WORONORA RESERVOIR STRATEGY REPORT – STAGE 1
Metropolitan Coal
Longwall mining near and beneath Woronora Reservoir

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Disclaimer

Bruce Hebblewhite is employed as a Professor within the School of Mining Engineering, at The University of New South Wales (UNSW). In accordance with policy regulations of UNSW regarding external private consulting, it is recorded that his contribution to this report has been prepared in his private capacity as an independent consultant, and not as an employee of UNSW. The report does not necessarily reflect the views of UNSW, and has not relied upon any resources of UNSW.

1.0 INTRODUCTION AND SCOPE

This strategy investigation and report was initiated by the Department of Planning and Environment (DPE) for the proposed longwall mining by Metropolitan Coal Pty Ltd (MCPL) near and beneath the Woronora Reservoir.

Extension of mining at Metropolitan Coal (MC) site was previously approved for Longwall 20 onwards under Section 75 J of the New South Wales (NSW) Environmental Planning and Assessment Act, 1979 (EP&A Act) on 22 June 2009. This approval was granted by the Planning Assessment Commission panel at the time that indicated that it included mining the entire 300 series of longwall panels[1] many of which are located beneath the Woronora Reservoir.

Conditions set out by the DPE *Record of Decision* (DPE 2017) indicated in *Condition 2* that there should be: *"Engagement of independent experts to prepare a Woronora Reservoir Impact Strategy, which provides a staged plan of action for further investigations and a report into the impacts of mining near the Reservoir".* The DPE indicated that the issues to be covered in that report should relate to:

- the likelihood of diversion of surface waters into the underlying strata;
- probable leakage rates;
- connectivity between the reservoir and mine workings;
- characterization of fractures (pre and post mining) including shear planes;
- recommendations for additional subsidence monitoring;
- possible bathymetric survey of the Reservoir; and
- preparation of a report outlining the findings of the investigations to provide the basis of an assessment of future mining near and beneath the Reservoir.

On the 24 May 2017 the DPE advised Metropolitan Coal that three experienced individuals with many years of extensive experience in the coal industry and academia had been appointed to develop the Strategy Report for the proposed mining. The individuals include Professor Bruce Hebblewhite, (BH) private mining/geotechnical consultant, and Chair of Mining Engineering, School of Mining Engineering, University of NSW, to deal with the geotechnical aspects; Professor Emeritus Tom McMahon (TM), Department of Infrastructure Engineering, University of Melbourne to deal with surface water aspects; Dr Frans Kalf (FK) of Kalf and Associates Pty Ltd, a hydrogeologist and a specialist numerical modelling developer and consultant in both government and private industry to deal with the groundwater issues. Resource Strategies, a company with wide experience in environmental review of investigations in the mining industry, is co-ordinating the work. Reporting on each discipline from the experts is provided in separate sections presented below.

The report represents just the first stage of the Impact Strategy required in response to this scope, and will be followed up by further staged reports, as the investigations continue,

[1] Up to LW316, that is the most distant longwall to the NW and LW317 west shown in Figure 3-2 or 3-3

based on further data and analysis arising from the proposed monitoring programs recommended in this report.

2.0 BACKGROUND

Metropolitan Coal is a wholly owned subsidiary of Peabody Energy Australia Pty Ltd (Peabody). The Metropolitan Colliery is located within the Southern Coalfield situated about 30km north of Wollongong in New South Wales. The Colliery operates an underground coal mine that extracts coal from the Bulli Seam at geological strata depths in the range of 400-500m. The extent of the approved longwall mining at the Metropolitan Coal site area is depicted in Figure 2-1.

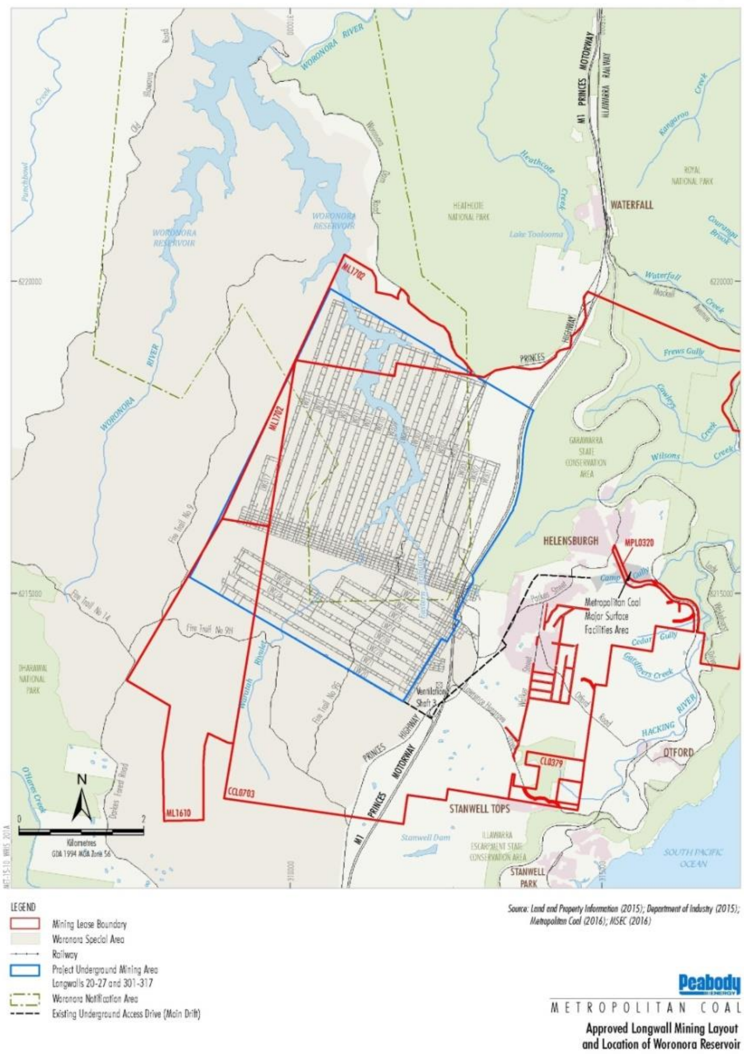

Figure 2-1: Approved longwall mining layout and location of Woronora Reservoir

Mining has been completed in the lease area to the south of the reservoir in panels LW 20 to 27 (Figure 2-1 i.e. all longwalls south of bore 9GGW2B in Figure 3-3). Currently the panels

301 to 302 east of the reservoir are approved for mining extraction (Figure 2-1; see also Figure 5-1 for more detail).

Because Woronora Reservoir is an important component of the Sydney water system, the 2016 Audit of the Sydney Drinking Water Catchment (Alluvium, 2017) is an important background document used to develop this impact strategy. The Audit identifies a number of water issues (water availability, water quality and wetland health) relating to underground mining in the Catchment. The Strategy reviewers note that Metropolitan Longwall mining activities, which are located in the Woronora River catchment, are not identified as a problem site in the Audit (TM).

In addition to the issues outlined by the DPE, it has also been considered necessary to outline previous investigation findings from longwall mining projects. This is so because these previous investigation findings and conditions at other mine sites are not well known in the broader community. These include previous mining of the Bulli coal seam under stored waters during the 80's and 90's at both the South Bulli and Bellambi West Collieries that are situated near and beneath the Cataract Reservoir some kilometres south of the Metropolitan site. These were successfully mined without significant inflow and without extensive vertical fracture propagation through the stratigraphic profile.

3.0 GROUNDWATER (FK)

3.1 Conceptual Metropolitan Coal Groundwater System

The mining area is situated within a sedimentary rock sequence comprising deeper Permian and shallower Triassic aged geological strata. The total thickness of all the rock units and formations from the top of the sequence to the bottom is between 400m to 500m thick with the main geological units comprising from the top to bottom:

- Hawkesbury Sandstone (170m)
- Newport Formation (Not shown in Figure 3-1)
- Bald Hill Claystone. (extensive claystone/shale layer)
- Bulgo Sandstone, (a thick bedded sandstone with shale horizons (175m)
- Stanwell Park Claystone
- Scarborough Sandstone
- Wombarra Claystone
- Coal Cliff Sandstone
- Illawarra Coal Measures (shales and sandstone with 10 coal seams with the Bulli coal seam situated at the top of the Permian Coal Measure sequence.

Groundwater is recharged by infiltration of rainfall at the ground surface over the wider region with flow within natural occurring fractures at shallow depth and also through the rock matrix with groundwater flow directed towards lower lying topography including, the

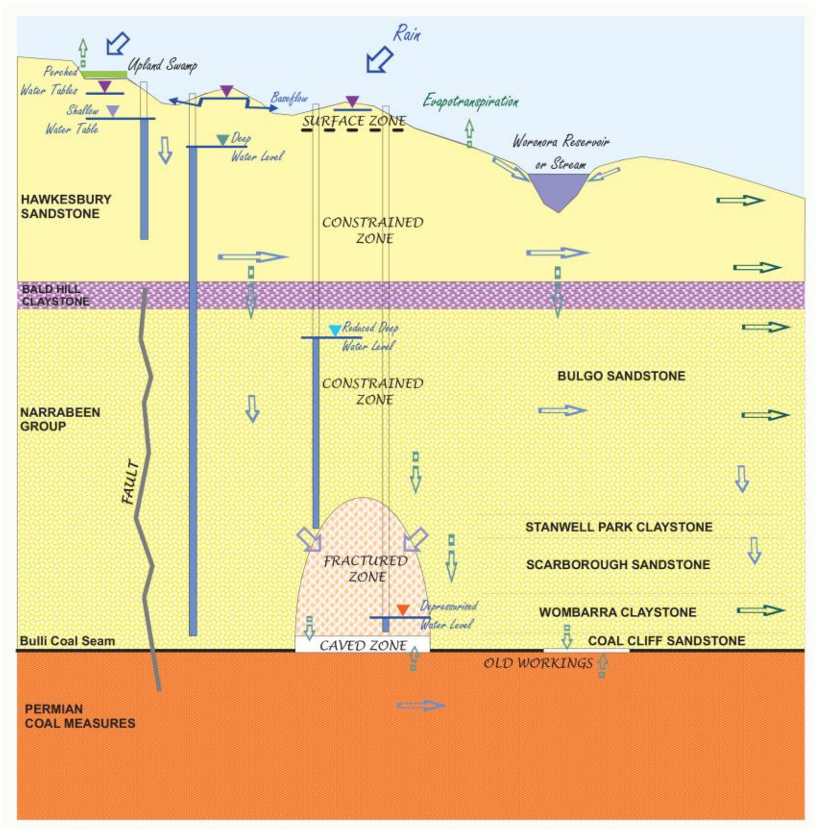

Figure 3-1: Conceptual groundwater system for Metropolitan Coal mining conditions (Not to scale)

Woronora Reservoir. At shallow depth perched watertables can occur within the swamp zones that are not directly connected to a deeper groundwater system. Groundwater flow rate is restricted in the vertical direction downwards by layers of shale and claystone of much lower permeability (hydraulic conductivity) and lower vertical permeability overall of the entire rock sequence compared to horizontal permeability. Vertical groundwater flow in the Southern Coalfield with a stratified geological sequence is determined by the layer of lowest permeability in the geological profile.

Hence groundwater tends to flow horizontally above any impeding horizons and therefore in the Hawkesbury and Bulgo Sandstone predominately out into the lower elevation regional groundwater system. Under mining conditions groundwater seepage is directed to the caved zone below where coal is extracted and into the overlying fracture zone. Groundwater inflow is predominately from the surrounding strata, that is, the geological layers within and directly above the coal measures strata and the lower part of the Bulgo Sandstone.

A ‘constrained zone’ above the mined out panels is created by the compression and vertical tension of the rock above the mined out seam. This zone tends to maintain the insitu (i.e. pre-mine) vertical permeability of the strata and therefore continues to restrict vertical flow but can display an increase in the horizontal permeability within and above the parabolic fracture zone that has however little effect on vertical groundwater flow rate.

The piezometers shown in Figure 3-1 show the pressure head only at the lower end of each piezometer which is open. For example the water level in the piezometer within the caved zone in Figure 3-1 is near the bottom but this does mean that the groundwater above the fracture zone and higher in the profile along this piezometer has been completely drained. As indicated in figure 3-1 the watertable above the caved zone piezometer is maintained in the surface zone. That is, an open borehole penetrating the Hawkesbury Sandstone down to the Bald Hill Claystone would have pressure heads representing the watertable as these pressure heads would be unaffected by the caved/fracture zone disturbance[2]. Also while there is reduced pressure head at the base of the adjacent piezometer just above the fracture zone with a corresponding lower water level, there is also no complete drainage of groundwater above this piezometer opening. Similarly the third piezometer further to the left records much less reduced pressure head at its base and hence much higher water level in the piezometer tube. The corollary is that the piezometer tubes that are open to the groundwater system at their base or within a short interval within the tube have water levels that do not necessarily represent the positions of a variable water table depth but only the pressure head at the particular piezometer opening.

Hydrosimulations (HS 2017a) have also noted that:
"Although geological structures are known to exist in underground workings or are inferred to extend into the approved mining area, there is no definitive evidence of structural control on groundwater levels or flow directions. In general, individual structural features located on the floor of the Bulli Coal Seam have not been identified at surface despite focused searches over the years, nor have individual surface features been successfully projected and proven at the Bulli Coal Seam horizon."
Due to some ground level subsidence above the mining zone there is the probability of some shallow (< 20m) limited vertical conduits created in the rock with corresponding shallow horizontal connected bed separation strata cavities beneath the ground surface. These cavities can redirect oxygenated surface runoff into the shallow sub-surface with subsequent reduction of oxygen and re-emergence of this sub-surface flow further downgradient outside of the subsidence zone and hence result in limited loss of flow volumes. Re-emergence of this flow, that has undergone reducing conditions, into the oxygen rich atmosphere can cause ferrous iron in solution to precipitate into a ferric iron form indicating the sub-surface origin of the temporary shallow sub-surface flow. Generally low iron concentration levels that are non-toxic within emergent coloured flow although variable, depends on complex redox geochemical and bacterial mechanisms (Cullimore 1993, Appelo & Postma 1993, Alan H. E, Perdue E. M. Brown D. S. 1993, Deutsch 1997, Domenico ad Schwartz 1998)[3]. These iron concentrations levels at the MC site area can also be shown to depend on ambient temperature and stream runoff volumes.

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[2] See also the response of piezo 2E in the Hawkesbury Sst in similar conditions at the South Bulli mine (Figure 4.2 herein).

[3] These references only discuss the redox reactions of oxygen charged recharge water and subsequent reactions of oxygen loss, ferrous iron increase and subsequent creation of ferric compounds. They do not discuss specific conditions that might occur in a shallow mining cavities and subsequent exit of groundwater into the atmosphere. Nevertheless the redox processes would be similar in the mining case as is evident by the ferric hydroxide suspended brown and precipitate material in the emerging groundwater. Naturally occurring groundwater seepages, in unmined regions, emerging along valley escarpment fractures and bedding cavities can also often, due to the same processes, exhibit the formation of iron staining due to and including natural seepage flow from the exposed escarpment faces.

3.2 Metropolitan Coal Previous Mining, Monitoring and Modelling

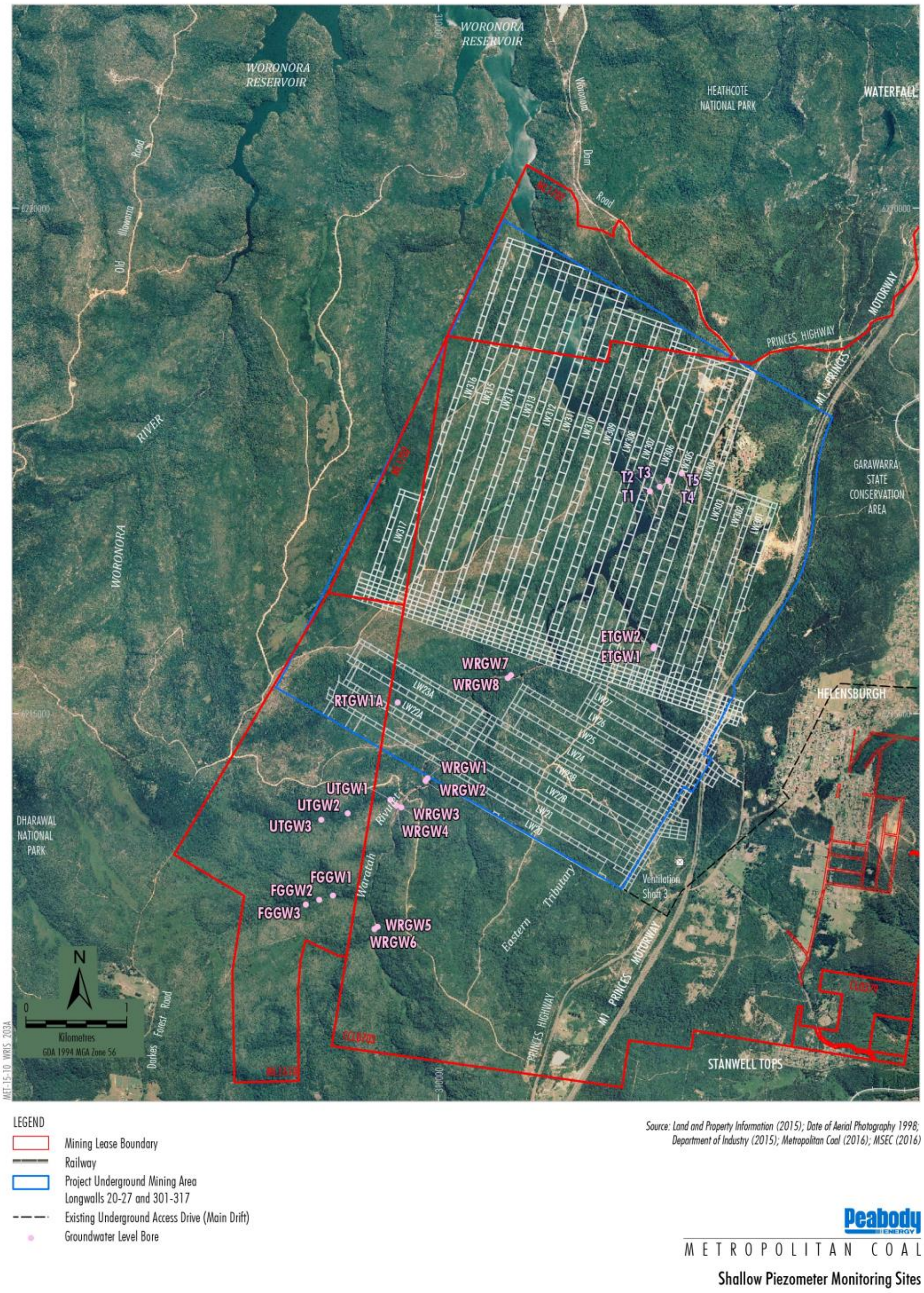

Figure 3-2 Shallow piezometer monitoring sites.

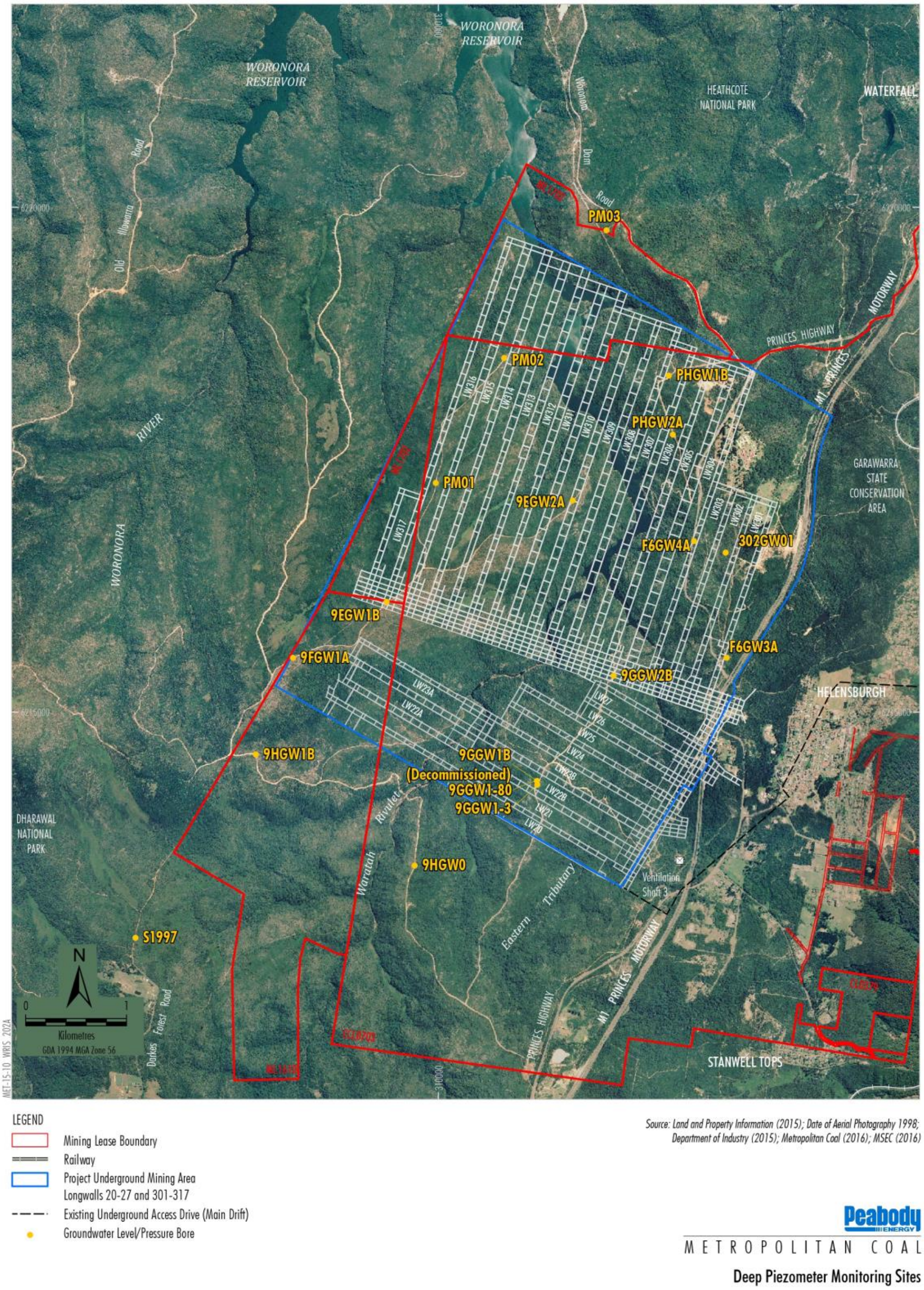

Figure 3-3 Deeper piezometer monitoring sites

Groundwater monitoring and modelling at the Metropolitan site has evolved since 2008. As noted previously longwall mining has so far been completed in all of the southern area up to and including LW27 (shown just south of piezometer 9GGW2B in Figure 3-3). Groundwater monitoring has been conducted in upland swamp shallow piezometers monitoring the upper parts of the geological sequence (Figure 3-2) and vibrating wire piezometers (VWP) that monitor deeper parts of the geological sequence (Figure 3-3).

Two goaf holes[4] (Figure 3-3) have been established and one is in progress at the Metropolitan site. These include Longwall 10 (9HGW0) post mining; Longwall 22B (9GGW1-3) post mining and also Longwall 302 (302GW01) currently being drilled in the central area of the LW302 panel footprint (Figure 5-1).

A recent data review on groundwater monitoring of existing piezometers has been reported and an updated calibrated numerical model of the current operations has been run by HydroSimulations (2017a). These monitoring results and simulation have made an important contribution in understanding the effects of longwall mining on the geological profile with respect to groundwater and subsidence and their likely effects.

In addition, comparisons with previous longwall mining under storage reservoirs are also available and discussed later in this report. However, the current debate regarding the estimation of height and degree of connected fracturing above longwall panels, and the whether the presence of shear planes extending toward the base of the Woronora reservoir within the 300 series of longwalls is relevant, will require more detailed monitoring and review. The issue of shear planes is discussed in further detail in the Geotechnical Issues Section 6 in this report.

3.3 Metropolitan Mine Water Balance (MCPL)

Metropolitan Coal Pty Ltd (MCPL) monitors the mine water balance to infer the water make (i.e. groundwater that has seeped into the mine through the strata) by calculating the difference between total mine inflows (reticulated water into the mine, moisture in the downcast ventilation, water in the backfill slurry and the in-situ coal moisture content) and total mine outflows (reticulated water out of the mine, moisture in the exhaust ventilation, and moisture in the raw coal).

Monitoring of the mine water balance comprises:

- Metered water reticulated into the mine (recorded continuously and downloaded monthly).
- Metered water reticulated out of the mine (recorded continuously and downloaded monthly).
- Manual measurement of moisture content into and out of the mine through the mine ventilation system using a digital psychrometer. The frequency of readings are as follows:
  - every hour over a 9 hour period on two occasions during a 12 month period;

[4] Goaf holes are drill holes that extend from the ground surface down to the fracture/caved zone above the mined out voids.

  - daily (week day) except public holidays or other circumstances (access, fan maintenance, etc.) that prevent readings to be taken; and
  - once per week as a minimum.
- Measurement of the in-situ moisture content of the coal during channel sampling for coal quality.
- Metered water reticulated into the mine from backfill plant (recorded continuously and downloaded monthly).
- Measurement of the moisture content of run-of-mine (ROM) coal conveyed out of the mine at the drift portal using an automated moisture scanner. A fully automated data acquisition system records and stores the data.

During Longwall 301-303 mining, the predicted mine inflows to these panels is predicted to lie in the range from 0.06 ML/day (low-inflow) to 0.6 ML/day (high-inflow), on average, based on the HydroSimulations modeling report.

In addition to the quantitative assessment of mine water make, MCPL maintains a register of all geological structures (faults, dykes) identified from underground workings that (if continuous) would intersect the surface within the Dams Safety Notification Zone. The register includes a description of the geological structure, and of relevance here, whether there is any water make associated with the structure, either after initial exposure or with time. To date there has been no geological structures exposed in the underground workings with water make. The register and inspection information is provided to the DSC in a monthly report (Management Status Report for Metropolitan-4 & 2 approvals).

Figure 3-4, below, is the daily data and 20 day moving average of mine water make since the commencement of monitoring in 2009. The figure indicates that daily fluctuations of approximately 2.0 ML/day (either inflow or outflow) are common due to the nature of mining. For example the Longwall machine alone uses approximately 0.7 ML/day for dust suppression when operating. There have also been periods of campaign pumping to dewater adjacent workings such as in May 2011. These times will appear as 'water-make' since outflow exceeds inflow.

Whilst there are significant fluctuations on a daily basis, the 20 day moving average water make provides an adequate indicator of a change in conditions. Since 2009, with the water make has averaged at 0.09 ML/day and, with the exception of May 2011, the 20 day average water make has been below 0.5 ML/day.

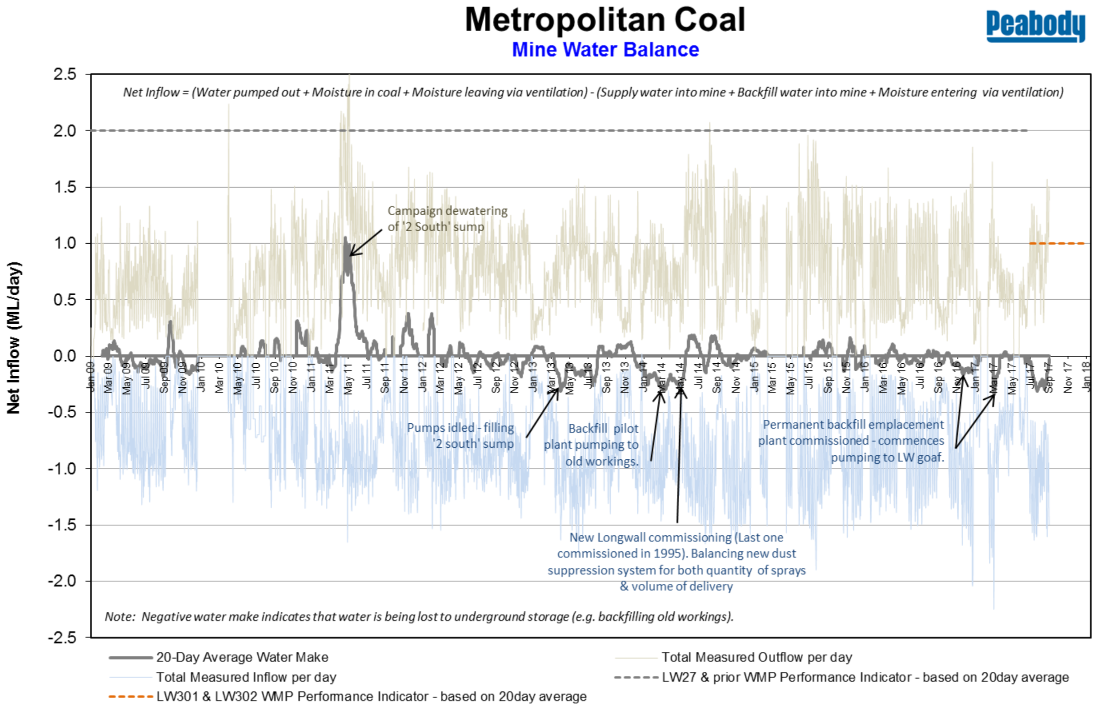

Figure 3-4 Metropolitan Coal Water Balance (Supplied by MCPL)

4.0 COMPARISONS WITH OTHER MINING (FK)

4.1 Comparison with Dendrobium Mining Influence

Concerns by the DPE have been raised regarding the Metropolitan Coal (MC) proposal for mining beneath the reservoir given the groundwater conditions and inflow reported at the Dendrobium (DB) mine. These inflow conditions at Dendrobium site are, in part, the reason for the current strategy review. There are however differences in the mining geometry at Metropolitan Coal (MC) and Dendrobium (DB). Table 4-1 is the Longwall mining geometry parameters comparison at the MC and DB site areas.

Table 4-1: Comparison of Metropolitan Coal and Dendrobium Area 3B Longwall Mining Parameters (**Table prepared by MC**)

Mining Parameter	Metropolitan Coal Longwalls 301 – 303	Metropolitan Coal Longwalls Beneath Woronora Reservoir	Dendrobium Mine Area 3B
Longwall Void Width	163 m	138 m	305 m
Extraction Ratio *Longwall void width to Depth of Cover*	41% (163 m / 395 m)	35% (138 m / 395 m)	98% *At minimum depth of cover - valley*
Extraction Height	2.7 m to 3.2 m	2.7 m to 3.2 m	3.9 m to 4.6 m
Depth of Cover	395 m to 555 m	395 m to 435 m	310 m to 450 m
Chain Pillar Width	45 m	70 m	45 m
Seam Mined	Bulli Seam	Bulli Seam	Wongawilli Seam
Water make	~0.1 ML/day	~0.1 ML/day	~11 ML/day

In summary, the panels at DB are much wider; extraction seam thickness much greater; depth of cover is less and DB mines a different seam. These differences in geometry, extracted seam thickness and therefore height and resultant degree of connected fracturing are most likely to have resulted in substantial differences in pressure head propagation and inflow. At Dendrobium the panel width to depth of cover ratio (*w/d*) is in the range 0.68 to 0.98 whilst at the MC site the ratio would be in the range 0.29 to 0.41 beneath longwalls 301 to 303 (similar to existing longwall mining at Metropolitan) and below the Woronora Reservoir in the range 0.32 to 0.35 (Table 4-1). It is reasonable to expect that higher ratios such as those at Dendrobium could have led to increased inflow due to the increased height of vertical fracture propagation[5]. In addition the maximum extraction seam thickness at Dendrobium is 1.4 greater than the maximum extracted seam thickness at the MC site. This will also influence to some extent fracture height propagation. The reduction of the MC mining geometry parameters was a direct response to the concerns by stakeholders during the Planning Commission Assessment process about Dendrobium mining conditions.

4.2 Longwall mining near and under Cataract Reservoir- groundwater influence

A question that has arisen is whether a precedent has been set for previous mining near and under stored waters. In NSW longwall mining was conducted under at the Cataract Reservoir between 1983 and 1986 and again during the period 1992 and 1998. These periods of mining have been reported on by Singh and Jakeman (1999); Holla and Barclay (2000) and Seedsman and Kerr (2001). The Cataract Reservoir is situated about 22km south of the Metropolitan site in similar hydrogeological strata.

According to Holla and Barclay (2000) during 1983 to 1986 *"shortwall"* panels *"were mined in the Bulli seam in the* [South] *Bulli Colliery under the Cataract Reservoir".* Three short panels 80m wide with 60m wide pillars were mined with 2.5m seam extraction at 230m depth below the deepest part of the reservoir and 340m under the adjacent plateau. According to Holla and Barclay (2000) *"Measurement of water levels in the boreholes indicated a close relationship between water movement and mining at deeper levels. At shallow levels in the Hawkesbury Sandstone, there was no discernible mining effect."* This is illustrated in Whitfield (1988) in Figure 4-1 below copied from his report that show Stanwell Park Claystone and Bald Hill Claystone of low vertical permeability and the piezometer water level responses (Figure 4-2) with no decline in the water level measured in the Hawkesbury Sandstone (i.e. piezometer 2E).

It is reported by Holla and Barclay (2000) that the mine workings remained *"dry"* and the piezometer monitoring indicating that there were *"no hydraulic connections between surface water and mine workings."* That is analysis of the mine water indicated no evidence of seepage from the storage. These results were also independently determined and validated by two experienced hydrogeological and geological qualified reviewers Williamson and Whitfield (1987).

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[5] See Galvin (2016) page 434 Fig 10.8 showing vertical strata fracture propagation numerical simulation conducted by Strata Control Technology (SCT) for various width/depth ratios in the range 0.5 and 1.4. Although Galvin (2017) indicates concerns regarding empirical models of 'height of fracturing' he notes that *"for a given set of site specific conditions (geology, stress field etc.), the mode of failure and extent of disturbance of the overlying strata…caused by forming an excavation* <u>*is strongly controlled by the ratio of panel width-to-mining depth*</u>*".* He also notes that strata disturbance is also a function of the overall lateral extent, that is, width of mining as well as the width of individual panels.

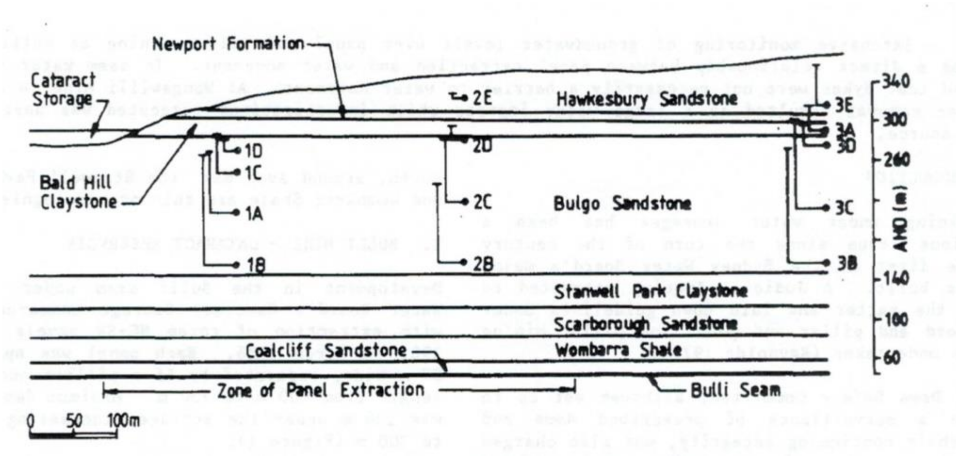


Figure 4-1: Stratigraphic section and piezometer locations (From Whitfield 1988).

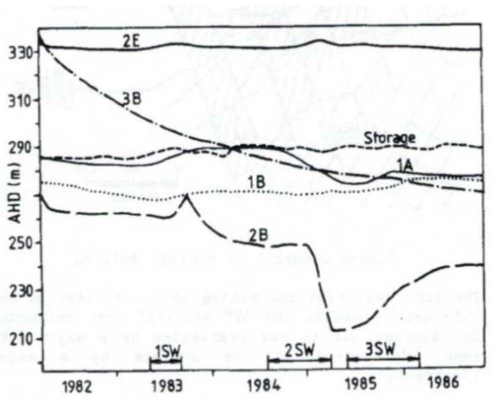


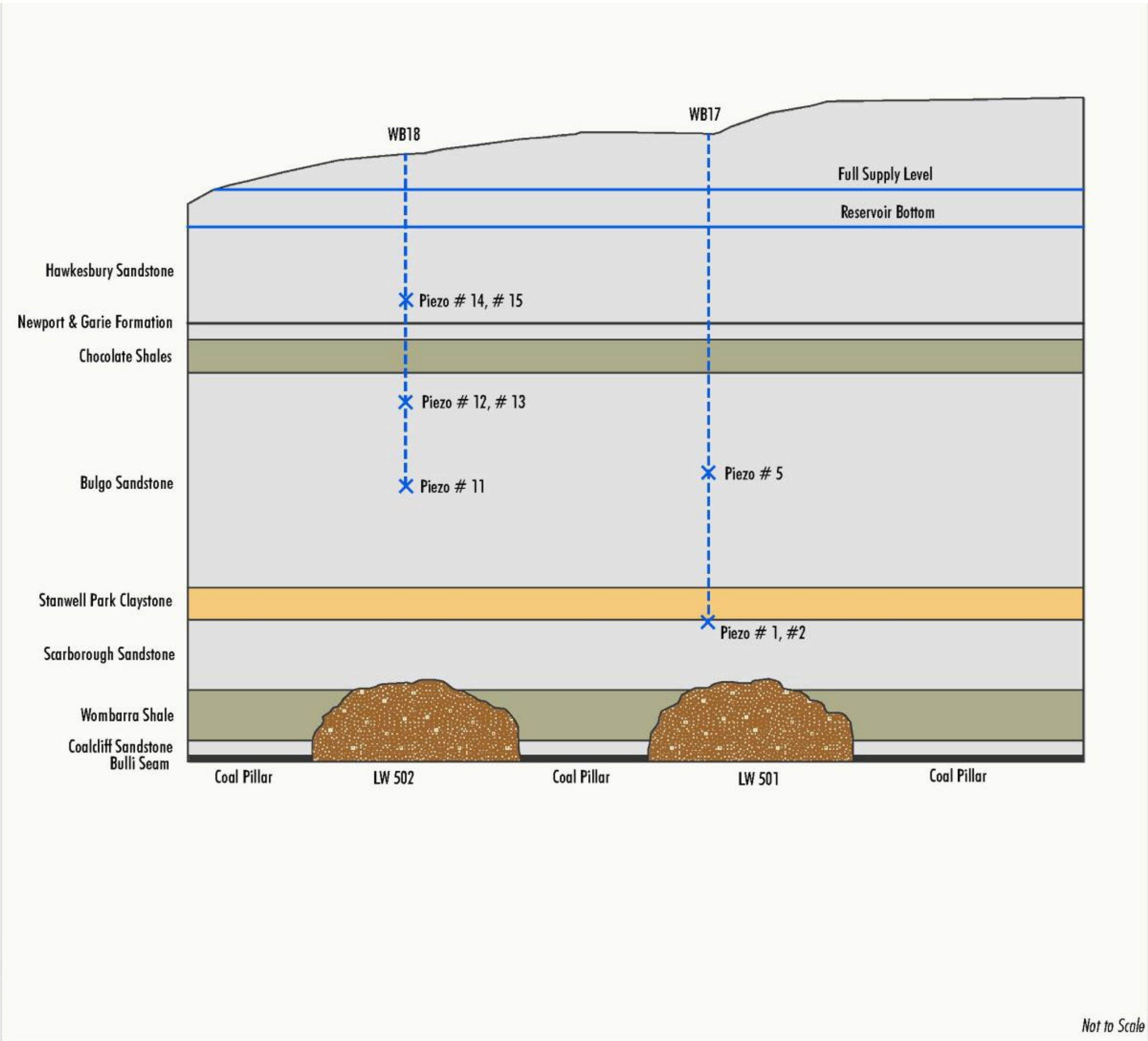
Figure 4-2: Piezometer groundwater Levels (from Whitfield 1988).

Whitfield (1988) summarized the Williamson and Whitfield (1987) paper findings at the South Bulli mine as follows: *"Workings in the Bulli seam have generally been dry and monitoring of water movement within this area of the Bulli mine confirmed that situation. Although some water make was measured during extraction of three panels this did not exceed 1120 litres/hour* [0.027 ML/day] *and as such was not noticeable within the mine. There is some evidence to suggest that throughout development and extraction water make was associated with drivage through the dyke zones."* Whitfield (1988) also records that water levels in the deepest piezometers remained within the Bulgo Sandstone (as shown in Figure 4-2). Because there are two low permeability shale/claystone horizons (responding as aquitards)[6] between the Bulgo Sandstone and the Coal Measures, he suggested that any water make into the mine was probably localised groundwater from the immediate overlying Coalcliff Sandstone. He concludes the discussion with: *"It would appear that disruption to the strata from panel extraction has not been of sufficient magnitude to evoke any significant change in the hydraulic connection between the surface storage and the mine workings".*

[6] The Stanwell Park Claystone and Bald Hill Claystone layers - these layers are incorrectly designated as *"aquiclude layers"* in Singh and Jakeman 1999. An *aquiclude* is a layer that does not allow flow of groundwater across that layer (i.e. the layer is impermeable). What is meant is an *aquitard layer* that restricts and impedes but does not prevent groundwater flow across such a layer the flow rate depending on its low or very low vertical permeability (hydraulic conductivity). It was common at the time to refer to impeding layers as aquicludes rather than aquitards (FK).

4.3 Mining at the Bellambi West Colliery near and beneath Cataract Reservoir

Commencing in 1993 extensive longwall mining was conducted in the vicinity and under the Cataract storage at the Bellambi West Colliery. The initial six panels were 110m wide with pillars 66m wide and mining depth 320m to 430m with an extracted seam 2.5m thick. Singh and Jakeman (1999) indicate that the first two panel longwall lengths were 880m and 1040m. Figure 4-3 shows the piezometers WB18 and WB17 above the longwalls LW502 and LW 501 which were immediately adjacent to the reservoir. Panels mined below the reservoir are shown in Figure 4-4 (Singh and Jakeman 1999).



Source: Singh and Jakeman (1999)

Figure 4-3: Piezometers WB18 and 17 locations above longwalls LW502 and LW501. ('Chocolate Shales' = Bald Hill Claystone) (Redrawn from Figure 5 Singh and Jakeman 1999).

Figure 4-4 Longwalls at Bellambi West Colliery adjacent and beneath the Cataract Reservoir.
(redrawn from Figure 3 in Singh & Jakeman 1999)

Details of the monitoring are also provided by Holla and Barclay (2000). Piezometers over the centre of the panels indicated that over the 5 years of mining there was loss of groundwater below the Stanwell Park Claystone by vertical fractures. Singh and Jakeman (1999) indicate a caved zone extending up to 40m and the zone of *“linked”* fractures extending up to 85m above the Bulli seam.

Some head loss in the Bulgo Sandstone was also apparent that re-established after mining moved away. Holla & Barclay (2000) note that the groundwater in the Hawkesbury Sandstone above the Bald Hill Claystone *"appeared unaffected by mining" and "that there has not been a development of extensive vertical fractures in the middle level"* (i.e. the Bulgo Sandstone). Singh and Jakeman (1999) note that while there was a horizon of flexed strata near the ground surface there was no apparent formation of shallow bed separation cavities.

No excessive inflows recorded in the mines were observed that required pumping out according to Holla & Barclay (2000). More water was pumped into the Cataract mine workings than was pumped out. A water balance study conducted in the Cataract District showed that the water pumped out of the mine was 38% of the water supplied to the mine; the rest of the water was lost in dust suppression and evaporation. The groundwater from the roof strata and emanating from the goaf was too small to measure (Singh& Jakeman 1999).

Geotechnical results and discussion regarding stress, strain and subsidence at this site are reported in Holla & Barclay (2000) and Seedsman and Kerr (2001). None of the papers quoted above have referred to shear plane or planes although the minimal inflows would suggest initially that there was no significant pathway(s) created by such structures. Because there were no detrimental effects on the integrity of the reservoir by the end of 1999 a total of 14 panel and pillar geometries were designed and mined successfully with widths of 100m to 150m and pillars 60m to 65m wide (Holla & Barclay 2000).

A comparison between the Metropolitan Coal longwalls proposed beneath the Woronora reservoir and those near and below the Cataract Reservoir at the Bellambi West Colliery during 1990 is summarised in Table 4-2.

Table 4-2: Mining parameters between MC proposed longwalls, near and below the Cataract Reservoir (**Table prepared by MC**)

Mining Parameter	Metropolitan Coal Longwalls 301 – 303	Metropolitan Coal Longwalls Beneath Woronora Reservoir	Longwalls Beneath Cataract Reservoir
Longwall Void Width	163 m	138 m	110 m to 150m
Extraction Ratio *Longwall void width to Depth of Cover*	41% (163 m / 395 m)	35% (138 m / 395 m)	46% (150 m / 325 m)
Extraction Height	2.7 m to 3.2 m	2.7 m to 3.2 m	2.5 m to 2.7 m
Depth of Cover	395 m to 555 m	395 m to 435 m	295 m to 445 m
Chain Pillar Width	45 m	70 m	60 m – 66 m
Seam Mined	Bulli Seam	Bulli Seam	Bulli Seam
Water make	~0.1 ML/day	~0.1 ML/day	Dry

Table 4-2 indicates panel width to depth of cover ratios (*w/d*) at the Bellambi West Colliery for all combinations of *w/d* in the range 0.25 to 0.51 whilst at the MC site beneath the Woronora Reservoir it would be 0.32 to 0.35 as discussed previously. Again the comparison of these ratios with the much higher *w/d* ratios for Dendrobium is relevant and the essentially *"dry"* conditions experienced at the Bellambi West Colliery with ratios within the range of that Colliery likely for the MC mining beneath the Woronora Reservoir.

There has been some discussion at Metropolitan Coal about the possibility of increasing the width of panels beneath the reservoir to 163m, consistent with existing extraction widths and current knowledge of groundwater behaviour based on 163m extraction width. However, it is considered (FK,BH) that this should be based on further validation depending on the results of the proposed monitoring at LW 301, 302 and later at LW303.

4.4 Mining at the Wongawilli mine near the Avon Reservoir

Whitfield (1988) also discusses the Wongawilli Mine associated with the Avon Reservoir and 'Blue' panel extraction (Figure 4-5). Both zones were not directly under the reservoir but adjacent to the Marginal Zones (MZ) as depicted in Figure 4-5. Although initially groundwater inflow in the first workings was low (2000 litres/hour – 0.048 ML/day) this flow increased at Blue 4 at completion in 1982 and was attributed to pillar extraction adjacent to a 2m thick dyke with inflow increasing up to 29,000 litres/hour (0.69 ML/day). Later during extraction at the Blue 2 panel adjacent to a sill, inflow rose to 100,000 litres/hour (2.4 ML/day) that eventually stabilised at 80,000 litres/hour and halted mining.

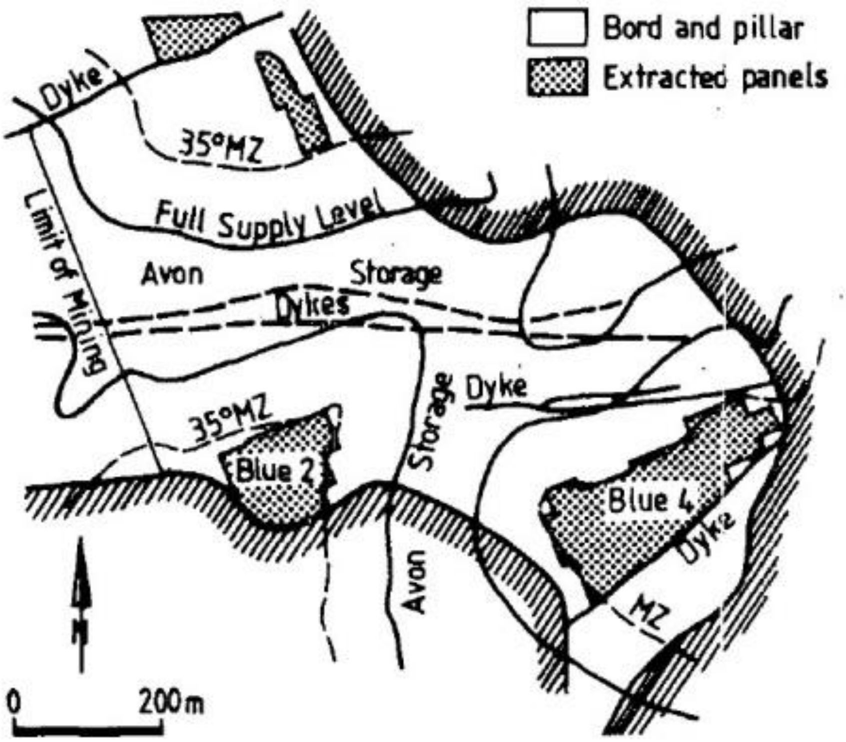


Figure 4-5: 'Blue' panel extraction and Avon Reservoir
(from Whitfield 1988 Figure 4)

The analysis of groundwater inflow from the Blue2 and Blue 4 panels occurred with a limited depth of cover over the mined out seams (less than 140m). This also meant that impeding low permeable layers (aquitards) were essentially absent. While Blue2 panel inflow decreased over time the inflow to Blue4 panel although decreasing did respond to rainfall with a time lag of a few days. Analysis of inflow water samples suggested that the inflow contained components of both surface and groundwater, and according to Whitfield (1988), surface water being a most likely Avon Reservoir water source.

Whitfield (1988) however points out that:
"..there are a number of unfavourable conditions in the area which help to explain the inflows. The strata between seam and storage are principally massive sandstones, the main claystone horizons being thin or absent. Therefore, in the absence of a major aquiclude [sic] *downward drainage would be unimpeded".*

Whitfield (1988) also notes that the particular overall geological structure of a NW trending syncline with a major fault in the area would have induced tensile strain and dilation that would have in turn most probably led to the fracture openings encountered. It is evident that limited depth of cover would also been have been a factor in the high rate of inflow conditions recorded at the Wongawilli mine. This is so given the height of fracture zone propagation that could have extended near to or at ground surface due to the limited thickness of the overburden, lack of aquitard layers but also due to the presence of several permeable dyke and sill structures.

With regard to possible geological structures within the Woronora Reservoir zone geological strata, it is worth repeating that Metropolitan Coal Section 3.3 above has stated that:

"MCPL maintains a register of all geological structures (faults, dykes) identified from underground workings that (if continuous) would intersect the surface within the Dams Safety Notification Zone. The register includes a description of the geological structure, and of relevance here, whether there is any water make associated with the structure, either after initial exposure or with time. To date there has been no geological structures exposed in the underground workings with water make. The register and inspection information is provided to the DSC in a monthly report (Management Status Report for Metropolitan-4 & 2 approvals)".

5.0 PROPOSED MONITORING AND HYDRAULIC TESTING AT THE METROPOLITAN SITE (FK, BH)

5.1 Proposed Piezometers

One deep piezometer hole within the approximate central position above the footprint of longwall panel 302 was proposed before the strategy review by Metropolitan Coal.
It is understood that this particular piezometer above the footprint of LW302 would be sunk to a deep level (up to several hundred metres to the goaf) to monitor mining fracturing at depth in the geological profile at LW302. It is also understood from Metropolitan Coal's recent advice that a mid-depth piezometer is to be constructed above the LW302 footprint suggested by WaterNSW. While the strategy reviewers (FK, BH) consider that this is suitable and desirable, additional monitoring at mid to shallower depth should be established in a line extending toward the reservoir extending from LW301 to LW302 and beyond (Figure 5-1). In addition inclinometers should also be established in the upper sections of overburden strata for detecting any significant shear plane movement extending toward the reservoir (see Geotechnical Issues discussed by BH later in this report).

Figure 5-1: Proposed locations for test bed boreholes for packer testing, VWPs and standard piezometer installation TBS1 to TBS5 (TBS4 and TBS5 depending on access) and approximate location of proposed deep piezometer to goaf above LW302.

The requirement for monitoring at shallow depth has been stated in the conditions in item 1 part *'7 Conditions on Longwalls 302 and 302 Extraction Plan'* (DPE 2017).

It is considered that strata above longwall panels 301 to 303 should be viewed as a 'test bed' (Figure 5-1) for detailed deeper and shallower monitoring and hydraulic testing that should also include the area situated between the footprint of LW303 and the Woronora Reservoir proper, subject to accessibility and possibly alternative sites.

Vibrating Wire Piezometers (VWP's) should be installed in a hole at each monitoring site some metres above the Bald Hill Claystone and the second zone some metres below this unit in the Bulgo Sandstone. The Bald Hill Claystone section could therefore be cased off.

The zones for monitoring in LW301, 302 and subsequently 303 should also include the relatively shallow zone centred between 10m to 20m depth monitored by a standard piezometer at each site to intersect any potential shallow bed separation cavities

The main purpose of the increased monitoring is to establish a better understanding from a larger number of site responses, since an individual VWP site can often lead to inaccurate readings of pressure head, as has already been evident in the currently available VWP piezometers. However, the Vibrating Wire Piezometers should be suitable for monitoring pressure head response that would be related to fracture pressure head propagation due to longwall mining. Because the sites are in relative close proximity they should therefore provide better monitoring samples of mining influence of the fracture zone extent, permeability variations and any pressure head decline within the Upper Hawkesbury Sandstone above the Bald Hill Claystone and immediately beneath this unit in the Upper Bulgo Sandstone.

Monitoring using good quality VWP's and piezometer construction across LW301 to 302 and hydraulic testing of the formations to determine fracture distribution would allow connective influence to be assessed particularly before and after mining is completed before any mining commences beneath the reservoir. If VWP's are found to yield anomalous results it may be necessary to construct appropriate standard piezometers to resolve these error measurements and/or responses.

5.2 Hydraulic Testing

For the groundwater piezometer boreholes packer testing should be initially conducted to determine permeability (hydraulic conductivity) distribution with depth, prior to, but also post mining of LW 301 and 302 and in time, if approved, following mining of LW 303. It may be necessary to conduct inflow 'fall-off' head test(s) in zones of much higher permeability unsuitable for packer test determination post mining. The proposed monitoring and hydraulic testing should confirm or otherwise the *'no connective cracking'* requirement as set out in the *'Schedule 3 Specific Environmental Conditions – Mining'* Project Approval (Minister for Planning 2009) at least for LW301 to 302 at this stage.

Following the completion of mining at LW302 a full set of monitoring results, including packer and inflow tests results, should be made available to relevant agencies including the strategy reviewers for assessment. Comparison of the currently available empirical model(s) estimation of height of fracturing and the height of groundwater loss in the goaf hole above longwall 302 should also be reported.

Metropolitan Coal have agreed with the proposed sites for monitoring as shown in Figure 5-1 for panels 301 and 302 with the actual sites positioned in reasonably close agreement with the original suggested locations. Slight differences in position have been necessary due to accessibility issues. Details of the proposed piezometer installations and hydraulic testing are as listed in the Proposed Works Section 8, Table 8-1 herein.

The proposed monitoring at the Metropolitan site at LW 301, LW302 and later at LW303 will provide validation of the current empirical analytical models for determining the 'Height of Fracturing' (HoF) above longwall mined out panels at the Metropolitan site.

Those modelling validation comparisons using empirical models should be made without the use or inclusion of field evidence (as a calibration point or points) of piezometer response to mining, but only pre-mine piezometer pressure heads and then empirical model predictions made as if mining was yet to proceed. Limited Monte-Carlo simulated responses (running the models for different assumed affected hydraulic parameters due to mining and therefore HoF) would be a useful outcome of the validation process and provide further demonstration of the suitability of the current HoF empirical methodologies.

6.0 GEOTECHNICAL ISSUES (BH)

The Approval Condition requires consideration of the following *"geotechnical"* issues relating to the proposed longwall mining operations in the vicinity of the Woronora Reservoir at Metropolitan:

- characterisation of fractures (pre and post mining) including shear planes;
- recommendations for additional subsidence monitoring;
- possible bathymetric survey of the Woronora Reservoir.

In order to understand these issues more clearly, Figure 6-1 provides an overall cross section of the overburden strata above the Bulli Seam, through to the surface in the area of interest, including identification of the major strata units present, as well as showing the nature of the surface topography, including the floor profile of the Reservoir. This confirms that the majority of the overburden is made up of the Bulgo Sandstone, overlain by the Bald Hill Claystone, and then Hawkesbury Sandstone. The Reservoir floor is located entirely within the Hawkesbury Sandstone, and is typically of the order of 400m above the Bulli Seam.

The above Condition of Approval refers to *"characterisation of fractures (pre and post mining) including shear planes"*. This is a very broad requirement which is extremely difficult, if not impossible to fulfil, for the following reasons. Firstly, fracture patterns associated with overburden rock strata subjected to undermining by longwall mining can be extensive and quite variable, ranging from complete rock failure in the immediate caving zone above the coal seam, through to some level of surface tensile cracking within the subsidence impacted zones of curvature. It would simply not be possible to fully analyse or characterise all fracture patterns throughout the overburden – either pre- or post-mining. It is considered more important to focus on what is commonly referred to as the *"height of fracturing",* as is often discussed in relation to impact of mine subsidence on groundwater. DPE have confirmed that this is the issue requiring characterisation.

Even the concept of height of fracturing is difficult to fully and accurately *"analyse and characterise"*, and remains a subject of some debate amongst the geotechnical and hydrogeological community (see Galvin, Mackie 2017). However, it is accepted as being very important to gain a meaningful understanding and best-estimate analysis of such a region of fracturing and *"connective cracking"* within the overburden, using whatever practical means available.

Furthermore, the issue of the presence of induced shear planes is understood to be important. However, it is simply not possible to identify every individual plane of induced shear in the overburden strata, since shearing can occur on almost all bedding planes in the overburden above mining and towards the edges of the subsidence zone. It is considered that the primary focus of this aspect of the strategy should be on major, mining-induced bedding plane shear detected in the upper sections of the overburden, in the region between the reservoir and the mining activity.

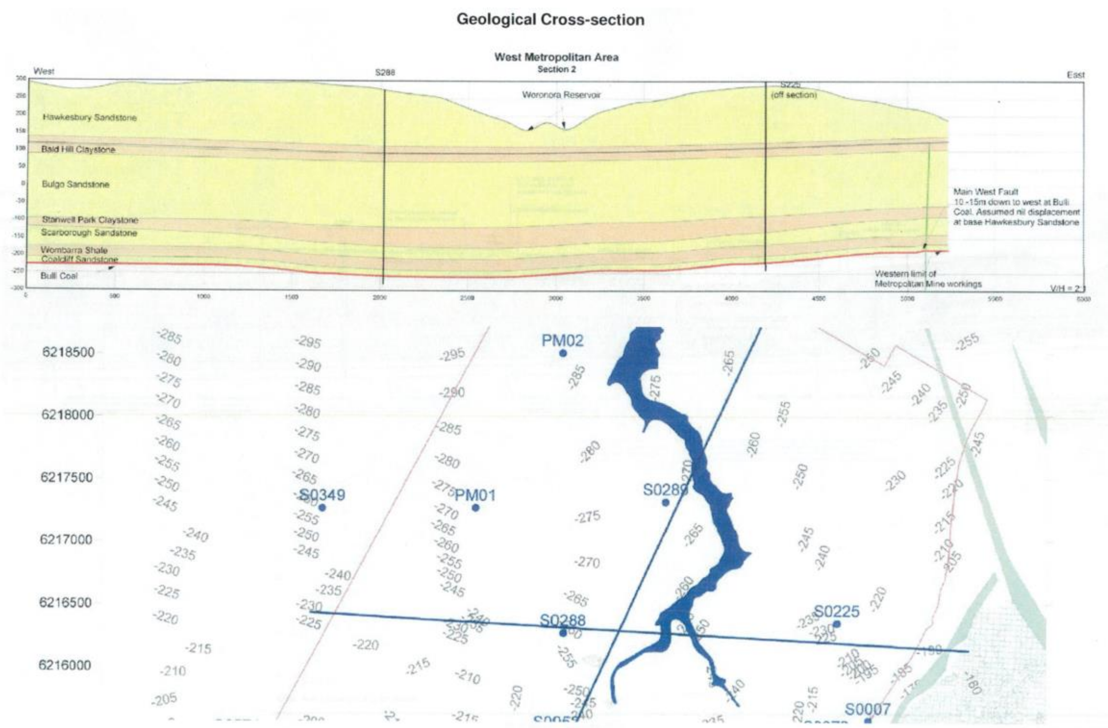


Figure 6-1: Geological cross-section – West Metropolitan Area, showing seam horizon, major geological units and surface topography. *(source: Metropolitan Coal (unpublished)).*

The following sections provide some further insights and issues regarding both *"height of fracturing"* and horizontal shear planes.

6.1 Characterisation of Fractures – Height of Fracturing (HoF)

A major review of height of cracking above the Dendrobium Mine, conducted by PSM for the Department of Planning and Environment, together with two Peer review reports (Galvin, Mackie 2017), was released just prior to completion of this Stage 1 Strategy Report. A detailed review and discussion of the findings of that report and the peer reviews will be conducted and included in the Stage 2 Strategy Report for this present study. However, some comments by the groundwater peer reviewer have already be quoted from this HoF review in Section 5 of this report and emphasized again in this Section.

It is important when discussing the height of fracturing zone to establish some common and consistent terminology. The actual nature of the fracturing above a longwall panel cannot be directly measured, but can only be inferred from indirect observations and measurements. Such measurements may include borehole fracture and calliper logging; geophysical logging; borehole extensometry and groundwater pressure head monitoring. The conceptual model of the fracture zone has been discussed internationally by many authors through the use of a number of simplified conceptual models which describe a series of zones of different types of rock failure, fracturing and deformation above longwall panels. Figure 6-2 is one such conceptual model, above a single longwall panel where commonly four zones are defined:

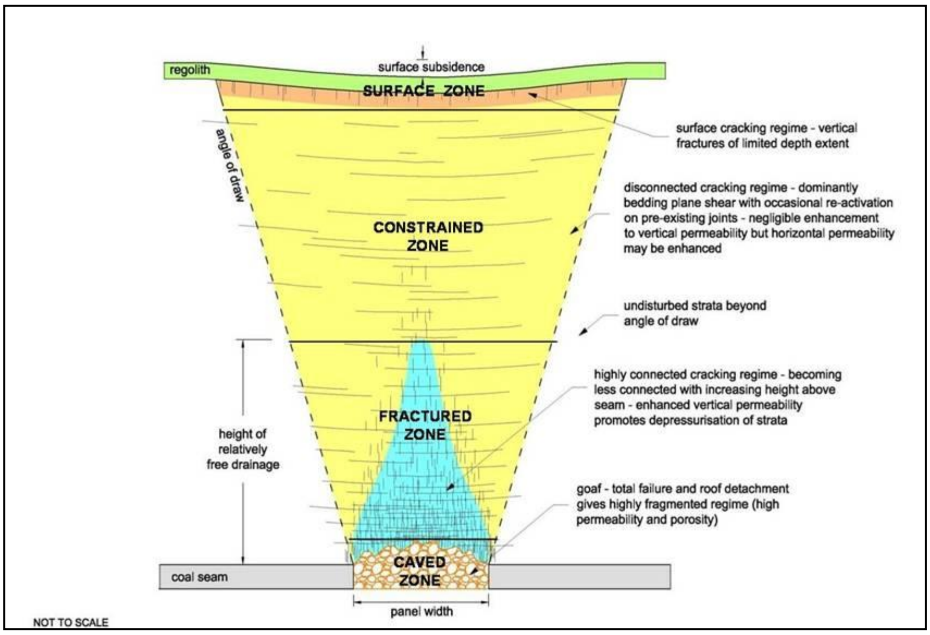


Figure 6-2: "Height of Fracturing" concept. *(source: NSW Department of Planning, 2008, original source Dr. C. Mackie).*

- **caved zone** – where there is complete rock failure and large scale downward movement and some rotation of rock blocks, resulting in a significant amount of void space.
- **fractured zone** – where the rock has undergone significant vertical and horizontal deformation, with dilation of some discontinuities (bedding planes and joints) and also

incurred connective cracking of intact rock. The result is a fractured rock mass that allows increased permeability permitting depressurisation of groundwater in this zone.

- **constrained zone** – contains deformation, but significantly less cracking, without connective fracturing occurring, such that depressurisation does not occur to any significant extent. The deformation includes a significant extent of bedding plane shear as the layers of rock strata bend. (In some conceptual models the constrained zone is divided into two different zones where the upper region consists of much more simple bending, without any major fracturing, but also with shear movement on bedding planes).
- **Surface zone** – the near-surface region where cavities associated with tensile fractures opening up as the surface strains create a limited depth of open vertical fractures and horizontal cavities in the shallow strata. These cavities are often said to lie within a zone 10m to 20m below ground level.

On the basis of this form of conceptual model and definitions, the term *"height of fracturing"* is used to refer to the region of connective fracturing which results in significant depressurisation of the strata. Pressure monitoring is therefore used as the primary means of detection of the upper limit of this zone. An upper limit of height of fracturing was detected by groundwater seepage loss in a post-mining hole drilled over longwall 10 (9HGW0, see Figure 3-3 for location) at Metropolitan site indicating a height of fracturing of approximately 130m as *" no drilling fluid was lost until the Stanwell Park Claystone"* (N. Merrick, HydroSimulations FK pers. comm.). Figure 6-4 shows another conceptual model of ground behaviour above a series of adjacent longwall panels. Although the description of the zones and their geotechnical behaviours differ somewhat from above, the fracture zone (2) is of a similar nature, and is also reflected in a scaled physical model.

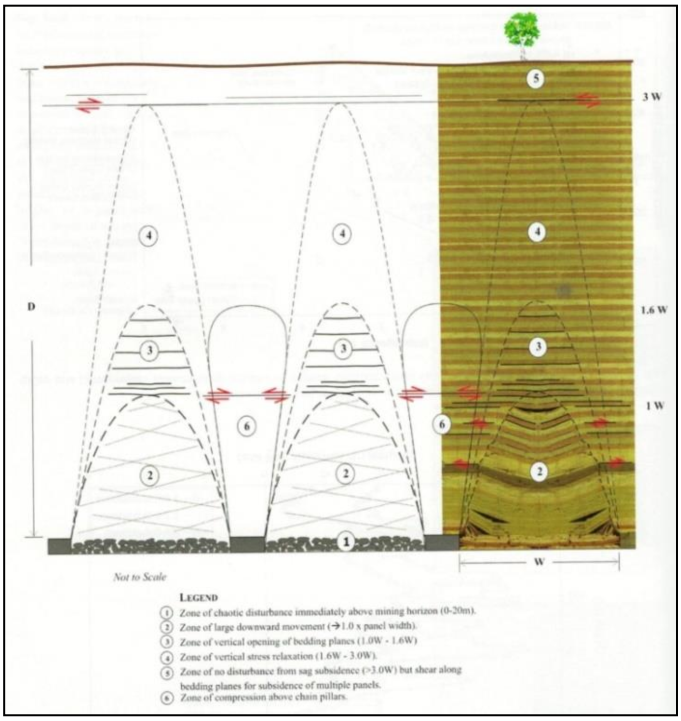


Figure 6-4: Conceptual model of overburden caving behaviour above a longwall panel

(source: Galvin (2016) states " inferred by Mills (2012) on the basis of accumulated surface and subsurface monitoring data from a range of sources")

On the basis of these models, several empirical prediction models have been developed in Australia to estimate height of fracturing based on mining geometries (primarily depth, panel width and mining height). Two such empirical models are the Tammetta and the Ditton models – both of which have been applied at Metropolitan and other Southern Coalfield mines. Figure 6-5 shows the application of both of these models using the Metropolitan site goaf hole at LW10 data which are remarkably consistent in their prediction of a height of fracturing of approximately 130m above the mined seam. This however, is no coincidence, since both models used the data derived from the LW10 borehole pressure testing as a calibration point. It is worth noting that a subsequent post-mining hole was also drilled over the goaf of longwall 22B (9GGW1-3 – see figure 3-3 for location). This indicated a total loss of water at a height of 137.5m above the Bulli Seam, which is quite consistent with the 130m for height of fracturing at borehole 9HGW0 above longwall 10.

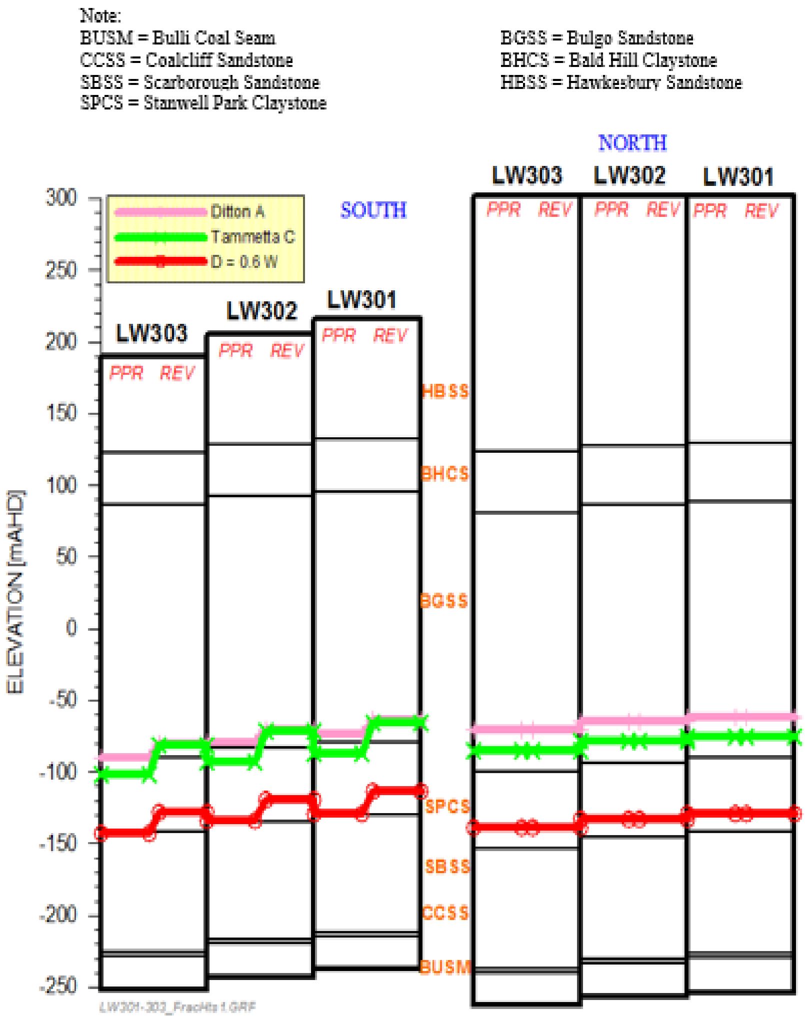


Figure 6-5: Fracture zone height predictions using Ditton & Tammetta models
(source: HS 2017a, and PowerPoint presentation to DSC and Metropolitan Coal)

It is important to note that these empirical models are only an approximation for height of fracturing, as they do not necessarily reflect variations due to changes in overburden geology, structural geology impacts or stress conditions (See also Galvin, Mackie 2017). Furthermore, the database from which they are derived is limited in the range of mining it contains. Measurement of pressure heads in each new mining region is necessary, including where possible post mining pressure head responses due to initial panels mined, to validate any forward reliance on these empirical models. The contributions in this strategy report (FK, BH) have emphasized the importance of width to depth ratios (*w/d*) as a simple screening estimate in the Metropolitan site area prior to mining for determining the likely height of *"connective cracking"* as a 'first pass' estimate, that is validated based on past mining responses beneath the Cataract Reservoir. As noted in Section 5 above, Galvin (2017) indicates that: "… *the mode of failure and extent of disturbance of the overlying strata…caused by forming an excavation is strongly controlled by the ratio of panel width-to-mining depth".*

As noted previously, there is agreement (BH) with the groundwater monitoring discussed above in Section 5 that should be ideally installed as a basis to estimate the height of fracturing in the proposed and current mining region LW 301 and 304 adjacent to the Woronora Reservoir.

6.2 Shear Plane Movement

The other issue identified in the Approval Condition, and briefly discussed above, is the presence of horizontal shear movement that is known to occur, largely on pre-existing bedding planes in the upper sections of overburden, due to underground mining. As already mentioned, shearing is taking place throughout the overburden sequence as strata deforms, largely cantilevering above the edges of the fracture zone as well as bending strata present in the upper "constrained" zone and causing strata bedding planes to separate.

However, it has also been observed that some more far-field or regional bedding plane shear can occur in the near-surface strata, induced by the effects of longwall mining. These bedding plane shears are more likely to be associated with what is termed non-conventional subsidence (NSW Department of Planning, 2008), where irregular surface topography – down-slopes and valleys – lead to regional strata movements, often away from the mining direction, towards the down-slope, or valley centrelines, resulting in what is known as *"valley closure".*

Such behaviour has been measured in the Southern Coalfield at a number of locations, including a study conducted to determine the impact of mining by Dendrobium Mine on the Sandy Creek Waterfall (Walsh et al, 2014). Figures 6-6 and 6-7 show this behaviour.

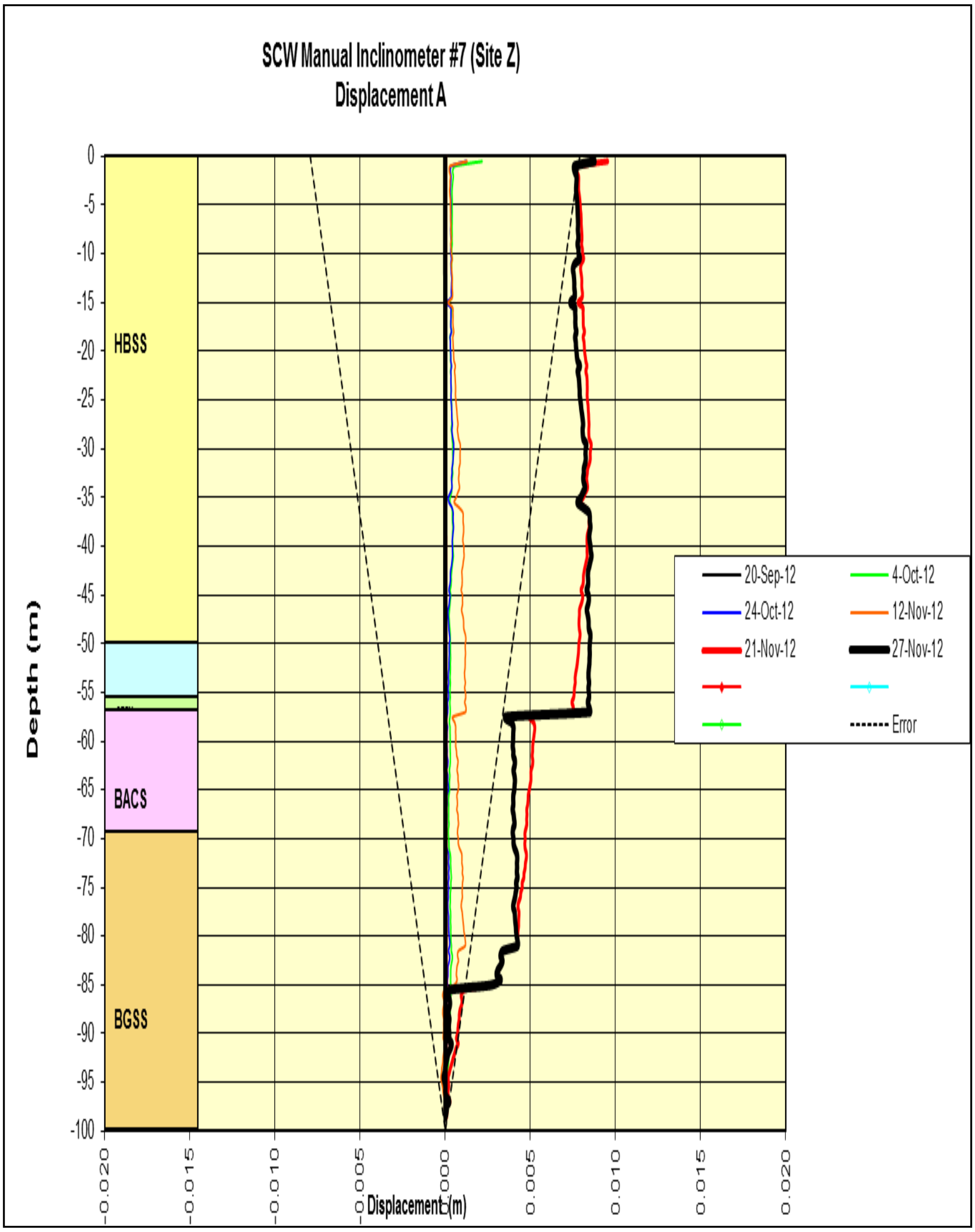


Figure 6-6: Bedding plane shear detected above Dendrobium Mine, near Sandy Creek Waterfall, detected using borehole inclinometer. *(source: Walsh et al., 2014)*

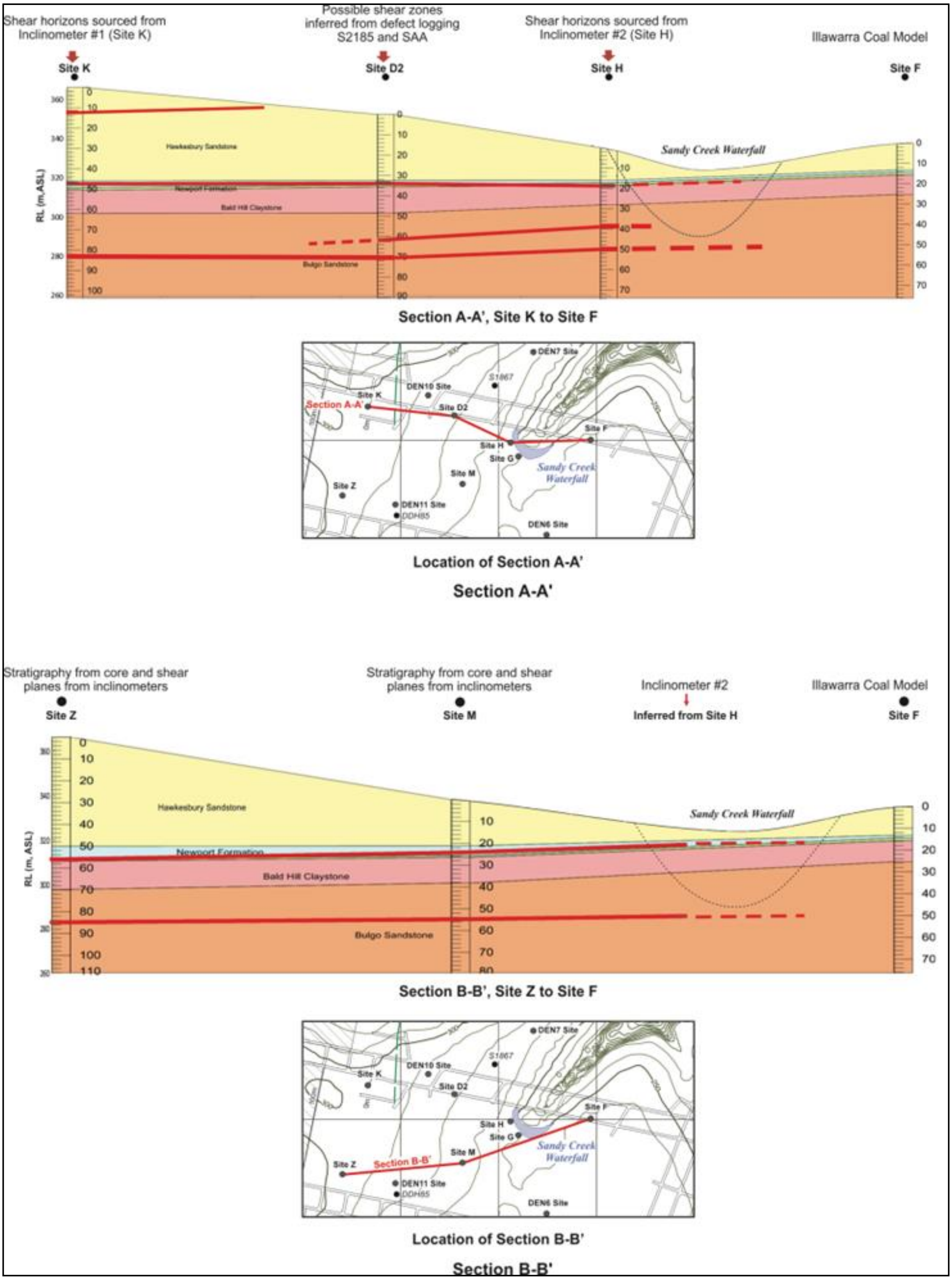


Figure 6-7: Correlation of near-surface shear movements relative to strata units - Dendrobium Mine, near Sandy Creek Waterfall. *(source: Walsh et al., 2014)*

Figure 6-6 is a plot taken from a borehole inclinometer (Site Z), measuring incremental horizontal deflections detected by an instrumentation string installed down a deep vertical borehole. Two distinct shear plane movements are visible in this dataset – at depths of 57m and 85m, with the movements indicating shear movements of approximately 10mm and 5mm respectively. Figure 6-7 is a composite of two cross-section lines of multiple inclinometer hole datasets superimposed onto a geological cross-section. Remarkable correlation is exhibited between five different inclinometer installations, confirming the presence of shear movements corresponding to a shallow horizon in the Hawkesbury Sandstone; the top of the Bald Hill Claystone; and then within the Bulgo Sandstone. Whilst bedding plane shear has been detected in this example, it should not be automatically assumed that such shear planes (which are under significant vertical confinement or clamping force) are planes of significantly increased permeability, hence a potential water flow path.

However, in the case of the proposed strategy for mining towards the Woronora Reservoir, it is recommended that a series of inclinometer holes are installed in advance of longwall extraction, in the region between LW301, 302 and the reservoir, in order to detect the presence and horizons of any such major shear planes. These inclinometer holes should extend from the surface to a depth that will penetrate into the top levels of the Bulgo Sandstone. Associated groundwater monitoring should also be used in an attempt to determine any changes in strata permeability as a result of such shear movements.

6.3 Structural Geology

As indicated above, areas of dominant structural geological features can change the expected nature of overburden response to mining, and can also provide localised zones of elevated, cross-strata, groundwater flows (e.g. along fault planes), especially where strata movements can cause shearing or dilation on such structures. It is therefore necessary to review the extent of known or anticipated faulting or other structural disturbances (such as dykes) in the proposed mining region of LWs 301, 302 and beyond. Figure 6-8 provides a representation of the current understanding of the structural features present in the mining area. Fortunately, the area appears to be relatively clear of any high density or dominant fault structures, and no dykes are known to be present in the area.

It is recommended that any future boreholes drilled in the area – either for exploration, or for instrumentation purposes, also be used to update the structural interpretation for the region.

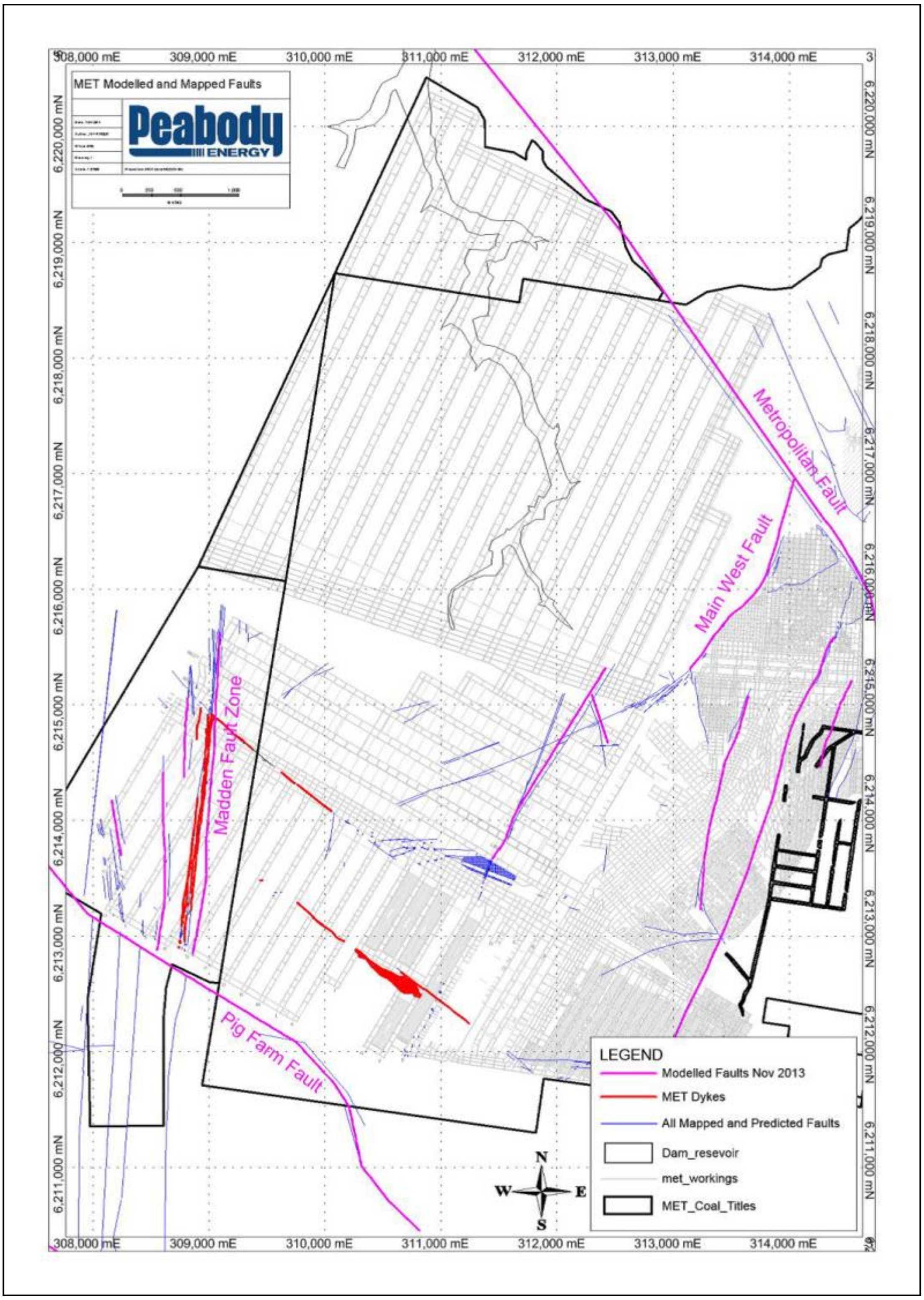


Figure 6-8: Metropolitan mapped and predicted major fault structures. *(source: Peabody, 2014).*

6.4 Surface Subsidence Monitoring

A program of proposed monitoring of surface subsidence has been put forward, consisting of a series of survey lines, as illustrated in Figure 6-9.

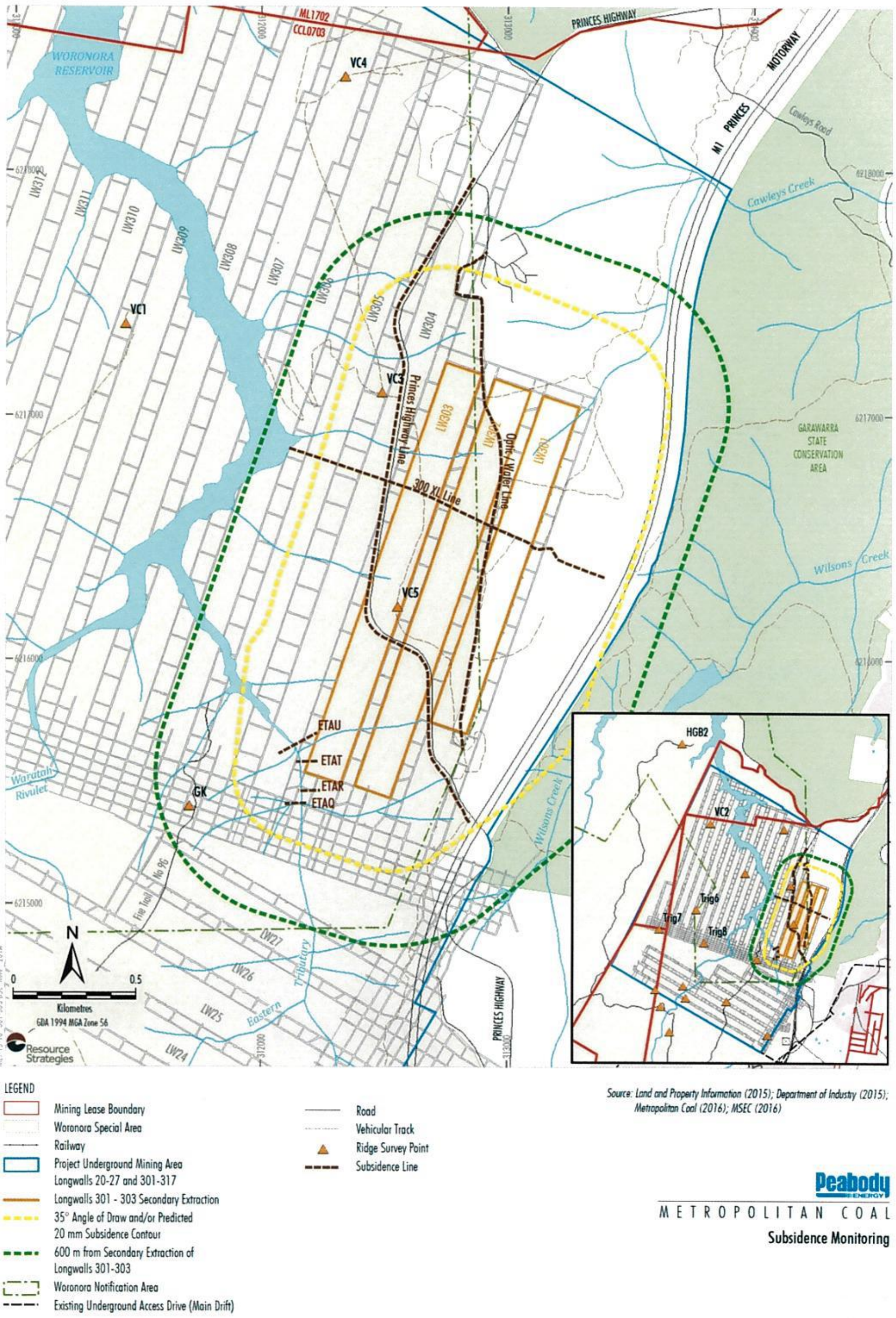


Figure 6-9: Metropolitan Coal – Proposed surface subsidence monitoring plan.
(source: Peabody Metropolitan Coal).

This monitoring program is considered to be reasonable and appropriate, given the major limitations of access in some parts of the ground surface approaching the reservoir (steep slopes and dense vegetation). It has also been proposed that aerial LIDAR surveying be considered to give an overview of the incremental trends in vertical subsidence development across the whole of the region. The benefit of such technology, or also the satellite-based InSAR technology, is that it provides a comprehensive coverage of the surface, without the need for individual measuring points at discrete locations. However, both LIDAR and InSAR suffer from accurate surface discrimination under steep slope conditions and dense vegetation, so their use in this application may be limited. A pilot LIDAR study has already been undertaken by Metropolitan, and has highlighted these exact problems of definition over much of the area. It is recommended that further investigations continue to review the potential use of one of these types of technologies, so that the accuracy and reliability under such terrain conditions may be improved.

The remaining challenge for surface subsidence monitoring relates to monitoring of the subsidence effects on the floor of the reservoir, below the water-line. To this end, consideration of the use of underwater bathymetry survey technology has been suggested in the Approval Condition. This technology has been used for undersea subsidence monitoring in the past, as reported by Forrester & Courtney (1995). They discussed monitoring subsidence of the seabed above the Phalen Colliery in Nova Scotia, Canada, which was achieved with reasonable success.

In 2014, the Sydney Catchment Authority conducted a bathymetric survey of the floor of the entire Woronora Reservoir (Ramsay et al, 2014). A sample of that survey result is shown in Figure 6-10 which clearly shows, in a 3D image, the floor of the Waratah Rivulet. The contractors who conducted that survey quoted the vertical accuracy to be *"much better than 0.1m"* resolution.

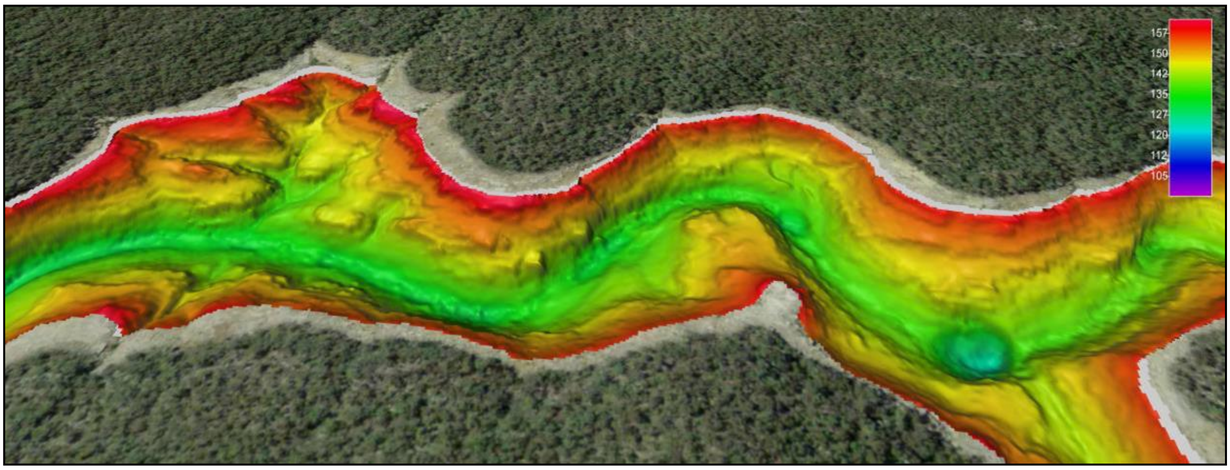


Figure 6-10: Bathymetric survey results showing 3D image of reservoir floor for Waratah Rivulet. Coloured levels are noted in mAHD. *(Source: Ramsay et al., 2014)*

This technology therefore warrants further investigation as a possible means of surveying incremental subsidence effects on the floor of the Reservoir, which is at depths of up to 40m or more below reservoir water level but within the Hawkesbury Sandstone Formation that previous mining below the Cataract reservoir showed no water level response to longwall mining of the coal seam. However, it is firstly necessary to establish not only the exact vertical accuracy achievable (on a repeatable basis), but also the horizontal accuracy for positioning the images and if they are to be used for repeated surveys to determine any movements of the reservoir floor. Whilst it would be invaluable to be able to detect and quantify any evidence of subsidence-induced *"valley closure",* such an expectation is likely to be beyond such technologies at the present time.

7.0 SURFACE WATER ISSUES (TM)

Surface water issues relate to the impact of longwall mining on catchment runoff, on mining-induced diversions of surface waters into underlying aquifers, and on reservoir leakage rates from the bed of Woronora Reservoir. To address these issues a short term monitoring program and analysis is proposed as well as a longer term water balance study of Woronora Reservoir.

7.1 Short-term monitoring program and analysis

The short-term monitoring program is directed towards assessing any impact of mining of LWs 301-303 on the surface flows in the small sub-catchments that drain westerly from the area above LWs 301-303 (see Figure 7-1), although it is noted there is no evidence that mining of Longwalls 20-27 has influenced the surface flows into Woronora Reservoir via Waratah Rivulet (GS2132102) and Eastern Tributary (GS300078) (Peabody, 2017, page ES1). Figure 7-1 shows the sub-catchments in relation to LWs 301-303 and Woronora Reservoir. Due to the sequence of development of the Longwall 300 series, the sub-catchments that drain westerly from the area above LWs 301-303 will be the only opportunity except for sub-catchment C, to monitor the effects of future longwall mining on the tributary flows entering the Reservoir. (Sub-catchment C is a small catchment draining to Eastern Tributary upstream of GS300078.) Tributaries entering the Woronora from the western side would subside before there is any opportunity to monitor effects higher in the catchments.

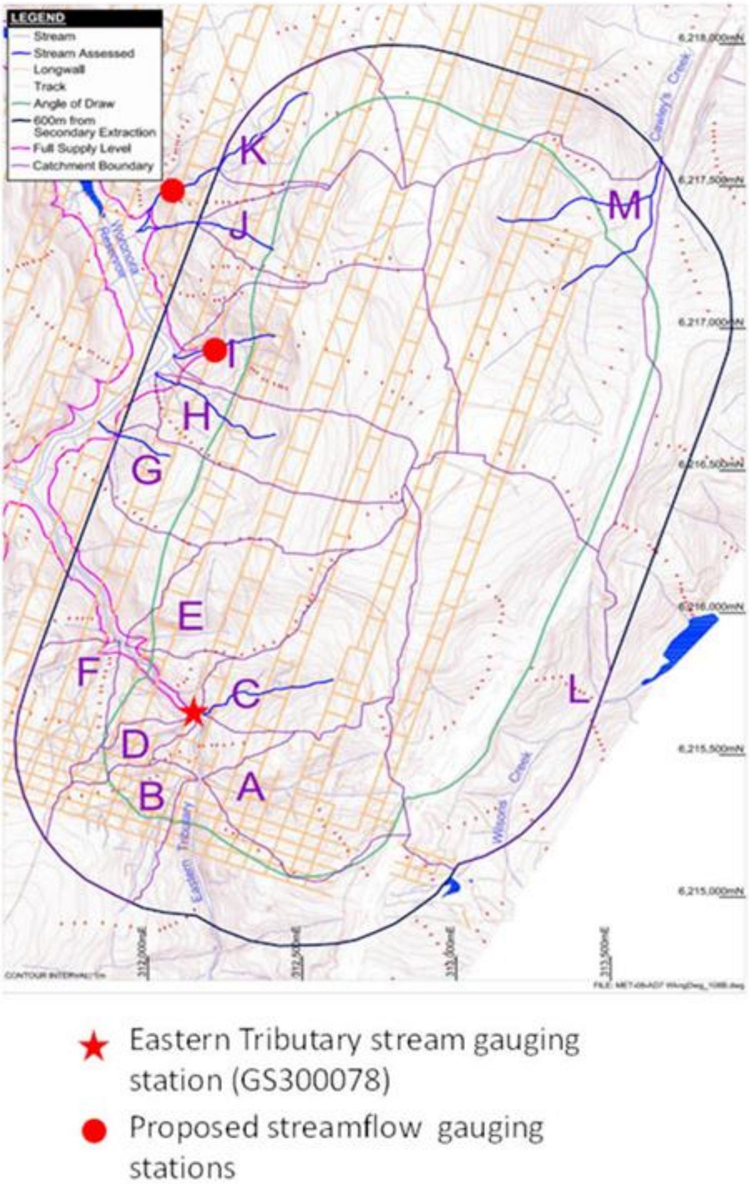


Figure 7-1. Small sub-catchments in the vicinity of Longwalls 301-303 (Extracted from Gilbert & Associates (2015), Figure 1)

If no additional monitoring is carried out, the Eastern Tributary stream gauging station, GS300078, is the only station that would be potentially affected by LWs 301-303. The area potentially affected is sub-catchment C, an area of 0.28 km^2 compared with the catchment area of the Eastern Tributary at GS300078 of 6.7 km^2. Consequently, if as a result of mining all flows ceased in sub-catchment C, this impact would be observed as an overall reduction of streamflows at GS300078 of approximately 4%. An analysis of uncertainty at the gauging station would probably show that such an extreme reduction in flow at GS300078 would be within the uncertainty band of the magnitude of the monitored streamflow estimates at that station. In view of this, streamflow monitoring should be carried out in one or more of the catchments that drain westerly from the area above LWs 301-303.

Therefore, it is important that a streamflow monitoring station be installed in one of the sub-catchments as soon as feasible. It is understood that it will take a minimum of 6 months to design, manufacture and install a small accurate flow measuring flume including approvals. Catchment I (Figure A) is recommended as it appears that it would not be significantly influenced by LW301 but potentially affected by LW302 and LW303.

It is probable there will be little un-impacted streamflow data for sub-catchment I available for AWBM model calibration. Therefore, sub-catchment K should also be concurrently monitored as a control catchment. This would allow any progressive changes in sub-catchment I to be assessed. In addition, it is assumed that the three stream gauging stations O'Hares Creek at Wedderburn (GS213200), Woronora River upstream of the Reservoir (GS2132101) and Honeysuckle Creek (GS300077) will continue to be monitored which would also be used as control catchments. Once mining progresses beyond LW303, sub-catchment K will become progressively influenced leaving O'Hares Creek, Woronora River upstream and Honeysuckle Creek stream gauges as the control catchments.

As noted in the following section the proposed performance indicator for the western flowing sub-catchments is 0.060 ML/day; for sub-catchment I, this is equivalent to 0.019 ML/day (0.22 L/sec). Monitoring flumes to measure such low flows are available (see Bos, 1989, Table 7.3) but under the field conditions to be encountered at the site adequate accuracy at such low flows may not be realised. Nevertheless, with considerable care in construction and field installation the discharge measurements should provide evidence of any significant departure from unaffected flows as a result of longwall mining. Because the flumes need to be designed/sized to provide adequate resolution at these low flows there will be insufficient resolution to detect losses at higher flows.

A regular check would need to be made to ensure the streamflow measuring flumes, located in catchments I and K, continue to be appropriately sited and aligned correctly, given that they may be subjected to movement during mining.

The strategy reviewers note that Metropolitan Coal has accepted the proposal to install the two additional measuring flumes, and flume design is underway. Approvals are being sought with installation expected by December 2017.

There is a need for an additional pluviometer in the vicinity of the northern end of LW307 to infill a gap in the rainfall network, especially as it is planned to assess streamflow in the northern part of the Lease. There may be difficulty finding a suitable site as the area is heavily wooded. It is recommended that the feasibility of locating a pluviometer be investigated and if a suitable site is available, approvals sought and a pluviometer to be installed as soon as feasible.

It is proposed that the analysis to assess the impact on surface flows of mining LWs 301-302 (303) will be similar to the previous procedures. Here the potentially impacted flows, measured in sub-catchment I, will be compared with those in sub-catchment K, which should be little affected by the LWs 301-302, and with the larger control catchments located on the western side of the mining lease. Also the modified AWBM model should be calibrated for both sub-catchments I and K periods when the flows are potentially least affected by mining.

7.2 Assessing impacts

In regard to catchment yield to Woronora Reservoir, the Project Approval requires that there is *"negligible reduction to the … quantity of water resources reaching the Woronora Reservoir"* (Minister for Planning, 2009, Schedule 3, Table 1). This condition is defined more specifically in a measurable way in the Water Management Plan, Table 17 (Peabody Energy, 2016) as follows: *"The performance indicator will be considered to have been exceeded if data analysis indicates a statistically significant reduction in the quantity of water entering Woronora Reservoir in the post-mine period relative to the pre-mine period that is not also occurring in the control catchment(s), specifically: - if the median of the ratios for the sliding 1 year period in the Waratah Rivulet falls below the 20th percentile of the baseline data, unless the same is also occurring in data for the control sites."* This approach and criterion were used to assess the performance measures for Longwalls 20-27 (see HEC, 2017, Section 3.1 for application to Longwalls 20–27).

Under the requirement that *"Negligible reduction to the quantity of water resources reaching the Woronora Reservoir"* in the Metropolitan Coal Longwalls 301-303 Extraction Plan (Peabody, 2017, Table 2) the definition of 'negligible' is further clarified. *"As documented in the original model presented in the Project Environmental Assessment, the Waratah Rivulet catchment model is capable of reliably identifying a loss of 1 ML/day. One (1) ML/day meets the definition of 'negligible' (being small and unimportant, such as not to be worth considering) on the basis that it is a small component of overall inflows – it represents about 1.4% of annual average inflow to the reservoir; and is small compared to changes in inflows caused by changes in climate and catchment conditions. It is also noted that 1 ML/day is well above the reduction in catchment yield that is actually predicted."*

It is noted that 1 ML/day, equivalent to 365 ML/year, is considerably less than 830 ML/year loss of water into the Dendrobium mine workings that the DPE considers being *"negligible in comparison to the total capacity of the catchment dams (0.03%) and annual losses from evaporation and environmental flows (0.19%)"* (DPE, 2016)

In assessing the influence of Longwalls 301-303 on surface flow to Woronora and based on the above discussion, it is recommended that a loss of less than 1 ML/day adjusted for the difference in catchment area between the Waratah Rivulet (20.2 km^2 at GS2132102) and the group of western flowing catchments (E, G, H, I and J) (1.22 km^2) identified in Figure 5-12 is acceptable. Under this criterion losses from the sub-catchments should be less than 1.22/20.2 = 0.060 ML/day (or 22 ML/year). The losses would be assessed through a comparison between the monitored flows in the newly established flow gauging stations on catchments I and K and also with the control stations used in the assessing the impact of Longwalls 20 -27. The assessment procedure would also include Waratah Rivulet as sub-catchment C drains upstream of the Easter Tributary Stream gauging station (GS300078).

7.3 Woronora water balance

It is appropriate to examine the possibility of applying a water balance analysis of Woronora Reservoir to assess whether there is a loss of water from the Reservoir due to mining of the Longwall 300 series. This approach may not be feasible without a major upgrade of the present monitoring because of the uncertainty in the magnitudes of the water balance components. The water balance analysis is proposed as a two-stage procedure.

The first stage would be a preliminary water balance analysis of Woronora to ascertain the potential uncertainties in each component of the water balance. This preliminary analysis should be carried out in order to determine whether the approach even with additional monitoring of the key variables could reduce the estimation uncertainties to a level where losses from the reservoir would be meaningful and scientifically defensible. Based on this preliminary analysis and a review of all monitoring equipment, a recommendation would be made whether or not to proceed with the second stage which could entail upgrading the streamflow, meteorological or other monitoring equipment.

Several points need to be noted here. Firstly, the general water balance over a given period will consist of the following daily components:

$$L = R + I – E – D - S - \Delta C$$

where L is the loss of water through the base of the reservoir to groundwater, R is rainfall on the reservoir water surface, I is inflow contributing from the total catchment excluding the reservoir water surface area, E is the evaporation from the reservoir water surface, D is the discharge or release from the reservoir, S is the spill from the reservoir, and ΔC is the change in storage volume, all in volume units. Secondly, several time periods would be chosen to minimise uncertainty. These would extent for some months when there were no spill, minimum reservoir evaporation and minimum inflow, and the overall change in reservoir contents also being minimal. To compute actual evaporation accurately, advected energy and lake heat storage will need to be accounted for. It is noted that estimating uncertainty using daily monitored data will require the analysis to take into account the high auto-correlation of daily values for several of the variables. Thirdly, inflows to the reservoir are the major input in the water balance, representing about 90% of the total inputs. However, at present, only 70% of the Woronora catchment is monitored. If it is decided after stage one analysis to proceed to the second stage, it is anticipated that monitoring some of this ungauged area may be necessary. Fourthly, it is expected that uncertainties in rainfall and evaporation would be small compared to the uncertainty in inflow. Finally, any water balance analysis is predicated on having an accurate bathymetric profile of the reservoir so that relationships among reservoir water level, reservoir water surface area and reservoir water content are known accurately.

It is would expected that the first stage the water balance analysis would be completed by mid-2018 noting, however, there is a considerable amount of data to be sourced from the relevant agencies. If stage two is recommended, it should follow immediately with the objective of the additional data collection, if required, to begin operation by January 2019. It would be expected that the first water balance analysis would be performed on the data available for the calendar year 2019.

8.0 PROPOSED WORKS

Table 8-1
Implementation of Initial Groundwater and Geotechnical Monitoring and Hydraulic Testing

301GW01A: Multi-level piezometer and pre-installation packer test. VWPs installed at:

- o 190m -- Hawkesbury Sandstone (directly above the Bald Hill Claystone)
- o 235m – Bulgo Sandstone (directly below the Bald Hill Claystone)

301GW01B: Standard piezometer and pre-installation packer test. Piezometer installed at

- o 15m – Hawkesbury Sandstone.

301GW02: Hole drilled post-mining for packer or inflow testing. Total depth 245m

302GW01: Open piezometer to depth of 80m (WaterNSW recommendation).

302GW02A: Multi-level piezometer and pre-installation packer test. VWPs installed at:

- o 190m -- Hawkesbury Sandstone (directly above the Bald Hill Claystone)
- o 235m – Bulgo Sandstone (directly below the Bald Hill Claystone)
- o 250m – Inclinometer – full column of hole back to collar.

302GW02B: Standard piezometer and pre-installation packer test. Piezometer installed at

- o 15m – Hawkesbury Sandstone.

302GW03: Hole drilled post-mining packer or inflow testing. Total depth 250m

Assessment of results of monitoring and hydraulic testing above longwalls 301 and 302. HS conducted numerical model calibration.

Proposed Longwall 303 monitoring subject to results of 301 and 302 monitoring and testing. Anticipated monitoring similar to that indicated for longwalls 301 and 302 shown above.

Table 8-2
Implementation of Initial Surface Water Monitoring

- o Surface monitoring at sub-catchments I and K gauging stations
- o Conduct initial survey of proposed gauging station locations
- o Co-ordinate HEC design of proposed gauging stations
- o Review gauging station design
- o Prepare and lodge approval for WaterNSW to permit installation.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Groundwater

1. The extension of mining at the Metropolitan Coal site was previously approved by the Planning Assessment Commission panel that included mining the entire 300 series of longwall panels many of which are located beneath the Woronora Reservoir.

2. Mining already completed at the southern Metropolitan Coal site (up to LW27) adjacent to the Woronora reservoir has indicated low rate of groundwater inflow. Since 2009, water make has averaged at 0.09 ML/day and the 20 day average water make has been below 0.5 ML/day.

3. Comparison of geological strata conditions at the Metropolitan Coal site with previous mining during the 80's and 90's at the South Bulli Mine and Bellambi West Colliery near and below the Cataract Reservoir, with similar geological conditions to Metropolitan, indicate that mining was successfully conducted beneath the Cataract reservoir with a very low inflow rates.

4. Comparison of groundwater conditions with relatively much higher groundwater inflow experienced at the Dendrobium mine (~ 11 ML/day) and the very much lower inflows at the Metropolitan site (< 0.5 ML/day) is invalid in one important respect because the geometry of mining parameters is markedly different at the two sites. The ratios of width of panel and depth of cover[7] at the Dendrobium site, are relatively much higher (0.68 to 0.98) compared to the lower ratios at the Metropolitan site proposed at LW301, LW302 and LW303 (0.29 to 0.41); proposed below the Woronora Reservoir LW304 to LW317 (0.32 to 0.35), and also at the successful mining conducted with very low localised inflow at the South Bulli mine and Bellambi West Colliery below the Cataract Reservoir (*w/d* in the range 0.25 to 0.51).

5. To further confirm suitable groundwater conditions at the Metropolitan site, extensive monitoring is proposed as part of the strategy initiative at Longwall panel footprints LW301 and LW302 and later at LW303 that lie immediately east and outside of the Woronora storage area. Monitoring is to include the deep (down to the mining goaf), central and shallow stratigraphic levels with standard and vibrating wire piezometers. Groundwater level responses will be assessed as these longwalls are mined and at the completion of mining LW301 and LW302 before any mining is conducted at LW303 and below the Woronora Reservoir. The proposed piezometer installation works are outlined in Section 8, Table 8.1 herein.

6. The proposed extensive monitoring at the Metropolitan site at LW 301 , LW302 and later at LW303 will provide additional validation and comparison of the currently used empirical

[7] *w/d*, which is a major factor that influences the extent of vertical fracture propagation, and therefore the height of fracturing above the mined out seam.

model analytical equations versus the monitored pressure heads for determination of the 'Height of Fracturing' above longwall mined out panels at the Metropolitan site.

9.2 Geotechnical

1. On the basis of current conceptual models and definitions, the term *"height of fracturing"* is used to refer to the region of connective cracking or fracturing which results in significant depressurisation of the strata. Pressure monitoring is therefore used as the primary means of detection of the upper limit of this zone. Height of fracturing of approximately 130m extending just beyond the Stanwell Park Claystone unit was evident from the pressure testing data at the Metropolitan Colliery after extraction of longwall 10 (9HGW0) and in a second hole at longwall 22B (9GGW1-3) with a total loss of groundwater at a height of 137.5m above the Bulli Seam, which is quite consistent with the 130m for height of connective fracturing at borehole 9HGW0 above longwall 10.

2. Measurement of pressure heads pre-mining in each new mining region is seen as necessary, including where possible post mining pressure head responses due to initial panels mined, to validate any forward reliance on the empirical 'Height of Fracturing (HoF)' models. The contributions in this strategy report (FK, BH) has emphasized the importance of width to depth ratios (*w/d)* as a simple screening estimate in the Metropolitan site area prior to mining for determining the likely height of *"connective cracking"* as a 'first pass' estimate, that is, validated based on past mining responses of very low inflow in similar strata at Metropolitan Coal site beneath the Cataract Reservoir.

3. There is agreement with the program of groundwater monitoring discussed in Section 5, as a basis to estimate the height of fracturing within the current mining region adjacent to the Woronora Reservoir including surface cavity development if any at the Metropolitan site.

4. It has also been observed in other regions that far-field or regional bedding plane shear can occur in the near-surface strata, induced by the effects of mining. These bedding plane shears are more likely to be associated with what is termed non-conventional subsidence.

5. It is recommended that a series of inclinometer holes are installed in advance of longwall extraction, in the region between LW301, 302 and the reservoir, in order to detect the presence and horizons of any major shear planes. These inclinometer holes should extend from the surface to a depth that will penetrate into the top levels of the Bulgo Sandstone. Associated groundwater hydraulic testing should also be used in an attempt to determine any changes in strata permeability as a result of such shear movements.

6. Major structural geological features are not dominant in the region between LWs 301/302 and the reservoir. However, it is recommended that any future boreholes drilled in the area – either for exploration, or for instrumentation purposes, also be used to update the structural interpretation for the region.

7. The proposed surface subsidence monitoring program appears to be reasonable and appropriate, given the major limitations of access in some parts of the surface approaching the reservoir (steep slopes and dense vegetation).

8. Further investigations into the use of LIDAR, or InSAR technologies should also be carried out, although their limitations due to increased topographic slopes and vegetation are acknowledged.

9. Bathymetric technology warrants further investigation as a possible means of surveying incremental subsidence effects on the floor of the Reservoir. However, it is firstly necessary to establish the exact vertical accuracy achievable (on a repeatable basis) and also the horizontal accuracy for positioning the images, if they are to be used for repeated surveys to determine movements of the reservoir floor.

10. It is recommended that all monitoring data be available for review after each longwall panel is mined, to inform and update this staged Impact Strategy.

9.3 Surface Water

The purpose of the surface water strategy is to assess any impact of mining of longwalls (LW) 301-303 on the surface flows in the small sub-catchments that drain westerly from the area above LWs 301-303. In addition, a water balance analysis of Woronora Reservoir is planned to assess whether there is a loss of water from the Reservoir through seepage due to mining of Longwall 300 series. To achieve these objectives the following actions are in progress or proposed:

1. Installation of two streamflow monitoring stations in the sub-catchments above the foot-print of LW301-303 (to be operative by January 2018);
2. Installation of a pluviometer in the vicinity of the northern end of LW307 (to be operative by January 2018);
3. Implementation of a preliminary water balance of Woronora Reservoir (to be completed June 2018); and
4. Depending on the outcome of the preliminary water balance, implementation a more detailed water balance including additional hydrologic monitoring as required (instrumentation to be operative by January 2019 and a water balance to be performed for calendar year 2019).

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A copy of the consolidated Project Approval is available from the link below.

https://majorprojects.accelo.com/public/228398f0a4e7abbf754a13aa451e80b1/Metropolitan%20Coal%20Mine%20Mod%203_Consolidated%20Consent.pdf

Condition 2, Schedule 2 of the Project Approval states that the "general layout of the project is shown in Appendices 2 to 4". Appendix 3 (attached) indicates that the approved project includes the entire 300 series panels (including those located beneath the Woronora Reservoir).

Consistent with Condition 3, Schedule 3 of the Project Approval, Metropolitan Coal prepared an Extraction Plan prior to undertaking second workings in Longwalls 301 to 303. The Extraction Plan approval is available from the link below. The Woronora Reservoir Impact Strategy that you and the other independent experts are completing is required under Condition 2 of the Extraction Plan approval.
https://majorprojects.accelo.com/public/4d2850dd9af7fc05c11231737d1f5477/Metropolitan%20LW%20301-303%20EP_Approval.pdf