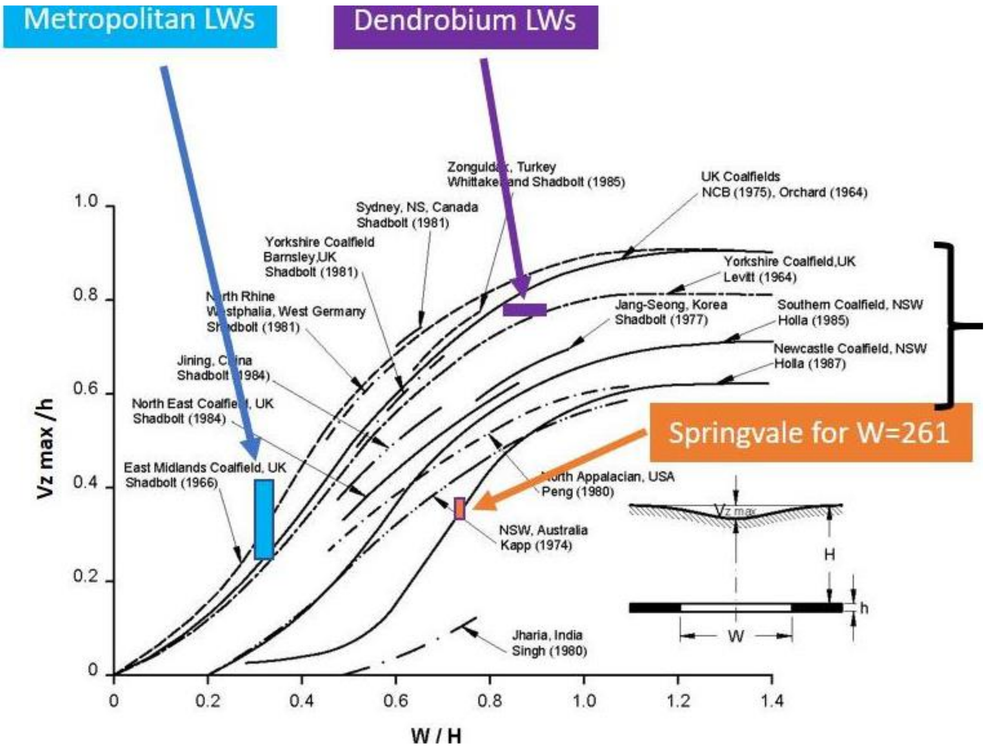
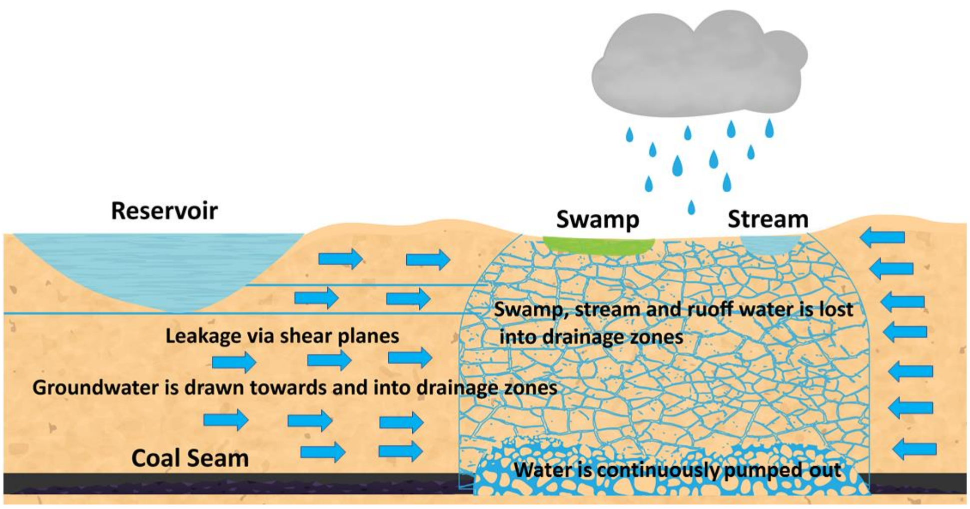
Some Concerns Regarding the Dendrobium Extension Project Proposal SSD 8194





"*The single most important land use in the Southern Coalfield is as water catchment*".

Southern Coalfield Inquiry, 2008

"*The Panel is of the view that it is no longer a viable proposition for mining to cause more than negligible damage to pristine or near-pristine waterways in drinking water catchments or where these waterways are elements of significant conservation areas or significant river systems. As noted in the Metropolitan PAC Report, this level of damage would not be acceptable in any other assessment of water resource use*."

"*The Panel finds that the exclusion of first and second order streams from consideration of consequences ignores the vital role that these streams play in the interconnectivity of the system. In particular they are important in protecting the continuity of flow and the quality of water conveyed between the upland swamps and the larger streams*."

Bulli Seam Operations Project, PAC Report, 2010.

"*Given the inherent uncertainty of predicting and estimating the magnitude of stream flow losses to fracture networks and the potential long term implications of fracture networks for water quantity and, in particular, water quality in the Greater Sydney water catchment, the Panel considers that it would be wise to adopt a precautionary approach and base mine design on preventing the height of free drainage in the Special Areas from extending to the surface or interacting with surface fracture networks*."

IEPMC Report, Part 2, 2019.

The cover graphics are Figs. 4 and 21 within.

General Disclaimer

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Summary

- The DPIE has recommended a notably damaging proposal accompanied by an inadequate assessment of impacts and consequences, no assessment of reduced width on impacts, substantial water take, inadequate modelling, inadequate compensation and offsets, no mine closure plan and in perpetuity consequences in a context of advancing climate change and fire risk.
- The proposal seeks to extend a mine distinguished from others in and around the Special Areas by its large extraction widths and heights. The aggressive mining is correspondingly damaging. The proposal stands in stark contrast to that of the Russell Vale mine expansion.
- Notwithstanding the recommendations of the IEPMC and others, the project will consume a substantial amount of water in a long standing context of unacceptably inadequate knowledge of cumulative losses. Compounding this, again notwithstanding the IEPMC's recommendations, there has yet to be a determination of acceptable surface water take by the mines in and around the Special Areas. In taking water from the Special Areas, unlike other consumers, mining irreversibly damages that source.
- A 2016 tally of information provided in publicly available reports from mines in and around the Special Areas suggests an inflow range of 24 to 42 million litres a day, of which an unknown proportion would be water that would otherwise have entered storage. Recent work by WaterNSW suggests up to 17 million litres a day (Ml/day), possibly up to 24 Ml/day, are lost from the surface and near surface as a consequence of mining. The proposed mining would significantly add to these losses.
- Limited in not incorporating historical mine losses, and likely underestimating losses at Wongawilli and from the reservoirs, the IEPMC's estimate of 8 Ml/day is a significant underestimate.
- There is no recognition in the proposal or DPIE assessment that conventional subsidence, which is extraction width sensitive, compounds the impacts and consequences of non-conventional subsidence, and vice versa. Conventional subsidence impacts of 305m panels would be significantly greater than 150m. Though of a lesser extent, non-conventional subsidence has a width dependence. The DPIE appears to either misunderstand or misrepresent comments made by the IAPUM.
- Application of the Tammetta equation finds the drainage zone heights for 150 metre extractions approximately half of those for 305 metre extractions.
- There would appear to be no credible means of compensating or offsetting in perpetuity consequences arising from the proposed mining. In perpetuity losses caused by the Dendrobium mine would compound those the neighbouring Wongawilli mine, and possibly other mines. Past assessments, including Dendrobium, did not recognise such consequences.
- Allowing in perpetuity losses and drainage zones the either reach the surface or approach close enough to interact with the surface fundamentally contradicts the intent of the Special Areas.

- The DPIE misrepresents the relatively rapid, non-laminar and non-Darcian flow though the drainage zone as ‘percolation’.
- The DPIE is dismissive of long term contamination concerns, notwithstanding media reports in December 2019 demonstrating contamination during a drought period. Neither the DPIE nor the proponent appear to consider mining induced contamination of subsurface flows, which may transport contaminants over a wider area than surface flows.
- The Special Areas contain some of the few areas of pristine bushland and streams, with associated habitat and ecosystems, left in New South Wales. They contain most of the upland swamps, some 83%. While the project proposal includes provision for some offsets and compensation, not all of the impacts and consequences of the proposed mining can be adequately addressed. There would appear to be no credible means of compensating for in perpetuity consequences.
- The DPIE evidently overlooks the BSO PAC Panel’s assessment that impacts of the kind found at Waratah Rivulet are no longer acceptable. The BSO report explicitly recognises the importance of pristine and near pristine watercourses, and of first and second order streams.
- The DPIE overlooks the BSO PAC Panel’s stream assessment and overlooks the IAPUM’s concerns regarding stream impacts and the proponents inadequate assessment. The proposal lacks a stream assessment of the kind carried out by the BSO PAC Panel.
- The unexpected impacts to Waratah Rivulet and Eastern Tributary demonstrate the difficulty of anticipating impacts and consequences of mining in the Special Areas, even where relatively modest mining geometries are used. These impacts do not provide a rational basis for allowing 305 metre wide extractions. On the contrary, they argue for rejection of the proposed mining of the Special Areas.

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1. Introduction

The Metropolitan and Woronora Special Areas are referred to herein as ‘the Special Areas’ and Figure 1 depicts the extent of mining within and around these Special Areas. Clearly the extent of mining is substantial relative to the storage reservoirs. It’s unlikely mining operations within and around the Special Areas have been of no more than negligible consequence.

Context for this submission is provided by the open letter, and it’s attachment, from a group of concerned scientists with relevant backgrounds, sent to the Premier in May of this year.[1] The now long standing recognition of inadequate monitoring, inadequate modelling, inadequate knowledge, inadequate understanding and limited access to data and information held by mining companies, is highlighted by the uncertainties and knowledge gaps surrounding the current proposal. The Dendrobium mine is distinguished from others in the area by its notably wide extraction widths and heights. It is then, the most aggressive and damaging of the mines in and around the Special Areas.

This submission expands on some of the concerns raised on behalf of the NPA at the IPCN Public Hearing for the proposal.[2] Time constraints prevent further consideration of concerns and the provision of additional information.

Allowing the drainage zone, the zone through which water drains relatively rapidly (Section 7), to reach the surface would reasonably be regarded as accepting one of the worst impacts to have in a drinking water catchment. This is recognised in the Planning Assessment Commission’s (PAC’s) approval conditions for the Wallarah-2 project, which included “*No connective cracking between the surface, or the base of the alluvium, and the underground workings*". Mining of this kind, which includes in perpetuity consequences, fundamentally contradicts the intent of the Special Areas.

The Special Areas contain some of the few areas of pristine bushland and streams, with associated habitat and ecosystems, left in New South Wales. They contain most of the upland swamps, some 83%. While the project proposal includes provision for some offsets and compensation, not all of the impacts and consequences of the proposed mining can be adequately addressed. Notably, there would appear to be no credible means of compensating for in perpetuity consequences.

The proposal has been put forward at a time of heightened recognition of the advance of climate change and its consequences, including increasing drought severity and fire risk. While rainfall for the Illawarra is not expected to change overall in the medium term, fire risk is expected to increase. This will be compounded by the mining induced decline of the groundwater system in the Special Areas.

Within this submission, ‘Department of Planning, Industry and Environment is abbreviated as DPIE’, Independent Expert Panel for Mining in the Catchment is abbreviated as IEPMC, Independent Advisory Panel for Underground Mining is abbreviated as IAPUM, Planning Assessment Commission is abbreviated as PAC, Independent Planning Commission of NSW as IPCN, Bulli Seam Operations is abbreviated as BSO, ‘Longwall’ is abbreviated as LW, ‘Dendrobium Extension Project’ is abbreviated as DEP. ‘Reduced level’ is abbreviated as RL and ‘mAHD’ is the abbreviation for elevation in metres with respect to the Australian Height Datum. The term non-conventional subsidence is used here, whereas others may refer to site-specific or non-systematic subsidence. End of panel is abbreviated as EoP, millions of litres a day is represented as Ml/day and gigalitres (1000 Ml) year as Gl/yr. Limited time has constrained proof reading and correction.

2. Lack of balance

The DPIE assessment[3] is presented as balanced, while overlooking, misunderstanding or misrepresenting issues of significance and concern. The Department's focus on non-conventional subsidence overlooks the compounding impacts of conventional subsidence; both would be worse for 305 metre extractions than for 150 metre extractions. Also discussed within, the Department appears to either misunderstand or misrepresent comments made by the IAPUM.[4]

The DPIE has insufficient regard for the PAC Panel reports for the Bulli Seam Operations (BSO) project[5] and the Metropolitan Expansion Project (MEP).[6] The DPIE accepts watercourse damage, in the absence of an adequate stream assessment with respect to significance, inconsistent with the assessment of the BSO Panel and the intent of the Special Areas. The BSO report recognises the importance of pristine and near pristine watercourses, and the importance of first and second order streams.

The DPIE's assessment of negligible impacts rest on inadequate modelling for the project; the IEPMC cautions against dependence on modelling. Among other problems, modelling has limited capability to incorporate shear plane activation and valley bulging occurrence and consequences. Concerns have been raised in the relatively recent past by WaterNSW, NPA and others, regarding the groundwater assessments by consultants engaged by the proponent. The DPIE has not acted on the recommendation of the BSO PAC Panel regarding concerns arising from proponents selecting and funding consultants, which arise both for peer reviews and impact assessments.

The proponent has a history of denying or downplaying impacts, rejecting concerns brought to the attention of the Department and agencies by the community; the same community denied access to key data and information held by the company. Recognition and understanding of mining impacts has often been driven by community attention. The 2014 report[7] of the Chief Scientist, among others, recognises the problem of lack of access to data and information held by mining companies. The problem remains.

The DEP groundwater assessment evidently had access to a significant record of mine inflows.

Notwithstanding the recommendations of the IEPMC and previous reports of others, the project will consume a substantial amount of water in a long standing context of unacceptably inadequate knowledge of cumulative losses. Compounding this, again notwithstanding the IEPMC's recommendations, there has yet to be a determination of acceptable surface water take by the mines in and around the Special Areas. In taking water from the Special Areas, unlike other consumers, mining irreversibly damages that source.

In the final session of the Public Hearing, the DPIE misrepresented the upland swamps of the Woronora Plateau, incorrectly discounting the character and significance of these swamps with respect to those of the Blue Mountains. Notably, the swamps of eastern NSW have been recently been recognised[8] as carbon stores of significance.

The DPIE assessment lacks context for the economic benefit of the project. Reflecting change since the 1980's, the available information suggests mining is now a very minor part of the Illawarra economy.

3. Inadequate mining width assessment

In making the following statement in its assessment report[3] the DPIE would appear to either misunderstand or misrepresents the IAPUM:

> "*6.2.54 In particular, the Mining Panel has confirmed the Department's view that the key control over surface cracking of watercourses is non-conventional subsidence (ie valley closure)*."

The IAPUM report for the Dendrobium Extension Project (DEP) proposal does not appear, however, to suggest that non-conventional subsidence is the key control over watercourse impacts and consequences. Nor does the IAPUM report appear to suggest that non-conventional subsidence dominates, overrides or counters conventional subsidence, at or near watercourses. There would appear to be no physical basis for the DPIE view. Consistent with the MSEC letter-report[9], the IAPUM[4] states no more than that width is not the key control when considering impacts arising from non-conventional subsidence:

> "*panel width is not the key control when considering environmental impacts on natural surface features due to mining-induced non-conventional subsidence*"

The DPIE doesn't provide a basis for its view and nor is it supported in the available literature.[10]–[12] Of note, the directly relevant Planning Assessment Commission (PAC) review report[5] of July 2010 for the then proposed Bulli Seam Operations (BSO) project, includes the following observation in its consideration of watercourse impacts:

> "*At the same time, in the deeply incised gorge landforms that predominate in the sandstone geology, the "conventional" and "non-conventional" impacts of mining compound along the valley systems*."

The BSO PAC report is further discussed within.

The IAPUM report's conclusion with respect to non-conventional subsidence is included in its executive summary shortly after the following comment:

> "*It is well established that mining panel width, height of extraction and depth of mining are important factors in determining the environmental impacts of mining-induced subsurface and surface ground subsidence. The EIS does not include any substantive sensitivity analysis of the influence of longwall panel width or mining height on subsidence effects, impacts and consequences.*"

And before the following comment made with respect to surface impacts:

> "*While the same type of impact (cracking) due to conventional subsidence may occur as longwall panel widths become narrower, the intensity of the impacts (fracturing width, frequency and depth) can be expected to reduce. This may have important implications for the volume of*

surface water that can be diverted into the subsurface, and into the mine through connected fractures."

The DPIE further comments in 6.2.54 of its assessment report:

"*It is expected that most watercourses would experience some cracking and reduced pool holding capacity even with longwalls of an uneconomically narrow width. Similarly, even with narrow panels there would be enough surface cracks within most swamps for water retention following large rainfall events to also be reduced.*"

In overlooking or ignoring conventional subsidence, the DPIE does not recognise that it would be reasonable to expect that the surface impacts of 150 metre panels would be significantly less than of 305 metre panels, where a given watercourse is within the angle of draw surface footprint of an extraction panel.

The DPIE further comments:

"*As Conclusion 1 states, narrowing longwall void width is unlikely to significantly reduce the severity of impacts on the key surface features located above and adjacent to the two mining areas (ie the network of drainage channels and watercourses and the upland swamps).*"

Again, this comment misunderstands or misrepresents the IAPUM report's conclusion, which does not state that reducing longwall width would be unlikely to significantly reduce the severity of surface impacts. The DPIE's view is not consistent, for example, with the IAPUM and BSO PAC Panel comments quoted above. Conventional and non-conventional subsidence are further discussed in Section 4.

The DPIE assessment and the proponent overlook the role extraction width has in the severity of valley closure. That width is a contributing factor is evident, for example, in Figure 1.16 of MSEC's 2007 discussion paper[13] (Fig. 2 below), which graphs valley closure with respect to distance from the maingate of the longwall relative to the width of the panel plus the width of the pillar. It's also reflected in Figure 1.19 of that paper (Fig. 3), which graphs a valley closure adjustment factor with respect to maximum incremental subsidence. Subsidence is sensitive to panel width.

The IAPUM report finds that the proposal lacks an adequate assessment of the environmental benefit of reducing the proposed extraction width of 305 metres. Related to this failure, neither the EIS nor the DPIE's assessment report appear to include a comprehensive topographical assessment of the watercourses in the project area, with respect to non-conventional subsidence.

Also related, the IAPUM report has the following comment:

"*In respect of the Department's initial request for the Panel to provide advice on the relative environmental costs and benefits associated with different longwall widths, including whether a reduction in the void widths would materially reduce the environmental impacts of the project, the Panel cannot provide this advice. This is because the EIS and supporting documentation, including the Proponent's responses to some of the Panel's questions, do not provide the necessary information and analysis to enable the impact of different longwall panel widths to be fully and adequately assessed.*"

Neither the proponent nor the DPIE have adequately assessed the surface impacts and environmental benefits of extraction width reduction, and the IAPUM was unable to make such an assessment. Neither the DPIE nor the proponent appear to recognise the compounding nature of conventional and non-conventional subsidence impacts.

4. Compounding impacts of conventional and non-conventional subsidence

As noted above, the 2010 PAC Panel report[5] for the BSO proposal has the following observation in its consideration of watercourse impacts:

> "*At the same time, in the deeply incised gorge landforms that predominate in the sandstone geology, the "conventional" and "non-conventional" impacts of mining compound along the valley systems*."

4.1 Subsidence differences for 305 and 150 metre extractions

The DPIE assessment observes:

> "*In the Southern Coalfield, the critical width occurs at a longwall width-to-depth ratio of approximately 1.4. The width-to-depth ratios for the proposed longwalls vary between 0.78 ~ 1.1 (average of 0.85) in Area 5 and vary between 0.66 ~ 0.81 (average of 0.70) in Area 6. The proposed longwalls in Areas 5 and 6 therefore have void widths less than the critical width.*"

Reference to the graph in Fig. 4 below, from Part 1 of the 2019 IEPMC report[14] and evidently overlooked by the DPIE, suggests that the proposed Area 5 and 6 extraction widths are approaching the critical width and super-critical width plateau for Dendrobium. That is, the subsidence for Areas 5 and 6 (see Figure 1 of MSEC's September 2019 letter-report[9]) would approach the maximum possible, which ranges from 60 to 90% of the extraction height.[12], [15] Subsidence of 2.1 metres would constitute 65% of the proposed 3.2 metre Area 5 extraction height, and subsidence of 2.5 metres would correspond to 64% of the 3.9 metre extractions proposed for Area 6. The graph in Fig. 4 suggests that the critical width subsidence at Dendrobium would approach 80% of the extraction height.

In contrast, the MSEC letter-report suggested maximum subsidence for 150 metre wide extractions of 0.6 and 0.7 metres respectively for Areas 5 and 6, corresponds to 19 and 18% of the proposed extraction heights for these areas. The width to depth ratios for 150 metre extractions are half of those of 305 metre extractions, and the graph in Fig. 4 affirms that subsidence arising from 150 metre extractions would be markedly less than that of the critical width.

4.2 Valley closure and upsidence impacts

Valley closure and upsidence (see Figs 5 and 6) associated with non-conventional subsidence, also known as non-systematic or site-centric subsidence, can cause bedding plane separation, void creation, extensive vertical fracturing, and shearing, buckling and shattering of stream bedrock.[10], [12], [13]

Galvin[12] gives the following consequences arising from these impacts:

"*Environmental consequences can include visible fracturing of bedrock within the bed of the watercourse; physical dislocation of slabs of rock from the bed and subsequent transport and downstream breakdown of these slabs into finer material; loss of water from pools; loss of low flows from the bed of the watercourse; and increased concentrations of dissolved metals, leading to surface iron staining, iron floc matting, algal growth and discolouration of water in pools.*"

Referring to valley closure and upsidence, Galvin comments; "*Both behaviours can extend up to several hundred metres beyond the angle of draw.*" Where the angle of draw defines the effective limit of conventional subsidence. He also notes the following:

"*Studies have also revealed that besides upsidence extending for tens of metres laterally beneath valley sides, it may also not follow the line of the valley floor. Rather, it can cut across valley headlands and bends in the valley*."

Mills reports in his 2007 paper on watercourse impacts[10]:

"*The basal shear fracturing zone extends laterally from the main fracture zone under the flanks of the valley. This zone tends to be better developed and more laterally extensive on the side of the valley closest to mining. The basal shear fracturing zone appears to comprise more than one bedding plane shear with shear movement progressively getting deeper with greater levels of subsidence and valley closure*."

And

"*Horizontal shear on these bedding planes has the potential to cause dilation and an increase in hydraulic conductivity along the bedding plane*."

Mills comments that in a gaining system bedding plane dilation and increased hydraulic conductivity associated with valley closure and upsidence, may increase baseflow support for a watercourse. Where mining results in a change from gaining to losing, however, shearing and dilation would increase loss from the watercourse:

"*In a losing system, some flow in the subsurface fracture network may continue in the groundwater system without returning to surface. The amount of flow diverted into the groundwater system depends on the hydraulic conductivity of the rock strata and the significance of this flow diversion to the groundwater system depends on the total flow in the river channel.*"

The IEPMC comments in Part 2 of its final report[16]:

"*Diversions into deeper, dilated shear surfaces on bedding planes, where these form a conduit for lateral water flow, which may or may not report to the same catchment (i.e. it may become a permanent loss).*"

Such diverted flows may bypass storage and, in the absence of adequate monitoring or drainage to the mine, losses of this kind would be undetected and 'silent'.

Surface water diverted into subsurface flows that return to the surface downstream will be contaminated as a consequence of interaction with the freshly exposed rock surface of cracks. [11], [17] Subsurface flows that enter the storage without joining surface flows will likewise become contaminated with passage over the surface of fractures and sheared planes.

4.3 Conventional subsidence impacts

Conventional subsidence impacts are associated with ground curvature as a trough forms over an extraction. Tension fractures relieve stress where the ground curves outwards near the perimeter of the trough and compression results in fracturing and deformation where it curves inwards towards the centre of the trough. As the IAPUM points out in its DEP report[4], as the surface curves with increased subsidence associated with increased extraction width, rock fractures become wider and/or more numerous. In addition to fracturing, conventional subsidence can also tilt a watercourse.

4.4 Conventional and Non-conventional subsidence impacts within the angle of draw

The 2008 Southern Coalfield Inquiry (SCI) report[11] comments as follows:

> "*Buckling and shear in the near-surface strata, which leads to upsidence, can also generate an extensive network of fractures and voids in the valley floor. Ground movements due to conventional subsidence can also contribute to the formation of this network if the upsidence occurs within the angle of draw of the mine workings.*"

Referring to observations at Waratah Rivulet, the SCI report also comments;

> *"In general, the extent and intensity of the fracture network increases with upsidence which, in turn, increases with subsidence.*"

In his 2007 study[10], Mill comments:

> **"***The main upsidence zone typically occurs within a 20-30m wide corridor where most of the differential horizontal movements and resulting vertical dilation is concentrated. The fractures in this zone develop progressively downward with increasing subsidence, usually to a final depth of about 6-12m below the surface.***"**

And

> "*The basal shear fracturing zone extends laterally from the main fracture zone under the flanks of the valley. This zone tends to be better developed and more laterally extensive on the side of the valley closest to mining. The basal shear fracturing zone appears to comprise more than one bedding plane shear with shear movement progressively getting deeper with greater levels of subsidence and valley closure*."

The paper notes that, at that time, subsidence in the Southern Coalfield was typically in the range 0.8-1.3 metres. The MSEC letter-report[18] provided to South32 suggests that subsidence in Area 5 and 6 would be 0.6 and 0.7 metres respectively for 150 metre extractions. In contrast, it would be 2.1 and 2.5 metres for 305 metre extractions; significantly greater than the range reviewed by Mills.

Section 10.4.4.4 in Prof. Jim Galvin's 2016 textbook[19] on coal mine engineering includes the following observations:

> "*Hence, the ground movements that occur around excavations are complex and may include classic subsidence ground responses to mining; elastic ground movements associated with redistribution of horizontal stress on a regional scale; gravity induced unravelling; and localised buckling and shear failure. It is difficult to identify the individual contributions of these*

components. Some components may even operate simultaneously in opposite senses. For example, an area could be subjected to downwards vertical displacement at the same time that it is being subjected to upwards valley bulging.

If upsidence occurs within the angle of draw of the mine workings, ground movements due to classic subsidence can also contribute to buckling and shear in the near-surface strata, thus generating an extensive network of fractures and voids in the valley floor."

Given the observations quoted above, it would be reasonable to expect that the impacts and consequences of 305 metre extraction would be markedly greater than of 150 metre extractions.

4.5 Eastern Tributary

As described in Part 1 of the final report[14] of the IEPMC, Condition 1, Schedule 3 of the 2009 Metropolitan Mine Expansion 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 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.

The mining company finds that more than 15% of pools on the Eastern Tributary have experienced loss of pool water levels at predicted valley closure values of less than 200 mm and less than 100 mm in some instances. The IEPMC accordingly concludes:

"*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.*"

The IEPMC relates the origin the 200mm closure threshold:

"*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).*"

The unacceptability of the impacts to Waratah Rivulet are reflected in the following comments from the 2010 PAC review report for the then proposed Bulli Seam Operations project (BSO):

"*The Panel is clearly of the view that the level of impacts proposed in the BSO Project Proposal for some significant natural features are no longer acceptable practice. A simple example will* *suffice to make the point. The level of subsidence-induced damage to Waratah Rivulet (Woronora Catchment) that was allowed to occur in 2004 was determined to be not acceptable in the Approval issued for the Metropolitan Coal Project in 2009*."

The unexpected impacts to Waratah Rivulet and Eastern Tributary were brought about by comparatively modest extraction geometries, notably 163 metre widths at a depth of 420 to 535 metres and seam thickness of 2.8 to 3.2 metres. Considerably narrower longwall extractions would evidently be required in order to avoid the unexpected and unacceptable impacts above Metropolitan Mine. The impacts that would arise were 305 metre wide extractions used at the mine, would reasonably be expected to be markedly greater and more extensive.

4.5.1 Insights at 9GGW2B

The Eastern Tributary surface impacts that appeared unexpectedly in October and December 2016, appear to be associated with significant groundwater pressure changes in the upper Hawkesbury Sandstone that commenced in September 2015, late in the extraction of LW24. As is the case at the Dendrobium mine, the monitoring network at the Metropolitan mine is inadequate.

Significant groundwater declines are recorded in the hydrographs obtained from multi-wire piezometer bore 9GGW2B and shown in Figs. 7 and 8 below. Such pronounced consequences would not be expected of the conventional subsidence associated with the mine's relatively modest extractions (see Fig.4). As noted in the discussion below, 9GGW2B is some 890 metres away from the centreline of LW24.

Multi-piezometer bore 9GGW2B is used as a performance indicator reference site for both fracture connection to the mine and leakage from Woronora Reservoir.

Also of note, to the end of the reporting period for the most recent Annual Review, December 2019, there is no indication of groundwater recovery in the Hawkesbury Sandstone at 9GGW2B. Ordinarily, settlement and recharge from the surrounding groundwater system would result in at least partial recovery in the subsequent months.[20] An expectation of at least some recovery is supported by Tammetta's observation[21] that bulk hydraulic conductivity in the Southern Coalfield is controlled by defects and fractures in the top 200 metres of an unmined area. The ground disturbance caused by mining further increases bulk hydraulic conductivity.

The lack of recovery might suggest ongoing lateral loss to drainage zone reaching a height, over the extracted seam, equivalent to that of the piezometers. Application of the Tammetta equation suggests, however, that the height of the drainage zone would be too low. At the western end of LW27, for example, the estimated height would be 155 metres and this would be approximately 315 metres below the surface.

Installed in April 2010 and hosting 10 piezometers, 9GGW2B is located over the 300 series mains and is approximately 240 metres north of the centreline of LW27, 155 metres from its northern edge, approximately 430 metres from the centreline of LW26, approximately 650 metres from the centreline of LW25 and 890 metres from the centreline of LW24. The bore appears to be approximately 480 metres south west of the reservoir full supply level at Eastern Tributary entrance, and 875 metres south east of the reservoir full supply level at Waratah Rivulet. At its closest, Easter Tributary is approximately 430 metres to the east, with Waratah Rivulet approximately 600 metres to the west.

Following installation and in the lead up to the extraction of LW22A, the pressure head reported by the instrument at 55 metres, closest to the surface, slowly increased to approximately 18 metres, declining to 13 metres during the extraction of LW23. Moderated by compression effects, the pressure head drops to 4 metres between the start of LW 26 in May 2016 and December 2016. The extraction of LW27 commenced in September 2016. This approximately nine metre loss, 69%, shows no significant sign of being recovered through to the end of the December 2019.[22]

The elevation of the sensor is 186 mAHD and the elevation of the bed of Eastern Tributary at the shortest distance to the bore appears to be approximately 190 mAHD, dropping to 170 mAHD at the reservoir entrance.

The instrument at 80 metres in 9GGW2B has an elevation of 161 mAHD and is used as the reference sensor for the performance indicator for water loss from Woronora Reservoir. The sensor reports a slow pressure head rise to approximately 45 metres in the period before the extraction of LW22A, falling slightly to approximately 41 metres ahead of the start of LW24 in April 2015. Puzzlingly, the pressure head fell sharply to 34 metres between September and mid October 2015, shortly before the completion of LW24. Like the instrument at 50 metres, the pressure head begins to stabilise from December 2016. Following the passage of LW27, the pressure head essentially flattens at approximately 20 metres, a 51% net loss of 21 metres, from the start of LW24 through to the end of 2019.

All most all of the 51% pressure head loss to June 2019 occurred before June 2017 and the commencement of LW301. The approved extraction plan for Longwalls 301 to 307 allows a further reduction of up to 40% before a performance assessment is triggered. The approved extraction plan for Longwalls 23 to 27 did not quantify a tolerance limit.

In the period between the start of LW21 and the start of LW24 the piezometer at a depth of 106 metres, and elevation of 135 metres, reports a largely steady pressure head of approximately 47 metres. The pressure head sequentially rises with compression effects associated with LWs 24 to 27, and then steadily falls to 33 metres by December 2019. The extraction of LWs 301 and 302 may have contributed to this decline. Of note, the pressure head loss is less than at the 80 metre sensor.

Presumably reflecting shear plane movements, the instrument at 138 metres fails in October 2016 following the commencement of LW27, while the sensor at 163 metres fails during LW25. The next piezometer in the array is at a depth of 304 metres and it fails in November 2016, following what appears to be a sharp pressure head rise associated with compression effects from the commencement of LW27. The instrument at 340 metres reports a sharp pressure head loss of approximately 33 metres in October 2016, shortly after the commencement of LW27. This loss is preceded by a loss of approximately 30 metres between the commencement of LW26 in May 2016 and October 2016. The instrument fails in June 2017, with the start of LW301.

The significant pressure head losses in the Hawkesbury Sandstone at 9GGW2B appear to be persistent, suggesting the introduction of new or enhanced diversion to an unknown sink. The significant pressure loss reported by the performance indicator reference bore at 80 metres would seem to be cause for particular concern.

The changes suggest the possibility that at least parts of Eastern Tributary may have changed from being a gaining to a losing stream, as appears to be the case for Waratah Rivulet. The limited monitoring installations above the mine preclude a conclusive assessment. Further insight may be gained in the next Annual Review, which should become available in mid-2021. The next report should reveal how the instruments respond to the increased rain of 2020.

The mining company proposes remediation for a dozen impacted pools along Eastern Tributary. It will not be possible to remediate the underlying impacts and groundwater consequences.

The groundwater changes associated with the expansion project, approved in 2009, compound drainage caused by earlier mining. Referring to mid to lower Hawkesbury Sandstone monitoring at the expansion project's deep groundwater monitoring bores, which are limited in number, the LW305-307 Water Management Plan (WMP) has the following observations:

> "*It should be noted that the heads at these bores have potentially been affected to some degree by previous mining at Metropolitan Coal and/or other nearby mines (e.g. North Cliff and Darkes Forest)*."

And in discussing 9GGW2B near Longwall 27 (LW27):

> "*Significant depressurisation appears to have occurred in 2000-2001 or earlier from the old Helensburgh workings to the east.*"

The LW23-27 WMP comments:

> "*Bore 9GGW2B is located at the western end of Longwall 27, approximately 1.5 km on the northern side of previously extracted Longwalls 6 and 7 which were mined in 2000-2001. Significant depressurisation appears to have occurred at that time (Figure 46). No definite additional depressurisation has resulted from Longwall 20 and Longwall 21*."

Of note, the figure referred to does not provide hydrographs and does not include data prior to 2011. Further limiting the utility of the figure, it only presents 'potentiometric heads', the sum of sensor elevation and pressure head, which often obscure the significance of pressure head losses.

Using relatively modest extractions widths, the Metropolitan Mine has caused significant and unacceptable[5] impacts to Eastern Tributary and Waratah Rivulet, and their catchment area in the Woronora Special Area. It would be reasonable to expect that the impacts would have been markedly greater had 305 metre wide extractions been used.

5. Inadequate Stream Impact Assessment

Finding the proponents stream impact assessment inadequate, the following concerns raised by the IAPUM do not appear to be recognised in the DPIE's assessment report:

> "*As discussed in Section 4.3.3 of this report, the Panel considers that the rock bar model predictions over-generalise the likelihood of Type 3 impacts and more attention should be given to relevant specific features of the rivers and named creeks: at present there is a risk of*

underestimating the frequency of Type 3 impacts. Further, relying on Type 3 impacts as a performance measure would neglect the potential for cumulative effects of other impacts (Type 1, Type 2 and baseflow reductions) as is an existing issue at Wongawilli Creek (Section 3.2.1 of OCSE (2019b))."

"*Experience of cumulative impacts of previous mining areas on Wongawilli Creek means that the emphasis on managing Type 3 impacts is questionable. The IEPMC (OCSE 2019b) noted that there is debate over whether performance measure of no more than minor impacts has been met at Wongawilli Creek due to cumulative impacts of Type 1 impacts, Type 2 impacts and loss of flow due to groundwater depressurisation.*"

"*Further, while the EIS describes the role of remediation as "It is proposed that similar remediation methods would be implemented for the Project where subsidence-related physical damage occurs at named watercourses and key stream features", the IEPMC report recommended "Remediation should not be relied upon for features, including watercourses and swamps, that are highly significant or of special significance (as per the guidance provided by the Planning Assessment Commission Panels for the Metropolitan Coal Project and the Bulli Seam Operations Project)". The Stream Risk Assessment does not identify any features of special significance and does not explicitly identify any highly significant features, while all stream reaches were assessed as being pristine. Avon River and Cordeaux River are identified as the most significant, for which remediation is expected to be relied upon for small lengths.*"

"*Without the benefit of a site inspection and site specific geotechnical assessments, the Panel cannot form a view at this point in time on the likelihood and consequences associated with Type 3 impacts in Areas 5 and 6. Likelihood may or may not be greater than predicted in the EIS.*"

"*Similarly, the Panel is neither endorsing the Proponent's selection of the two key stream feature types nor the threshold values for them. It is mindful of the Bulli Seam Operations Project where the PAC concluded that it was not satisfied that stream values were protected by a focus on limiting fracturing only at rockbars but allowing for fracturing elsewhere in the valley floor. This may or may not be relevant to the DEP. It is difficult to determine without the benefit of a site visit and/or more in-depth discussion on the topic by the Proponent.*"

The proposed mining has similarities with that of the North Cliff and south eastern domains of the original Bull Seam Operations project proposal, which was reviewed by the then Planning Assessment Commission in July 2010. Regarded as a benchmark, the Panel's report includes the following comments with respect to watercourse impacts:

"*The Panel is of the view that it is no longer a viable proposition for mining to cause more than negligible damage to pristine or near-pristine waterways in drinking water catchments or where these waterways are elements of significant conservation areas or significant river systems. As noted in the Metropolitan PAC Report,[1] this level of damage would not be acceptable in any other assessment of water resource use.*"

"*The Panel is clearly of the view that the level of impacts proposed in the BSO Project Proposal for some significant natural features are no longer acceptable practice. A simple example will suffice to make the point. The level of subsidence-induced damage to Waratah Rivulet*

(Woronora Catchment) that was allowed to occur in 2004 was determined to be not acceptable in the Approval issued for the Metropolitan Coal Project in 2009. The Panel"s assessment is that there are more than 50 km of streams in the Study Area with similar stream characteristics to Waratah Rivulet. Some of these are protected by the Proponent in the Base Case mine layout. But others are proposed to be subjected to the same (or worse) subsidence impacts as occurred at Waratah Rivulet."

The DPIE's assessment report assumes impacts of the kind seen at Waratah Rivulet and Eastern Tributary, both above the Metropolitan mine, are acceptable in Areas 5 and 6. This assumption is made in the absence of an adequate assessment of the benefit and value of the watercourses that would be subject to such impacts. These impacts would be markedly greater for 305 metres extractions, relative to the 163 metres extractions used at the Metropolitan mine.

Emphasizing the importance of first and second order streams, the BSO review report includes the following observations:

> "*The Panel finds that the exclusion of first and second order streams from consideration of consequences ignores the vital role that these streams play in the interconnectivity of the system. In particular they are important in protecting the continuity of flow and the quality of water conveyed between the upland swamps and the larger streams*."
>
> "*The loss of surface flow to sub surface fracture networks can result in dry periods for otherwise perennial streams and increased periods of zero flow in intermittent streams. The Panel finds that the likely magnitude of this impact would exceed standards generally accepted for allowable impacts on the flow regime in assessment of water resources development projects*."

The BSO PAC Panel's important observations are not recognised in the DPIE's report.

5.1 Streams of special significance

The DPIE's report appears to be largely dismissive of the IAPUM's stream assessment comments made with respect to special significance

> "*The concept of "special significance" in regard to both watercourses and upland swamps was first raised by the Commission's predecessor (the Planning Assessment Commission) in considering the Metropolitan Coal Project in 2009 and then again in considering the Bulli Seam Operations Project in 2010. However, the concept has not since been defined for watercourses or otherwise pursued by DPIE – Water or other agencies.*"

That the DPIE has not subsequently pursued this approach reflects the particular perspective of the DPIE, not the merits of this approach to assessing watercourse impact acceptability.

Having found the proponent's assessment of streams inadequate, the BSO PAC Panel undertook its own assessment and identified streams meriting recognition as being of special significance. The BSO Panel sets out its assessment approach in Section 7.1 of the July 2010 review report. In contrast to the DPIE's report, the BSO PAC Panel review recognises the importance of pristine and near pristine watercourses and of 1^{st} and 2^{nd} order streams. Comments in this section of the PAC review report include:

"*The Panel does not subscribe to streams being represented as a series of discrete features in the landscape. Streams form a connected linear network. Many stream values depend on the recognition of the stream system as a continuum with the value of any segment heavily dependent on what happens up and downstream and in higher and lower order components of the system.*"

"*In the remote areas of sandstone gorges to the east and south of the Study Area, the Panel's assessment finds that much of the value of the stream network is closely associated with its natural characteristics and its pristine setting.*"

"*Even small impacts can have major consequences for naturalness values*."

The importance of 1st and 2nd order streams is discussed in Section 7.6.4, which includes the following:

"*In reality, the condition of third order streams cannot be divorced from the condition of their first and second order tributaries or for that matter, the condition of the swamps that supply their base flow. It follows that if any third order or larger stream qualifies for special protection or special significance status on these grounds, then assessment of all of its tributaries is required to determine whether subsidence-induced impacts could compromise the protection status of the stream itself.*"

In addressing special significance in Section 7.6.6 of its report, the BSO Panel applies seven considerations to a set of watercourses and concludes that "*a number of streams in the sandstone gorge classification warrant special significance status.*" In Sections 7.9.1 to 7.9.6 the Panel reviews six groupings of water courses and, of note, finds that all watercourses in the Hawkesbury Sandstone of the North Cliff domain and all but two in the south east domain merit recognition as being of special significance. The Panel notes that despite not achieving special significance status because of previous impacts, Cataract Creek and Lizard Creek exhibit highly significant values and the consequences of further impact makes them worthy of protection.

The Panel recommends that all watercourses recognised as being of special significance should be protected from no more than negligible subsidence-related impacts;

"*no diversion of flows, no change in the natural drainage behaviour of pools, minimal iron staining, minimal gas releases and continued maintenance of water quality at its pre-mining standard*".

The North Cliff and south east domain of the BSO proposal were to mine beneath the then O'Hares Creek Special Area and penetrate beneath the Woronora and Metropolitan Special Area. Following publication of the July 2010 PAC Panel report, these area were withdrawn from the project and Dharawal National Park was subsequently declared.

6. The Tammetta equation

The Tammetta equation is an empirically determined hydrological equation; it calculates a hydrological observable and was obtained from hydrological data; the equation has no direct knowledge of geology or geomechanics. Nonetheless, on the basis of the available information, including its Groundwater publication, the equation offers at least a first approximation estimate of the height above the centreline of a longwall coal extraction at which a piezometer would report zero pressure head as a consequence of relatively rapid drainage (see Fig. 9). That is, where a piezometer would report a zero groundwater pressure head and show no more than transient responses to rainfall/recharge. There is a physical limit to that height; the surface. Highlighted for the first time in a July 2015 NPA letter to the then Planning Minister[23], and in a detailed review of piezometer data sent to the Minister in December 2016[24], the Tammetta equation predicts the drainage zone will intersect the surface over parts of the Dendrobium mine. Recent mining company reports find that data from the mine's piezometer bores are consistent with that expectation.[25]–[28] The 2016 report recommended that the Tammetta equation should be used in the assessment of underground mining impacts:

> "*Given the available evidence and leading science journal publication, the use of the Tammetta equation to be required for groundwater assessments for all underground mining proposals, including the next phase of existing projects, unless and until it can unequivocally be shown to be erroneous, to a standard that would satisfy the requirements of publication in a leading international science journal.*"

7. The drainage zone and the collapsed zone

In taking a hydrological perspective to underground mining impacts, Tammetta identifies two zones, with the drainage zone being desaturated, fully depressurised, relatively rapidly draining and unable to sustain a non-zero pressure head. The rock beyond the drainage zone, characterised as the disturbed zone, remains saturated and able to support a positive pressure head. Tammetta gives the following description of the drainage zone:

> "*This zone is severely disturbed and is completely drained of groundwater during caving, and is subsequently unable to maintain a positive pressure head. It will behave as a drain while the void is kept dewatered, and during early recovery. Within this zone, the matrix of rock blocks may continue draining for extended periods however the defects will immediately transport this water downward to discharge from the mine. Groundwater flow is not laminar and Darcy's law is unlikely to be obeyed.*"

That is, flow around and through the rotated and fractured spalls (rock blocks) in this zone tends to be chaotic and non-Darcian. Distinguishing his work from that of others, his work on underground mining impacts has been published[29]–[36] in three papers, with supporting material, in a peer reviewed science journal (Groundwater). To date there have been no peer reviewed journal refutations.

Tammetta uses centreline piezometer bore data to locate the height of the drainage at a point in the interval between the shallowest piezometer that reports a zero pressure head (or rapid fall to zero head) and the deepest that reports a positive pressure head. The PSM report[37] and IEPMC reports recognise that piezometer data provide the best means of locating the height of the drainage zone. The PSM report for example states:

> "*The real measure of connection are the piezometric profiles over time, they are the best available means for quantifying the impact of mining on the hydrogeological regime, because*

they are a direct large scale measurement of any changes in the hydrogeological system. As such they are also a measure of hydraulic connectivity."

And

"*The most relevant direct evidence were the piezometer records due to their spatial and temporal coverage, the high reliability of the predominant instrument used (vibrating wire piezometer) and the response of groundwater pressures to interconnected fracturing, which is the basis of permeability*."

Tammetta finds that the drainage zone coincides with a zone distinguished from its surrounds by a sharp increase in downward rock movement, corresponding to collapse below the formation of a pressure arch that spans the extraction void and supports the overburden (see Figs. 10 to 18). Tammetta describes the development of the collapsed zone, with then recent references, in the supplementary material for his 2015 paper.[32]

Implicit in the overlapping and complementary geomechanical accounts of the response of the rock over and around a coal extraction provided by Galvin[12], Tammetta[32], [38] and Mills[39] is that the height of the collapsed zone is determined by the height at which a stable pressure arch (see Figs. 10 to 16) forms over the extraction. Step-wise pressure arch formation is suggested by the 'torn-edge' evident in the photograph shown in Figure 13 below and Tammetta's summary of the collapse process. The geomechanical accounts provided by Galvin, Tammetta, Mills and others suggest the height of the pressure arch will be determined by the extraction geometry (extraction width, extraction height/thickness and overburden depth/height), geology and horizontal stresses.

Tammetta's work is consistent with modelling studies of Whittaker and Reddish[40], seismic studies by Kelly and others[32], [41], extensometer studies by Mills and O'Grady[42] and numerical simulations and observations by Gale.[43] These studies find the collapsed zone profile has the shape approximating that of an inverted parabola (see Figs. 10 to 17). In his 2013 Groundwater paper Tammetta also refers to a 1968 study by Dowdell[44] that finds a parabolic profile for the collapsed zone.

Consistent with the prior work of others, Tammetta finds that the key parameters are extraction width, extraction height/thickness and overburden depth/height. This dependence is captured in his empirically determined equation. His work recognises there may be local geological circumstances[30][45] for which his equation is less suited.

8. Utility of the Tammetta Equation

The IAPUM includes the following comment on the Tammetta equation as a footnote in its advice:

"*The use of the Tammetta equation, as recommended by the IEPMC (OCSE, 2019a) is not because it is necessarily a technically sound technique or the most accurate but because of all the predictive techniques, it generally produces the highest estimates of the height of connective fracturing for Dendrobium Mine and, therefore, predicts worst-case outcomes. The Tammetta equation predicts that over a large proportion of Area 5 the deep subsurface connective fracture* *zone will not overlap with the shallow near-surface connective fracture zone. (Figure 3B of the Submissions Report).*"

The IAPUM may be unaware of the observations and conclusions given in the end of panel (EoP) reports for Dendrobium Longwalls 13[25], 14[26] and 15[27] and a January 2020 'height of fracture' (HoF) report for Area 3.[28] The August 2018 LW13 EoP report for example observes:

"*The review by consultants PSM (2017) concluded that such empirical approaches carry significant uncertainty and limitations related to the data on which they were based, and that fracturing above the (305 m wide) panels in Area 3B likely extends to the surface (Galvin 2017; PSM 2017). The latter conclusion is consistent with the predictions of the Tammetta model at Dendrobium Area 3B, and observations presented here.*"

"*Observations during installation of S2220, S2306, S2335A and S2338, indicate that the Hawkesbury Sandstone undergoes fracturing to the surface, accompanied by depressurisation of most strata (Table 3; Appendix A). Pressure head in all piezometers at S2306 declined to near-zero, whereas positive pressure head is observed in sensors at S2220 and S2338*."

"*These results indicate that fracture networks propagate to shallow depths causing depressurisation of adjacent strata above mined longwalls over much of Area 3B. However, there is evidence that drainage of the Hawkesbury Sandstone above goafs is not complete in all areas and some perched groundwater horizons remain in shallow sandstone strata. In the case of S2220, perched horizons appear to respond to groundwater recharge events. Perching at S2338 is not clear, since piezometers at a similar depth in the immediately adjacent S2337 record near-zero pressure head suggesting full depressurisation of monitored strata (Hawkesbury Sandstone).*"

Referring to the 2020 HoF study, the LW15 EoP reports:

"*VWPs installed after longwall extraction indicate significant depressurisation throughout all strata, with near-zero pressure heads recorded in most piezometers. Complete depressurisation is recorded throughout the HBSS in most holes drilled above goaf.*"

The HoF report finds as follows:

"*In the context of previous models it is interpreted that the height of connected fracturing (and depressurisation) extend to the surface in Areas 3A and 3B and likely also in Areas 1 and 2. Observations from this investigation are most consistent with the empirical model of Tammetta (2013).*"

As mentioned above, a detailed 2016 review[24] of hydrographs from a number of piezometer installations at Dendrobium found the data to be consistent with the Tammetta equation. That review followed an initial review sent to the Minister for Planning in July 2015. Sent to the Planning Minister in December 2016, the detailed piezometer data review suggested that end of panel report assessments to that time for the Dendrobium mine had not adequately recognised that horizontal conductivities are one to three orders of magnitude greater than vertical conductivities.

Of relevance, apparently overlooking transcendental functions being dimensionless, the IEPMC incorrectly suggests that the Tammetta equation is dimensionally inconsistent. As pointed out in the NPA's 2018 comments[46] on the Galvin review[19], [47] of the PSM report, like Kepler's laws of planetary motion, Tammetta's empirical equation offers a valuable first order estimate of a physical outcome that bypasses the currently intractable problem of explicitly representing its underlying physical cause. The available information suggests that the Tammetta equation should be regarded as providing an estimate of the likely height of the drainage zone.

10. Application of the Tammetta equation

The graphs in Figures 19 and 20 below reflect the application of the Tammetta equation to Areas 5 and 6, for 305 and 150 metre wide extractions and the minimum, mean and maximum depths of cover, using information provided in Table 1-7 of the groundwater assessment[48] for the proposed mining. Both graphs include a 90 metre depth reference line, in recognition of the following advice[49], [50] from consultants GeoTerra, which suggests that the drainage zone doesn't need to reach the surface to exert an adverse influence:

> "*A minimum thickness of unfractured overburden is required to maintain hydraulic separation between a mine and saturated aquifers, with the critical value depending on lithology, structure and topography. The minimum separation has been established through observation and research in NSW mines as ranging from less than 90m up to 150m*."

This observation would also suggest that drainage zones should not reach an elevation greater than 90 to 150 metres below the floor elevation of a nearby reservoir (see Fig. 21). Horizontal conductivities are 10 to 1,000 times greater than vertical. Where a drainage zone rises above the elevation of the floor of a nearby reservoir, baseflow diversion and loss will be correspondingly greater. Shear plane activation can compound this consequence; shear planes can diver water from both reservoirs and watercourses.

The advice is reinforced by the following observation of the IEPMC:

> "*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*."

As noted in Section 4.5.1, Tammetta finds[21] that bulk hydraulic conductivity in the Southern Coalfield is controlled by defects and fractures in the top 200 metres of an unmined area. The ground disturbance caused by mining further increases bulk hydraulic conductivity.

Figure 19 suggests that for the minimum depth of cover, the drainage zone would generally be within 50 metres of the surface. The separation is generally 50 to 80 metres for the mean depth of cover and 80 to 110 metres for the maximum depth of cover. In part, these differences reflect that the equation is least sensitive to depth of cover. Reflecting this, Mackie put forward a simplification that didn't include depth of cover.[35] In doing so, he comments; "*The paper by Tammetta provides a useful empirical equation for predicting the height of complete drainage above longwall panels*".

In contrast, Figure 20 finds that the drainage zones for 150 metre extractions are generally more than 120 metres from the surface for the full range of cover depths, and generally more than 200 metres away for the mean and maximum cover depths.

11. Lack of constrained zone at Dendrobium

In its comments on the risk of contaminated mine water discharge at the surface (discussed in Section 14) the DPIE assessment report overlooks a key finding of the 2017 PSM report, which reflects the height of the drainage zone arising from the extraction widths and heights used at Dendrobium:

> "*1. There is no widespread evidence of a Constrained Zone limiting effects of mining and impacts on the more shallow ground and surface water systems.*"

The DPIE assessment also overlooks the advice noted above, of consultants GeoTerra[49], [50]:

> "*A minimum thickness of unfractured overburden is required to maintain hydraulic separation between a mine and saturated aquifers, with the critical value depending on lithology, structure and topography. The minimum separation has been established through observation and research in NSW mines as ranging from less than 90m up to 150m.*"

As Figure 19 reflects, application of the Tammetta equation suggests that there would not be a sufficient separation between the peak of the drainage zone and the surface or surface fracture network over much of the project's mining area. That is, there would not be a constrained zone.

Figure 22 below shows the hydrographs from instruments installed in the Hawkesbury Sandstone in multi-piezometer bore S2220, which installed over the centreline of the eastern third of Dendrobium Longwall 9 in October 2014. The bore has the same piezometer number and depth placement as the nearby centreline bore S2192, which was installed in March 2013, before the site was undermined by Longwall 9. The S2220 installation was completed approximately a year after the longwall face had passed below S2192 in October 2013 and four months after the LW9 extraction was completed in June 2014.

The bore was installed as part of a project[51] undertaken by Parsons Brinkerhoff to determine the height of the drainage zone over the eastern end of the extraction. Possibly a consequence of unusual local geological circumstances[24], the project was unable to make a reliable determination of the drainage zone height:

> "*current observations do not allow a precise measurement of the height of intense fracturing using any criteria*".

Understanding the outcome at the eastern end of LW9 has been obstructed by a lack of availability of key data. In their submission comments on the then proposed subsidence management plan (SMP) for LW16, WaterNSW state the following

> "*Further, the HoCR (PSM, 2017) noted that extensometer data which has been referred to in the PB(2015) report were not able to be furnished to them by IC despite repeated requests*."

And:

> "*One issue reported by PSM is that some data that should have been available was not, for example the extensometer data referred to by Parsons Brinckerhoff (2015). WaterNSW requests*

that this data be sought by OPE and provided to DRG or an independent consultant for review and/or explanation."

The extraction height used below S2220 was 3.4 metres, slightly more than the 3.2 metres proposed for Area 5, with a width of 305 metres and depth of cover of 388 metres.[27] The Tammetta equation accordingly returns a drainage zone height estimate of 319 metres, suggesting the drainage zone height would reach to 71 metres below the surface at S2220.

The instruments in the Hawkesbury Sandstone at S2220 are at depths of 50, 95 and 140 metres. The lower three instruments were lost shortly after installation, approximately a year after the longwall face had passed below the site, evidently as a result of ongoing formation of the collapsed zone. The delayed collapse may reflect unusual geological circumstances over the eastern end of LW9.

The Tammetta equation would suggest a drainage zone peak between the 50 and 95 metre deep instruments, with the latter then expected to report a zero pressure head. Reference to Fig. 23 shows instead a residual pressure head fluctuating between 10 and 18 metres in response to rainfall recharge. Figure 22 might suggest correlation with Avon Reservoir, however the reservoir is too distant for a connection to be likely. The sensor at 140 metres shows a more muted rainfall response over a slowly rising pressure head that increases from approximately 15 to 20 metres between late 2014 and early 2020. Figure 24 highlights a notably large pressure head loss at 140 metres as a consequence of the extraction below the bore site.

These observations are inconsistent with the expectations of a drainage/collapsed zone reaching to 319 metres above the extraction and 71 metres below the surface. That is, the Tammetta equation appears to overestimate the height of the drainage zone below the S2192/S2220 site. The LW13 EoP suggests the presence of perched water within the collapsed zone:

"*In the case of S2220, perched horizons appear to respond to groundwater recharge events.*"

Again, this would be inconsistent with Tammetta's characterisation of the collapsed zone, but may reflect unusual geological circumstances. The extraction of the eastern half of Longwall 9, in particular its final third, appear to have been problematic and this may reflect high horizontal stress conditions.[52]–[54] The bore site is on a ridge between Donalds Castle Creek and Wongawilli Creek tributary WC21, not far from its junction with Wongawilli Creek. High horizontal stress can be associated with valleys/gorges and contribute to non-systematic subsidence.

In the context of the DEP proposal, the S2220 hydrographs demonstrate an apparently immediate rainfall response at 90 metres, with a slower but nonetheless relatively rapid subsequent drainage. The contrastingly insensitive sensor at 50 metres suggests it may not be functioning. The S2220 hydrographs, which may reflect high horizontal stress effects, are consistent with there being no constrained zone over the extraction. In a complementary manner to those of bore 9GGW2B over the Metropolitan Mine (Section 4.5.1), the S2220 hydrographs highlight the difficulty of predicting and assessing the outcomes of mining in the Special Areas,

12. Inadequate Modelling

The proponent, and IAPUM, characterises the groundwater modelling and, accordingly, surface water modelling as conservative, on the basis that connected seam to surface fracturing is assumed for the project area. The Tammetta equation suggests that this would be the case for some parts of the project area, but not otherwise. Of importance, the PSM report and subsequent end of panel reports, find that there is no constrained zone over the Dendrobium extractions (see Section 11).

Whether or not the modelling is conservative in nature depends on the site specific circumstances of each of the proposed extractions. Also of importance, it would depend on the adequacy of model calibration and on how the drainage and disturbed zones (Section 7) are represented. The IAPUM raises concern with respect to both calibration and the manner in which hydraulic conductivities are set.

While the model assumes connected fracturing from the seam to the surface, several comments in the assessment report suggest the model does not accommodate Tammetta's characterisation[29]–[36] of the drainage zone. In particular, these comments suggest the model does not represent a fully depressurised drainage zone reaching the surface, nor reaching a freely draining surface fracture network, nor having a height estimated by the Tammetta equation. For example:

> "S*pecific storage (Ss) has not been enhanced in simulations. David et al. (2017) made some estimates of enhanced Ss above longwalls, however we consider that this parameter is likely the least sensitive of the four parameters (kh, Kv, Sy and Ss) given that it occurs within or above the connected fracture zone of which the lower 'half' is at low or zero pressure.*"

Though unclear, the comment seems to suggest that the model only recognises (full) depressurisation in the lower half of the drainage zone (connected fracture zone), whether or not it reaches the surface or surface fracture zone, and doesn't recognise seam to surface (full) depressurisation.

If this is the case, then the model would not be conservative and would instead effectively reflect the Ditton-Merrick model[55], [56] of fracturing. The height of the depressurised/drainage zone in the Ditton-Merrick model, referred to as the 'A zone', is approximately half that of the Tammetta equation, for extractions at Dendrobium. The upper part of the model representation in Figure 5-2 in the groundwater assessment is more suggestive of the Ditton-Merrick B Zone. A poor representation of the drainage zone, the depiction of zone 2 in Fig. 5-2 suggests incorporation of both the Ditton-Merrick A zone and the B zone.

Restrictions on the drainage zone in the model also seem to be suggested by the following:

> "*Where the downward drainage of water in the fracture system encounters restrictions (partially closed fractures or fracture terminations), the fractures may fill or perch and would then drain at a rate dependant on the rock matrix or fracture hydraulic conductivity.*"

This unsupported comment doesn't recognise spall formation and rotation in the development of the collapsed zone.[32] While perching would be accommodated in the Ditton-Merrick B Zone and Tammetta's disturbed zone, the Ditton-Merrick A zone and the drainage/collapsed zone, as characterised by Tammetta, would not support perching. Tammetta relates[31] spall formation to hydraulic behaviour of the drainage/collapsed zone:

“*However, at a larger scale, it is the poorly mated breakage surfaces of the collapsed spalls, in conjunction with their connection to the goaf and strata dilation zone, that may dictate the hydraulic behavior of the collapsed zone and provide the greatest influence on its overall K*.”

While Tammetta’s clearly relevant 2015 paper[31] on hydraulic conductivity changes and 2016 paper[33] on storativity are listed as references, they are not used or referred to within the report. That the modelling may not represent Tammetta’s drainage zone is also suggested in the following observations in the groundwater assessment report:

“*Within and adjacent to the connected fracture zone ② which, at Area 3B includes the Scarborough and Bulgo Sandstones, and in the Hawkesbury Sandstone. The drawdown is often > 50m or the strata become completely depressurised (pressure head is zero). Drawdown in the mid Hawkesbury Sandstone is about 10-20 m, and in the shallower horizons of the Hawkesbury Sandstone it has been observed to be <5 m (e.g. at S2192-S2220 directly overlying Longwall 9). The declining drawdown might be due to decreasing fracture connection③, although PSM (2017) concluded that the fracturing above Longwall 9 is connected right through to the surface*.”

The suggested observations are unhelpful in failing to specify which instrument bores are being referred to and whether or not they are over the extraction centreline. The observations fail to recognise Tammetta’s characterisation of the drainage zone as being the (fully) depressurised collapsed zone, comprised of fractured spalls below a pressure arch (see Fig.14) that spans the goaf and supports the overburden (see Section 7).

That this may be so is reinforced by Figure 5-2 in the groundwater assessment, which doesn’t recognise spall formation and separation of the collapsed zone from the pressure arch. Nor does it include vertical fracturing in the upper part if the drainage/collapsed zone. The model represented in this figure would appear to be inconsistent with the hydrological and geotechnical accounts provided by Tammetta and by Mills. Both Tammetta and Mills identify a zone of significant downward movement below a pressure arch, through which there would be relatively free drainage. As noted above, zone 2 in the depiction in Fig. 5-2 is suggestive of a union of the Ditton-Merrick A and B zones.

As noted above, perching and partial depressurisation would not be expected within the drainage/collapsed zone. Currently the only publicly available post-extraction hydrographs from a piezometer bore penetrating through the drainage zone profile over the centreline of a Dendrobium extraction, would appear to be those of bore S2220 over the eastern end of Longwall 9 (see Section 11). The LW15 end of panel report[27] and the 2020 height of fracture report[28] summarise findings from subsequent centreline bores, but the hydrographs derived from those bores ae not provided in either report. They do not otherwise appear to have been made publicly available or otherwise made available to WaterNSW. This is puzzling and troubling, given the central importance of piezometer data in assessing the height of the drainage zone (see Sections 6 and 7).

As discussed in Section 11, the S2220 data do not permit a definitive determination of the drainage zone height. The hydrographs suggest the height is lower than suggested by the Tammetta equation, possibly because of unusual local geological circumstances. It would be unsafe, however, to assume that this would be the case elsewhere over the mine. The LW15 end of panel report[27] and the 2020 height of fracturing report[28] suggest this is not the case elsewhere in Area 3.

The following comment seems to suggest that the model doesn't incorporate vertical and sub-vertical entry into the drainage zone, either directly at the surface or via the surface fracture network:

> "*HS has conceptualised flow to be both horizontal (when entering vertical fractures) or vertical (when entering shears, dilated bedding planes), so conductance needs to account for this.*"

The account given in the groundwater assessment doesn't describe how, or if, non-Darcian drainage is modelled. Flow in the drainage zone would primarily be non-Darcian. The model used for the EIS appears to be framed in a now dated perspective that doesn't recognise relatively recent progress in understanding collapse over the extraction void.

As the IAPUM points out, the model is primarily calibrated only with respect to hydraulic heads. Compounding this limitation, the IAPUM points out the following:

> "*Changes in hydraulic properties (particularly for low hydraulic conductivity values) may be varied over quite a wide range without the modelled head distribution being significantly altered because changes in the groundwater flows will only induce small changes in head at the recharge and discharge zones, if compensatory changes to evapotranspiration/recharge are present as is the case here.*"

Changes in hydraulic conductivity would, however, have a significant effect on fracture drainage. This is highlighted by the model's fracture radius being determined by hydraulic conductivity and, in turn, height above the goaf floor. Of note, highlighting a long standing obstacle to understanding mining impacts in the Special Areas, the SCT reports referred to in setting these relationships do not appear to be publicly available.

The water balance calibration summary in Table 7-2 of the groundwater assessment report likewise offers little to give confidence in the model. The component labelled "Drains" appears as an undifferentiated aggregate of mine inflows:

> "*Dendrobium (up to Longwall 13), historical mining around Dendrobium (e.g. Nebo, Elouera, Wongawilli, Kemira etc.), and the parts of BSO, Tahmoor and Cordeaux Mines within the active model domain (Figure 6-1).*"

In not providing details, including component data and sources, the assessment fails to adequately demonstrate calibration with respect to mine inflows. That the consultant's apparently have access to data to 1940 highlights the long standing concern of mining companies holding data and information of considerable public interest. Uncertainties over the period used would hinder robust calibration.

The inadequate mine inflow calibration is contrasted by that of the more comprehensive modelling undertaken in 2012 by Tammetta on behalf of Coffey and BHP-B for the then proposed Area 3B mining.[21], [57]–[59] The then Sydney Catchment Authority (SCA) included the following in its comments[60] on the proposed Area 3B mining:

> "*The SCA considers the information presented in the SMP Attachment C Groundwater Study by Coffey Geotechnics is sound and well researched and provides an important step in the development of a rigorous regional groundwater model*."

The contrast with the current DEP modelling is further highlighted by the comprehensive assembling and assessment of field hydraulic conductivities in the 2012 assessment. Unlike the DEP modelling, this includes demonstrating calibration of the model hydraulic conductivities with respect to the substantial database of field measurements.

The IAPUM report points out the unusual approach used to set hydraulic conductivities, using a geology agnostic depth function and a depth multiplier. The approach does not appear to recognise Tammetta's finding[21] that "*the top 200m of an unmined rock profile in the mine area, the bulk hydraulic conductivity of a large rock volume is controlled mostly by open defects and fracture flow*." The top 200 metres are of particular importance at Dendrobium, because of the considerable height of the drainage zones. Tammetta's finding is not reflected, for example, in the following comments:

> "*Vertical hydraulic conductivity is considered to be more controlled by lithology, particularly the increased frequency of fine-grained laminations and horizons in the dominantly claystone units*."

And:

> "*The conceptual model is that vertical hydraulic conductivity (Kv) is governed more by the dominant lithology than depth.*"

The IAPUM comments:

> "*The risk is that the model is underestimating the total groundwater flows by underestimating the hydraulic properties of the formations and that the calibration approach, which has been largely based on head calibration and mine inflow calibrations, is desensitised by this selection of a self-balancing recharge model across the majority of the modelled area.*"

In addition to limited calibration, there would appear to be no sensitivity testing of the model with respect to extraction width, drainage zone height, conductivities or fracture apertures. A significant weakness in the modelling for the then proposed extraction of Longwall 16, noted by NPA and WaterNSW, was its implausible lack of sensitivity to the height of the drainage zone.

Demonstrating the limitations of the modelling is the finding that "*Water table drawdown is typically restricted to within about 200 m of the longwall footprin*t". This would be highly implausible even for 150 metre extractions in the Special Areas.

13. Water quantity loss

Neither the DPIE nor the proponent appear to consider the projects substantial surface water and groundwater take in the context of cumulative losses to date, arising from mining in and around the Special Areas.

In Part 2 of its final report the IEPMC provided a surface water loss estimate of 8 Ml/day, based on inflow data for the Dendrobium, Russell Vale and Wongawilli mines in the Metropolitan Special Area. The estimate does not include inflows to the historical mines and mine areas in and around the Special Areas. Additionally, as discussed below, the IEPMC's loss estimates for the Wongawilli mine and for the reservoirs appear likely to be incorrect. The IEPMC estimate is likely to be a significant underestimate of cumulative surface water loss.

13.1 Wongawilli Mine inflows

The current Wongawilli mine is an 'amalgam' of the old mine, the Nebo mine, the Elouera mine, Avondale mine and part of the Huntly mine lease. The old Elouera mine was a merger of the adjacent Nebo and 'old Wongawilli' mines, the former extracting coal from the Wongawilli seam and the latter from both the Wongawilli seam and, to a lesser extent, the overlying Bulli seam.

The loss listed for the Wongawilli mine in Table 3 of the IEPMC report appears to be incorrect. This tabulated estimate reflects an average pump out volume of 0.8 Ml/day for the period 2014 to 2019 and would appear to implicitly assume that the inflow volume retained within the mine is not lost to the surface. It would seem more appropriate, however, to assume that inflow retained within the mine includes a component lost from the surface (and subsurface) and unlikely to be returned to the surface.

The amount of water discharged by the mine depends on inflow levels and the availability and usage of pooled water during operations. It might be suggested that the usage of some of the pooled inflow for mine operations avoids a need to take 'tap water' from the drinking water supply system. Supply water would be purchased, however, whereas there is currently no compensation for inflow take.

The large inflows listed in Table 1 below are similar to those of the adjacent Dendrobium mine. It's understood that at least some of the inflow to the Elouera domain of the Wongawilli mine is from the Dendrobium mine. The unquantified component from Dendrobium would not be included in the inflow figures for that mine. Up until May 2011 the water pooling in the Elouera domain had been used as a source for mine operations. Access was, however, lost with the extraction of Longwall 19. This is reflected in the mine's annual review reports. The 2015 report, for example, has the following:

> " *Extraction of LW19 resulted in restricted access to key storages of the underground reticulation system. Due to the restricted access to water underground, de-watering was stopped on 28th May 2011 to increase water storage levels underground. During the reporting period, mine de-watering has started again mainly due to lack of underground water usage for mining purposes and recent very intense rainfall events.*"

The resumption of dewatering reflects the mine's closure in 2014, following the burial and loss of its longwall machine. The 2019 annual review repeats comments in previous reviews back to 2013:

> "*The groundwater inflow to the mine is approximately 50 to 60 L/second during normal conditions with* ***increases*** *to approximately 120 L/second during prolonged periods of substantial regional rainfall. Mine de-watering can occur at an average rate of approximately 4.2 ML/day during normal mining operations."*

Table 2 lists 1978 historical discharge volumes that then suggest significantly higher inflow volumes at that time. A 1986 symposium paper notes inflows to the Nebo mine of 0.96 to 24 Ml/day during periods of prolonged rain.[61]

The annual reviews 2012, 2013 and 2014 annual reviews comment; "*Wongawilli Colliery is generally considered a "wet" mine as it needs to be routinely dewatered*" and its inflows are reported to be sensitive to rainfall.

The Nebo and old Wongawilli and neighbouring Mt Kembla and Kemira, mines used 'bord and pillar' extraction with significant areas of full pillar extraction. Total pillar extraction suggests the possibility that at least some of the resulting extraction widths may have exceeded the critical width and, accordingly, the bridging capacity of the overlying strata. Nebo for instance used full pillar extraction to form panels up to 385 metres wide and 765 metres long[62] in the vicinity of new longwall mining approved in 2010; wider pillar extraction panels may have been used elsewhere in the old Nebo domain. As Table 2 indicates, as of 1978 pillars were removed from 30.4% of the mined areas. The depth of cover in some areas of the mine appears to be as low as 100 metres.[62] Maps giving the dimensions and locations of the total pillar extraction areas do not appear to be publicly available.

The Mt Kembla, Kemira and the north eastern corner of Nebo, near the first longwall of Dendrobium, have been reported to have substantial levels of inundation.[63][64] A 2004 estimate[63] has 900 million litres of water in the Mt Kembla workings; mining included extraction from beneath Cordeaux Reservoir with a depth of cover of approximately 120 metres.

Huntley, Like Nebo, was regarded as a 'wet' mine, with algal studies suggesting an inflow contribution from Avon reservoir[65][66], following shallow first workings some 60 metres below an arm of the reservoir. The mine closed in 1989 and the Avondale-Huntley complex was closed off in 1993.[67] Water is reported to drain from the portals of the Avondale mine to the Huntley Heritage area[68], while anecdotal reports suggest water is being discharged from the Huntley mine.

The closed Bulli seam workings of the old Wongawilli mine have been reported to hold a large body of water, with the volume estimate in the report being the equivalent of 252 Olympic swimming pools.

The 2010 surface water management assessment report for then new longwalls being proposed for the Nebo area notes "*Groundwater inflow rates vary, and tend to increase during prolonged periods of substantial regional rainfall*".[69] Similarly, the 2010 end of panel report for Longwall 12 in the Elouera area of the current Wongawilli Mine notes that the old Wongawilli, Nebo, Kemira, Elouera mines and the adjacent Dendrobium mines have "*reported significant increased inflow subsequent to significant rain events*".[70]

The 2010 groundwater impact assessment for the 2010 Nebo area longwall mining proposal reports:

> "*bord and pillar as well as pillar extraction and longwall mining has been conducted in the adjacent Wongawilli, Elouera and Dendrobium Area 2 workings, and that vertical hydraulic connection has been observed at some locations between surface streams and the underlying workings*".[62]

The assessment report further comments that a significant but unquantified component of the water entering the Elouera mine comes "*from surface water seeping through subsidence cracks following extraction of Elouera Longwalls 6 and 7 under Wongawilli Creek*".[62] That is, the longwall mining evidently resulted in a direct hydraulic connection from the creek into the mine. The appended Fig. 25 shows a substantial crack across Wongawilli Creek above the old Elouera longwalls.[71] Of note, as Tables 1 and 2 indicate, the Elouera area experiences similar peak inflows to those reported for the Dendrobium and Nebo mines.

Consultants GHD note in their 2008 hydrogeology impact assessment for then proposed changes to longwall mining planned and approved for Area 3 of the Dendrobium mine, that "*BHP Billiton have advised that inundation of the workings by mine water has reached the main heading servicing Elouera Longwalls 7 & 8*". They also suggest inflows into the Dendrobium mine may drain into the old Elouera workings. As noted above, relatively recent mining has closed off this part of the Wongawilli mine, resulting in an accumulating body of underground mine water and much lower inflow volume reports.[72] That is, the reported inflow volumes don't appear to reflect the overall inflow in this area of the mine.

A substantial body of water is also reported[62] to have been accumulating in the south western area of the Wongawilli mine, against a downward slope in the lowest part of the old workings in the Wongawilli seam. Described as having up to 42 metres of "head', the source and inflow rate of the water wasn't known at the time of the report. It's not known if the water has since been pumped out; if not, inflow into this body of water would not contribute to reported inflow figures. A similarly large body of water is accumulating at Cordeaux Colliery. The IAPUM comments:

> "*The DEP proposal provides for holing into Cordeaux Colliery. This in turn requires consideration of what impacts and consequences this might have for water quality and quantity in the catchment due to leakage paths in Cordeaux Colliery. The EIS and supporting information do not acknowledge this risk and how it might be controlled.*"

The assessment reports variously suggest average daily inflows into the Wongawilli mine somewhere between 4.2 and 16.4 Ml/day. The apparently conflicting figures may reflect reference to different mine workings, changing water body access, inflow records reported for different periods with varying rainfall and, possibly, confusion between inflow and dewatering rates. Noting the rainfall sensitivity of the mine's inflows, the surface component would seem likely to be considerably greater than suggested by the IEPMC.

At the December 2019 Wongawilli Community Consultative Committee meeting the mine operators advised that, following the cessation of mining and recent closing of the Nebo area, the area's discharge pump had become submerged and was no longer functional. The mine can't be sealed and, accordingly, is expected to continue to flood until it reaches a 'spill point' and begins to discharge at the Illawarra Escarpment near Dombarton. This discharge would be expected to continue in perpetuity. Lodgement in the Wongawilli mine is depicted in Figure 26 below; the date that this was recorded in not known.

13.2 Reservoir Leakage

The IEPMC's estimate of leakages from Avon and Cordeaux Reservoirs are from modelling studies on behalf of the proponent and may underestimate storage leakage. This is suggested by a 2018 SCT study[73] of shear plane activation using data from a bore near Dendrobium Area 3B Longwall 14, that finds leakage from the reservoir of up to 1 ML/day/km of shoreline. Commenting on the then proposed extraction of LW16, WaterNSW expressed concern[74] that, given that there is a reservoir shoreline length of around 1.65 km adjacent to LWs12-16, the SCT study would suggest leakage of up to 1.6 ML/day. This would be greater that the DSC's tolerable loss limit. The length of shore between LWs12 and 18 appears to be approximately 2.7 km. While the SCT study doesn't suggest a uniform leakage around the boundary of the reservoir, the level of leakage induced by mining in Area 3B hasn't been reliably determined. It would reasonable to expect that the proposed Area 5 mining would compound the leakage induced by the Area 3B mining.

As yet there has been no corresponding assessment of leakage from Cordeaux Reservoir, notwithstanding concerns raised by PSM in their study[37] of Dendrobium impacts:

> "*The interpretation from these patterns is that pressure levels in the geological units under the reservoir are being increased and or maintained by recharge through the rockmass. This is as a result of mining induced effects on the rockmass around and probably under the reservoir. This effect dissipates further away from the reservoir. The interpretation is that this pattern is consistent with some losses from the reservoir into the groundwater in the rock mass. It is considered that Area 2 and 3A mine inflows are also anomalous and probably reflect some losses, both ground and surface water, from the catchments and or reservoir.*"

A 2014 study by the Dams Safety Committee[75] finds evidence of shear pane leakage. Cataract Reservoir is not included in the IEPMC's estimate summation.

13.3 Cumulative loss estimates

A slight revision here of a 2016 tally[24] (Table 3 below) of information provided in publicly available reports from mines in and around the Special Areas suggests an inflow range of 24 to 42 million litres a day, of which an unknown proportion would be water that would otherwise have entered storage.

Table 3 uses the limited publicly available information to obtain two estimates for inflows into the mines within and adjacent to the Metropolitan and Woronora Special Areas. As a simplifying and conservative assumption, mines that closed before 1970 are assumed not to have used pillar extraction, large panel continuous mining or longwall mining and accordingly have had minimal subsidence related impacts, including minimal water inflow. Some of these mines may however have used more aggressive mining methods before closure.

Adding together the Table 3 entries for mines in and around the Metropolitan and Woronora Special Areas for which figures are available gives an Estimate-1 total of 20 Ml/day and an Estimate-2 total of 33 Ml/day.

Two approaches are used to include the five Metropolitan Special Area mines listed in Table 3 for which there would appear to be no publicly available inflow information. The first approach assumes a nominal inflow of 0.2 Ml/day for each of the five mines, while the second uses the respective medians of the Table 3 Estimate-1 and Estimate-2 inflow figures as an inflow estimate for each of the five mines. The first approach gives an Estimate-1 total of 23.6 Ml/day and an Estimate-2 total of 36.2 Ml/day. The second approach gives an Estimate-1 total of 28.9 Ml/day and an Estimate-2 total of 42.6 Ml/day. Given the wide range of the inflow estimates, adopting a figure of 33 Ml/day, comprised of 32 Ml/day for the Metropolitan Special Ares and 1 Ml/day for the Woronora Special Area, provides a mid-range indicator with which to consider the significance and implications of mine inflows.

Recent work[76], [77] undertaken by WaterNSW suggests up the 50% of the inflow to mine in and around the Special Areas may be catchment surface water. This estimate is consistent with that of a 2018 scoping study[78], obtained by an independent estimation method. The IAPUM observes that, ultimately, all inflow comes from the surface. Using streamflow data, the 2018 study highlights the importance of subsurface loss:

> "*Using gauges with reasonable results (KCW1 and DCS2), the average proportion of loss that is contributed by runoff is calculated as about 25%. This is interpreted as indicating the higher chance of successfully exiting a catchment for large short-term discharges (which in fact form the majority of total stream discharge for many catchments). This suggests the baseflow component of streamflow is more prone to mining impact than the runoff component.*"

The 2018 study suggests a surface and subsurface water loss of 24 Ml/day. The estimate is unreliable, however, reflecting the limited and variable quality of the available data. Using a complementary approach, the more recent work estimates current surface water losses at up to 17.3 Ml/day.

13.4 Silent surface water diversion

Currently there is no means of reliably estimating how much water is lost through surface water diversion into groundwater flows that leave the catchment area and bypass storage.

13.5 Regional depressurisation

The extent of mining in and around the Special Areas is depicted in Fig. 1. Clearly its already substantial relative to the size of the reservoirs. An unknown fraction of the mined area has seam to surface hydraulic connections, while other areas have no constrained zone and drainage zones approaching the surface.

The extent of the mining is such that it has significantly reduced groundwater levels in these areas. Inadequate monitoring leaves the extent of depressurisation unknown. It would seem unlikely that this has caused no more than a negligible reduction in baseflow supply to the reservoirs, and the streams on which they depend, from the areas above and around the mines. In the current context, it would seem unlikely that mining at Dendrobium has caused no more than a negligible impact to baseflow supply to the Avon and Cordeaux Reservoirs, from that area of the Metropolitan Special Area. Inadequate monitoring precludes establishing this is the case to the satisfaction of all stakeholders, notably the DPIE.

Demonstrating the problem, Table 4 below is a 2016 tabulation[24] of large drawdowns at the Dendrobium mine, including drawdowns that were not given attention in the mine's end of panel reports. Some triggered Level 3 TARP alerts.

The IAPUM observes:

> "*The Panel notes that the NSW Bushfire Inquiry (2020) identified soil dryness as a significant factor in fire severity and the severe impacts of the Gospers Mountain fire on undermined swamps on the Newnes Plateau. It suggests that both the ecological and community-related risks of potentially enhanced fire severity across the mining domains should be considered*."

13.6 How much loss is too much?

The proponent has proposed compensation for water lost as a consequence of mining in the absence of consideration of compounding cumulative losses to date. A loss of up to 25 million litres a day, some perpetual, would correspond to approximately 10% of the current capacity of the desalination plant and approximately 8% of the average daily volume of water supply taken in total from the Avon, Cataract, Cordeaux and Woronora Reservoirs. The significance of these losses would increase during periods of extreme drought.

14. Water Quality Loss

Surface water diverted into subsurface flows that return to the surface downstream will be contaminated as a consequence of interaction with the freshly exposed rock surface of cracks.[17] The contaminants will accumulate on and near the floor of a reservoir. Subsurface flows that enter the storage without joining surface flows will likewise become contaminated with passage over the surface of fractures and sheared planes. Neither the DPIE nor the proponent appear to consider mining induced contamination of subsurface flows, which may transport contaminants over a wider area than surface flows.

The IAPUM finds the proponents assessment of long term water quality consequences inadequate, with comments that include the following:

> "*The assessment of potential for adverse consequences on stream and reservoir water quality lacks consideration of long term cumulative contaminant loads, including emergence of contaminated shallow and deep groundwater post-closure. It is not sufficient to assume, as the EIS does, that the current lack of evidence of water quality consequences will continue long term*."

Absence of evidence is not evidence of absence. The amount of contamination that has accumulated on and near the floors of the reservoirs isn't known. That is may be becoming of significance during low rainfall periods is reflected in the ABC report[79] of December last year, and highlighted by Dr Ian Wright in his presentation to the DEP Panel on Friday 4th of December. The proposed mining could also pose a risk to the quality of water in watercourses that don't flow to the nearby reservoirs, but instead contribute at Pheasants Nest Weir.

14.1 Mine water discharge to the catchment surface

A critical concern of the proposed mining is that if the mine can in fact be sealed following the cessation of operations, the drainage zone will facilitate the discharge of contaminated water at the surface, either directly or through the surface fracture network. This risk was first identified by Tammetta in a Department of Planning commissioned June 2013 review[80] of the groundwater assessment for the then proposed Gujarat NRE No.1 Colliery expansion:

> "*The analysis of the height of the collapsed zone, and the areas where this zone connects with the surface tensile zone, identify areas where migration of high salinity water from the goafs can easily exit the surface, depending on the geometry of the mine workings and the post mining hydraulic head field (especially the equilibrium void water levels).*"

In this case, there was concern that the drainage zone would reach the surface over multi-seam extractions then being proposed as part of the Russell Vale expansion proposal. Water moves relatively freely through the drainage zone.

The DPIE is dismissive of the concern on the basis of an assumption that a 'constrained zone' of sufficient thickness will separate the top of the drainage zone from the surface and surface fracture network:

> "*However, there is some likelihood of a solid rock remaining between the surface fracture zone and the height of connected cracking (see Surface to Seam Cracking in Section 6.5). Such a 'constrained zone' acts not only to prevent or limit the percolation of surface waters to the mine but also acts to prevent or limit repressurised coal seam aquifers from rising to the surface, where they may discharge.*"

Of note, the DPIE's characterisation of the flow of water through the drainage zone as 'percolation' misrepresents the non-Darcian and relatively rapid flow that characterises this zone.

The IAPUM finds the proponents consideration of the possibility of in perpetuity discharges inadequate:

> "*Other issues are the quantity and quality of seepage from the escarpment potentially induced by groundwater recovery and the potential for flushing of contaminants from shallow groundwater during groundwater recovery. Based on the Panel's review of the EIS and discussions with the Proponent, these types of issues are yet to be fully investigated and assessed.*"

> "*In the course of undertaking this review, a memo (dated 7 September 2020) was prepared for the Proponent summarising the outcomes of numerical modelling that is concerned with the potential for upflow of contaminated water from the mining horizon to the surface. The groundwater modelling and its outcomes for the period post mining does not appear to be appropriate for assessing the likelihood of upflow of contaminated water. The hydraulic connections through and between the mines and presumably also at the mine outlets have not apparently been modelled to reflect a prescribed closure plan. It still needs to be demonstrated to a standard commensurate with the potential risks that the extraction of Areas 5 and 6 as designed will not result in unacceptable post-closure discharge of mine water into the catchment.*"

South32 does not appear to have adequately responded to these concerns. In responding to the IAPUM the company states:

> "*Additional analysis undertaken following the EIS and provided to DPIE indicates there is a low risk of adverse impacts to water quality in the Special Catchment Areas following groundwater recovery post-mining*."

This analysis does not appear to be available for public review and it's not known if this is the memo referred to by the IAPUM. The DPIE's assessment report suggests that proponent has yet to adequately address water quality risk concerns. Discharge from abandoned mines in the UK has emerged as a costly and long term legacy.

15. In Perpetuity

As is the case at the adjoining Wongawilli mine, some of the consequences of the impacts of the Dendrobium mine will be perpetual. There would appear to be no credible means of providing adequate compensation for such consequences, which are fundamentally inconsistent with the intent of the Special Areas.

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Tables

Table 1. Wongawilli inflow volumes reported in 2010[62]

MINE	Extraction	Depth of Cover (mbgl)	Max Mine Inflow
Elouera BHP / Delta Mining	Longwall	290 - 390	120l/sec (**10.4 Ml/day**)
Wongawilli BHP	Bord and Pillar	0 - 360	40l/sec max (**3.5 Ml/day**), background 20l/sec (**1.7 Ml/day**)
Wongawilli Panels 11 to 19 Gujarat	Longwall	300 - 360	120l/sec max (**10.4 Ml/day**), background 50l/sec (**4.3 Ml/day**)

Table 2. Statistics from 1978 for some bord and pillar mining with pillar extraction[81][82]

Colliery	Area Worked (Ha)	Area of Total Extraction (Ha)	Total Extraction as a Percentage	Typical Water Discharge (Ml/day)	Wet Season Water Discharge (Ml/day)
Nebo	1129	340	30.1	4.97	9.93
Wongawilli				2.62	5.45
(a) Bulli Seam	275	109	39.6		
(b) Wongawilli Seam	995	299	30.1		
Huntley				3.93	3.93
(a) Wongawilli Seam	866	174	20.1		
(b) Tongarra Seam	216	85	30.1		
(Old) Bulli - Bulli Seam	1942	712	36.7	0.24	0.24
Kemira - Bulli Seam	1141	457	40.1	0.8	0.8
Corrimal - Bulli Seam	1092	549	50.3	1.30	1.30
South Bulli (now Russell Vale)				2.16	2.16
(a) Bulli Seam	1950	1364	70		
(b) Balgownie Seam	198	40	20.2		

Table 3. Estimates of water inflow to mines in and adjacent to the Illawarra Special Areas

Woronora Special Area Mines	**Coal Seam**	**Estimate 1 (Ml/day)**	**Estimate 2 (Ml/day)**	**Peaks (Ml/Day)**
Darkes Forest	Bulli	0.10	1.00	
Coal Cliff	Bulli	0.10	1.00	
Metropolitan	Bulli	0.10	0.1	
Total		**0.3**	**2.1**	
Total - Gl/yr		**0.11**	**0.77**	
Metropolitan Special Area Mines				
Appin[21]	Bulli	1.20	1.20	
Bulli[21]	Bulli	0.24	0.24	
Cordeaux[83]	Bulli	1.47	1.47	
Corrimal[21]	Bulli	1.30	1.30	
Dendrobium[84]	Wongawilli	8.0	8.0	13.1
Huntley 1 and 2[21]	Wonga and Tongarra	3.93	3.93	
Kemira[21]	Bulli and Wongawilli	0.80	0.80	
Russell Vale - East (South Bulli)	Wongawilli	1.1	2.76	
Russell Vale - West (Bellambi West)	Bulli and Balgownie	0.4	1.0	
Wongawilli - longwalls (inc. BHP Elouera)[62]	Wongawilli	-	(4.32)	10.37
Wongawilli - Nebo area[21] [82]	Wongawilli	-	(4.87)	9.93
Wongawilli bord and pillar	Bulli and Wongawilli	-	(1.73[62])	5.45[82]
Wongawilli - closed Blue Panel area[61]		-	(0.86)	
Wongawilli - all of mine		4.20	11.78 (sum of above)	
Avon	Wongawilli	?	?	
Avondale	Wongawilli and Tongarra	?	?	
Mt Kembla	Bulli	?	?	
North Bulli	Bulli	?	?	
South Clifton	Bulli	?	?	
Mean (Ml/day)		**2.26**	**2.50**	
Median (ML/day)		**1.25**	**1.47**	
Total (Ml/day)		**22.64**	**35.24**	
Total (Gl/year: 1 Gl = 1000 Ml)		**8.26**	**12.86**	

Table 4. Examples of significant drawdowns recorded by piezometers at the Dendrobium mine tabulated in 2016.[24]

Piezometer Bore	Drawdown (metres)	Depth below surface (metres)	Stratum
S2192+S2220[a]	67	140	L. Hawkesbury S.
DDH104/S1908[a]	60	155	L. Hawkesbury S.
DDH108/S1925[a]	50	144	L. Hawkesbury S.
DDH105/S1910[a]	40	125	L. Hawkesbury S
DDH111/S1929[a]	30	76	L. Hawkesbury S.
DDH97/S1889	21	123	L. Hawkesbury S.
DDH90/S1877[b]	70	136	Bulgo S.
DDH88/S1875	50	130	Bulgo S.
DDH86/S1871[b]	40	88	Bulgo S.
DDH119/S1992[b,c]	53	92	Bulgo S.
DDH85/S1870[b,c]	31	55	Bulgo S.
DDH117/S1953	21	83	Bulgo S.
DDH39/S1578[b]	20	122	Stanwell Park C.
DDH42/S1588	15	116	Stanwell Park C.

[a]Falls below Avon
[b]Falls below Cordeaux
[c]TARP bore

Figures

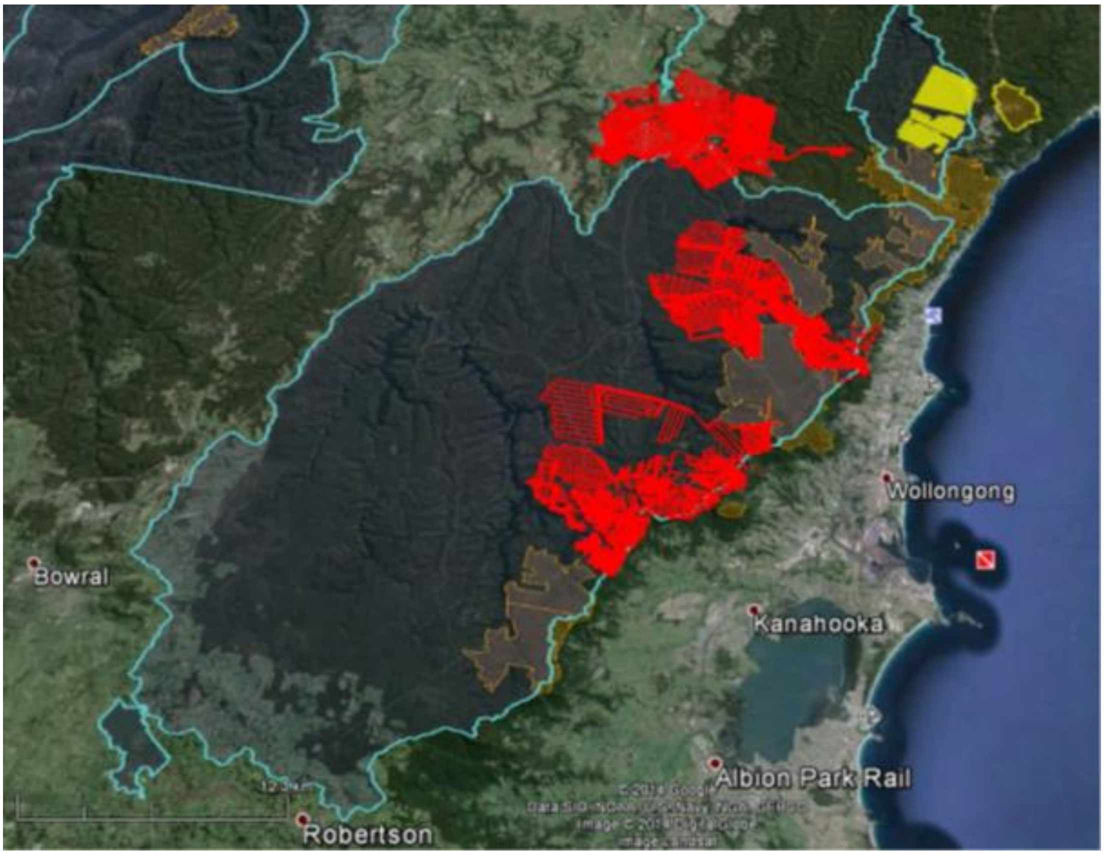


Figure 1. Google Earth depiction of coal extractions (with current approvals) within and adjacent to the Metropolitan and Woronora Schedule 1 Special Areas**.**

The Special Areas are depicted with pale-blue boundaries. The Metropolitan Special Area is centred in the image while the Woronora Special Area is the smaller region in the top right of the image. Part of the Schedule 1 Warragamba Special Area is shown at the top left. The red and yellow areas represent longwall mines, while the 'amorphous' shaded regions, represent older bord and pillar mine areas. The extent of pillar removal from the bord and pillar mine areas is uncertain. The proposed Area 5 and 6 longwalls are not shown.

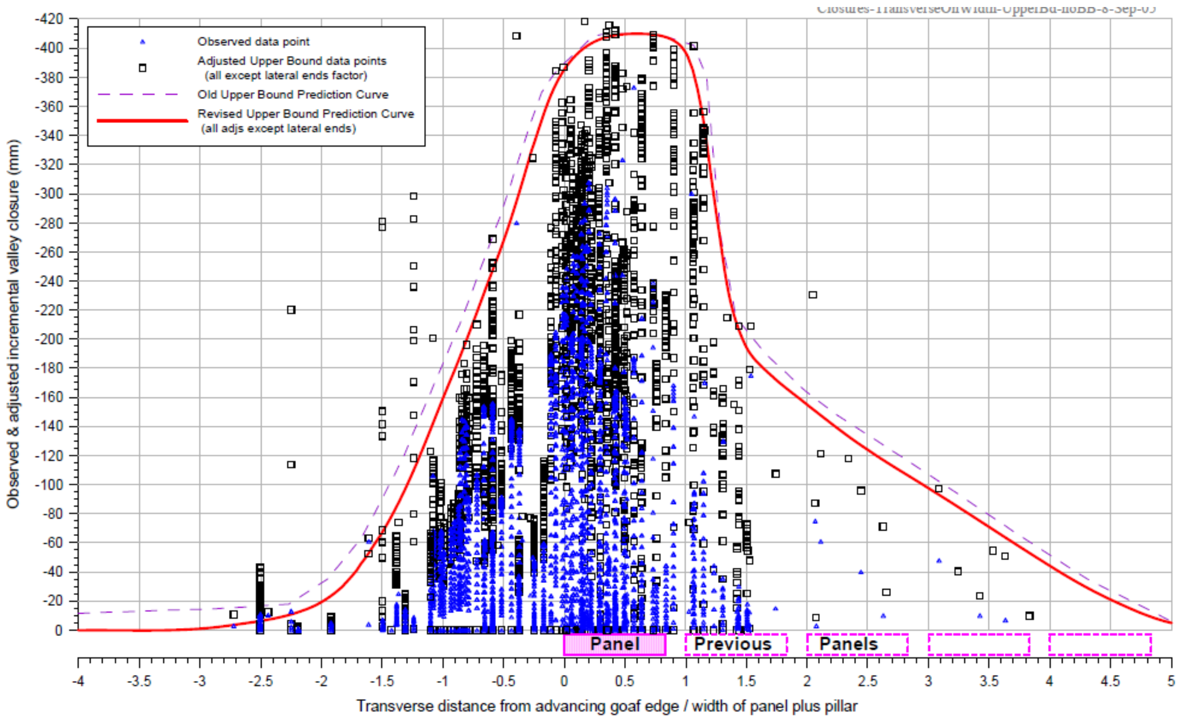


Figure 2. Valley closure dependence on extraction width.

Taken form a 2007 MSEC discussion paper[13], valley closure versus distance from the maingate of the longwall relative to the width of the panel plus the width of the pillar.

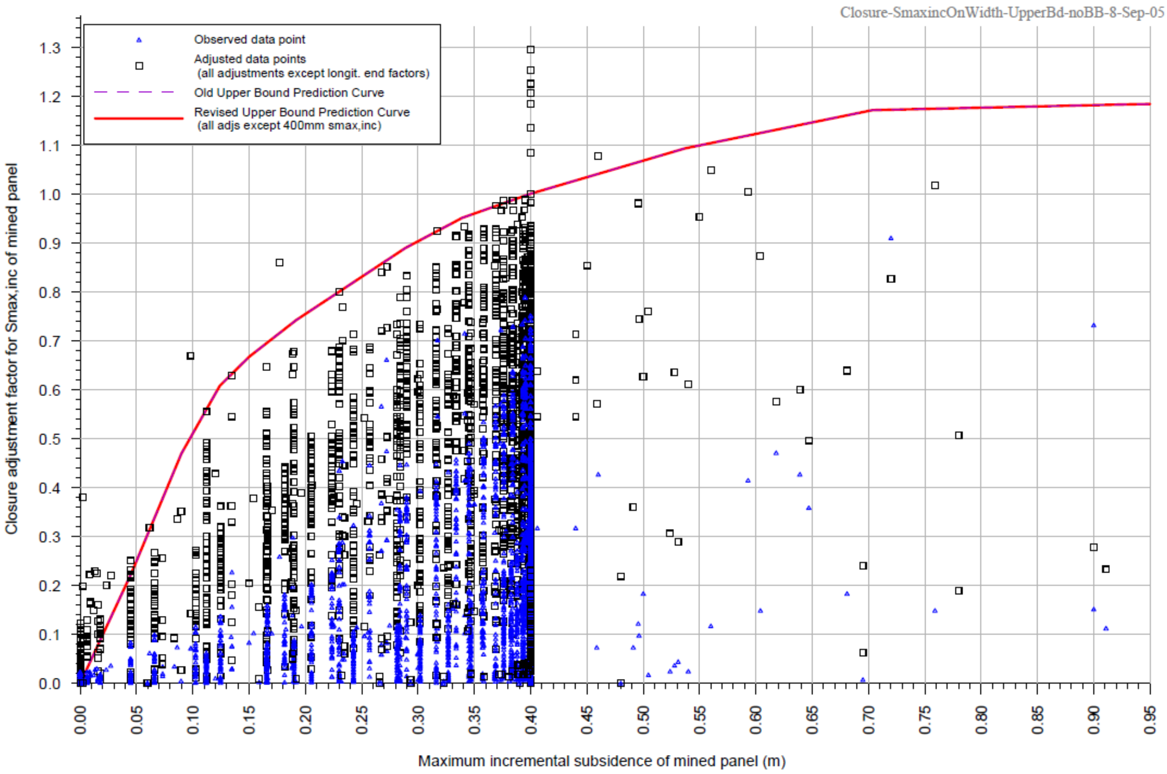


Figure 3. Valley closure correction factor for subsidence

Taken form a 2007 MSEC discussion paper[13], valley closure adjustment factor versus maximum incremental subsidence, which depends on extraction width.

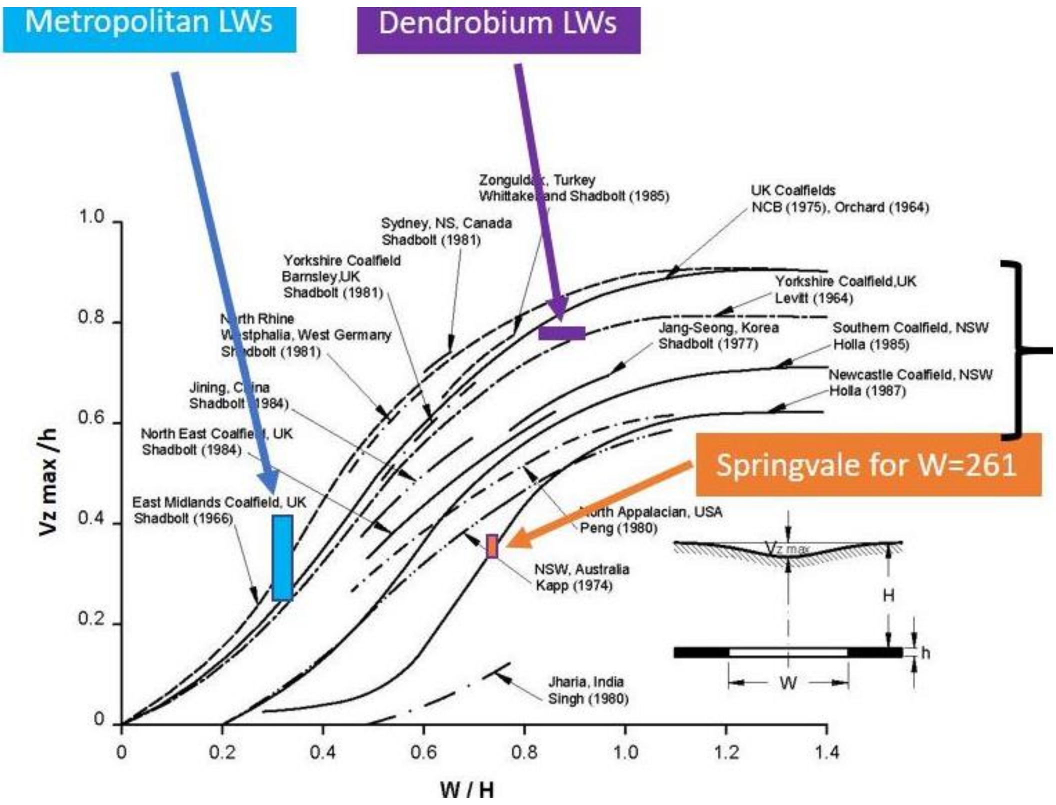


Figure 4. Subsidence variation with width to depth ratio

The above graph is from Fig. 12 in Part 1 of the 2019 final report of the IEPMC[14], illustrating the influence of site-specific conditions and extraction panel width-to-depth ratio (W/H) on maximum vertical surface displacement (Vz) normalised with respect to extraction height (h). The extractions proposed for Areas 5 and 6 would induce subsidence approaching the maximum possible.

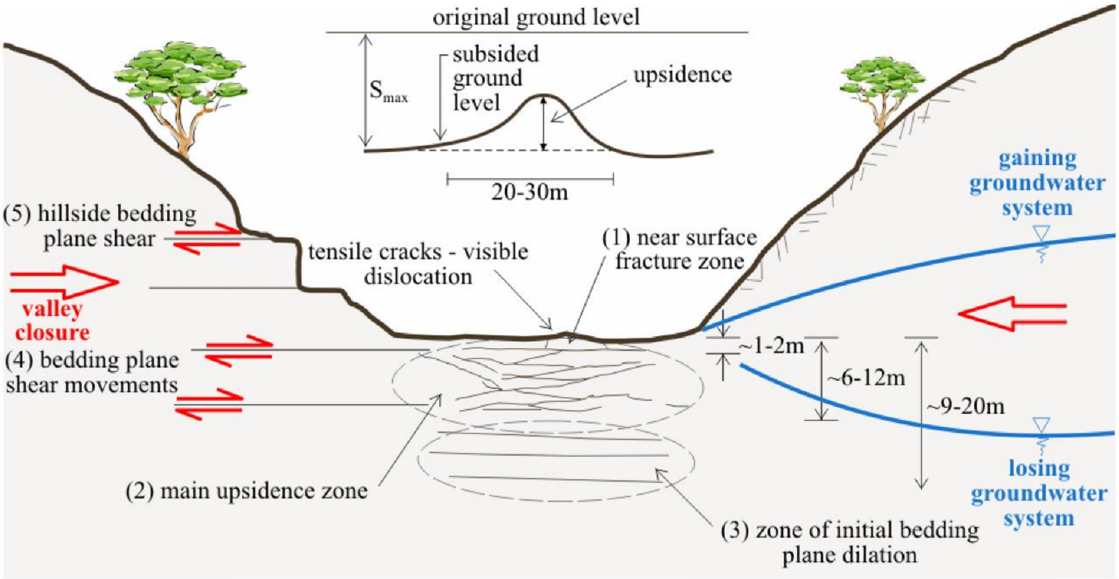


Figure 5. Depiction of valley closure impacts from Mills**[10]**

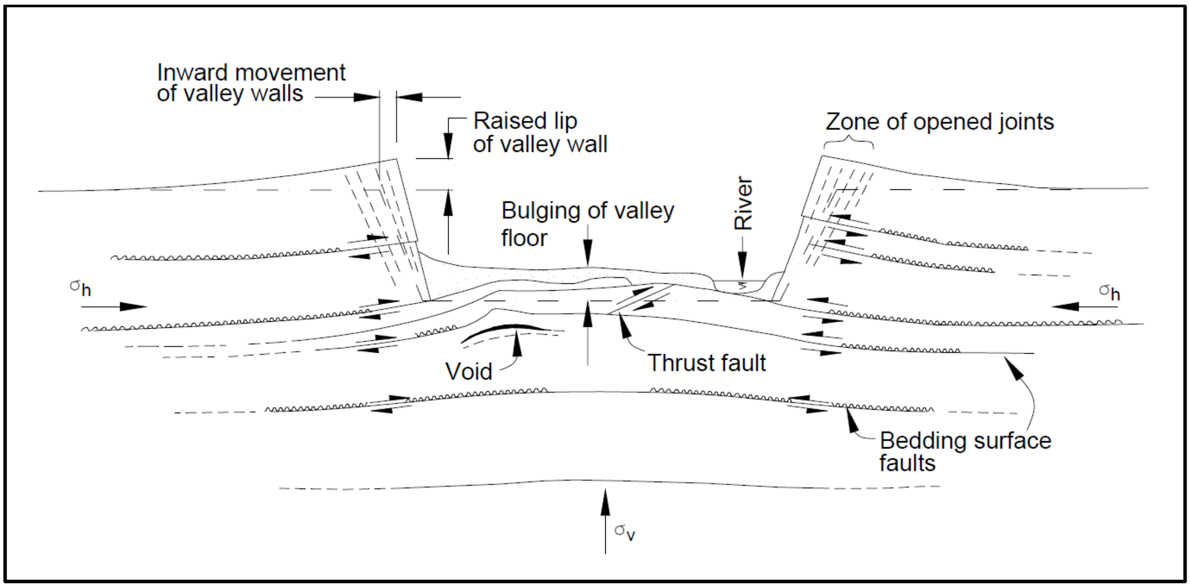


Figure 6. Depiction of natural valley bulging from MSEC.**[13]**

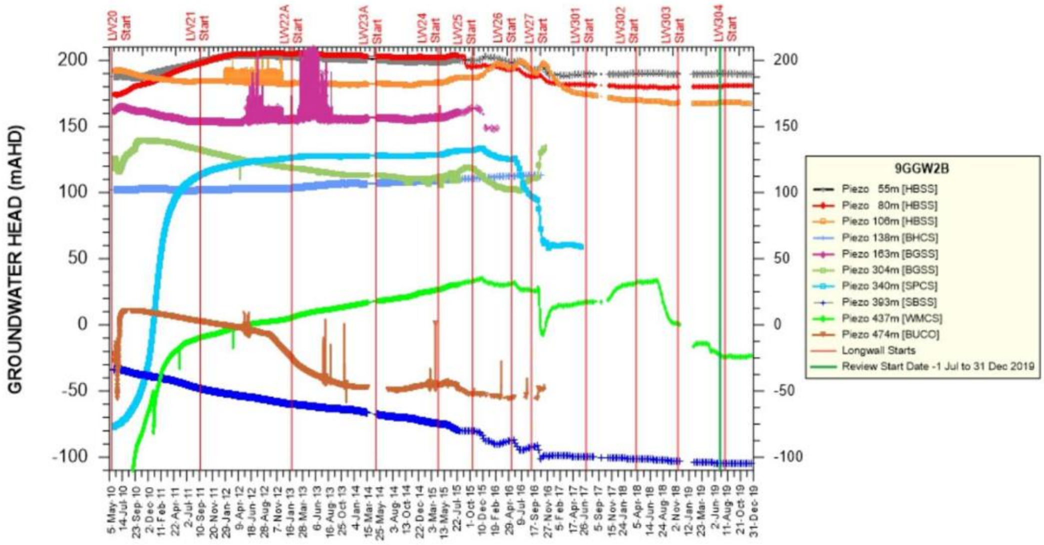


Figure 7. Hydrographs to December 2019 from performance indicator bore 9GGW2B near LW27 at the Metropolitan Mine.**[22]**

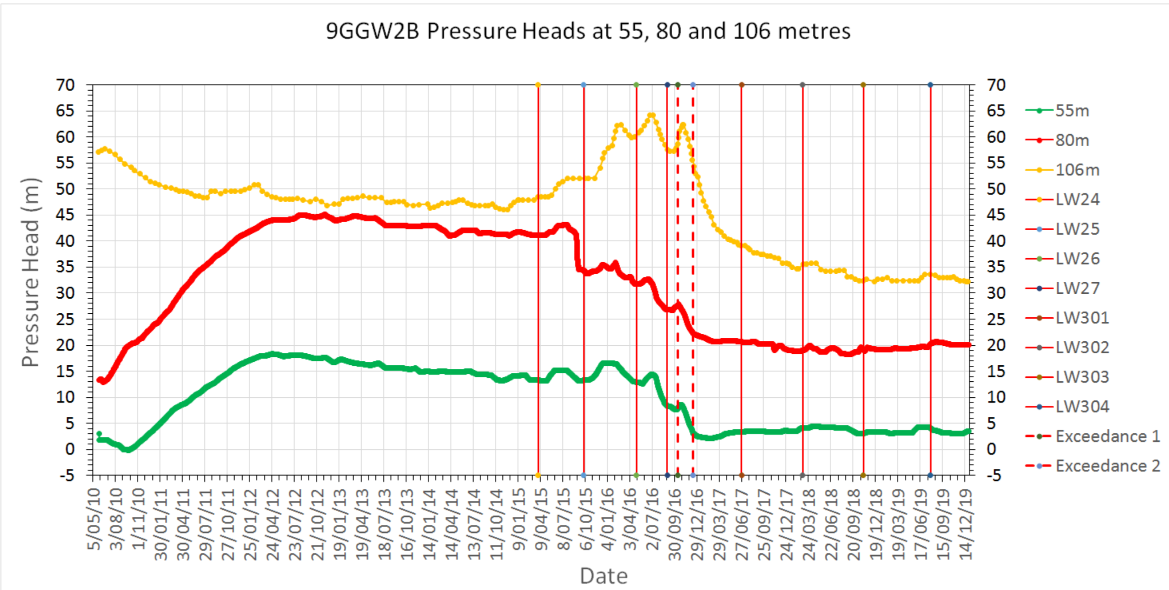
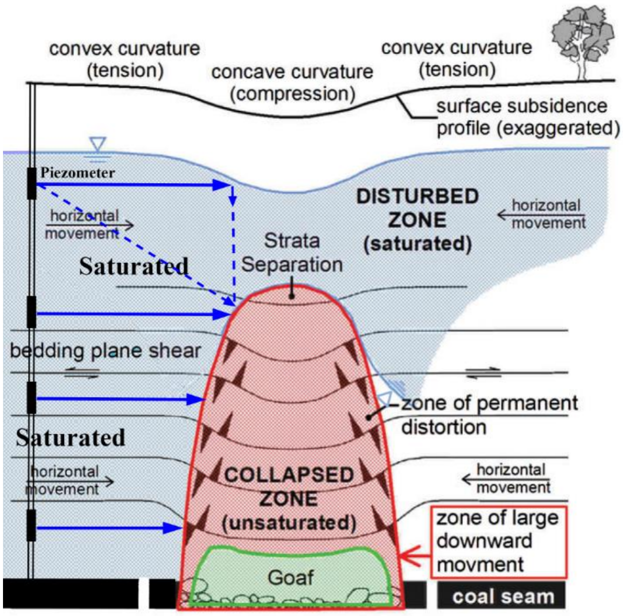
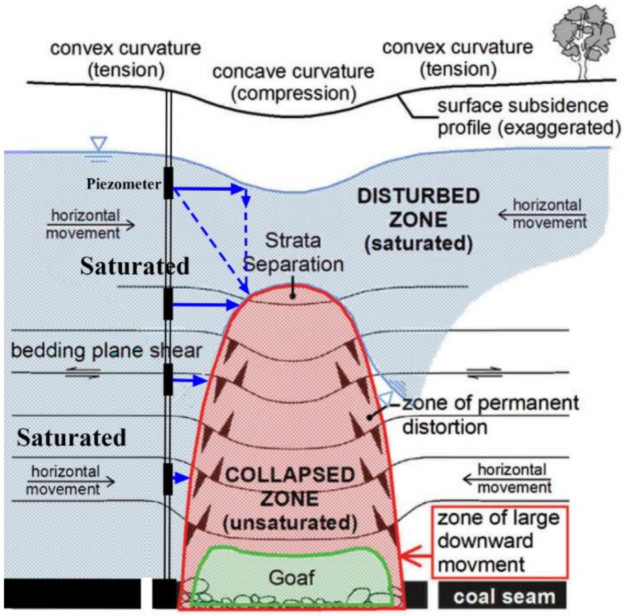


Figure 8. Pressure heads extracted from hydrographs from performance indicator bore 9GGW2B (see Fig. 7).

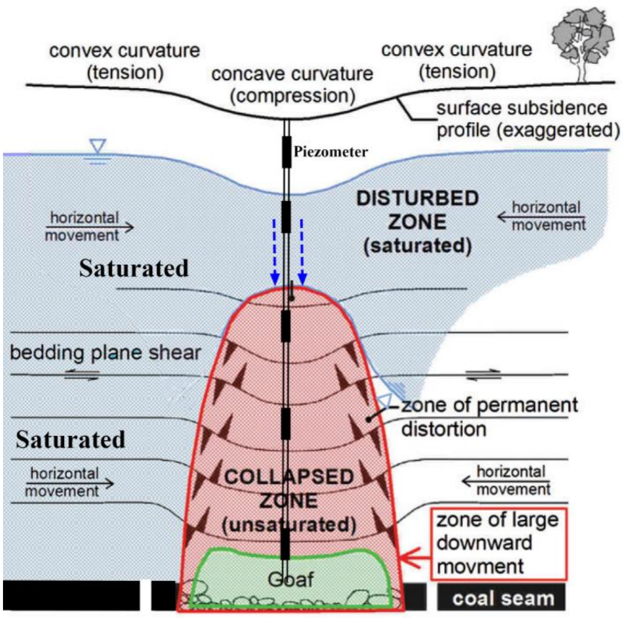
Pressure heads are obtained by subtracting a piezometer bore's elevation from the reported hydrostatic/potentiometric head.



(a) Off-panel piezometer bore



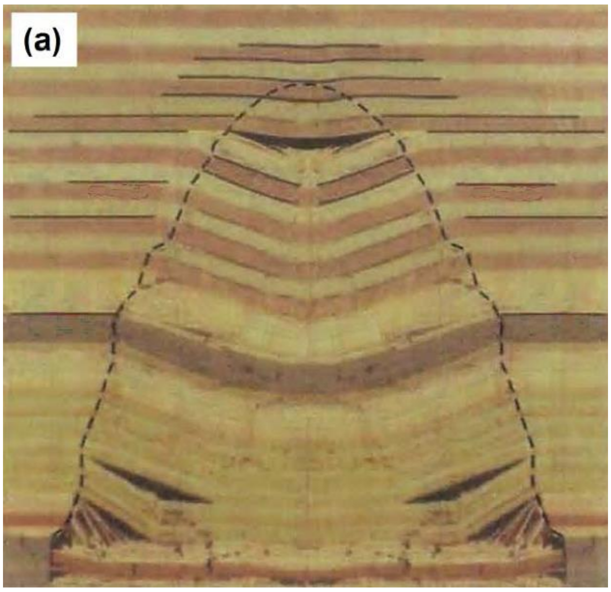
(b) Pillar bore with single adjacent extraction



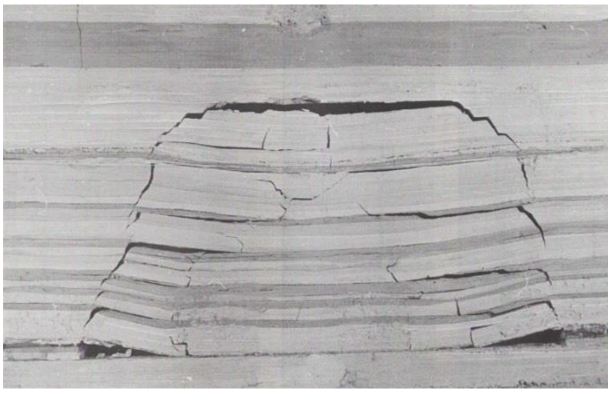
(c) Centre-panel bore

Figure 9. Depiction of (a) off-panel, (b) pillar and (c) centre-panel piezometer bores

These depictions are adapted from that given by Tammetta[32], with the addition of representations of piezometer containing bores located (a) off-panel, (b) over the pillars and (c) over the centreline of a longwall coal extraction with one adjacent extraction to the right. The one to two or more order of magnitude difference between horizontal and vertical hydraulic conductivity is represented by the use of solid (horizontal) and dashed (vertical) arrows. Depending on distance and elevation, off-panel piezometers horizontally in line with the drainage (collapsed) zone would be expected to report greater rates of pressure loss than those located above the drainage zone. Centreline piezometer bores provide the most reliable means of determining the height of the drainage zone.



(a)



(b)

Figure 10. Models of the collapsed zone.

Figure 10(a) is from a 2007 GHD assessment[64] for Dendrobium Area 3A, where its attributed to a 2005 study by Dr Ken Mills of consultancy SCT, of Longwall 7 in the adjacent Elouera domain of what is now the Wongawilli coal mine. Figure 10(a) is also Fig. A2(a) from the supplementary material for Tammetta's second Groundwater paper[32]. Figure 10(b) is Fig. 6 in a 2012 conference paper[85] by Mills and is from a 1989 publication[40] by Whittaker and Reddish. Mills makes the following comments with respect to 10(b):

> "*The zone of large downward movement (Zone 2) is clearly evident in this model. The shear constraints associated with the glass side panels in a physical model reduce the height of Zone 2 to less than the full panel width, whereas field observations indicate that the height of Zone 2 is equal to about the panel width in most geological settings. Nevertheless, the level of disturbance illustrated by this model clearly shows that there is likely to be significant disturbance to the overburden strata in Zone 2 with depressurisation of the groundwater system in this zone likely.*

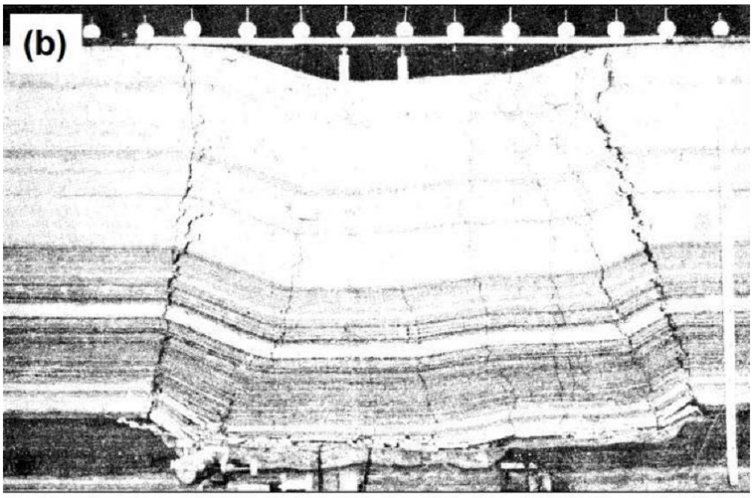


Figure 11. Physical model of supercritical collapse and a collapsed zone that has reached and extended over the surface.

Physical model of supercritical collapse and a collapsed zone that has reached and extended over the surface above an extraction where the extraction width is greater than the critical width. The image is Figure A2(b) from the supplementary material for Tammetta's second Groundwater paper.[32]

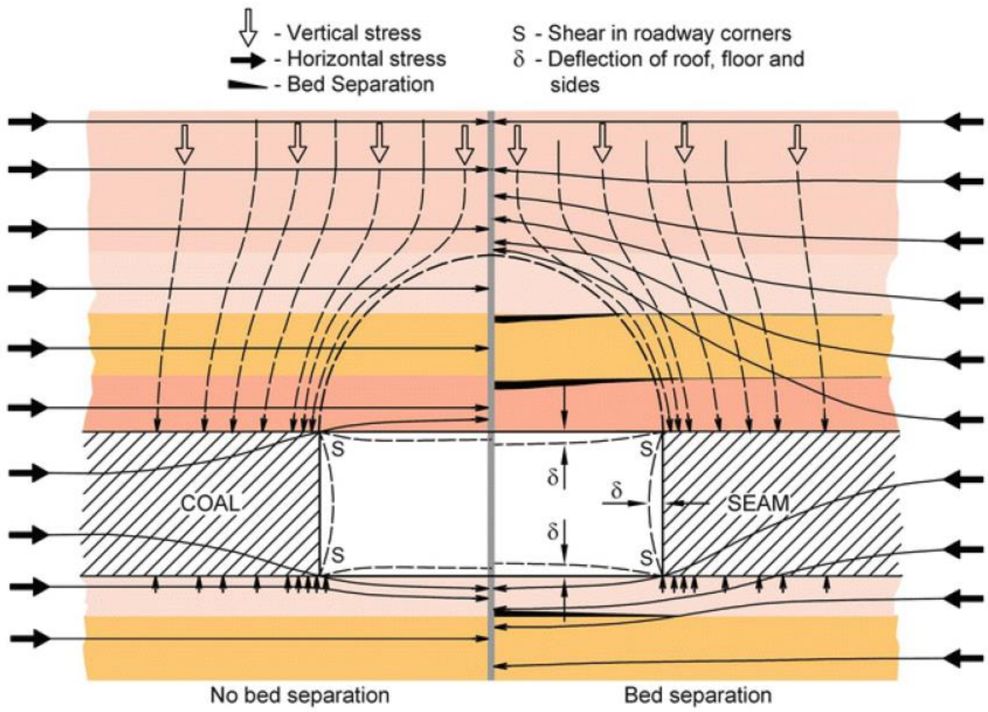


Figure 12. Depiction of stress redistribution around a pressure arch formed over a coal extraction.

Depicting the redistribution of vertical stress over a coal excavation, Fig. 12 is Fig. 3.3 from Prof. Galvin's 2016 book[12] on coal mine engineering. The collapse process that follows coal removal redirects vertical stress to the sides of the extraction, with the 'roof' becoming vertically 'de-stressed'. Imparting a degree of depth dependence, some fraction of the vertical (lithostatic) stress contributes to the horizontal stress via the Poisson effect. A pressure arch is clearly evident in the photograph shown in Fig. 13 below.

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Figure 13. Parabolic profile over a roof collapse onto a roadway into a mining highwall.

Figure 12 is Figure 6.8 in a 2014 knowledge report[86] to the Commonwealth Interim Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining, prepared by Tammetta on behalf of Coffey Geotechnics. The image appears as Figure 19 in Whittaker and Reddish's 1989 book[40] on subsidence. Highlighting a pressure arch (see Fig. 12), the original roof has collapsed onto the roadway. Step-wise formation of the pressure arch is suggested by the 'torn-edge' evident in the photograph and Tammetta's summary of the collapse process.

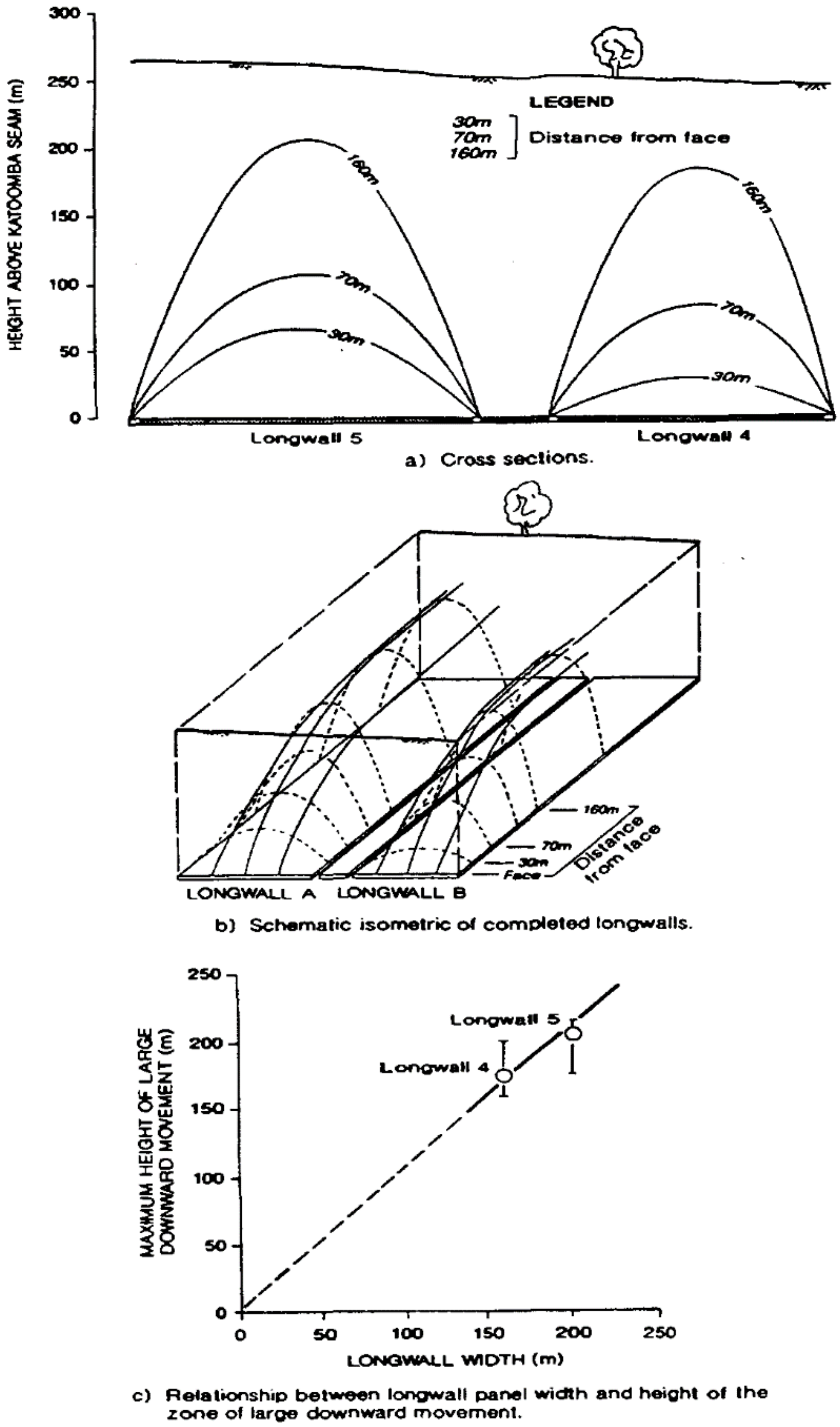

Figure 14. Collapsed zone profile found by Mills and O'Grady at Clarence Colliery.

Figure 14 is Figure 7 from a 1998 paper by Mills and O'Grady reporting an extensometer study over the centreline of Longwalls 4and 5 at the Clarence colliery in the Blue Mountains. The height of the collapsed zone, the zone of significant downward movement, is found to correspond to the width of the extractions. The profile shape suggests a pressure arch.

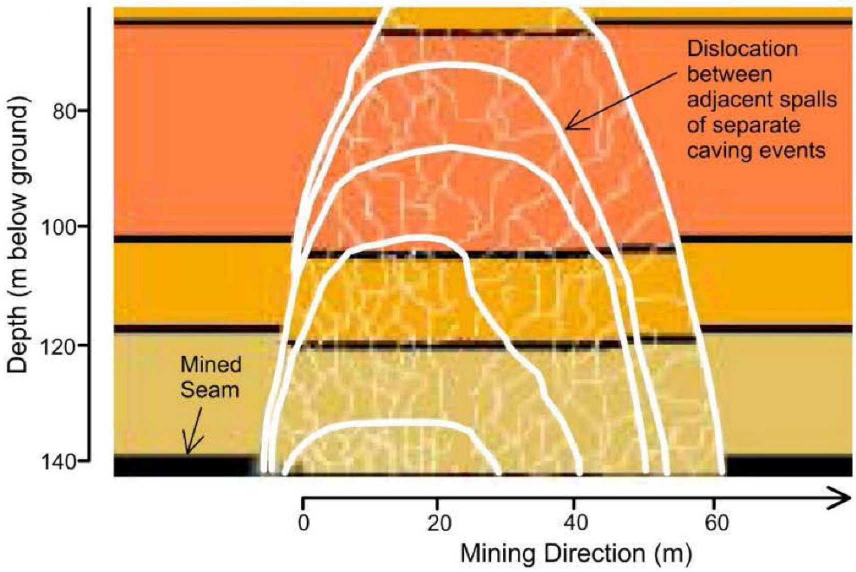

Figure 15. Development of the formation of the collapsed zone.**[32]**
Tammetta finds the collapsed zone coincides with the drainage zone.

Figure 16. Cut-away view of the developing collapsed zone
Cut-away view[32] of the developing collapsed zone over a completed longwall extraction and over the early stage of a second extraction.

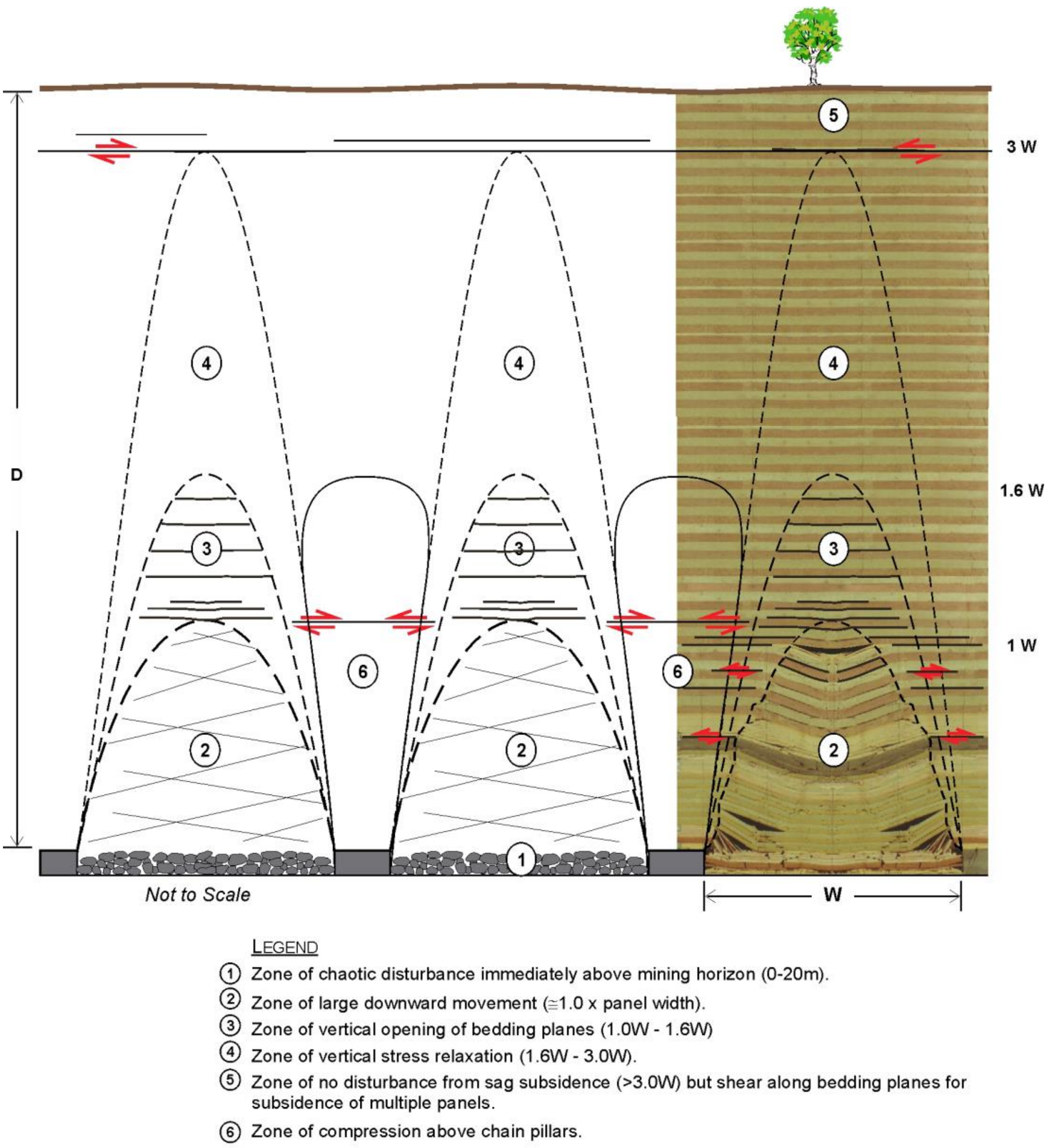

Figure 17. Six zone overburden subsidence model proposed by Mills

Figure 17 is Fig. 5 in a 2012 conference paper by Mills and is provided as Fig. 10.11 in Prof. Gavin's 2016 coal mine engineering book. Based on subsidence measurements, camera observations, packer testing, piezometer data, micro-seismic data, extensometer monitoring, and stress change monitoring, the graphic highlights six overburden disturbance zones. Zone 2 is a zone of significant downward movement that Tammetta finds coincides with the drainage zone. Mills finds that, for the set of extractions studied, the height of Zone 2 is approximately the same as the extraction width. The Tammetta equation suggests that this also depends on the depth and extraction height. Tammetta regards the zones beyond Zone 2 as a hydrological continuum of non-zero water pressure that he refers to as the 'disturbed zone'.

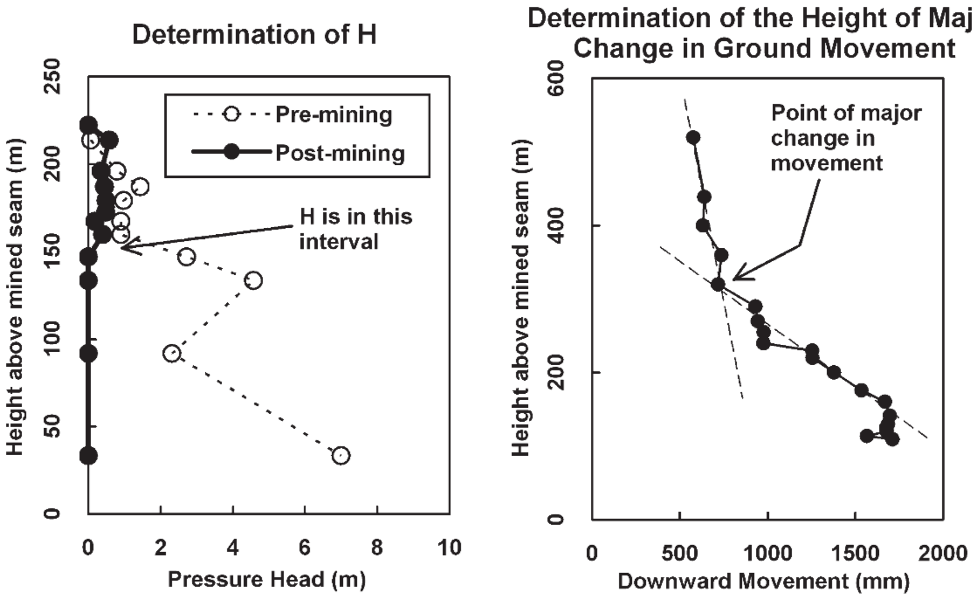

Figure 18. Examples of the determination of the drainage and collapsed zone heights from Tammetta's 2013 Groundwater paper

Figure 18 is Figure 2 from Tammetta's first Groundwater paper[29], published in 2013. The left-hand side illustrates the determination of the drainage zone height using data from the Beech Fork mine in Appalachia in the US. Illustrating the determination of the height of the collapsed zone, the righthand side shows a relatively sharp change in slope through extensometer data from the Westcliff Colliery in the Southern Coalfield of NSW. Tammetta finds the heights of the drainage zone and the collapsed zone essentially coincide.

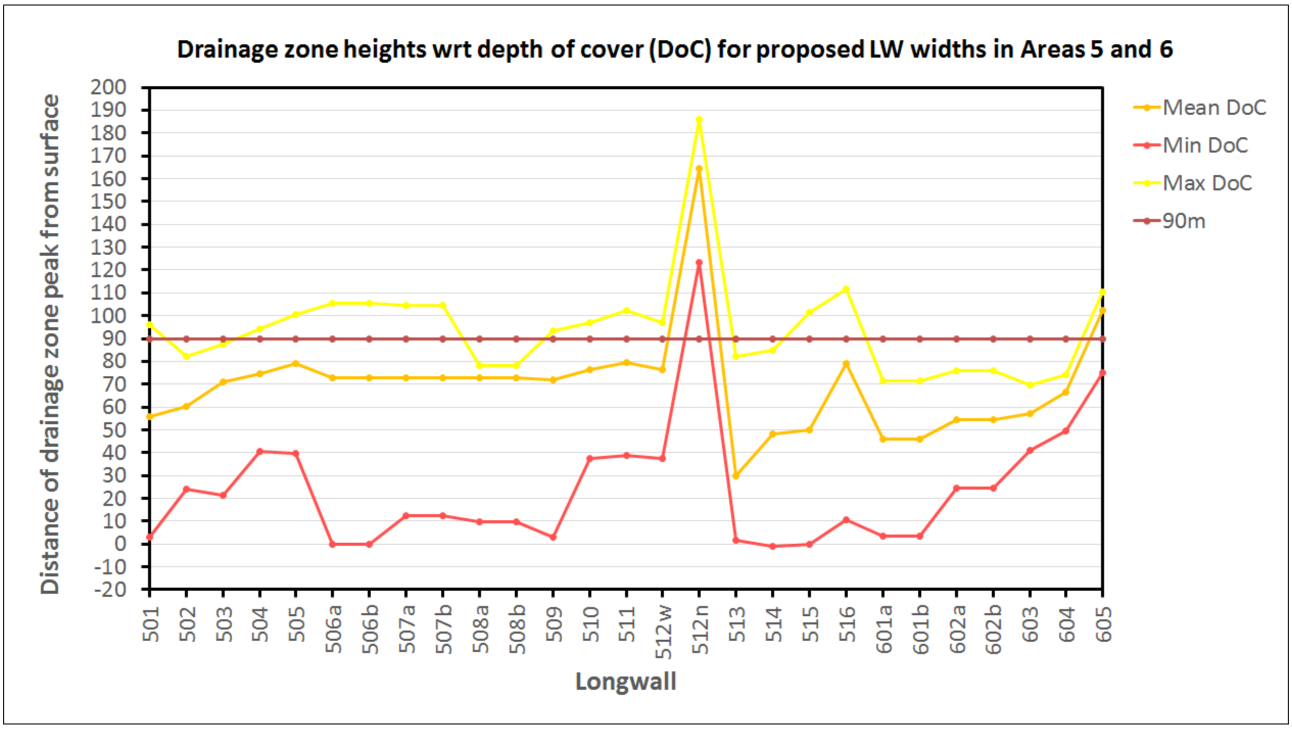

Figure 19. Application of the Tammetta equation for 305 metre Area 5 and 6 extractions

The Tammetta equation has been applied for the mean, minimum and maximum depth of cover for Areas 5 and 6, using information provided in Table 1-7 of the groundwater assessment[48]

Included is a 90 metre depth reference line, in recognition of the following advice[49], [50] from consultants GeoTerra, which suggests that the drainage zone doesn't need to reach the surface to exert an adverse influence:

> "*A minimum thickness of unfractured overburden is required to maintain hydraulic separation between a mine and saturated aquifers, with the critical value depending on lithology, structure and topography. The minimum separation has been established through observation and research in NSW mines as ranging from less than 90m up to 150m.*"

Of importance, PSM find there is no constrained zone over extractions to date at the Dendrobium mine.

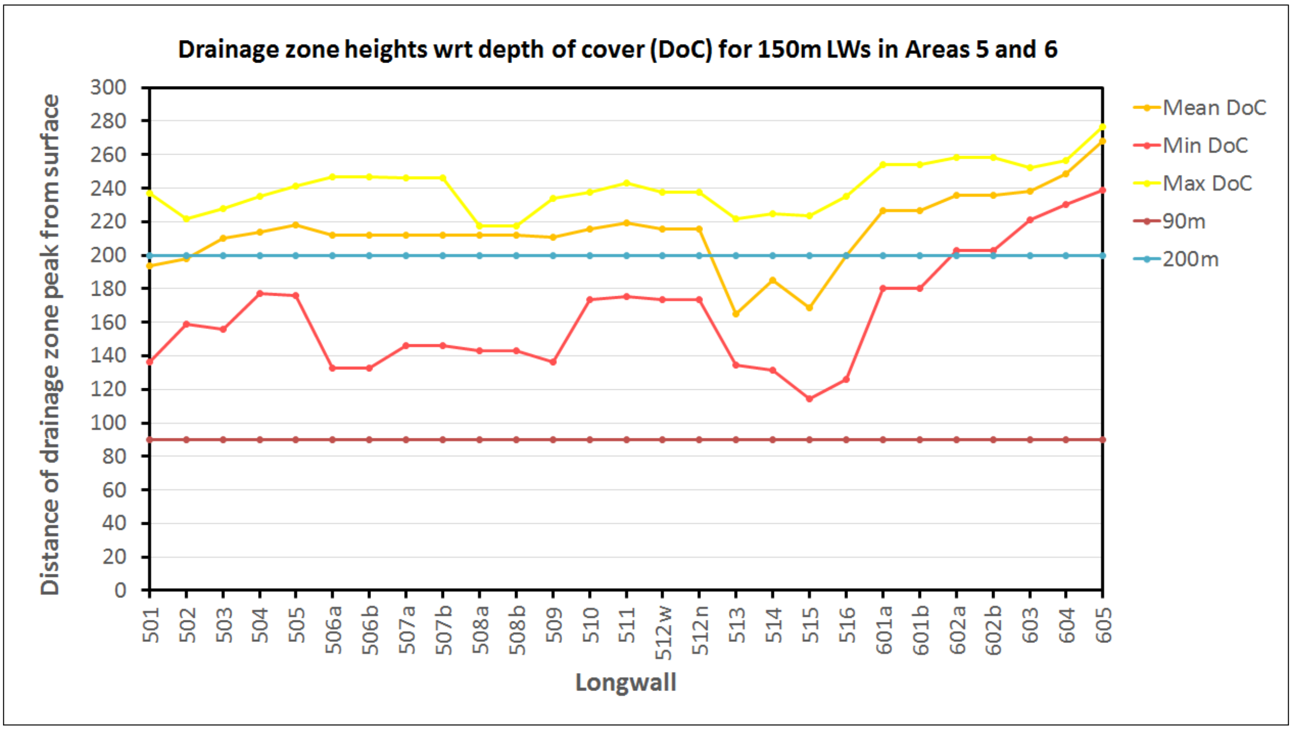

Figure 20. Application of the Tammetta equation for 150 metre Area 5 and 6 extractions

The Tammetta equation has been applied for the mean, minimum and maximum depth of cover for Areas 5 and 6, using information provided in Table 1-7 of the groundwater assessment[48]

A minimum separation of 300 metres would seem prudent.

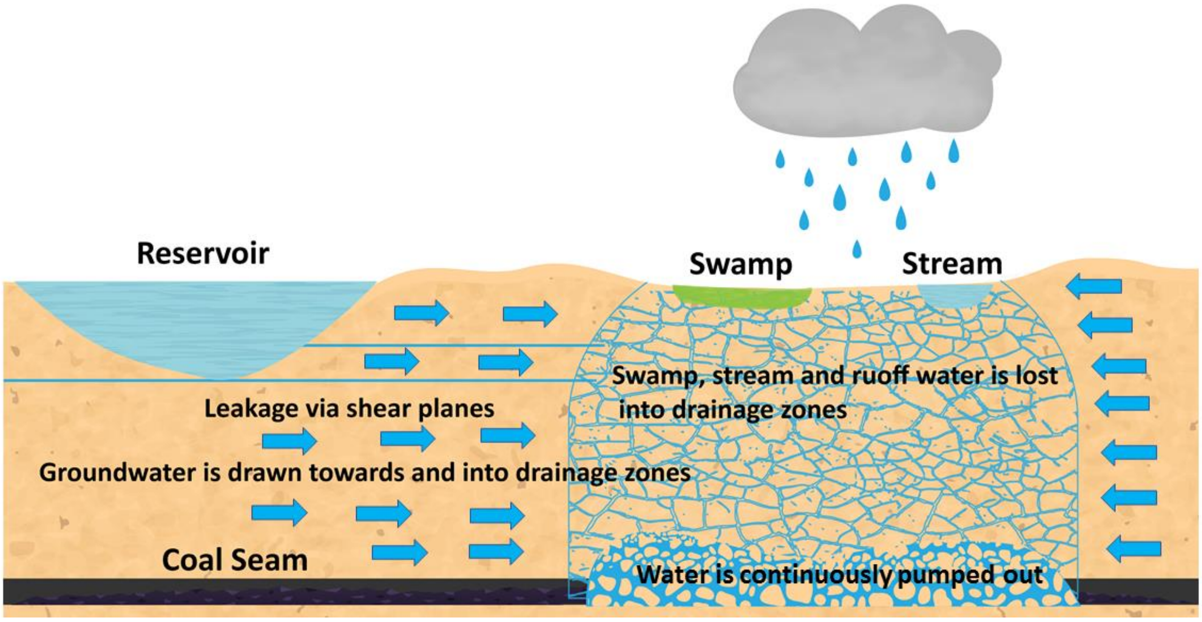

Figure 21. Depiction of a drainage zone reaching the surface below a swamp and stream and near a reservoir.

Shear plane activation may also divert surface and baseflow from watercourses.

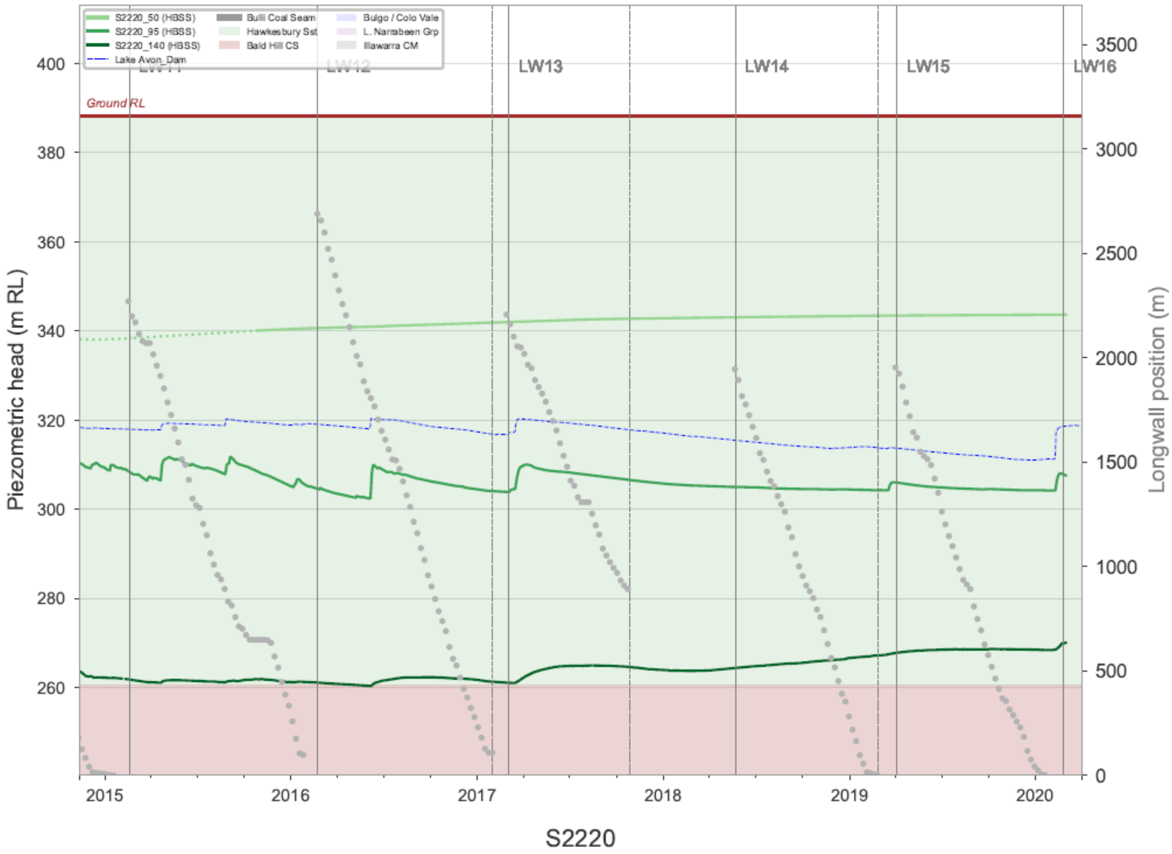

Figure 22. Hydrographs from centreline bore S2220 at the eastern end of Dendrobium Longwall 9.**[27]**

The very pale green line is that for instrument 1 at 50 meters, the green line is that for sensor 2 at 90 metre sensor and the dark green line is for piezometer 3 at 140 metres. The blue line depicts the water level of Avon Reservoir. Both the piezometers and the distant reservoir are responding to rainfall.

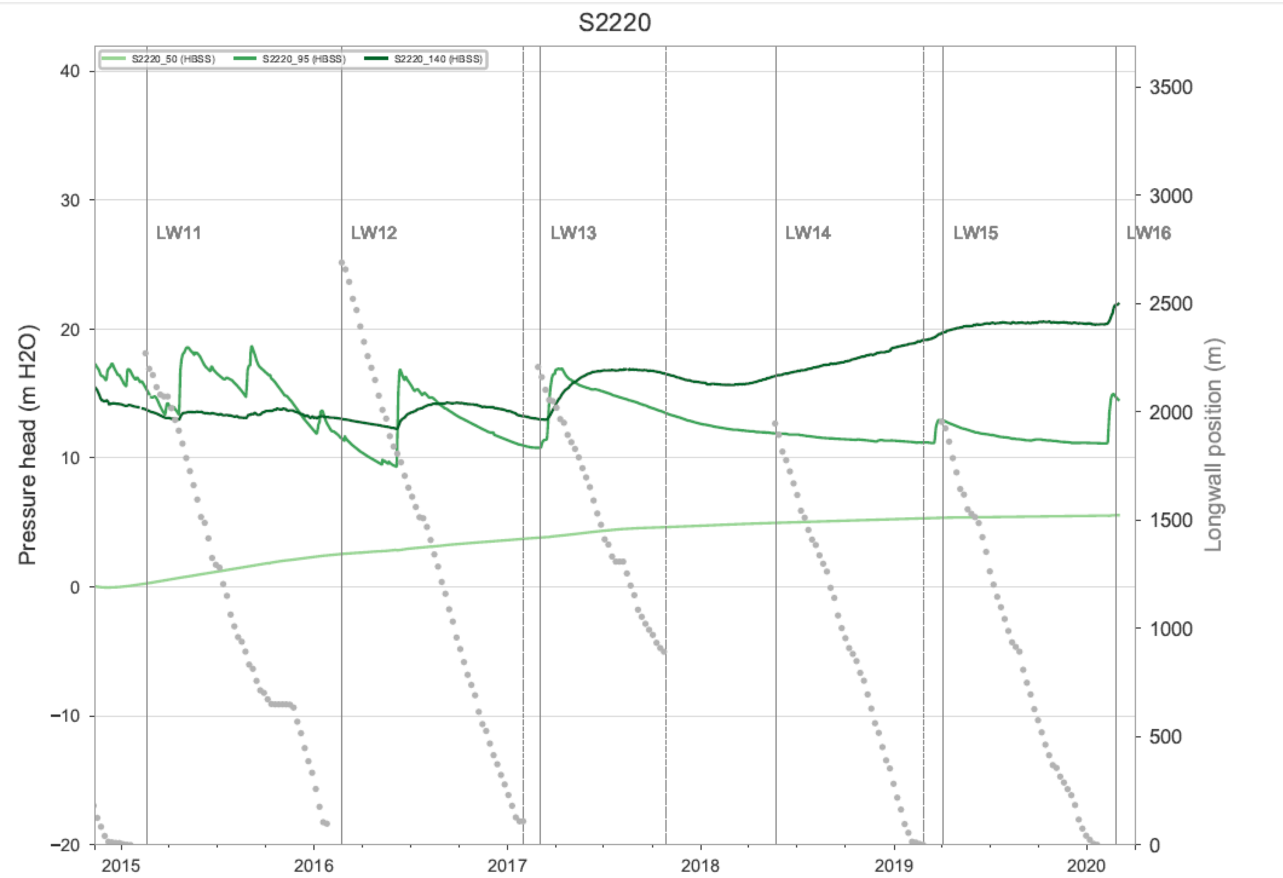

Figure 23. Pressure heads from centreline bore S2220 at the eastern end of Dendrobium Longwall 9.**[27]**

The very pale green line is that for instrument 1 at 50 meters, the green line is that for sensor 2 at 90 metre sensor and the dark green line is for piezometer 3 at 140 metres.

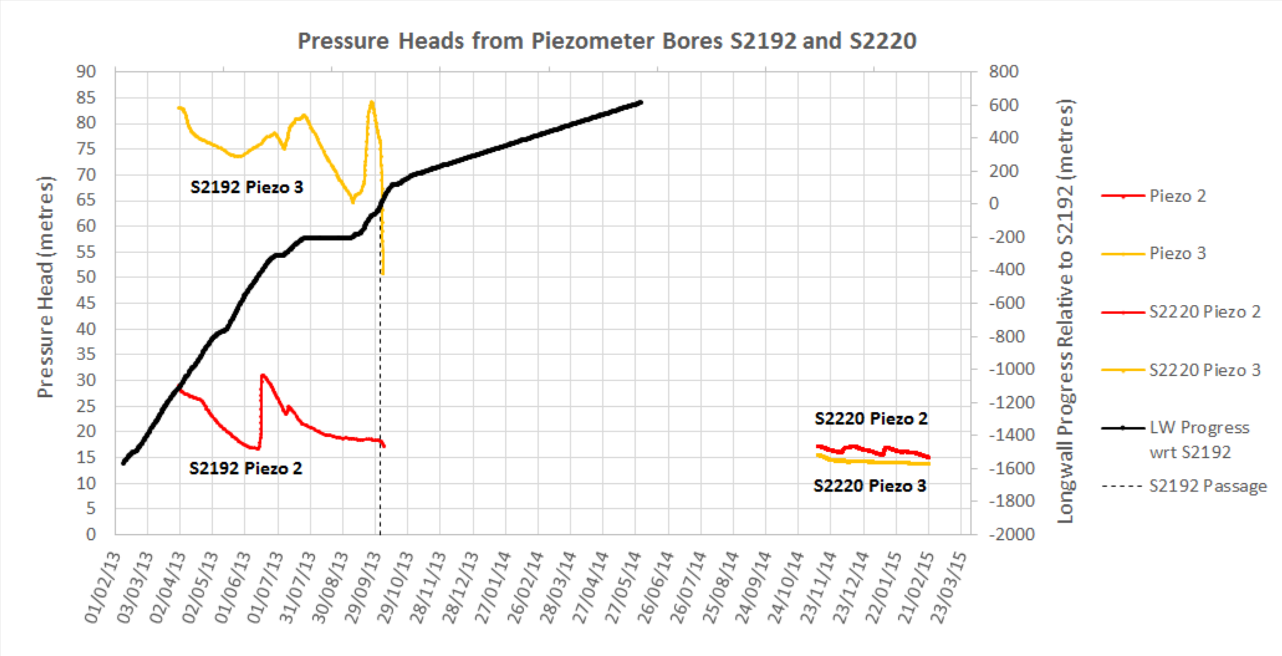

Figure 24. Pressure head changes from S2192 to S2220 piezometers 2 and 3.

The pressure heads were obtained by digitising the hydrographs in Figure 2.5 of the HydroSimulations groundwater impact assessment[84] for the May 2016 Longwall 11 end of panel report and those in Figure 5.7 of the March 2015 Parsons Brinckerhoff connected fracturing report.[51] Piezometer elevations were subtracted from the hydrostatic (potentiometric) heads to obtain the pressure heads. ‘Piezo 2’ is the 90 metre sensor and ‘Piezo 3’ is at 140 metres.

Figure 25. Damage and drainage on Wongawilli Creek resulting from subsidence at Elouera Colliery.**[71], [87]**

Adjoining the Dendrobium Mine, the Elouera Colliery is now part of the Wongawilli mine.

The 2010 groundwater impact assessment for the 2010 longwall mining proposal for the Nebo area of the Wongawilli mine reports:

> "*bord and pillar as well as pillar extraction and longwall mining has been conducted in the adjacent Wongawilli, Elouera and Dendrobium Area 2 workings, and that vertical hydraulic connection has been observed at some locations between surface streams and the underlying workings*".[62]

The assessment report further comments that a significant but unquantified component of the water entering the Elouera mine comes "*from surface water seeping through subsidence cracks following extraction of Elouera Longwalls 6 and 7 under Wongawilli Creek*"

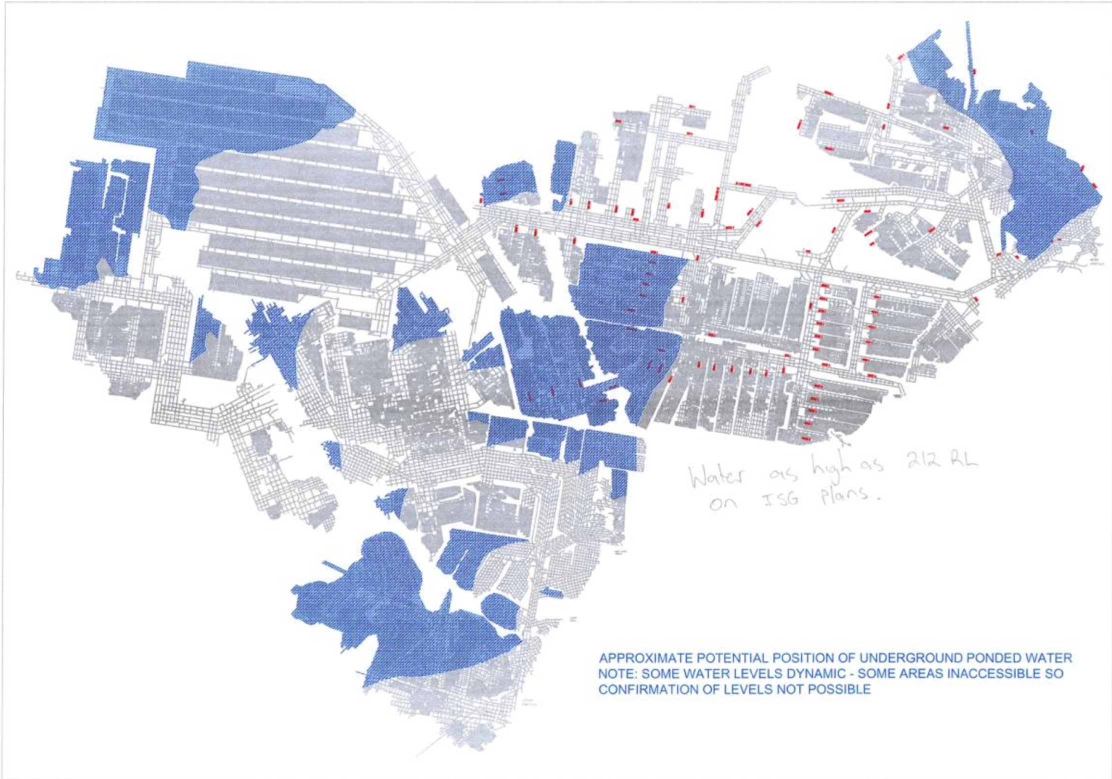

Figure 26. Water lodgement in Wongawilli coal seam extraction areas at the Wongawilli mine.

Provided on request by Wollongong Coal, the date of the above water lodgement map is not known. The printed text states: "A*pproximate potential position of underground ponded water. Note: some water levels dynamic - some areas inaccessible so confirmation of levels not possible*". The handwritten note states "*Water as high as 212 RL on ISG plans*"; it's not known which part of the mine is referred to in this comment. Wollongong coal had been extracting remnant in the Nebo section when operations ceased in 2019 because of safety concerns. The area has been sealed and the Community Consultative Committee has been told that its anticipated that when the ponding reaches about 205 RL, water will drain from a portal in the escarpment, near Dombarton.

The Bulli seam above has also been mined and may hold water. Ponding and draining is known to be occurring at the other mines in and around the Special Areas.