chapter firstly provides an overview of surface water features, including watercourses and swamps, and current knowledge of surface hydrology relevant to the Special Areas. It then discusses how monitoring and modelling has been applied at the Dendrobium and Metropolitan mines under their respective planning approval requirements. Monitoring considerations include the type, number and location of gauges, their accuracy and the adequacy of the time-period of data collections. Considerations relating to modelling include model accuracy, analysis and reporting and the adequacy of TARPs.

Issues around water quality and ecological significance of surface water including swamps will be addressed as part of Term of Reference 2. The impacts and consequences of mining on these features and the monitoring and modeling techniques used to determine and assess impacts are discussed.

5.1 SURFACE WATER SYSTEMS

5.1.1 Watercourses and swamps

The Dendrobium Mine is located between Lakes Cordeaux and Avon within the Upper Nepean Catchment and thus in the Metropolitan Special Area (Figure 42). This Catchment is approximately 900 km^2 and includes the catchments for the Avon, Cataract, Cordeaux and Nepean Rivers and their associated dams (Table 1). The major rivers of the Upper Nepean catchment (Cataract, Cordeaux, Avon and Nepean) flow down north/northwest before joining the Hawkesbury River.

The Metropolitan Mine is located in the Woronora Catchment and lies almost entirely within the Woronora Special Area (Figure 42). This Catchment is approximately 75 km^2 and supplies the Woronora River and its associated dam (Table 1). The Woronora River and its tributaries (including Waratah Rivulet) flows northwards; with its course following the major joint directions within the Hawkesbury Sandstone. It joins the Georges River near Botany Bay.

Although a small area of the upper Georges River lies within the Special Area, no flow from that stream enters a water storage.

Watercourse size and scale is most commonly classified using the Strahler system. The classification is relevant to how watercourses in the catchment have been assessed and valued in terms of mining impacts, focusing on those watercourses classified as 3rd order or higher.

The system assigns an 'order 1' classification to each headwater stream without upstream tributaries. When two 1st order streams intersect, the order rises to 2, and so on. The order only increases when two streams of the same order intersect. For example a stream below a 1st and a 2nd order stream still is a 2nd order stream, not a 3rd order stream. A number of 3rd and higher order streams in the Southern Coalfield that could be impacted by mining were identified in the Southern Coalfield Report and are listed in Table 7.

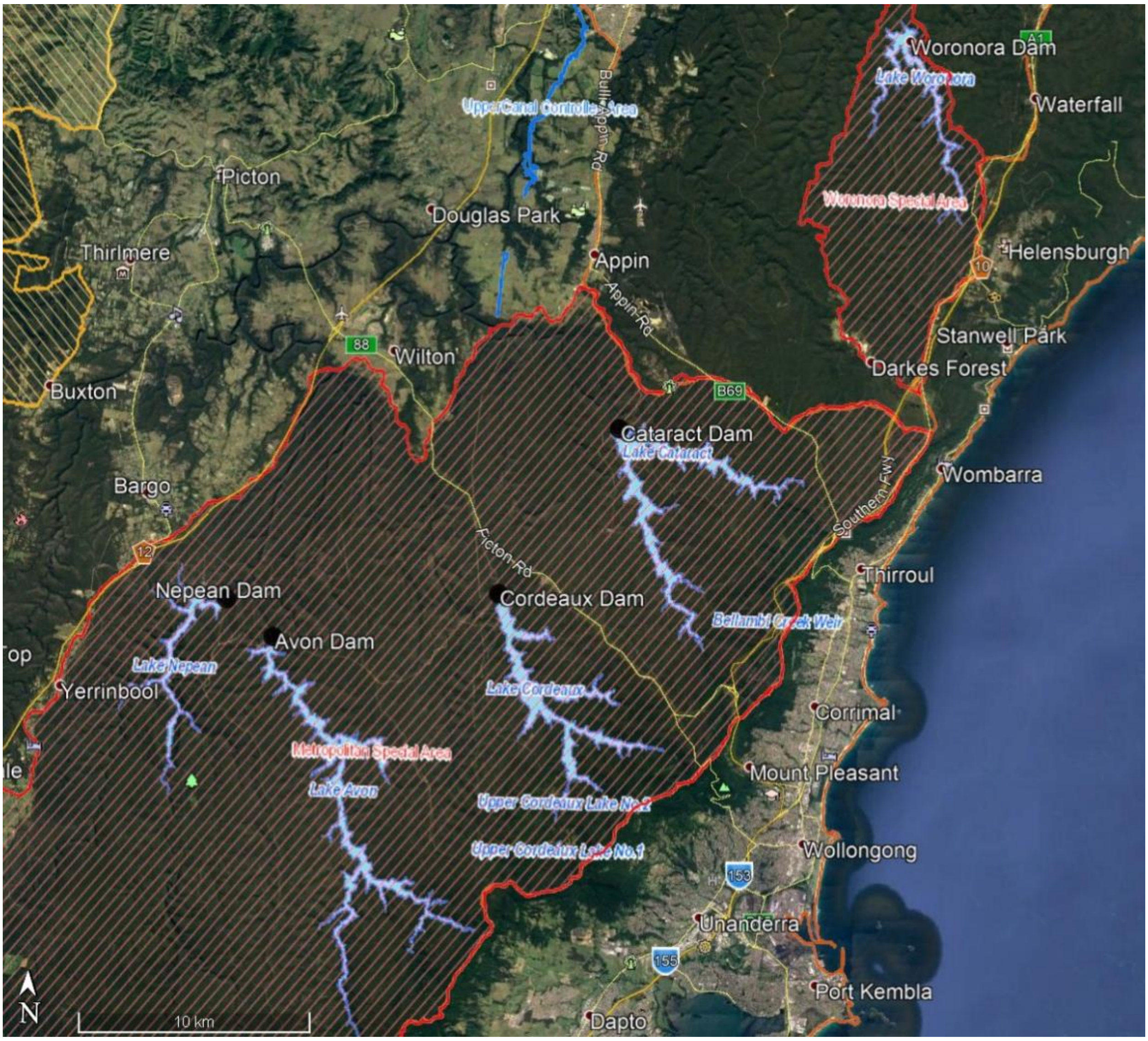

Figure 42: Location of the Metropolitan and Woronora Special Areas and major reservoirs within the Southern Coalfield (Google earth, 2016)

Table 7: Examples of third and higher order streams potentially impacted by mining in the Southern Coalfield (Hebblewhite et al., 2008)

Order no.	Examples within the Southern Coalfield
3	Wongawilli Creek, Waratah Rivulet (above Flat Rock Creek), Brennans Creek, Elladale Creek, Simpsons Creek, Flying Fox Creek (Nos 1,2 and 3), Kembla Creek, Sandy Creek, Native Dog Creek, Rocky Ponds Creek, Ousedale Creek, Foot Onslow Creek, Mallaty Creek, Harris Creek, Navigation Creek
4	Georges River, Cordeaux River (above Kembla Creek), Waratah Rivulet, Stokes Creek
5	Bargo River, Avon River, Cataract River (above Lizard Creek), Cordeaux River (below Kembla Creek)
6	Cataract River (below Lizard Creek), Cordeaux River (below Avon River)
7	Nepean River

Upland swamps in the Sydney Basin develop on gently sloping areas on the sandstone plateaus, where sandy sediment has accumulated over several thousand years. They are saturated for most of the year, are largely treeless and covered in heath and sedgelands, and have soils which are grey or black due to the presence of organic matter. The location of swamps across the Southern Coalfield is shown in Figure 43.

Upland swamps support a diverse and specific array of vegetation and fauna and make up approximately 5% of the catchment areas of the Metropolitan and Woronora Special Areas (Advisian, 2016). While classified in a number of different ways, there are two main types (as defined by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) (Commonwealth of Australia, 2014a)) found on the Woronora Plateau:

- **Headwater swamps** (also called valley side swamps) – these sit near or across ridges in the headwaters of streams and are predominately fed by rainfall or short-distance surface flows. Sediment depth is usually 0.5-1 m and the water table rises and falls quickly in response to rainfall. These swamps can be quite large and may merge downslope with swamps on the valley floor
- **Valley infill swamps** (also called valley floor swamps) - these occupy the broad shallow valleys on the plateau. They are fed by rainfall and runoff, interflow (seepage via the bedrock enclosing the swamp sediments) and groundwater (if the local water table rises above the swamp's bedrock base). Sediment depth is generally 1-2 m and can be higher along the valley axes. The water table is usually stable and close to the surface except during prolonged periods of dry weather [82]

It has been proposed that the headwater and valley infill swamps in their unimpacted condition contribute to sustaining baseflows. Properties of the swamps that support this proposition are:

- **topography**, the low gradients contribute to storage of water in the swamps
- **soil**, swamp soils have a higher water-holding capacity than the drier and generally shallower soils on the valley sides and ridges and therefore have the capacity to release water downstream for longer than other areas in the catchment
- **vegetation**, the high surface roughness created by the vegetation acts to slow surface flows and encourage infiltration
- **water source**, high surface and subsurface runoff from the valley sides will be intercepted by valley infill swamps
- **water table**, the swamps in natural condition are partially saturated for long periods following rainfall, which is likely to induce slow subsurface flow to the outlet creek.

[82] It is worth noting that the literature review for WaterNSW (Advisian, 2016), uses a classification that differs:

- Headwater swamps lie in broad shallow trough valleys in 1st order and sometimes 2nd order streams. This class would include 1st order valley infill swamps as defined above.
- Valley infill swamps are on relatively flat sections of more incised streams, usually 2nd order but sometimes 3rd order.
- Valleyside swamps on steeper terrain where seepage flows over bedrock outcrops. This class would be included in headwater swamps as defined above.

Hanging swamps are defined compatibly with the IESC class as swamps on very steep slopes or cliffs. A very few are found on the Woronora Plateau, for example along Bargo and Cataract gorges.

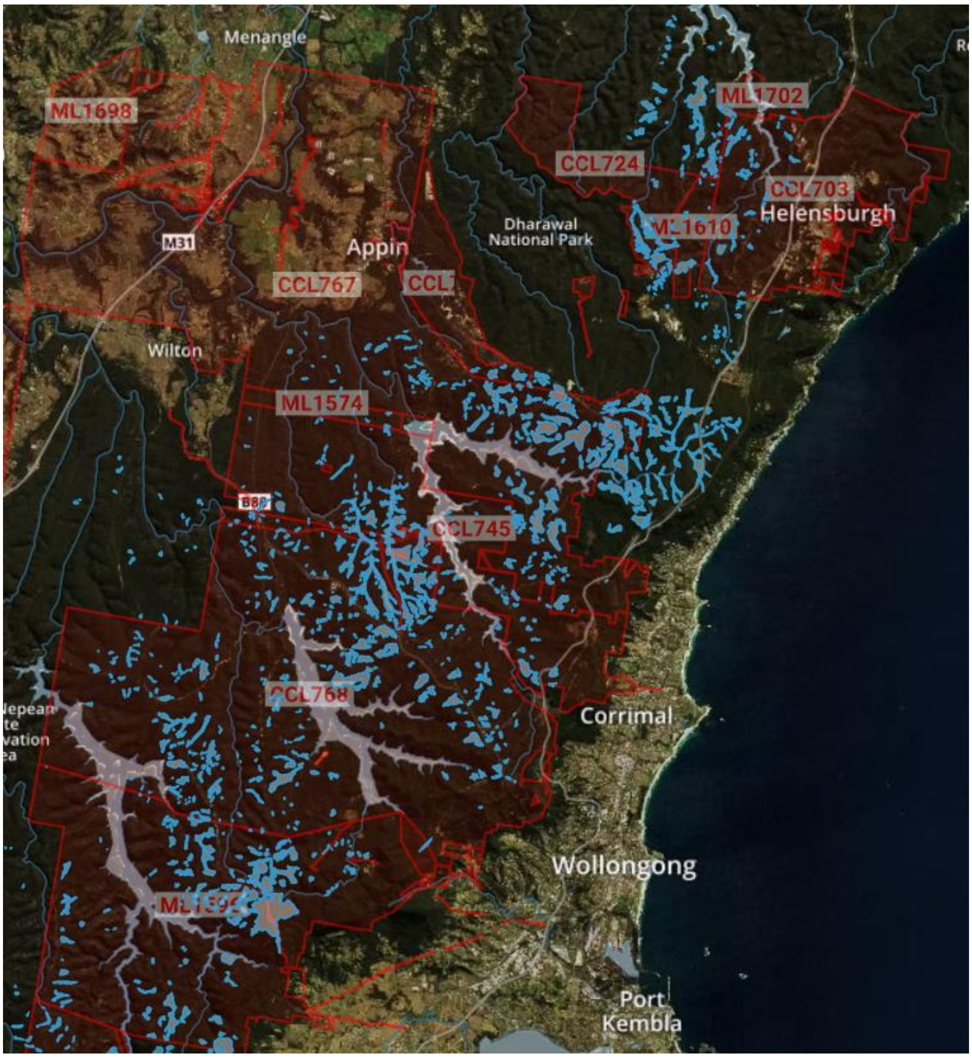

Figure 43: Location of swamps across the coal leases in the Southern Coalfield. Swamp locations (blue) (WaterNSW, 2018e)[83], base map and lease locations from MinView (red) (DPE, 2018)
Leases for this report: Metropolitan Mine: CCL703, ML1702, ML1610; Dendrobium Mine: CCL768, ML1510

The interaction of water with swamp soils and vegetation tends to produce baseflow that is high quality, clear and acidic, and with very low salinity.

Headwater swamps have a higher water holding capacity than the drier and generally shallower soils on the valley sides and ridges and therefore have the capacity to release water downstream for longer periods of time than other areas in the catchment.

Upland Swamps were listed as an Endangered Ecological Community under NSW law in 2012 (NSW Scientific Committee, 2012) and a ‘Threatened Ecological Community’ by the Commonwealth Government in 2014 (Department of Environment, 2014). Impacts arising from longwall mining had been identified earlier (NSW Scientific Committee, 2005) and were recognised as a key threatening process in these listings. Longwall mining and approvals for mining under many of the areas occupied by swamps predate these listings.

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[83] The swamp locations are based on digital aerial photography interpretation that was undertaken by the Sydney Catchment Authority (now WaterNSW) GIS specialists in 2012 and updated in 2014. This analysis comprised comparing photos from different times and climatic conditions and as well as remotely sensed soil-moisture conditions to identify likely swamp boundaries. A classified dataset of ecosystem polygons was derived, representing 47,505 hectares containing wetland areas in Sydney’s drinking water catchments.

There have been a number of other maps produced of upland swamps in the Sydney Basin, notably NSW OEH (2018) and Professor Kirstie Fryirs, Department of Environmental Sciences, Macquarie University (Fryirs & Hose, 2016).

5.1.2 Scale considerations

Underground mining is known to have two principal potential consequences for surface water quantity:

- reduced baseflow inputs to watercourses and reservoirs due to lowered groundwater pressures
- increased infiltration of flow or stored water through watercourse and reservoir beds due to changes in pressure gradients and/or mining-induced cracking in the beds of watercourses and reservoirs.

Consequences for watercourse flow quantity can be assessed according to scale, while consequences for both watercourse flow quantity and reservoir storage relate to temporal dimensions, as follows:

- **Localised scale** - affecting watercourse flows only for relatively short lengths
- **Catchment-scale** - with wider consequences for the environment, communities and water supplies. Whether the consequences are localised or catchment-scale depends on the location of mining, the magnitude of the flow reduction, and the flow pathways created by surface and subsurface cracks.
- **Short-term** - affecting watercourse flows for short periods of time (weeks to months) with temporary consequences for the environment, communities and water supplies
- **Long-term** - years to decades or indefinitely; depending on whether cracks seal and/or groundwater pressures recover following mining or whether the nature of cracking and voids permits permanent diversion of surface flow.

The approach to assessing consequences depends primarily on whether ecological criteria, cultural criteria (including religious and recreational values) or human use criteria (domestic, commercial and industrial uses) are being considered. For ecological and cultural purposes, localised and short-term variations in surface flows can be important. Where there are large reservoirs, such as in the Special Areas, consequences for human use are unlikely to be significant unless there are long-term reductions in flows into reservoirs or at other water supply extraction points, and/or long-term leakage from reservoirs.

In accordance with its Terms of Reference 1, the Panel has focused on long-term and catchment-scale consequences for water supplies in this report, while acknowledging the importance of cultural and ecological consequences (including those for upland swamps).

5.1.3 State of current knowledge

Knowledge about consequences of mining on surface water supplies in the Special Areas has progressed over the last decade. An overview of the potential impacts and consequences of mining on swamps, surface flows and storages is presented in Table 8.

Grouting has been used to restore some rockbars and pools in streambeds. The Panel observed the successful application of this technology at Waratah Rivulet. However, no strategies, other than changes to mining layouts, have effectively mitigated longwall mining impacts.

Table 8: Summary of subsidence effects, impacts and consequences for surface flows, storages and swamp hydrology (Adapted from Commonwealth of Australia (2014b))

Subsidence effects	Impacts	Consequences
• Tensile cracking, tensile, compressive or shear movement of joint and bedding plane • Fracturing of sandstone blocks • Buckling and localised upsidence in the stream bed below the swamp • Tilting of bedrock	• Cracking of rock bars • Lowered water tables and soil moisture • Potential erosion and scouring • Altered water chemistry e.g. enhanced release of iron • Change to the size of swamps	• Loss of surface flow and storage through leakage • Loss of baseflow generation including from swamps • Vulnerability of swamps to fire and further erosion and reduction in baseflow generation capacity • Increased loads of contaminants to water storages

The current state of knowledge may be summarised as follows:

- **Reservoir leakage rates** - there is no measured evidence of significant long-term leakage from reservoirs due to mining in the Special Areas. Due to concerns about future potential leakage, investigations have been and continue to be undertaken into potential leakage through faults and basal shears. Measured pressure gradients between the reservoirs and the mined coal seams are also used to estimate potential leakage rates. Reservoir water balance models have been used to conclude that expected rates of leakage due to the mines are not significant relative to other water balance components.
- **Watercourse leakage (localised)** - the recognised impacts of underground mining include valley closure, valley floor upsidence and buckling, and cracking and shearing of watercourse beds. The consequences on pool levels and localised surface flows are well known, from monitoring at mining-affected sites showing changes to pool levels, flow and shallow groundwater.

  The consequences for undermined watercourses and at visibly fractured sites range from visibly drained pools and flow losses to no visible depletion or diversion of surface water (Peabody Energy, 2018a; South32, 2018c).[84] The predictability of valley closure impacts is currently based on an upper limit approach, as presented in Chapter 2, with impacts then being correlated to consequences on the basis of past experience as shown for example in Figure 17. The consequences exhibit a considerable degree of site-to-site variability and, as already noted, the consequence rating criteria may need to be revised.
- **Watercourse bed leakage (at catchment scale)** – from material presented to the Panel, there remains no strong evidence that cracking of watercourse beds leads to significant losses of water at catchment scales relevant for water supplies. Several years of surface flow monitoring are now available at 12 sites within or near downstream of the Dendrobium and Metropolitan mines.

  Significant losses have been observed at 1st and 2nd order watercourses but monitoring of 3rd and 4th order watercourses[85] shows no strong evidence that there are losses significant for surface water supplies. However, the absence of strong evidence does not necessarily mean that significant consequences do not exist. The numerical models used to detect or predict flow consequences cannot provide the accuracy required to conclude on small (but potentially significant) consequences. A summary of modelled flow losses is included in Chapter 4 of this report.

[84] Table 7-12, Metropolitan Annual Report 2017 and Section 3, Dendrobium LW 13 EOP Report.
[85] From material presented to the Panel - 1st and 2rd order sites where flow consequences have been concluded: tributary of Lake Avon (LAS41), upper Donalds Castle Creek and tributary sites (DCS2, DC13S1), Wongawilli Creek tributary (WC21S1); 3rd and 4th order sites where flow consequences have not been concluded: Wongawilli Creek (WWL), Donalds Castle Creek (DCU) (up to LW 13), Waratah Rivulet (GS 2132102), Eastern Tributary (GS 300078).

- **Swamp leakage** - in cases where the groundwater in the sandstone lying directly underneath a swamp is depressurised due to mining, downward pressure gradients can accelerate the vertical drainage of the swamp. This reduces horizontal surface flow and subsurface flow towards the swamp outlet, although the increased vertical flow may express as surface flow further down the watercourse.
- **Swamp contribution to catchment baseflows** - it has been proposed that swamps provide an ecologically important component of base flow to watercourses during dry periods (IESC, 2015b; Advisian, 2016). Work by Evans and Peck (2014) and (Krogh, 2015a) has considered swamp contributions to baseflow. Valley-infill swamps are likely to make a greater contribution than headwater swamps, reflecting the larger volume and water-holding capacity of their sediments (Advisian, 2016).

The 2016 Audit of the Sydney Drinking Water Catchment (the 2016 Catchment Audit) observed that mining can have consequences for surface flow, but these are poorly understood and that assessment of losses is difficult (Alluvium, 2017a).[86] Although 11 sites in the Upper Nepean River catchment were considered, each of these was either outside the mining-affected areas or is downstream of the reservoirs, meaning that any mining consequences would not be discernible.[87] Only one of the upper Nepean sites, which is not in the area affected by mines, was considered to have 'poor' flow status. As well as these 11 Upper Nepean River sites, The 2016 Catchment Audit considered two flow stations (Woronora River inflow and Waratah Rivulet inflow) in the mining-affected Woronora River catchment and both were noted as having "poor" status. It did not conclude on the reason for this "poor" status but noted that surface water extraction licence entitlements have increased by more than 400% in the Upper Woronora since the Audit for the period 2007-2010 (NSW DECCW, 2010).

The Southern Coalfield Report found no evidence that undermining of swamps had affected water supplies (Hebblewhite et al., 2008). A large body of new knowledge has developed since then; however the integrated monitoring and modelling needed to understand the contribution of swamps to baseflows continues to be extremely limited, and it remains the case that there is no strong evidence of consequences of swamp impacts on catchment-scale water supplies

Despite the advances in knowledge over the last decade through improvements in monitoring and modelling, debate continues about the level of consequences of mining in the Special Areas for surface water supply.

Quantitative knowledge is currently limited by:

- the **ability to accurately monitor** the relevant water balance components and how these change in response to mining. This may be related to technological limitations, legal obstacles to installing monitoring equipment, costs of monitoring (financial and environmental costs), limitations in baseline data, and lack of integrated monitoring programs.
- the **ability to quantify flow consequences.** The swamp areas pose particular challenges for quantifying flow consequences because of the difficulty of monitoring inflows and outflows, of installing and maintaining monitoring equipment inside the swamps, of generalising over a number of hydrologically different swamps and of

[86] The Alluvium (2017a) Audit (p21, Vol. 1) concluded "*Evidence of the impacts of mining on surface water flows is very limited. WaterNSW gauging station density has inadequate coverage to identify direct longwall by longwall impacts or cumulative effects. (For example, only two gauging stations are present in the Woronora sub-catchment). This is supplemented by monitoring requirements placed on mining companies by the Department of Planning and Environment. Once volumes of loss from surface water and groundwater sources are determined, DPI Water can ensure that water take from mines are appropriately licensed under the relevant NSW surface and groundwater Water Sharing Plans for the area ((DPE, 2015c), p.42) and the NSW Aquifer Interference Policy* (DPI, 2012).

[87] (Alluvium, 2017b) Vol 2, Figure 3 and Figure 36.

estimating important parameters (notably evapotranspiration). No accurate water balance is available for any swamp within the Southern Coalfield.

- the **ability to unambiguously identify the hydrological and geomechanical processes** that link mining effects with surface water consequences. In particular: low ability to identify the location of exchanges between surface water and groundwater; limited ability to identify the flow paths that govern whether that water returns to the surface water system; and limitations in characterising the hydraulic connectivity between reservoirs/ creek beds and mine voids.
- **current modelling and monitoring technologies** which do not permit accurate prediction of future surface water losses, preventing a precise attribution of creek flow changes between mining and/or other environmental changes.

5.1.4 Monitoring

Watercourse flow is measured using flow gauges to detect and quantify any consequences of mining on surface flows, including providing data to support surface flow modelling. At present, the surface water flow monitoring requirements in the conditions of consent are specified in general terms, requiring monitoring to assess compliance against project approval conditions. This places the responsibility on the mining company to provide sufficient (timeframes, locations and accuracy of) flow gauges.

The required length of baseline flow (and climate) data is dictated by the amount of data needed to determine baseline flow duration curves, and to calibrate[88] and validate[89] the rainfall-runoff model with sufficient confidence.

For some purposes, the flow condition of a watercourse can be qualitatively assessed by observing water levels and presence/absence of water without necessarily measuring flow. The continuous measurement of flow is considerably more expensive and of lower accuracy than the measurement only of water levels. Therefore, flow gauges are used only where and when quantification of flow is considered to be high-value.

The installation of a weir or flume is often recommended to achieve accurate flow measurements. However, the technical feasibility of installation and operation depends on the geomorphology of the watercourse, access for construction and maintenance, and the potential for damage during operation. The consequences of installation may include creating obstacles to aquatic wildlife, and disturbance and generation of sediments during and post construction. Appropriate consideration of these potential impacts and operational difficulties is needed before recommending specific flow monitoring technology. While there have been cases where permissions to install high accuracy flow monitoring in the catchment have not been granted by WaterNSW due to concerns about related environmental impacts, recently three high accuracy gauges have been installed in the Woronora reservoir catchment.[90]

Recommendations have been made relating to surface water quantity and monitoring in a number of the reviews and reports relating to the Southern Coalfield. These include:

- the Southern Coalfield Report which recommended:
    - rainfall measurement at a sufficient number of locations so as to permit assessment of runoff contributions (quick flow and base flow) and aquifer recharge characteristics in potentially affected areas

[88] Calibration is the process of tuning the model parameter to improve model accuracy.
[89] Validation is the process of testing the model prediction accuracy.
[90] The 2007 'Surface Water Quality and Hydrology Assessment' report for the Dendrobium mine (Ecoengineers Pty Ltd, 2007) states: "The deployment and use of standard flow gauging devices such as V notch or rectangular weirs, Cippoletti weirs or Parshall flumes for continuous measurement of flow in watercourses was not approved by the [Sydney Catchment Authority] SCA" (now WaterNSW). The recently installed gauges are included in Chapter 5 review of the Metropolitan mine surface water monitoring.

  - stream flow gauging with automated daily or more frequent recording of flows at strategic gauging stations, distributed in such a manner so as to accurately characterise the flow regime and to reflect mining-related consequences within 3rd and higher order stream channels. (Hebblewhite et al., 2008)

- the PSM study which did not significantly cover the surface water monitoring or modelling. However, the nine concepts for monitoring noted in that report (Sullivan & Swarbrick, 2017)[91] and its concluding recommendations, particularly recommendations 1, 2, 3, 5, 7 and 9 (Appendix 5) provide a sound basis for quantifying surface water losses.
- the 2016 Catchment Audit which recommended the need to:
  - identify surface water flow monitoring requirements in mining approval conditions
  - integrate locations and timing for monitoring of macroinvertebrates, water quality and stream flow, including environmental flow monitoring sites (Alluvium, 2017a)

In relation to swamp hydrology, current gaps and uncertainties in the knowledge base and hence of contribution of swamps to surface water flow and baseflow reflect a lack of long-term strategic monitoring and investigation, including that:

- very few swamps have exit weirs and those few have been established for short periods
- there are no published measurements of evapotranspiration and so estimates are made from climatic data modified for generalised vegetation classes
- there has been minimal investigation of swamp sedimentary characteristics, such as porosity, to estimate swamp soil water-holding capacity.

5.1.5 Modelling

Surface flow modelling is conducted in two ways. The primary approach is to use rainfall-runoff models such as the Australian Water Balance Model (AWBM); the second being use of groundwater models. Rainfall-runoff modelling is used to quantify the consequences of completed longwalls on surface flows. Groundwater models also have been used to predict the consequences of planned longwalls on surface flows.

The AWBM uses simple concepts of how water moves through a catchment to estimate the watercourse flow at a selected site in response to rainfall. The AWBM is used to simulate what watercourse flows would have been if mining had not happened. The outcomes are then compared with the measured flows to quantify the mining-induced consequences, such as flow reduction.

Rainfall-runoff models like the AWBM have limitations. This includes their assumption that the spatial variation of rainfall is not important and their exclusion of groundwater flows across the catchment boundary. However, if the errors in the model are taken into account when interpreting model results, these limitations may be acceptable.

Groundwater models focus on accurate modelling of groundwater pressures and underground mine inflows, and their surface flow results tend to have low accuracy.

5.2 DENDROBIUM MINE

5.2.1 Surface water monitoring

In the current and recent mining domains at Dendrobium Mine of Areas 3A, Area 3B and Area 3C, the major surface water resources are Lake Avon, Lake Cordeaux, Donalds Castle

[91] pp.56-57

Creek and Wongawilli Creek. The major monitoring locations for surface flows are shown in Figure 44 along with swamps and related monitoring sites.

In general terms, the requirement for surface flow monitoring is set out in the Dendrobium Mine consolidated consent, specifically within the requirement of the Watercourse Impact, Monitoring, Management and Contingency Plan (WIMMCP). The WIMMCP sets out the surface flow monitoring used and includes four sites on Donalds Castle Creek (two on tributaries and two on the main channel), three sites on Wongawilli Creek (one on a tributary and two on the main channel, three sites on Sandy Creek (two on tributaries and one on the main channel) and a further monitoring site on a tributary of Lake Avon adjacent to LW 13 (South32, 2017d).[92]

All of these sites measure flows from catchment areas potentially affected by mining subsidence. One of the sites on Wongawilli Creek is upstream of the area likely to be affected by mining LW 1 to LW 18, although flows at this site may be affected by historical mining.[93]

WaterNSW also has a long-term flow monitoring program including the Avon and Cordeaux catchments; however, there are no reported WaterNSW gauges in the 1st to 3rd order watercourses potentially affected by the Dendrobium Mine.

[92] WIMMCP Figure 2.36; see also attachment D1 of the LW 12 EOP report (HGEO, 2017c).

[93] EOP reports refer to an additional three sites on tributaries of Sandy Creek outside of areas expected to be impacted by mining (HGEO, 2017c) EOP report for LW 12, Attachment D1, Table 2.

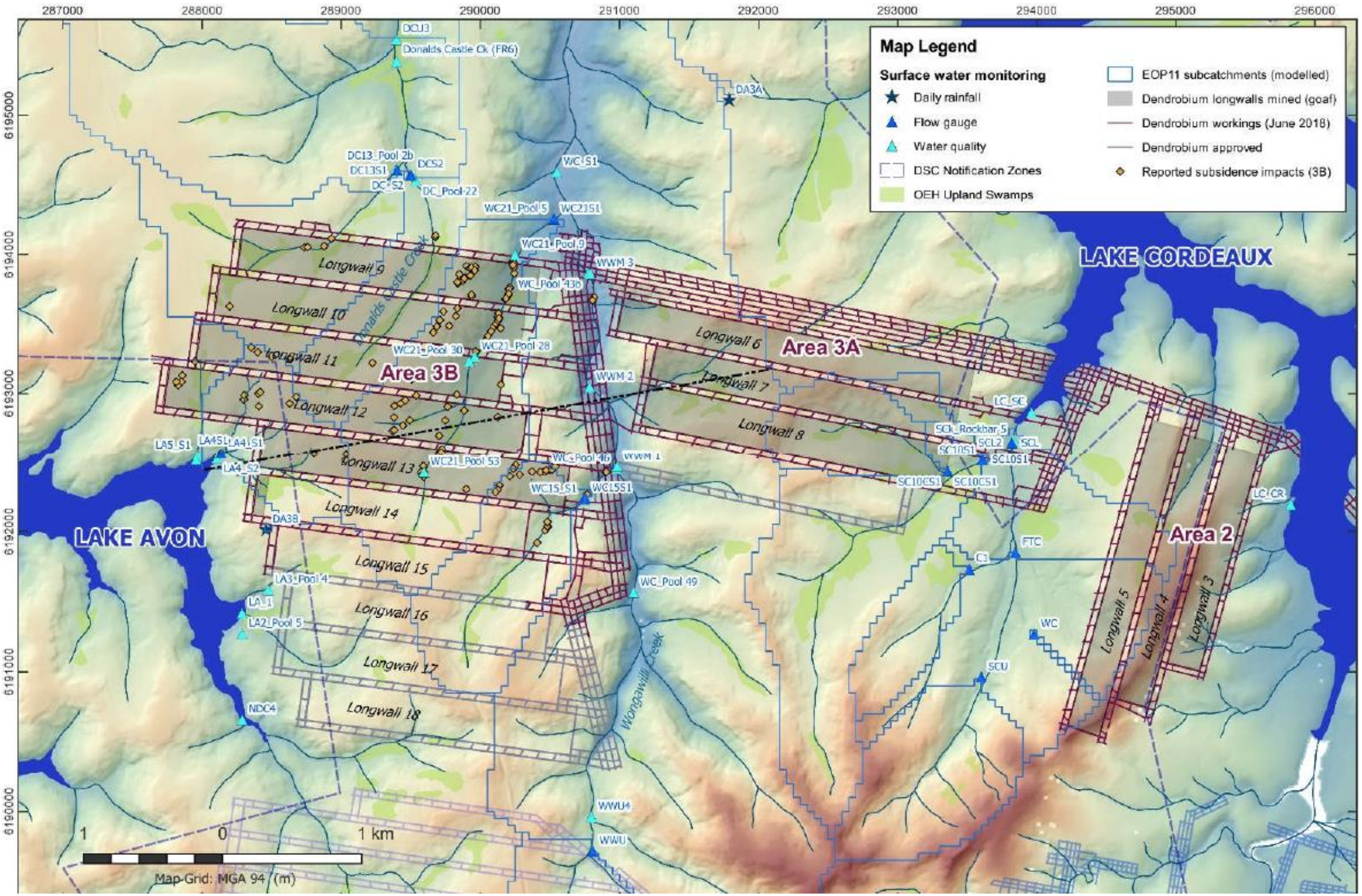

Figure 44: Surface water resources around the Dendrobium mine including water quantity and quality monitoring sites (HGEO, 2018a)

5.2.1.1 Panel observations

Accuracy of monitoring

The 10 monitoring sites currently used to assess consequences for surface water at the Dendrobium Mine are naturally rated sections.[94] The accuracy of each data point on a rating curve[95] for each site is categorised as 'reliable', 'fair quality' and 'poor quality'.[96] Low flow measurements tend to be fair to reliable, and higher flows tend to be less reliable. No rating curve data were presented in the reports reviewed by the Panel, therefore the sufficiency of the flow monitoring accuracy has not been fully assessed.

The accuracy is important for assessing compliance. A technical peer review with access to the monitoring sites, procedures and data would be necessary to determine the accuracy being achieved. For natural rated sections, plus or minus (±) 10% accuracy should be the target for low to medium range of flows. In the EOP reports, ± 10% accuracy is the stated accuracy, with the exception of DCS2, which is thought to have lower accuracy.

If it is feasible to install weirs or flumes, it is reasonable to expect a greater accuracy, which may be ± 3% accuracy (i.e. an upper limit to the measurement errors of ± 3% of the measured flow) depending on the gauge design, construction and maintenance.

The only peer review of surface water flow monitoring for Dendrobium Mine that the Panel has seen is a review undertaken for the Dendrobium Community Consultative Committee (DCCC) by Professor McMahon (McMahon, 2015) of surface water monitoring reported in the LW 9 and LW 10 EOP reports. This included comment about the accuracy of the weirs installed in the Environmental Trust Grant study by Krogh (2015a).[97] Professor McMahon's review for the DCCC of LW 9 and LW 10 reports noted:

> *"A new section (Section 1.5) on hydrographic monitoring is added to the EOP reports. This provides some guidance as to the potential error in the observed flow data. However, given the importance of the streamflow to the downstream water supply system I would have expected some analysis of the rating curve data and, hence, an estimate of error of the daily streamflow data"* (McMahon, 2015).

The Panel agrees with Professor McMahon's statement and that the analysis of flow monitoring errors and their impact on assessing compliance should be published and peer reviewed.[98]

Number and location of gauges

The existing coverage of flow monitoring, although extensive compared to most mining areas in Australia, does not adequately represent the potential consequences of Dendrobium Mine on flows to Lake Avon. There are large areas of the catchment that are predicted to be impacted by LW 16 to LW 18 that are not monitored, and which are unlikely to be represented accurately by the results from existing monitored sites.

Given that there are costs and environmental impacts of installing flow gauges, it would not be appropriate for every potentially impacted watercourse feeding Lake Avon to be

[94] The EOP reports note that a mix of rated natural sections and small weirs are present but do not provide details of any site.
[95] Naturally rated sections are those where the rating curve is derived for a natural section in the creek without the use of a constructed weir of flume. The rating curve translates measurements of water level to flow. The curve is constructed by taking manual, high accuracy measurements of flow over a range of flows, plotting these data against the corresponding water level measurements, and fitting an equation (or equations) that describes the plotted relationship. The errors between the fitted equation and the manual flow measurements can be used to quantify the accuracy of the flow gauge. Any flows more than 20% above the maximum flow used to construct the rating curve should be considered unreliable. The rating curve is updated using new measurements to allow for any shifts, e.g. movement of the creek bed.
[96] Rating curve quality ratings: (where P=poor quality; F=Fair quality; G=Reliable) for Sandy Creek (quality G-P), Sandy Creek tributaries x 2 (mainly P), Wongawilli Creek downstream (G) and upstream (F), Wongawilli tributaries x 2 (F), Donalds Castle Creek (F-P), DC tributary x 2 (F-P), LA4 (F).
[97] Surface flow monitoring and assessment was not in the scope of the Mackie (MER, 2017) and Galvin (Galvin, 2017b) reviews of the SMP for LWs 14 to18, nor covered significantly by the PSM 'Height of Cracking' study (Sullivan & Swarbrick, 2017).
98 Although in the LW 11 report says "*Ecoengineers Pty Ltd (2015) [the LW10 report] provide background to the monitoring data, including the rating of flow and the maximum reliable flow at each site*" this background is presented only in summary and has not been presented in any of the seen reports.

monitored. Instead, conclusions for monitored sites may be transferred to non-monitored sites where it may reasonably be judged that impacts are similar.

Assessing compliance requires the separation of any reductions in flow due to climate variability from those due to mining. Approaching this solely by rainfall-runoff modelling should be supplemented by comparing reference (control) sites that are un-impacted by ongoing mining with the potentially impacted sites. Comparative techniques such as flow ratios or double mass plots [99] can then be used to isolate non-climate-related impacts, as a supplement to rainfall-runoff modelling. This has been done in some EOP reports, including for LW 11 (South32, 2016a), using the tributaries of Sandy Creek as the reference unimpacted sites; but has been excluded from the LW 12 and LW 13 EOP reports. Comparison with suitable reference sites should be consistently used as a complement to modelling results.[100] A priority is the use of a suitable control site to assess potential losses of flow at the WWL site.

Length of monitoring

The length of baseline monitoring is variable and in cases insufficient. Using the rainfall-runoff modelling approaches employed at Dendrobium Mine, in general good practice would involve more than two years of baseline monitoring including both relatively dry and wet years for calibration plus at least another two years for validation, with the latter period including flow conditions that are more extreme (low flow periods) than in the calibration period. The license conditions requirement for two years of baseline monitoring to cover both calibration and validation periods may result in models with low or unknown levels of accuracy.

When concluding on suitable periods of data for model calibration and validation the time-scales of mine planning should be considered, and there is a need to distinguish between design of temporary (life of mine) gauges and planning gauging at strategically important sites. The period of data used for model calibration and validation, as well as the accuracy of the flow monitoring and how well the model fits the measured flows, should be reflected in statements of model accuracy.

The Southern Coalfield Report recommended "*rainfall measurement at a sufficient number of locations so as to permit assessment of runoff contributions*" (Hebblewhite et al., 2008). Whether the former recommendation has been addressed at Dendrobium Mine is questionable. The WIMMCP and most of the recent EOP reports mention a single rain gauge, which is likely to be inadequate for modelling flows. The EOP report for LW 13 shows two rain gauging stations[101]; however this may not be sufficient considering the strong precipitation gradients.

5.2.2 Swamp monitoring

A requirement of the 2013 Area 3B SMP development consent is a Swamp Research and Rehabilitation Plan (SRRP). The investigations and studies are designed to:

- *"Characterise the near-surface fracture zone in terms of fracture distribution and spatial extent beneath swamps and controlling rockbars*
- *Characterise the post-mining hydrogeological regime (perched and regional groundwater) within swamps*

[99] This plots the time-series of cumulative flow series at a site with the time-series of cumulative flow from the same period at a second site in the same region. Significant changes in the flow-flow relationship show that there has been a non-climatic impact at one or the other site.
100 Supported by Professor McMahon's review (McMahon, 2015): "*a paired catchment approach maybe more satisfactory*" (than modelling) due to potential non-stationarity of hydrology.
[101] The LW 13 EOP report, Appendix D (HGEO, 2018a) p.12 notes "*Rainfall data are collected from several gauging stations across the mining lease"* and at p.25: "*Rainfall and potential evaporation inputs were obtained from Dendrobium's Centroid rainfall station and from SILO 'Data Drill' for the Dendrobium Mine location (DSITI 2011).*" Two stations are shown in Figure 1 of that report.

- *Identify areas of flow diversions and quantify or estimate the proportion of the diverted flow*
- *Inform the design of grout injection and other remediation options."* (South32, 2016d)[102]

The Swamp Impact Monitoring Management and Contingency Plan (SIMMCP) lists the monitoring program and performance criteria for swamps undermined by Dendrobium Mine (South32, 2017c). The SIMMCP lists 17 impacted (either current or future) swamps and 19 control swamps (Swamp 15A, which is to be undermined by LW 19, is on both lists). A range of data types are specified - observational data (photo point, pool water level and erosion), shallow groundwater and soil moisture, vegetation (species and size/sub-community distribution), some endangered faunal species, and size/distribution data for a range of impacted and control swamps.

The SIMMCP does not include the swamps over Area 2 or any activity for Swamp 12 and Swamp 15B in Area 3A apart from photo point and pool monitoring. Hence, the SIMMCP does not include an ongoing analysis of data from swamps with the longest period of record since undermining.

The current monitoring covers the impacts on upland swamps including:

- Changes in shallow groundwater, mainly in the swamp sediments but sometimes in adjacent bedrock.
- Changes in soil moisture at a few sites, but for limited periods to date
- Vegetation by photo point observation, quadrats, transects. However, the Panel notes these have not always been designed on a Before-After-Control-Impact (BACI) basis
- Evidence of impacts such as cracks in soil or rock, drying of pools in relation to pegged levels.

Two additional flow monitoring sites represent the surface flow outlets of Swamps 1b and 14 from 2012-2014. These were installed as part of an Environmental Trust Grant study (Krogh, 2015a) and complemented by water level, soil moisture and weather monitoring. These weirs were in place at the time of the Panel's field visit in February 2018, but were not operational.

Above Dendrobium Mine, the impact of longwall mining on the groundwater within the swamp sediments is well documented.

The April 2013 EOP report for LW 8 (BHP Billiton Illawarra Coal, 2013) reported a range of impacts on swamps in Area 3A and 3B that included "*increased rates of shallow groundwater recession*" at Swamps 12 and 15b following extraction of LW 7 and LW 8. These triggered Level 3 of the Trigger Action Response Plan (TARP) for groundwater at Swamp 12. The Panel understands that this was the first time that the Dendrobium Mine had interpreted monitoring data as showing direct impacts on the swamps' hydrology due to mining.

DPE (2015c) concluded that: *"it is clear that monitoring results identify that Longwalls 9 – 11 have impacted on every swamp that has been directly undermined or is located immediately adjacent to the longwall panel being mined. These impacts … mostly relate to increases in groundwater recession rates and/or significant changes in the shallow groundwater regimes. It is accepted by all agencies that all undermined piezometers within swamps have exhibited an increase in groundwater recession rates and/or water level lower that pre-mining baseline."*

[102] p.20

Figures 47 to 50 of the PSM study illustrate a consistent pattern of rapid drawdown of shallow groundwater within all swamps as they have been undermined, with no piezometer above or closely adjacent to a longwall having a response that was considered ‘normal or unchanged’ (Sullivan & Swarbrick, 2017).

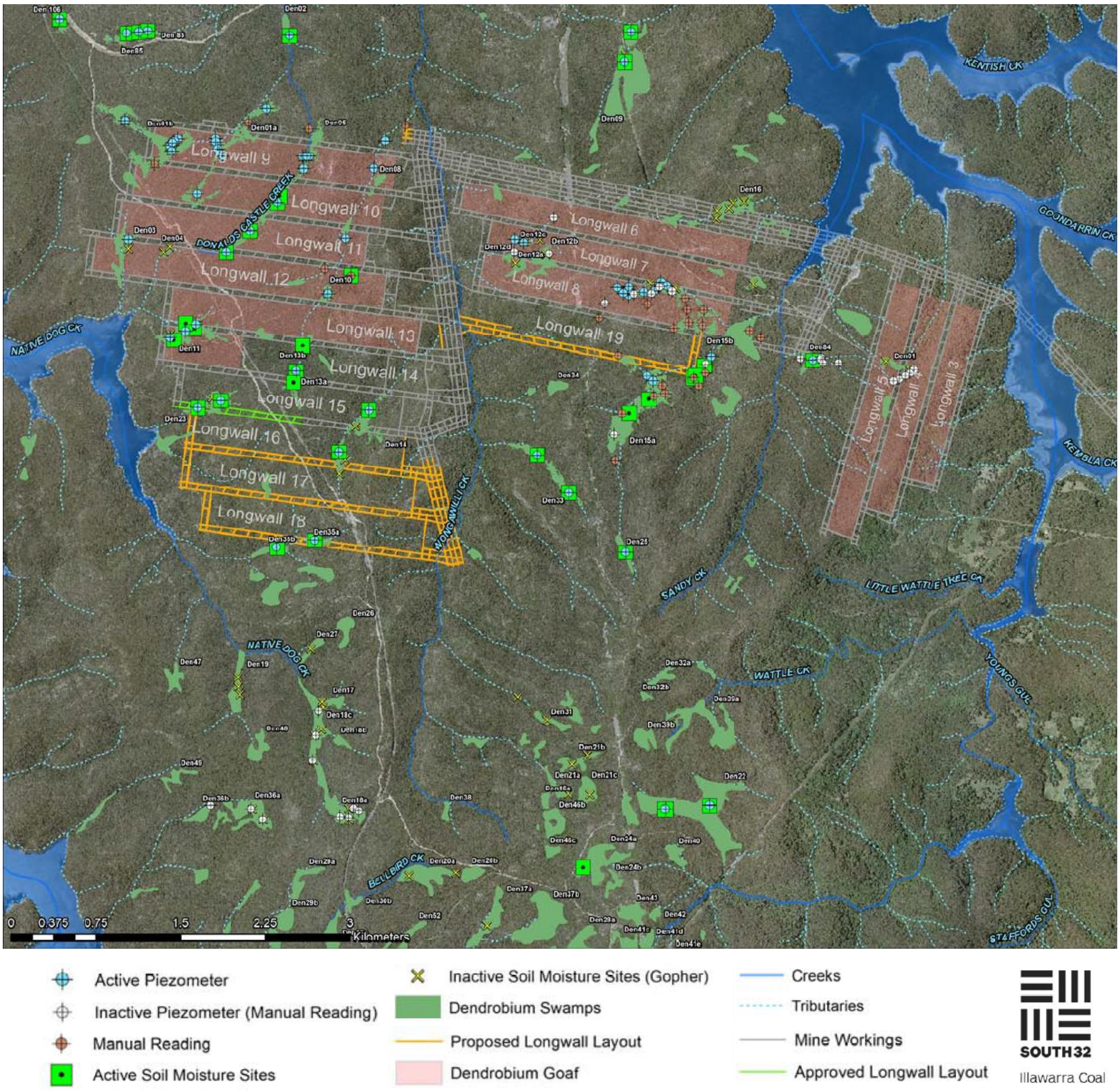

Figure 45: Shallow groundwater and soil moisture monitoring at Dendrobium Mine Area 3 (Map supplied by South32)

5.2.3 Surface flow modelling

Rainfall-runoff modelling has been used at Dendrobium Mine for all EOP reports since LW 5. The modelling is used to quantify reductions of flows in Wongawilli Creek, Donalds Castle Creek and the inflow to Lake Avon at the monitored sites, and to conclude on activation of the triggers defined in the TARP. The AWBM rainfall-runoff model is used for LW 11. LW 12 and LW 13 EOP reports (South32, 2016a, 2017a).[103]

Rainfall-runoff models have limitations regarding assumptions, although these may be acceptable if the errors are accounted for in drawing conclusions. Professor McMahon’s review of the LW 9 and LW 10 surface water modelling stated: “*I’m satisfied that*

[103] Previous EOP reports used the comparable RUNOFF-2005 model. The LW 13 EOP report also uses a slightly amended AWBM that aims to improve accounting for evapotranspiration losses in dry periods (South32, 2018c).

RUNOFF2005 is a suitable model to assess whether there is any impact on streamflow in the Dendrobium 3A area due to longwall mining" (McMahon, 2015). This statement may reasonably be extended to the AWBM although recent dry weather has raised questions about this model's accuracy in extreme low flow conditions.

The rainfall-runoff modelling applied for LW 11 and LW 12 subsequent to these reviews was substantially different (its adequacy is covered below). WaterNSW has criticised the approaches to surface water loss estimation (WaterNSW, 2016); however, the WaterNSW review does not add to Professor McMahon's comments on the rainfall-runoff models and relates mainly to the groundwater model predictions of surface flow losses.

Up to the model described by Hydrosimulations (2016), the groundwater models for the Dendrobium Mine use the MODFLOW Stream Flow Routing (SFR) boundary condition to calculate the stream water balances from cell to cell within the regional flow model HydroSimulations (2015b)[104]. This is achieved by calculating gains or losses via vertical infiltration into the underlying aquifer along a specific reach. Results are accumulated with the upstream inflow in order to determine the downstream outflow of particular model cells. The process is then repeated in the next downstream reach.

The most recent groundwater modelling of the Dendrobium Mine (HydroSimulations, 2018b) reverted to a simpler stream boundary condition. The Panel considers this to be justifiable in view of the high computational effort required when using the SFR option. However there are a number of scale related issues that complicate representation of surface drainage lines. These include stream bed conductance's that regulate infiltration, and the assignment of reference heads that drive the exchange of stream/river waters with the underlying aquifer system. It is therefore highly likely that a high level of uncertainty is associated with the simulation of channel flows and rock pool water budgets at the regional scale.

The HGEO review (HGEO, 2018b) of groundwater and surface water consequences at WC21, a tributary of Wongawilli Creek undermined by LWs 9 – 13, included the recommendation:

> "*Analysis and modelling of rainfall runoff processes in the Wongawilli Creek catchment should be reviewed to assess the catchment water balances and determine if there has been a detectable loss at WWL (Wongawilli Creek Lower gauge). The assessment should include gauges WC21_S1, WWL, WWU and WC15_S1*".

This recognises that the increasing hydraulic gradients from Wongawilli Creek to the groundwater may cause losses from the creek. Following this, the LW 13 EOP report reported no evidence of losses at the WC15_S1 and WWL gauges, and continuing evidence of losses at WC21_S1 although lower losses than during LWs 11-12 (South32, 2018c). WWU was not assessed.

Apart from the rainfall-runoff models and groundwater models used by the mine's consultants, the Panel is aware of only two attempts to conduct surface flow modelling. Krogh (2015b) uses a simple water balance to estimate 0.3-0.4 ML/day unexplained reduction in water outputs from Swamp 1b after LW 9 and LW 10. This was presented as a preliminary result and recognised as not being based on comprehensive data. It does not necessarily imply a loss of water from the catchment due to potential re-emergence of groundwater downstream of the weir.

The other attempt at surface flow modelling was within the Commonwealth Government Bioregional Assessment Program. This concluded:

> "*current scientific methods are not well suited to bringing together uncertain local-scale information about subsidence and water losses due to underground mining into a regional assessment. The importance of subsidence and water loss due to*

[104] p.7

underground mining for modelling impacts in the Sydney Basin bioregion meant that the program could not model regional impacts on water resources. Other methods are better suited to local scale assessments of the impacts of individual projects. The program therefore decided not to proceed to detailed regional modelling."
(Department of the Environment and Energy, 2018)

Flow losses were not predicted. However, surface flows potentially affected by mining were quantified using simple hydrological models (Budyko curves) in order to guide a "*preliminary assessment extent*". For various subcatchments containing the Dendrobium Mine the proportion of annual average surface flow potentially affected by the mine was quantified. It was assumed that if this proportion was less than 5% then this was a neglible consequence based on the consideration that less than a 5% change in stream flow is generally not detectable.[105]

For Dendrobium Mine, in the context of the regional-scale aims of the assessment, it was considered that the flow reduction in the smallest subcatchment considered (85.3 km^2) was negligible. Therefore, the preliminary assessment extent was defined only by groundwater considerations.

5.2.3.1 Panel observations

Accuracy of Surface Water Models

The accuracy of the surface water models is variable between modelled sites. Reasons for the lack of accuracy are likely to be a combination of lack of pre-mining data to support model calibration; errors in flow monitoring; errors in rainfall inputs related to the position of the weather station and other sources of data; and limitations of the models used.[106] This includes:

- **pre-mining flow data for model calibration** at the newer flow monitoring sites (DCS1, DC13S2, WC21S1) the length of calibration period is insufficient, and there is no validation on flow measurements from outside the calibration period.[107] This cannot now be addressed for existing sites. Action should be taken to ensure at least two years of pre-mining data for new monitoring sites in Area 3B (see above section on flow monitoring) and at least four years for priority sites around future mining areas
- **errors in flow monitoring**. Errors in flow monitoring should be assessed, reported and reduced where feasible (note observations in surface flow monitoring section)
- **errors in rainfall inputs and other sources of data.** Action should be taken to assess how well the available weather stations/rain gauges represent rainfall in the modelled catchments; and to assess how sensitive the model results are to this source of error (note observations in surface flow monitoring section)
- **limitations of the rainfall-runoff model used**. Reliability of the AWBM model to accurately simulate low flows is critical to its fitness for purpose. The model has been known to have low accuracy during very low flow periods since it was first used for LW 11. The inability to accurately determine low flows is the basis for the mine's conclusion that there is no evidence of non-negligible flow consequences at the WWL monitoring site and no TARP triggers at either the WWL or DCU monitoring sites. Although it may not be possible to improve low flow performance with available monitoring data, given the criticality of low flows for this project, attempts to improve the low flow modelling should continue, and should be reported and peer reviewed.

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[105] Product 1.3 from the Sydney Basin Bioregional Assessment (Herron et al., 2018, pp. 29-33).
[106] It is not clear in the reports whether and how the rainfall data from the weather station are combined with the SILO data.
[107] McMahon included in his 2015 report a recommendation for validation period- apparently still not addressed, and there is no reason why for sites with longer pre-mining flow monitoring periods (McMahon, 2015).

- The groundwater models should not be relied upon to give accurate estimates of future surface water losses. Complementary approaches should be investigated. This may include adjusting groundwater model results according to their under- or over-estimation of losses for previous LWs.

Analysis

The surface flow modelling outputs are analysed using appropriate methods, which consider the 'noise' and 'bias' in the data.[108] While statistical methods might be used to analyse the model outputs, the semi-qualitative interpretations used are appropriate in this context. However, complementary analysis using suitable reference (control) sites should be used more consistently. In particular, the conclusion that there is no evidence of flow reductions at WWL needs to be supported by comparisons with suitable control sites.

Modelling conclusions

The conclusions in the EOP reports are not sound for all sites, appearing to be conservative in terms of the potential for mining consequences for some sites given the uncertainties in the surface flow modelling. In instances where the model performs poorly (i.e. has important errors), it has been claimed to perform well[109], which diminishes the credibility of the modelling.

Between the LW 12 and LW 13 reports, the modellers modify their conclusion regarding the consequences of LW 11 and LW 12 on flows at DCU.[110] Updating conclusions based on new data is acceptable, but illustrates that there is significant uncertainty in model-based conclusions. As well as DCU, there are conclusions for WWL that appear to be on the conservative side and are not consistent with the "*reverse onus of proof*" recommended in the Southern Coalfield Report (Hebblewhite et al., 2008).[111]

5.3 METROPOLITAN MINE

5.3.1 Surface water monitoring

The major water resources in the recent mining domains at Metropolitan Mine including LW 20 to LW 27 and LWs 301 to 317 are Lake Woronora, Waratah Rivulet and Eastern Tributary. The locations of the main surface flow monitoring sites on the Eastern Tributary, Waratah Rivulet and Woronora River are shown Figure 46.

Requirements for surface water monitoring are set out in the Water Management Plan (WMP) for LWs 301 to 303 (Peabody Energy, 2018c). This includes the general requirement for monitoring impacts in the Project Approval Schedule 7, Condition 2 and for baseline monitoring in Schedule 3, Condition 7. In particular, monitoring is required to assess the performance measures and associated indicators in the WMP (Peabody Energy, 2018c).[112]

The WMP shows five rain gauge locations owned by the Metropolitan Mine, starting in 2006, and there are four longer-term BOM gauges near the site (Peabody Energy, 2018c).[113]

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[108] In modelling, 'noise' refers to apparently random differences between the model results and measured flows. Bias refers to the systematic differences that may be due to systematic errors in measurement of flows or climate, or errors in the model.

[109] "*Low flows are well matched*" p27 of HGEO (2017c). Poor calibration R2 value (~0.32 in LW11 and 0.50 for LW12) for DCU and for WC15S1.

[110] *"Evidence that undermining by recent longwalls affected the pattern of flow and the magnitude of recession flows at DCU through Longwalls 11-12; as well as during Longwall 13. Cease to flow conditions increased by about 6%."* (HGEO, 2018a, p. 29) p.29 This contrasts with HGEO (2017c) p.27: "There is a suggestion that flow has declined late in LW11 and again in mid-LW12; however, this may just be the response to weather patterns during mid/late 2015 and 2016, as the recession in early 2016 is well-matched".

[111] McMahon (2015) concluded "*maybe" for impacts on flow of WWL for LW10. There is a larger "maybe" for LW11, LW12 and LW13. For LW13 the modellers conclude "There is no evidence that undermining has affected recession behaviour or reduced sub-catchment flow / yield". An equally valid conclusion is ""There is no evidence that undermining has **not** affected recession behaviour or reduced sub-catchment flow / yield*".

[112] Table 6

[113] Figure 14

Surface flow monitoring sites shown in the WMP include Eastern Tributary, Honeysuckle Creek, Woronora River (WaterNSW GS2132101), Waratah Rivulet (WaterNSW GS2132102) and the DPI-Water flow site, O'Hares Creek at Wedderburn, approximately 8km northwest of the mine (Peabody Energy, 2018c).[114]

O'Hares Creek at Wedderburn, Woronora River and Honeysuckle Creek are not expected to be affected by mining and so act as control sites. The gauges at O'Hares Creek at Wedderburn, Eastern Tributary and Honeysuckle Creek are V-notch weirs; Waratah Rivulet and Woronora River are natural rated sections. In general, V-notch weirs provide greater accuracy especially at low flows.

The Woronora Strategy report recommended two new monitoring sites on tributaries above LWs 301 to 303 to quantify consequences of these and future longwalls on tributary flows (Hebblewhite et al., 2017). This recommendation was made on the basis that potential reductions in inflow to Woronora Reservoir caused by LWs 301 to 303 are unlikely to be registered at the Eastern Tributary flow monitoring site. The two new gauges are flumes installed in May 2018. The Woronora Strategy report also recommended a new rain gauge at the northern end of LW 307.

[114] Figure 6 and Table 8

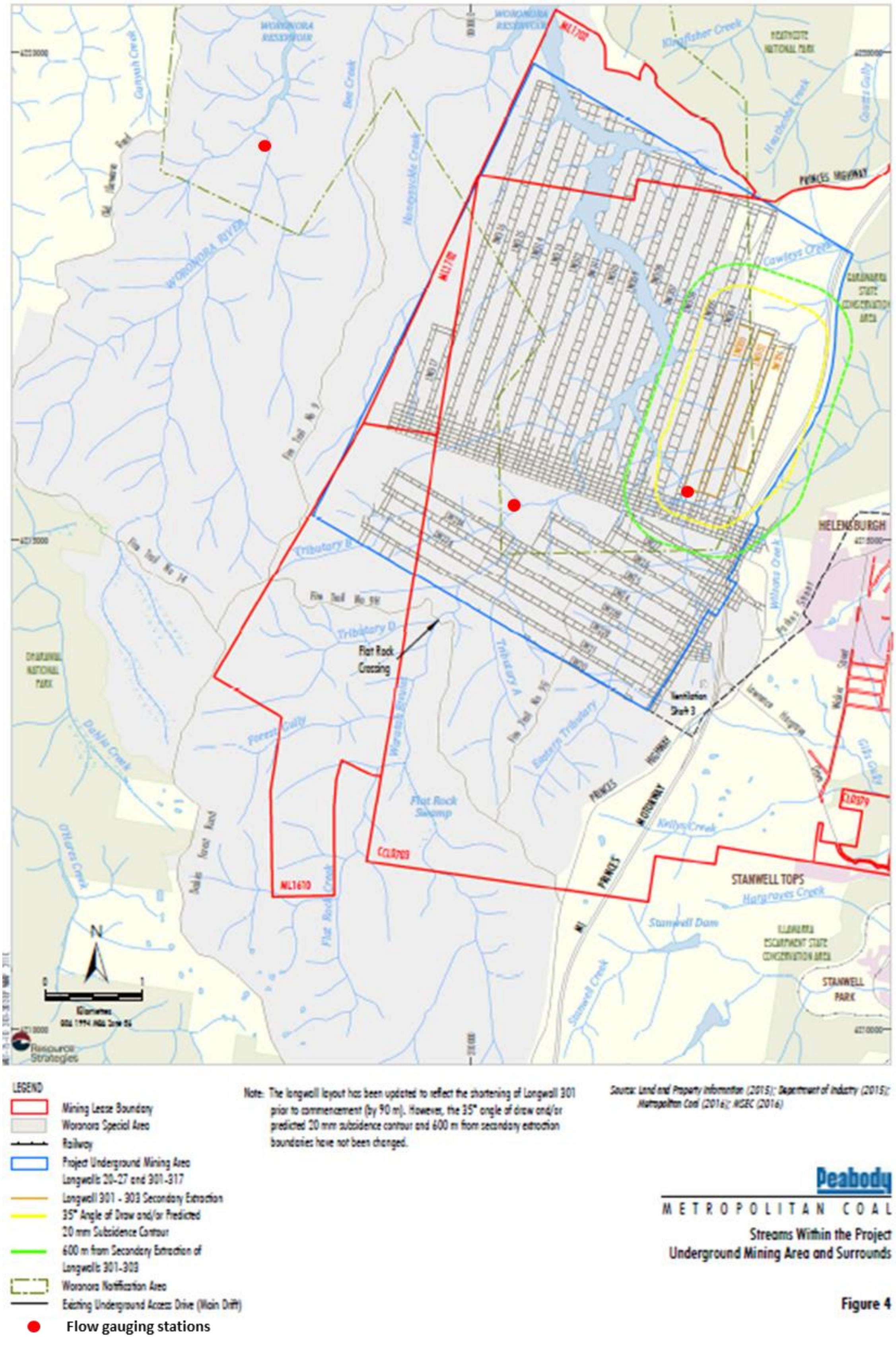

Figure 46: Surface water resources surrounding the Metropolitan Mine including the main flow quantity and quality sites (Peabody Energy, 2018c), with gauging stations superimposed

5.3.1.1 Panel observations

Approval conditions for Metropolitan Mine require a monitoring program to collect sufficient baseline data for future Extraction Plans, and require monitoring to be sufficient to calibrate and validate surface and groundwater models. It is unclear to what extent this is being followed in particular with regard to validating rainfall-runoff models.

The observations made previously in this Chapter for Dendrobium Mine regarding the length of calibration and validation periods, planning and design of operational and strategic flow gauges; and the need for data lengths and quality to be reflected in statements of uncertainty apply equally to Metropolitan Mine.

The new flumes installed on the eastern tributaries of Woronora Reservoir, which are necessary to assess consequences of LWs 301 to 307 on the quantity of resources reaching the reservoir, were installed following recommendations in the Woronora Strategy report. However, earlier planning of these flumes would have led to a more satisfactory period of baseline data.

The Metropolitan Mine Project Approval (MOD 3) Schedule 7, Condition 3 requires that annual reviews assess trends in data over the project life. This should encompass all longwalls in this mining area, including operational closure and rehabilitation stages of the project. However, there is insufficient explicit commitment to continue monitoring over the entire project life.

The Woronora Strategy report recommends regular checks of the accuracy of the new flumes because of the potential for their movement due to subsidence (Hebblewhite et al., 2017). These accuracy checks should be included in reporting.

The Panel notes that recent (2015 and 2018) environmental audits of the mine (Trevor Brown & Associates, 2015; Panikkar, 2018) found that the WMP and its revisions were being implemented and made no recommendations on surface water monitoring or modelling of flows into the Woronora reservoir.

5.3.1.2 Swamp monitoring

Details of the swamp monitoring program are given in the Metropolitan Coal Catchment Management Monitoring Program (Peabody Energy, 2018b). The swamps above and near the recent and current active mining areas are all small swamps. Of the swamps available as control swamps, only S101 is of comparable size. A groundwater monitoring site is shown at Swamp 92 but no shallow groundwater site is monitored there or at the other large swamps under proposed longwalls 311-316 (Swamps 75, 76, 77, 78, 80, and 105).

The sediment and near-surface bedrock groundwater system at the upland swamps is monitored by separated paired piezometers. While the method of construction and slotted intervals are not defined, most of the sites were developed prior to longwall mining in their area and provide pre-mining data.

At Metropolitan Mine, the performance indicator[115] for groundwater in swamps has been exceeded at Swamp 20 since 2012 and at Swamp 28 since 2016. At other swamps, falls in the swamp piezometers were considered similar to those in control swamps, in response to low rainfalls. The groundwater level and climatic information is provided in HydroSimulations (2018d); Table 5 of that document summarises the performance indicator information.

[115] The performance measure for swamps at Metropolitan Mine is *"Negligible impact on Threatened Species, Populations, or Ecological Communities"*, with the associated performance indicator being *"Surface cracking within upland swamps resulting from mine subsidence is not expected to result in measurable changes to swamp groundwater levels when compared to control swamps or seasonal variations in water levels experienced by upland swamps prior to mining"(HydroSimulations, 2018d, Table 5).*

5.3.2 Surface flow modelling

The AWBM rainfall-runoff model is employed at Metropolitan Mine. A revision to the model to improve the baseflow estimation has been peer-reviewed and considered to be a successful revision (Peabody Energy, 2018c)[116,117] Recent results indicate that the model continues to have low accuracy during very low flow periods (HEC, 2018a)[118]. Low accuracy during very low flows is a characteristic of rainfall-runoff models, and analysis of accuracy is confounded by low flow observations errors, hence this accuracy issue may not be resolvable. Nevertheless, the potential for improving the model for each site should be re-assessed annually.

The Bioregional Assessments of the Sydney Basin bioregion did not include analysis of potential surface or groundwater consequences of the Metropolitan Mine (Department of the Environment and Energy, 2018).

5.3.2.1 Panel observations

The approval requires monitoring to be undertaken to calibrate and validate the models; and the generally accepted good practice of using a validation period to assess the errors of the model when making predictions. The Panel did not find evidence of a validation period being used in the AWBM modelling (e.g. Peabody Energy, 2018a, Chart 3).

The procedure for using the rainfall-runoff model on the Waratah Rivulet is described in the Six Monthly Surface Water Review (HEC, 2018a)[119] and summarised in the WMP (Peabody Energy, 2018c)[120]. The Panel noted the following issues in relation to these:

- **veracity of calculations** – a moving window of one year is used to create a continuous series of median values (of the ratio between 14-day observed and modelled filtered flows). The series of median values is then compared with percentiles of the baseline data. In contrast, a coherent statistical test would compare the same two statistics, i.e. the assessment period median should be compared with the baseline median. Since the definition and calculations of the "*percentile of the baseline data*" have not been provided, it is unclear if a coherent test has been done.

  If the percentiles of baseline data have been calculated incorrectly (i.e. they are percentiles of the 14-day ratios rather than percentiles of the baseline median of 14-day ratios), there is a danger that significant changes in low flows will not be signalled. Large differences were also observed in the same result between successive six-monthly reports.[121]

- **presentation of data** - the multiple stages of processing (the filtering procedure, followed by taking 14-day averages, followed by taking medians over a 12-month window) means the information in the original modelled and observed flows is not shown.

  The original modelled and observed flows should be plotted together as time-series (probably on a logarithmic scale to emphasise low flows), and the 14-day ratios should be plotted as well as their 12-month sliding window medians. This should be done for both the Waratah gauge and the control site to allow review of the differences.

[116] Peabody Energy, 2018c p.49
[117] *"The revised rating curves and associated recalibration of the catchment models were peer reviewed by Emeritus Professor Tom McMahon (School of Engineering, The University of Melbourne)"* (Peabody Energy, 2018c).
[118] Chart 5
[119] p.17
[120] Table 17
[121] For example HEC (2018a, Chart 4) and HEC (2018b, Chart 4).

- **the performance indicator** – this is "*Changes in the quantity of water entering Woronora Reservoir are not significantly different post-mining compared to pre-mining, that are not also occurring in the control catchment(s)*".

  Woronora and O'Hares Creek gauges are mentioned as control catchments in the WMP; however, a control catchment is not mentioned in the analysis of HEC (2018a).

These issues mean that whether or not the performance measure has been met cannot be determined from the analysis provided. There are substantial difficulties in applying a rigorous statistical comparison in absence of relevant, long-term baseline and control data sets. However, given that the detection of changes of flows in the Waratah Rivulet and Eastern Tributary are critical parts of performance assessment, at the very least:

- the original unfiltered, un-aggregated flow data, and 14-day ratios, should be provided for both target and control sites
- the definition of the baseline percentiles should be clarified.

HEC (2018a) shows modelled and observed flows for the Eastern Tributary. This is a straightforward comparison of modelled and observed flows from September 2012 to December 2017, without the procedure followed for Waratah Rivulet. The primary limitation of the Eastern Tributary result is the absence of comparison with a control station; hence the changes between the baseline and post-mining periods are difficult to interpret. However, since the observed low flows are substantially higher than the modelled low flows, it is reasonable to conclude that the performance measure is met at the Eastern Tributary site.

At present the water quantity TARP only refers to the Waratah Rivulet. This is inadequate to assess the performance requirement given the collective catchment areas of the Eastern Tributary and smaller tributaries. This is reflected in the Woronora Strategy report and the consequent two new gauges in sub-catchments I and K. Since the recently installed flow gauges in sub-catchments I and K will not have a sufficient baseline period, it is unclear whether and how modelling will be applied for these low-order tributaries.

5.4 PANEL OBSERVATIONS ON SWAMP MONITORING

The network of swamp monitoring sites is extensive and much data is collected, particularly at Dendrobium Mine. There are multiple piezometers and impact monitoring sites within the swamps and associated streams, although no data from paired piezometers for the swamp sediments and shallow bedrock are available to date for the Dendrobium Mine areas.

At Dendrobium Mine, there is extensive, and some long-term, monitoring of the shallow groundwater and vegetation within swamps and associated soil moisture information from some swamps (although this is more limited). However, the reports of the monitoring for both mines have been on an annual, 6 monthly or panel-by-panel basis and the full range of data and coordinated assessment of the data are not available. This means that the outcomes reported may not be convincing to all stakeholders in the absence of quantitative verification.

There is a general lack of coordination between the different suites of data collected, both within each mine area and between mines. Baseline data often is not available for a suitable period, despite long-standing recognition of the need for a minimum period of baseline data collection pre-mining. This is of particular importance where impacts may begin to occur when mining is well distant from the swamp, as is the case at the Dendrobium Mine (Sullivan and Swarbrick 2017).

Although moisture probes and shallow groundwater piezometers are usually closely adjacent, their data are not co-analysed to relate water table changes to soil moisture changes. Whilst significant research is being carried out, the programs do not appear to be well-coordinated and this may limit their effectiveness.

Therefore, while a considerable body of data has been collected and reported in the current swamp monitoring programs, the design and outcomes do not match the monitoring systems recommended by the IESC (Commonwealth of Australia, 2014a; IESC, 2015a). Some of the shortfalls are historic, in that establishment of baseline monitoring did not precede mining by at least two years; and that conditions of approval had not required aspects such as reporting of long-term analysis of monitoring data and use of BACI design.

Importantly, there is a general lack of coordination between the different suites of data collected. For example, while soil moisture probes and shallow groundwater piezometers are usually closely adjacent, their data are not co-analysed to relate water tables changes to soil moisture changes.

In particular, in relation to the Terms of Reference for this Report, the monitoring does not allow the water storage capacity of the swamps, the volume and persistence of outflow and the contribution to stream baseflow to be assessed. Until full hydrological balances are available, for pre-mining and post-mining and between mined and control swamps, estimation of the contribution of swamps to catchment yield, the volumes of water stored in them and the potential changes due to mining cannot be quantified.

5.5 PERFORMANCE MEASURES AND TARPS

The harm management hierarchy of 'avoid, minimise and offset', discussed in more detail in Appendix 2, establishes the approach for managing identified activity risks and harms for major developments, with avoidance the primary objective; implemented through development approval and review processes.

Because management plans are approved prior to mining activities commencing, approvals generally include performance measures and conditions requiring development of contingency management plans (CMPs). Performance measures represent the maximum approved impacts of a development, with CMPs defining how future unanticipated subsidence effects and exceedances of performance measures will be monitored, measured and managed.

Under existing regulatory arrangements, environmental CMPs must be in the form of a scaled Trigger Action Response Plan (TARP) structure, which are developed by proponents, but approved by DPE. Exceedances of TARP triggers (performance indicators) require specified actions and responses.

Where residual impacts cannot be avoided, mitigated or managed through rehabilitation, offsets are designed to offer a consistent and scientifically based approach to ensure that there are no net adverse impacts from a development to the state overall.[122] Intended as an approach of last resort (DPE, 2015b)[123], offsets entail identifying and securing sites of equivalent environmental value. That is, they provide a compensatory mechanism for environmental or biodiversity impacts at one site through beneficial activities at another.

There is currently an offset in place for the Dendrobium Mine for the impacts on swamps in Areas 2 and 3. Mining in Area 3B at the Dendrobium Mine was predicted to result in damage to up to 12 upland swamps arising from mine subsidence. These swamps are listed as EECs under the NSW TSC Act and under the Commonwealth EPBC Act.

It was determined that it was not economically feasible, given that the layout for the initial longwall panels had been established, to fully avoid or substantially reduce the predicted swamp impacts (DPE, 2015c). In December 2016, the Dendrobium Mine application for a Strategic Biodiversity Offset (South32, 2016c) was approved in accordance with the

[122] For example, the *Biodiversity Conservation Act 2016* expressly provides for the Biodiversity Offsets Scheme – a mechanism to offset residual adverse impacts on biodiversity, through the protection or improvement of environmental interests at other sites.
[123] p.2

Development Consent;[124] fulfilling the requirements of the 2013 approval of the Subsidence Management Plan (SMP) for Area 3B.[125] This involved transfer of 598 ha of land at Maddens Plains (including 140 ha of upland swamp) to the NSW National Parks Estate. As a result, impacts on, and consequences for, upland swamps due to extraction of longwalls above Dendrobium Areas 2 and 3 are offset fully. Other than some possible efforts at remediation, no further action is required of the company in relation to any damage to the swamps in these areas arising from mining.

To date, no offset has been required for impacts to swamps above Metropolitan Mine.

5.5.1 Panel observations

5.5.1.1 Surface water

The performance measures for Dendrobium Mine include "negligible" reductions to flows to Avon Reservoir and Cordeaux River, and no more than "minor" consequences for flows in Wongawilli Creek and Donalds Castle Creek, and at Metropolitan Mine "negligible" reduction to the quantity of resources reaching the Woronora Reservoir and "negligible" leakage from Woronora Reservoir.

The Dendrobium Mine TARP triggers related to surface water quantity are ineffective, for the following reasons:

- the TARPs express the reduction in flow as a percentage of annual average rainfall. However, because flow rates are only a proportion of annual average rainfall (order of 10-20% in these catchments[126]), the percentage reductions in flows are much greater. This is evident where there are clear flow consequences yet the level 1 TARP is not triggered (HGEO, 2018a).[127]
- the TARP level 3 is "Change >18% less than average annual precipitation" (which may be interpreted as "A reduction in flows of more than 18% of average annual precipitation").

  A reduction in flows of less than 18% would generally be considered non-negligible (e.g. the Bioregional Assessment considered < 5% change to be negligible (Herron et al., 2018)[128], yet a reduction in this range would not trigger the TARP at level 3, indeed a 10% reduction would not trigger the TARP at level 2.
- the result of the rainfall-runoff modelling is presented, not in terms of changes in flows, but in terms of change in (modelled flow + modelled evaporation). How this maps to the TARP is ambiguous, in particular how it evaluates the consequences of mining.
- the TARP trigger levels (18%, 12% and 6%) originate from an assessment of the accuracy of the RUNOFF2005 model in 2014 (Ecoengineers Pty Ltd, 2014). In other words, a TARP is only triggered if the reduction in flow is large enough to be detectable with some level of confidence by the RUNOFF2005 model. It is not related to the materiality of the flow loss. Furthermore, the RUNOFF2005 model is no longer relevant.

The Metropolitan Mine TARP triggers related to surface water quantity are also potentially ineffective. The Level 1 trigger is: *"The median of the ratios does not fall below the 35th percentile of the baseline data".* As described in this report, depending on how the percentile is calculated, it leaves room for significant losses to happen with no trigger activation.

[124] Integrated State Significant Consent, Dendrobium Mine (DA 60-03-2001) Modification 7, Sch 2 Condition 15.
[125] Department of Planning and Infrastructure, Dendrobium Mine Area 3B Subsidence Management Plan Approval (6 February 2013), Sch 3 Conditions 6-8.
[126] See ratios of flow to precipitation shown in Ecoengineers Pty Ltd (2014, p. 38).
[127] p.29
[128] p.28

5.5.1.2 Swamps

The development consents for the mines specify conditions related to preventing negative environmental consequences for only four upland swamps (Swamp 15a at Dendrobium Mine and Swamps 76, 77 and 92 at Metropolitan Mine). Exceedance is specified as a breach of consent conditions in only one case (at Dendrobium Mine, if mining were to cause damage to the structural integrity of the rockbar of Swamp 15a which could not be restored).

The TARP triggers related to swamps are ineffective, for the following reasons:

- The nature of the impacts covered by TARPs (erosion over time, decline in swamp size and change in vegetation composition) mean that any consequences identified will be recognised as exceedances only after several other longwalls have been extracted.
- TARPs do not reflect the groundwater-dependence of the upland swamp ecosystems.

5.6 CONCLUSIONS

5.6.1 Level of knowledge

a. Although knowledge of the consequences of mining on surface water quantity in the Catchment Special Areas has progressed substantially over the last 10 or so years, limitations in monitoring and modelling mean that it is difficult to verify conclusions by some stakeholders that mining has had negligible consequences on surface water supplies.

b. Knowledge of the contribution of swamps to water supplies is particularly undeveloped due to lack of integrated monitoring targeting swamp water balances.

c. Nevertheless, what is observed with increasing certainty is that when a longwall panel passes under watercourses and swamps (and in their vicinity in some cases) there is at least localised loss of water. How much of the lost water re-emerges to surface watercourses further downstream is not accurately quantified.

d. As well as the potential but unquantified direct consequences on water supplies, there is concern that the reduced water content of swamps is likely to make the swamps less resilient to bushfires which, in turn, can lead to an increased susceptibility to erosion and loss of baseflow. Drying of swamps is considered by the Panel to be indicative of dehydration of the plateau surface more generally.

5.6.2 Monitoring and modelling

a. More focus is needed on the monitoring of surface water flow. The current surface water flow monitoring, although it is more extensive than usually applied in mine regions, has significant limitations with respect to the locations of monitoring, time periods covered and flow gauge accuracy. Higher accuracy monitoring may be required if small changes in flow are considered to have non-negligible consequences.

b. Detecting the impacts of mining on surface water requires separating the dominant impacts of climate variability. This requires long-term gauging of flows, ideally including during pre-mining and post-mining conditions, and including control sites that are not subject to impacts of ongoing mining yet represent the mine area hydrology. For both the Dendrobium and Metropolitan mines, there is a lack of baseline flow data at some monitoring sites, and there is a lack of long-term historical flow records at key locations downstream of the mines. Greater foresight, including during early stages of mine planning and in approval conditions, is needed to address this. For Dendrobium Mine, the adequacy of the climate monitoring is also questionable due to the small number of monitoring sites.

c. As the challenges of establishing and maintaining flow and climate monitoring sites are significant, new sites should be prioritised based on value for gaining new knowledge about mining consequences on water supplies and also on the practicality of installing and maintaining an accurate gauge.

d. Rainfall-runoff modelling is used to separate the impacts of mining from those of climate. It is relied upon for quantifying surface flow losses due to mining. The models used at the Dendrobium and Metropolitan mines have low accuracy during very low flow periods, despite efforts by the mining companies to address this. This low accuracy increases ambiguity about the relative impacts of climate and mining. Only relatively large losses in low flows may be attributed to mining with confidence. Attempts to improve low flow accuracy should continue and be reported and peer-reviewed.

e. Although elements of accepted good practice for rainfall-runoff modelling have been followed, there are gaps. Elements of good practice that should be considered include: statement of relevant assumptions, model validation, uncertainty analysis, post-auditing of model accuracy and periodic independent peer review of modelling reports. A good practice guide or standard should be referred to so that it is clear what standards are being followed.

f. For swamps, an integrated monitoring and modelling program is needed whereby hydrological models of control and impacted swamps can be developed and calibrated with an acceptable level of confidence, so that losses of water due to under-mining and change to baseflow contribution can be estimated.

g. The responsibility to ensure a monitoring network that is adequate to demonstrate compliance with project approval conditions should remain with the mining company. The specifications of the flow monitoring in the project conditions should be explicit about the minimum periods of baseline (pre-mining impacts) data, use of relevant control sites, and the period of monitoring following mining.

h. The lack of long-term flow monitoring sites capable of detecting hydrological change in mining areas is apparent in the 2016 Catchment Audit (Alluvium Consulting Australia, 2017a). WaterNSW should re-evaluate the adequacy of its monitoring network considering current and future pressures on the catchments, and give consideration of the future long-term value of monitoring sites developed by the mining companies.

i. The Panel agrees with the 2016 Catchment Audit (Alluvium Consulting Australia 2017a) recommendation that locations and timing of monitoring for macroinvertebrates, water quality and stream flow should be integrated.

5.6.3 TARPs

a. At both the Dendrobium and Metropolitan mines, the nature of surface water TARP triggers is not suited to determining the level of confidence that can be placed in surface water modelling results.

b. The TARPs for surface flow losses are not explicitly related to materiality of flow losses, rather they are defined only by terms such as “negligible”. This limits the objectivity of performance evaluation.

c. In the present situation, TARPs classify the seriousness of events that have already occurred rather than fulfilling a role of early signalling to prompt intervention that prevents escalation of impacts.

5.7 RECOMMENDATIONS

5.7.1 Surface water monitoring and modelling

14. In future, surface water monitoring requirements should include:
    i. a distinction between primary watercourse monitoring sites, which are the sites at which performance measures are specified; and secondary watercourse monitoring sites, which will provide additional information as identified as necessary as the mine plan evolves
    ii. a specification of the minimum flow measurement accuracy required at the primary and secondary sites
    iii. the identification of the primary sites in proposed future mining areas and the installation of flow monitoring at these sites at least four years in advance of mining activities
    iv. the identification of the secondary sites as the mine plan evolves and the installation of flow monitoring at these sites at least two years in advance of mining activities or a shorter time if approved as part of the mine plan approval
    v. paired piezometers in swamp sediments and nearby bedrock, and flow gauges at the swamp exit stream, at minimum for representative large valley infill swamps, and complemented by soil moisture sensors at selected sites
    vi. consistent use of inter-site comparisons using suitable control sites to complement rainfall-runoff modelling
15. Surface flow monitoring associated with mining should be required to be continued until the consequences of mining (including any rehabilitation) have stabilised and/or the mine is considered by the relevant regulatory authorities to have been rehabilitated. This requires clear metrics of stabilisation.
16. To ensure confidence in the accuracy and validation of surface water models and conclusions and to support transparency in decision-making:
    i. a statement is provided on all relevant modelling assumptions and which good practice guides have been followed and how they have been followed, with justification of any departures from good practice
    ii. updated peer reviews of rainfall-runoff modelling and reporting be undertaken by a suitable independent experts and published
    iii. the principle of ‘reverse onus of proof’ is applied, whereby the mining company should demonstrate that on the balance of probabilities there is no significant consequence.
17. Monitoring requirements at the Dendrobium Mine should include:
    i. an assessment of flow monitoring procedures, their accuracy and implications for confidence in compliance is undertaken by a suitable independent expert and published
    ii. installation of weirs and/or flumes at selected sites agreed by WaterNSW and the Dendrobium Mine, having regard to the observations made in this report. The selection of sites should consider the benefits in terms of assessing compliance within the remainder of the Area 3B operations and include at least one site representing the catchments draining to Lake Avon potentially affected by LW 16 to LW 18

iii. publishing of rating curve data (including the manually gauged reference data) and photographs of flow gauges, so that accuracy can be judged when interpreting performance reports

iv. additional basal shear monitoring, implemented as a priority between the Avon Dam and LW 14 to 18 before mining commences. The sites should be designed to complement the construction and monitoring strategy (geotechnical and groundwater) used at sites S2313 and S2314.

18. Metropolitan Mine should be required to provide a detailed report about how conclusions of 'no consequences' have been reached using the observed and modelled flow data

5.7.2 Performance measures and TARPs

19. In the future:

    i. In setting performance measures, government should have regard for those measures relevant to strategic resources (such as flow to storage)and sanctions which rapidly prevent escalation of impacts and consequences if there are exceedances, clearly linked to monitoring results. Consent conditions should clearly specify the acceptable levels of impacts and consequences on catchment resources, and that assessment of these should continue at strategic locations beyond the life of mine.

    ii. TARP triggers should be based on meaningful surface water loss indicators developed in consultation with relevant agencies with oversight and regulatory responsibilities for mining.

    iii. TARPs should be related to the desired outcomes (such as maintenance of water flows) and be consistent both within and between mine domains. TARP triggers for surface and groundwater should be based on meaningful flow loss indicators developed in consultation with relevant agencies and authorities with oversight and regulatory responsibilities for mining.

    iv. In situations where performance measures of negligible or minor environmental consequences are set by government, mine planning should incorporate appropriate factors of safety to avoid marginal situations associated with gaps in the current knowledge base.

    v. Consideration should be given to whether a performance measure of 'minimal iron staining' over a specified length of a watercourse is practically achievable if mining that results in iron staining is approved upstream of that designated area.

6 CATCHMENT, GROUNDWATER AND RESERVOIR WATER BALANCES

Recognition is increasingly being given to the importance of more accurately calculating losses to water bodies, at scale and over appropriate time scales. As part of this there is a need to distinguish between:

- **a catchment water balance** which may be used to quantify inflows to, outflows from and storages within a catchment
- **a groundwater balance** which may be used to quantify the water balance on only the groundwater
- **a reservoir water balance** which may be used to quantify the water balance on only the surface reservoir.

6.1 CALCULATING WATER BALANCES

Precipitation, runoff and surface water storage volumes can be estimated directly from measurements while other components such as evapotranspiration, recharge and groundwater flows cannot. Instead, numerical models are relied upon to develop estimates.

A catchment water balance for the Dendrobium and Metropolitan mining areas can be calculated by applying the following equations, which relate to a defined catchment over a defined period.

Precipitation + GW inflows – Evapotranspiration – GW outflows – SW outflows = Change in SW storage + Change in GW storage + Change in soil moisture

Equation 9: Catchment equation No. 1

As applied in rainfall-runoff models used for Dendrobium and Metropolitan mines, assuming that there are no GW inflows or outflows over the catchment boundary, this can be simplified to:

Precipitation – Evapotranspiration – SW outflows = Change in SW storage + Change in GW storage + Change in soil moisture

Equation 10: Catchment equation No. 2

To calculate a groundwater balance, the equation input is recharge instead of precipitation, and soil moisture, and surface water storage and flows are not included:

Recharge + GW inflows – Evapotranspiration from GW – GW outflows = Change in GW storage

Equation 11: Groundwater balance equation No. 1

The groundwater models used for the Dendrobium and Metropolitan mines separate recharge through watercourse beds from other recharge (here called ‘diffuse’ recharge), and mine water take from other groundwater outflows:

Recharge through watercourse beds + diffuse recharge + GW inflows – Evapotranspiration from GW – Mine water take – Other GW outflows = change in GW storage

Equation 12: Groundwater balance equation No. 2

Reservoir water balances in simple terms can then be calculated based on:

Precipitation + GW inflows + SW inflows – Evaporation – GW outflows – reservoir water releases – reservoir water spills = Change in Reservoir storage

Equation 13: Reservoir water balance

6.2 APPLICATION OF WATER BALANCES

Water balance models are used at the Dendrobium and Metropolitan mines to assess the volumetric impact of mining on surface and groundwater resources. At both mines, catchment water balances have been conducted using the AWBM rainfall-runoff simulator to evaluate stream flow losses, while water balances generated by the Modflow groundwater models have been used to inform losses along stream beds and changes in groundwater storage. The modelling processes are as follows:

- **For rainfall-runoff modelling**: Model parameters are calibrated for pre-mining conditions against measured watercourse flows. The model is then used to simulate watercourse flows in the post-mining period. The post-mining model results are compared with the post-mining flow measurements. If the former are consistently higher than the latter, and this cannot be explained by model uncertainty, then it indicates flow losses due to mining.
- **For groundwater modelling**: Hydrogeologic parameters and boundary conditions are specified for a given historical period. The model parameters are calibrated against nested piezometer levels and the metered mine water capture data. The calibrated model is then applied under altered boundary conditions that represent selected mining scenarios. Comparing results from pre-mining, mining and post-mining periods allows the impacts of mining on all included water balance components to be quantified.

Both these 'modelling' procedures are well-established at the Dendrobium and Metropolitan mines. Issues relating to uncertainty with these applications have been commented on in previous Chapters in this report.

The application of reservoir water balances to estimate reservoir water losses due to mining is less well established[129]. This would require all other components in Equation 13 to be estimated with sufficient accuracy. This is a challenge, especially considering that some of these other components would need to be estimated by the rainfall-runoff and groundwater models.

Notwithstanding this challenge, the need for a refined reservoir water balance is acknowledged in the Woronora Strategy, which recommended a water balance for Woronora Reservoir (Hebblewhite et al., 2017). Recognising the high monitoring requirements of such a study and uncertainty regarding its outcomes, this recommendation included a stage 1 and a stage 2 assessment. The value of establishing a reservoir water balance is also recognised in the PSM study in relation to Lake Cordeaux. HydroSimulations (2017b) concurred with this conclusion although noting the difficulty of obtaining sufficient accuracy to discriminate groundwater outflows from other water balance components.

6.3 A SUMMARY OF WATER BALANCE DATA

Although there are uncertainties and limitations in the catchment water balance calculation methods, selected results are presented here in order to view the relative magnitude of surface flow losses.

[129] The Metropolitan WMP (Peabody Energy Australia Pty Ltd, 2018c) states that Gilbert & Associates (2008) prepared a water balance for Woronora Reservoir, and its results indicated that predicted water losses due to LWs 301 to 303 were to be negligible. However that application did not use the reservoir water balance to quantify water losses due to mining, rather the losses were assumed from the groundwater modelling.

Table 9 shows water balance data for the Dendrobium Mine Area 3B derived from climate and flow measurements and rainfall-runoff modelling. The results of groundwater modelling and measurements of mine water inflows are shown for comparison (while not being directly comparable – see Table 9 note 4).

The table shows that the surface flow losses, which include the effects of LW 13 and on-going effects of previous LWs, are estimated to average 2.4 ML/day or 3% of the incident rainfall. The table also shows that estimates from the three different approaches – rainfall-runoff modelling, groundwater modelling and mine water inflow measurements – are variable but are the same order of magnitude in terms of ML/day losses.

A comparable table cannot be produced for the Metropolitan Mine due to the nature of published data for that mine.

When assessing the significance of these losses for Sydney's water supplies, the challenges of scale as explained in the next section need to be considered.

Table 9: Selected results from water balance calculations and measurements from Area 3B of the Dendrobium Mine

Area	Long-term rainfall input (ML/day)[1]	Long-term flow rate (ML/day)[2]	Surface flow loss due to mining estimated by rainfall-runoff models (ML/day)[3]	Surface flow loss due to mining (% of long-term rainfall)	Surface flow loss due to mining (% of long-term flow)	Surface flow loss due to mining estimated by a groundwater model (ML/day)[4]	Mine water inflow attributable to surface water losses (ML/day)[5]
Wongawilli Creek catchment above WWL	63.3	16.5	1.9	3%	12%	0.6	-
Donalds Castle Creek catchment above DCU	19.6	1.8	0.4	2%	22%	0.04	-
Lake Avon tributary catchment above LA4_S1	2.6	0.2	0.1	5%	56% [6]	0	-
Total of above catchment areas	85.5	18.5	2.4	3%	13%	0.64	-
Area 3B	-	-	-	-	-	-	< 4.68

1. All based on annual average rainfall of 1,150 mm.
2. Using runoff ratios of 0.26, 0.09 and 0.09 for WWL, DCU and LA4_S1 respectively based on Ecoengineers Pty Ltd (2014), p 38 and 43.
3. Estimates are based on % losses derived using the AWBM rainfall-runoff model reported in the EOP report for LW 13 (South32, 2018c).
4. As estimated for period 2016-2020 using the groundwater model of HydroSimulations (2018b), T5.4. The value for Donalds Castle Creek is for a larger catchment area than captured by flow gauge DCU, so groundwater model and rainfall-runoff model estimates are not directly comparable.
5. 4.68 ML/day is estimated by the EOP report for LW 13, Tab E1, Table 2 (measured mine inflows during LW 13) (South32, 2018c). A proportion of this may be attributed to surface flow losses.
6. It is likely that at least some of the flow loss from this catchment is directed into Lake Avon.

6.4 CHALLENGES OF SCALE AND CUMULATIVE CONSEQUENCES

A limitation of using either groundwater or rainfall-runoff models as currently applied is that these models do not necessarily correspond to the space or time scales relevant for quantifying the significance of water losses to the Sydney water supplies.

Water balances need to be put in the context of an appropriate time domain. The greatest consequences of mining on surface water supply volumes are likely to be during extreme drought periods. Therefore, water balances should include drought periods and results for these periods should be highlighted.

The principal water volumes of relevance for Sydney water supplies are the reservoir storage volumes. However the current water balance models do not attempt to simulate the reservoir catchment scale. For this reason, the outflows and evaporation losses from any reservoir should not be compared with the surface water losses calculated from the existing groundwater models.[130] A more useful and appropriate comparison would require the groundwater model to cover the groundwater catchment area of the reservoir and include cumulative losses due to mining.

A cumulative assessment used to assess water balances over a long period of time can capture the consequences of historical, present and future mining and other influences; while its application over a large region can capture the consequences of more than one mining project as well as other influences.

A cumulative assessment of water losses was recommended by the 2016 Catchment Audit (Alluvium, 2017a); a key finding being:

> "*The Audit found an emerging issue of unquantified loss of surface flows associated with the cumulative impacts of underground coal mining activities. This issue requires attention and should be considered in implementation of the Metropolitan Water Plan and activation of licencing under Section 60I of the Water Management Act 2000 and in accordance with the NSW Aquifer Interference Policy. Greater understanding of the effect of multiple mine workings on Catchment water yield is required, and this understanding should be reflected in relevant mine planning, appropriate water licencing, and the regulation of those licences*".

Other actions recommended by the 2016 Catchment Audit included:

> "*Establish the scope and commence a state-owned regional surface water and groundwater geotechnical model*" and
>
> *"Compile all empirical evidence of mining impacts in the Sydney Drinking Catchment in a regional cumulative impact assessment"* (Alluvium, 2017a).[131]

The Panel agrees with the 2016 Catchment Audit's finding that there is an emerging question over the cumulative impacts of flow losses. At present, estimates of surface flow losses due to mining rely on surface flow gauges and rainfall-runoff models, and performance indicators are related to estimated losses at individual gauge sites (the groundwater models are discounted due to low accuracy for surface water loss estimation). Control sites that are compared with these gauges may themselves be affected by groundwater depressurisation due to historical mining (the WCU control site at Dendrobium Mine is an example). However, the achievable accuracy and value of quantitative cumulative impacts analysis is also questionable due to limitations of models and limitations in data especially for pre-mining periods. The Panel intends to address this question under Term of

[130] The DPE conclusions in Dendrobium Area 3B Subsidence Management Plan Reasons for Approval for LWs 14 and 15 (DPE, 2016) regarding the importance of surface water losses due to Dendrobium relative to lake evaporation and storage are misleading in this respect.

[131] pp. 26-27

Reference 2. The Panel will also give further consideration to the related 2016 Catchment Audit finding and recommendation that

> *"this understanding should be reflected in relevant mine planning, appropriate water licencing, and the regulation of those licences"* and
>
> *"Compile all empirical evidence of mining impacts in the Sydney Drinking Catchment in a regional cumulative impact assessment*" (Alluvium, 2017a).

The Panel does not fully agree with the Audit recommendation to *"commence a state-owned regional surface water and groundwater geotechnical model*" since this is unlikely to be feasible, and in any case would repeat at great expense much of the work already done by the mining companies.

However, the Panel recognises the potential value in having a state-owned regional water balance model with a suitable level of complexity that could integrate information from the existing groundwater and geotechnical models.

6.5 CONCLUSIONS

a. The principal water volumes of relevance in the Upper Nepean and Woronora catchments are the reservoir storage volumes

b. The need for a reservoir water balance model has been recognised in the PSM study, the 2016 Catchment Audit and the Woronora Reservoir Strategy report and acknowledged by the groundwater consultants for Dendrobium Mine.

c. The water balance data for the Dendrobium and Metropolitan mines currently rely on rainfall-runoff models (catchment water balance) and groundwater models (groundwater balance), with a minimal amount of work undertaken to date on reservoir water balances.

d. A limitation of these models is that they do not necessarily correspond to the space or time scales relevant for quantifying the significance of water losses to the Sydney water supplies.

e. The greatest consequences of mining on surface water supply volumes are likely to be during extreme drought periods. Therefore, water balances should include drought periods and results for these periods should be highlighted.

f. Although there are uncertainties and limitations in the catchment water balance calculation methods, the Panel has undertaken a reservoir water balance for Dendrobium Mine that estimates surface flow losses, which include the effects of LW 13 and on-going effects of previous longwalls, to be 2.4 ML/day or 3% of the incident rainfall.

g. A comparable estimate cannot be produced for the Metropolitan Mine due to the nature of published data for that mine.

6.6 RECOMMENDATIONS

20. A reservoir water balance model needs to be developed that should include drought periods and results for these periods should be highlighted.

7 CONCLUSIONS AND RECOMMENDATIONS

In this report, issues have been discussed and conclusions and recommendations have been developed under the relevant specialist discipline headings. Some of these issues were originally envisaged to fall under Term of Reference 2 but have needed to be considered, at least in part, under Term of Reference 1 in order to properly inform the Panel and the reader and to contextualise the Panel's observations and findings. Regard to a range of reports including those specified in the Panel's Terms of Reference is embedded throughout this document.

There is universal agreement that the issues are complex and complete reading of the detail contained in chapters is needed to understand the full range of the Panel's conclusions and recommendations. Therefore, for the benefit of the non-specialist reader, the principal conclusions and recommendations have been extracted and summarised in this chapter under headings that give them context in terms of mine design, mine approval and monitoring and performance.

MAJOR CONCLUSIONS

Mine Design

- The knowledge base regarding mining-induced subsidence and its impacts on groundwater and surface water continues to grow. In some cases, these advances have identified aspects not appreciated at the time of mine approval and may require the originally proposed mine layouts to be revised in order to satisfy performance measures
- The existing development consent for Dendrobium Mine was granted almost two decades ago and expressly allows mining in Areas 1, 2, 3A, 3B and 3C, with LW 14 currently being extracted in Area 3B. The consent conditions only place performance measures on three watercourses and one reservoir and offset provisions are in place to compensate for any exceedance of swamp performance measures. These legacy mine approval conditions are embedded and provide a significant degree of flexibility in mine planning. They provide considerable scope for maximising mining dimensions which, in turn, is reflected in the high percentage extraction of the coal resource, the high level of vertical surface displacement and the significantly higher daily water inflow than at Metropolitan Mine
- There has been a major effort over the last decade by Metropolitan Mine and Dendrobium Mine to employ up to-date 3-dimensional groundwater models and best practice modelling methods undertaken by suitable experts, with expert peer review. The models have improved in accuracy and predictive capacity and peer reviews of the models and modelling have provided valuable direction without which the process may have been less focussed
- The modellers, peer reviewers and the Panel recognise the fundamental limitations of the groundwater models for predicting impacts and consequences of mine subsidence, including those related to grid scales, computation time, and hydrogeologic parameter estimation
- The height of complete groundwater drainage is an important consideration in groundwater modelling and the Tammetta equation and the Ditton equations were developed in Australia for this purpose some 5 years ago. There are significant and fundamental differences between the characteristics of the Tammetta and DGS (Ditton) databases which preordain that, irrespective of the methodologies adopted to process this data, the respective predictions of the height of complete drainage based on the data are likely to be very different

- Field performance at Dendrobium Mine suggests that irrespective of whether the Tammetta equation is predicting the height of complete drainage reasonably accurately, its outputs can be useful as an indicator of the potential for water ingress from the surface

Mine Approval

- The Panel endorses the Department of Planning and Environment's approach for dealing with legacy issues and evolving knowledge bases whereby:
    - the management plans for longwall panels at Dendrobium and Metropolitan mines are being approved on an incremental basis that provides for considering existing and emerging information and knowledge gaps that have the potential to jeopardise compliance with performance measures
    - conditions are attached to approved Subsidence Management Plans and Extraction Plans that require mine operators to undertake a range of investigations and monitoring and engage independent experts to review and prepare advice to address geotechnical and hydrogeological information and knowledge gaps
    - some mining applications are being referred to independent experts and bodies, including the Panel, for advice

Monitoring and Performance

- Although knowledge of the consequences of mining on surface water quantity in the Catchment Special Areas has progressed substantially over the last 10 or so years, limitations in monitoring and modelling mean that it is difficult to verify conclusions by some stakeholders that mining has had negligible consequences on surface water supplies.
- Knowledge of the contribution of swamps to water supplies is particularly undeveloped due to lack of integrated monitoring targeting swamp water balances.
- Supported by its own analysis, the Panel concludes that in the case of Dendrobium Mine:
    - water inflow into all four mining areas (Areas 1, 2, 3A & 3B) exhibits some correlation with rainfall, ranging from weak in Area 3B to strong and rapid for Area 2
    - it is very likely that the high rate of influx is associated with a connected fracture regime that extends upwards to the surface
    - it is plausible that an average of around 3 ML/day of surface water and seepage from reservoirs is currently being diverted into the mine workings
- In the case of Metropolitan Mine:
    - The average daily water inflow of about 0.5 ML/day displays no evidence of a connected fracture regime to surface or correlation with rainfall
    - the potential for water be diverted out of Woronora Reservoir and into other catchments through valley closure shear planes and geological structures including lineaments will require careful assessment in the future because it is planned that most of the remaining longwall panels in the approved mining area will pass beneath the reservoir
- At both the Dendrobium and Metropolitan mines, the nature of surface water TARP triggers is not suited to determining the level of confidence that can be placed in surface water modelling results

- The performance measures for surface flow losses are not explicitly related to materiality of flow losses, limiting the objectivity of performance evaluation.
- In the present situation, TARPs classify the seriousness of events that have already occurred rather than fulfilling their more usual role of early signalling to prompt intervention that prevents escalation of impacts

MAJOR RECOMMENDATIONS

Mine design

- Notwithstanding that uncertainty is associated with both the Tammetta and the Ditton height of complete drainage equations, it is recommended to err on the side of caution and defer to the Tammetta equation until:
    - field investigations quantify the height of complete drainage at the Dendrobium Mine and Metropolitan Mine, and/or
    - alternative geomechanical modelling of rock fracturing and fluid flow is utilised to inform the calibration of groundwater models
- The potential implications for water quantity of faulting, basal shear planes and lineaments need to be very carefully considered and risk assessed at all mining operations in the Catchment Special Areas
- The concept of restricting predicted valley closure to a maximum of 200 mm to avoid significant environmental consequences should be revised for watercourses

Mine Approval

- Government should verify that sufficient entitlements are retained by Dendrobium and Metropolitan mines to cover surface water losses resulting from mining-induced effects.
- The Panel recommends that in future:
    - mine design methodologies and procedures that underpin critical aspects of mining proposals should be supported by robust, independent peer review and/or a demonstrated history of reliability when applications are submitted to government
    - all applications to extract coal within Catchment Special Areas should be supported by independently facilitated and robust risk assessments that conform to ISO 31000 (the international standard for risk management subscribed to by Australia)
    - government needs a sustainable mechanism for accessing objective expert advice when assessing mining applications.

Monitoring and Performance

- In future, mines operating in the Catchment Special Areas need to develop, in consultation and with the agreement of regulators and key stakeholders, a standard for field investigations, data collection, and data processing that provides for and integrates the interests of all stakeholders and facilitates the sharing of the information by being presented on a common platform. This should be canvassed in submissions to inform Term of Reference 2
- This monitoring standard in relation to groundwater should include provision for:
    - Installation of multi-level piezometers on the centreline of panels at Dendrobium and Metropolitan mines in order to monitor pore pressure changes associated with subsidence. These should include at least five transducers per borehole with installation being completed at least two years in advance of being undermined

    - Daily monitoring of local rainfall and mine water ingress from overlying and surrounding strata, and separation of rainfall correlated inflows for base flow volumetric analyses
    - Dendrobium Mine and Metropolitan Mine to develop site-specific databases in relation to the height of complete drainage in-lieu of relying on height of drainage equations
- In future, surface water monitoring requirements should include:
    - a distinction between primary watercourse monitoring sites, which are the sites at which performance measures are specified; and secondary watercourse monitoring sites, which will provide additional information identified as necessary as the mine plan evolves
    - a specification of the minimum flow measurement accuracy required at the primary and secondary sites
    - the identification of the primary sites in proposed future mining areas and the installation of flow monitoring at these sites at least four years in advance of mining activities
    - the identification of the secondary sites as the mine plan evolves and the installation of flow monitoring at these sites at least two years in advance of mining activities or a shorter time if approved as part of the mine plan approval
    - paired piezometers in swamp sediments and nearby bedrock, and flow gauges at the swamp exit stream, complemented by soil moisture sensors at selected sites.
    - consistent use of inter-site comparisons using suitable control sites to complement rainfall-runoff modelling
- Surface flow monitoring associated with mining should be required to be continued until the consequences of mining (including any rehabilitation) have stabilised or the mine is considered by the relevant regulatory authorities to be closed. This requires clear metrics of stabilisation
- There is a need for groundwater modellers to address apparent inconsistency in the hydrogeologic parameters used to model Dendrobium and Metropolitan mines as it calls into question the robustness of current model predictions
- Research needs to be progressed into the use of tritium for calculating ‘modern’ water contributions at Dendrobium Mine, including the potential for results to be affected (skewed) by adsorption
- A reservoir water balance model needs to be developed. A limitation of using either groundwater or rainfall-runoff models as currently applied is that these models do not necessarily correspond to the space or time scales relevant for quantifying water losses to the Sydney drinking water supplies. Water balances should include drought periods and results for these periods should be highlighted
- In setting performance measures, government should have regard for those measures relevant to strategic resources (such as flow to storage) and to sanctions which rapidly prevent escalation of impacts and consequences if there are exceedances, clearly linked to monitoring results. Future consent conditions should clearly specify the acceptable levels of impacts and consequences on catchment resources, and that assessment of these should continue at strategic locations beyond the life of mine
- TARP triggers should be based on meaningful surface water loss performance measures developed in consultation with relevant agencies with oversight and regulatory responsibilities for mining

- TARPs should be related to the desired outcomes (such as maintenance of water flows) and be consistent both within and between mine domains. The TARP triggers for surface and groundwater should be replaced by meaningful flow loss indicators developed in consultation with relevant agencies and authorities with oversight and regulatory responsibilities for mining
- In situations where performance measures of negligible or minor environmental consequences are set by government, mine planning should incorporate appropriate factors of safety to avoid marginal situations associated with gaps in the current knowledge base.

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GLOSSARY

Table 10: Definitions

Term	Definition
Act	A Law made by Government
Angle of Draw	Defines the lateral extent of mining-induced vertical displacement on the surface. It is the angle between two lines drawn from the edge of the mine workings, one a vertical line and the other a line to the limit of vertical displacement on the surface.
Aquiclude	A body of rock which is effectively impermeable.
Aquifer	A permeable body of rock or regolith that both stores and transmits water (DoP, 2010).
Aquitard	A body of rock which has a very low permeability, sufficient to significantly impede the transmission of water.
Bedding Plane Shear	Shear displacement along a bedding plane.
Cleat	A natural system of joints, or cleavage, within a coal seam. Cleat is usually comprised of two conjugate joint sets that are perpendicular or near perpendicular to stratification. It is often confined to specific coal plies. One joint set is usually more dominant and is referred to as *face* cleat; the other joint set is known as *butt* cleat.
Consequence	a. With respect to risk: Outcome of an event affecting objectives (ISO 31000, 2009b). b. With respect to ground subsidence: Any change in the amenity, function or risk profile of a natural or man-made feature due to the impact of ground subsidence.
Control	A process, policy, device, practice or other action which modifies risk (ISO 31000, 2009b). A control can act to minimise negative risk or enhance positive opportunities.
Dip	The angle at which a bed, stratum, or vein is inclined from the horizontal, measured perpendicular to the strike in the vertical plane. Also referred to as 'hade'.
Discontinuity	A mechanical break in the fabric of the rock mass across which there may or may not have been relative displacement. Discontinuities include fault planes, dykes, joints and bedding planes.
Dyke	A near vertical intrusion of igneous rock.
Fault	Geological - A planar discontinuity between blocks of rock along which relative shear displacement has occurred.
Fracture	A natural or mining induced planar discontinuity between blocks of rock along which extremely little or no discernible displacement has occurred.
Fracturing	The formation of planes of separation in the rock material, involving the breaking of bonds to form new surfaces. The onset of fracture is not necessarily synonymous with failure or with the attainment of peak strength (Brady & Brown, 2006).
Geological Structure	a. Refers to all natural planes of weakness in the rock mass that pre-date any mining activity and includes: joints, faults, shears, bedding planes, foliation and schistosity (NSW Dept. Mineral Resources, 2004). b. Any disturbance whereby a coal seam is altered from its original depositional state.
Geomechanics	Is concerned with the physical and mechanical properties and responses of soils and rocks and their interactions with water and encompasses the subject of rock mechanics (Brown, 1998).
Goaf	An area in which mining has been completed and left in a partially or totally collapsed state or in an inadequately supported state to assure safe entry. An abandoned area. Also referred to as 'gob'. 'Goaves' is the plural of goaf.

Ground Control	A term used more commonly in mining than in the civil construction industry and taken to mean the maintenance of the stability of the rock around an excavation and the more general control of displacements in the near-field of an excavation (Brady & Brown, 1993).
Hazard	A source of potential harm or a situation with a potential to cause a loss (including to people, property, the natural environment, business, or reputation).
Hydrogeology	Branch of geology which is concerned with the distribution and movement of groundwater in soil and rock.
Immediate Roof	The nether roof of the mine workings, defined to extend to various heights above the mine workings roof, typically ranging from 10 m to ten times the mining height.
Inbye	In a direction into the mine; in the direction of the working face.
Inrush	A sudden and unplanned or uncontrolled inflow into mine workings of fluid (in a gaseous or liquid phase) or other material that has the potential to result in unacceptable risk to health and safety.
Intact Rock	Rock which contains no discontinuities.
Inundation	An inflow of fluid (in a gaseous or liquid phase) or other material that develops over a period of time sufficient for it not to present an immediate risk to health and safety.
Joint	A natural planar discontinuity between blocks of rock along which little or no discernible displacement has occurred. Joints which are parallel in dip and strike over a considerable area constitute a joint set. Two or more joint sets that intersect at more or less a constant angle constitute a joint system.
Lineament	A topographic alignment of features that appears to be structurally controlled. Also referred to as a ‘fracture trace’ or ‘photolineament’.
Lithology	The character of the rock described in terms of its structure, colour, mineral composition, grain size, and arrangement of component parts (Gates et al., 2008).
Massive	In geology, the term is used to describe a rock mass that has a paucity of well-developed bedding planes.
Overburden	A generic term encompassing all solid and liquid material overlying a mine.
Parting	a. A mechanical weakness within bedding comprised of a lamina or thin bed of weak material which may vary in thickness from a fraction of a millimetre to some tens of millimetres. The weak material promotes separation of the strata (adapted from Cook et al., 1974). b. An opening due to separation between bedding planes.
Permeability	A measure of the rate at which fluid can be transmitted through a body.
Piezometer	A non-pumping well or borehole, generally of a small diameter, used to measure the elevation of the water table or potentiometric surface (DoP, 2010).
Regolith	The blanket of soil and loose rock fragments overlying bedrock. It includes dust; soil; broken and weathered rock; and other related materials (DoP, 2010).
Regulation	Subordinate legislation in support of an Act.
Risk	a. A combined measure of the consequences of an event and the likelihood that the event will occur. Risk may have positive or negative consequences. b. The effect that uncertainty has on an organisation’s objectives (ISO 31000, 2009b).
Rock Mass	The sum total of the rock as it exists *in situ*. This includes intact rock material, groundwater, fractures, faults, dykes and other planes of weakness.
Rock Mechanics	Is the theoretical and applied science of the mechanical behaviour of rock and rock masses; it is that branch of mechanics concerned with the response of rock and rock masses to the force fields of their physical environment (Brady & Brown, 2006, as offered by the US National Committee on Rock Mechanics).
Sill	A laterally extensive intrusion of igneous material.
Span	The shortest distance between two abutments.

Strike	The direction of a line that defines the intersection of a rock bed with a horizontal plane.
Tabular	Bedded and laterally extensive.
Threat	A means by which a hazard can materialise.
Trigger	a. Risk Management – a predetermined type or magnitude of behaviour prompting intervention. b. Physics - a threshold value which, if exceeded, results in instability that produces a sudden change in system properties.
Trigger Action Response Plan (TARP)	A plan designed to prevent a threat from escalating by identifying potential precursors, or triggers, to the threat event, assigning a hierarchy of alarms, or trigger levels, to each potential precursor, and specifying responses for each trigger level.
Upsidence	The difference between measured vertical displacement and that predicted by classical subsidence theory if the surface was flat.

Table 11: Acronyms

Acronym	Complete Term
AIP	Aquifer Interference Policy
AWBM	Australian Water Balance Model
BACI	Before-After-Control-Impact
DCU	Donalds Castle Upper
DGS	Ditton Geotechnical Services
DOI	Department of Industry
DPE	Department of Planning and Environment
DPI	Department of Primary Industries
DRE	Division of Resources and Energy, Department of Planning and Environment
DRG	Division of Resources and Geoscience, Department of Planning and Environment
DSC	Dams Safety Committee
EPA	Environment Protection Authority
EPL	Environmental Protection Licence
EIS	Environmental Impact Statement
EOP	End of Panel
GL	Giga Litres
GW	Groundwater
GWMMP	Groundwater Monitoring and Modelling Plan
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
IPC	Independent Planning Commission
IPM	Incremental Profile Method
LW	Longwall
ML	Mining Lease or Mega Litres
MNES	Matters of National Significance
MOD	Modification
NRAR	National Resources Access Regulator
OEH	Office of Environment and Heritage
PAC	Planning Assessment Commission (now the Independent Planning Commission)
PEA	Preliminary Environmental Assessment
PSM	Pells Sullivan Meynink
RMP	Rehabilitation Management Plan

SCA	Sydney Catchment Authority
SEARs	Secretary's Environmental Assessment Requirements
SEPP	State Environmental Planning Policy
SFR	Stream Flow Routing
SIMMCP	Swamp Impact, Monitoring, Management and Contingency Plan
SMP	Subsidence Management Plan
SSD	State Significant Development
SW	Surface Water
TARP	Trigger Action Response Plan
WAL	Water Access Licence
WC	Wongawilli Creek
WIMMCP	Watercourse Impact, Monitoring, Management and Contingency Plan
WMP	Water Management Plan
WWL	Wongawilli Creek Lower

APPENDICES

APPENDIX 1: TERMS OF REFERENCE

Purpose

The Independent Expert Panel has been established to provide informed expert advice to the Department of Planning and Environment on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a particular focus on risks to the quantity of water in the Catchment.

Advice will include, but is not confined to risks to the total water quantity and holding capacity of surface and groundwater systems, including swamps and reservoirs, and the types and reliabilities of methodologies used to predict, monitor, assess and report on mining effects, impacts and consequences.

As needed, the Independent Expert Panel will provide a source of expert advice to the Department of Planning and Environment on mining applications, including monitoring and management plans.

Scope of Work

The Independent Expert Panel will:

1. **Undertake an initial review and report on specific coal mining activities at the Metropolitan and Dendrobium coal mines in the Greater Sydney Water Catchment Special Areas**, including:
    a. A review of the findings and recommendations of studies and reports deemed appropriate by the Panel, including but not confined to the reports:
        i. *Height of Cracking – Area 3B*, prepared by PSM, dated 16 March 2017
        ii. *2016 Audit of the Sydney Drinking Water Catchment*, prepared by Alluvium, dated June 2017.
    b. A review of the types and reliability of prediction, monitoring and response methodologies (including mitigation, remediation and rehabilitation) currently used for assessing and managing the effects, impacts and consequences of mining activities at the Metropolitan and Dendrobium coal mines as they relate to water quantity, including having regard to historical data and performance.
    c. Provide advice and recommendations on measures required to improve approaches to prediction, monitoring, responses and reporting at the Metropolitan and Dendrobium coal mines, including having regard to cumulative risks posed to the quantity of drinking water available in the Greater Sydney Water Catchment Special Areas.
    d. Based on the outcomes TOR 1(a) to 1(c), provide advice to Government on how to respond to the findings and recommendations of reports reviewed as part of TOR 1a.
    e. In developing its advice, the Panel will meet, undertake site visits, seek information and data, and consult as needed.
    f. In delivering its report, the Panel will provide comment on and make observations or recommendations about any information or factors the Panel believes relevant; or further work that should be undertaken.
    g. A progress update on the report is to be delivered no later than 30 April 2018 and the report is to be delivered no later than 31 July 2018.

2. **Undertake a review of current coal mining in the Greater Sydney Water Catchment Special Areas with a particular focus on risks to the quantity of water available, the environmental consequences for swamps and the issue of cumulative impacts**, including:

a. A review and update of the findings of the *2008 Southern Coalfield Inquiry (Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield – Strategic Review)* for mining operations at the Dendrobium, Metropolitan, Russell Vale and Wongawilli mines, including recommending measures to improve the way mining effects, impacts and consequences in relation to water quantity are assessed and managed.
b. In developing its advice, the Panel will meet, undertake site visits, seek information and data, and consult as needed.
c. Establish a process for and invite public submissions, including from public authorities and special interest groups.
d. In delivering its report, the Panel will provide comment on and make observations or recommendations about any information or factors the Panel believes relevant, including requirements to strengthen monitoring networks or undertaking further scientific research.
e. The report is to be delivered no later than 31 December 2018.

3. **Provide advice as required to the Department of Planning and Environment on mining activities in the Greater Sydney Water Catchment Special Areas, which may include but is not confined to:**
   a. A Subsidence Management Plan application for Longwall 16 at the Dendrobium mine.
   b. An Extraction Plan application for Longwall 303 at the Metropolitan mine.
   c. An Environmental Impact Statement for the Dendrobium Extension Project.
   d. A Preferred Project Report for the Russell Vale Underground Expansion Project.
   e. A modification application for the Wongawilli mine.

The Panel

The Independent Expert Panel is comprised of a Chair and technical experts with expertise in mining, mining subsidence, surface water, ground water and swamps.

- Emeritus Professor Jim Galvin (Chair)
- Professor Neil McIntyre
- Dr Ann Young
- Mr Michael Williams
- Dr Christopher Armstrong
- Professor Bruce Hebblewhite (to 8 April 2018)

The Panel draws on other sources of specialist expertise as needed at the discretion of the Chair.

Secretariat support for the Independent Expert Panel is provided by the Office of the Chief Scientist & Engineer.

APPENDIX 2: REGULATORY FRAMEWORK AND APPROVALS

As set out in Chapter 1, the regulatory framework for major developments, including mines, has evolved over time. The approval process in place for the Dendrobium and Metropolitan mines at the time of their approval in the early 2000s is discussed first and then an overview of the current regulatory assessment and approvals process is provided.

A2.1 HISTORICAL PROCESS AND APPROVALS FOR THE DENDROBIUM AND METROPOLITAN MINES

A2.1.1 Dendrobium Mine

Dendrobium Mine, owned and operated by Dendrobium Coal Pty Ltd, is located 8 km west of Wollongong, adjacent to the township of Mt. Kembla. The Dendrobium Mine pit top is situated on the site of the former Nebo Colliery, which operated from 1946. In 1992, the Elouera Colliery was created from an amalgamation of Kemira, Nebo and Wongawilli Collieries. Construction of Dendrobium Mine began in 2002, with longwall mining commencing in 2005; the approval process in place at the time at Figure A2.1. Nebo Colliery's surface facilities were reworked to incorporate them into the new Dendrobium Mine. The approved mining domain has been divided into several zones as shown in Figure 3 and Figure 4. Mining in Area 3B is ongoing (LW 14) as at October 2018.

In addition to the Development Consent, Dendrobium Mine is also required to hold various other approvals such as a current Mining Lease, Environmental Protection Licence and Water Access Licence. An overview of approvals and major developments is provided in Table A2.1.

Table A2.1: Timeline of approvals and major developments at Dendrobium Mine

Year	Significant developments and approvals
1991	**Consolidated Coal Lease (CCL) 768. Exploration activities under Authorisations 143 and 338**
2001	**Commission of Inquiry (Cleland & Carleton, 2001)** **Development Consent Approval (DA 60-03-2001)**, expiry 21 December 2023
2002	**Mine construction began** **Mining Lease 1510,** expiry: 24 April 2023 **DA-60-03-2001 MOD1, DA-30-03-2001 MOD2**
2003	**DA 60-03-2001 MOD3 -** modified with limits on volume of water to be discharged into Allans Creek
2005	**LW 1 extracted** **Mining Lease 1566**, expiry: 6 September 2026
2006	**LW 2 extracted** **DA 60-03-2001 MOD4 -** construct and operate an above-ground coal sizing plant **DA 60-03-2001 MOD5 -** approval to extend Longwall (LW) 2 into Staged Development Area A ***Inquiry into the Impacts of Underground Coal Mining in the Southern Coalfield commenced***
2007	**Subsidence Management Plan (SMP) LWs 3-5**- requirement to establish a subsidence monitoring program; undertake environmental monitoring (surface and groundwater, flora and fauna, landscape and heritage) and infrastructure and property management monitoring; and develop a plan to manage swamps likely to be affected by subsidence impacts **LW 3** and **LW 4 extracted** **Stage 3 Emplacement Area for washery reject material at West Cliff** - utilising 66.3 hectares with a total capacity of 33.5 million tonnes over a period of 13 years. Development includes a Vegetation and Fauna Management Plan (including a Broad-headed Snake Management Plan) and commitment to a Pollution Reduction Program to investigate, trial and implement appropriate strategies, technologies or works to achieve agreed water quality discharge criteria from the West Cliff site
2008	**LW 5 extracted** **Development consent MOD6**; expiry 31 December 2030. Approval to mine Area 3. Application increased the size of Area 3 and subdivided it into three small longwall domains (Areas 3A, 3B and 3C), expanding by 1,460 hectares. Approval for Area 3A granted, with approval to mine in Areas 3B and 3C requiring further specific applications and assessment of SMPs. Conditions applied to ensure 'no impacts' at Sandy Creek Waterfall, and impacts to Sandy Creek and Wongawilli Creek are no greater than the 'minor

	impacts' predicted
2010	**Move to Area 3A** **SMP approval LW 6-8 and LW 19** **LW 6 extracted** **Environmental offset in the Cataract Dam catchment** – approval of 33 hectare environmental offset to satisfy a biodiversity offset obligation under the development consent for impacts in Area 2
2012	**LW 7** and **LW 8**
2013	**Move to Area 3B** **SMP 9-13 (Area 3B)** - specific approval required before commencing gate road development and prior to extraction of LWs 14-18. Requirements for a Swamp Rehabilitation Research Program including remediation trial, research and monitoring activities remediating subsidence impacts on upland swamps ($3.5m/5yrs); a Biodiversity Offset Strategy to compensate for any impacts of LW 14-18 on upland swamps; and a revised groundwater model and monitoring. **LW9 extracted**
2014	**LW 10 extracted** **CCL 768 renewed**, expiry 7 October 2029
2015	**LW 11 extracted** **Company** writes to DPE seeking approval for a strategic offset to meet requirements for both Bulli Approval and Dendrobium Mine Consent, proposing land at Maddens Plains and Douglas Park would meet and exceed the relevant offset requirements under NSW and Federal approval processes for impacts on upland swamps **Development consent MOD7 Strategic Biodiversity Offsets** - made provision for the acceptance of Strategic Biodiversity Offsets by the Secretary DPE in consultation with OEH. **Minister for Planning requests inspection of mining impacts within Area 3B** - the impacts of longwall mining on Wongawilli Creek (WC21) were greater than predicted, with significant rock fracturing, reduction in water levels in pools and an absence of surface flows **DPE requests remediation program for impacts to WC21**
2016	**LW12 extracted** **SMP LW14-15** - company had requested approval for SMP for LW14-18; approval for LW14-15. Conditions included extraction of no more than 3.9m from coal seam; setback of 320m from Avon Dam for LW14; minimum set-back distance of 50m for LW14 to reduce the level of impacts to the lower reaches of Wongawilli Creek; remediation programs for WC21 and Donalds Castle Creek; biodiversity offsets; height of cracking monitoring and revised groundwater modelling and monitoring. **Strategic Biodiversity Offset** –approval for the transfer of 598 hectares from Maddens Plains to the NSW Government for inclusion in the National Parks Estate as satisfying the strategic biodiversity offset requirements for any impacts on upland swamps at the Dendrobium Mine and Bulli Seam Operations
2017	**SEARs issued for Extension Project (Areas 5 and 6)** – to develop an EIS for a proposal to mine up to 5.2 Mtpa of ROM Coal (combined) from Areas 5 (Bulli Seam) and 6 (Wongawilli Seam) to 2048. **LW 13 extracted** **Height of Cracking - Dendrobium Area 3B report PSM3021-002R March 2017**
2018	**LW 14 extraction ongoing** **SMP approval LW16** – condition to extract no more than 3.9m from coal seam; monitoring strategy for WCWF54; flow gauges at LA2, LA3 and WC12; Groundwater Monitoring and Height of Cracking investigation of LW6-12; revise Watercourse and Swamp Impact Management Monitoring Contingency Plan TARPS; Area 3B Groundwater Model **DA 60-03-2001MOD8** - to install a 2 MVA 11/6.6 kV transformer to migrate to a new energy supplier **Strategic Biodiversity Offset** – final transfer of land at Maddens Plains to National Parks Estate in May 2018.

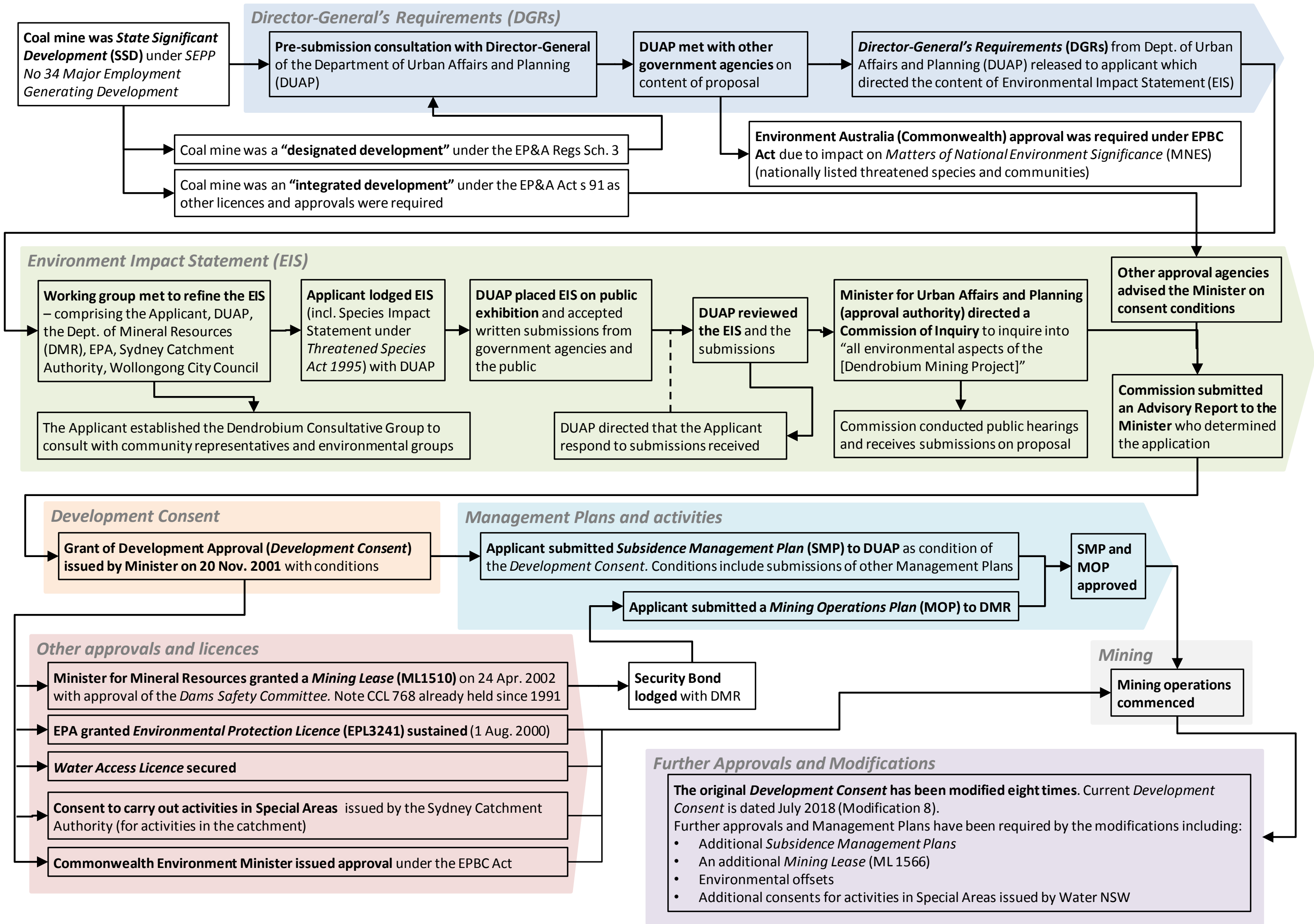

Figure A2.1: Overview of the Dendrobium Mine approval process in place in 2001

Note: Development Consent refers to Project Approval DA 60-03-2001

A2.1.2 Metropolitan Mine

Metropolitan Mine is located adjacent to the township of Helensburgh, approximately 30 km north of Wollongong. Opened in 1888, it is currently owned and operated by Metropolitan Collieries Pty Ltd, a subsidiary of Peabody Energy Australia Coal Pty Ltd.

Between 1995 and 2009, as part of a previous approval, Metropolitan Coal extracted longwalls 1 to 18. The Metropolitan Project Approval (08_0149), approved under the requirements of the *Environmental Planning and Assessment Act 1979* (EP&A Act), was granted on 22 June 2009 and has since been modified three times, the most recent modification approved on 3 October 2013 (Table A2.2). Figure A2.2 provides an overview of the regulatory assessment process in place at the time of the 2009 approval.

Extraction Plans for LW 20 to LW 27 were approved in 2010 (LW 20 to LW 22) and 2014 (LW 23 to LW 27), and the extraction of these longwalls were completed between 2010 and 2017. Metropolitan Coal is extracting LW 302 as at October 2018. The longwall layout for LW 301-317 is shown in Figure 5.

Table A2.2 Timeline of approvals and major developments at Metropolitan Mine

Year	Significant developments and approvals
1888	**Mine opened**
1989	**Consolidated Coal Lease (CCL) 703**
1993	**Mining Purposes Lease 320**
1995	**Development Consent D90/832**
1996	**Coal Lease (CL) 379**
2000	**Environment Protection Licence 767**
2004	**CCL 703 renewed**, expiry date: 26 January 2024
2006	***Inquiry into the Impacts of Underground Coal Mining in the* Southern Coalfield commenced**
2009	**Project approval 08_0149**, expiry date 22 June 2032 **Mining Lease 1610**
2010	**LW 20-22 Extraction Plan (EP) and Catchment Monitoring Program (CMP)**- company directed to continue to consult with relevant agencies to identify additional improvements to the EP and CMP, with particular attention to providing ongoing calibration and verification of the groundwater model; incorporating any additional agreed monitoring points and/or criteria; and incorporating the results of increasing baseline datasets, where appropriate **LW 20 extracted** **Project approval 08_0149 MOD1** - construct a replacement underground drift, including construction of a new drift portal at the mine's Major Surface Facilities Area. DPE satisfied there would be a negligible difference in groundwater effects and potential impacts to flora and fauna would be minimal
2011	**LW 21 extracted** **Project approval 08_0149 MOD2** - increase the limit for off-site trucking of product coal by 50,000 tonnes per annum; daily maximum limits of truck departures
2013	**Project approval 08_0149 MOD3** - administrative modification to streamline and harmonise annual reporting requirements **LW 22A and LW 22B extracted** **CL 379 renewed**, expiry date 4 October 2033
2014	**LW 23-27 EP** - requirement to develop a Grouting Protocol and Grouting Procedure for proposed remedial grouting works within Waratah Rivulet and/or other watercourses; the applicant shall ensure the existing Waratah Rivulet flow gauging station is not subject to subsidence impacts; and implement a monitoring and reporting procedure **LW 23A SMP approval** Requirement to include Subsidence Monitoring Programme, Environmental Management Plan and Incident and Ongoing Management Reporting **LW 23A extracted** **LW 23B extracted** **Mining Leases 1610 and 1702 renewed**, respective expiry dates 18 December 2031, 13 October 2035 **Mining Purpose Lease 320 renewed**, expiry date: 9 December 2035
2015	**LW 24 extracted** **LW 25 extracted**
2016	**LW 26 extracted** **LW 27 extracted**
2017	**LW 301-303 EP –** Decision reasons acknowledge uncertainty about the potential impacts of LW303,

	particularly on Woronora Reservoir and Eastern Tributary. Approval given for LW 301 and 302 with conditions including additional groundwater monitoring (both shallow and deep) with installation of multi-level piezometers; preparation and implementation of a Woronora Reservoir Impact Strategy; improved monitoring of Garrawarra Centre; revised TARPs with a greater focus on early recognition of mining impacts and proactive measures to reduce further impacts or exceedances; and further details on the evidence used to support statements of compliance with performance measures and indicators. Further specific approval for LW303 required **LW 301 extracted**
2018	**LW 302 extraction begins**

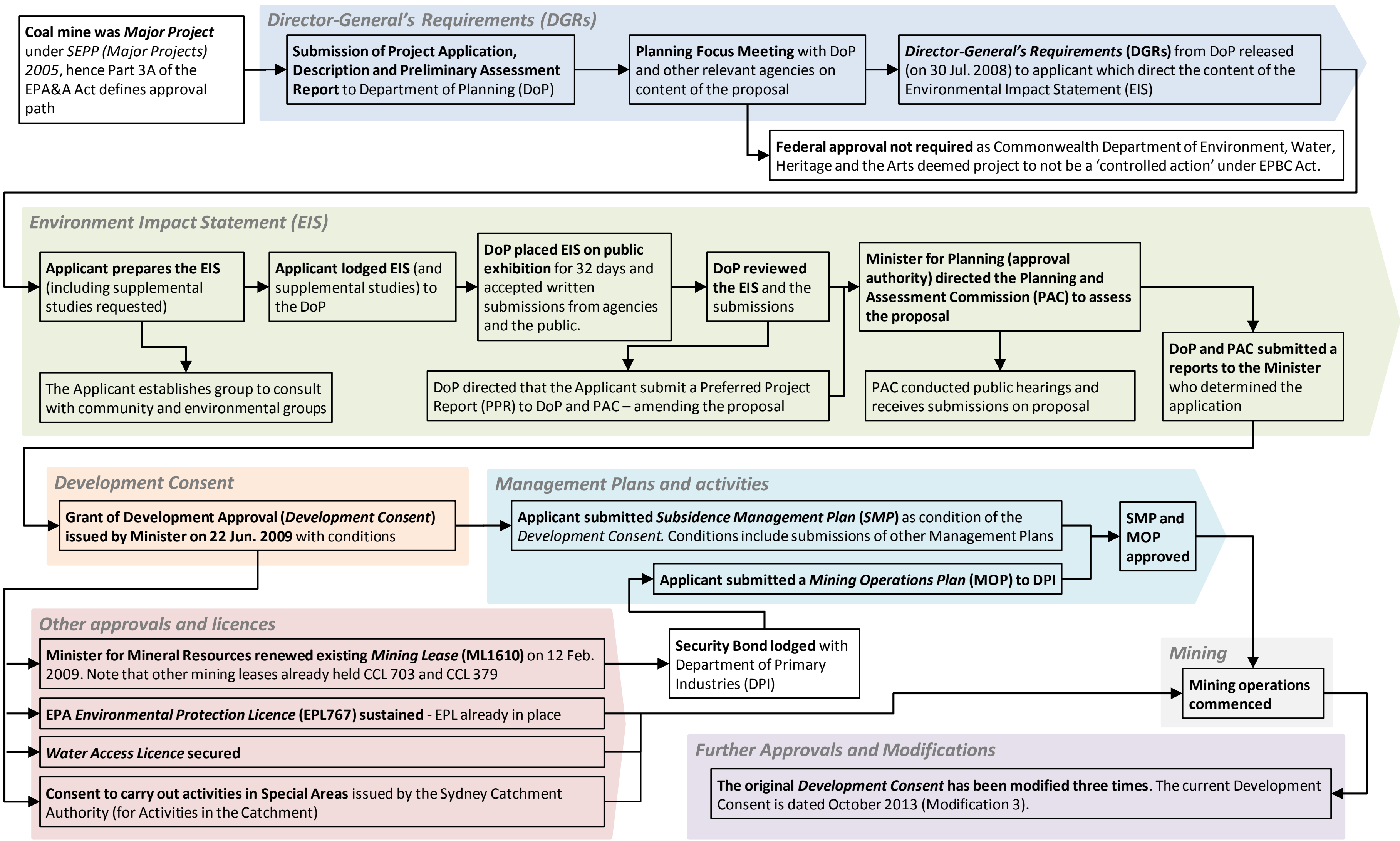

Figure A2.2: Overview of the Metropolitan Mine approval process in place, 2008-09

Note: Development Consent refers to Project Approval 08_0149

A2.2 CURRENT REGULATORY FRAMEWORK

Mining activity in New South Wales is subject to a number of statutory approval processes (Figure A2.3). New coal mining projects, including underground coal mines, and expansion of existing projects require a Development Consent under Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) and a Mining Lease under Part 5 of the *Mining Act 1992*.[132]

Coal mining activities are a State Significant Development (SSD) under Schedule 1 of the *State Environmental Planning Policy (State and Regional Development) 2011* and therefore are considered under the SSD provisions of the EP&A Act (Division 4.7 of Part 4).

A2.2.1 Legislative objects and principles

Statutes regulating mining activities in NSW express principles and objects in which the risks, impacts and consequences of developments, including mining, must be considered (Table A2.3). Certain Acts refer to multiple interests; others focus on regulating activities to protect specific types of interests. Interests specified under the overall framework are diverse and include:

- **environmental interests** - promotion of ecological sustainability; protection of land and water; protection of ecosystem diversity and quality, threatened species, native flora and fauna; reduction and prevention of pollution; and the rehabilitation of disturbed land and water
- **social interests** - public health and safety; public and private amenity, via habitable, affordable and well planned community spaces; community engagement, consultation and responsibility in decision making; and historical and cultural recognition
- **economic interests** - investment and employment opportunities; equitable and efficient allocation of resources amongst communities and businesses; and protection of property.

While collectively, the objects of legislation regulating mining generally refer to these interests, much of the detail of how interests are to be balanced and objectives met is defined through a hierarchy of regulations, policy and guidance. These objects anticipate benefits and adverse impacts to different interests and propose different policy approaches for their management.[133] However, most legislation, regulations and policies addressing environmental harm also reflect a hierarchy of harm management approaches:

- **avoid** - alter or suspend development or operations to avoid the adverse impacts
- **minimise** - mitigate, remediate and rehabilitate damage caused by developments which cannot be avoided
- **offset** - conduct other beneficial activities to outweigh unavoidable adverse impacts which cannot be mitigated.

[132] *State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* cl 7(1)(a); *Environmental Planning and Assessment Act 1979* s 4.2(1); and *Mining Act 1992* s 5..

[133] For example, the objects of the *Mining Act 1992* anticipate economic and social benefits from mining, and that loss or damage can be minimised by payment of compensation or funding of mine rehabilitation (*Mining Act 1992 (NSW)* s 3A).

Table A2.3: Legislative principles and objects relevant to mining in New South Wales

The following table summarises the principles and objects specified in major pieces of legislation regulating mining activities in NSW. The sections of these Acts are presented to align with the major environmental, social and economic interests articulated in the law.

Act	Ecological	Social				Economic	
	Environmental and biological *Environmental enhancement, protection and sustainability for ecosystems, species*	**Health & safety** *Protected water, safe land*	**Amenity** *Habitable, affordable, well planned*	**Community** *Engagement, consultation, coordinating government, shared responsibility*	**Cultural** *Cultural recognition, protection incl. Aboriginal heritage*	**Production** *Economic activity for NSW & communities*	**Resource allocation** *Efficient, equitable*
***Environmental Planning and Assessment Act 1978* (NSW) s 1.3**	(b) **Facilitate ecologically sustainable development by integrating relevant** economic, environmental and social considerations in decision-making about environmental planning and assessment (e) **Protect the environment**, including conservation of threatened **species, native** flora and fauna, ecological communities and habitats	(a) **Promote social, economic welfare of community and a better environment** by proper management, development and conservation of natural and other resources					
		(h) Promote proper, **safe construction,** maintenance of buildings	(d) Promote **affordable housing,** (g) **good design**	(i) **Share planning, assessment** between levels of government (j) Provide for community **participation in planning and assessment**	(f) Promote **sustainable management** of **built, cultural, Aboriginal heritage**	(c) Promote **orderly and economic land use and** development	
***Mining Act 1992* (NSW) s 3A**	(g) Ensure **mineral resources are identified and developed** in ways that **minimise environmental impacts**	(a) Foster **social and economic benefits** from mineral resource development					
	(f) **Ensure rehabilitation** of disturbed land and water					(d) Ensure **appropriate return to NSW** from mineral resources	(b) Provide **integrated framework** to regulate mining
***Environmental Protection and Biodiversity Conservation Act 1999* (Cth) s 3(1)**	(a) Provide for **protection of environment**, especially **matters of national environmental significance** (b) Promote **ecologically sustainable development** through conservation and ecologically sustainable use of natural resources (c) Promote the **conservation of biodiversity**			(d) Promote **co-operative protection, management** of environment with governments, community, land-holders, indigenous peoples (e) Assist **co-operative implementation** of international environmental responsibilities	(ca) Provide for **protection** and conservation of **heritage** (f) **Recognise indigenous people in conservation, biodiversity use** (g) Promote **cooperative use of indigenous knowledge**		
***Protection of the Environment Operations Act 1997* (NSW) s 3**	(a) **Protect, restore, enhance environment**, incl. ecological sustainable development (e) **Simplify, strengthen the regulatory framework** for environment protection (g) Assist the objectives of *Waste Avoidance and Resource Recovery Act 2001.*			(b) Provide increased opportunities for **public involvement** and **participation** in environment protection, (c) Ensure that the **community has access** to relevant and meaningful **information** about pollution,			(f) Improve the **efficiency of environment protection legislation**
	(d) **Reduce health risks, prevent environment damage** by mechanisms for: (i) **pollution prevention,** cleaner production, (ii) **reducing harmful discharges**, (iia) **elimination of harmful wastes**, (iii) **reducing materials use**, and re-use or **recycling**, (iv) progressive environmental improvements, (v) **monitoring & report**-environment quality						

Act	Ecological	Social				Economic	
	Environmental and biological *Environmental enhancement, protection and sustainability for ecosystems, species*	**Health & safety** *Protected water, safe land*	**Amenity** *Habitable, affordable, well planned*	**Community** *Engagement, consultation, coordinating government, shared responsibility*	**Cultural** *Cultural recognition, protection incl. Aboriginal heritage*	**Production** *Economic activity for NSW & communities*	**Resource allocation** *Efficient, equitable*
Protection of the Environment Administration Act 1991 **(NSW) ss 4, 6**	6(2)(c) Conserve biodiversity & direct EPA to conduct **environmental audits, reports** 6(1)(a) **protect, restore and enhance** environment, with **ecologically sustainable development**; s 6(2) ecologically sustainable development achieved through **'precautionary principle'** – lack of scientific certainty should not postpone measures where threats of serious or irreversible environmental damage	6(1)(b) reduce risks to **human health** by promoting pollution prevention, reduction, control		6(1)(b) promote community involvement in environmental decisions, ensure community access to information about hazardous substances			4(b) Provide **integrated administration** for environment protection
Biodiversity Conservation Act 2016 **(NSW) s 1.3**	(a) **Conserve biodiversity**, (b) **Maintain diversity** and quality of ecosystems, (c) Improve, share and use **knowledge**, incl. local, Aboriginal, **for conservation**, (d) Support **biodiversity conservation** in a changing climate, (e) Support biodiversity and conservation **data collection, monitoring, reporting**, (f) **Assess extinction risk** of species and ecological communities, (g) Regulate **human interactions with wildlife**, (h) Support **conservation** and **threat abatement** action, (i) Support **strategic investment in biodiversity conservation**, (j) Encourage, enable landholders to enter **voluntary conservation agreements**, (k) Establish **framework to offset impact** of development on biodiversity, (l) Establish **scientific method to assess biodiversity impacts** of development,			1.3 Maintain a **healthy, productive and resilient environment for the greatest well-being of the community**, now and into the future, consistent with the principles of **ecologically sustainable development** (n) Support **public consultation**, participation and decision-making in biodiversity conservation,			(m) Establish **market-based conservation mechanisms** for biodiversity impacts
Water Management Act 2000 **(NSW) s 3**	(c) Foster social, cultural, community, heritage, economic and environmental benefits from **sustainable, efficient water use**,						
	(a) Apply principles of **ecologically sustainable development**, (b) **Protect, enhance, and restore water sources**, their ecosystems, biological diversity, water quality (f) **Integrate management** of water sources and other environment management			(d) **Recognise community** as partner with government to resolve water management issues (g) Encourage **shared Government and water user** responsibility	(c) Foster **cultural and Aboriginal benefits** from sustainable, efficient water use		(e) Provide for **efficient, equitable sharing** of water (h) Best practice water management
Water NSW Act 2014 **(NSW) ss 6, 7**	6(1)(a) **Capture, store and release water** in an **efficient, effective, safe and financially responsible** manner,						
	6(1)(c) Ensure **catchment areas are managed** to protect water quality, public health, safety, environment (see also s 47(2)(b) to protect the ecological integrity of special areas)			6(2)(b) Exhibit **social responsibility** by considering community interests, 6(2)(c) Exhibit responsibility for regional development and **decentralisation**,		6(1)(e) Operate Water NSW **efficiently and economically** as any comparable business 7(1)(g) to **protect and enhance** the quality and **quantity of water** in declared catchments	
	6(2)(d) Conduct operations consistent with **principles of ecologically sustainable development** (contained in the *Protection of the Environment Administration Act 1991* s 6(2)).	6(1)(b) Supply water of **appropriate quality**					
	7(1)(g) **protect, enhance quality** and quantity of water in declared catchments						
Dams Safety Act 2015 **(NSW) s 3 – yet to commence**		(a) Ensure dam risk level is acceptable to the community		(b) Promote **transparency** in regulating dams safety, (c) Encourage proper, **efficient** dam safety **management**		(d) Apply risk management and cost benefit analysis principles to dam safety	

Note: The *Dams Safety Act 2015* is yet to commence, the Dams Safety Act 1978 remains in force**.**

A2.2.2 Approval process

Under current regulatory arrangements, the Department of Planning and Environment (DPE) is the lead approval authority for mining applications. [134] DPE consults with other relevant agencies in conducting assessments and determining the conditions of approval. However, for certain SSD applications, the Independent Planning Commission (IPC) is the lead consent authority and determines the conditions of approval.[135]
In addition to the Development Consent and Mining Lease, other approvals and licences are generally required to undertake coal mining activities.[136] However, it is intended that these other statutory requirements are incorporated into the development assessment process and cannot be refused for a SSD activity that has been given development approval.[137] These other approvals must also be 'substantially consistent' with the consent.[138] Activities prior to development of the mine, such as exploration and assessment, are subject to separate statutory approval processes and require specific licences.

Prior to commencing an application for a Development Consent, the mine proponent may elect to submit a Conceptual Project Development Plan (CPDP) for the project to the Division of Resources & Geoscience in DPE.[139] The CPDP provides an opportunity for the proponent to demonstrate that the proposal is a reasonable and sustainable mining development, and to identify any matters requiring attention in the Environmental Impact Statement (EIS) assessment phase.[140]

The SSD assessment and approval process is administered by DPE, which also exercises functions on behalf of the IPC.[141] These administrative functions include charging of the application fee, public exhibition of the application and preparation of an Environmental Assessment Report.[142] The decision (determination) is made by either DPE or, under specific circumstances, the IPC as the consent authority.[143]

As coal mining activities are a SSD,[144] a development application must be accompanied by an EIS.[145] The intent of the EIS is to satisfy the duty of the determining authority under the EP&A Act to consider environmental impacts of the development in determining consent.[146] The EIS is based on the requirements set out in the Secretary's Environmental Assessment Requirements (SEARs) issued to the proponent. The SEARs define the factors decision-makers must take into consideration concerning the impact of the proposed development.[147]

Community participation is a mandatory requirement of the assessment of SSD applications and is undertaken in accordance with a community participation plan with mandated

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[134] Instrument of Delegation, Minister for Planning (signed 11 October 2017) (DPE, 2017b); Instrument of Delegation, Secretary, Department of Planning and Environment (signed 26 September 2017) (DPE, 2017c); *Environmental Planning and Assessment Act 1979*, s 4.5(a).
[135] *Environmental Planning and Assessment Act 1979*, s 4.5(a); *State Environmental Planning Policy (State and Regional Development) 2011*, cl 8A(1).
[136] *For example: (i) a site verification certificate or gateway certificate under the State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* (Mining SEPP); (ii) an Environmental Protection Licence under Chapter 3 of the *Protection of the Environment Operations Act 1997*; (iii) a Water Access Licence to access available water governed by Part 3 of the *Water Management Act 2000*; (iv) consent to enter and carry out activities permitted by statutory approvals issued by WaterNSW under Part 3 of the *Water NSW Regulation 2013* for activities in Special Areas or Controlled Areas.
[137] *Environmental Planning and Assessment Act 1979* s 4.42(1)
[138] *Environmental Planning and Assessment Act 1979* s 4.42(1)
[139] *Environmental Planning and Assessment Act 1979* Div 4.4
[140] The proponent may also be required to apply for a gateway certificate, if required under the Mining SEPP. This assessment is undertaken by an independent expert panel (the Mining and Petroleum Gateway Panel). The Panel assesses the impact of the proposed development on strategical agricultural land and its associated water resources.
[141] *Environmental Planning and Assessment Act 1979* s 4.6
[142] The Environmental Assessment Report is considered by but is not binding on the IPC and does not limit the assessments that the IPC may undertake. See Environmental Planning and Assessment Act 1979 s 4.6(b) .
[143] Instrument of Delegation, Minister for Planning (signed 11 October 2017) (DPE, 2017b); Instrument of Delegation, Secretary, Department of Planning and Environment (signed 26 September 2017) (DPE, 2017c); *Environmental Planning and Assessment Act 1979* s 4.5; *State Environmental Planning Policy (State and Regional Development) 2011*, cl 8A(1): IPC is the consent authority for SSDs where a local council has objected, more than 25 persons have made submissions in objection, or a reportable political donation has been made.
[144] *State Environmental Planning Policy (State and Regional Development) 2011* Sch 1.
[145] *Environmental Planning and Assessment Act 1979* s 4.12(8)
[146] *Environmental Planning and Assessment Act 1979* s 5.5
[147] *Environmental Planning and Assessment Regulation 2000* cl 228

minimum periods.[148] DPE must have regard to the following when preparing a community participation plan: the provision of plain language information about the proposed plan; encouraging partnerships with the community; seeking views representative of the whole community to be shared; provide opportunities for participation in strategic planning as early as possible; and in the case of major developments, community consultation, led by the proponent, prior to the submission of the development application.[149]

The legislation and process for planning and assessment of major mining developments have undergone changes over time. Therefore, conditions of consent reflect planning and assessment law and policy from the relevant period when the project was initially approved or when the most recent modifications to the conditions of consent were approved.

A2.2.3 Secretary's Environmental Assessment Requirements

The proponent of a mining development must apply for the SEARs prior to preparing an EIS.[150] The SEARs define the comprehensive environmental assessment requirements to be addressed in the EIS.

The request for SEARs is generally accompanied by a Preliminary Environmental Assessment that summarises the proposed development and informs the development of the SEARs by DPE in consultation with other NSW Government agencies and, in certain cases, the Commonwealth Government.[151] The SEARs are prepared by the Secretary of DPE for each SSD application.[152] The Secretary must have regard to the need for the SEARs to address key issues raised by other NSW government agencies and the Commonwealth.[153] Where a gateway certificate has been issued with respect to the SSD, the SEARs must address any recommendations of the Gateway Panel set out in the certificate.[154] The SEARs for each development application must be made available to the public on the DPE website.[155]

Mining developments impacting Matters of National Environmental Significance (MNES) require Commonwealth approval under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act). A 2015 bilateral agreement between the NSW and Commonwealth Governments accredits assessments undertaken under Part 4 of the EP&A Act for assessing MNES impacts.[156] The purpose of this agreement is to establish a single environmental assessment process, while still promoting conservation and ecologically sustainable use of natural resources.[157] To ensure compliance with the EPBC Act is appropriately evaluated under the NSW assessment process, the Commonwealth Department of Environment and Energy's environmental assessment requirements are incorporated into the SEARs, and assessed by DPE as part of EIS process.

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148 *Environmental Planning and Assessment Act 1979* Div 2.6 and Sch 1

149 *Environmental Planning and Assessment Act 1979* s 2.23(2)

150 *Environmental Planning and Assessment Regulation 2000* Sch 2 cl 3(1)

151 *Environmental Planning and Assessment Regulation 2000* Sch 2 cl 3(4)

152 *Environmental Planning and Assessment Regulation 2000* Sch 2 cl 3(4), Indicative SEARs published by the Secretary also provide proponents with guidance about common SEARs which could be reasonably expected to apply, such as the scope of the proposed project, rationale, strategic context, consultation, and environmental impact and rehabilitation assessments e.g. (DPE, 2015a)

153 *Environmental Planning and Assessment Regulation 2000* Sch 2 cl 3(4)

154 *Environmental Planning and Assessment Regulation 2000* Sch 2 cl 3(4A), The Gateway Certificate is required for proposals for state significant mining and coal seam gas projects on strategic agricultural land and its associated water resources. The Certificate must be obtained prior to the Development application proceeding. Applications for a Gateway certificate are assessed by the Mining and Petroleum Gateway Panel, comprised of independent scientific experts.

155 *Environmental Planning and Assessment Regulation 2000* cl 85B(a)

156 Bilateral agreement made under section 45 of *the Environment Protection and Biodiversity Conservation Act 1999* (Cth) relating to environmental assessment, Commonwealth of Australia and The State of New South Wales (February 2015) (Department of the Environment, 2015)

157 Section Objects (p3), Bilateral agreement made under section 45 of I relating to environmental assessment, Commonwealth of Australia and The State of New South Wales (February 2015) (Department of the Environment, 2015)

A2.2.4 Environmental Impact Statement

The Environmental Impact Statement (EIS) is the primary mechanism used to inform the assessment of a proposed mine development and the determination of the Development Consent, Mining Lease, and other associated approvals. EIS requirements include provision of a detailed description of the proposed development and existing site, description of the anticipated environmental, social and economic impacts of the development, and how adverse impacts will be avoided, mitigated or offset.[158] The SEARs provide detailed guidance on the content of the EIS and indicate where this content should be informed by environmental and technical studies. The EIS must address the environmental, social and economic impacts that the consent authority should consider in the assessment phase. Consistent with the Mine Application Guideline, a rigorous EIS should define both existing and potential environmental impacts to a high degree of certainty.[159]

Once submitted to DPE, the EIS is subject to an adequacy test with input from relevant agencies to ensure that it provides the information requested in the SEARs. The EIS must be put on public exhibition for at least 30 days and made available on the DPE website, and submissions from the public and government agencies invited.[160] The Secretary of DPE may require the proponent to provide a response to issues raised in submissions via a Submissions Report or Response to Submissions report, which is published on the DPE website, and evaluated by DPE (with input from relevant agencies) to ensure it adequately addresses any concerns raised.[161] DPE review the proposed development and prepare an Environmental Assessment Report which is made available on the DPE website.[162]

The Minister for Planning has delegated the consent authority for SSD applications to DPE.[163] The IPC is the consent authority for SSD applications (and modifications) where there have been 25 or more public objections to the application, or the local council has objected, or a reportable political donation has been made.[164] Where the IPC is the consent authority, DPE carries out the administrative arrangements to inform this assessment including public exhibition and preparation of the Environmental Assessment Report.[165] The consent authority is responsible for assessing the application and relevant materials in accordance with the EP&A Act and Regulations, any environmental planning instrument, and any other environmental or planning laws; and may approve the application with conditions, reject the application or request further information or changes to the proposed development.[166]

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[158] *Environmental Planning and Assessment Regulation 2000 Sch 2 cl 3(2);* Mine Application Guideline, October 2015 (DPE, 2015b).

[159] Mine Application Guideline, October 2015 (DPE, 2015b)

[160] *Environmental Planning and Assessment Act 1979* s 5.8(1) and Sch 1 cl 11; *Environmental Planning and Assessment Regulation 2000* cl 85 and 85B(a).

[161] *Environmental Planning and Assessment Regulation 2000* cl 85A(2) and 85B(c) and (g).

[162] *Environmental Planning and Assessment Regulation 2000* cl 85B(d).

[163] Instrument of Delegation, Minister for Planning (signed 11 October 2017) (DPE, 2017b); Instrument of Delegation, Secretary, Department of Planning and Environment (signed 26 September 2017) (DPE, 2017c); *Environmental Planning and Assessment Act 1979*, s 4.5(a); *State Environmental Planning Policy (State and Regional Development) 2011*, cl 8A(1)

[164] *State Environmental Planning Policy (State and Regional Development) 2011*, cl 8A(1).

[165] *Environmental Planning and Assessment Act 1979*, s 4.6.

[166] *Environmental Planning and Assessment Act 1979*, s 4.38.

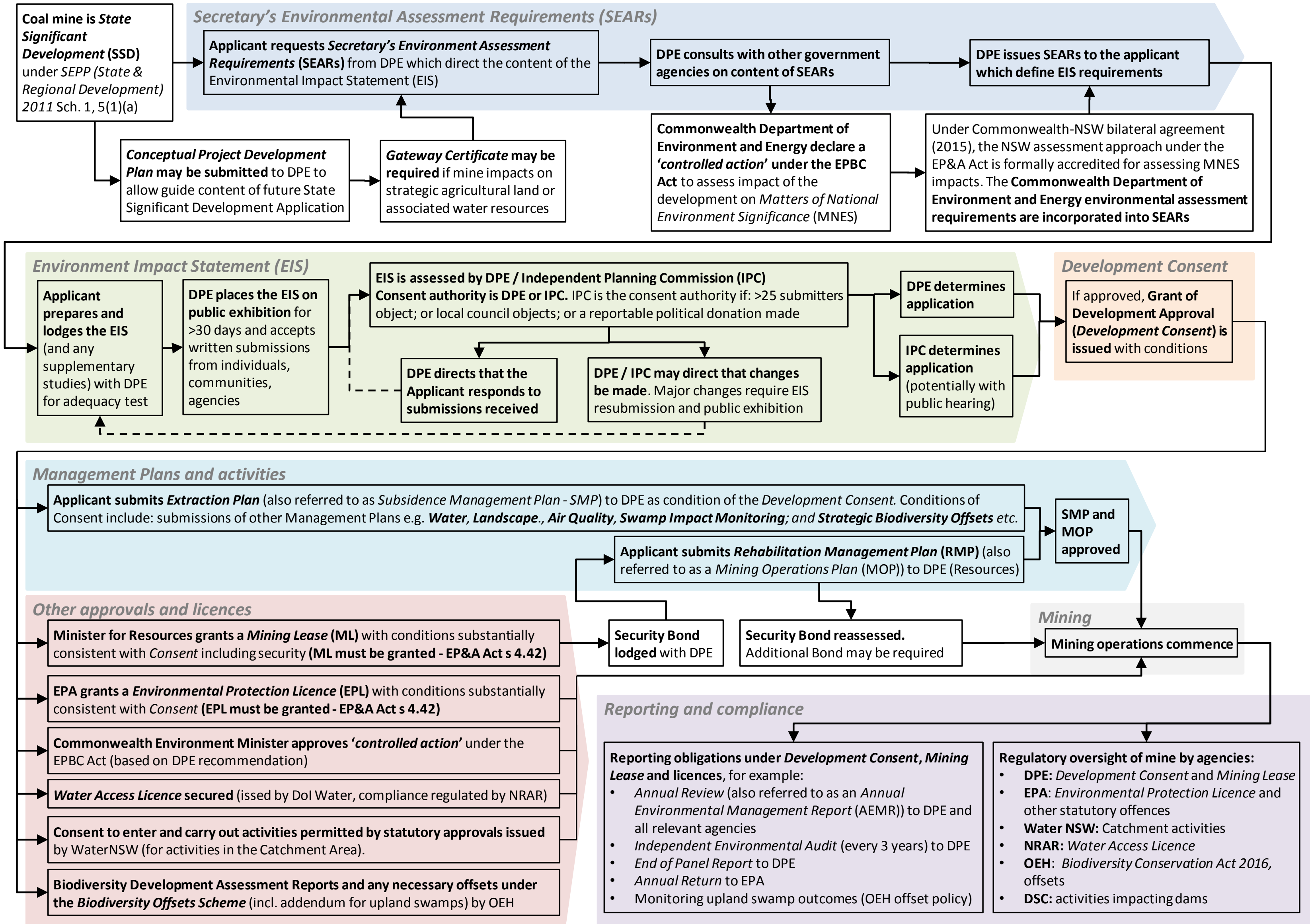

Figure A2.3: NSW Coal Mining Development Approvals Process

A2.2.5 Other approvals and licences

A2.2.5.1 Water – related requirements and approvals

Mining activities in the Sydney Drinking Water Catchment are subject to the *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011* which informs the acceptable impacts on water quality from any proposed development including a mining SSD, and therefore the conditions of consent. This SEPP requires the consent authority to not grant consent for a proposed development unless it is satisfied that the proposed development will have a neutral or beneficial effect on water quality.[167] However, where a mine proponent is seeking a consent for a 'continuing development', the proposed development need only have a neutral or beneficial effect on water quality compared to the impact on water quality if the extension occurred under similar conditions as the existing Development Consent.[168] A 'continuing development' is defined as any development for which Development Consent was granted for a particular time, areas or intensity but was likely to be the subject of future applications for consent for its extension or expansion.[169]

A new *State Environmental Planning Policy (Environment)* has been proposed and draft has been subject to public consultation by DPE. The intent of the proposal is to consolidate a number of existing SEPPs, and to retain but clarify the requirement for a proposed SSD to have a neutral or beneficial effect on water quality under the current *SEPP (Sydney Drinking Water Catchment) (DPE, 2017f)*.

A number of agencies have legislative and policy roles in water accounting and management (Table A2.4). A Water Access Licence (WAL) is required to access available water to ensure the appropriate management of limited water resources.[170] Under the *Water Management Act 2000*, the Minister for Regional Water, with concurrence from the Minister for the Environment, develops Water Sharing Plans covering particular water sources.[171] These plans define how water is to be allocated from a particular water source for a 10 year period.[172] In accordance with Water Sharing Plans and the Aquifer Interference Policy, a WAL entitles the holder to passive and consumptive take in a share of the available water in a particular water source consistent with the licence shares or water allocations. The WAL includes an 'extraction component' which defines: times, rates and circumstances when water can be taken; type of water source from which the water can be taken, for example surface water or groundwater; and whether water can be taken from the whole water source or only from within a specified management zone. Specific conditions also apply based on the applicable Water Sharing Plan.

The *Water Management Act 2000* clarifies that a WAL must be held whenever a person takes water in the course of, or in connection with, a current or past mining activity.[173] This includes where "water is removed or diverted from a water source (whether or not water is returned to that water source) or water is re-located from one part of an aquifer to another part of an aquifer."[174] However, under the *Water Management (General) Regulation 2011*, the requirement for a WAL or controlled activity approval is exempt for mining activities which take up to 3 megalitres in any water year.[175]

For SSDs, WALs are issued by the Department of Industry, Division of Lands and Water (DoI Water).[176] In most cases, licence shares or water allocations for each licence must be purchased from the water market, however the right to apply for new WALs to unassigned

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[167] *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011*, cl 3(b)
[168] *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011*, cl 11A(3)
[169] *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011*, cl 11A(2)
[170] *Water Management Act 2000* Part 3
[171] *Water Management Act 2000* s 41
[172] *Water Management Act 2000* s 43(1)
[173] *Water Management Act 2000* s 60I.
[174] *Water Management Act 2000* s 60I(2)
[175] *Water Management (General) Regulation 2011* Sch 4 cl 7.
[176] (NSW DoI, 2018): Note that Water Access Licences for rural landholders, rural industries, or developments which are not state significant developments or state significant infrastructure are issued by WaterNSW.

water can be provided through a controlled allocation order.[177] Controlled allocation orders are subject to a competitive process, for example in accordance with the Department of Primary Industries' *Strategy for the controlled allocation of groundwater* (May 2017) (DPI, 2017). The Natural Resources Access Regulator (NRAR) is the independent regulatory body responsible for the ensuring compliance with the conditions of WALs.

The *Water Management Act 2000* also anticipates that a proponent is required to obtain an aquifer interference approval where their activities would involve:

> "(a) the penetration of an aquifer,
>
> (b) the interference with water in an aquifer,
>
> (c) the obstruction of the flow of water in an aquifer,
>
> (d) the taking of water from an aquifer in the course of carrying out mining, or any other activity prescribed by the regulations,
>
> (e) the disposal of water taken from an aquifer as referred to in paragraph (d)."[178]

However, the enforcement provisions of the *Water Management Act 2000* which require these approvals have not been activated, as a proclamation has not been issued stating that these provisions apply to the State or relevant water sources.[179]

Although aquifer interference approvals are not required at present, the NSW Aquifer Interference Policy (AIP) applies to support the assessment and advice provided by the Minister for Primary industries or DOI Water, to a gateway panel (at the gateway stage), or to DPE or the IPC (at the planning and assessment phase).[180] This advice informs both the development of the SEARs and the assessment of the proponent's EIS.

The AIP specifies minimal impact considerations which are to be considered when the Minister for Primary Industries and DOI Water assesses and provides advice regarding the impact of the proposed development on groundwater sources. These considerations relate to impacts on groundwater sources, connected water sources, and their dependent ecosystems, culturally significant sites and water users.[181] Minimal impact considerations are defined in the AIP for multiple categories of groundwater sources including highly productive alluvial, coastal sands, porous rock and fractured rock groundwater sources; and less productive alluvial, porous rock and fractured rock groundwater sources. [182]

Where a development's predicted impacts are greater than certain thresholds (specified in the AIP), but exceed the thresholds by no more than the accuracy of an otherwise robust model, then the project will be considered as having acceptable impacts, and the advice will include a request that appropriate conditions be imposed to ensure that the impacts are acceptable. Where the predicted impacts are greater than certain thresholds (specified in the AIP), then the assessment will involve additional studies to fully assess these predicted impacts. If this assessment shows that the predicted impacts do not prevent the long-term viability of the groundwater source, then the impacts will be considered acceptable.[183]

WaterNSW is responsible for ensuring that the catchments and controlled areas are protected, and that the quality of water in catchment and controlled areas are protected and enhanced.[184] These protected areas create a buffer zone from human activity to reduce the risks from contamination and protect Sydney's drinking water. Certain activities associated with mining developments, which are otherwise prohibited under the *Water NSW Regulation 2013* within the Special and Controlled Areas managed by WaterNSW, require the written

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[177] *Water Management Act 2000* s 65
[178] *Water Management Act 2000*, Dictionary.
[179] *Water Management Act 2000* ss 88A and 91F.
[180] *NSW Aquifer Interference Policy 2012*, p.11
[181] *NSW Aquifer Interference Policy 2012*, p.12
[182] *NSW Aquifer Interference Policy 2012*, p.13-14
[183] *NSW Aquifer Interference Policy 2012*, p.13
[184] *Water NSW Regulation 2013*, cl 5

consent of WaterNSW.[185] WaterNSW also advises regulatory authorities of the potential impacts of existing and proposed mining activities on stored water, water supply infrastructure and the catchment.

Table A2.4: Overview of major NSW agency water-related roles

Department of Industry	WaterNSW[1]	Natural Resource Access Regulator[2]	Environment Protection Agency	Office of Environment and Heritage	NSW Health
Legislative and policy frameworks managing surface water and groundwater, including exercise of functions under the *Water Management Act 2000* and *Water Act 1912*	Management of water infrastructure, supply and delivery under the *WaterNSW Act 2014* and some functions *Water Management Act 2000* and *Water Act 1912*	Ensure effective, efficient, transparent, accountable compliance and enforcement of natural resources management law; exercises functions under the *Water Management Act 2000*	Pollution prevention, monitoring and compliance functions under the *Protection of the Environment Operations Act* 1997	Manage NSW environmental water holdings, including through annual water plans, research, monitoring, evaluation and managing water trading	Protect human health, including through standard-setting and response protocols for water quality, the drinking water database and *Public Health Act 2010*
State-Commonwealth agreements and regional water security strategies, water sharing plans, trade in water	Protection of water in catchment areas, development of catchment health indicators, evaluate and report on 3-yearly catchment audits	Advice relating to administration of natural resources management legislation	Protection of water quality, including impacts of pollution discharge and downstream impact of extraction and subsidence on other users and water characteristics		Protection through monitoring drinking water quality, public and environmental health programs and quality and audit requirements of drinking water suppliers
Water licences for government, utilities, major developments, mining, floodplain harvesting	Water licences for rural landholders and industries and non-SSDs	Compliance and enforcement powers	Environmental Protection Licenses, compliance and enforcement powers	Threatened Species Licenses, compliance and enforcement powers	Compliance and enforcement powers

1. The establishment of WaterNSW under the *Water NSW Act 2014* combined the functions previously exercised by the Sydney Catchment Authority and the NSW State Water Corporation.
2. Established under the *Natural Resources Access Regulator Act 2017*

A2.2.5.2 Environment Protection Licences

Environment Protection Licences are issued by the NSW Environment Protection Authority (EPA) under Chapter 3 of the *Protection of Environment Operations Act 1997* (POEO Act) for activities specified in Schedule 1 of the Act, including major coal mining activities.[186] Conditions of EPLs generally include monitoring requirements, administrative conditions and limit conditions on the nature and scale of pollution of water and air, certification of compliance with conditions, mandatory environmental audit program, reporting and recording requirements. Pollution Studies or Reduction programs may be required under an EPL. There is also a duty to report incidents causing or threatening material harm to the environment as set out in Part 5.7 of the POEO Act.[187] EPLs remain in force until

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[185] *Water NSW Regulation 2013*, Pt 3
[186] *Protection of Environment Operations Act 1997*, Sch 1, cl 28
[187] Section 147(1) of the POEO Act defines 'Material harm to the environment' as harm to the environment that "(i) …involves actual or potential harm to the health or safety of human beings or to ecosystems that is not trivial, or (ii) … results in actual or potential loss or property damage of an amount, or amounts in aggregate, exceeding $10,000 (or such other amount as is prescribed by the regulations)" where "loss includes the reasonable costs and expenses that would be incurred in taking all reasonable and practicable measures to prevent, mitigate or make good harm to the environment".

suspended, revoked or surrendered and must be reviewed by the EPA at least every five years.[188]

A2.2.5.3 Commonwealth Government approval: Matters of national environmental significance

Mining developments impacting matters of national environmental significance (MNES) require approval from the Commonwealth Minister for the Environment under the EPBC Act. The definition of MNES includes a water resource, in relation to large coal mining development that has, will, or is likely to have a significant impact on that water resource.[189] The Commonwealth Department of the Environment and Energy has released guidelines to assist a determination of whether a proposed large coal mining development will have a significant impact on the water resource.[190]

The 2015 bilateral agreement between NSW and the Commonwealth Government accredits assessments undertaken under Part 4 of the EP&A Act for assessing impacts on MNES.[191] At the completion of the environmental assessment, NSW provides the Commonwealth with a report assessing the likely impacts of the project on matters of national environmental significance.[192] The Commonwealth Minister for the Environment makes the decision on project approval and conditions as they relate to the EPBC Act.

A2.2.5.4 Dams Safety Committee

The Dam Safety Committee (DSC) has the responsibility for protecting the security of prescribed dams and their stored waters including from the effects of mining activities.[193] The DSC defines Notification Areas around prescribed dams near which mining may occur.[194] The DSC also provides recommendations to the Secretary of DPE and the Minister for Resources regarding the proposed mining lease, and may object to the grant of a proposed mining lease or propose that specified conditions relating the safety of a prescribed dam be incorporated into the proposed mining lease.[195] Generally, mining leases granted within Notification Areas include conditions which require the leaseholder to apply for special permission to mine within the Notification Area at least 12 months prior to mining.[196]

A2.2.6 Management Plans and Offsets

A2.2.6.1 Extraction Plans (Subsidence Management Plans)

Development Consents, Mining Leases and other statutory approvals are issued with conditions governing operational activities in and around a proposed mine or extension, and with conditions governing acceptable environmental and social impacts of those activities. It is a standard condition of both the Development Consent and the Mining Lease that the

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[188] *Protection of Environment Operations Act 1997* ss 77(1) and 78(1)

[189] *Environment Protection and Biodiversity Conservation Act 1999* (Cth), s 24D. Note that 'large coal mining development' is defined under s 528 of the Environment Protection and Biodiversity Conservation Act 1999 (Cth) as "any coal mining activity that has, or is likely to have, a significant impact on water resources (including any impacts of associated salt production and/or salinity): (a) in its own right; or (b) when considered with other developments, whether past, present or reasonably foreseeable developments."

[190] Department of the Environment (2013) Significant impact guidelines 1.3: Coal seam gas and large coal mining developments— impacts on water resources (Department of the Environment, 2013)

[191] Bilateral agreement made under section 45 of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) relating to environmental assessment, Commonwealth of Australia and The State of New South Wales (February 2015) (Department of the Environment, 2015) , cl 4.1 and Sch 1, cl 2.

[192] Bilateral agreement made under section 45 of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) relating to environmental assessment, Commonwealth of Australia and The State of New South Wales (February 2015) (Department of the Environment, 2015), p 3

[193] See, e.g., *Mining Act 1992* ss 80 and 91, Sch 1

[194] *Dams Safety Act 1978* s 14; see also *Dams Safety Act 2015* s 48; see also *Mining Act 1992* s 89

[195] *Mining Act 1992* s 91(2); the DSC has other statutory functions under the *Dams Safety Act 1978* including surveillance (s 14(a)), examination and investigation (s 14(b)), and reporting (ss 14(e)-(f)) of the safety of prescribed dams; conducting inquiries into the safety of prescribed dams (ss 19-20); giving notices to ensure the safety of prescribed dams (s 18); and State of Emergency powers (ss 21-23).

[196] Dams Safety Committee, Mining near prescribed dams administrative procedures, (Published: June 2010, Updated: August 2015) (NSW Dams Safety Committee, 2015)

applicant submits an Extraction Plan (which replaced the former Subsidence Management Plan (SMP) process from July 2014).

Extraction Plans define how the expected subsidence impacts of the mine will be monitored and managed to satisfy the conditions of the Development Consent. Subsidence is defined in various mine approvals and under legislative instruments (Table A2.5).

Table A2.5: Definitions of subsidence in legislative instruments

Instrument	Reference	Provision
Coal Mine Subsidence Compensation Act 2017 No 37	Part 1 Preliminary Definitions	S 4(1) subsidence means subsidence due to the extraction of coal, and includes all vibrations or other movements of the ground related to any such extraction (whether or not the movements result in actual subsidence), but does not include vibrations or other movements of the ground that are due to blasting operations in an open cut mine and that do not result in actual subsidence.
Work Health and Safety (Mines and Petroleum Sites) Regulation 2014	Part 1 Preliminary Definitions	Cl 3(1) subsidence means the deformation or displacement of any part of the ground surface or subsurface strata caused by the extraction of mineral

Subsidence impacts focus on environmental impacts, but also refer to health and safety impacts. Extraction Plans summarise the intended mining activities, including mining method and schedule, and the expected economic impact of the mine on the state and local community. Conditions of Development Consent require the proponent to prepare an Extraction Plan to the satisfaction of the Secretary DPE or delegate in consultation with relevant agencies (e.g. EPA, Office of Environment and Heritage (OEH), WaterNSW, Department of Industry, NRAR, and DSC). Once approved, it is a condition of both the Development Consent and Mining Lease that the proponent implements the Extraction Plan.

A2.2.6.2 Rehabilitation Management Plans

Development Consents and Mining Leases are issued with conditions requiring rehabilitation of land or water disturbed by mining activities where such disturbances cannot be avoided or minimised. Proponents are required to develop and implement a Rehabilitation Management Plan (RMP, otherwise addressed by the requirement to implement a Mining Operations Plan under the Mining Lease). The preparation of an RMP to the satisfaction of the Secretary DPE is a condition of the Development Consent and Mining Lease. Current practice in regulating rehabilitation includes requirements that the rehabilitation of land and water occurs progressively (during and post-mining operations); ensures a safe and stable environment; maintains or improves on its pre-mine condition; and ensures it is fit for approved future final land uses (for example agriculture, tourism, ecological sites) (DPE, 2017a).

Rehabilitation activities typically include removal of infrastructure, geotechnical stabilisation, remediation of contaminated land, revegetation and landscaping. To ensure compliance with the RMP and rehabilitation obligations under project approvals, DPE retains a security deposit to be fully released only upon complete satisfaction of the rehabilitation obligations. Where there is non-compliance, this deposit may be used to cover cost of the residual rehabilitation activities incurred by the NSW government.[197]

A2.2.6.3 Additional Management Plans

Development Consent conditions generally include requirements to prepare additional management plans that define how specific environmental conditions will be monitored and

[197] The calculation of the security deposit is informed by the *Rehabilitation Cost Estimation Guidelines* and Tool updated in 2017 including changes to the cost schedule and calculation methodology. In November 2017 DPE also released a discussion paper, *Improving Mine Rehabilitation in NSW* (DPE, 2017a) seeking feedback on proposed improvements to the regulatory framework for rehabilitation of major mining projects.

managed, to the satisfaction of the Secretary DPE (or other relevant decision maker).[198] These plans are mine-specific, require consultation with relevant agencies and relate to:

- water or watercourse impacts, to manage the environmental consequences of the mining operations on watercourses, aquifers and catchment yield
- swamp impacts, to manage the environmental consequences of the mining operations of swamp condition and function
- biodiversity, terrestrial flora and fauna and ecology, to manage the potential environmental consequences of the mining operations on flora, fauna, and swamps
- landscape, to manage the potential environmental consequences of the mining operations on land features including cliffs and steep slopes
- Aboriginal and other cultural heritage, to manage the potential environmental consequences of the mining operations on heritage sites or values
- built features, to manage the potential environmental consequences of the mining operations on any built features including electrical, communications and other infrastructure
- public safety, to ensure public safety in the mining area.

Extraction Plans and other management plans are generally subject to condition of the consent requiring them to be regularly updated based on experience gained as mining progresses and to incorporate any recommended measures to improve the environmental performance of the development.[199] These updates would be triggered by submission of modifications to the project approval, independent environmental audits, incident reports or annual reviews submitted as a condition of the development consent. [200]

A.2.2.6.4 Environmental and Biodiversity Offsets

Offsets are designed to provide a compensatory mechanism for the negative environmental or biodiversity impacts of development at one site, which cannot be avoided or minimised further, to be offset by positive activities at another site with the goal of maintaining and enhancing overall conservation outcomes. Both state and Commonwealth statutes and policy frameworks are predicated on efforts being first made to avoid and mitigate impacts.

The NSW *Biodiversity Offset Scheme* is a new statutory framework under the *Biodiversity Conservation Act 2016*. The Scheme provides for a mechanism to offset impacts from developments that are likely to have a significant impact on biodiversity. The Scheme requires proponents to retain an accredited assessor to apply the Biodiversity Assessment Method (BAM) to the proposal. The BAM defines a method for assessing biodiversity impacts of a proposed development, guidance on actions to avoid or minimise biodiversity impacts; and a method for calculating the residual obligation which needs to be offset to ensure 'no net loss' of biodiversity.[201] The residual obligation is specifically defined to reflect the ecosystem and species impacts, and must be offset by biodiversity credits which represent equivalent biodiversity stewardship sites, or in some cases, other biodiversity conservation actions or mine site rehabilitation. The outcome of this assessment is a Biodiversity Development Assessment Report (BDAR) that is submitted to the consent authority. The consent authority considers the likely impact of the proposed development on biodiversity values as assessed in the BDAR;[202] whether the proposal will have a 'serious

[198] Note that these management plans may be separate or a part of the Extraction Plan.
[199] Dendrobium development consent (p22) and Metropolitan development consent (p19)
[200] Dendrobium development consent (p22) and Metropolitan development consent (p19)
[201] Office of Environment and Heritage (2017) Biodiversity Assessment Method. See generally, *Biodiversity Conservation Act 2016* Pt 6 Div 2.
[202] *Biodiversity Conservation Act 2016* s 7.14(2).

and irreversible impact';[203] and what biodiversity credit obligation must be retired before the development (or the relevant potion of the development residual biodiversity impacts) can proceed.[204]

The BAM is supplemented by the *Addendum to NSW Biodiversity Offsets Policy for Major Projects: Upland swamps impacted by longwall mining subsidence* ('Uplands Swamp Policy') which was in place prior to the commencement of the *Biodiversity Conservation Act 2016*.[205] The Uplands Swamp Policy extends the BAM (and the offsets framework under the former policy) specifically for the calculation and determination of biodiversity offsets for subsidence impacts of longwall coal mining on upland swamps and associated threatened species. The Uplands Swamp Policy specifies that offsets are not required for predicted negligible environmental consequences; offsets are required for where greater than negligible environmental consequences are predicted; and outcomes will be monitored during and following mining, guided by a standing independent expert panel which will determine if actual impacts are greater than those predicted and additional offsets are required.

Similarly, Environmental offsets are specifically provided for under Commonwealth legislation and policy for controlled actions affecting MNES.[206] The Commonwealth *Environmental Offsets Policy* states that "*avoidance and mitigation are the primary strategies for managing adverse impacts,"* and that *"offsets will not be considered until all reasonable avoidance and mitigation measures are considered*".[207] Under the 2015 bilateral agreement between NSW and the Commonwealth Government, these can be assessed under Part 4 of the EP&A Act and are included in the conditions of the Development Consent.[208]

The *NSW Biodiversity Offsets Policy for Major Projects* commenced in 2014 and is only relevant for savings and transitional arrangements for major projects under the former legislation and policy while the *Biodiversity Offsets Scheme* under the *Biodiversity Conservation Act 2016* is implemented.[209] Under transitional arrangements, the *NSW Biodiversity Offsets Policy for Major Projects* applies to development applications for mining projects that had submitted a conceptual project development plan to the Division of Resources & Geoscience, DPE, prior to 25 August 2017; or if substantial environmental assessment was undertaken prior to 25 August 2017;[210] or if SEARs were issued prior to 25 August 2017.[211] The Policy requires that adverse environmental impacts must first be avoided and "unavoidable impacts minimised through mitigation measures" before offsets are considered to compensate for any residual impacts.[212] The mandated activities are to be delivered in an efficient and timely matter; deliver benefits proportionate to the adverse

[203] *Biodiversity Conservation Act 2016* s 7.16(2)-(4). Note that for SSD consent may still be granted even if serious and irreversible impacts of the proposed development on biodiversity values would remain after measures proposed to be taken to avoid or minimise those impacts.

[204] *Biodiversity Conservation Act 2016* s 7.14(4): A condition to retire biodiversity credits is required to be complied with before any development is carried out that would impact on biodiversity values. If the retirement of particular biodiversity credits applies to a stage of the development, compliance with the condition for their retirement is postponed until it is proposed to carry out that stage of the development.

[205] Office of Environment and Heritage (2016), Addendum to NSW Biodiversity Offsets Policy for Major Projects: Upland swamps impacted by longwall mining subsidence. See also, Office of Environment and Heritage (2017) Biodiversity Assessment Method.

[206] *Environment Protection and Biodiversity Conservation Act 1999* (Cth), Pt 14; and Department of Environment and Energy, Environment Protection and Biodiversity Conservation Act 1999 Environmental Offsets Policy (October 2012)

[207] Commonwealth of Australia, Environment Protection and Biodiversity Conservation Act 1999 Environmental Offsets Policy, (October 2012) (Department of Sustainability Environment Water Population and Communities, 2012)

[208] Commonwealth of Australia and The State of New South Wales (2015) Bilateral agreement made under section 45 of the Environment Protection and Biodiversity Conservation Act 1999 (Cth) relating to environmental assessment (Department of the Environment, 2015)

[209] The *NSW Biodiversity Offsets Policy for Major Projects* and the *Framework for Biodiversity Assessment* (FBA) applies to projects with SEARs issued up to August 2017. Only projects with SEARs issued from August 2017 will be subject to the new Biodiversity Offset Scheme under the *Biodiversity Conservation Act 2016*. Former legislation includes the *Threatened Species Conservation Act 1995* and the *Biodiversity Conservation Act 1999*.

[210] And, where the application is made within 18 months of the Secretary's determination of that environmental assessment.

[211] And, where the application is made before 25 February 2019.

[212] Office of Environment and Heritage for the NSW Government, NSW Biodiversity Offsets Policy for Major Projects (September 2014) (Office of Environment and Heritage, 2014)

environmental impacts; and be transparent and scientifically robust, to ensure public accountability.

A2.2.7 Regulatory oversight and reporting

Conditions of development consent and other approvals and licences for underground coal mining include obligations to report on specific activities or at specified times. Under the development consent and EPL, standard reporting obligations include:

- An **Annual Review** (or Annual Environmental Management Report) submitted each year to the Secretary DPE and other relevant agencies reviewing the environmental performance of the development. This report is to encompass past and planned development (and rehabilitation activities); monitoring results from the previous year, including comparison against statutory and consent requirements and performance measures; the previous year's results and predicted results; non-compliance and responses; compliance with consent performance measures, criteria and operating conditions; discrepancies between the predicted and actual impacts of the development, including causes; and future plans to improve the environmental performance of the development.
- An **Independent Environmental Audit** is required every three years. The audit must be conducted by qualified, independent experts whose appointment has been endorsed by the Secretary DPE. The audit must include consultation with relevant agencies; assess the environmental performance of the development and whether it is complying with conditions in the consent, mining lease, EPL or other required plans; review the adequacy of management plans; and recommend measures or actions to improve the environmental performance of the development and any management plan.
- An **End of Panel Report**, submitted after the completion of each longwall panel, to DPE, DRG, WaterNSW, OEH, DOI Water and any other relevant agencies. The report must: describe subsidence effects, impacts and environmental consequences for the longwall panel and compare this with predictions; and describe the environmental consequences for ecological and environmental features, including swamps and groundwater.
- An **Annual Return**, submitted each year to the EPA. The Annual Return comprises a Statement of Compliance attesting to compliance with the conditions of the EPL and details of any non-compliance; a Monitoring and Complaints Summary describing the number and type of complaints received, and a summary of results of mandated environmental monitoring.
- Event-specific reporting obligations, including the contemporaneous reporting of incidents that harm the environment, their causes, and ongoing and planned actions in response to the incident.
- Regular reporting obligations, for example the requirement under s 66(6) of the POEO Act, for a holder of and EPL to provide environmental monitoring data to the general public within 14 days of that data being obtained.

Other statutory reporting obligations also exist, for example the duty under s 148 of the POEO Act for a person carrying on an activity to notify relevant regulatory authorities of pollution incidents that causes or threatens material harm to the environment.

Other regulatory oversight is undertaken through audits, and targeted compliance and enforcement activities under statutory powers for breaches of licences and approvals. Depending on the relevant authorisation, action can be taken by DPE, EPA, WaterNSW, DOI Water, NRAR, OEH and DSC. Where multiple agencies have enforcement powers over potential non-compliance, these agencies may liaise to determine the most appropriate agency to conduct compliance and enforcement activities in each instance.

A2.2.8 Modifications to approved developments

Development consents may be modified by the consent authority (DPE or IPC depending on the circumstances) on an application made by the holder of the mine consent or lease or other authorised person.[213] The consent authority may modify the consent where the modification is of minimal environmental impact; it is substantially the same development as under the original consent; it has consulted and made relevant notifications about the application in accordance with the regulations and considered any submissions made concerning the proposed modification.[214]

Where a modification is not of minimal environmental impact, the consent may still be modified by the consent authority provided that it is substantially the same development as under the original consent; the consent authority has consulted with approval bodies to the original consent in respect of conditions of the consent and those bodies have not objected to the modification; it has made relevant notifications in accordance with the regulations; and has considered any submission made concerning the proposed modification, the standard development application assessment criteria[215] and the reasons given for the grant of the original consent.[216]

[213] *Environmental Planning and Assessment Act 1979* s 4.55, *Mining Act 1992* s 380AA.
[214] *Environmental Planning and Assessment Act 1979* s 4.55(1A)
[215] See, e.g., *Environmental Planning and Assessment Act 1979* s 4.15
[216] *Environmental Planning and Assessment Act 1979* s 4.55(3)

A2.2 CONSOLIDATED CONSENT CONDITIONS, DENDROBIUM AND METROPOLITAN MINES

Note: The tables summarise consent conditions DA 60-03-2001 MOD 8 and 08_0149 MOD 3

Table A2.6: Subsidence conditions of approval

Focus	Dendrobium Mine DA 60-03-2001 MOD 8	Metropolitan Mine 08_0149 MOD 3
General	The reasons for the imposition of the conditions are to: (i) minimise the adverse impact the development may cause through water and air pollution, noise, vegetation and visual disturbance and subsidence effects; provide for environmental monitoring, reporting and independent review; and (iii) set requirements for mine infrastructure provision.	These conditions are required to: prevent, minimise, and/or offset adverse environmental impacts; set standards and performance measures for acceptable environmental performance; require regular monitoring and reporting; and provide for the ongoing environmental management of the project.
Definitions	**Subsidence or subsidence effects:** Deformation of the ground mass due to mining, including all mining-induced ground movements, including both vertical and horizontal displacement, tilt, strain and curvature. **Subsidence impacts:** Physical changes to the ground and its surface caused by Subsidence Effects, including tensile and shear cracking of the rock mass, localised buckling of strata caused by valley closure and upsidence and surface depressions or troughs. **Environmental consequences:** Environmental consequences of Subsidence Impacts, including 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 on aquatic ecology, ponding, etc.	**Subsidence:** The totality of subsidence effects, subsidence impacts and environmental consequences of subsidence impacts **Subsidence effects:** Deformation of the ground mass due to mining, including all mining-induced ground movements, including both vertical and horizontal displacement, tilt, strain and curvature. **Subsidence impacts:** Physical changes to the ground and its surface caused by Subsidence Effects, including tensile and shear cracking of the rock mass, localised buckling of strata caused by valley closure and upsidence and surface depressions or troughs. **Environmental consequences:** The environmental consequences of subsidence impacts, including: damage to infrastructure, buildings and residential dwellings; 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 on aquatic ecology; ponding. **Adaptive management:** Adaptive management includes monitoring subsidence impacts and subsidence effects and, based on the results, modifying the mining plan as mining proceeds to ensure that the effects, impacts and/or associated environmental consequences remain within predicted and designated ranges.
Schedule 3 Specific Environmental Conditions – Mining Area		
Subsidence • 11 conditions highlighting requirements for plans and reports including: o Watercourse, Impact Monitoring, Management and Contingency Plan o Swamp Impact Monitoring, Management and Contingency Plan o Subsidence Management Plans o End of Panel Reports within 4 months of completion o Payment of DPE costs in engaging experts when assessing SMPs • **Condition 2** The Applicant must ensure that underground mining operations do not cause subsidence impacts at Sandy Creek and Wongawilli Creek other than “minor impacts” (such as minor fracturing, gas release, iron staining and minor impacts on		• **Condition 1** The proponent shall ensure that the project does not cause any exceedances of the ‘Subsidence Impact Performance Measures’ in Table 1 (p.5). • **Condition 3** If the subsidence effects and subsidence impacts of the project exceed the relevant predictions by more than 15% at any time after mining has progressed beyond the halfway mark of Longwall 21, or if the profile of vertical displacement does not reflect predictions, then the Proponent shall use appropriate numerical modelling to supplement the subsequent predictions of subsidence effects and subsidence impacts for the project to the satisfaction of the Director-General.

water flows, water levels and water quality) to the satisfaction of the Secretary.

- **Condition 3** The Applicant must ensure the development does not result in reduction (other than negligible reduction) in the quality or quantity of surface water or groundwater inflows to Lake Cordeaux or Lake Avon or surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek, to the satisfaction of the Secretary.
- **Condition 5** The Applicant must ensure that subsidence does not cause erosion of the surface or changes in ecosystem functionality of Swamp 15a and that the structural integrity of its controlling rockbar is maintained or restored, to the satisfaction of the Secretary.
- **Condition 7** Prior to carrying out any mining operations that could cause subsidence in Areas 3A, 3B or 3C, an SMP must be prepared, approved and satisfactorily implemented and must include monitoring of subsidence effects; include a WaterNSW Assets Protection Plan; include monitoring, management, and contingency plans for all other significant natural features and all significant man-made features which may be impacted by subsidence, including landscape; groundwater; terrestrial flora and fauna and ecology; Aboriginal and other cultural heritage and other infrastructure.
- **Condition 8** SMPs for Areas 3B and 3C must include a detailed subsidence impact assessment, setting out all predicted subsidence effects, impacts and environmental consequences; a minimum of 2 years of baseline data, collected at appropriate frequency and scale, for all significant natural features; identify and assess the significance of all natural features located within 600 m of the edge of secondary extraction; distinguish between, clearly describe and adequately quantify all subsidence effects, impacts and environmental consequences; propose limits on subsidence impacts and environmental consequences to be applied within the relevant Area.

- **Condition 4** The Proponent shall not undermine Swamps 76, 77 and 92 without the written approval of the Director-General. In seeking this approval, the Proponent shall submit a comprehensive environmental assessment of the potential subsidence impacts and environmental consequences of the proposed Extraction Plan (EP):
  - a comprehensive environmental assessment of the:
    - potential subsidence impacts and environmental consequences of the proposed Extraction Plan;
    - potential risks of adverse environmental consequences; and
    - options for managing these risks;
  - a description of the proposed performance measures and indicators for these swamps; and
  - a description of the measures that would be implemented to manage the potential environmental consequences of the Extraction Plan on these swamps (to be included in the Biodiversity Management Plan - see condition 6(f) below), and comply with the proposed performance measures and indicators.
- **Condition 6** Prior to undertaking second workings in the mining area, the Applicant must submit an EP that includes:
  - a detailed plan for the second workings, which has been prepared to the satisfaction of DRE, and provides for adaptive management (from Longwall 23 onwards);
  - detailed plans of any associated surface construction works;
  - the following to the satisfaction of DRE:
    - a coal resource recovery plan that demonstrates effective recovery of the available resource;
    - revised predictions of the conventional and non-conventional subsidence effects and subsidence impacts of the extraction plan, incorporating any relevant information that has been obtained since this approval; and
    - a Subsidence Monitoring Program to:
      - validate the subsidence predictions; and
      - analyse the relationship between the subsidence effects and subsidence impacts of the Extraction Plan and any ensuing environmental consequences;
  - include a:
    - Water Management Plan, which has been prepared in consultation with OEH, SCA (now WaterNSW) and NOW (now DPI Water), to manage the environmental consequences of the Extraction Plan on watercourses (including the Woronora Reservoir), aquifers and catchment yield;
    - Biodiversity Management Plan, which has been prepared in

	consultation with OEH and DRE (Fisheries) (now DPI), to manage the potential environmental consequences of the Extraction Plan on aquatic and terrestrial flora and fauna, with a specific focus on swamps; – Land Management Plan, which has been prepared in consultation with SCA, to manage the potential environmental consequences of the Extraction Plan on cliffs, overhangs, steep slopes and land in general; – Heritage Management Plan, which has been prepared in consultation with OEH and the relevant Aboriginal groups, to manage the potential environmental consequences of the Extraction Plan on heritage sites or values; – Built Features Management Plan, which has been prepared in consultation with the owner of the relevant feature , to manage the potential environmental consequences of the Extraction Plan on any built features; and o include a Public Safety Management Plan, which has been prepared in consultation with DRE and the DSC (for any mining within the DSC notification area), to ensure public safety in the mining area. **Condition 7** In addition to the standard requirements for management plans (see condition 2 of schedule 7), the Proponent shall ensure that the management plans required under condition 6(f) above include: o a program to collect sufficient baseline data for future Extraction Plans; o a revised assessment of the potential environmental consequences of the Extraction Plan, incorporating any relevant information that has been obtained since this approval; o a detailed description of the measures that would be implemented to remediate predicted impacts; and o a contingency plan that expressly provides for adaptive management. • **Condition 9** The Proponent shall prepare an implement a Research Program for the project and allocate $320,000 towards the implementation of the program. It must be directed at encouraging research into improving the: o the prediction of valley closure and upsidence, and the resultant subsidence impacts; o the assessment of the environmental consequences of subsidence impacts on natural features; o the remediation of subsidence impacts on watercourses; o the understanding of subsidence impacts and their environmental consequences on swamps; o the conservation of the Eastern Ground Parrot on the Woronora Plateau; o the environmental management of underground mining operations in the Southern Coalfield.

Table A2.7: Monitoring conditions of approval

<table>
<tr><th>Dendrobium Mine DA 60-03-2001 MOD 8</th><th>Metropolitan Mine 08_0149 MOD 3</th></tr>
<tr><td colspan="2">General</td></tr>
<tr><td>A condition of the Consent is to provide for environmental monitoring, reporting and independent review.</td><td>A condition of the Consent is to require regular monitoring and reporting.</td></tr>
<tr><td colspan="2">Schedule 2– Administrative Conditions</td></tr>
<tr><td>• Condition 8 With the approval of the Secretary, the Applicant may submit any management plan or monitoring program required by this consent on a progressive basis.
• Condition 9 The Applicant must ensure that monitoring programs, management plans and the Environmental Management Strategy, as in existence at the date of modification of consent in November 2008, continue to be implemented (to the satisfaction of the Secretary) until replaced by monitoring programs and management plans approved in accordance with the conditions of this consent.</td><td></td></tr>
<tr><td colspan="2">Schedule 3 – Specific Environmental Conditions – Mining Area</td></tr>
<tr><td>• Condition 4 Prior to carrying out any underground mining operations that could cause subsidence (in 3A, 3B or 3C) the applicant must prepare a Watercourse Impact Monitoring, Management and Contingency Plan, with
○ a monitoring program and reporting mechanisms for close and ongoing review of subsidence effects and impacts
○ a general monitoring and reporting program addressing surface water levels, water flows, water quality, surface slope and gradient, erodibility, aquatic flora and fauna and ecosystem function.
• Condition 6 Prior to carrying out any underground mining operations that could cause subsidence in either Area 3A, Area 3B or Area 3C, the Applicant must prepare a Swamp Impact Monitoring, Management and Contingency Plan to the satisfaction of the Secretary. See table Appendix 3 – Table 1 for inclusions.
• Condition 7 Prior to carrying out any underground mining operations that could cause subsidence in either Area 3A, 3B or 3C, the Applicant must prepare a Subsidence Management Plan (SMP) to the satisfaction of the Secretary and the DRG. Each SMP must:
○ integrate the Watercourse and Swamp Impact Monitoring, Management and Contingency Plans required under conditions 4 and 6;
○ include monitoring of subsidence effects;
○ include monitoring, management, and contingency plans for all other significant natural features and all significant man-made features which may be impacted by subsidence, including landscape; groundwater; terrestrial flora and fauna and ecology; Aboriginal and other cultural heritage; electrical, communications and other infrastructure- and be approved prior to the carrying out of any underground mining operations and be implemented to the satisfaction of the Secretary and the DRG.</td><td>• Condition 2 The Proponent shall prepare and implement a comprehensive Catchment Monitoring Program for the project to the satisfaction of the Director-General. This program must include:
○ detailed baseline data of the existing surface and groundwater resources in the project area;
○ a program for the ongoing development and use of appropriate surface and groundwater models for the project; and
○ a program to monitor and assess any impacts of the project on the quantity and quality of surface and ground water resources in the project area, and in particular the catchment yield to the Woronora Reservoir.
• Condition 6 The Proponent shall prepare and implement an Extraction Plan for all second workings in the mining area, including a Subsidence Monitoring Program to validate the subsidence predictions and analyse relationships between subsidence impacts and effects.</td></tr>
</table>

• **Condition 13** The SMPs prepared under Groundwater monitoring program including ○ detailed baseline data to benchmark the natural variation in groundwater levels, yield and quality ○ a program to monitor the impact of the development on groundwater levels, yield and quality (particularly any potential loss of flow to, or flow from, WaterNSW water storages) coal seam aquifers and overlying aquifers; and groundwater springs and seeps.	
Schedule 4 Specific Environmental Conditions - Surface Facilities	**Schedule 4 Specific Environmental Conditions - General**
• The Consent lists the noise impact criteria that must be met and a requirement to implement a Noise Monitoring Program with quarterly updates. • The consent lists criteria that must be met and a requirement for an Air Quality Monitoring Program. The Applicant must ensure that it has a suitable meteorological station in the vicinity of the site in accordance with Approved Methods for Sampling of Air Pollutants in New South Wales. **Water Management** • **Condition 12** The Applicant must ensure all surface water discharges from the surface facilities meet the relevant ANZECC water quality objectives for the protection of aquatic ecosystems and water quality of existing receiving waters; and comply with the discharge limits (volume and quality) in any EPL. • **Condition 13 - 17** The Applicant must prepare and implement a Water Management Plan for the surface facilities to the satisfaction of the Secretary including a: ○ *Site Water Balance (14)* ○ *Erosion and Sediment Control Plan (15)* - identified activities that could cause soil erosion and generate sediment; describe measures to minimise soil erosion and transport of sediment to downstream waters; the location, function, and capacity of erosion and sediment control structures; and measures that would be implemented to monitor and maintain the structures over time. ○ *Surface Water Monitoring Program (16)* - baseline data on surface water flows and quality in streams and other waterbodies that have been or could be affected by the surface facilities; surface water quality and stream health assessment criteria, including trigger levels for investigating any potentially adverse surface water impacts; a program to monitor the impact of the surface facilities on surface water flows and quality, stream health and channel stability; procedures for reporting the results of this monitoring. ○ *Ground Water Response Plan (17)* – describing what measures and/or procedures would be implemented to respond to any exceedances of the surface water, stream health, and groundwater assessment criteria; and mitigate and/or offset any adverse impacts on groundwater dependent ecosystems, aquatic ecosystems or riparian vegetation. • **Condition 30** The Applicant must monitor the amount of waste generated by the development.	**Conditions 1 – 13** Specific to monitoring, the Proponent must: ○ monitor amount of coal and coal reject transported from the site annually and report results on its website 6 monthly ○ include real time monitoring within the Noise Management Plan and Air Quality & Greenhouse Gas Management Plan ○ monitor the amount of coal and coal reject transported from the site by road and rail each year, and report the results of this monitoring on its website every six months. • **Condition 14** The Proponent shall ensure that all surface water discharges from the site comply with the discharge limits (both volume and quality) set for the project in any EPL. • **Condition 15** The Proponent shall prepare and implement a Water Management Plan for the surface facilities area and two ventilation shaft sites to the satisfaction of the Director-General (Secretary). This plan must be prepared in consultation with NOW and OEH by a suitably qualified expert/ whose appointment has been endorsed by the Director-General, and submitted to the Director-General for approval by the end of June 2010. In addition to the standard requirements for management plans (see condition 2 of schedule 7), this plan must: ○ include a comprehensive water balance for the project; and ○ ensure that suitable measures are implemented to minimise water use, control erosion, prevent groundwater contamination, and comply with any surface water discharge limits.

Schedule 5 Specific Environmental Conditions – Other site components	Schedule 5 Additional Procedures for Air Quality and Noise Management
• **Condition 3** The Applicant must monitor the amount of coal washery reject emplaced in the West Cliff Coal Wash Emplacement; investigate ways to reduce emplacement of coal washery reject at West Cliff, including beneficial use or improved disposal options; and report on these matters in the West Cliff Annual Environmental Management Report. • **Condition 5** The Applicant must review its water quality monitoring program for the West Cliff Mine in consultation with DECC and DOI and to the satisfaction of the Secretary.	• **Condition 3** The Secretary can request an independent review of the project to monitor the land and determine compliance against impact assessment criteria if a landowner considers the project to be exceeding assessment criteria in Schedule 4.
Schedule 8 Environmental Management, Monitoring, Auditing and Reporting	**Schedule 7 Environmental Management, Reporting and Auditing**
• **Condition 1** Requirement to prepare and implement an Environmental Monitoring Program that describes how the environmental performance of the development would be monitored and managed for the mining area; surface facilities; other site components; and extended site. It should reference any strategies, plans and programs approved under conditions of the consent, with a clear plan depicting all the monitoring to be carried out under the consent. • **Condition 2** Management Plans must include ○ a summary of relevant background or baseline data; ○ details of the relevant statutory requirements (including any relevant approval, licence or lease conditions); any relevant limits or performance measures and criteria; and ○ the specific performance indicators that are proposed to be used to judge the performance of, or guide the implementation of, the development or any management measures; ○ a description of the measures to be implemented to comply with the relevant statutory requirements, limits, or performance measures and criteria; ○ a program to monitor and report on the impacts and environmental performance of the development; and effectiveness of the management measures set out pursuant to condition 2(c); ○ a contingency plan to manage any unpredicted impacts and their consequences and to ensure that ongoing impacts reduce to levels below relevant impact assessment criteria as quickly as possible; ○ a program to investigate and implement ways to improve the environmental performance of the development over time; ○ a protocol for managing and reporting any incident and any non-compliance (specifically including any exceedance of the impact assessment criteria and performance criteria); complaint; failure to comply with statutory requirements; ○ a protocol for periodic review of the plan. • **Condition 2A** Within three months of submitting the incident report, Annual Review, Independent Environmental Audit and modification of the conditions of the consent, existing strategies, plans and programs under the consent must be reviewed. **Condition 5** The Annual Review must describe the development (including any	• **Condition 1** The Proponent shall prepare and implement an Environmental Strategy that describes: ○ the role, responsibility, authority and accountability of all key personnel involved in the environmental management of the project; ○ the procedures that would be implemented to: ○ keep the local community and relevant agencies informed about the operation and environmental performance of the project; ○ receive, handle, respond to, and record complaints; ○ resolve any disputes that may arise during the course of the project; ○ respond to any non-compliance; and ○ respond to emergencies; and includes: – copies of the various strategies, plans and programs that are required under the conditions of this approval once they have been approved; and – a clear plan depicting all the monitoring currently being carried out within the project area. • **Condition 2** The proponent shall ensure that the management plans required under this approval are prepared in accordance with any relevant guidelines and include: ○ detailed baseline data and a description of: – the relevant statutory requirements; any relevant limits or performance measures/criteria; the specific performance indicators that are used to judge the performance of, or guide the implementation of, the project or any management measures; ○ a description of the measures that would be implemented to comply with the relevant statutory requirements, limits, or performance measures/criteria; ○ a program to monitor and report on the: – impacts and environmental performance of the project;

rehabilitation) that was carried out in the previous financial year or that is proposed (including any rehabilitation) over the current financial year; must include a comprehensive review of the monitoring results and complaints records of the development over the previous financial year; identify any trends in the monitoring data over the life of the development; identify any discrepancies between the predicted and actual impacts of the development, and analyse the potential cause of any significant discrepancies.

Condition 8 Any condition of the consent that requires the carrying out of monitoring or an environmental audit whether directly or by way of a plan, strategy or program, is taken to be a condition requiring monitoring or an environmental audit under Division 9.4 of Part 9 of the EP&A Act. This includes conditions in respect of incident notification, reporting and response, non-compliance notification, compliance report and independent audit. *Monitoring" is monitoring of the development to provide data on compliance with the consent or on the environmental impact of the development, and an "environmental audit" is a periodic or particular documented evaluation of the development to provide information on compliance with the consent or the environmental management or impact of the development.*

- **Condition 11**Before beginning Modification 8 and until the completion of all rehabilitation required under the consent, the Applicant must make the following information and documents publicly available on its website, and keep information up to date:
  - the documents referred to in condition 2 of Schedule 2 of this consent;
  - all current statutory approvals for the development;
  - all approved strategies, plans and programs required under the conditions of this consent;
  - minutes of Community Consultative Committee meetings;
  - regular reporting on the environmental performance of the development in accordance with the reporting requirements in any plans or programs approved under the conditions of this consent;
  - a comprehensive summary of the monitoring results of the development, reported in accordance with the specifications in any conditions of this consent, or any approved plans and programs;
  - a summary of the current stage and progress of the development;
  - contact details to enquire about the development or to make a complaint;
  - a complaints register, updated monthly;
  - the Annual Reviews of the development;
  - audit reports prepared as part of any Independent Environmental Audit of the development and the Applicant's response to the recommendations in any audit report;
  - any other matter required by the Secretary

    - effectiveness of any management measures (see c above);
  - a contingency plan to manage any unpredicted impacts and their consequences;
  - a program to investigate and implement ways to improve the environmental performance of the project over time;
  - a protocol for managing and reporting any:
    - incidents;
    - complaints;
    - non-compliances with statutory requirements; and
    - exceedances of the impact assessment criteria and/or performance criteria; and
  - a protocol for periodic review of the plan.
- **Condition 3** By the end of March each year, the Proponent shall review the environmental performance of the project that
  - describe the works that were carried out in the past calendar year, and the works that are proposed to be carried out over the current calendar year;
  - include a comprehensive review of the monitoring results and complaints records of the project over the past calendar year, which includes a comparison of these results against the
    - the relevant statutory requirements, limits or performance measures/criteria;
    - the monitoring results of previous years; and
    - the relevant predictions in the Environmental Assessment, Preferred Project Report and Extraction Plan;
  - identify any non-compliance over the last year, and describe what actions were (or are being) taken to ensure compliance;
  - include a review of the monitoring results over the year and compared against previous years and trends over the life of the project, and identify any trends in the monitoring data over the life of the project.
- **Condition 8** By end of December 2011, and every 3 years thereafter, unless the Director-General directs otherwise, the Proponent shall commission and pay the full cost of an Independent Environmental Audit of the project. This audit must:
  - be conducted by suitably qualified, experienced and independent team of experts whose appointment has been endorsed by the Director-General;
  - include consultation with the relevant agencies;
  - assess the environmental performance of the project and assess whether it is complying with the relevant requirements in this approval and any relevant EPL or Mining Lease (including any assessment, plan or program required under these approvals);

	○ review the adequacy of strategies, plans or programs required under these approvals; and, if appropriate; and ○ recommend measures or actions to improve the environmental performance of the project, and/or any assessment, plan or program required under these approvals. • **Condition 10** From the end of 2009, the Proponent shall make the following information publically available on its website, a summary of the monitoring results of the project (in accordance with various plans and programs in the consent should be publically available on its website.
Appendix 4 Statement of commitments • **Condition 2** Pre, during and post mining Subsidence Impact Monitoring will be undertaken in accordance with the approved Subsidence Management Plan. The monitoring component of the Subsidence Management Plan includes but is not necessarily limited to Subsidence movement of natural and man-made features; Surface waters; Groundwater; Terrestrial flora and fauna; Aquatic flora and fauna; Aboriginal cultural heritage sites and Swamps. • **Condition 7** Illawarra coal is required to monitor and report greenhouse gas emissions from Dendrobium Mine in accordance with the National *Greenhouse and Energy Reporting Act 2007* in the Annual Review.	

Table A2.8: Modelling conditions of approval

Dendrobium Mine DA 60-03-2001 MOD 8	Metropolitan Mine 08_0149 MOD 3
Schedule 3 Specific Environmental Conditions – Mining Area	
• **Condition 13** The SMPs prepared under condition 7 must include a Groundwater Monitoring Program, which must include: ○ proposals to develop a detailed regional and local groundwater model, with special reference to flows to and from nearby water storages; ○ detailed baseline data to benchmark the natural variation in groundwater levels, yield and quality; ○ groundwater impact assessment criteria; ○ a program to monitor the impact of the development on: – groundwater levels, yield and quality (particularly any potential loss of flow to, or flow from, WaterNSW water storages); – coal seam aquifers and overlying aquifers; and – groundwater springs and seeps; and ○ consideration of the requirements of the latest version (or subsequent replacement) of WaterNSW's *The Design of a Hydrological and Hydrogeological Monitoring Program to Access the Impacts of Longwall Mining in SCA Catchment*.	• **Condition 2** The Proponent shall prepare and implement a comprehensive Catchment Monitoring Program for the project to the satisfaction of the Director-General. This program must include: ○ detailed baseline data of the existing surface and groundwater resources in the project area; ○ a program for the ongoing development and use of appropriate surface and groundwater models for the project; and ○ a program to: – monitor and assess any impacts of the project on the quantity and quality of surface and ground water resources in the project area, and in particular the catchment yield to the Woronora Reservoir; and – validate and calibrate the surface and groundwater models. • **Condition 3** If the subsidence effects and subsidence impacts of the project exceed the relevant predictions by more than 15% at any time after mining has progressed beyond the halfway mark of Longwall 21, or if the profile of vertical displacement does not reflect predictions, then the Proponent shall

	use appropriate numerical modelling to supplement the subsequent predictions of subsidence effects and subsidence impacts for the project to the satisfaction of the Director-General.

Table A2.9: Cumulative impact conditions of approval

Dendrobium Mine DA- 60-03-2001 MOD 8	**Metropolitan Mine 08_0149 MOD 3**
Schedule 3 Specific Environmental Conditions – Mining Area	
• **Condition 4b** Prior to carrying out any underground mining operations that could cause subsidence in either Area 3A, Area 3B or Area 3C, the Applicant must prepare a Watercourse Impact Monitoring, Management and Contingency Plan that includes a monitoring program and reporting mechanisms to enable close and ongoing review by the Department and DRG of the subsidence effects and impacts (individual and cumulative) on Wongawilli Creek, Sandy Creek and Sandy Creek Waterfall. • **Condition 6b** the Applicant must prepare a Swamp Impact Monitoring, Management and Contingency Plan to the satisfaction of the Secretary. Each such Plan must include a monitoring program and reporting mechanisms to enable close and ongoing review by the Department and DRG of the subsidence effects and impacts (individual and cumulative) of each Area 3A longwall on Swamp 15a. • **Condition 9a** the Applicant must prepare an end-of-panel report, reporting all subsidence effects (both individual and cumulative) for the panel and comparing subsidence effects with predictions; describing in detail all subsidence impacts (both individual and cumulative) for the panel.	N/A
Schedule 8 Environmental Management, Monitoring, Auditing and Reporting	
Condition 1 the Applicant must prepare and implement an Environmental Management Strategy that describes the procedures that would be implemented to manage cumulative impacts.	N/A

Table A2.10: Reporting conditions of approval

Dendrobium Mine	**Frequency / Due**	**Metropolitan Mine**	**Frequency / Due**
Schedule 2 (Dendrobium) Strategic Biodiversity Offsets			
Condition 15 Strategic Biodiversity Offset	When required		
Schedule 3 Specific Environmental Conditions - Mining			
Conditions 1 to 4 Watercourse Impact, Monitoring, Management and Contingency Plan	**Condition 4g** incorporate means of updating the plan based on experience gained as mining progresses	**Condition 2** Catchment Monitoring Program	Ongoing[1]

Conditions 5 to 6 Swamp Impact, Monitoring, Management and Contingency Plan	**Condition 6g** incorporate means of updating the plan based on experience gained as mining progresses	**Conditions 6 to 8** Extraction Plan To include: • Coal Resource Recovery Plan • Subsidence Monitoring Program • Water Management Plan • Biodiversity Management Plan • Land Management Plan • Heritage management Plan • Built Features Management Plan • Public Safety Management Plan	**Condition 6c** states: include a detailed plan for second workings, which has been prepared to the satisfaction of the DRE (now DPE), and provides for adaptive management (from Longwall 23 onwards)
Conditions 7 to 8 Subsidence Management Plan To include: • WaterNSW Assets Protection Plan • Monitoring, management and contingency plans for all other significant natural and man-made features including landscape, groundwater, terrestrial flora, fauna and ecology, Aboriginal and other cultural heritage etc.	Prior to carrying out any underground mining operations that could cause subsidence in either Area 3A, 3B or 3C.		
Conditions 9 to 10 End of Panel Reporting	Within 4 months of completion of each longwall		
Condition 12 Aboriginal Heritage Plan	Same as SMP conditions above		
Condition 13 Groundwater Monitoring Program	Same as SMP conditions above		
Schedule 6 Rehabilitation & Offsets			
N/A	-	Rehabilitation Management Plan	Ongoing[1]
Schedule 8 - Environmental Management, Monitoring, Auditing and Reporting		**Schedule 7 - Environmental Management, Reporting and Auditing**	
Condition 1 Environmental Management Strategy	Ongoing[2]	**Condition 1** Environmental Management Strategy	Ongoing[1]
Condition 5 Annual Environmental Management Report	Yearly	**Condition 3** Annual Review	Yearly
Condition 3 to 4 Incident Reporting	Within 21 days	**Condition 6** Incident Reporting	Within 7 days
Conditions 6 to 8 Independent Environmental Audit	Every 3 years	**Conditions 8 to 9** Independent Environmental Audit	Every 3 years

[1] Condition 4 of Schedule 7 of the Metropolitan Development Consent MOD 3 states that the Proponent shall review and revise strategies/plans/programs within 3 months of the submission of an audit (Condition 8), incident report (Condition 6), Annual Review (Condition 3) or modification to the project approval.
[2] Condition 2A of Schedule 8 of the Dendrobium Mine Development Consent MOD 8 states that the Applicant shall review the suitability of existing strategies, plans and programs required under this consent within 3 months of the submission of an incident report (Condition 4), Annual Review (Condition 5), independent expert audit (Condition 6) or approval of any modification of the conditions of this consent.

Table A2.11: Rehabilitation conditions of consent

<table>
<tr><th>Dendrobium Mine DA 60-03-2001 MOD 8</th><th>Metropolitan Mine 08_0149 MOD 3</th></tr>
<tr><td colspan="2">Definition</td></tr>
<tr><td>N/A</td><td>The treatment or management of land disturbed by the project for the purpose of establishing a safe, stable and non-polluting environment.</td></tr>
<tr><td colspan="2">Obligation to Minimise Harm to the Environment</td></tr>
<tr><td colspan="2">Schedule 2 Administrative Conditions</td></tr>
<tr><td>Condition 1 The Applicant must implement all reasonable and feasible measures to prevent and/or minimise any harm to the environment that may result from the construction, operation, or rehabilitation of the development.</td><td>Condition 1 The Proponent shall implement all reasonable and feasible measures to prevent and/or minimise any harm to the environment that may result from the construction, operation, or rehabilitation of the project.</td></tr>
<tr><td colspan="2">Objectives/requirements</td></tr>
<tr><td>Appendix 3 West Cliff Stage 3 Coal Wash Emplacement Statement of Commitments</td><td>Schedule 6 Rehabilitation and Offsets</td></tr>
<tr><td>Rehabilitation
Pre-translocation actions
o Identify clearing compartments
o Timing of vegetation clearing
o Collection and storage of seed
o Identification and preparation of recipient sites
Soil salvage and handling
o Vegetation clearing and stockpiling
o Stripping of soil in relevant horizons
o Soil and rock stockpiling
Soil replacement
o Respreading soil horizons
o Redistribution of rocks, logs, cleared/stockpiled vegetation and habitat features on recipient sites
o Sediment and erosion control
Revegetation supplementary to soil translocation
o Direct seeding of previously collected seed
o Weed control (where necessary)

The Broad headed Snake Management Plan will be implemented in three key stages including:
o Relocation of Broad headed snakes during the pre-clearing period, preferably during the winter season;
o Progressive two-stage clearing and habitat translocation;
o Monitoring and maintenance during the post-clearing period

Water
The Brennans Creek diversion channel will be rehabilitated to incorporate; riffles, pools, bedslope, channel roughness, floodplain pockets and riparian vegetation that</td><td>Rehabilitation and Offsets
Condition 1 The Proponent shall achieve the rehabilitation objectives in Table 11 to the satisfaction of the Executive Director Mineral Resources.

Table 11 Rehabilitation Objectives
<table>
<tr><th>Domain</th><th>Rehabilitation</th></tr>
<tr><td>Surface facilities area</td><td>Set through conditions 2 below</td></tr>
<tr><td>Waratah Rivulet, between the downstream edge of Flat Rock Swamp and the full supply level of the Woronora Reservoir
Eastern Tributary, between the maingate of Longwall 26 and the full supply level of the Woronora Reservoir</td><td>Restore surface flow and pool holding capacity as soon as reasonably practicable</td></tr>
<tr><td>Cliffs</td><td>Ensure that there is no safety hazard beyond that existing prior to mining</td></tr>
<tr><td>Other land affected by the project</td><td>Restore ecosystem function, including maintaining or establishing self-sustaining native ecosystems: ¡ comprised of local native plant species; with r a landform consistent with the surrounding environment</td></tr>
<tr><td>Built features</td><td>Repair/restore to pre-mining conditions or equivalent</td></tr>
<tr><td>Community</td><td>Minimise the adverse socio-economic effects associated with</td></tr>
</table></td></tr>
</table>

approximate as close as possible the characteristics of Brennans Creek.	(nested table) | | mine closure including the reduction in local and regional employment Ensure public safety | • **Condition 2** By the end of October 2011, the Proponent shall prepare a Rehabilitation Strategy for the surface facilities area to the satisfaction of the Director-General. This strategy must: o be prepared by a team suitably qualified and experienced experts whose appointment has been endorsed by the Director-General; o be prepared in consultation with relevant stakeholders, including Wollongong City Council and the Community Consultative Committee o investigate options for the future use of the area upon the completion of mining; o describe and justify the proposed rehabilitation strategy for the area; and o define the rehabilitation objectives for the area, as well as the proposed completion criteria for this rehabilitation. • **Condition 3** To the extent that mining operations permit, the Proponent shall carry out rehabilitation progressively, that is, as soon as reasonably practicable following the disturbance. • **Condition 4** The Proponent shall prepare and implement a Rehabilitation Management Plan for the project to the satisfaction of the Executive Director Mineral Resources. This plan must be prepared in consultation with the relevant stakeholders, and submitted to DRE (now DPE) for approval prior to carrying out any second workings in the mining area. *Note: In accordance with condition 12 of Schedule 2, the preparation and implementation of Rehabilitation Management Plans are likely to be staged, with each plan covering a defined area (or domain) for rehabilitation. In addition, while mining operations are being carried out, some of the proposed remediation or rehabilitation, measures may be included in the detailed management plans that form part of the Extraction Plan. If this is the case, however, then the Proponent will be required to ensure that there is good cross-referencing between the various management plans.*
Costs	
Schedule 2 Administrative Conditions	
Condition 14 The Applicant must be responsible for the costs of all management measures (including	

measures to minimise, mitigate, offset or remediate impacts of the development which are not recoverable by a third party through the *Coal Mine Subsidence Compensation Act 2017* or the *Mining Act 1992*) including but not limited to remediation of natural features, *rehabilitation of ecological systems*, the provision of supplementary waters and monitoring of the effectiveness of the works, as determined by the Secretary.	
Management and management plans	
Schedule 4 Specific Environmental Conditions – Surface Facilities	**Schedule 6 Rehabilitation & Offsets**
Rehabilitation Management Plan The Applicant must rehabilitate the surface facilities sites to the satisfaction of DRG. • **Condition 20** The Rehabilitation Management Plan must include: o the rehabilitation objectives for the surface facilities sites; o a general description of the short, medium and long term measures that would be implemented to rehabilitate these sites; o performance and completion criteria for the rehabilitation of these sites; o a description of how the performance of the rehabilitation works would be monitored over time to achieve the stated objectives and against the relevant performance and completion criteria; o any measures necessary to ensure that abandoned mine workings do not impact on stored waters or dams; and o details of who is responsible for monitoring, reviewing and implementing the plan. **Condition 22A** The Applicant must undertake photographic archival recording of significant built and landscape elements affected by Modification 8 prior to the commencement, during the works and after the completion of works, in accordance with the NSW Heritage Division publications. **Condition 22B** If unexpected archaeological artefacts are uncovered during ground disturbing works, the Applicant must ensure work ceases in the subject area and a suitably trained archaeologist should attend the site to inspect the find. If material identified has heritage significance, the Applicant must obtain any necessary further approvals before works can proceed.	• **Condition 4** The Proponent shall prepare and implement a Rehabilitation Management Plan for the project to the satisfaction of the Executive Director Mineral Resources. This plan must be prepared in consultation with the relevant stakeholders, and submitted to DRE (now DPE) for approval prior to carrying out any second workings in the mining area. *Note: In accordance with condition 12 of Schedule 2, the preparation and implementation of Rehabilitation Management Plans are likely to be staged, with each plan covering a defined area (or domain) for rehabilitation. In addition, while mining operations are being carried out, some of the proposed remediation or rehabilitation, measures may be included in the detailed management plans that form part of the Extraction Plan. If this is the case, however, then the Proponent will be required to ensure that there is good cross-referencing between the various management plans.*
Landscape management and management plan	
Schedule 4 Specific Environmental Conditions – Surface Facilities	
• **Condition 18** The Applicant must rehabilitate the surface facilities sites to the satisfaction of DRG. For rehabilitation works within the Metropolitan Special Area, the Applicant must also ensure that these works are carried out to the satisfaction of WaterNSW. • **Condition 19** The Applicant must prepare and implement a Landscape Management Plan for the surface facilities to the satisfaction of the Secretary and the DRG. This plan must:	

○ be submitted for approval by 30 April 2009; ○ be prepared by suitably qualified expert/s whose appointment/s have been endorsed by the Secretary; ○ be prepared in consultation with OEH and WaterNSW; and ○ include a: – Rehabilitation Management Plan; and – Mine Closure Plan.	
Brennan Creek Diversion Bypass Rehabilitation Plan	
Condition 6 Brennans Creek Diversion Bypass Rehabilitation Plan - The Applicant must, by 30 June 2009, develop a Brennans Creek Diversion Bypass Rehabilitation Plan in consultation with OEH, DOI and DRG and to the satisfaction of the Secretary.	
Measures of success	
Appendix 3 West Cliff Stage 3 Coal Wash Emplacement Statement of Commitments	
Success of Emplacement Area Rehabilitation (Zone 1) **Performance target** • Adequate regeneration of translocated communities, Exposed Sandstone Scribbly Gum Woodland and Sandstone Gully Peppermint Forest. Regeneration to reflect composition and structure of the two communities. • Condition; no more than 20 per cent weed cover in translocated compartments after 2 years. • 15 per cent accepted plant losses over 2 years. Additional losses to be replaced by tubestock. • 50 per cent vegetative cover of compartments achieved after 2 years. • The degree to which fauna, threatened or otherwise, use the rehabilitated emplacement area including constructed habitats and nest boxes. **Proposed Monitoring Methods** • Permanent photographic points within translocated compartments. • Monitoring vegetation quadrats in translocated patches measuring species richness, structure and composition, condition, death rates and replacement requirements, growth rates of key indicator species. • Control sites to be set up in remnants. • Random meanders for threatened flora that may have regenerated from translocation. • Site assessments. Condition of bushland mapping. • An assessment of areas regenerated per unit effort. A comparison of the environmental outcome to the type and size of the input. • Soil testing (materials characterisation where revegetation fails). • A BHP staff member qualified and experienced in natural area restoration to project manage monitoring	N/A

Table A2.12: Offsets conditions of consent

Dendrobium Mine DA 60-03-2001 MOD 8	Metropolitan Mine DA 08_0149 MOD 3
	The conditions of the consent are required to: prevent, minimise and/or offset adverse environmental impacts.
Schedule 2 Administrative Conditions • **Condition 15** If the Applicant is required to provide a biodiversity offset pursuant to this consent (including any biodiversity offset that is required under the conditions of a subordinate approval issued in accordance with this consent), the Secretary, in consultation with OEH, may accept in satisfaction of the requirement for the biodiversity offset, the provision of land that has conservation values which exceed the conservation values required to meet the relevant offsetting requirement. If the Secretary accepts such an offset under this condition, the Secretary shall issue a written statement to the Applicant advising: o the details of the proposed offset land; o the offset requirements that are being met; o the conservation values that have been relied upon to meet the offsetting requirements; and o that in the opinion of the Secretary: o the land has offsetting values in addition to those that have been relied upon to meet the offsetting requirement in condition 15(b); or o if the land has been subject to a previous statement from the Secretary under this condition, confirmation that the land continues to have conservation values in addition to those that have been relied upon to meet the previous offsetting requirement, or that there are no further conservation values available in respect of the land. If the Secretary has issued a statement under this condition, the Applicant can rely on that statement and the residual conservation values that the land subject to the statement may hold, to meet further offsetting requirement(s) that may be required under this consent or the project approval for the Bulli Seam Operations Project (08_0150). The Secretary's statement under this condition can be relied on a number of times in respect of the same land until all of the conservation values of the land the subject of the Secretary's statement have been relied upon to meet offsetting requirements under this consent or the approval for the Bulli Seam Operations Project (08_0150). The Applicant must make suitable arrangements to provide appropriate long-term security for the biodiversity offset area(s) accepted under this condition, within 2 years of the date of the Secretary's statement in respect of that land,	**Schedule 6 Rehabilitation & Offsets** • **Condition 5** The Proponent shall: o pay SCA (now WaterNSW) $100,000 by the end of 2011 to carry out catchment improvement works within the Woronora catchment area; or o carry out catchment improvement works within this area that have an equivalent value to the satisfaction of SCA. • **Condition 6** If the Proponent exceeds the performance measures in Table 1 of this approval, and either o the contingency measures implemented by the Proponent have failed to remediate the impact; or o the Director-General determines that it is not reasonable or feasible to remediate the impact, then the Proponent shall provide a suitable offset to compensate for the impact to the satisfaction of the Director-General. *Note: Any offsets required under this condition must be proportionate with the significance of the impact.*

<table>
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<td>
unless otherwise agreed with the Secretary.

Schedule 3 Specific Environmental Conditions – Mining Area

Condition 14 The Applicant must provide suitable offsets for loss of water quality or loss of water flows to WaterNSW storages, clearing and other ground disturbance (including cliff falls) caused by its mining operations and/or surface activities within the mining area, unless otherwise addressed by the conditions of this consent, to the satisfaction of the Secretary. These offsets must:

be submitted to the Secretary for approval by 30 April 2009;
be prepared in consultation with WaterNSW;
provide measures that result in a beneficial effect on water quality, water quantity, aquatic ecosystems and/or ecological integrity of WaterNSW's special areas or water catchments.

Schedule 4 Specific Environmental Conditions – Surface Facilities

Condition 17 The Surface and Ground Water Response Plan must describe what measures and/or procedures would be implemented to:

respond to any exceedances of the surface water, stream health, and groundwater assessment criteria; and
mitigate and/or offset any adverse impacts on groundwater dependent ecosystems, aquatic ecosystems or riparian vegetation.

Appendix 4 Statement of Commitments
Condition 5 Illawarra Coal will negotiate an offset with the WaterNSW to account for the small and unquantifiable water quality impact resultant from the proposal.
</td>
<td></td>
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</table>

Table A2.13: Performance measures conditions of consent

<table>
<tr>
<th>Dendrobium Mine DA 60-03-2001 MOD 8</th>
<th>Metropolitan Mine DA 08_0149 MOD 3</th>
</tr>
<tr>
<td>N/A</td>
<td>These conditions are required to set standards and performance measures for acceptable environmental performance.</td>
</tr>
<tr>
<td>
Schedule 4 Specific Environmental Conditions – Surface Facilities

Condition 21 The Mine Closure Plan must describe how the performance of these measures would be monitored over time.

Schedule 6 Specific Environmental Conditions – Extended Site

Condition 1 The Applicant must prepare and implement a Greenhouse and Energy Efficiency Plan for the development. This plan must include a program to monitor, and a framework, for investigating greenhouse gas emissions and energy use generated; include a research program and describe how the performance of the measures would be monitored over time.

</td>
<td>
Schedule 3 Specific Environmental Conditions – Mining

Condition 1 The Proponent shall ensure that the project does not cause any exceedances of the performance measures in Table 1.

Table 1: Subsidence Impact Performance Measures
<table>
<tr><th colspan="2">Water Resources</th></tr>
<tr>
<td>Catchment yield to the Woronora Reservoir</td>
<td>Negligible reduction to the quality or quantity of water resources reaching the Woronora Reservoir
No connective cracking between the surface and the mine</td>
</tr>
</table>
</td>
</tr>
</table>

Schedule 8 Environmental Management, Monitoring, Auditing and Reporting

- **Condition 5** By the end of September each year (or other such timing as may be agreed by the Secretary), and for at least 3 years following the cessation of mining at the development, the Applicant must submit an Annual Review to the Secretary, Community Consultative Committee and all relevant agencies reviewing the environmental performance of the development to the satisfaction of the Secretary. This report must relate to the previous financial year and:
    - identify the standards and performance measures that apply to the development;
    - identify any non-compliance or incident which occurred in the previous financial year, and describe what actions were (or are being) taken to rectify the non-compliance and avoid reoccurrence.

- **Condition 6** By 31 December 2011, and every 3 years thereafter, unless the Secretary directs otherwise, the Applicant must commission and pay the full cost of an Independent Environmental Audit of the development. This audit must recommend measures or actions to improve the environmental performance of the development, and/or any strategy, plan or program required under these approvals.

Appendix 3

The Vegetation and Fauna Management Plan will be implemented to achieve the following performance indicators and targets.

Performance Target	Proposed Monitoring Methods
Weed management	
• Zone 1; Low levels of weed infestation in soil translocation compartments. • Zone 2; A reduction in weed cover of perennial exotic grasses on disturbed edges. • Zone 3; Weed free condition maintained. • Eradication of noxious and serious environmental weeds from the colliery. Focus particularly on Cortaderia selloana and Juncus acutus.	• Control methods used and justification • Species treated and rates of herbicide application • Weed density/condition of bushland mapping • Inspections targeting noxious weeds
Success of Emplacement Area Rehabilitation (Zone1)	
• Adequate regeneration of translocated communities, Exposed Sandstone Scribbly Gum Woodland and Sandstone Gully Peppermint Forest. Regeneration	• Permanent photographic points within translocated compartments. • Monitoring vegetation quadrats in translocated patches measuring species

Woronora Reservoir	Negligible leakage from the Woronora Reservoir Negligible reduction in the water quality of Woronora Reservoir
Watercourses	
Waratah Rivulet between the full supply level of the Woronora Reservoir and the maingate of Longwall 23 (upstream of Pool P).	Negligible environmental consequences (that is, no diversion of flows, no change in the natural drainage behaviour of pools, minimal iron staining, and minimal gas releases)
Eastern Tributary between the full supply level of the Woronora Reservoir and the maingate of Longwall 26	Negligible environmental consequences over at least 70% of the stream length (that is no diversion of flows, no change in the natural drainage behaviour of pools, minimal iron stamina and minimal gas releases}
Biodiversity	
Threatened species, populations, or ecological communities	Negligible impact
Swamps 76 77 and 92	Set through condition 4 below
Land	
Cliffs	Less than 3% of the total length of cliffs (and associated overhangs) within the mining area experience mining-induced rock fall
Heritage	
Aboriginal heritage sites	Less than 10% of Aboriginal heritage sites within the mining area are affected by subsidence impacts
Items of historical or heritage significance at the Garrawarra Centre	Negligible damage (that is fine or hairline cracks that do not require repair), unless the owner of the item and the appropriate heritage authority agree otherwise in writing
Built Features	
Built features	Safe, serviceable and repairable, unless the owner agrees otherwise in writing

- **Condition 4** The Proponent shall not undermine Swamps 76, 77 and 92 without the written approval of the Director-General. In seeking this approval, the Proponent shall submit a description of the proposed performance measures and indicators for these swamps with the relevant Extraction Plan.

to reflect composition and structure of the two communities. • Condition; no more than 20 per cent weed cover in translocated compartments after 2 years. • 15 per cent accepted plant losses over 2 years. Additional losses to be replaced by tubestock. • 50 per cent vegetative cover of compartments achieved after 2 years. • The degree to which fauna, threatened or otherwise, use the rehabilitated emplacement area including constructed habitats and nest boxes.	richness, structure and composition, condition, death rates and replacement requirements, growth rates of key indicator species. • Control sites to be set up in remnants. • Random meanders for threatened flora that may have regenerated from translocation. • Site assessments. Condition of bushland mapping. • An assessment of areas regenerated per unit effort. A comparison of the environmental outcome to the type and size of the input. • Soil testing (materials characterisation where revegetation fails). • A BHP staff member qualified and experienced in natural area restoration to project manage monitoring system.
Site stabilisation	
• Success of translocation as per the above targets. • Stabilisation of sediment and erosion control measures.	Regular self audit and inspections including photographs of structures and the Emplacement benching, especially post storm flows.
Protection of Threatened Flora	
Loss of threatened plants (Persoonia hirsuta, Acacia bynoeana and Pultenaea aristata) restricted to those identified in area described by Figure 1.	• Inspections of on-site exclusion zones to ensure protection of remnant populations. • Inspections and assessment of translocated Persoonia hirsuta (if required)
Protection of Threatened Fauna Habitats	
No additional losses or loss of potential habitat outside the area described by Figure 1.	Annual habitat level surveys.
Phytophthora infection	
• Prevention of the introduction of Phytophthora • Identification of Phytophthora infection • If detected, development and implementation of a Phytophthora infection control plan	Annual soil sampling in vegetation within proximity to on site traffic (track, drainage and roadside edges) and areas of previous disturbance. Further sampling from areas in the stage 3 footprint pre-construction and

	post construction will be undertaken if detected.
Bushfire	
• The entire West Cliff mine lease currently operates under a fire exclusion policy. This policy will continue. • Boundary and internal fire trails and other suppression advantages will be maintained. • A hot work permit system will be maintained on the site. • The Rural Fire Service will be offered regular orientations of the lease site. • West Cliff Colliery is not subject to a hazard reduction burn regime and hazard reduction burns are not planned for the site. Any future bushfire management will consider fire regimes that are appropriate to ecological requirements of the site. Any proposed hazard reduction activities will only be undertaken in consultation with all relevant stakeholders.	Reporting by exception on the extent and intensity of unplanned bushfire.
Reporting	
Annual Report to be supplied to regulatory authorities addressing outcomes of the project to date in relation to the above performance targets.	• Reporting of project to regulatory authorities. • Annual review of monitoring system and management methods. • Adjustments made to systems and methods as required. • Pro-formats.

APPENDIX 3: SITE VISITS, BRIEFINGS AND SUBMISSIONS

Table A3.1: Site Visits

Date	Location	Present
20/02/2018	• Sandy Creek Tributary SC10C • Water Course WC21 • Swamp Den01b • Swamp Den14	**Panel members:** Emeritus Professor Jim Galvin Dr Ann Young Professor Neil McIntyre Mr Michael Williams (morning only) Dr Christopher Armstrong **WaterNSW:** Ms Fiona Smith, Executive Manager Water and Catchment Protection (morning only) Mr Malcolm Hughes, Manager Catchment Protection Mr Peter Dupen, Manager Mining (morning only) Mr Kel Lambkin, Senior Catchment Officer (morning only) Ms Amanda Ryan, Catchment Field Officer (morning only) **South32 Illawarra Coal:** (afternoon only, Den14 and Den01b site visit) Mr Gary Brassington, Principal Approvals Mr Kai Whitaker, Illawarra Coal Field Team **Secretariat:** Dr Suzanne Pierce Dr Jaclyn Aldenhoven
26/03/2018	Waratah Rivulet, specifically • Flat Rock Swamp • Pool A and rockbar WRS3 • Pool F and rockbar WRS4 • Flat Rock Crossing at Fire Road 9H and Eastern Tributary Crossing at Fire Road 9J	**Panel members:** Emeritus Professor Jim Galvin Dr Ann Young Professor Neil McIntyre Professor Bruce Hebblewhite Dr Christopher Armstrong **WaterNSW:** Mr Peter Dupen, Mining Manager **Peabody Energy Metropolitan Coal:** Mr Jon Degotardi, Technical Services Manager Mr Stephen Love, Environment & Community Superintendent Mr Andy Hyslop, General Manager Mr Peter Baker, SVP Underground Operations Mr Micheal Alexander, Director Projects & Portfolio Management NSW Ms Suzanne Cryle, Manager Community Relations **Resource Strategies:** Ms Stacey Gromadzki, Senior Environmental Manager **Secretariat:** Dr Suzanne Pierce Dr Jaclyn Aldenhoven
31/08/2018	• Reservoir below full supply level of Eastern Tributary • All pools from ETO to ETAU (upstream to Eastern Tributary) • Pool ETF • Swamp 50 • Catchment K Gauge Station	**Panel members:** Emeritus Professor Jim Galvin Dr Ann Young Professor Neil McIntyre **WaterNSW:** Mr Malcolm Hughes, Manager Catchment Protection

		Peabody Energy, Metropolitan Coal: Mr Jon Degotardi, Manager Technical Services Mr Stephen Love, Environment & Community Superintendent Mr Andy Hyslop, General Manager Mr Kane Organ, Environment & Community Coordinator **Secretariat:** Ms Ella Rasmussen

Table A3.2: Briefings

Date	Location	Present
5/03/2018	Pardalote Meeting Room Level 48, MLC Centre 19 Martin Place, Sydney	**Panel members:** Emeritus Professor Jim Galvin Dr Ann Young Professor Neil McIntyre Mr Michael Williams Professor Bruce Hebblewhite Dr Christopher Armstrong **Peabody Energy Metropolitan Coal:** Mr Jon Degotardi, Technical Services Manager Mr Stephen Love, Environment & Community Superintendent Mr Micheal Alexander, Director Projects and Portfolio Management NSW **Resource Strategies:** Ms Stacey Gromadzki, Senior Environmental Manager **Secretariat:** Dr Suzanne Pierce Dr Jaclyn Aldenhoven Mr Jerein Kailath
5/03/2018	Pardalote Meeting Room Level 48, MLC Centre 19 Martin Place, Sydney	**Panel members:** Emeritus Professor Jim Galvin Dr Ann Young Professor Neil McIntyre Mr Michael Williams Professor Bruce Hebblewhite Dr Christopher Armstrong **South32 Illawarra Coal:** Mr Gary Brassington, Principal Approvals Ms Rachel Cameron, Manager External Affairs Dr Stuart Brown, Director HGEO Mr Will Minchin, Senior Hydrogeologist, HydroSimulations Dr James Barbato, Engineering Associate, Mine Subsidence Engineering Consultants (MSEC) Ms Bryony Andrew, Dendrobium Mine Operations Manager **Secretariat:** Dr Suzanne Pierce Dr Jaclyn Aldenhoven Mr Jerein Kailath
26/03/2018	Conference Room Metropolitan Coal Parkes Street, Helensburgh	**Panel members:** Emeritus Professor Jim Galvin Dr Ann Young Professor Neil McIntyre Mr Michael Williams (teleconference) Professor Bruce Hebblewhite Dr Christopher Armstrong

		WaterNSW: Ms Fiona Smith, Executive Manager Water and Catchment Protection Mr Malcolm Hughes, Manager Catchment Protection Mr Peter Dupen, Manager Mining **Secretariat:** Dr Suzanne Pierce Dr Jaclyn Aldenhoven Mr Jerein Kailath (teleconference)
3/04/2018	Pardalote Meeting Room Level 48, MLC Centre 19 Martin Place, Sydney	**Panel members:** Emeritus Professor Jim Galvin Dr Ann Young Professor Neil McIntyre Mr Michael Williams Dr Christopher Armstrong **South32 Illawarra Coal:** Mr Jason Economidis, Vice President Operations Mr Gary Brassington, Principal Approvals Ms Rachel Cameron, Manager External Affairs **Secretariat:** Dr Suzanne Pierce Dr Jaclyn Aldenhoven Mr Jerein Kailath

Table A3.3: Submissions

No.	Organisation
1	National Parks Association of NSW
2	WaterNSW
3	Wollondilly Shire Council
4	National Parks Association of NSW
5	Lock the Gate Alliance

APPENDIX 4: MAJOR REVIEWS AND REPORTS

Year	Report	Author	Brief Overview
1976	Coal Mining Under Stored Water: Report on an Inquiry Into Coal Mining Under Or in the Vicinity of the Stored Waters of the Nepean, Avon, Cordeaux, Cataract and Woronora Reservoirs ('Reynolds Inquiry')	The Hon. Mr Justice R.G. Reynolds, as commissioned by the NSW Government	• The Inquiry was to determine *"if mining should be permitted under or underground in the vicinity of stored waters of Nepean, Avon, Cordeaux, Cataract and Woronora Reservoirs, and if so, what would extent and to what conditions"* and examined the relationship between geology, groundwater, mining-induced subsidence and mining practice in the Southern Coalfield. • The Inquiry found *"that relevant mining should be permitted and would not endanger security of stored water if the mining is carried out with proper safeguards".* • To maintain water security, the Inquiry recommended restrictions on mining to zones around the margin of stored waters; restrictions to the width of pillars, depth of boards and minimum depths of cover; and that detailed plans were needed to be submitted to the Department for all proposed mining under stored waters.

2001	Dendrobium Underground Coal Mine Project, ('Dendrobium Inquiry')	BHP Billiton Illawarra Coal: Cleland, K., and Carleton, M. Delivered to the (then) Minister for Urban Affairs and Planning	• The Commission assessed all environmental aspects of the proposed project. It found that the proposed mining and associated activities would "*result in a number of adverse environmental impacts*" to threatened flora and fauna species through subsidence and water loss.
			• However, the Commission raised uncertainty about the extent of potential impacts due to a lack of data and knowledge.
			• The Commission then recommended amendments to the proposed project and consent conditions to minimise potential environmental impacts to upland swamps, watercourse and Sydney's drinking water catchment; flora and fauna, including:
			    ○ restricted mining in Area 1, Area 2 and Area 3
			    ○ staged conditional approval for the Stage 3 area at the West Cliff emplacement site.

2008	Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield ('Southern Coalfield Report')	NSW Department of Planning	• The Inquiry was established to explore Government concerns about subsidence impacts in the Southern Coalfield and defined subsidence effects, subsidence impacts and environmental consequences.
			• While the Panel noted impacts to valley infill swamps, it could not be confident it was due to mine subsidence. The Panel stated no evidence was presented "*to support the view that subsidence impacts on rivers and significant streams, valley infill or headwater swamps, or shallow or deep aquifers have resulted in any measurable reduction in runoff to the water supply system*".
			• The Inquiry recommended:
			    ○ identification of Risk Management Zones (RMZs) to assess and manage potential impacts on significant natural features which are subject to increased monitoring and assessment requirements
			    ○ a precautionary approach to the approval of mining (reverse onus of proof) with contingency planning from the mining companies where information is limited
			    ○ environmental assessments for applications lodged under Part 3A of the EP&A Act to

			address subsidence effects, impacts and consequences (such as a minimum of two years of baseline data for significant natural features), increased communication between subsidence engineers and specialists in ecology, hydrology, geomorphology, and increased use of peer reviewed science and independent expert opinion ○ Government and the industry should undertake further research into subsidence impacts on valley infill swamps, headwater swamps and into remediating stream bed cracking.
2009	The Metropolitan Coal Project Review Report	NSW Planning Assessment Commission	• The PAC was required to *"carry out a review of the potential subsidence related impacts of the Metropolitan Coal Project on the values of Sydney's drinking water catchment"* and *"advise on the significance and acceptability of these potential impacts, and to recommend appropriate measures to avoid, minimise, or offset these impacts".* • The Panel found that the methodology used to predict non-conventional subsidence effects was still under development and there was considerable uncertainty around predictions. It was noted that the relationship between these predictions and related impacts and consequences were poorly defined. • The Panel recommended approval of the Metropolitan Coal Project Proposal, subject to a number of conditions. These included (amongst others): ○ improved environmental outcomes – in particular, protection of the lower reaches of the Waratah Rivulet and the Eastern Tributary to the standard of negligible environmental consequences ○ collection of data to resolve outstanding issues (such as the impact of conventional / non-conventional subsidence on surface water, groundwater and upland swamps) and inform future management decisions and strategies the incorporation of RMZs (as described in the Southern Coalfield Report) into a broader risk framework which would identify natural features at risk from subsidence, assess the potential risk and identify options to deal with them in order to form a management plan ○ the approval conditions for the current project have a specific focus on the monitoring of upsidence and valley closure impacts and the mine plan be capable of modifications to manage consequences arising out of these impacts within predetermined levels ○ a review of the Reynolds Inquiry conclusions regarding mine under stored waters with a focus on advances in knowledge since 1977 development of a program to examine catchment yield impacts (in conjunction with SCA) ○ that approval conditions include groundwater monitoring regimes, as identified by the Southern Coalfield Report.
2010	Bulli Seam Operations (BSO)	NSW Planning Assessment Commission	• In 2009, the PAC was directed by the former Minister of Planning to carry out a review of the Bulli Seam Operations with regards to subsidence impacts on significant natural features and Sydney's drinking water catchment, and recommend measures to minimise, remediate or offset these impacts. • The Panel found that the information submitted by the Proponent to be largely deficient, and thereby recommended no approval for the eastern and southern portions of the study area, and conditional approval for the western and northern areas. • The Panel provided several recommendations based on their review including: ○ studies through exploratory drilling, core testing, mineralogical assessments, sediment profiling in swamps and numerical modelling to determine whether 'negligible impact' standards could be met for the proposed extraction

			○ revision of groundwater model including an independent audit of the revised model and conducting further studies in relation to deep groundwater systems ○ implementation of methods for the protection of upland swamps ○ 'special significance status' be afforded to a number of rivers, creeks and streams within the Study Area and these be protected by 'negligible impact' performance criterion.
2012	Thirlmere Lakes Inquiry: Final Report of the Independent Committee	Independent Thirlmere Lakes Inquiry Committee, as commissioned by the NSW Government	• Established to understand the reasons for low levels of Thirlmere lakes following community concerns. • The Committee concluded that: ○ the changes in lake levels could be due to droughts, heavy rains and some groundwater losses and there was no evidence of direct impacts of mining on the lakes ○ substantial research was required to understand lake levels and groundwater.
2013 & 2014	Initial report on the Independent Review of Coal Seam Gas Activities in NSW (2013) and On measuring the cumulative impacts of activities which impact ground and surface water in the Sydney Water Catchment (2014)	NSW Chief Scientist and Engineer, commissioned as a response to a request from the (then) Minister for Resources and Energy	• The initial review was conducted to identify the issues surrounding Coal Seam Gas (CSG) in NSW, and investigate various issues surrounding land access, geology, water, air quality, subsidence, health and safety etc. • The 2014 review was to build on the initial report and "*specifically examine the cumulative impacts of all activities which impact ground and surface water in the Sydney Catchment Special Areas*". • The review studied current approaches to cumulative impacts and investigated whether a more quantitative approach was possible with respect to the Sydney Catchment Area. • The review found that there was insufficient data to build a complete model that could understand the cumulative impacts of activities in the catchment and recommended: ○ the development of a whole-of-Catchment environmental monitoring system and data repository ○ the commissioning of computational models for assessment of impacts on the quality and quantity of surface water and groundwater and encouraging the use of 3D data visualisation tools ○ the establishment of an expert group to provide ongoing advice on cumulative impacts in the Catchment.
2014	Temperate Highland Peat Swamps on Sandstone (THPSS): ecological characteristics, sensitivities to change, and monitoring and reporting techniques	Prepared by Jacobs SKM, as commissioned by the Department of the Environment on the advice of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC)	• The report categorised THPSS ecological community into three conceptual models: ○ headwater swamps – swamps that are reliant on rainfall and run-off and forms near catchment divides where topographic gradients are shallow ○ valley infill swamps – swamps that occur in steeper topographies filling the valleys of incised second or third-order streams and are likely to be connected to perched or regional aquifers ○ hanging/valley side swamps – swamps that occur on steep valley sides where there is groundwater seepage. • This report was intended to "*provide a hydrological and geological characterisation of the peat swamp communities*"; model its sensitivity to changes in surface and groundwater flows and water quality caused by longwall mining and advise on approaches to detect potential impacts of such mining. • The report also identified that there is little information on how swamp ecology responds to changes to the surrounding environment including limited data linking subsidence effects and ecological impacts. Multiple BACI approach is recommended for designing an ecological monitoring programme.
2014	Temperate Highland Peat	Prepared by Coffey	• This report was aimed to provide scientific advice to the Department of the Environment on the

	Swamps on Sandstone: longwall mining engineering design - subsidence prediction, buffer distances and mine design options	Geotechnics, as commissioned by the Department of the Environment on the advice of the IESC	impact of subsidence from longwall mining on temperate peat swamps in the Southern and Western Coalfields. It addressed the following priority areas:
			  ○ predicting the impact of subsidence from longwall mining on peat swamps
			  ○ relationship between mine design and potential subsidence risks, in terms of the orientation and dimensions of longwalls
			  ○ defining buffer and stand-off distances between longwall panels and aquatic ecosystems.
			• The focus of the report is "*on the physical impacts of longwall mining on the rock strata that underlies peat swamps, the potential for impacts on groundwater systems, and the opportunities for management of the impacts through prediction, engineering intervention (including mine design and provision for suitable buffers), mitigation and remediation*".
			• The main points to come out of this review are:
			  ○ adjusting the length and width of individual longwall panels can change the magnitude and nature of surface movements, and thereby mitigate impacts on peat swamps
			  ○ TARPs are ineffective in the management of impacts of longwall mining on peat swamps due to the difficulty of quickly finding suitable parameters that indicate impacts
			  ○ physical disturbances that occur immediately below peat swamps are "*typically the result of horizontal movements and valley closure effects that fracture rock strata*" below the swamps.

2014	Temperate Highland Peat Swamps on Sandstone: evaluation of mitigation and remediation techniques	Prepared by Water Research Laboratory, School of Civil and Environmental Engineering, University of New South Wales, as commissioned by the Department of the Environment on the advice of the IESC	• This report provides background information on longwall mining and upland peat swamps, and details of attempts at remediation. • The report notes that numerous swamps have been impacted by longwall mining subsidence and that there are no proven mitigation strategies other than alterations to the mine layout. • There are currently no examples of remediation of undermined upland peat swamps and restoration times could be between tens to hundreds of years because of slow aggradation rates. In fact, there are no signs of self-amelioration for swamps that were impacted over 25 years ago. • The report also notes that "*direct remediation to combat vertical seepage beneath upland peat swamps has not been attempted. Existing remediation techniques are unproven and appear insufficient without the destruction of the surface environment*".

2015	Mining Impacts at Dendrobium Coal Mine Area 3B	Prepared by the Department of Planning and Environment	• This investigation report was undertaken by DPE following public concerns and media interest on potential environmental impacts with Dendrobium Mine's Area 3B. The key areas of interest included:
			  ○ fractures and resultant water flow diversions in WC21 for a length of approximately 600 m
			  ○ loss of soil moisture and changed hydrogeological conditions within swamps and associated monitoring
			  ○ condition of the vegetation health within swamps.
			• DPE recommended engaging an independent expert to analyse surface water and groundwater modelling, including reviewing all available data sources, modelling methods, investigation techniques and evidentiary data types.
			• The review also contained recommendations regarding a remediation program for the impacts to WC21, finalisation of the *Swamp Rehabilitation and Research Program* in consultation with other agencies, and engaging an independent expert to assess potential impacts to Littlejohn's Tree Frog.

2017	2016 Audit of the Sydney Drinking Water	Alluvium Consulting Australia	• The 2013-2016 audit of Sydney's water supply catchment was in accordance with the requirements of Section 42 of the *Water NSW Act 2014*, and the eighth such audit since 1999.

	Catchment		• The Audit found “*an emerging issue of unquantified loss of surface flows associated with the cumulative impacts of underground coal mining activities*” and that increased knowledge and monitoring of the impact of multiple mining activities on Catchment water yield is required.
			• The Audit noted that concern remained around the availability and quality of data and monitoring, and that this point had been raised in previous audits.
			• The Audit recommendations included:
			  ○ establishing a state-owned regional surface water and groundwater geotechnical model
			  ○ establishing an independent panel to “*review the monitoring, analysis and reporting program relevant to mines operating in the Catchment*”
			  ○ investigating thresholds at which mining activities cause loss of surface water to mine workings, and impact the yield of individual water supply systems.
			  ○ compliling a regional cumulative impact assessment in the Sydney Drinking Water Catchment with all empirical evidence of mining impacts
			  ○ updating and implementing plans and programs to reduce land degradation and bushfire risk, address water quality issues and improve monitoring data quality.

2017	Height of Cracking – Dendrobium Area 3B	Pells Sullivan Meynink, commissioned by the Department of Planning and Environment	• This study arose from the 2015 DPE report ‘Mining Impacts at Dendrobium Coal Mine Area 3B’ and was aimed at looking into current information, techniques and available data, methodologies used for predictions and to identify further work and monitoring required to study geotechnical and hydrogeological behaviour over longwalls.
			• The study detailed the limitations of the Tammetta (2013) and Ditton and Merrick (2014) models, the two height of cracking/fracturing models used at Dendrobium Mine. It noted that a key conclusion from the models was that “the groundwater response at Dendrobium had not exhibited full depressurisation (desaturation) at any height apart from near the surface zone”.
			• The study recommended that additional work be conducted to improve the confidence of the study findings, with specific recommendations including:
			  ○ an audit of the mine inflows and associated monitoring network
			  ○ reviewing the water balance for Cordeaux Reservoir and the potential current and future impacts of continued mining on Avon Reservoir including additional monitoring between Area 3B and Avon Reservoir investigating unexplained rises in the intermediate level of groundwater pressures away from mining
			  ○ pre- and post-mining investigations to better define and confirm cracking and dilation of rock mass above longwall panels in Area 3B and investigate the effects of valley bulging.

2018	Inquiry: Water use by the extractive industry	Senate Standing Committees on Environment and Communications, Commonwealth Government	• The Committee inquired into and reported on the adequacy of the regulatory framework governing water use by the extractive industry, in particular on the social, economic and environmental impacts of projects’ take and use of water; existing safeguards for aquifers and water systems; gaps in regulatory framework; difference in regulatory regimes between industries and the effectiveness of ‘water trigger’ under the EPBC Act. • The Committee received a number of submissions from the public, advocacy groups, professional bodies, industry associations and government agencies. • The Committee’s Report made 20 recommendations with respect to: amendments to the EPBC Act; bilateral agreements under the EPBC Act; compliance; the National Water Account; baseline modelling; bioregional assessments; research informing regulatory decisions; and the National Water

			Initiative.
Current	Inquiry: Rehabilitation of mining and resources projects as it relates to Commonwealth responsibilities Scheduled reporting date: 28 November 2018	Senate Standing Committees on Environment and Communications, Commonwealth Government	• The Committee is primarily investigating: the costs of outstanding rehabilitation obligations; the adequacy of existing legislation, policy and institutional arrangements; the effectiveness of current Australian rehabilitation practices, abandoned mines programs, and power station ash dams; whether industry has avoided obligations; the social, economic and environmental impacts of inadequate rehabilitation and benefits of adequate rehabilitation; international case studies; proposals for reform; and any other related matters. • Some of the overarching issues raised by those that argued that the current framework is inadequate include that: ○ rehabilitation expectations and standards are inadequately defined, including the standard of ecosystem and biodiversity recovery necessary ○ there is a lack of technical capability and scientific understanding of how to achieve functional, representative and resilient ecosystems post-mining ○ costs of rehabilitation are not being adequately determined prior to planning approval, and that there is a lack of measures to ensure long term sustainability. • Comments from those that argued that the current framework is adequate include: ○ rehabilitation is already adequately secured through legally binding rehabilitation obligations and state security deposit schemes ○ regulation should remain a responsibility of state governments who can adequately oversee and enforce these obligations, and any federal obligations (for example, monitoring and compliance) should be streamlined with state obligations through better coordination and/or alignment of regulations and approvals.

APPENDIX 5: RECOMMENDATIONS FROM THE HEIGHT OF CRACKING DENDROBIUM AREA 3B REPORT AND THE 2016 AUDIT OF THE SYDNEY WATER CATCHMENT

Table A5.1: Recommendations from the Height of Cracking Dendrobium Area 3B report (PSM study) and the 2016 Audit of the Sydney Water Catchment

Recommendations	No	Source
A thorough analysis of mine inflows including audit of the layout and monitoring network	1	PSM study
A review of the water balance for Cordeaux Reservoir including a more thorough analysis of the potential connection or partial connection of the Mine Areas 2 and 3A with Cordeaux Reservoir	2	PSM study
Review of the potential current and future impacts of continued mining on Avon Reservoir. This includes all aspects of current monitoring and the underpinning geological and geotechnical models	3	PSM study
Some unexplained rises in the intermediate level groundwater pressures away from mining have been identified and these should be investigated further	4	PSM study
There are no geological/ geotechnical/hydrogeological profiles beneath the swamps and most of the piezometers are installed at very shallow depths, around 1 to 2 m. More comprehensive models of the swamps would improve the interpretations and give increased confidence in the future predictions	5	PSM study
Additional monitoring is required between Area 3B and Avon Reservoir	6	PSM study
Further investigations pre and post mining are required to better define and confirm cracking and dilation of the rock mass above longwall panels in Area 3B	7	PSM study
The effects of valley bulging do not appear to be recognised or incorporated into modelling or the understanding of the effects and impacts of mining at Dendrobium. This aspect needs to be evaluated in regard to future mining near Avon Reservoir	8	PSM study
This study has focussed on mining impacts, whether they are occurring and if so when and to what extent. However, it has not been possible as part of this study to provide quantitative estimates of the impacts. Hence the key areas for the DPE and the major stakeholders to consider, arising from this study are: • Firstly, do any of these impacts need to be better quantified, and • Secondly, the appropriate acceptability criteria for their impacts	9	PSM study
Establish the scope and commence a state-owned regional surface water and groundwater geotechnical model	M1	2016 Audit
Establish an independent panel to review the monitoring, analysis and reporting program relevant to mines operating in the catchment	M3	2016 Audit
Investigate thresholds at which mining activities cause loss of surface water to mine workings, and impact the yield of individual Sydney Water catchment water supply systems. Results to be considered in the Metropolitan Water Plan	M4	2016 Audit
Identify surface water flow monitoring requirements in mining approval conditions	M5	2016 Audit
Compile all empirical evidence of mining impacts in the Sydney Drinking Water Catchment in a regional cumulative impact assessment	M6	2016 Audit

Note: Recommendation M2 from the 2016 Catchment Audit is outside the Panel Terms of Reference

Table A5.2: Monitoring Program recommendations from the Height of Cracking Dendrobium 3B (PSM study)

	Monitoring Program Recommendations
Fundamental concepts to effective monitoring of very large scale complex systems	Monitoring must be holistic and conceptualised from sound models including geological, geotechnical, groundwater and surface water.
	All natural and man-made infrastructure must be identified, characterised and the sensitivities identified.
	The monitoring program should be objective driven by the characteristics of the site conditions and the demands of the infrastructure that needs to be protected and/or managed.
	The monitoring must be installed early enough to give an effective baseline.
	The monitoring must continue throughout and after the mining has been completed.
	The monitoring must be cognizant of potential for interactions between mining areas.
	There must be sufficient monitoring remote from the mining to define the extent of the effects and impacts.
	Each new mine or area will require a site specific monitoring program.
	The monitoring program must be flexible and may require a number of cycles of design in order to ensure all the aspects of the 'complex system' are captured.
Recs from detailed investigations over LW 9*	Fully cored holes must be drilled pre and post mining.
	There should be full Acoustic and or Optical Televiewer logging (ATV and OTV) of these holes.
	Monitoring should include comprehensive geotechnical logging of both the core and the televiewer logs, using advanced data processing and screening techniques.
	Packer testing of boreholes must be conducted both pre and post mining.
	Multipoint piezometers must be installed well before mining in the area.
	Monitoring program should include installation of borehole extensometers

* Presented as summary points in the report, p. 57