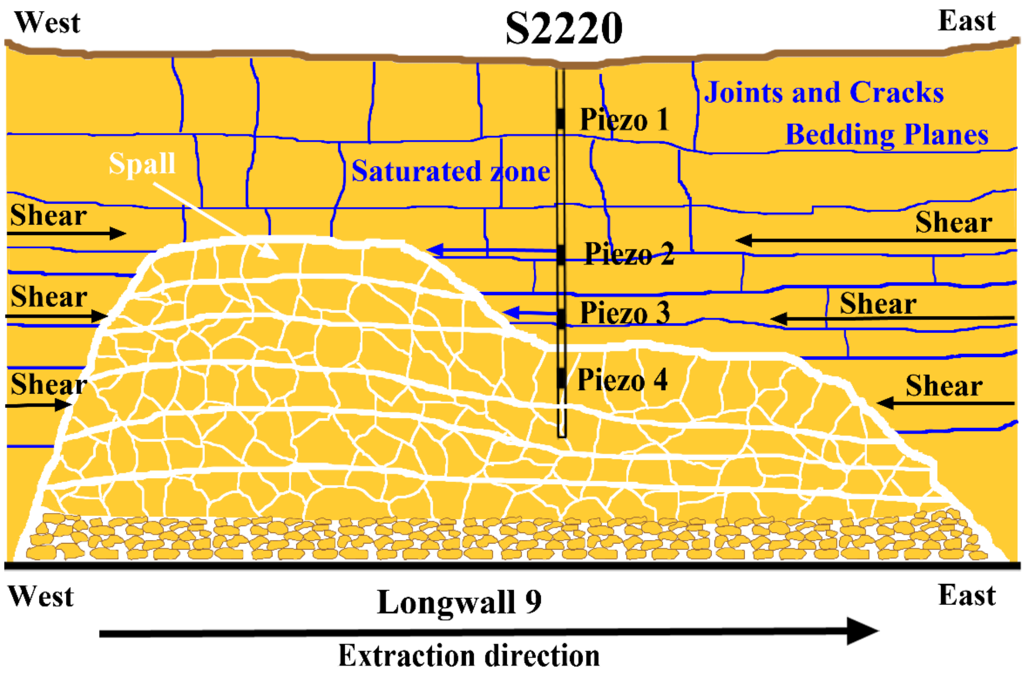
Some Concerns Regarding Groundwater Impact Assessments for Coal Mines in NSW



Above figure: qualitative depiction of a lengthwise drainage zone profile for Longwall 9 in Area 3B of the Dendrobium mine that could account for data from post-extraction centreline bore S2220, pre-extraction centreline bore S2192 (approx. 18m south of S2220) and off-panel bores S1910, S1925 and S1929 (not shown) over Area 3B. See Sections 15 and 16 within.

Cover picture: Sydney Catchment Authority photograph of a rock bar and small waterfall on Sandy Creek, just downstream of Fire Road 6C, within Dendrobium Area 3. Copied from the front page of the 2008 report of the Southern Coalfield Inquiry titled "*Impacts of underground coal mining on natural features in the Southern Coalfield: Strategic Review*".

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protecting nature through community action

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Concerns Regarding Groundwater Impact Assessments for Coal Mines in NSW

Summary

- In July 2015 the NSW National Parks Association wrote to the NSW Minister for Planning raising concerns regarding the estimation of the height of the drainage zone that forms over a coal extraction. Water within and entering the drainage zone drains relatively freely towards the extraction and water beyond the zone is diverted towards the zone. A credible assessment of groundwater impacts and, accordingly, surface water impacts requires a reliable assessment of the height of the drainage zone. The letter to the Minister reported concern that the underpinning database for the equation favoured by a number of NSW mining company consultants for estimating the height of the drainage zone is fundamentally flawed. The equation was developed by mining company consultant engineer Steven Ditton, in collaboration with the founder and principal hydrogeologist for HydroSimulations, formerly Heritage Computing, Dr Noel Merrick.
- The letter to the Minister of July 2015 was copied to WaterNSW, the OEH and relevant NSW politicians. The concerns were also raised in a letter to the NSW Planning Assessment Commission (PAC) in August 2015. The concerns are echoed by WaterNSW in their April 2016 comments on longwall plans for the Dendrobium mine that are currently being assessed by the Department of Planning.
- The database underpinning the Ditton equation appears to be critically compromised in containing data ill-suited to its intended purpose. Some of the database content also appears to reflect errors and misinterpretations. As a consequence of the nature of the underpinning database, the drainage zone height estimated by the Ditton equation (A zone height) would appear to be greatly underestimated for aggressive longwall geometries, such as those of the Dendrobium mine (see Table 4 and Figs 5 to 7). This mine is located in the Schedule 1 Metropolitan Special Area of the drinking water catchment for Greater Sydney and the Illawarra.
- This report significantly adds to information provided in the letter sent to the NSW Minister for Planning in July 2015 and a follow-up letter sent in February 2016. Much of the report is focussed on the Dendrobium mine as it would appear to be the only coal mine in NSW where assessments have been made using both the Ditton equation (HydroSimulations, March 2014 and March 2016) and the Tammetta equation (Coffey Geotechnics, October and November 2012). Developed in 2012, before the Ditton equation, the Tammetta equation is uniquely distinguished in having been published in a leading international science journal. The data from comparatively extensive, though patchy, Dendrobium piezometer network offers a means of comparatively evaluating the Ditton and Tammetta equations.
- The Dendrobium longwall extractions appear to be the most aggressive to have been approved for the Special Areas of Sydney's drinking water catchment and among the most aggressive anywhere in NSW. Existing and proposed panels are notably wide at 305 metres and have particularly large cutting heights of up to 4.6 metres. The Tammetta equation predicts that the drainage zone would intersect the surface above such extractions at the Dendrobium mine. The NSW Planning Minister was advised of this possibility by the NPA in July 2015.
- The NSW Department of Planning has been unable to advise whether it was aware of this possibility when the current mining was approved in February 2013. The October 2012 Coffey assessment was based on 3.4 metre high extractions while the November 2012 report assessed

4.5 metre high extractions. The November report will have found that the drainage zone above 4.5 metre high extractions would intersect the surface. The November report was not, and has not since, been made available and WaterNSW and the OEH were not advised of its existence by the Department of Planning. The controversial nature of the Department's approval is reviewed in Section 19.

- During 2016 the Department of Planning has provided assistance in seeking information from the current owners of the Dendrobium mine, BHP-Billiton spin-off South32. The company has to date refused to provide the November 2012 Coffey assessment. It has however provided the November 2012 data analysis report that underpins the withheld impact assessment. The data analysis report confirms that the Tammetta equation predicts that the drainage zone would intersect the surface over 4.5 metre high extractions.
- As pointed out to the Minister in July 2015, short of a significant direct fracture connection between a water storage reservoir or a watercourse and underground mine workings, the intersection of the drainage zone with the surface would be the worst mining impact for a water catchment.
- BHP-Billiton, then owners of the Dendrobium mine, rejected both Coffey groundwater assessments for Dendrobium in late 2012, in particular it's finding that the then proposed mining for Area 3B of the mine would result in drainage zones reaching the surface. The assessment was rejected without a scientific basis. The NSW Dept. of Planning accepted this rejection without notifying or consulting WaterNSW or the OEH. Public and agency submissions were based on the October 2012 assessment (see Section 19).
- As pointed out to the Minister in 2015, the height of the drainage zone above a longwall is best determined using piezometer data from a bore installed over its centreline. The drainage zone height information provided by a piezometer in a bore located laterally some distance beyond the drainage zone above an extraction is less readily and reliably interpreted than that from a bore that penetrates this zone. The Ditton database appears to be a mixture of piezometer and extensometer data obtained primarily from side and off panel bores. Extensometer data are more problematic than piezometer data.
- The nature of the Ditton database is contrasted by that underpinning the Tammetta equation. Tammetta segregates data types and obtained his equation solely from centreline piezometer data. Doing so avoids the need to characterise the degree and extent of fracturing and recognises the more problematic nature of extensometer data.
- As Figure 5 within illustrates, where the mining geometry is other than modest the Tammetta equation returns greater drainage zone height estimates than does the Ditton equation. Figures 6 and 7 demonstrate the insensitivity of the Ditton equation to mining width and height.
- Examples of mines represented in the Ditton database for which the content appears to be problematic include Springvale, Dendrobium, Metropolitan, Mandalong, Kemira, West Bellambi, Able, Appin and Wyee. Springvale, Metropolitan, Mandalong and Dendrobium are discussed in some detail in this report. As an example, in part a Ditton database entry for a longwall at the Springvale mine is based on extensometer data that a 2007 CSIRO study found unreliable.
- The noteworthy case of Mandalong Longwall 9, which is of significant relevance to Dendrobium Longwall 9, is discussed in Section 10; Sections 15 and 16 include a discussion of Longwall 9 at

the Dendrobium mine. Dendrobium Longwall 5 and Metropolitan Colliery Longwall 20 are respectively discussed in Sections 15 and 8 below. Further anomalies are noted in Section 7.

- The Dendrobium mine has 10 centreline or near centreline bores with three or more piezometers, however of these only two, in combination, have provided before and after undermining data. The others have either failed as the longwall face approached or have yet to be undermined. Piezometer bores sunk over longwalls in the US appear to be more likely to survive being undermined.
- Centreline bores with vibrating wire piezometer strings that penetrate the drainage zone provide the most means of determining the height of the drainage zone. In the absence of such bores, provided there are no unusual hydrogeological circumstances, side-panel and nearby off-panel bores may provide an indication of the likely height of the drainage zone. This appears to be possible because of the typically large differences in horizontal and vertical hydraulic conductivity in the strata over a coal seam.
- The piezometer information provided in the end of panel groundwater assessments for Dendrobium Longwalls 3 to 11 and in the 2012 (Coffey), 2014 (HydroSimulations) and 2016 (HydroSimulations) Area 3B groundwater impact assessments provide an indicative means for comparatively evaluating the Ditton and Tammetta equations and, accordingly, their underpinning databases. The concerns of 2015 are deepened by a review of hydrographs representing data from piezometers in 20 key bores at the Dendrobium mine (Section 15 and Table 4).
- The review undertaken here finds the data represented in the Dendrobium piezometer hydrographs challenge the Ditton equation and the groundwater impact assessments undertaken by HydroSimulations. Table 4 within lists the drainage zone heights indicated by piezometers in 18 Dendrobium bores, together with the drainage zone height estimates provided by the Ditton and the Tammetta equations.
- Ditton additionally provides an expression to estimate a 95% confidence limit height, denoted as A95. This is a calculated height for which, according to Ditton, there would only be a 5% chance of the measured height being greater than estimated. Implausibly, while the additional term needed to calculate an A95 estimate depends on extraction width and depth of cover, it has no dependence on extraction height. HydroSimulations prefer to use the A95 estimate rather than the lower A50 estimate.
- The review of Dendrobium piezometer information given in Section 15 finds that the assessments undertaken by HydroSimulations, both before and after their 2014 adoption of the Ditton equation, do not appear to have adequately taken into account the typically very large differences in horizontal and vertical hydraulic conductivity in the strata over a coal seam. The consultants suggest rates of vertical propagation of water pressure reduction (depressurisation) that would appear to be physically implausible.
- The magnitude and rate of pressure head loss measured by a piezometer located in saturated surroundings, depends on its vertical and horizontal distance from the causal drainage zone and the hydraulic diffusivity determining vertical and horizontal hydraulic conductivity over the path between the piezometer and the drainage zone. The rate of depressurisation is described by a diffusion equation. Illustrative use of the solution to the one dimensional form of the diffusion equation (see Fig. 1) suggests the rates of pressure loss reported by the Dendrobium piezometers

reviewed here are, in general, too high to be consistent with the interpretations made by HydroSimulations.

- Discussed within and indicated above, in the absence of unusual hydrogeologic circumstances it would appear that the rate of depressurisation reported by a piezometer in an off-panel bore (see Fig. 3(a) within) relatively close to an extraction can provide an indication of whether or not the instrument is located at a depth above or below the peak height of the drainage zone. This is possible because of the typically large differences between vertical and horizontal hydraulic conductivities and, accordingly, vertical and horizontal hydraulic diffusivities. The differing responses of off-panel piezometers above and below the height of the drainage zone appears to be evident, for example, in the hydrographs provided for the instruments in bore 9GGW1B over the centre of Longwall 22B of the Metropolitan Colliery (Section 8 and Fig, 12). Compression effects associated with subsidence settlement may erode this distinction, as may distance.
- In their groundwater assessments, both before and after their adoption of the Ditton equation, HydroSimulations appear to have misinterpreted the Dendrobium piezometer data and underestimated drainage zone heights for the mine. For example, the groundwater assessment reports for Longwall 9 and 10 present data from piezometer bore DDH105/S1910 as a test of the Ditton and Tammetta equations and find in favour of the Ditton equation. The observed rates of change do not appear to be consistent with HydroSimulations' suggestion of vertical propagation of depressurisation (Section 15.1.13). The data from DDH105 and other Area 3B bores appear to be consistent with the drainage zone height estimates provided by the Tammetta equation. Hydrographs from key piezometer bores are discussed in Section 15.
- Of note, the hydraulic head reported by DDH105/S1910 Piezometer 2, placed at 125 metres below ground, falls from being approximately 5 metres above the water level of Avon Reservoir to about 35 metres below as a consequence of the extraction of Longwall 9. A number of Dendrobium piezometers in the lower Hawkesbury Sandstone and upper Bulgo Sandstone report hydraulic heads that fall from being above the level of the nearby storage reservoir to being below that of the reservoir.
- A limitation of the extensive Dendrobium piezometer network is the typically large separation between instruments in the Hawkesbury Sandstone, which is in general the uppermost stratum above the mine (see Fig. 11). There appear to be few suitably located bores with piezometers at depth between approximately 100 and 20 metres below the surface. This weakness limits the precision with which the height of the drainage zones over the Dendrobium extractions may be gauged. This also limits the precision with which the Tammetta equation may be evaluated.
- This weakness also limits a gauging of the height to which significant depressurisation has occurred over the Dendrobium mine. As Table 5 indicates, significant drawdowns have reached to at least the lower Hawkesbury Sandstone.
- Not infrequently mining company consultants fail to provide sufficient information to allow adequate review of their assessments by Government agencies or concerned members of the public. Illustrating this problem, HydroSimulations provide piezometer data from bore instruments as graphs of hydraulic head. Pressure head graphs provide clearer insight into the impact of mining on groundwater pressures than do hydraulic head graphs; the inclusion of instrument elevations in the latter can obscure impacts. This is compounded by the graphical style used for the hydrographs provided by HydroSimulations in their assessments for Longwalls

6 to 10. Additionally these hydrographs have a limited data-point frequency. Without access to the instrument data, it was necessary to digitise the hydrographs provided by HydroSimulations and subtract piezometer elevations from the hydraulic pressures in order to obtain pressure heads for Dendrobium.

- It would appear that in their October 2015 height of connected fracturing assessment and March 2016 groundwater impact assessment for the Dendrobium mine, HydroSimulations misunderstand and/or misrepresent Tammetta's work and its implications. The consultants evidently expect complete depressurisation to extend beyond the drainage zone. For example the March 2016 report states "*Zero pressures, or near-zero pressures, were not often recorded in the sequence above the longwalls*". No specific examples are identified in support of this statement. With one exception, of a kind, there appear to be no centreline or off-centreline Dendrobium piezometer bores hosting piezometers that would be expected to be within the Tammetta drainage zone and that survived being undermined.
- The exception is bore S2220, which was installed over the centreline of Dendrobium Longwall 9, near the start of the eastern (final) quarter, as part of a study undertaken by Parsons Brinckerhoff to determine the height of the extraction's drainage zone. Six piezometers were installed in bore S2220 in October 2014, approximately a year after the longwall face had passed below the bore site in October 2013 and four months after the extraction was completed in June 2014. Of note, Parsons Brinckerhoff incorrectly give the completion date as being in January 2014.
- As a consequence of ongoing collapse, the three deepest S2220 instruments failed shortly after installation. Puzzlingly and without explanation, data were only collected from the remaining piezometers for just over 15 weeks. Given the circumstances, it seems likely one or more of the surviving three instruments subsequently failed. Supporting this possibility, the May 2016 Longwall 11 end of panel report provides a small amount of additional data, not previously provided, for the three corresponding instruments in nearby pre-mining bore S2192, more than a year after they evidently failed in October 2013 as the Longwall 9 extraction approached and passed this bore site. This suggests that had more data been obtained from S2220, it would also have been provided. In addition to providing further insight into any further Longwall 9 drainage zone development, continued monitoring would have provided insightful data for the extraction of at least Longwall 11 (Longwall 10 was completed on January 20 2015). The installation cost of a bore is high.
- Reflecting the instrument loss, the Parsons Brinckerhoff study was unable to reliably determine the height of the drainage zone over the eastern end of Longwall 9. The instrument loss, a consequence of delayed ongoing collapse, seems likely to reflect the presence of high horizontal stress over the eastern section of the extraction (Section 16 within).
- Of note, the hydraulic heads reported by the S2192 instruments at 95 and 140 metres below the surface fall below the level of Avon Reservoir before they apparently fail in October 2013.
- There would then appear to be no piezometers in the "*sequence above the longwalls*" able to record zero or near zero pressure. Without substantiation, HydroSimulations suggest "*The data does do not support the concept of a zero pressure extending upward from the goaf up to the Tammetta H height*". DDH89 and DDH117 are examples of side-panel bores with instruments

that respond in accord with the Tammetta equation. The DDH117 data are supported by extensometer data that's also in accord with the Tammetta equation.

- Figures 21 and 22 of the October 2015 HydroSimulations height of connected fracture report (Figs. 24 and 25 within) are presented as a summary of piezometer data from Dendrobium and are used by the consultants to argue that the data contradict the Tammetta equation. These misleading figures fail to locate the represented piezometers with respect to the extractions with which they are associated in the report and, additionally, omit several piezometers that report significant pressure head losses. While some of the piezometers reporting significant pressure loss are identified, none of the represented instruments that show little or no significant pressure loss are identified. This omission precludes an assessment of whether or not they contradict the Tammetta equation. That is, the assertion that the represented instruments contradict the Tammetta equation is not substantiated by HydroSimulations.
- Tammetta used the DDH117 data as a calibration target for the 2012 Coffey assessments for Dendrobium. The March 2014 HydroSimulations assessment states that the same set of targets were used for their modelling. Puzzlingly however, DDH117 does not appear to have been used as a target by HydroSimulations and appears to have been replaced by a much less informative bore, DDH90. This suggests the possibility that HydroSimulations were unable to model the DDH117 data.
- The October 2015 HydroSimulations report echoes an assertion made in their March 2014 groundwater impact assessment for Dendrobium that there is a "*good match between observed data above Longwall 5 and the predictions of the Ditton (2013) method for estimating the height of connected fracturing*". The HydroSimulations' reports do not identify which piezometer bore provided the data referred to in the quote. The consultants declined a request for clarification and the mining company has not responded to requests for that and other information. A review of the hydrographs available for the bores in the vicinity of Longwall 5 fails to find a candidate for this bore (Section 15.1.4). On the contrary, the bore best placed to gauge the height of drainage zone, DDH117, reports data that challenges the Ditton equation (Section 15.1.8). The March 2014, October 2015 and March 2016 HydroSimulations assessments do not include mention or representation of DDH117.
- Piezometer data from a bore located over the centreline of a longwall extraction currently provide the most reliable means of determining its drainage zone height. While there are very few such bores in NSW, there is one over Elouera Longwall 7. Both former BHP-Billiton mines, the Dendrobium mine is effectively an extension of the immediately adjacent Elouera mine, which is now part of the Wongawilli mine. Figure 6 of the October 2012 Coffey groundwater assessment for Dendrobium Area 3B represents piezometer data from this bore, DDH9, and a second located over the northern pillars of the northern most longwall, Longwall 8. Digitising and extracting the pressure heads from this figure provides a drainage zone height estimate of 186 meters. The height estimate provided by the Ditton (geology) equation, using the t' value of 30 recommended by HydroSimulations, is 131 metres. The estimate provide by the Tammetta equation is 198 metres; an adjustment term is not needed for the Tammetta equation.
- The assessments provided by HydroSimulations do not refer to the centreline data from the Elouera domain. Of note, neither the hydrographs nor the underlying data from this bore are

publically available. This is remarkable, given the bore probes mining impacts in a Schedule 1 Special Area of Sydney's drinking water catchment.

- In order to obtain calculated drainage heights from the Ditton (geology) equation that match the heights suggested by the piezometer data at Dendrobium and the adjoining Elouera domain, exceptionally small values of the equations adjustment parameter (t') are required (see Fig. 8 within, which also shows the drainage height indicated by the piezometer data from bore DDH9). As Figure 9 within indicates, there are no unusual geological features over the extractions at Dendrobium or Elouera that might explain this need. The adjustment term is discussed in Section 5 within.
- The drainage zone height estimate provided by the Elouera Longwall 7 piezometer data is consistent with a 2005 assessment of extensometer data from this longwall and Longwall 8 by consultants SCT. That assessment finds that the height of the zone of significant downward movement over an extraction is approximately equal to the panel width. The width of Elouera Longwall 7 is 190 metres.
- In assessing data from Elouera and other mines Tammetta finds that the height of the drainage zone coincides with the height at which there is a change from small to significant downward movement. That is, the drainage zone coincides with the collapsed zone.
- A notable finding of Tammetta's work is that a knowledge of longwall extraction width and height and mining depth is sufficient to estimate the height of the drainage zone to within 10%, across a variety of rock types comprised of "*claystones, coarse-to-fine sandstones (lithic and quartzose), and limestones, in widely varying strengths, grain sizes, compositions, layer thicknesses, and recurrence patterns*". Tammetta notes that super-strong dolerite sills in South Africa have an observed drainage zone height slightly lower than calculated using his equation and comments "*Despite a thorough search of the literature, no other published data could be found to show significant deviations from the equation*". That is, the available data indicate an adjustment term is not needed for drainage zone height estimates to within 10%.
- Notwithstanding this science journal published finding, the NSW Department of Planning recently echoed the assertion of some in the mining community in stating "*the height of the fractured zone cannot simply be predicted as a function of longwall panel geometry*". To date there has been no refutation of Tammetta's work and its findings in a peer reviewed journal of good standing.
- In their October 2015 height of connected fracture assessment provided for the next set of extractions proposed for the Dendrobium mine, HydroSimulations advise that their application of the Ditton and Tammetta equation used the cutting heights actually used for Longwalls 1 to 11 and the proposed maximum heights for Longwalls 12 to 18. This appears to be the case for Longwalls 9, 10 and 11, however for the earlier extractions the consultants appear to have used the planned/maximum extraction height rather than the cutting height actually used. The limited available information indicates the average employed cutting heights would generally be significantly less than the planned/maximum heights. The estimated drainage heights returned by the Ditton and Tammetta equations would accordingly be reduced when the actual heights are used. Clarification was sought from the consultants and the mining company regarding their use of extraction heights in applying the Ditton and Tammetta equations, but has not been provided.

- The Dendrobium mine is a notably ‘wet’ mine, with rain dependent peak inflow of up to 13 million litres a day - the equivalent of five Olympic swimming pools. The mine appears to be the wettest of the mines currently and recently operating in the Schedule 1 Special Areas of Sydney’s drinking water catchment and appears to be the wettest of all mines in the Special Areas. HydroSimulations argue that inflow records and water chemistry contradict the Tammetta equation prediction that the drainage zone would intersect the surface over some of the Dendrobium longwalls. In doing so HydroSimulations overlook studies by the Dams Safety Committee and evidence noted by Tammetta.
- The March 2014 HydroSimulations groundwater impact assessment for Dendrobium replaced assessments provided in October and November 2012 to BHP-Billiton by Coffey Geotechnics and undertaken on behalf of the consultancy by Tammetta. The principle difference in the modelling undertaken for these assessments was the replacement of the Tammetta equation with that of Ditton by HydroSimulations. Though presented by HydroSimulations as a step forward, the evidence suggests this change was instead a significant step backwards.
- The 2012 Coffey assessments introduced the use of a regional scale groundwater model that WaterNSW (then the SCA) has described as an important step forward. Though the details are held in reports that are not publically available, the limited available information indicates that the earlier modelling for Dendrobium, undertaken by HydroSimulations (then trading as Heritage Computing), was significantly more limited in scope and rigour. Without explanation, the groundwater impact assessments for the Longwall 6, 7 and 8 end of panel reports advise that the fractured zone (assumed to be equivalent to the drainage zone) height incorporated in the model underpinning the groundwater assessments was set at the base of the Bulgo sandstone. Fixing the drainage zone at the base of the Bulgo Sandstone contradicts or misinterprets the piezometer evidence. Hydrographs from key piezometer bores are discussed in Section 15.
- The Ditton equation underpinned model used for the March 2014 HydroSimulations groundwater impact assessment is also used for the groundwater impact assessments for the Longwall 9, 10 and 11 end of panel reports.
- Irrespective of the use of the Ditton geology equation, the modelling undertaken by HydroSimulations does not appear to be of the same calibre as that of Tammetta for Coffey Geotechnics. In contrast to the work of Tammetta, the inflow modelling undertaken by HydroSimulations does not require simultaneous calibration to measured hydraulic conductivities, hydraulic heads and regional mine inflows. This puzzling (see Section 17) weakness in the HydroSimulations modelling may partly explain the physically unrealistic finding of their 2016 modelling that mine inflow is insensitive to drainage zone height. Another factor may be that the 2016 modelling differs from their previous modelling in using a new technique known as Connected Linear Networks. The current implementation of this method does not appear to be suitable for modelling non-Darcian flow through fractures in unsaturated media.
- Tammetta’s modelling provides a comprehensive regional flow budget and this includes consideration of base flow diversion. Baseflow provides a significant contribution to storage inflow and may be the dominant during dry periods. The modelling provided by HydroSimulations is not regional, does not provide a flow breakdown and does not discuss

baseflow diversion. As noted above, the Dendrobium mine has caused a significant disruption to the regional groundwater regime.

- Table 1 below lists the hydraulic diffusivities derived from the calibrated aquifer properties used for the Coffey and the HydroSimulations modelling. While those of the Coffey modelling are typical of the Southern Coalfield sandstone, some of the values used by HydroSimulations appear to be anomalous. The vertical diffusivity given by the parameters used by HydroSimulations for the upper Bulgo Sandstone are more typical of shale than sandstone. The difference stems from the conductivities used by the two authors (see Table 2); they use the same specifics storage values. Tammetta obtained his conductivities by calibration against field data.
- The available information suggests the November 2012 groundwater impact assessment undertaken by Tammetta on behalf of Coffey Geotechnics is likely to provide the most robust modelling and impact assessment undertaken to date for the Dendrobium mine. Having rejected it soon after receiving it in 2012, BHP-Billiton and South32 have refused requests made by the NPA and, more recently, the NSW Department of Planning for copies of this important report. This refusal hinders the assessment of the current and proposed mining in Area 3B.
- In responding to requests for the November 2012 Coffey groundwater impact assessment report the mining company provided its underpinning data analysis report. That they provided the data analysis report and not the impact report is puzzling and cause for concern that the predicted impacts are grave.
- The approval conditions for the mining currently underway in Area 3B require a determination of the drainage zone heights for Longwalls 6 to 10 and reliable estimates for the height of the drainage zones formed by the extraction of Longwalls 11 to 12, prior to the extraction of Longwall 12 (see Section 24). There has yet to be a reliable direct determination of the drainage height for any of the Area 3B longwalls (see Sections 12, 15 and 16). As noted above, Parsons Brinckerhoff failed in an attempt to directly measure the height of the drainage zone over Longwall 9.

  The October 2015 HydroSimulations connected fracture report for Area 3B is presumably provided with the 2016 SMP material in order to, in part, satisfy the prerequisite for the approval of further mining. This assessment, like the March 2016 HydroSimulations groundwater impact assessment, is underpinned by Ditton’s geology equation and appears to be deeply flawed and misleading.

  Longwall 12 is currently being extracted and the subsidence management plan (SMP) for the second set of Area 3B longwalls, Longwalls 14 to 18, is currently being reviewed by the Department of Planning.

  The Area 3B approval condition has not been credibly satisfied.
- The Area 3 (3A, 3B and 3C) mining approval requires no more than negligible change to the groundwater support for the storage reservoirs and watercourses (Section 24). The hydrographs reviewed here suggest that the Dendrobium mine has caused a significant disruption to the groundwater regime between the Avon and Cordeaux Reservoirs, with large drawdowns occurring as close to the surface as 55 meters (Table 5). Large drawdowns may have occurred closer to the surface than can be measured by the Dendrobium piezometer network; there is a paucity of piezometers installed over the interval between around 100 metres and 20 metres below the surface (typically the lower and near surface Hawkesbury Sandstone). Table 5 within

lists large drawdowns in the upper strata above the coal mine. For example, piezometers at 140 metres below the surface in nearby bores S2192 and S2220, located over the centreline of Longwall 9, show a pressure head loss of 67 metres following the extraction of Longwall 9. This corresponds to a pressure head loss of approximately 82% at a depth of 140 metres over the centreline of Longwall 9, relative to the pre-mining level. Most of the bores listed in Table 5 have Lower Hawkesbury Sandstone or upper Bulgo Sandstone piezometers a hydraulic head fall from being above to being at or below that of the nearby storage reservoir (see Table 5).

- Highlighting the severity of the disruption, the groundwater impact assessment for the Longwall 11 end of panel report advises that of the four piezometer bores used as groundwater TARP (Trigger Action Response Plan) reference sites for the current Dendrobium mining, one is at Level 3 (DDH85/S1870) and the others are at Level 2 (Section 15.1.20). Of note, one of the bores at Level 2 returns patchy and possibly unreliable data (DDH120/S1994) and another (DDH84/S1867) reports an unusual mining response. The response may reflect subsidence related compressions effects or its close proximity to Cordeaux Reservoir (Section 15.1.11).
- Of note, the near surface DDH84/S1867 instrument, 10 metres below ground, appears to have fallen to dryness and the DDH84/S1867 instrument at 15 metres below ground appears to have become close to being dry as a consequence of the Dendrobium Area 3A mining. This is also the case for the shallow instrument in TARP bore DDH85/S1870; a significant number of near surface instruments in the Dendrobium piezometer bores considered here are found to be dry or close to being dry.
- The May 2016 HydroSimulations groundwater assessment for the Longwall 11 end of panel report advises that the highest Area 3 groundwater TARP alert, a Level 3 alert according to that report, is triggered when the pressure heads reported by all Bulgo Sandstone piezometers in a reference bore fall below the water level of Cordeaux Reservoir. In contrast, the May 2015 Longwall 10 end of panel report does not have a Level 3 groundwater alert and instead the level above Level 2 is given as "*unacceptable*". The Longwall 11 end of panel report does not explain the change in characterisation of the highest alert level. The TARP bores are discussed in Sections 15.1.11, 15.1.12 and 15.1.20.
- All three of the Bulgo Sandstone piezometers in bore DDH85/S1870 have fell below the level of the stored waters of Cordeaux Reservoir during the Longwall 11 reporting period, triggering a Level 3 TARP alert, the highest groundwater TARP alert level. Between July 2009 and July 2015 the shallowest of these instruments, that at 55 metres below the surface, recorded an approximately 83% pressure head decline from approximately 35 metres to approximately 6 metres. The hydraulic head was by then approximately at the level of Cordeaux Reservoir (Sections 15.1.12.3 and 15.1.20, and Fig. 36 below). The elevation of this piezometer is 296 metres (mAHD), in line with Cordeaux Reservoir. The loss of pressure reported by this relatively shallow piezometer would seem to signal a more than negligible loss of groundwater support for Sandy Creek and the storage reservoir.
- The three DDH85/S1870 Hawkesbury Sandstone piezometers all show increasing response to rainfall from the completion of Longwall 6 onwards. The shallowest instrument, at 10 metres below the surface, falls to dryness by January 2013, with only transient recovery following rainfall. This is something that had not happened in the period from the start date of the

hydrographs in October 2006. That is, the instrument did not become dry during the Millennium drought, but did so following the completion of Longwall 8.

- Given the withholding of the November 2012 Coffey assessment for Area 3B and the flawed and misleading nature of the October 2015 height of fracture report and the March 2016 groundwater assessment submitted to the Government as part of the SMP material, the proposed new mining in Area 3B lacks a credible and comprehensive groundwater assessment.
- Data from post-mining centreline piezometer bore S2220 reveals a lack of water retention at 50 metres below the surface and rainfall sensitivity to a depth of 95 metres over Dendrobium Longwall 9. This indicates that the surface fracture zone can extend to much greater depths than the 15 to 30 metres suggested by mining companies and their consultants (Section 16.7).
- Consultants GeoTerra indirectly advise 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.*"

  See Section 22.
- Dendrobium piezometer bore DDH108/S1925 (Section 15.1.18) would appear to demonstrate that horizontal pressure loss can extend rapidly for considerable distances. This suggests that the highest drainage zone peak from a set of extractions can determine the height at which significant adverse groundwater, and possibly surface water, impacts occur for a significant area beyond the causal longwall. Noting the comments by GeoTerra, this would become particularly concerning where the highest drainage zone approaches within 150 metres of the surface.
- The publically available assessments undertaken by Tammetta for Coffey and provided to BHP-Billiton for the Dendrobium mine and commissioned by the Department of Planning for the proposed expansion of the Russell Vale colliery, are rich in information of significance. In recommending approval for the proposed Russell Vale expansion to the PAC, the Department of Planning evidently overlooked or discounted important information in these assessments. This includes the possibility of the drainage zone above the mine's overlapping triple seam extractions reaching the surface (Section 25). There is also a possibility that the drainage zone above the mine's overlapping double seam extractions will intersect a shear plane bearing water from Cataract reservoir.
- Though the publically available information is limited and in some cases unclear, Section 26 obtains two estimates for the daily inflow of water into the mines located within and adjacent to the Metropolitan and Woronora Special Areas. It's likely the mining companies, particularly BHP-Billiton/South32, hold information that would be of considerable assistance in assessing inflows to these mines. The two inflow estimates are 29 and 40 million litres a day (Ml/day). The mid-range sum of 34 Ml/day provides an indicator with which to consider the significance and implications of mine inflows. The figure may be conservative as not all inflows are captured by the reticulated water systems of the mines and, reflecting this, large bodies of water are accumulating in the workings beneath the Special Areas. Providing some context, the long term average daily supply from the Avon, Cataract, Cordeaux, and Woronora Reservoirs totals approximately 334 Ml/day. A loss of 34 Ml/day would then be numerically equivalent to 10.2%

of the daily supply from these dams. Current and approved mining would increase the loss to 12.6%.

- How much of the lost water would otherwise have entered storage isn't known. The inflows to mines in the Metropolitan Special Area show relatively short response times to rainfall, suggesting a significant amount of the water will have been diverted from storage. In addition to the diversion of water into the mines, an unknown amount of water is being diverted and lost into groundwater flows that leave the storage reservoir catchment areas.
- The Department of Planning advises that the extraction of water from rivers or aquifers to use for commercial purposes requires a water licence or other approval from DPI-Water under either the Water Management Act 2000 or the Water Act 1912. The Dendrobium and Wongawilli mines appear to be unable to meet the requirements of their current licences (Sections 25 and 26). Licence allocations are currently unable to take into account the unknown inflows accumulating in old mine workings, such the large pool accumulating in the Elouera domain of the Wongawilli mine.
- This report was hindered by the lack of publically available information and data pertaining to the impacts of coal mining beneath Sydney's most important public health asset; its drinking water catchment. The mining companies operating within the catchment hold and withhold information and data that would provide considerable insight into the impacts of the extraction of coal from beneath and around the Schedule 1 Special Areas. Requests for information sent to HydroSimulations and BHP-Billiton/South32 were ether denied or have had no reply. The first recommendation of the May 2014 report by the NSW Chief Scientist on the cumulative impacts of activities which impact ground and surface water in the Sydney Water Catchment was "*That Government create a whole-of-Catchment data repository*". Neither this nor the other four recommendations made by the Chief Scientist appear to have been acted on by the Government.
- The NSW Department of Planning has established a record of setting aside the advice and concerns of the tax payer funded expert agencies in favour of advice provided by mining company funded consultants, such as HydroSimulations. The Department's approval recommendation for the proposed expansion of the Russell Vale Colliery provides a recent example (Section 25). In this case the Department also appears to have set aside four reviews provided by Coffey; these assessments were commissioned by the Department. The groundwater impact assessments undertaken by HydroSimulations considered in this report appear to be flawed and misleading.
- The concerns raised here and in the letter sent to the NSW Minister for Planning in July 2015 and February 2016 extend beyond the Dendrobium mine. The Ditton equation has underpinned groundwater impact assessments for other NSW mining project assessments, such as Springvale, Moolarben and Narrabri. HydroSimulations and Heritage Computing, the former trading name for HydroSimulations, have provided groundwater impact assessments and peer reviews for a significant number of coal mining projects in NSW. HydroSimulations have provided Ditton equation based groundwater impact advice to Adani and the Queensland Land Court regarding the Carmichael proposal.
- The interpretation of the hydrographs from the Dendrobium mine piezometers given in this report is underpinned by Section 1.

Recommendations

The letter the NSW Planning Minister of July 2015 and that of February 2016 included a set of recommendations of which to date one has been undertaken by the NSW Department of Planning. The recommendations are revised and augmented below.

Section 22 within considers cutting height restrictions that the Tammetta equation and advice from consultants GeoTerra suggests might protect the baseflow regime supporting water inflow to the storage reservoirs adjacent to the Dendrobium mine. As quoted in Section 22 below, consultants GeoTerra advise:

> "*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*."

The Tammetta equation indicates that limiting the cutting height to 1.1 metres would, on average, limit the drainage zone of new Area 3B longwalls that have a width of 305 metres to a height equivalent to 150 metres below the approximately 270 metres (mAHD) elevation of the base of the Cordeaux Reservoir (Section 22).

Limiting the height to 2.4 metres would on average limit the height of the drainage zone to 150 metres from the surface above Longwalls 14 to 18 (Section 22). The cumulative local and regional impacts to date however appear to be such that no further mining should be approved.

The following recommendations begin with Dendrobium and widen in scope:

(i) Given the established width of 305 metres, the cutting height for any further mining in Area 3B should be limited to 1 metre.

(ii) Release of post February 2015 data from bore S2220 over Area 3B Longwall 9. If no data or only limited data have been recorded since February 2015 and assuming the instruments have not been damaged by ongoing growth of the collapsed zone, resumption of data collection from piezometer bore s2220. If the instruments have been lost, clarification of the nature and timing of those losses.

(iii) At least three bores, each with closely spaced piezometers, to be sunk in a line across a suitable location in the western half of LW10 in order to determine the drainage zone height and profile. One bore to be placed centre-panel, one midway between centre panel and the side and one over the side-pillars.

The vicinity of existing bore S1908 would appear to be a suitable location (see Fig. 31(b)). The terrain in the western half is comparatively flat (see Figs. 31(b) and 52) and does not appear to have the stress conditions found in the eastern half of Area 3B. The extraction height in the western half of LW10 is such that the drainage zone is expected to be generally less than 30 metres from the surface, the exception being between 1140 and 1040 metres from the western end, where the extraction height was 4.5 metres and the drainage zone would be expected to have intersected the surface.

The bores should be drilled as soon as possible, with a first report provided within three months of sinking and piezometer commissioning. Data collection to continue for at least a year and the data reports to be owned by the State of NSW and publically available.

Of note, the 2010 PAC report for the Bulli Seam Operations project recommends "*That a network of pore pressure monitoring bores and vertical arrays of pore pressure transducers be established to assess/quantify the height of connected and freely drainable fracturing*"

(iv) Sinking of multi-piezometer bores on the centre-line of overlapping double and triple seam extractions at the Russell Vale Colliery. Remarkably, this has not been done. As pointed out in the Sydney Morning Herald in December[1], the drainage zone may intersect a shear plane bearing water from Cataract Reservoir (Section 25 within). Currently there is insufficient data from overlapping coal extractions to allow the development of an equation for the estimation of the drainage height over multi-seam extractions.

(v) Review and expand, with new piezometer bores funded by industry, the database of reliable centre-panel piezometer measurements of the height of the drainage zone. This must include overlapping multiple extractions, such as those at Russell Vale.

(vi) Industry funded research programme to sink bores and gather piezometer data from a set of representative longwall extractions, selected in agreement with the agencies and community, in order to obtain a set of cross-section profiles of the drainage zone above longwall extractions.

(vii) 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.

(viii) Revision of the groundwater model for Dendrobium such that the drainage zone is set by the Tammetta equation with the extraction heights used to date and the planned maximum mining height for longwalls and longwall sections not yet extracted. It would appear that Tammetta is best placed to revise the groundwater modelling for Dendrobium.

(ix) Require the public release by Illawarra Coal of the November 2012 Coffey Area 3B groundwater assessment report.

(x) Public release of the hydrographs and data from the bores over the underground mines in NSW represented in Tammetta's databases, including those not directly identified because of confidentiality obligations. Examples of the latter include the bores over and adjacent to Elouera domain in the Wongawilli mine. Tammetta's databases are provided with the supplementary material accompanying his Groundwater publications (see Section 7).

(xi) Public release of all data from monitoring bores and sites over mines operating beneath Sydney's drinking water catchment and other sensitive public lands in NSW.

(xii) Independent update assessment, with fresh samples and chain of custody records, of the water age and algal profile for each of the domains of the Dendrobium mine. This to include the provision of sampling access to Longwalls 1 and 3. Independent update assessment of rainfall correlation for each of the domains of the Dendrobium mine.

(xiii) Independent determination and assessment of the water age profiles and rainfall correlations for each the mines operating beneath Sydney's water catchment.

(xiv) Mapping and monitoring of the bodies of water accumulating in the mines in and around the Special Areas.

(xv) Regular independent auditing of mine inflow records and measurement processes.

(xvi) Verification of water licence compliance by the mines operating within and around the Schedule 1 Special Areas.

(xvii) Piezometers to be installed at underground mines in NSW at height intervals that allow a sufficiently precise gauging of the drainage zone height.

(xviii) End of panel and proposal assessments to include the following: (a) Extraction height profile details in the manner provided for instance in the subsidence report for Longwall 3 of the Dendrobium mine. (b) Both hydraulic and pressure head hydrographs, with as short an interval between data points as possible and heads of relevant storages. (c) All instruments depths and collar heights. (d) Seam floor, depth of cover and surface elevation contour maps. (e) Clear graphical depictions of sufficient resolution to allow features of interest to be clearly enlarged. (f) Extensometer data at least provided as displacements and not just strains.

(xix) Removal of the direct linkage between assessments and mining companies; accredited and licensed consultants selected at random by the Government. Accreditation and licensing to be funded by an industry levy. Engagement of the selected consultant to be funded by the proponent.

(xx) In accord with the 2014 recommendations of the NSW Chief Scientist, data collected by and on behalf of mining companies and reports and other documents prepared for mining proposals and post approval reporting to be the property of the State of NSW and publically available. This must include any reports or documents referred to in the reports and documents provided by proponents. It is impossible for the Government, the agencies or members of the public to properly assess a report or document if related reports or documents are retained and withheld by proponents.

(xxi) The PAC to determine all proposals for mining in sensitive areas of importance, with public submissions and consultation; this includes mining proposals for the next phase of an approved project. This is necessary, given Planning's history of setting aside best practice science, including that from the SCA, OEH and IESC, in favour of poor advice from the industry and acceptance of flawed, if not ludicrous, economic benefit assessments from the industry, such as originally provided for Wallarah 2 and the proposed expansion of the Russell Vale Colliery (see Section 25).

(xxii) A genuinely and clearly independent inquiry into the actions, recommendations and determinations made by the Department of Planning with respect to impact and benefit assessments for mining proposals, and its assessment of post-approval reports.

(xxiii) Identification of areas where the Tammetta equation suggests the drainage zone will have intersected, or will intersect, the surface or surface fracture network and where there is then potential for discharge of post closure contaminated mine water.

(xxiv) Preparation of a plan for the management of post closure contaminated mine water seepage in the Schedule 1 Special Areas, where the drainage zone reaches the surface or surface fracture network.

(xxv) Funding for WaterNSW to reliably determine the likely volume of surface water being diverted into groundwater flows that leave the catchment area of the storage reservoirs in the Special Areas.

(xxvi) Funding for WaterNSW to reliably determine the likely volume of runoff being lost as a consequence of mining beneath the Special Areas. This would likely require satellite imaging.

(xxvii) In consultation with the agencies and public, determination of a time frame and plan for the cessation of mining beneath the Schedule 1 Special Areas of Sydney's drinking water catchment

1. Preliminary Comments

The comments and concerns herein are underpinned by acceptance of the following:

(i) Tammetta's recent description[2] of the strata collapse process, with fractured spall formation, triggered by coal extraction is correct. A summary is given in Section 2 below.

(ii) Pre-mining hydraulic conductivities in the strata of the Southern Coalfield are highly anisotropic, with vertical conductivity being one to two or more orders of magnitude (powers of ten) smaller than horizontal conductivity. Vertical hydraulic conductivity of the lower Hawkesbury Sandstone for example is 0.00075 metres per day (m/day)[3], equivalent to 0.75 millimetres per day (mm/day). The corresponding horizontal conductivity is 0.025 metres per day[3] - 33 times greater than the vertical conductivity. Assuming Darcian flow, and no vertical defects (fractures, joints), under a unit pressure gradient the vertical flow rate would be 274 mm per annum; the horizontal flow would be 9.13 metres a year. Under a pressure gradient of 10 the Darcian vertical flow rate would be no more than 2.7 metres per annum; the flow rate would decrease as the higher pressure head declined. The horizontal flow would be 91.3 metres a year.

(iii) The hydraulic conductivity anisotropy reflects the frequency, extent and continuity of bedding planes relative to that of (vertical) joints. Pells comments[4] "*where boreholes do not intercept joints, permeability is largely controlled by near horizontal bedding planes*". In the Hawkesbury Sandstone bedding planes occur at intervals of a few centimetres to five metres, though typically around a metre.[5] The planes may be may be continuous for hundreds of metres and are marked by continuous separations and clay seams. Vertical joints are less common, generally greater than two metres apart, discontinuous and terminate on bedding planes.[5]

(iv) The propagation of a sudden loss of pressure in a saturated medium is described by a diffusion equation of the same type that describes the propagation of thermal, electrical and chemical disturbances.[6][7] The solution to the one dimensional form of this equation[8][9][10] provides a ready means to gain an indicative qualitative insight into the character of the propagation of a pressure change. Known as the hydraulic diffusivity[11], the determining parameter for the rate of pressure change recorded by a piezometer at a certain time and distance from the origin of the perturbation, is the ratio of the hydraulic conductivity to the specific (hydraulic) storage of the host medium. The vertical conductivity and the specific storage of sandstone aquifers in the Special Areas suggest that its vertical diffusivity would be around 0.001 m^2s^{-1}.[3][10] Given its conductivity dependence, diffusivity in the horizontal direction would be expected to be 10 to 100 or more times greater than in the vertical direction. Pressure change would accordingly propagate more rapidly horizontally than vertically. Figure 1 below graphs, for the one dimensional case, the change in pressure with time at a distance (vertical or horizontal) from an initial point of pressure head loss of 250 metres, for diffusivity values of 0.0001, 0.001, 0.01 and 0.1 m^2s^{-1}. The greater the diffusivity, the greater the rate of pressure change at a given distance from the source of the disturbance.

(v) Reflecting energy transfer to the surrounding medium (rock), the rate of pressure change declines with distance from the point of initial pressure loss.[8][12] This appears to be illustrated by the sequential responses of Piezometer 2 in Dendrobium bore DDH108/S1925, to the extractions of Area 3B Longwalls 9, 10 and 11 (Section 15.1.18). Tammetta gives[12] an example of the response of piezometers in a bore the chain pillars of an extraction and contrasts this with an example where the instruments are in a bore several hundred meters away.

(vi) Figure 1 lacks recognition of recharge or the complex character of the three dimensional propagation of pressure change through strata and boundaries of varying type, arising from an incrementally progressing longwall extraction. It does however indicate that, in the absence of unusual circumstances, the horizontal propagation of pressure loss will be considerably more rapid than vertical propagation. Actual rates of pressure change would be expected to be less than suggested by Figure 1, for a given diffusivity. Caving may also complicate the groundwater response reported by an off-panel piezometer that's at or below the height of the drainage zone. Referring to piezometer hydrographs as time series, Tammetta comments[12]:

> "*Longwall caving imprints a frequency distribution on time series obtained over panels that is easily identifiable in the time domain (high frequency and large amplitude) and, in the vast majority of cases, beyond doubt*."

The response of Piezometers 2 and 3 in bore DDH105/S1910 would appear to provide an example of this effect. Tammetta also comments that distance softens and smooths the caving imprint.

(vii) Subsidence above a longwall extraction increases average horizontal hydraulic conductivity by one to two or more orders of magnitude[4] and the increase arising from horizontal shear may considerably greater. Vertical conductivity is changed little by mining; this is reflected for instance in the following comment from a 2007 review by Sinclair Knight Merz for the NSW Department of Environment and Climate Change (since absorbed into the Office of Environment and Heritage):

> "*Very little of the near-surface water is transmitted through the elastic zone, which in a typical Australian longwall mine at depth 400 m might be over 300 m thick*."

The elastic zone refers to the zone between the surface fracture zone and the collapsed zone and is also referred to as the constrained zone or the disturbed zone.

The increase in horizontal hydraulic conductivity is reflected in the following comment made by HydroSimulations in their 2016 groundwater impact assessment for the Subsidence Management Plan (SMP) for the second set of longwall extraction proposed for Area 3B of the Dendrobium mine:

> "*Beyond the margins of the longwall, surface movements are generally towards the centre of the longwall as strata move laterally to "fill" the void. This causes bedding plane shear and associated increases in horizontal permeability that extend outside the longwall footprint*."

Illustrating this, in their March 2015 height of fracture assessment[13] for the Dendrobium mine, Parsons Brinckerhoff make the following comments with respect to centreline bore data collected in the Bulgo Sandstone, lower Hawkesbury Sandstone and upper Hawkesbury Sandstone strata (intervals) over Longwall 9 in Area 3B of the mine (discussed in Section 16):

> "*Hydraulic conductivity (horizontal) in these three intervals after mining is approximately two to three orders of magnitude higher than before mining*."

The post-mining horizontal conductivity increase arises from bedding plane dilation and horizontal shear impacts.

(viii) Subsidence induced increases in horizontal hydraulic conductivity can extend for several hundred or more metres but, variably and unpredictably, decrease with lateral distance from the causal coal extraction. The end of panel subsidence report for Dendrobium Longwall 9 shows horizontal movements of two or more centimetres at around a kilometre from the extraction. The subsidence report for the Longwall 11 end of panel report graphs horizontal displacements of more than two centimetres at distances of up to two kilometres. Elsewhere Waddington and Kay report[14] movements at distances in excess of 3 km and Eade and Wood (BHP-Billiton) report movements at up to 5 km.[15]

(ix) The zone above an isolated extraction where groundwater begins to flow relatively freely towards an underlying coal extraction is contained within the footprint of the extraction and has a concave (open at the bottom) parabolic upper boundary (see Fig. 2). Depending on the context, this zone is referred to as the desaturated zone, the depressurised (to atmospheric pressure) zone or the drainage zone.

(x) Tammetta finds the drainage zone coincides with the collapsed zone and identifies the collapsed zone as the point at which extensometer measurements identify a change from small to significant downward movement of the overburden towards an extraction.

(xi) Extensometer data are less reliable (precise) than piezometer data. Tammetta comments; "*Extensometer results have a larger scatter than hydraulic head results, because of the more chaotic nature of seismic energy release and the disproportionate effects of localized, unrepresentative defects or structural features*."[16]

(xii) Extensometer measurements provided as displacements are more immediately informative and directly relevant than as strains in assessing the height of the collapsed zone formed over a coal extraction.

(xiii) The point below the surface that groundwater begins to flow relatively freely towards an underlying coal extraction void is most reliably determined with the installation of a string of piezometers above the centreline of the extraction (see Fig. 3(c)). The point at which this occurs will be between the deepest piezometer that records a non-zero hydraulic head and, below this instrument, the shallowest/uppermost piezometer that either records a zero hydraulic head or that no longer provides data as a result of strata collapse (not shear) at that location in the piezometer array.

(xiv) The response of a piezometer laterally located beyond the depressurised zone formed above an extraction and at depth equivalent or greater than that of the peak of that desaturated zone, will primarily reflect a complex three dimensional convolution of the horizontal hydraulic conductivity profile over the saturated path between the piezometer and the depressurised zone, the pressure gradient over that path and the slope or 'dip' of the path (with respect to a horizontal plane).

As a consequence, the drainage zone height information provided by a piezometer in a bore located some distance laterally beyond the drainage zone over an extraction is less readily and reliably interpreted than that from a bore that directly penetrates this zone. The drainage zone height information provided by a piezometer will deteriorate with distance from the zone, to an extent and in a manner determined by local hydrogeological circumstances. Figure 3(a) depicts an ‘off-panel’ piezometer bore some distance from an extraction that has an adjoining extraction on the opposite side, while Figure 3(b) depicts a bore over the pillars adjacent to an extraction.

Some of the data given in this review were obtained by digitising graphs and maps in reports provided on behalf of mining companies, which will accordingly add to errors in the source data. The source data is held by the mining companies and not publically available. The errors introduced by digitising graphical information are expected to be relatively small.

2. Introduction

2.1 Background

In July 2015 the NSW National Parks Association (NPA) wrote to the Minister for Planning raising concerns about the manner in which groundwater impacts were estimated and assessed in NSW. In particular the NPA was concerned that the database underpinning the Ditton geometry and geology equations is fundamentally flawed in holding data not well suited for its intended purpose (Section 6 within). The database appears to be further compromised by errors and misinterpretations of instrument data (Sections 6 and Sections 8 to 12). The Ditton equations are preferred by several mining consultancies, notably HydroSimulations, for the calculated estimation of the height above a longwall coal extraction at which groundwater would begin to drain relatively freely towards the mine workings.

The letter sent to the Minister was copied to WaterNSW and the Office of Environment and Heritage. The concerns in the letter of July 2015 were also raised with the NSW Planning Assessment Commission in August 2015, in providing comment on planned mining at Springvale. The concerns ae echoed by WaterNSW in their April 2016 comments[17] on longwall plans for the Dendrobium mine that re currently being assessed by the Department of Planning

The NPA also expressed concern that an alternative equation that the available information indicates is underpinned by a more appropriate database was being ignored or rejected without a sound scientific basis. Developed by Coffey Geotechnics hydrologist Paul Tammetta, the equation is underpinned exclusively by piezometer (water pressure) data obtained from bores over the centreline of a set of extractions. Tammetta appears to have been the first to explicitly recognise the beneficial simplification provided by the use of piezometer data obtained from bores installed over the centreline of a coal extraction as a means of measuring the height of the drainage zone. Doing so avoids the need to characterise the degree and extent of fracturing and recognises the more problematic nature of extensometer data (see Section 3). Tammetta's work is distinguished from that of others in having been published[16][18][19] in a leading international science journal.

Of note, it's understood the Independent Monitoring Committee for the Springvale mine has recently recommended the use of centreline piezometer data for the determination of the height of the drainage zone.

Ditton's equation includes an adjustment term intended to accommodate local variations in overlying geology through 'back analysis'. Discussed within, the problematic nature of the equations underpinning database are such that the term amounts to a meaningless 'fudge factor'.

A notable finding[16] of Tammetta's work is that a knowledge of longwall extraction width and height and mining depth is sufficient to estimate the height of the drainage zone to within 10% of the height obtained from piezometer data, across a variety of rock types comprised of "*claystones, coarse-to-fine sandstones (lithic and quartzose), and limestones, in widely varying strengths, grain sizes, compositions, layer thicknesses, and recurrence patterns*". An adjustment term is not needed.

The letter to the Minister included an application of the Tammetta equation that found that the drainage zone would intersect the surface above the approved and planned mining in Area 3B of the Dendrobium mine. Concern was expressed that this possibility was not made known to the agencies and public prior to the approval of the mining currently underway at this mine (see Section 19). The Dendrobium mine is located in a Schedule 1 Special Area of the drinking water catchment for Greater Sydney and the Illawarra known as the Metropolitan Special Area.

There may be significant consequences if the drainage zone approaches or reaches the surface above a coal extraction, including impacts to watercourses and swamps and loss of runoff. Short of a significant direct fracture connection between a water storage reservoir or a watercourse and underlying mine workings, the intersection of the drainage zone with the surface would be the worst mining impact for a water catchment.

The letter sent to the NSW Planning Minister in July 2015 prompted the Minister to request a site inspection of the Dendrobium mine. Accordingly, Government agencies and departments visited parts of Area 3B on the 8th September 2015. A Department of Planning report[20] on the inspection was released the day before the department closed for Christmas in December 2015. In noting aspects of the NPAs concerns the report provided a commitment to undertake a review of the databases underpinning the Ditton and Tammetta equations. Significant flaws in this report are noted in Section 23.

In April 2016 the Department of Planning commissioned consultants PSM to undertake the database review and its report is expected to be released in the very near future. A database review was one of a number of recommendations included in the letter sent to the Planning Minister in July 2015. Included was a recommendation to either reduce the extraction height approved for Dendrobium Area 3B or halt the mining pending a review by the PAC. In the year since the letter was sent to the Minister no changes to the Area 3B mining have been required and the plans for the second set of five longwalls, currently being reviewed by the Department of Planning, retain the exceptionally aggressive nature of the first set.

The longwalls of Dendrobium Area 3B are the widest currently being extracted beneath the Special Areas and appear to be wider than most if not all previously extracted long wall series. In combination with an approved extraction height of 4.6 metres, significantly higher than past extractions, the Area 3B longwall extractions appear to be the most aggressive longwalls ever approved in the Schedule 1 Special Areas of Sydney’s drinking water catchment and among the most aggressive anywhere in NSW. The Departments highly controversial approval of the mining currently underway in Area 3B is discussed in Section 19.

Further review of the publically available information has strengthened and deepened the concerns raised on behalf of the NPA in 2015. This report revises and expands on the letter and attachment sent to the NSW Planning Minister in July 2015 and includes consideration of groundwater impact assessments provided by consultants HydroSimulations. It would appear that these assessments are deeply flawed in failing to adequately take into account the considerable difference between horizontal and vertical conductivities in the strata of the Southern Coalfield. Compounding this concern, recent assessments by HydroSimulations are underpinned by the use of Ditton’s equation.

Much of this report is focussed in groundwater impact assessments for the Dendrobium mine, particularly assessments for Area 3B of the mine. In large part this is because it would appear to be the only coal mine in NSW where assessments have been made using both the Ditton equation (HydroSimulations) and the Tammetta equation (Coffey Geotechnics).The Dendrobium mine provides a direct comparison of the suitability of these equations. HydroSimulations argue that bore data from the Dendrobium mine finds in favour of the Ditton equation and contradicts the Tammetta equation. This does not appear to be the case however.

2.2 The drainage zone, Ditton, Tammetta and Dendrobium

A credible assessment of groundwater impacts arising from a coal extraction requires a reliable knowledge of the height of the zone formed over the extraction where water is not retained to any measurable extent. Unable to retain water to any significant extent, with water draining towards the mine below, this zone is referred to as the drainage zone, desaturated or depressurised zone depending on the context.[3], [16], [18], [19] Tammetta finds[16] that this zone coincides with the collapsed zone. Tammetta identifies boundary of the collapsed zone as the point at which extensometer data identifies a change from small to significant downward movement of strata towards an extraction; see Section 7.

As noted above, Tammetta appears to have been the first to explicitly recognise that the height of the drainage zone is best determined using data from nested piezometers in bores that directly penetrate the drainage zone over the centreline of a coal extraction. Data from piezometers in off-centreline bores would additionally require knowledge of the drainage zone profile in order to determine the peak height of the zone. Piezometer bores that do not penetrate the drainage zone, or that do penetrate but lack an instrument within the zone, cannot provide direct insight into the height of the drainage zone.

Tammetta provides[2] a summary of the current understanding of the caving and collapse process that occurs in the strata above a coal extraction. Involving the formation of ill-fitting and fractured spalls (see Fig. 4), the process is quasi-discrete with variable intervals between events:

> "*At some mines, the first caving event may occur when the distance of advance is comparable to the panel width (depending on structural features and rock strength). The first collapsed block frequently has a pseudo conical shape. The shapes of subsequent collapsed blocks are concave-down spalls whose upper surfaces resemble a part of a pseudo cone and whose lower surfaces have the shape of the upper surface of a preceding block.*"

And

> "*the collapse process is not just dimensionally-based (that is, according to void size), but that part of the process is time-dependent (that is, there occurs a gradual weakening or relaxation of strata prior to a collapse)*"

Unusual horizontal stress conditions can delay the collapse process (see Sections 10 and 16). Tammetta's summary[2] indicates that as an extraction progresses, the height of the collapsed zone and its influence increases as spalls sequentially separate and move toward the caved zone in discrete events (see Fig. 4(a)). Piezometers in a nearby (not overhead) bore will respond as the collapsed zone and its hydrological influence approaches a corresponding height above the extraction. The rise in the height of the hydrological influence of the collapse zone flattens out as the zone approaches and attains its full height.

Two recent reports[13], [21] provide related summaries of several drainage zone height estimation methods developed and used in NSW over the past two or more decades. Of these methods, as mentioned, that of Tammetta is distinguished in having been published[16] in a peer reviewed science journal of high international standing. The method of Ditton and collaborator Dr Noel Merrick has been presented[22] at the 2014 Australian Earth Sciences Convention, while the others are provided in consultant’s reports or reports for projects funded by the Australian Coal Association. These industry funded projects and associated reports are not subject to the rigorous independent scrutiny of papers published in high quality international science journals; nor are conference abstracts and presentations. Merrick is the founder of HydroSimulations, which formerly traded as Heritage computing.

Tammetta developed his equation as part of a 2012 Coffey Geotechnics groundwater impact assessment[3] for ten longwall extractions then being proposed for Area 3B of the Dendrobium coal mine. The Area 3B groundwater impact assessment, and its height estimation method, was rejected in late 2012 by then mine owner BHP-Billiton. A scientific basis was not and has not been provided for this rejection. The assessment was provided to the mining company in two parts; an initial assessment in October 2012 and a revised assessment in November 2012. The November report provided a predictive assessment of impacts arising from extractions with a width of 305 metres and cutting height of 4.5 metres.

The geometry of the then proposed mining is slightly different in having an extraction height of 4.6 metres. The first five of the ten proposed longwalls were approved in controversial circumstances (see Section 19) by the NSW Department of Planning in February 2013. The fourth of the five currently approved, Longwall 12, is currently being mined. The Department of Planning is currently assessing plans for the second set of longwalls, Longwalls 14 to 18.

Having been rejected by BHP Billiton, the key Coffey groundwater impact assessment of November 2012 was not and has not since been made publically available. A 2015 request for a copy of the report made on behalf of the NPA has had no response and a more recent request made by the Department of Planning has bene refused by the mine operator. In responding to the Department’s request the mining operator provided a November 2012 data analysis report that partnered the November 2012 Coffey groundwater impact assessment.

The data analysis report confirmed that the 2012 groundwater impact assessment, undertaken for Coffey by Tammetta, had found that the drainage zone would intersect the surface above the then proposed mining (see Fig. 23). As noted above, the NPA suggested this possibility in its July 2015 letter to the NSW Planning Minister.

The Tammetta equation was replaced with an earlier version of Ditton’s equation in a March 2014 assessment[23] by HydroSimulations that the Dendrobium mine operators commissioned as a replacement for the Coffey assessments they’d rejected in 2012. The equation presented at the 2014 Australian Earth Sciences Convention is a revision of that used for the March 2014 HydroSimulations groundwater impact assessment. This revised method is used for an October 2015 HydroSimulations assessment[21] of the height of connected fracturing above the Dendrobium extractions and a March 2016 revision[24] of the March 2014 HydroSimulations groundwater assessment for Dendrobium.

The Ditton and Tammetta equations are similar in being empirically determined from data provided by instruments in bores over and, for the Ditton equation, in the vicinity of coal extractions (see Section 3). Both the Ditton and the Tammetta equations provide drainage height estimates based on extraction width, extraction height (thickness) and depth of cover. Though they should then be much the same, the drainage zone height estimates provided by the Tammetta equation for the 2012 Coffey assessment for Dendrobium are very different to those provided by the Ditton equation for the 2014 HydroSimulations assessment for Dendrobium(see Figs. 5, 6 and 7). Discussed in Section 3, this disagreement reflects differences in the databases used to obtain these equations.

Of note, the empirically derived Ditton and Tammetta equations provide an estimate of the most likely height of the drainage zone, which corresponds to a mean height estimate. Ditton additionally provides an expression to estimate a 95% confidence limit height, which is denoted as A95. This is a calculated height for which, according to Ditton, there would only be a 5% chance of the measured height being greater than estimated. Implausibly, while the additional term needed to calculate an A95 estimate depends on extraction width and depth of cover, it has no dependence on extraction height.

The comparison and assessment of the database underpinning the Tammetta equation and that underpinning Ditton’s equations given within is hindered by lack of ready access to the source data and information, some of which is retained by mining companies, used to populates these databases. Tammetta’s three Groundwater publications provide clarifying information in the associated Supplementary Material. This material states the nature of the data used, piezometer or extensometer, and whether the data was obtained from instruments in centreline bore, side-panel bores or off-panel bores (see Fig. 3 below). This information is not provided with the publically available information for the Ditton database and Ditton was unable[25] to provide clarification in responding to a 2015 query regarding the makeup of his database. There is however sufficient information available elsewhere to be able to deduce the nature of some of the content of the Ditton database. This information suggests that, as noted above, at least some of the database content is ill-suited to its intended purpose and that the database is further compromised by errors and misinterpretations. Examples are discussed in Sections 6 and Sections 8 to 12.

2.3 Dendrobium as a test case for the Ditton and Tammetta equations

The Dendrobium mine appears to be the only mine in NSW where groundwater assessments have been undertaken using both the Ditton and the Tammetta equations. HydroSimulations used the Ditton equation for their 2014 and 2016 assessments and the 2012 Coffey assessment used the Tammetta equation. The mine has 10 centreline or near centreline bores with three or more piezometers and of these only two, in combination, have provided before and after undermining data. The others have either failed as the longwall face approached or have yet to be undermined. Of significance, it would appear that piezometer bores sunk over longwalls in the US are more likely to survive being undermined.

Discussed in Sections 15.1.14, 16.2 and 16.7, Dendrobium bores S2192 and S2220 are the two centreline nested piezometer bores that, taken together, provide before and after undermining piezometer data. The two bores are in effect ‘twins’ in hosting the same number of instruments at the same depths below the surface at essentially the same location over eastern quarter of Dendrobium Longwall 9. Unfortunately, as discussed in Section 16, the data have not provided a conclusive measure of the height of the drainage zone over Longwall 9. This appears likely to be a consequence of unusual horizontal stress conditions across the strata over the eastern part of the extraction. The high stress may explain the unusual survival of the S2192 instruments as the longwall face approached and passed beneath.

The six piezometers in pre-mining bore S2192 nonetheless failed as the longwall face approached and passed below. Masked by compression effects as the subsidence trough approached, their data unfortunately provide limited insight into the height of the Longwall 9 drainage zone (Section 15.1.14).

Six instruments were installed at the same depths in nearby bore S2220 as part of a project to determine the height of the drainage zone (Section 16). Installed in October 2014, some four months after the completion of Longwall 9 and a year following the passage of the longwall below S2192, the lower three S2220 piezometers failed before data recording commenced in November 2014. The failure was a consequence of ongoing development of the collapsed zone; the high stress noted above seems likely to be have delayed the formation of the collapsed zone. Data were only collected from the remaining three instruments only until February 2015, a period of just 15 weeks. The circumstances suggest the data collection period was terminated by instrument failure, however the mining company has not responded to requests for clarification. Whatever the reason, the instrument loss and limited data recording period preclude a reliable direct determination of the Longwall 9 drainage zone.

Though the data from S2192 and S2220 do not provide a reliable drainage zone height measure, the Dendrobium mine has a notably extensive network of piezometer bores that offer an indirect means of evaluating the relative suitability of the Tammetta and Ditton equations, and their respective underpinning databases.

The response of a piezometer laterally located beyond the depressurised zone formed above an extraction and at depth equivalent or greater than that of the peak of that desaturated zone, will primarily reflect a complex three dimensional convolution of the horizontal hydraulic conductivity profile over the saturated path between the piezometer and the depressurised zone, the pressure gradient over that path and the slope or ‘dip’ of the path (with respect to a horizontal plane).

As a consequence the drainage zone height information provided by a piezometer in a bore located some distance laterally beyond the drainage zone over an extraction is less readily and reliably interpreted than that from a bore that directly penetrates this zone. The drainage zone height information provided by a piezometer will deteriorate with distance from the zone, to an extent and in a manner determined by local hydrogeological circumstances. Figure 3(a) depicts an ‘off-panel’ piezometer bore some distance from an extraction that has an adjoining extraction on the opposite side, while Figure 3(b) depicts a bore over the pillars adjacent to an extraction.

Depending on the local hydrogeological circumstances, nested piezometers in bores that do not penetrate the drainage zone (see Figs. 3 (a) and (b)) may nonetheless provide indirect insight into the height of the drainage zone. This possibility is suggested by the one to two or more orders of magnitude difference between vertical and horizontal hydraulic conductivities (see Section 1). The rate of change of hydraulic pressure (measured as the pressure ‘head’ in metres) measured by a piezometer at a given distance from an abrupt change in pressure, as occurs with the creation of the void and depressurised zone with coal extraction, is determined by the hydraulic diffusivity.

The hydraulic diffusivity is determined by hydraulic conductivity and, accordingly, horizontal diffusivity maybe one to two or more orders or magnitude greater than vertical diffusivity (see

Table 1 below). As a consequence, depending on the local hydrogeological circumstances, the rate of pressure change at a given distance from the source of the pressure change, will be considerably greater if the change is transmitted horizontally than if transmitted vertically.

For the simple one dimensional case, as an illustration of the pressure head change dependence on diffusivity, Figure 1 below graphs pressure head with respect to time for an initial pressure head of 150 metres at a distance (vertical or horizontal) of 250 metres from a location where the pressure head has fallen to zero, for hydraulic diffusivities of 0.0001, 0.001, 0.01 and 0.1 m^2s^{-1}. As noted in Section 1, the vertical diffusivity of sandstone is typically 0.001 m^2s^{-1}. Of note, in contrast to those of the Coffey assessment, the diffusivities obtained from the March 2016 HydroSimulations groundwater assessment are generally significantly smaller than would be expected and smaller than obtained from the Coffey assessment (Table 2 provides a comparison). This is most notably so for the upper Bulgo Sandstone, for which the HydroSimulations vertical diffusivity is $1.29x10^{-5}$ m^2s^{-1}, which would appear to be more typical of shale than sandstone.[10] The difference stems from the conductivities used by the authors; their specific storages are the same. Tammetta's conductivities were obtained by calibration against field data.

The rate of pressure head change may then give an indication of the vertical placement of a piezometer with respect to the height of the drainage zone. In the absence of unusual conditions, a piezometer vertically ‘in-line’ with a nearby drainage zone would be expected to report a significantly greater rate of pressure change than an instrument at the same horizontal distance but above the drainage zone. Section 15 considers the piezometer information provided in the groundwater impact assessments for the end of panel reports for Dendrobium Longwalls 3 to 11 and the 2012, November 2012 Coffey data analysis report for Dendrobium, March 2014 and March 2016 HydroSimulations Area 3B groundwater impact assessments and the March 2015 Parsons Brinckerhoff and October 2015 HydroSimulations height of fracture reports for Area 3B in this context.

HydroSimulations argue in their assessments for the Longwall 9 and 10 end of panel reports and in their March 2014 and October 2015 assessments, that the Dendrobium piezometer evidence favours the Ditton equation. Summarised in Table 4, the review below of information from 21 Dendrobium piezometer bores in Section 15.1 suggests that this is not the case. As noted above, it would appear that the assessments provided by HydroSimulations have not adequately taken into account the one to two order of magnitude difference between the vertical and horizontal hydraulic conductivities of the strata above the coal seams of the Southern Coalfield. Additionally, in arguing that the Dendrobium piezometer data contradict the Tammetta equation, HydroSimulations appear to misunderstand and/or misrepresent Tammetta.

Determining the suitability of the two alternative and, in effect, competing equations and databases has significant implications that extend beyond the Dendrobium mine. The revised form of the equation used the 2014 Dendrobium groundwater impact assessment has been used for other NSW mining project assessments, such as, Springvale[26], Moolarben[27] and Narrabri[28], and forms the basis of groundwater impact advice[29], [30] provided to Adani and the Queensland Land Court regarding the Carmichael proposal.

Concerns regarding related aspects of the modelling undertaken for Dendrobium are also discussed below and these concerns may also have relevance elsewhere.

3. Comparing apples with apples – the Ditton and Tammetta equations

Coffey Geotechnics hydrologist Paul Tammetta was evidently the first to explicitly recognise[3], [16] that the drainage zone height is most reliably and directly determined from data returned from a sting of piezometers (water pressure instruments) installed in a bore located on the centreline of the surface projection of an extraction. Given no need in the context of a groundwater impact assessment, Tammetta does not further seek to characterise fracturing within the drainage zone or differentiate zone of fractures. He observes "*Transformation of borehole fracture data to reliable hydraulic conductivity estimates is known to be extremely difficult, even when borehole imaging data are available*."[18]

As noted in Section 2, Tammetta finds[16] that the drainage zone coincides with the collapsed zone - the zone of overlying strata that moves markedly towards the void formed by coal extraction (see Figs 3 and 4). He identifies the transition to significant downward movement as the point of slope change in a plot of extensometer displacement with respect to depth below ground (Figure 2 in [16]).

Extensometer data, such as that highlighted by Tammetta, indicate that the profile of the collapsed zone approximates that of a concave or 'upside down' parabola centred over the longwall and 'sitting' within or over the coal pillars that form the sides of the extraction and support the overlying strata (see Fig. 2).[2], [16], [31], [32] The work of Gale[33], [34] and that of Holla and Barclay[35] finds no significant lateral extension beyond the pillars. Gale comments "*The zones of significantly enhanced conductivity about a longwall panel are contained inside the panel, and slope inward to the panel*".[34] That is, the collapsed zone and, accordingly, the drainage zone does not extend significantly beyond the sides of an isolated longwall extraction.

Reliable knowledge of the likely vertical extent of the drainage zone is essential in predicting and assessing mine inflows, the potential for associated surface water impacts and loss of stream flow, runoff, swamp and biodiversity. This is, in effect, pointed out by Merrick in the context of Area 3B of the Dendrobium mine: "*Simulated future Dendrobium mine inflows are highly sensitive to the assumptions made regarding the height of the fractured zone above longwalls*".[23] Merrick is the director and founding hydrogeologist for Heritage Computing, which now trades as HydroSimulations.

The quote above is from a March 2014 HydroSimulations groundwater impact assessment for Dendrobium Area 3B. As noted in the introduction, this assessment replaced October and November 2012 assessments[3], [36] undertaken by Tammetta on behalf of consultancy Coffey Geotechnics, who at that time had been engaged by then mine owners BHP-Billiton to provide a groundwater impact assessment for mining planned for Area 3B of the Dendrobium mine. BHP-Billiton rejected both Coffey assessments on receiving the revised assessment of November 2012. Not publically available, the revised assessment will have found that the drainage zone reached the surface above parts of completed extractions and most of those planned (see Figs. 4(c), 21 and 23).

In the above quote from 2014 Merrick refers to "*the fractured zone*" and its relationship to mine inflows. In contrast, in focussing on determining the drainage zone height from piezometer data, Tammetta's hydrological approach avoids the complication and potential confusion that may arise in attempting to identifying zones of varying degrees and distributions of fracture intensity and connectivity above an extraction.

Merrick collaborates with engineer Steven Ditton, who provides consultancy services as Ditton Geotechnical Services Pty Ltd and provided the September 2014 Springvale subsurface fracture zone assessment.[26] In undertaking the Springvale assessment, Ditton used a pair of equations[22] he'd empirically determined to predictively estimate the height of the zone of connected fractures formed above a coal extraction (see Sections 5, 6 and 9). The assessment includes a detailed account of the equations and some of the underpinning data. An earlier formulation was used for the March 2014 Dendrobium assessment and this form appears to have been introduced for an August 2013 assessment[37] for the West Wallsend coal mine. HydroSimulations have suggested[24] the equations used for Springvale were introduced in 2012, but this does not appear to be the case.

In contrast to Tammetta's hydrological approach, Ditton's approach is fundamentally geotechnical, stemming from his work on subsidence assessment and prediction.[38] Ditton refers to the zone of connected fractures formed over a coal extraction as the A zone and, in principle, this zone should correspond to the drainage zone. Ditton characterises[26] the A zone as "*the zone of cracking above a longwall panel that is likely to result in a direct flow-path or hydraulic connection to the workings*" (see Section 5).

The equations used by Ditton in September 2014 are very similar in form to the equation introduced by Tammetta in the October 2012 Dendrobium Area 3B assessment[3] to predictively estimate the height of the drainage zone above the longwalls of the Dendrobium mine.

Both Tammetta and Ditton used standard mathematical methods (regression analysis) to 'fit' a small number of parameters to a set of measurements from instruments installed in bores used for monitoring and assessing coal mining impacts. That is, the equations used for the October and November 2012 Dendrobium Area 3B groundwater assessments from Coffey, the March 2014 Dendrobium Area 3B groundwater assessment from HydroSimulations and the September 2014 Springvale fracture zone assessment from Ditton Geotechnics were derived empirically.

Ditton adopted an empirical approach after being unable to obtain a satisfactory equation from 'first principles' conceptual modelling. This approach had proved too cumbersome and was abandoned with Ditton noting "*difficulties involved with using analytical or numerical techniques v. empirical methods*".[26], [38] The determination of the empirical equations presented in the September 2014 Springvale fracture zone assessment is given in the context of dimensionless analysis. Reflecting this, the equations are referred to by the author as Pi-Term equations. Puzzlingly, the Springvale account does not acknowledge or recognise Tammetta's work. Ditton offers two empirically derived equations for the calculation of the A zone height; one is referred to as the geometry equation and the other as the geology equation (see Section 5).

The great benefit of an empirical approach is that the determination of the equation is independent of models or theories that describe, conceptually and/or mathematically, the processes that caused or gave rise to the measurement data. That is, an equation obtained in this manner amounts to a 'theory independent' representation of the data. If the data is appropriate, reliably measured and representative of processes and conditions found elsewhere, then the equation has the potential to 'predict' measurements obtained elsewhere.

Both Tammetta's and Ditton's equations use mining depth, extraction width and extraction thickness or height as parameters to be fit to data. The Ditton equation used in the August 2013 West Wallsend assessment and the March 2014 Dendrobium assessment differs from the equations used for the September 2014 Springvale assessment in having an additional term referred to as the caving angle or break angle.[23], [26], [38] Ditton had recognised[26], presumably after March 2014, that use of the break angle was problematic and was itself dependent on mining depth, extraction width and extraction height.

Ditton and Merrick presented the revised form of the Ditton equations at the July 2014 Australian Earth Sciences Convention 2014; the presentation does not appear to be publically available. The revised geology equation was used by HydroSimulations in an October 2015 height of connected fracturing report[21] for the Dendrobium mine and a March 2016 revision[24] of their March 2014 groundwater assessment for Dendrobium.

Given the 2012 Tammetta equation and the 2014 Ditton equation use the same parameters and were empirically determined in the same manner, they should give similar height estimates. That they don't (see Figs. 5-7) is because the parameters have been 'calibrated' or fit to different data sets. Careful attention appears to have been given to the use of appropriate data in one case, but evidently not the other (see Sections 6 to 12).

In holding no measureable water pressure, the drainage zone boundary is most reliably identified by centreline hydrological data provided by piezometers (water pressure sensors).[16] In contrast, transitions between zones of differing types and intensities of fracturing are less readily identified and depend on less accurate and precise geotechnical data.[2], [13], [16]

The height of the drainage zone is then currently best determined by 'nested' piezometers placed in a bore over the centre-line of a coal extraction to provide a measurement of water pressure at different depths below ground. The drainage zone boundary, or 'horizon', is located by identifying the deepest piezometer that reads a non-zero hydraulic head and the shallowest underlying piezometer that reads a zero or near zero water pressure (e.g. Mandalong Longwall 9; see Section 10) and/or fails as a consequence of the vertical collapse (i.e. not a shear impact) of the host strata at the location of the piezometer (e.g. Springvale Longwall 409; see Section 9).

In the absence of additional information, the accuracy and precision of drainage height estimates obtained from nested centre-panel bore piezometers is dictated by the distance between the shallowest instrument located within the drainage zone and the deepest above this zone. Provided the separation is not too great, if the deepest piezometer is located above the drainage zone boundary its height can be estimated by extrapolation (e.g. Elouera Longwall 7; see Sections 12 and 15.5 and Fig. 16).

Tammetta determined his empirical equation by exclusively using hydrological data (piezometer data) obtained on or close to the centreline above coal extractions. In contrast Ditton used a mixture of hydrological and geotechnical (extensometer) data from various locations above and around an extraction. Tammetta comments[16] on the relative utility of piezometer and extensometer data:

> "*Extensometer results have a larger scatter than hydraulic head results, because of the more chaotic nature of seismic energy release and the disproportionate effects of localized, unrepresentative defects or structural features*"

Compounding the relative limitations of extensometer data, Ditton's heterogeneous database appears to reflect errors and misinterpretations of piezometer and extensometer data. A notable example discussed in Section 9 is Ditton's assessment of piezometer and extensometer data from the Springvale mine. As a consequence of the flawed nature of the database, the A zone connected fracture height estimate provided by Ditton's equations is markedly lower than the drainage zone height estimate from Tammetta's equation (see Figs. 5 to 7).

4. Other methods

As mentioned in Section 2, two recent reports have summarised methods for predictively estimating the height of the collapsed zone and both include that of Tammetta and that of Ditton and Merrick. Both reports provide a comparison of the Ditton and Tammetta equations with respect to field data from the Dendrobium mine. The first report[13] is that of Parsons Brinkerhoff in March 2015, discussed in Section 16 below, while the second[21] is an October 2015 assessment from HydroSimulations that's discussed in Section 15. An earlier and more informative review is included in the 2010 NSW Planning Assessment Commission review report[39] for the then proposed Bulli Seam Operations (BSO) project, which sought to expand the Appin and West Cliff coal mines. The Dendrobium, Appin and West Cliff mines were owned by BHP Billiton until mid-2015, when the company demerged and ownership passed to spin-off company South32.

Ironically, the collapsed zone height estimation method utilised by consultants MSEC in undertaking assessment work for the BSO project provided height estimates of similar magnitude to that which would be returned by the Tammetta equation. Work by Gale and by Mills found a similar dependence of collapse and fracture height on width. For example in a 2008 report[34] on aquifer inflow above longwall panels Gale observes:

> "*Caving and cracked beam subsidence movements tend to occur up to a height of 1-1.7 times the panel width. Examples of this have been monitored by surface to seam extensometers (Mills and 0'Grady 1998, Holla and Armstrong 1986, Holla and Buizen 1991, Guo et al. 2005, Hatherley et al. 2003) and predicted to occur from computer models (Gale 2006). This indicates that cracking and deflection related to such caving and cracked beam subsidence could extend to the surface for panel widths greater than 0.75-1 times depth.*
>
> *Empirical data of mine subsidence indicates that significant subsidence movements tend to initiate at panel width to depth ratios in the range of 0.7-1. This is presented in Figure 13 which shows subsidence measurements relative to panel width to depth ratio. The inference on this data is that for panel widths less an approximately 0.7 times depth there is sufficient overburden thickness above the caved and cracked zone to span across the panel.*

The BSO PAC panel was critically sceptical of the MSEC method, which provided height estimates based on extraction width alone - as is the case for the 'rule of thumb' estimates from Gale and Mills. The BSO PAC panel points out that beyond the critical width, the width where the void spanning capacity of the overlying strata is exceeded, the extraction width would be expected to have little bearing on the height of the connected fracture zone. Under those circumstances the height of the connected fracture would then be controlled by the extraction height; the MSEC method did not include consideration of the cutting height.

The PAC panel accepted that fracturing might extend to at least a height equivalent to the extraction width, as suggested by MSEC, Gale and Mills, but doubted that this height corresponded to the height of connected fracturing “*The issue is the height of the connected fractured zone as opposed to the height of fracturing. It remains unresolved*.”[39] The observations made by Mills are based on extensometer measurements of significant downward movement and would then seem likely to correspond to a zone of significant connected fracturing.

Puzzlingly the PAC panel didn’t comment on the prospect of connected fracturing reaching the surface when the extraction width exceeded the critical width; see Fig. 4(c). Nor does the panel appear to recognise that the core concern is hydrological, not geotechnical, and best addressed with piezometers rather than extensometers. Tammetta appears to have been the first and, it seems, the only person to date to explicitly recognise that the primary concern is hydrological and that centre-panel piezometer data currently provide the best means of addressing the problem. Problems that may arise in the interpretation of off-panel piezometer data are evident in the assessments provided for the Dendrobium mine (discussed in Section 15)

The Parsons Brinckerhoff report lists five methods for estimating the connected fracture zone height, including the A zone height equations of Ditton and the collapsed zone height equation of Tammetta. The list also includes a relationship derived by the CSIRO in a 2007 assessment[40] of hydrological mining impacts at the Springvale colliery. Using a combination of hydraulic conductivity data for Longwall 409 and computer simulation, the CSIRO study obtained a relationship dependent solely on cutting height. In being determined by cutting height alone, the relationship has limited utility and is only of relevance to the specific location from which the data were obtained. As discussed in Section 9, but not noted by Parsons Brinckerhoff, problems were encountered in collecting the conductivity data and the utility of the collected data was additionally compromised by the location of the bores.

5. The work of Ditton and Merrick

The equations used to estimate connected fracture zone heights for the March 2014 Dendrobium mine groundwater assessment[23] and used in the September 2014 fracture zone assessment for the Springvale mine extension[26] reflect a collaboration[22] between Ditton and Merrick. HydroSimulations have used Ditton’s equations for groundwater impact assessments in NSW, including the 2016 assessment for Dendrobium, and elsewhere.

Consistent with earlier work of others, Ditton refers to an extensively fractured and depressurised zone as the ‘A zone’ and characterises it as follows:

> “*Major vertical cracking due to bending that pass through strata units and allow a direct hydraulic connection to workings below. Full depressurisation of groundwater occurs in the Zone that may recover in the long term once mining is completed*.”

And

> “*Continuous sub-surface fracturing refers to the zone of cracking above a longwall panel that is likely to result in a direct flow-path or hydraulic connection to the workings. All groundwater (or surface waters) within this Zone would be expected to drain vertically into the mine workings goaf*.”

Of note, Ditton's suggestion of recovery in the quote above will refer to flooding of the mine over several decades.

Merrick similarly describes the A zone in the March 2014 groundwater assessment for the Dendrobium mine: "*The zone of desaturation is considered to occur in the connected cracking ('A') zone*".[23] In December 2014 advice to Adani for the Carmichael proposal he refers to the fracture zone as "*that part of the fractured zone that drains water freely to the mine void below*".[29]

Ditton describes a second zone above the A zone, the B zone, having comparatively minor and discontinuous vertical fractures and able to retain water, such that "*Only minor vertical permeability increases are expected in the B-Zone*".[26] In principle the A zone should correspond to Tammetta's drainage zone.

As mentioned above, the September 2014 Springvale subsurface fracture zone assessment[26] appears to have introduced the use of a pair of very similar equations to estimate the height of the A zone. These equations were empirically obtained by standard mathematical methods (regression analysis) used to 'fit' one or more parameters to a set of measurements of the property of interest.

Both equations have extraction width, height and depth below ground as parameters. One of the two equations has an additional term that Ditton presents as the "*effective strata unit thickness*" and is intended to accommodate instances where significant variations in geological circumstances occur with respect to the database used to obtain the equations. The two equations are accordingly referred to as the 'geometry equation' and the 'geology equation'.

In practice the additional term amounts to a 'fudge factor' or adjustment term used to provide a better fit between the estimate provided by the geometry only equation and a measurement at a particular site. This is recognised in Ditton' qualification of the term: "*the vagaries of the rock mass do not usually allow the strata unit thickness term to be assessed directly from borehole data without back analysis of overburden performance measurements"*.[26] Merrick comments[29] "*there is no easy way to estimate the effective beam thickness.*" The equation has limited predictive utility.

Table A6.4 of the Springvale fracture zone assessment report lists "*back analysed*" values - values retrospectively fitted to bore data. For example a value of 32 metres is set in order to provide a height estimate that matches data from a bore associated with Dendrobium Longwall 5 (see Sections 11 and 15; more recently a value of 30 has been used[21]). The nature of the data and location of the bore that provided the data against which the adjustment term was set at 32, such that the geology equation returns a height estimate matching that obtained from the bore data, is not provided in Ditton's report. Importantly, Longwall 5 does not have a suitable centre-panel bore. The data is most likely to be piezometer data and possible locations for bore the data are considered in Section 15.1.4. The interpretation of this data to provide a 'measured' A zone height against which to calibrate the adjustment term is likely to have been provided by Merrick. Clarification was sought from the consultant and the mining company but has not been provided.

In the absence of a measured height against which the adjustment term can be varied to provide a matching height estimate from the geology equation, Ditton recommends a minimum value for various coal fields in NSW in Table A6.3b of his Springvale report. For the Southern Coalfield Ditton suggests a value of 20 metres for mining depths to 350 metres and 40 metres for greater depths.

Figure 8 depicts changes in the Ditton's geology equation fracture zone (A zone) height estimate with varying adjustment parameter t’ for the mining parameters of Elouera Longwall 7. Data from piezometers installed in a centreline bore, DDH9, over this extraction indicate a drainage zone height of 186 metres (discussed in Section 12). A t’ value of 12.5 is needed in order for the Ditton’s geology equation to return a fracture zone height that matches the drainage zone height indicated by the centreline bore data. As Figure 9 indicates, there are no unusual geological features over this longwall panel. Geology does not provide an explanation for the low t’ value needed to match the piezometer data.

As noted above and discussed in Section 15, HydroSimulations use a t’ value of 30 in their most recent Dendrobium Area 3B modelling.[24] As Figure 10 indicates, the Elouera workings are immediately south of the Dendrobium mine; Dendrobium is in effect an extension of Elouera. Figure 10 also shows that the nephaline syenite intrusion evident in Figure 9 slightly protrudes into the south eastern corner of Area 3B to overlap very small parts of the eastern end of Dendrobium Area 3B Longwalls 16 and 17. Other than these small areas, there are no unusual geological features over the Area 3B longwalls.

Included in his database, Tammetta’s equation matches the height suggested by the Elouera Longwall 7 data without an adjustment parameter. Elouera Longwall 7 is discussed in more detail in Sections 12 and 15.5.

As Figure 5 indicates, Ditton’s ‘geometry’ equation[26] increasingly underestimates the drainage zone height as the observed height, determined from centre-panel piezometer data, increases. The largest deviation is for Longwall 409 of the Springvale mine. In order to return a fracture zone height matching the 258 metre drainage zone height indicated by the piezometer data from Longwall 409 (see Section 9 and Fig. 14), the t’ parameter of Ditton’s geology equation would need to be 7.8, using the mining geometry given by Tammetta.[16][41] Ditton recommends a minimum t’ of 40 for mining at the depth of Longwall 409. Ditton’s interpretation of the Springvale data is very different to that of Tammetta; the Springvale data are discussed in Section 9.

Figures 6 and 7 demonstrate that Ditton’s equations are notably insensitive to increasing longwall extraction width and height.

Also of note, as mentioned earlier, Ditton additionally provides an expression to estimate a 95% confidence limit height, denoted as A95. This is a calculated height for which, according to Ditton, there would only be a 5% chance of the measured height being greater than estimated. Implausibly, while Ditton’s equation for the A95 estimate depends on extraction width and depth of cover, it has no dependence on extraction height. HydroSimulations prefer to use the A95 estimate rather than the lower A50 estimate.

6. Ill-suited and misinterpreted data

As mentioned, Ditton and Merrick presented the equations used for the September 2014 Springvale at the July 2014 Australian Earth Sciences Convention. While the abstract is publically available[22], the presentation does not appear to be available. However Appendix 6 of the fracture zone assessment report[26] for the Springvale mine extension project provides some details of the determination of Ditton’s geometry and geology equations. The appendix includes a tabulated summary of the data used to calibrate the equations (Tables A6.5 and A6.6). Regrettably the tables don’t specify the types of instrument from which the data was obtained or its location with respect to the centreline of the extraction for which each summary is given. Mr Ditton was contacted for clarification, but he was unable to provide assistance.[25]

A crosscheck against relevant publically available reports finds that the data is a mix of piezometer and extensometer data (primarily piezometer) and that only a small number are centre-panel measurements; measurements from instruments installed over the centreline of an extraction.

The determination of Ditton’s empirical equations would then appear to be compromised in using a set of data that includes data obtained from instruments located to the side of a longwall extraction (side-panel data) and data obtained at a distance away from the longwall extraction (off-panel data). The database also appears to contain entries that reflect errors and misinterpretations.

The database includes an entry for Kemira Longwall 6 which does not appear to have a suitable bore. The Kemira Longwalls are further complicated in being some 30 metres below bord and pillar, with pillar extraction, workings in an overlying seam. The database includes a ‘measured’ A zone height for Springvale Longwall 409, obtained using nested piezometer data from a bore on the centreline of that longwall. However the data would appear to have been recorded during the passage of the adjacent Longwall 408 (see Section 9). Ditton’s assessment in not in accord with that of Tammetta and the hydrological zone of influence determined by the CSIRO. Ditton’s A-zone assessment also uses extensometer data that the CSIRO study concluded was unreliable. [16], [40] Springvale is discussed in more detail in Section 9.

The noteworthy case of Mandalong Longwall 9, which is of significant relevance to Dendrobium Longwall 9, is discussed in Section 10; Sections 15 and 16 include a discussion of Longwall 9 at the Dendrobium mine. Dendrobium Longwall 5 and Metropolitan Colliery Longwall 20 are respectively discussed in Sections 15 and 8 below. Further anomalies are noted in Section 7.

The response of a piezometer laterally located beyond the desaturated zone formed above an extraction and at a depth below ground equivalent or greater than that of the peak of that desaturated zone, will primarily reflect a complex three dimensional convolution of the horizontal hydraulic conductivity profile over the saturated path between the piezometer and the depressurised zone, the pressure gradient over that path and the slope or ‘dip’ of the path (with respect to a horizontal plane).

While off-panel piezometers in close proximity to an extraction may suggest the centre-panel height of the height of the drainage zone, depending on local hydrogeological circumstances, there is currently no scientific means of using the response of off-panel piezometers to robustly establish the centre-panel height of the drainage zone. Depending on the hydrogeological circumstances, the more distant the off-panel piezometer the weaker the information it might provide and the more vulnerable that information is to misinterpretation and misrepresentation.

As discussed in Section 15.1, the data provided by the piezometer network at the Dendrobium mine appears to have been misinterpreted and/or misrepresented. Data obtained from a bore that does not penetrate the drainage zone would then provide suitable content for a database used to empirically derive a relationship between mining parameters and the height of the drainage zone. In contrast to

Ditton, Tammetta is careful to separate centre-panel data from side and off-panel piezometer data (see Section 7).

As noted in Section 2, it's understood the Independent Monitoring Committee for the Springvale mine has recently recommended the use of centreline piezometer data for the determination of the height of the drainage zone. Centre-panel data are not immune to subjective interpretation, but the interpretation options are more sharply constrained and the most plausible interpretation more readily identified.

Ditton's equations have been derived by fitting extraction parameters to database content that includes data that do not directly represent the height of the drainage zone over a coal extraction void. It would appear that the majority of the data have been obtained from side-panel or off-panel instruments. That is, a significant amount of the data effectively being treated as if they were centre-panel measurements in Ditton's empirical equation determinations are instead interpretations of a mix of piezometer and extensometer data from off-centre panel instruments. Tammetta points out that extensometer data are less reliable (precise) than piezometer data.[16]

7. Tammetta's work

In undertaking the 2012 Dendrobium groundwater impact assessments on behalf of Coffey Geotechnics, part of a large international consultancy group, hydrologist Paul Tammetta empirically determined an equation to estimate the height of the drainage zone above the then proposed mining. Ditton subsequently used the same approach in obtaining the empirical equations he used for the September 2014 Springvale fracture zone report and used by HydroSimulations for the March 2016 groundwater assessment for Dendrobium Area 3B. The latter updated the March 2014 HydroSimulations assessment, which replaced the Coffey assessments following their 2012 rejection by BHP-Billiton.

In principle Ditton's and Tammetta empirical equations should produce essentially equivalent results. However the fracture zone height returned by Ditton's equations does not correspond to the drainage zone height returned by Tammetta's equation (see Figs. 5 to 7). This would appear to reflect Ditton's use of data ill-suited to characterising the extent of the drainage zone.

In contrast to Ditton, Tammetta used only centreline piezometer data to determine his equation; side-panel, off-panel or extensometer data were not used in empirically obtaining an equation to estimate the drainage zone height above a longwall extraction void. Tammetta instead used extensometer data to identify the collapsed zone, the zone of significant movement of overlying strata towards the void formed by coal extraction. Significantly, Tammetta finds[16] that the collapsed zone coincides with the drainage zone.

Consultants HydroSimulations have suggested[42] that Tammetta's equation determines the height of Ditton's B zone (see above). This is incorrect, as the following comment from the same consultants makes clear: "*The zone of desaturation is considered to occur in the connected cracking ('A') zone (Ditton, 2012).*" Tammetta's equation estimates the height of the desaturated zone - however, as noted, this does not correspond to the A zone height estimated by Ditton's equations.

Details of the databases used in Tammetta's work are provided in the Supplementary Material[41] that accompanies the October 2013 Groundwater publication[16] of the work that underpinned the

2012 Dendrobium area 3B assessments; assessments which were rejected by BHP-Billiton. In contrast to Ditton, Tammetta is rigorous in separating data types into five principal databases[41] :

(i) **S1**: Water level/pressure data from "ordinary" locations; the centreline of longwall extractions.

(ii) **S2**: Water level/pressure data from "special" locations; over (a) longwall pillars with an extraction on both sides, (b) longwall pillars with an extraction on one side, (c) centre panel bord and pillar operations with pillar extraction and (d) centre panel piezometer data from under a flowing river or a saturated high-permeability alluvial body.

(iii) **S3**: Ground deformations data (extensometer and reflectometry).

(iv) **S4**: Supplementary water level/pressure data providing an estimate of the minimum likely height of the drainage zone.

(v) **S5**: Supplementary water level/pressure data providing an estimate of the maximum likely height of the drainage zone.

His empirical equation was obtained from the S1 database.

A of the Tammetta and Ditton comparison finds the Ditton and Tammetta databases have entries for bore data from the former West Bellambi mine, now part of the Russell Vale mine. Tammetta uses data from a bore, WB17, just off centre over Longwall 501 for which the height of fracturing is reported to be between 85[43][44] and 153[45] metres above the mined seam. Ditton's database entry "*MW508*" seems likely to be referring to the same bore over Longwall 501; Longwall 508 does not appear to have a groundwater bore. Both the Ditton and Tammetta equations provide zone height estimates in accord with the bore data. Both databases include data for a bore over Longwall 10 of the Metropolitan Colliery and both equations are in accord with that data. Overlap and agreement between the two databases appears to be limited to these sites, for which the extraction dimensions ae modest.

Both Ditton's and Tammetta's databases have longwall sites from the Able, Appin and Wyee mines, But Tammetta finds the data suitable only for gauging either a lower or upper bound for the drainage zone at each site. Both have entries for the Springvale and Mandalong mines, but the database entries differ (see Sections 9 and 10).

Ditton's database does not include Elouera Longwall 7, which has a centreline piezometer bore. The Elouera data is discussed in Section 12, which includes illustrating how the drainage zone height is obtained from the piezometer data. The Tammetta equation is consistent with the piezometer data, whereas the Ditton equations are not.

Tammetta's work has been published in three Groundwater papers; one in October 2013[16], a second[18] in early 2015 and the third[19] in January of 2016. Groundwater is a highly regarded and peer reviewed science journal of international standing, published by the US National Ground Water Association. As noted, the data gathered and utilised by Tammetta are provided in the paper's Supplementary Material.

Of note, in their June 2014 subsidence assessment for the proposed expansion of the Russell Vale Colliery, consultants SCT use the Tammetta equation and describe the analysis behind the equation as "*very good work*".[46] In commenting on the groundwater assessment for Area 3B of the

Dendrobium mine in late 2012 the SCA, now a part of Water NSW, endorsed the Tammetta method in stating "*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*."[47] In short, Tammetta's work is of a high scientific calibre.

The Department of Planning engaged Tammetta to review the groundwater assessment for the proposed expansion of the Russell Vale Colliery. Referring[48] to him as "*The Department's surface water expert peer reviewer*", the Department however appears to have taken little heed of the comments and advice provided on the proponent's groundwater assessment and potential impacts arising from the mining.

The Department of Planning recently echoed[20] the assertion of some in the mining community in stating "*the height of the fractured zone cannot simply be predicted as a function of longwall panel geometry*". This statement effectively rejects Tammetta's demonstration, published in Groundwater, that a knowledge of longwall extraction width and height and mining depth is sufficient to estimate the height of the drainage zone to within 8%[49], across a variety of rock types comprised of "*claystones, coarse-to-fine sandstones (lithic and quartzose), and limestones, in widely varying strengths, grain sizes, compositions, layer thicknesses, and recurrence patterns*".[16] The stratigraphy above the mining in the Southern Coalfield is dominated by sandstone, with essentially the same repeat pattern (see Fig. 11).

Tammetta notes that super-strong dolerite sills in South Africa have an observed drainage zone height slightly lower than calculated using the equation[16][41][49], and comments "*Despite a thorough search of the literature, no other published data could be found to show significant deviations from the equation*".[49] Yet the Department again echoes some in the mining community in stating, without elaboration or example; "*In some circumstances, the stiff, competent nature of particular strata will lead to bridging across the panel*". Tammetta has addressed a similar comment from the mining community in a report commissioned by the Department.[49]

Tammetta developed and further established his equation using three different physical properties from two distinct global databases. Given the apparent strength if its underpinning, history suggests it's unlikely it will be refuted in a peer reviewed publication of good standing.

Refuting Tammetta's equation will require establishing that the underpinning data is flawed or the interpretation of that data is flawed and, to date, there has been no such demonstration. Off-the-record suggestions that piezometer data from the Springvale and Mandalong mines are not in accord with the equation have been addressed[49] by Tammetta. Springvale and Mandalong are discussed in Sections 9 and 10. Discussed in Sections 12 and 15.5, Ditton's equation is additionally not in accord with centreline piezometer data from Longwall 7 in the Elouera domain of what is the now the Wongawilli mine.

In June 2014 the Community Consultative Committee for the Tahmoor mine was advised[50] that measurements from a bore over the centre of Longwall 10 were in good agreement with the estimated drainage zone height returned by the Tammetta equation. The mine advised that further details will not be provided for at least a year, until the completion of the groundwater impact assessment for its proposed Tahmoor South project.[19] The project has since been abandoned and the mine is to be closed in 2019. Details of the drainage zone height measurements have not been released.

The quality, originality, effectiveness and significance of Tammetta's simplifying approach is recognised in its publication in three Groundwater publications. In the absence of refutation and or relegation in a peer reviewed science journal of good standing, the Tammetta equation would appear to provide the best means of estimating the height of the drainage zone above an extraction void. The equation may be further refined as additional data becomes available - for example there is an absence of suitable data for overlapping double or triple seam extractions, such as those of Russell Vale.

The Figure 5 comparison of the estimates provided by the Tammetta and Ditton equations indicates that for other than cases with modest mining parameters, the application of the Ditton's empirical equations will underestimate the height of the drainage zone obtained from centre-panel piezometer data.

8. Metropolitan Colliery Longwall 20

Relative to the notably aggressive longwalls of Dendrobium Area 3B, the longwalls of the Metropolitan Colliery are conservative and will have relatively low drainage zone heights. As noted in Section 7 and as Figure 5 indicates, the A-zone height estimates from the Ditton equations and the drainage height estimate of the Tammetta equation are similar when the longwall dimensions are modest. Nonetheless, Ditton's tabulation of a "*measured*" A zone height for Metropolitan Longwall 20 provides an example of the misinterpretation of unsuitable data.

The nearest nested piezometer bore to Longwall 20, containing 10 piezometers, is located over the centre of Longwall 22B.[51] Longwalls 20 to 22 have void widths of 163 metres and pillar widths of 40 metres and 50 metres. The distance from the bore to the centre of Longwall 20 is then approximately 410 metres.

The height of the drainage zone over Longwall 20 cannot be reliably estimated at that distance. Chart 16 in the 2013 Annual Review for the mine graphs the measurements from the 10 piezometers from March 2009 to December 2013 (see Fig. 12 below). This period includes the extraction of Longwalls 20, 21, 22A and 22B. The chart marks the point at which the extractions of Longwalls 20 and 21 pass the line of shortest distance to the bore. The disjointed nature of the readings associated with the passage of Longwall 20 would appear to preclude identification of the height of the drainage zone. Nonetheless Ditton tabulates[26] an interpreted height of 100 metres.

The edge of Longwall 21 is approximately 130 metres from the bore and the centre is about 212 metres away. Reflecting ease of flow through bedding planes relative to joints[52], in the absence of an underlying extraction, the permeability of strata to water is at least ten times greater horizontally than it is vertically (see the Preliminary Comments).[52][18] The pressure drop caused by the formation of the drainage zone would accordingly be expected to propagate with greater speed and effect horizontally than vertically, provided the intervening rock has not been impacted by mining or does not have an anomalous geological structure.

Accordingly, provided the distance between an off-panel bore and the extraction of interest isn't too great, the piezometers in a given bore that are 'inline' with the vertical extent of the drainage zone formed by the extraction would be expected to respond more rapidly than those at a greater height than the peak of the drainage zone. The marked and essentially simultaneous response (Fig. 12) of the Longwall 22B piezometers to the extraction of Longwall 21 then suggests the drainage zone reached somewhere between the height of piezometers 5 at 345 metres below the surface and 6 at 179 metres below the surface; somewhere between 140 and 300 metres above Longwall 21.

Figure 12 then provides an example of the differing responses of off-panel piezometers located above and below, or in line, with the drainage zone of an extraction.

Ditton's geometry only equation estimates an A zone fracture height of 115 metres for Longwall 21 and, with an adjustment parameter of 32 (see below) his geology equation returns an estimate of 141 metres for this extraction. The Tammetta equation provides an estimate of 184 metres. The available data weakly suggest that the Tammetta equation provides a more reliable height estimate than the Ditton geology equation.

9. Springvale Longwalls 409 and 411

9.1 Springvale piezometer data – Longwall 409

Both Tammetta and Ditton use piezometer data from a 2007 CSIRO study[40] of mining impacts at the Springvale Colliery in obtaining their respective equations. Highlighting their different approaches, they find the Springvale instruments provide very different drainage zone heights estimates.

Springvale Longwall 409 has a centre-panel bore, identified as SPR31 and hosting eight vibrating wire piezometers, for Ditton's database[26] lists a measured A zone height of 133 metres and for which Tammetta records[41] a drainage zone height of 258 metres.

Tammetta's interpretation of the Springvale piezometer data is represented in Figure 7 of his 2013 Groundwater publication (provided below as Fig. 13). In responding[49] to off-the-record criticism of the underpinning of his equation he points out agreement between his interpretation of the Springvale data and that of the CSIRO.

Puzzlingly, it appears that Ditton's A-zone height for Springvale Longwall 409 was obtained using measurements recorded before it was extracted. The Springvale fracture zone assessment report[26] notes the data was recorded from the 2nd to the 5th of December 2003, whereas Longwall 409 is reported[40] to have commenced on the17th of February 2004.

Further, the tabulation of 'before and after' extraction piezometer data given in Ditton's Springvale fracture zone assessment report reflects the extraction of the adjacent Longwall 408, not 409. This is evident on comparing the pressure head data given Table 4A of Ditton's report with the SPR31 hydrographs shown in Figure 38 of the 2007 CSIRO hydrogeological study[40] of longwall mining at Springvale and data in Table 13 of that report. The comparison shows that the 'after' pressure head data listed in Ditton's report corresponds to SPR31 data prior to the passage of Longwall 409. All but the near surface piezometer P8 fail during or shortly after the longwall machine passes below Longwall 409.

The failure of the SPR31 piezometers indicate that the collapsed zone extended to a height between piezometer P8 and P7, which were respectively placed at 90 and 173 metres below the surface. That is, for a seam depth of 384 metres, the drainage zone extends to between and 211 and 294 metres above the extraction. Presumably this observation provides the basis for Tammetta's database entry for Longwall 409. In contrast, the 133 metre fracture height given by Ditton is inconsistent with the drainage height indicated by the behaviour of the SPR31 piezometers.

The edge of Longwall 408 (LW408) is approximately 160 metres from the centre-panel bore over Longwall 409 (LW409) and the centre-panel to centre panel distance is approximately 300 metres. Ditton evidently uses the magnitude of the change in the water pressure measurements reported by the piezometers in the centreline over Longwall409 to conclude that the drainage zone height extends to a height equivalent to somewhere between the height of piezometers P6 and P7 in the piezometer bore. That is, a mining depth of 384 metres, between 91 and 211 metres above Longwall 408.

In using the magnitude of the pressure change as the guide Ditton overlooks the lower pre-mining' pressure of piezometer P7 and that piezometers P2 to P7 all drop to essentially the same pressures (tabulated as pressure head in metres) after the passage of Longwall 408. The average water level of these piezometers is 65 metres with a standard deviation of 6 metres and all show rapid pressure drops[26] in response to the longwall extractions. The data is then more consistent with the drainage height being somewhere between that of piezometers P7 and P8; between 211 and 294 metres above the extraction, a mining depth of 384 metres.

The 2007 CSIRO assessment[40] of SPR31 data during the mining of Longwall 409 found that the "*zone of influence*" of the extraction extended to 250 metres above the extraction (see Fig 14). The zone of influence was determined by monitoring the bore's piezometers as the longwall machine approached and plotting the distance at which a piezometer at a given height first registered a clear response (pressure head loss of 5 metres[53]) to the approaching drainage zone.

Very large differences between horizontal and vertical hydraulic conductivities mean that, at a given height at or below the peak of the collapse zone, the expansion of the hydrological influence of an extraction is largely horizontal over the time scale of a typical longwall panel extraction. Horizontal conductivity is typically ten to 100 times greater than vertical conductivity in strata that have not been impacted by mining and, outside the collapse zone. As a consequence of horizontal shear (see Fig. 2) impacts this difference is increased markedly by mining.

That the graphs in Figure 14 approach a plateau with decreasing distance to the longwall face indicates that the piezometer response primarily reflects horizontal propagation of depressurisation in line with the developing and approaching collapsed zone. Though much slower, vertical diffusion of pressure loss above the peak of the collapsed zone would preclude complete plateauing of the response - until depressurisation reached the surface.

As noted in the introduction, Tammetta's summary[2] of the collapse process indicates that as an extraction progresses, the height of the collapse zone and its influence increases as spalls sequentially collapse in discrete events toward the caved zone (see Fig. 4(a)). Piezometers in a nearby (not overhead) bore will sequentially respond as the collapsed zone and its hydrological influence approaches a corresponding height above the extraction. The rise in the height of the hydrological influence of the collapse zone flattens out as the zone approaches and attains its full height (geological circumstances may delay the growth of the collapse zone; see Sections 10 and 16). This is seen in Figures D (Figure 14 below), 17 and 62 in the CSIRO report.[40] The zone of influence graph from the centre-panel piezometer bore over Springvale Longwall 409 indicates a drainage zone height of 250 metres. The Tammetta equation estimates a height of 252 metres.

9.2 Springvale extensometer data – Longwall 411

Prior to extraction, a 20 anchor point extensometer was installed over Longwall 411 in a bore referred to as SPR40. The extensometer displacement graph shown in Figure 31 in the CSIRO assessment report indicates that when the longwall had passed 100 metres beyond the bore, the post-undermining change from small to rapidly increasing downward movement[16], [32] occurs at anchor point 13, positioned 250 metres above the longwall. With the mining 300 metres beyond the bore, the change from small to rapidly increasing downward movement occurs at anchor point 14, 262 metres above the longwall.

In contrast Ditton identifies the zone of significant downward movement and fracturing as commencing between extensometer anchor points 7 and 8 in SPR40. Table 3A in Ditton's report[26] shows the displacement of anchor point 8 had reached 1.04 metres by January 2008; nonetheless Ditton regards this point marking the uppermost extent of the A zone. Anchor point 7 has an even larger downward displacement of 2.8 metres and this point is included in Ditton's A zone.

In interpreting the piezometer data Ditton appears to overlook, or set aside, the CSIRO report caution that "*monitoring data from anchors 1 to 8 placed in borehole SPR40 close to the mining seam had to be discarded as the anchor readings indicated possible borehole damage and false readings*". The CSIRO report explains that after the longwall had passed the borehole position by some 30 metres all the anchors from 1 to 7 were displaced equally by 2.8 metres, possibly as a result of rock fall.

In Figure 4a of the 2014 Springvale fracture zone report, Ditton sets the A zone height at the height of anchor point 8, 139 metres above Longwall 411. The extensometer anchors over Longwall 411 that are within Ditton's A zone are those that appear to have been, implausibly, displaced downwards by at least 87% of the maximum mining height. As noted, the CISIRO team excludes these extensometer points as being not credible.

Overlooking the CSIRO caution, Ditton's assessment implausibly suggests downward strata movement of at least 1.4 metres, or 43% of the mining height, defines the extent of the A zone - the zone of connected fractures that provide "*a direct hydraulic connection to workings below*". In contrast Mills and O'Grady found in their extensometer study[32] at the Clarence Colliery that: "*The zone of movement extended through the overburden strata to a height of approximately 1.0-1.1 times the panel width.*". As noted in Sections 12 and 15.5, in assessing extensometer data at the Elouera mine (now part of Wongawilli) Mills likewise found that the zone of large downward movement above the longwall occurred to a height equivalent to the longwall width. Springvale Longwall 411 is 315 metres wide.

In Attachment A of the Springvale fracture zone assessment report Ditton defines the A zone as being characterised by vertical strains between -10 and 140 mm/m. Ditton's Figure 4c shows the strains at 250 metres above the Longwall 411 workings to be approximately 18 mm/m. Of note, this figure shows the strain measurements to be highly variable. The SPR40 data illustrate the caution given in the quote noted in point (viii) of Section 1:

> "*Extensometer results have a larger scatter than hydraulic head results, because of the more chaotic nature of seismic energy release and the disproportionate effects of localized, unrepresentative defects or structural features*."[16]

Of note, in a 2008 assessment and review[34] Gale finds the following:

> "*Overall, the data suggests that mine inflow (observed inflows) can occur for theoretical strain values above approximately 6mm/m and the severity of inflow increases as the strain increases. Strains above approximately 10mm/m are likely to be associated with significant inflow*."

Though the 2007 CSIRO report indicates the extensometer bore is located over the centre of Longwall 411, it appears to be located approximately one third of the way towards the centreline from the eastern pillars.[54][26] In this location it would not provide a direct determination of the collapsed zone height. This is not considered in the Ditton report.

Longwall 411 lacks a centre panel piezometer bore, however the CSIRO find that piezometer bores over the adjacent pillars indicate a height of "influence" of 275 metres at that location. The report recognises that the impact will be greater over the centre of the extraction.

Table 4B of Ditton's Springvale fracture zone report lists pre and post-mining changes in a bore with 9 piezometers over the pillars between Longwalls 411 and 412. All start with a relatively low pressure (hydraulic head) and all drop to pressure levels between 10 and 0 metres following the extraction of Longwall 411. Nonetheless Ditton concludes the drainage zone boundary occurs between piezometer 4, which is 108 metres above the pillars, and piezometer 5 at 138 metres above the pillars. Making no allowance for the piezometers being over the pillars and not the centre, in contrast to the CSIRO assessment, Ditton's database tabulates the A zone height above Longwall 411 as 139 metres. This is just six metres higher than Ditton suggests for Longwall 409, from data obtained during the passage of Longwall 408, yet the extraction width of Longwall 409 was 265 metres while that of Longwall 411 was 315 metres.

9.3 Springvale - further comment

Ditton's A zone height determinations appear to be erroneous. The assessment for Longwall 411 rests on unreliable extensometer data and, at best, the piezometer assessments for Longwalls 408 (though puzzlingly presented as being for LW409) and 411 at best demonstrate the subjectivity of 'interpreting' off-panel data.

A puzzling aspect of the CSIRO investigation is its computer simulation determination that the height of the fracture zone, with significant increases in hydraulic conductivity, is determined solely by the extraction height and is approximately 33 times this height. Yet the report makes it clear that the underpinning bore data are problematic. Two bores were used to assess conductivity changes, one of which was located over pillars at the end of Longwall 409 and the other was placed to the side at the end of the panel (see Figure 18 in the CSIRO report). That is, the location of the bores was not suitable for a determination of the extent of the zone of significant conductivity change over the longwall panel. Commenting on the data from the bore at the end of the longwall, the report states

> "*However, there seems to be wide variations in measured permeability values. A number of factors during the tests might have affected the measured values of permeability:*
>
> - *Swelling and smearing of the borehole, possibly lowering the permeability values;*
> - *Packer by pass by larger fractures, possibly resulting in lower permeability values;*
> - *Test section lying in small but intact (without fractures) rock segment, possibly resulting in lower permeability values; and*
> - *Test section lying right at the extensive fractures, possibly measuring higher permeability values.*"

The report also advises

> "*At a number of sections planned for testing, packers could not be properly inflated indicating possibilities of borehole breakout or extensive fracturing limiting the number of tests that could be conducted.*"

The conductivity investigation effectively failed and it's then puzzling that the investigators used the data in their computer simulation. In a March 2015 Dendrobium Area 3B connected fracture study[13] (see Section 16) Parsons Brinckerhoff include the extraction height dependence of the fracture zone obtained by the CSIRO in their tabulation of methods for estimating height of fracturing above longwall extractions, but don't mention the problematic nature of the data.

Of significance, Guo's depiction of the SPR40 extensometer data in Figure 30 of his report shows five sets of data from 50 metres before and 43 metres after the passage of Longwall 411 in June 2006. Of the 20 anchor points, only the lower 9 show displacement. The January 2008 and March 2009 data shown in Figure 4a of Ditton's Springvale report shows that the lower 14 anchors have been significantly displaced and all but three of the rest show some displacement. That is, it takes some time for the collapsed zone to be established. This also appears to have been the case over Longwall 9 at Mandalong.

10. Mandalong Longwall 9

Ditton's database includes an entry for Longwall 9 at Mandalong Mine, however the listing doesn't include a height for the A zone obtained from field data. Bore BH22 has three piezometers located over the centre of the panel; BH22A with screen depths between 205 and 208 metres above the coal seam, BH22B at 187 to 190 metres above the seam and BH22C at 162 to 165 metres above the seam. Undermined in June 2010, the 2014 AEMR for the mine records[55] that BHC22C became dry in June 2011 and has remained dry. Evidently taking a year to become established, the piezometer data indicate the fracture zone reaches to a height between BH22C and BH22B. Tammetta attributes the delay to the notably high horizontal stress above the mining, resulting in an unpredictably intermittent development of the collapsed zone.

Taking the average of the BH22C and BH22B upper screen heights, Tammetta estimates the drainage zone height to be 178 metres above the centreline of Longwall 9. Tammetta's equation returns a height of 188 metres[49][41], while Ditton's geometry and geology equations provide A zone height estimate of 115 metres 102 and 115 metres.

Of note, Tammetta also uses piezometer bore data from off-centreline bores over Longwalls 7 and 11 to demonstrate the drop in drainage zone height away from its centreline peak.

Also of note, Mandalong Longwall 5 also has a centre-panel piezometer bore, BH18, and this bore is listed in Table S4 of Tammetta's Supplementary Material, which tabulates sites providing a minimum height estimate. The bore contains only a single piezometer, at a depth of 83 metres above the seam, and is then unable to provide sufficient data to estimate the fracture zone height. It's not clear then how Ditton determines the 118 metre A zone height given for Longwall 5 in Table A6.1 of his Springvale assessment.[26]

11. Dendrobium Longwall 5

Extracted between the 3rd of December 2008 and the 18th of December 2009, Longwall 5[56] was the last to be extracted in Area 2. The extracted length was 2,310 metres, with a void width of 245 metres and a pillar width of 40 metres. The depth of cover to the mined Wongawilli Seam ranges from a maximum of 310 metres above the southern end to a minimum of 200 metres at 600 metres north of the southern end. The extraction height varied along the length of the longwall, depending on the local roof conditions, with the maximum extraction height being 3.75 metres. The extraction height profile does not appear to be available.

Of note, Longwall 5 does not have an adjoining extraction on its western side (see Fig. 3(a) for a depiction of an off-panel bore with respect to an extraction that has a single adjoining extraction on the side opposite to that nearest the bore).

Ditton's tabulation in Table A6.4 of the Springvale fracture zone assessment[26] includes an 'observed' fracture zone (A zone) height of 123 metres for Longwall 5 in Dendrobium Area 2. The data source isn't given; Longwall 5 lacks a centreline bore.

The March 2014 HydroSimulations report[23] introducing the Dendrobium groundwater model that, belatedly, replaced Tammetta's model states: "*The Ditton (2012) height of fracturing estimate is near-perfectly matched with the observed height of fracturing data for Longwall 5*". Echoing this, an October 2015 height of connected fracturing report[21] for Area 3B states: "*This is further confirmed with the Ditton (2013) method for calculating the height of fracturing found by HydroSimulations (2014) to be a good match with observed data from Longwall 5*".

The HydroSimulations reports provide neither Ditton's tabulated fracture zone height for Longwall 5[26], nor the A zone height estimates returned by Ditton's equations. Nor do the reports advise which bore site(s) provided the data referred to as being well matched with the Ditton equation A zone height estimate for Longwall 5. Clarification has been sought from HydroSimulations (see below) and South32, but as yet has not been provided. The piezometer review in Section 15.1 below fails to identify the data source.

Longwall 5 lacks a centre panel piezometer bore. Bores closer to the extraction indicate the drainage zone height is consistent with the estimate returned by the Tammetta equation. Using the mining geometry parameters given in Table A6.4 of the Springvale fracture assessment, the application of Ditton's geometry equation estimates a zone height of 116 metres. Using an adjustment term value of 32 metres, as given in Table A6.4 of the Springvale fracture assessment and used in the HydroSimulations groundwater impact assessment for Dendrobium of March 2014, Ditton's geology equation returns a height estimate of 125 metres for the A zone at the northern end of Longwall 5.

The geology equation adjustment term would appear to have been set 'after the fact' such that the equation returns a height estimate that matches the observed height reported by Ditton and presumably provided by Merrick. That is, irrespective of the lack of information about the data source, the statements given in the HydroSimulations reports would appear to be misleading.

Using the same mining geometry, the Tammetta equation returns a drainage zone height estimate of 270 metres.

12. Elouera Longwall 7

Longwall 7 of the old Elouera mine (now part of the Wongawilli mine) in the Metropolitan Special Area in Sydney's drinking water catchment has a centreline bore referred to as DDH9 and hosting four vibrating wire instruments. Figure 6 of the October 2012 Coffey groundwater assessment for Dendrobium Area 3B represents and interprets piezometer data from this bore and a second located over the northern pillars of the northern most longwall, Longwall 8, referred to as DDH8. Coffey Figure 6 is reproduced below as Figure 15.

Figure 16 below was obtained by digitising the Coffey figure, extracting the represented pressure heads and graphing these pressures with respect to the measurement depth. All of the instruments are above the depressurised zone, with the lowest instrument recording a pressure head of 32 metres at approximately 146 metres below the surface. It's possible that the hydraulic pressure then increases rather than continues to decrease below this depth, before then again falling with depth until the underlying drainage zone is reached. Requiring a second sink located above and independent of the drainage zone over the longwall extraction, this seems unlikely. The profile of in the graph of Figure 16 instead suggests an inverted water table perched at the drainage zone interface.

Conservatively extrapolating the profile to a pressure head of zero provides a drainage zone elevation estimate of 252 metres, corresponding to a height above the seam of 186 meters. In assuming a constant hydraulic pressure loss with depth towards the drainage zone, this is more likely to be an underestimate than an overestimate.

A 2007 GHD hydrogeologic assessment[57] for a then proposed Area 3 consent modification notes that a 2005 SCT assessment[58] of extensometer data from two bores sunk, like DDH8 and DDH9, over and beside a longwall at the Elouera Colliery. The SCT study finds that the zone of large downward movement develops in an arch shape, or perhaps flat-topped triangular shape (in recognition of horizontally bedded stratigraphy) above a longwall extraction (see Figure 17; the SCT report does not appear to be publically available). SCT define this zone by a change in the magnitude of downward movement from about 0.2 to 0.5 metres. The height of the arch is found to be approximately equal to the panel width, which is 190 metres for Longwall 7; essentially the same height as found from the DDH9 piezometer data and demonstrating Tammetta's published[16] finding that the heights of the collapsed zone and drainage zone coincide (see Section 7).

In the October 2015 height of connected fracture assessment[21] for the Dendrobium mine discussed in Section 16, HydroSimulations present a summary of the GHD assessment and its account of the

SCT extensometer study of longwall subsidence at the Elouera mine. However the summary doesn't mention that SCT find the zone of large downward movement above the longwall to be at a height equivalent to the longwall width, or that SCT found likewise at Clarence Colliery. SCT summarise[59] their observations and those of others in a 2011 conference paper.

GHD endeavour to combine the SCT findings with conclusions from a 1995 Forster review[60] of assessments that relate subsidence zones to mining height (width and depth are not considered). As a consequence GHD implicitly suggest that the zone of large downward movement identified by SCT would not result in depressurisation. As a consequence GHD place the upper 60% of the zone of large downward movement in the constrained zone, which is defined by GHD in following Forster and Enever as follows:

> "*A Constrained Zone will exist above the Fractured Zone, probably in an arch shape, up to a height of 1.5 m or to within 15 to 30 metres of the ground surface within which little variation in vertical permeability exists, but increases in horizontal permeability occur through shearing and limited bed separation.*" (Note: "1.5 m" appears to be a typographical error and should instead be '1.5 W')

The stark contradiction inherent in suggesting that 60% of the zone of large downward movement is within the constrained zone is effectively ignored by GHD. In summarising the GHD assessment, HydroSimulations refer only to the constrained zone and don't mention SCT's extensometer assessment or the centreline piezometer data from Elouera Longwall 7.

As noted in Section 5, there are no unusual geological structures over the Elouera longwalls. Figures 9, 10 and 48 show that a nephaline syenite intrusion slightly protrudes into the south eastern corner of Area 3B, but has minimal overlap with the Area 3B longwall extractions.

The height estimate returned by the Tammetta equation for Elouera Longwall 7 is 198 metres. In contrast, the height estimate returned by the Ditton geometry equation is 112 metres, while that from the Ditton geology equation with an adjustment term of 32 is 128 metres and 131 metres with an adjustment parameter of 30. An adjustment term of 12.5 is needed in order for the Ditton geology equation to provide a fracture zone height estimate that matches the height obtained from the centreline piezometer data from Elouera Longwall 7.

The Elouera Longwall 7 piezometer and extensometer data are not included in Ditton's database and are not mentioned in either the 2014 or the 2016 HydroSimulations groundwater assessments[23], [24] for Dendrobium Area 3B. Neither Elouera Longwall 7 or 8 are mentioned in the March 2015 Parsons Brinckerhoff connected fracture report for Dendrobium Area 3B Longwall 9, yet the piezometer and extensometer studies would seem of direct relevance. Perhaps the consultants were unaware of the data.

13. Dendrobium Area 3B - Tammetta

As noted in the introduction (Section 2), for the longwall geometry proposed in 2012 for mining in Area 3B of the Dendrobium mine the Tammetta equation predicts the drainage zone would intersect the surface above 9 of the ten planned extractions. As a consequence, in late 2012 BHP-Billiton rejected the groundwater modelling assessments[3], [36] undertaken by Tammetta on behalf of the mining company's then consultants Coffey Geotechnics.

The mining plans submitted by BHP-Billiton to the Department of Planning in October 2012 proposed an extraction (cutting) height of 3.9 metres for Longwall 9, the first Area 3B extraction, of

3.9 metres and 4.6 metres for Longwalls 10 to 18.[61] In a controversial manner the Department approved the first five of the proposed longwalls in February 2013; the approval is discussed in Section 19. Notwithstanding the significant damage caused by the panels extracted to date[20], Longwalls 9 to 11, in March 2016 the mine operator (now BHP-Billiton spin-off South32) proposed the same mining geometry for Longwalls 14 to 18.

As noted in the introduction, an extraction height of 4.6 metres would appear to be unprecedented for longwall mining beneath Sydney's drinking water catchment. At 305 metres wide, the longwalls of Area 3B are the widest currently being extracted beneath the Special Areas and wider than most if not all previously extracted long wall series. That is, the Area 3B longwall extractions appear to be the most aggressive longwalls ever approved in the Schedule 1 Special Areas of Sydney's drinking water catchment and among the most aggressive anywhere in NSW.

Figures 18 to 21 below contrast the different drainage heights that the Tammetta equation predicts would arise from 305 metre wide extractions undertaken with cutting heights of 3.0, 3.4, 4.0 and 4.6 metres. The physical consequence of estimates of heights that extend above the surface is that the width of the intersection of the drainage zone with the surface increases with that height, along the length of the longwall. Rainfall dependent inflow to the mine would be significantly increased where the drainage zone intersects the surface or the surface fracture network, with the magnitude of the increase depending on the extent of that intersection.

In modelling the groundwater impacts of the Dendrobium mine the Coffey assessment of October 2012, for reasons unknown, used an extraction height of 3.4 metres for all of the mine's longwalls. That work provided an estimate of post mining inflows to the mine of between 10 and 11.5 million litres a day, equivalent to four Olympic swimming pools or more a day, on completion of the Area 3B mining. The modelling assessment of November 2012 used cutting heights close to those that had been used for the longwalls that had been extracted at that time and 4.5 metres for the then proposed Area 3B Longwalls. The post mining inflow prediction given in the November 2012 assessment is not known.

Having rejected the Tammetta/Coffey assessments, BHP-Billiton engaged HydroSimulations to undertake a new groundwater impact assessment[23] for Area 3B. Presented by HydroSimulations as a step forward, the new assessment was completed in March 2014 and replaced the use of the Tammetta equation with an equation from Ditton. Revised modelling and impact assessments have since been presented in an October 2015 height of connected fracturing report[21] and a March 2016 groundwater impact assessment[24], prepared by HydroSimulations as components of Longwalls 14 to 18 mining plans submitted to the Department of Planning in March 2016.

As noted in Section 3, though in principle they should be the same, for a given mining geometry the A-zone height estimates provided by the Ditton equations are much lower than the drainage zone height estimate provided by the Tammetta equation (see Figs. 5 to 7).

Now trading as HydroSimulations, Heritage Computing provided groundwater impact assessments for the end of panel reports for Dendrobium Longwalls 6 to 10. Predating the Ditton equations, the piezometer data interpretations made by the Heritage Computing for the end of panel reports are in accord with the A-zone height estimates provided by those equations. As HydroSimulations, the consultants also provided the end of panel report groundwater assessments for Longwall 9 and 10.

These reports argue that the piezometer data are consistent with the Ditton equations and contradict the Tammetta equation.

Discussed in Section 15, in their October 2015 height of connected fracturing report[21] and March 2016 groundwater impact assessment[24], both submitted to the Department of Planning as part of the mining plans (Subsidence Management Plan; SMP) for Area 3B Longwalls 14 to 18, HydroSimulations further argue that the Dendrobium monitoring data affirms the Ditton geology equation and contradicts the Tammetta equation. However this does not appear to be the case.

14. Dendrobium - cutting heights used by Tammetta and by HydroSimulations

Modelling for the October 2012 Coffey groundwater impact assessment report[3] for BHP-Billiton was based on an extraction height of 3.4 metres for all areas of the Dendrobium mine, however the planned mining height[61] was 3.9 metres for Longwall 9 and 4.6 metres for Longwalls 10 to 18.

That is, presumably reflecting a communication or briefing error, the October 2012 report did not provide an assessment for the then proposed mining. A revised assessment using 4.5 metre high extractions in Area 3B was provided to BHP-Billiton in November 2012.[36]

Table 3 in the March 2014 HydroSimulations Area 3B assessment report lists the extraction heights used for that assessment's modelling. The report indicates that Table 3 reproduces Table 7 from the October 2012 Coffey modelling report for Area 3B. The reference to the October Coffey report appears however to be mistaken and may instead have been intended to refer to the November 2012 Coffey modelling report. While the November 2012 modelling report[36] is not publically available, the associated data analysis report[62] was made available in April 2016 and Table 10 in that report lists the extraction heights used in calculating that report's drainage zone heights. These extraction heights don't correspond to those of Table 3 in the 2014 HydroSimulations report. Without access to the November 2012 Coffey modelling report, the reason for the discrepancy is unknown.

The extraction heights given in Table 3 of the 2014 HydroSimulations report (and presumably then Table 7 of the withheld November 2012 Coffey modelling report) may be the planned heights and/or the maximum extraction height actually used. The tabled heights are 3.4 metres for Longwall 1 and 2, 3.8 metres for Longwalls 3, 4 and 5 and 3.9 metres for Longwall 6, 7, 8 and 9 and 4.5 metres for Longwalls 10 to 18. It's not known why a height of 4.5 metres was used by Coffey and HydroSimulations for Longwalls 10 to 18, when the planned height was 4.6 metres.

The heights in Table 10 of the November 2012 Coffey data analysis report are given as the average heights used for Longwall 1 to 8 and the planned heights for Longwall 10 to 18. The tabled heights in this report are 3.4 metres for Longwalls 1 to 6, 3.6 metres for Longwalls 7 and 8, and 4.5 metres for the then planned Longwalls 9 to 18.

Details of the extraction heights actually used appear to only be publically available for Longwall 3 and Longwalls 9 to 11. Madden reports[63] that Longwalls 1 and 2 of the Dendrobium mine were extracted at heights varying from 3.3 to 3.4 metres. Longwall 3 was extracted with heights varying from 3.15 to 3.7 metres. End of panel reports advise that Longwalls 4 and 5 were extracted at up to 3.75 metres high and Longwalls 6, 7, and 8 at up to 3.9 metres high.

The profiles for the cutting height actually used for the extractions would presumably have been available, or made available on request, to Coffey and HydroSimulations. If so, it's then puzzling that this information was not used in their modelling.

The March 2015 HydroSimulations height of connected fracturing report advises that the cutting heights used for the calculation of drainage zone heights are "*Actuals for Longwall 1-11*". While this appears to be the case for Area 3B Longwalls 9 to 11, Table 3 in the report suggests the planned or maximum extraction heights have instead been used for Longwalls 1 to 8. That is, though the actual mining heights for all of the Dendrobium longwalls would, presumably, have been available, in applying the Ditton and Tammetta equations the consultants only use the actual cutting heights used for the Area 3B longwalls (see Table 3) and instead use the planned or maximum heights for the earlier extractions. A request for clarification was sought from South32, but to date has not been provided.

Using the maximum or planned cutting height in calculating drainage or A zone height estimates results in an overestimate where a lower height was actually used in extracting a given longwall. The cutting height profiles for most of the extracted Dendrobium longwalls are not available, but those that are indicate that the employed cutting height is generally lower than the planned or the maximum employed height. This is also reflected in the difference between the average cutting heights given in Table 10 of the November 2012 Coffey data analysis report and the cutting heights given in Table 3 of the 2014 HydroSimulations groundwater assessment and in Table 3 of the March 2015 HydroSimulations height of connected fracturing report.

The problem of overestimation is illustrated in the difference between the Area 2 and 3A drainage height map provided in the March 2015 HydroSimulations report and that in the Coffey (Figures 22 and 23 below). Unless the cutting heights that were actually used in extracting a panel are used to calculate estimated drainage or A zone heights, it's not possible to properly compare those height estimates with field data (see Section 15).

Compounding the over estimation problem arising from HydroSimulations' use of the maximum or planned cutting heights, rather than those actually mined, in applying the Ditton and Tammetta equations, in their 2015 height of connected fracturing report the consultants fail to provide essential detail in their assessment of the Tammetta equation with respect to the data from the Dendrobium piezometer network. This is discussed in Section 15.

15. Dendrobium Area 3B - HydroSimulations

Table 3 is taken from the Department of Planning's December 2015 Area 3B mining impacts inspection report[20] and provides a breakdown of extraction heights for Longwalls 9 and 10 and part of Longwall 11. A graphical representation is provided in the December 2015 subsidence review[64] provided by MSEC for the 2016 SMP submission for Area 3B. This important information should be included in end of panel reports as a matter of course, but it appears this has not been the case since the end of panel report for Longwall 3 in February 2008 (see Section 15.1).[65]

In two reports[21], [24] provided for the 2016 SMP submission to Planning for Area 3B Longwalls 14 to 18, HydroSimulations argue that the available evidence does not support the drainage height estimates provided by the Tammetta equation, stating[24]:

“*Together, these various lines of evidence support a model in which mine-related fracturing and depressurisation do not propagate to the surface and there is no evidence for rapid surface-to-seam water pathways.*”

HydroSimulations argue that data from the mine’s groundwater piezometer network, mine inflow data and mine water chemistry are inconsistent with the drainage zone heights estimated by the Tammetta equation. The consultants conclude that the available evidence supports the Ditton equations, the geology equation in particular, and advise “*the calculated A-zone heights are found to match the findings of field investigation*”.[21] The available evidence suggests however that this conclusion lacks foundation and would be unlikely to withstand the review process of a good quality science journal. The available evidence does not appear to contradict the Tammetta equation, whereas it challenges the Ditton equation.

15.1. Piezometer data

In reviewing the data provided by the network of piezometer bores over the Dendrobium mine in their 2016 groundwater assessment[24] for Dendrobium Area 3B, HydroSimulations provide two graphical representations, Figures 21 and 22 in that report (provided below as Figs. 24 and 25), that group groundwater monitoring bores according to the nearest extracted or planned longwall. The instruments in the bores represented in Figure 21 of the report are classified as showing significant depressurisation, some depressurisation or no significant depressurisation.

HydroSimulations comment: “*There are numerous ‘little or no depressurisation’ points below the calculated Tammetta H level, which is conceptualised as the height of complete groundwater drainage. This suggests that the Tammetta (2013) method overestimates the height of complete drainage at Dendrobium (discussion of the reasons is presented below).*”

The presentation of the piezometer response assessment in Figures 21 and 22 of the HydroSimulations report (Figs. 24 and 25 below) is unhelpful and misleading. The majority of the instruments represented in Figure 21 are not identified and none are identified in Figure 22. Noting that counting is complicated by overlaps (see Fig. 24 below), of some 192 instruments represented in Figure 21 only 17 appear to be identified.

Of note, the instruments that are identified are those represented as reporting significant depressurisation. None of the instruments classified as reporting some depressurisation or no significant depressurisation are identified. It’s then impossible to gauge where they are located and, accordingly, whether or not their response classification would suggest they contradict the Tammetta equation. That is, Figure 21 in the HydroSimulations report provides no support or substantiation for the above quote.

Most of the instruments in Figure 21 of the report are placed on a vertical line that has a longwall number beneath it, while the rest are to the side of a labelled vertical line (see Fig 24 below). This might suggest that those on the vertical line are located over the centreline of the given extraction, but in general that’s not the case. For example, instruments in the TARP bores DDH85/S1870 and DDH119/S1992 are represented on a vertical line in Figure 21, but both bores are beyond the finishing ends of the associated extractions. Others are located in side-panel bores or bores over pillars.

There are only two centreline bores represented in the Figure 21 (Fig.24 below) and they are bores S2192 and DDH104, and their instruments fail well before the host bore is undermined (see Sections 15.1.14 and 15.1.15 below).

The significance or otherwise of the response of the unidentified instruments can't be gauged in the absence of knowledge of their location. The figure associates three unidentified instruments with Longwalls 12 and Longwall 13; at the time the report was prepared, neither had been extracted.

Noted in the sections below are examples of piezometers that record significant declines in pressure head, but do not appear to be represented in Figure 21. For example, the figure includes and identifies two instruments from Longwall 9 centreline bore S2192, with the uppermost shown being that at 140 metres below the surface. Reference to Figure 38 below finds that the instrument at 95 metres below the surface undergoes a similar decline to that of the lower instrument, yet it doesn't appear to be shown in Figure 21. Data from this bore are further discussed in Section 16. There would appear to be other instruments that have not been included in Figure 21 that would be regarded as showing a significant response.

Limiting the insight that might have been provided by Figures 21 and 22, HydroSimulations don't specify how the three categories represented in Figure 21 were defined and applied. The CSIRO Springvale study[40] (see Section 9 below) used a pressure loss of five metres in identifying the point at which a piezometer first responded to the approach of Longwalls 409 and 411. Depending on the distance between the drainage zone boundary and the piezometer, a loss of five metes or more recorded by an off-panel piezometer in a saturated zone may well be significant.

The HydroSimulations assessment finds few zero or near-zero pressure head measurements in the set of (unidentified) piezometers represented in Figure 22 of the report (Fig. 25 below). The consultants again suggest that this observation does not support the concept of a zone of complete depressurisation extending upward from the goaf up to the height estimated by the Tammetta equation; "*The data does do not support the concept of a zone of zero pressure extending upward from the goaf up to the Tammetta H height*." The spatial relationship of the bores to the relevant extraction isn't given and without identification can't be determined.

HydroSimulations may be referring to a set piezometers located over an extraction and that survived the passage of the longwall long enough to reliably report from within the drainage zone. However that's not stated or indicated in the report and there would appear to be no bores for which that would be the case. That is, there appear to be no instruments placed over extractions at a height that the Tammetta equation suggests should be reached by the drainage zone and that survived the formation of the drainage/collapsed zone around them. There is then no basis for the quoted statement.

If the quoted statement is not referring to piezometers that the Tammetta equation suggests would be located in a post extraction drainage zone, then the statement reflects a fundamental misunderstanding on the part of HydroSimulations, or an intent to mislead. Tammetta doesn't suggest that the collapsed zone, characterised by desaturation and a loss of hydraulic head (resulting in atmospheric pressure and not zero pressure as the quote might suggest), extends beyond the sides of an extraction[16], other than as follows:

> "*For longwall chain pillars with mined panels on both sides, H is about 40% smaller than ordinary cases. For a mined panel on one side only, H is about 70% smaller (with no*

desaturation suggested for u less than about 2000, probably due to the absence of goaf on one side)."

As noted in Section 3, Gale finds "*The zones of significantly enhanced conductivity about a longwall panel are contained inside the panel, and slope inward to the panel*".[34] That is, desaturated conditions do not extend significantly beyond the pillars of an extraction, except where the pillars separate adjacent longwalls.

With the exception of the small number of instruments identified in Figure 21 of the 2016 groundwater assessment (Fig. 24 below), it's not known which bores are being referred to in the HydroSimulations statements and accordingly which are located over extractions, which are located over pillars between extractions or which are off-panel. Nor is it known which have recorded extraction responses for the longwall with which they've been associated by HydroSimulations and which have only recorded responses for extractions preceding that with which they're associated.

There are instances among those identified in Figure 21 where the time period covered by the hydrographs provided in the report for data from a bore associated with a particular longwall panel excludes responses to the extraction progress of that longwall. It may well be that the extraction of the associated longwall resulted in loss of the instruments in the bore, however its possible useful information will have been recorded before loss occurred.

Without further information Figures 21 and 22 of the HydroSimulations report (Figs. 24 and 25 below) provide no insight into the height of the drainage zones over the Dendrobium mine and, on the contrary, appear to be misleading.

The following sections review hydrographs from instruments in twenty one key bores and find that the data do not provide support for the Ditton equation and are instead consistent with the Tammetta equation. The review is summarised Table 4 below, which tabulates the drainage zone heights suggested by the instruments in the listed bores, together with the height estimates provided by the Ditton equation and the Tammetta equation.

15.1.1. Longwall 3 – DDH39/S1578

Extracted from the 30th of March 2007 to the 17th of November 2007, Longwall 3 has a void width of 247 metres.[65] The longwall's extraction profile is provided in Table 1.1 of the end of panel report and an appended seam thickness contour map at the end of that report.[65] No other end of panel report for Dendrobium has since provided this important extraction information. The extraction height for the northern two thirds of Longwall 3 was 3.2 metres, in contrast to 3.7 metres for the first third of the panel.

Hosting four piezometers and also referred to as S1578 and DEN39, bore DDH39 is located approximately 260 metres south of the northern (completion) end of Longwall 3 and approximately 30 metres west of the longwall's surface centreline. Hydrographs for the period January 2005 to October 2007 are provided in the recently released November 2012 Coffey data analysis report[62] for Area 3B, together with the piezometer elevations and depths below ground and other valuable information. Hydrographs are also provided in the 2016 HydroSimulations groundwater assessment for Dendrobium, for the period January 2005 to September 2007. Elevations and depths however are not provided in the HydroSimulations report.

Figure 26 was obtained by digitising the hydrographs given on page 5 of Appendix E of the November 2012 Coffey data analysis report[62] for Dendrobium area 3B. Pressure heads were obtained by subtracting the given piezometer elevations from the hydraulic heads

The deepest DDH39 piezometer, 234 metres below the surface and in the Wongawilli coal seam, responds clearly to the mining of Longwalls 1 and 2 in Area 1, before failing as it begins to respond to the approach of the Longwall 3 face. A piezometer in the Stanwell Park Claystone at 122 metres underground (Piezometer 2) and another in the Scarborough Sandstone at 152 metres below the surface (Piezometer 3), respond sharply and simultaneously to the approach of Longwall 3. The shallowest of the four piezometer is 25 metres below the surface (Piezometer 1), in the Bulgo Sandstone. This piezometer is reported[62] to be dry throughout the recording period, perhaps indicating failure.

As reflected in Figure 26, the pressure head reported by Piezometer 3 at152 metres below the surface in the Scarborough Sandstone falls from approximately 40 to 7 metres between April and September 2007; a pressure head loss of 33 metres in just 6 months. The September pressure reading is the last reported, presumably reflecting failure at some point between mid-September and mid-October. By mid-September 2007 the approaching longwall face was approximately 170 metres south of DDH39.

Piezometer 2 in the Stanwell Park Claystone at 122 metres below the surface also failed between September and October 2007. Providing a lower bound of approximately 114 metres for the height of the Longwall 3 drainage zone, this piezometer reports a pressure head loss of approximately 20 metres and appears to have become dry shortly before failing. This instrument is not represented in either Figure 21 or Figure 22 of the 2016 HydroSimulations report (Figs. 24 and 25 below). The Tammetta equation estimates a drainage zone height of 216 metres for the 3.2 metre cutting height used for most of Longwall 3. The Ditton geology equation estimates an A zone height of 110 metres, just below the lower bound suggested by DDH39 Piezometer 2. The Ditton A95 height estimate is 135 metres; A95 is an estimated upper height limit for which there is a 95% probability the actual height will be somewhere below this limit.

The time dependent profile of the loss reported by Piezometer 2 (see Fig. 26) is intriguing in first reporting a relatively rapid fall of 5 metres as the longwall face approaches, slowing over the period of the rapid rise in the level of Cordeaux Reservoir between early June and mid-July 2007 and then again falling rapidly to become dry by September 2007. The elevation of Piezometer 2 is 293 metres, placing it somewhere between the elevation of the stored water surface and floor of the reservoir. This suggests the possibility that the response of the piezometer to Longwall 3 was moderated by the sharp rise in hydraulic head of Cordeaux Reservoir in mid-2007. That is, before failure Piezometer 2 may have signalled a hydraulic connection between Longwall 3 and the reservoir. The bore is approximately 460 metres from the western shore of Cordeaux, while the eastern side of the longwall is approximately 330 metres from the reservoir.

15.1.2. Longwall 3 – DDH50/S1652

Also known as S1652, bore DDH50 is located approximately 350 metres east of the eastern corner of the southern (commencement) end of the Longwall 3 void, 470 metres from the longwall centreline, approximately 200 metres south of Greenfields Creek and around 570 metres from the western shore of Cordeaux Reservoir. The end of panel subsidence report[65] for Longwall 3 indicates that the extraction height at the southern end of the longwall panel was 3.7 metres.

DDH50 hosts six piezometers. Hydrographs from January 2004 to January 2010 are provided in the recently released November 2012 Coffey data analysis report for Area 3B and are provided for the period of March 2005 to March 2009 in the 2016 HydroSimulations groundwater assessment of Area 3B. The latter doesn't provide the piezometer depths or the collar elevation provided with the Coffey hydrographs.

MSEC contour maps[65] show that the bore site is on a relatively gentle slope at the base of a steeper slope that rises from an elevation of 323 metres (mAHD) at DDH50 to 360 metres over eastern edge of Longwall 3 and to 480 metres over the centre of Longwall 4.

The bore's location is such that its piezometer at 10 metres below the surface is unable to provide insight into the height of the collapsed/drainage zone formed over the southern part of Longwall 3. The horizontal pressure head gradient from up to 10 metres at the piezometer to zero head pressure at the surface to the east will be significantly greater than that to the Longwall 3 depressurised zone some 350 metres to the west.

The instrument at 20 metres below the surface is essentially in-line with the surface of Cordeaux Reservoir. In contrast to the instrument above, this piezometer shows a sharp response to the extraction of Longwall 3, with the pressure head falling approximately 6 metres to become dry. Though it would appear to meet the criteria, this instrument is not represented in either Figure 21 or 22 in the 2016 HydroSimulations groundwater assessment for Dendrobium (Figs. 24 and 25 below).

The piezometer at 45 metres below the surface, in the Wombarra Claystone, also responds sharply but to a lesser extent and this appears to reflect prior pressure loss, presumably from mining in Area 1. It might alternatively reflect pressure from the reservoir.

The centreline seam elevation over the southern part of Longwall 3 appears to be approximately 190 metres, accordingly the response of the piezometer 20 metres below the surface suggests a drainage zone of somewhere between 113 metres and the surface. With a centre line depth of cover of approximately 185 metres at the southern end of the extraction, the Ditton geology equation provides a height estimate of 106 metres, for a 3.7 metre high extraction and adjustment parameter of 30. The Tammetta equation estimates a height of 252 metres, suggesting that the drainage zone would reach the surface over the southern section of Longwall 3. If so, this would at least partly explain the anomalous inflows reported for Area 2 (see Section 15.2).

The DDH50 piezometer data don't provide a distinction between the estimates of the Ditton and the Tammetta equations. The piezometer at 20 metres below the surface is however of importance in showing a fall to dryness at the water level of Cordeaux Reservoir.

15.1.3. Longwall 4 - DDH89/S1876

The site is comprised of a set of four bores, DDH89(1,a,b,c), categorised as shallow groundwater bores and for which hydrographs are provided in the 2016 HydroSimulations groundwater assessment as S1876/DEN89, EDEN89a/DEN89a, EDEN89b/DEN89b and EDEN89c/DEN89c.

The DDH89 site is located over Longwall 4, approximately 10 metres east of the surface projection of the pillars separating this extraction from Longwall 5; DDH89c is closer in being approximately 6 metres from the eastern side of the surface projection of the pillars. Longwall 4 was extracted from 17th December 2007 to 2nd October 2008.

Bore DDH89/S1876 hosts a single vibrating wire piezometer and the others house standpipes.[62] The piezometer elevations or depths are not provided in the 2016 HydroSimulations groundwater assessment. Depths are however provided in the shallow piezometer details listing in Table A1 in the 2014 HydroSimulations assessment report.

Three significantly different depths are reported for DDH89/S1876; 100 metres from EcoEngineers in 2008[66], 123 metres from Coffey in 2012[62] and 165.1 metres from HydroSimulations in 2014.[23]

A December 2008 EcoEngineers end of panel surface and shallow groundwater report for Longwall 4 provides valuable additional information not provided in the 2014 and 2016 HydroSimulations groundwater assessments for Area 3B. The end of panel report advises that the longwall extraction passed beneath the DDH89 sites on the 10th of May 2008.

DDH89c is 1.1 metres below the surface and would appear to be persistently dry. The January 2009 end of panel report for Longwall 4 attributes this to the onset of dry weather. However, though there appear to be some transient responses to rainfall, the ‘flatline’ behaviour of DDH89c continues over the period to early 2013 shown in the hydrograph provided in the 2016 HydroSimulations groundwater assessment. The behaviour change is evident from late May 2008, after the longwall face had passed below the instrument (Figure 5.74 in the end of panel report).

The DDH89a piezometer is 10 metres below the surface and reference to MSEC contour maps[67] suggests it has an elevation of 445 metres, which appears to correspond to a height above the coal seam of approximately 287 metres.

The December 2008 EcoEngineers report comments “*However in shallow piezometer EDEN89a there was a marked decline of the local hillslope aquifer by about 6 m to dryness shortly after Longwall 4 passed by on 10 May 2008. Recovery of water levels in this piezometer also appears to have been strongly retarded by the relatively dry weather which applied between July and end October 2008*.” The hydrograph provided by EcoEngineers (Figure 4.1 in that report) shows that the hydraulic head was approximately 446 metres and still falling in early August 2008 at the time of the last data point. Given the 445 metres elevation, the piezometer was very close to being dry. The period covered by the hydrograph provided by the 2016 HydroSimulations report ends in mid-2012, after the end of the Millennium drought, and shows that the piezometer remained dry or close to dry.

A fall from six metres to dryness is a significant response to the extraction of Longwall 4, a fall that precludes the recording of a response to Longwall 5. DDH89a should have been highlighted and associated with Longwall 4 in Figure 21 of the 2016 HydroSimulations report (Fig. 24 below). Though Figure 22 in the HydroSimulations report (Fig. 25 below) lacks bore identification information, it does not include Area 2 instruments.

DDH89b is 41.5 metres below the surface and this would appear to correspond to a height over the coal seam of 256 metres. The 2009 EcoEngineers surface and shallow wasters report observes;

"*immediately after Longwall 4 passed by shallow piezometer EDEN89b on 10 May 2008 the water level in the perched aquifer at that location declined from about 416.4 m AHD to complete dryness at about 414.3 m*". The low pressure head prior to the passage of Longwall 4 presumably reflects a response to Longwall 3.

The DDH89/S1876 hydrograph provided in the 2016 HydroSimulations groundwater report presents few data points and terminates at the start of May 2008. The resolution of the hydrograph provided by EcoEngineers suggests the sparse data shown in the HydroSimulations hydrograph does not reflect logging frequency.

Though not mentioned by HydroSimulations, EcoEngineers report that the DDH89/S1876 instrument failed on the 28th of May 2008 after becoming damaged shortly after the passage below of the longwall face on the 10th of May. Given the timing, the loss of the S1876 instrument is consistent with the break-up and downward movement of the surrounding rock as the collapsed zone forms behind the longwall face.

Tammetta finds[16] that in the absence of an adjacent extraction the collapsed zone extends over an extraction's pillars to a height of up to 30% of its centre-panel height and 60% of that height where there is an adjacent extraction. The Tammetta equation provides a centreline desaturated zone height estimate of 269 metres for this section of Longwall 4, assuming the maximum extraction height of 3.75 metres was used (Tammetta[62] gives the average cutting height as 3.4 metres). The estimated height of the collapsed zone over the pillars between Longwall 4 and 5, prior to the extraction of Longwall 5, would then be up to approximately 82 metres.

The DDH89/S1876 piezometer bore site is approximately 13 metre from the eastern side of the surface projection of the pillars separating Longwall 4 from Longwall 5 and 33 metres from the centre of that projection. That is, the site is above the Longwall 4 void, close to its western boundary. The piezometer is 165 metres below the surface and this appears to correspond to a height above the seam of approximately 132 metres. This height is consistent with it being within the Longwall 4 collapsed zone following the passage below of the longwall face. Prior to the extraction of Longwall 4, the mining of Longwall 3 appears to have resulted in a decline of approximately 10 metres at this instrument.

Taken together, the responses of DDH89a, DDH89b and DDH89/S1876 suggest the drainage zone has at least reached the surface fracture network over at least this part of Longwall 4. It's not possible to determine, on the basis of the piezometer data, whether it would have reached the surface in the absence of a surface fracture network.

As noted above the Tammetta equation estimates a centreline drainage zone height of 269 metres, while the Ditton geology equation estimates an A zone height of 125 metres (t' = 30); the Ditton equation estimate is not in accord with the data provided by the DDH89 bores.

15.1.4. Longwall 5 - unidentified data highlighted by HydroSimulations

Longwall 5 was extracted between December 3rd 2008 and the 18th of December 2009 with a void width of 245 metres, 45 metre wide pillars and a maximum extraction height of 3.75 metres; the cutting height profile does not appear to be available. The depth of cover to the mined Wongawilli Seam ranges from a maximum of 310 metres above the southern end to a minimum of 200 metres some 600 metres north of the southern end.

As noted and discussed in Sections 5, 11 and 15.1.4, HydroSimulations find that height of fracture data for Longwall 5 in Area 2 match the predicted height estimate obtained from the Ditton geology equation. Their 2014 revision of the November 2012 Coffey groundwater assessment for Dendrobium states[23]: "*The Ditton (2012) height of fracturing estimate is near-perfectly matched with the observed height of fracturing data for Longwall 5 (See Ditton, 2012*)." And their 2015 height of connected fracturing report[21] submitted for the 2016 Area 3B SMP assessment states: "*This is further confirmed with the Ditton (2013) method for calculating the height of fracturing found by HydroSimulations (2014) to be a good match with observed data from Longwall 5*".

Neither report identifies which bore or bores provided the data referred to in these statements and. accordingly, the statement cannot be verified. Clarification has been sought from South32, but at the time of writing has not been provided. Though the number of data source possibilities is small, the following discussion fails to resolve the mystery.

The March 2014 HydroSimulations groundwater assessment report[23] includes a map showing the location of the piezometers used for modelling calibration (Figure 27 below). This map is captioned: "*Figure 3 Coffey (2012a) Model Calibration Piezometer Locations*", evidently affirming use of the same set of the piezometers that were used as calibration targets for the 2012 Coffey assessments for Area 3B. The report also advises: "*Attachment B presents the details of the 87 'deep' piezometers used for calibration by Coffey (2012a), and in this study*." Attachment B is a reference to an appended table titled "*Table B1 'Deep' calibration piezometer details (from Coffey, 2012)*", which reproduces Table A1 from the October 2012 Coffey assessment.

The map in Figure 3 of the 2014 HydroSimulations report shows three sites relatively close to Longwall 5 that might have provided the data referred to in the quoted statements and characterised as "*near-perfectly matched*" with the A zone height estimated by the Ditton geology equation. These sites are DDH23, DDH38, and DDH60. Though further away, DDH90 is also a possibility. Reference to the groundwater monitoring map in the Coffey assessment (Fig. 28 below) additionally suggests DDH60, DDH88, DDH89 and DDH117.

Reference to Table C2 in the November 2012 Coffey data analysis assessment indicates bores DDH23 and DDH60 host a single vibrating wire piezometer. Hydrographs for data from these sites are provided in the Coffey assessment and appear to be provided in the 2016 groundwater assessment as S1102/DEN 23 and S1173/DEN 60; both are in the Wongawilli coal seam and would not be the source of data referred to the quotes above.

Considered in Sections 15.1.6 and 15.1.3, the DDH88 and DDH89 sites are not included in Table A1 (or HydroSimulations' 2014 Table B1) of the 2012 Coffey assessment and hydrographs are not provided for data from these bores. Similarly they don't appear to have been used as calibrations targets by HydroSimulations, though data are modelled and hydrographs provided in their 2016 assessment report. This report doesn't specify which sites were used for calibration targets, other than commenting: "*While most of the monitoring locations that form the calibration dataset are the same as in HydroSimulations (2014), some additional sites have been added for this study. This includes the two new 'Avon monitoring bores' (S2313 and S2314), and a few other multi-level monitoring sites around Area 3B and one near Elouera. Locations of these bores are mapped in Figure 6 and Figure 7*." Though not stated, the Elouera site mentioned in the quote appears to be that adjacent to Elouera Longwall 8; there's no mention of the centre panel bores over Elouera

Longwall 7. Discussed in Sections 12 and 15.5, data from the Elouera longwall bores contradict the Ditton equation.

DDH38, DDH90 and DDH117 remain as possibilities for the source of data that HydroSimulations find to be in agreement with the Ditton geology equation A zone height estimate for Longwall 5. Data from these bore are discussed individually below.

The two uppermost instruments of DDH38 respond to the extraction of Longwall 5, with the uppermost then indicating a lower bound for the drainage zone height of 250 metres. HydroSimulations may have been referring the piezometer below this instrument, which would offer a lower bound estimate of 145 metres. If so, HydroSimulations overlook the response of the higher piezometer. DDH38 is discussed further in Section 15.1.5.

DDH90 is an off-panel site approximately 230 metres beyond the northern end of the Longwall 5 void, with the seam elevation dropping about 25 metres over this distance. Discussed in Section 15.1.7, data from the DDH90 vibrating wire piezometer cannot be used to credibly identify a likely height of the drainage zone over Longwall 5; at best the data provide an uncertain lower bound.

DDH117 is a multi-piezometer bore over the western pillars of Longwall 5 and accordingly is the best placed of the available piezometer bore to provide insight into the height of the drainage zone over this extraction. The data from this bore are not in accord with the Ditton equation (see Section 15.1.8). This bore is listed in Table B1 in the 2014 HydroSimulations groundwater assessment for Area 3B, is among the dozen highlighted in Figure 21 of their 2016 Area 3B assessment (Figure 24 below) and is shown in the groundwater bore site maps provided in the end of panel reports for Longwall 6 to 11 as S1953 (see Fig. 31).

Puzzlingly DDH117 is not included in the groundwater bore maps provided in the 2014 (see Fig. 27) and 2016 HydroSimulations Area 3B groundwater assessments and is not discussed or referenced in either report. Yet data from DDH117 are used as calibration targets for the 2012 Coffey assessments. The absence of this bore from the 2014 and 2016 HydroSimulations contradicts their 2014 statement that the same calibration targets were used as had been used for the Coffey assessment. HydroSimulations appear to have replaced the use of data from DDH117 with that from the less informative DDH90 site. DDH117 is unlikely to be the source of data that HydroSimulations find supports the Ditton equation.

These bores and their implications are further discussed in the following sections. A candidate for the source of the Longwall 5 data referred to by HydroSimulations as being in good agreement with the Ditton geology equation has yet to be found. Information has been sought from the mining company, but has not been provided.

15.1.5. Longwall 5 - DDH38/S1577

Also labelled as S1577[42] and DEN38[24], DDH38 is an off-panel bore approximately 170 metres away from the western edge of the Longwall 5 void (see Fig. 28) and 292 metres from its surface centreline. The last to be extracted in Area 2, Longwall 5 doesn’t have an adjoining extraction on its western flank. DDH38 hosts four piezometer, one of which is in the Wongawilli coal seam. The 2016 HydroSimulations groundwater assessment doesn’t provide the depths or elevations for the piezometers however this information is provided in the 2012 Coffey assessments and in the 2014 HydroSimulations groundwater assessment.

The instruments in DDH38 were included in the calibration targets used for the October 2012 Coffey groundwater assessment for Area 3B and the provided hydrographs list piezometer depths as 25, 130, 170 and 259 metres below the surface.[67] Hydrographs are also provided with instrument depths in the March 2014 HydroSimulations assessment and without depths or elevations in the in the 2016 HydroSimulations assessment for Area 3B.

Though a key segment of data is missing, the instrument 25 metres below and closest to the surface shows a pressure loss of approximately 15 metres associated with the extraction of Longwall 5 (see Figure 29). Reflecting the extraction of Longwalls 3 and 4, the bore's three deeper piezometers show pressure loss well before the commencement of Longwall 5 - some six months before in one, twenty in the next deepest and about three years in the deepest instrument (see Fig. 29); the latter is located in the coal seam. Data is apparently missing for all for the important period from January to August 2009; the longwall was extracted between 3rd December 2008 and 18th December 2009.

A comparison of the modelling represented in Figures 29 and 30 finds that the Coffey modelling better reflects the instrument data. The HydroSimulations' graphical representation of the DDH38 data is truncated at what would appear to be October 2009, whereas that in the Coffey report terminates in January 2011. The instruments become erratic during the mining of Longwall 5, however the two uppermost appear to continue to provide at least indicative data.

The hydrographs provided in the November 2012 Coffey data analysis report show that the pressure loss recorded by the piezometer at 25 metres below the surface persists from 2009 to the end of the provided recording period in 2011. The response indicates that the drainage zone has reached at least the corresponding height above the centreline of Longwall 5.

The coal seam elevation appears[68] to drop by around 20 metres over the approximately 300 metres between the bore location and the extraction centreline. The corresponding height of the uppermost piezometer over the centreline of Longwall 5 then appears to be approximately 215 metres. This constitutes a lower bound estimate, depending on the degree to which the upper interval bedding planes deviate from being horizontal across the approximately 292 metre distance between the extraction and the piezometer location.

The height of the surface over Longwall 5 appears to be approximately 280 metres, where the distance to DDH38 is shortest. The piezometer responses suggests the Longwall 5 drainage zone height is somewhere between 215 and 280 metres. A height over the seam of 215 metres would then correspond to a depth below the surface of 65 metres. The drainage zone may then have joined the surface fracture network.

Assuming the extraction was undertaken at the maximum height of 3.75 metres, the Ditton geology equation provides a most likely A zone height estimate of 129 metres (with t' = 30), while the Tammetta equation estimates a drainage height of 272 metres. The average cutting height was 3.4 metres[62] for which the Ditton geology equation provides a most likely A zone height estimate of 123 metres (with t' = 30) and the Tammetta equation estimates a drainage zone height of 240 metres. In contrast to the Tammetta equation, the Ditton equation does not appear to be consistent with the data from DDH38.

15.1.6. Longwall 5 - DDH88/S1875

The DDH88 site is located on a gentle slope close to Creek 14, approximately 580 metres from the western edge of the Longwall 5 collapsed zone and approximately 700 metres from its centre-line. Classified by HydroSimulations in their 2014 Area 3B assessment[23] as a shallow piezometer site, this off-panel site is comprised of three bores, DDH88(1,a,b), for which hydrographs appear to be provided in the 2016 HydroSimulations groundwater assessment as S1875/DEN 88, EDEN88a/DEN88a and EDEN88b/DEN 88b. DDH88/S1875 hosts a single vibrating wire piezometer, while DDH88a and DDH88b are standpipes.

The instrument elevations and/or depths are not provided in the 2016 HydroSimulations report, however this information is provided in the 2014 HydroSimulations Area 3B assessment and in the November 2012 Coffey data analysis report. These reports give differing depths for the instruments. The HydroSimulations report has depths of 10, 28 and 156 metres respectively for DDH88a, DDH88b and DDH88/S1875, while the Coffey report has depths of 10, 31 and 130 metres respectively for the instruments

The deeper DDH88/S1875 vibrating wire piezometer shows a clear and significant pressure loss response to Longwall 5, falling approximately 50 metres between January 2008 and December 2009 – the period of the extraction of Longwall 5. This instrument's considerable distance from the Longwall 5 void is reflected in the rate of pressure loss at the piezometer. Given the distance, at best the piezometer provides an uncertain lower bound of approximately 148 metres for the Longwall 5 drainage zone height, assuming its depth below ground is 130 metres.

Though it records a significant response to Longwall 5, S1875/DDH88 is not highlighted in Figure 21 of the 2015 HydroSimulations height of connected fracturing report (Fig. 24 below) and may not be represented in that graphic. The HydroSimulations modelling is not in accord with the piezometer data.

The DDH88a and DDH88b shallow standpipe data don't appear to reflect a response to Longwall 5 and this is not surprising given its location and the distance between the bore site and Longwall 5. The DDH88 instruments do not appear likely to be the source of the data that HydroSimulations interpret as being in good agreement with the Ditton geology equation A zone height estimate for Longwall 5.

15.1.7. Longwall 5 - DDH90/S1877

DDH90 is an off-panel site comprised of three bores, DDH90(1,a,b), located on the north western corner of the first workings north of Longwall 5 (Northwest Mains), 'down dip' and some 230 metres or so away from the end of the extraction. The seam elevation appears to drops about 25 metres over the distance between the end of the extraction and the bore site. Bore DDH90, also known as S1877 and EDEN90, hosts a single vibrating wire piezometer, while DDH90a and DDH90b are standpipes.

The 2014 HydroSimulations groundwater assessment for Area 3B provides a hydrograph only for the DDH90/S1877 vibrating wire piezometer. Placing it in the Bulgo Sandstone, the hydrograph gives a depth of 121 metres for the instrument, whereas Table A1 in the assessment gives a depth of 141 metres and places the piezometer in the Scarborough Sandstone. The November 2012 Coffey data analysis report has a depth of 136 metres.

The HydroSimulations and Coffey reports provides matching depths of five metres for DDH90a and eleven metres for DDH90b. The 2016 HydroSimulations groundwater assessment provides hydrographs for all three DDH90 instruments, but doesn't provide their depths or elevations. The DDH90 instruments are classified as shallow piezometers in Table A1 of 2014 HydroSimulations assessment. The DDH90 data are not modelled in the 2012 Coffey assessments, perhaps because the piezometers are regarded as shallow instruments and outside the scope of those assessments.

The DDH90a pressure head varies between approximately 4 and zero metres, while the DDH90b head varies between approximately 4 and 6 metres. Given a low to zero pressure differential, down dip and down slope location and the distance from DDH90 to the Longwall 5 collapsed zone, which would be inclined away from the northern end of the extraction, it would seem unlikely that these instruments would respond to a collapsed zone intersecting the surface. The pressure gradient between the location of the standpipes and the surface to the north would be greater than that to the Longwall 5 collapsed zone. These instruments are unlikely to be the source of the data that HydroSimulations interpret as being in good agreement with the Ditton geology equation A zone height estimate for Longwall 5.

The HydroSimulations simulation of the standpipe hydrographs commences from a relatively low hydraulic pressure, corresponding to a large negative pressure head, and then rises approximately 30 metres to a zero head for DDH90a and a pressure head of approximately -7 metres for DDH90b. That is, the modelling does not reproduce the standpipe data.

The DDH90/S1877 vibrating wire piezometer shows depressurisation from March 2008, during the Longwall 4 extraction period, and then a notably sharp response to Longwall 5 in falling approximately 70 metres between December 2007 and January 2010, and 40 metres between October 2008 and January 2010. The piezometer then provides a lower bound for the height of the drainage zone above the Longwall 5 seam floor.

Of note, the 2016 HydroSimulations modelling fails to reproduce the response of the instrument to either Longwall 4 or 5. The simulated hydraulic head is near constant across the recording period, gradually rising from approximately 268 metres in September 2007 to 273 metres in December 2009.

The DDH90/S1877 piezometer elevation appears to be 250 metres[62] and that of the seam below the location of DDH90/S1877 appears to be approximately 115 metres. The seam elevation at the northern end of the extraction appears to be approximately 140 metres, suggesting the piezometer elevation corresponds to an approximately 110 metre height over the extraction's northern centreline. This provides a lower bound for the height of the drainage zone. That is, the DDH90/S1877 vibrating wire piezometer data suggests the height of the drainage zone over the northern section of Longwall 5 would be somewhere between 110 metres above the seam and the surface.

As noted above, HydroSimulations give conflicting depths of 121 and 141 metres for the vibrating wire piezometer, while Coffey gives the depth as 136 metres. Elevation and depth of cover contours[67] suggest that a DDH90 instrument depth of 121 metres would have a corresponding height of approximately 125 metres above the centreline of the northern quarter of the Longwall 5 void floor. This is suggestively similar to the 123 metre ‘observed’ A zone height for Longwall 5 given in Table A6.5 of Ditton’s 2014 Springvale assessment.[26] The 2015 HydroSimulations height of connected fracturing report states:

> “*HydroSimulations (2014) comments on a good match between observed data above Longwall 5 and the predictions of the Ditton (2013) method for estimating the height of connected fracturing. Using the ACARP (2003) database, Ditton (2012/13) provides an observed height of fracturing at 123 m, and calculates a mean height of fracturing at 122 m. The revised Ditton ‘Geology model’ (Ditton and Merrick, 2014) estimates a mean A of 124 m based on t’=32 m (updated for this project to t’=30 m based on Southern Coalfield data in Ditton and Merrick, 2014), which is in good agreement with the Ditton (2013) estimate and observed data*.”

This suggests that HydroSimulations might have used a depth of 121 metres for the DDH90/S1877 vibrating wire piezometer, corresponding to a height above the extraction centreline of 123-125 metres, and have assumed its sharp and substantial response to Longwall 5 identifies the peak of the A zone. If so, HydroSimulations would seem to be mistaken. A marked response from a single piezometer cannot of itself be used to identify the height of the A/collapsed zone. Compounding this limitation, the DDH90 vibrating wire piezometer is an off-panel instrument at some distance and, it would appear, ‘down dip’ from the collapsed zone.

Data from the DDH90/S1877 vibrating wire piezometer cannot be used to credibly identify a likely height of the drainage zone over Longwall 5; at best the data provide an uncertain lower bound.

15.1.8. Longwall 5 - DDH117/S1953 and DDH116

Also labelled S1953, in sitting over the western pillars of Longwall 5 (see Fig. 28) the multi-piezometer bore DDH117/S1953 is significantly closer to the Longwall 5 collapsed zone than is the DDH90 site. The bore hosts eight piezometers and the distance from the bore to the panel’s centre-line is approximately 145 metres.

DDH117 is used as a calibration target in the Coffey assessment and is shown on the map provided in Drawing 2 of the October 2012 Coffey assessment (Fig. 28 below). As bore S1953 it’s also shown in the end of panel reports for Longwalls 6 to 11 (see Fig. 31 below); these reports were prepared by HydroSimulations and, under its prior trading name, Heritage Computing.

It's then puzzling that the bore is not shown in the map provided in the March 2014 HydroSimulations groundwater report (see Fig. 27) and is not represented in the graphs appended to that report. Likewise, the bore does not appear to have been used in the 2016 update of the modelling.[24]

Though the bore is highlighted in Figure 21 of the 2016 Area 3B groundwater assessment (Fig. 24 below), hydrographs are not included in that report. Though the proximity of the bore to the Longwall 5 drainage zone would present a modelling challenge, its data is reasonably well reproduced in the Coffey work (see Fig. 32). The exclusion of these piezometers from the HydroSimulations modelling suggests the possibility that HydroSimulations have been unable to model the data from this bore.

The Coffey hydrographs (see Fig. 32) show that during the extraction of Longwall 5 the piezometers placed at 83, 118 and 132 metres below the surface show marked pressure loss occurring at essentially the same relatively rapid rate, indicating all are horizontally in line with and at a similar distance from the extraction's drainage zone (see above). Piezometer 3 is 83 metres below the surface and recorded a rapid and significant fall of approximately 21 metres before failing as the longwall approached. The pressure head recorded by the shallowest instrument, 10 metres below the surface, falls approximately five metres from about 10 metres to a fluctuating pressure head of approximately 5 metres. The instrument at 39 metres below the surface appears to be dry or failed before responding to the extraction. The piezometers appear to have been installed after the extraction had commenced in December 2008 and all but the surface instrument apparently fail from about August 2009, at which time the approaching longwall face would appear to have been approximately 120 metres south of the bore site.

Of concern, the instruments at 118 and 132 metres fall below the level of Cordeaux Reservoir before failing and it's likely that at 83 metres would have done likewise.

The reduced pressure recorded by the instrument at 10 metres below the surface, following the passage of Longwall 5, persists for the more than 12 months to the end of the recording period given in the Coffey hydrograph. The bore is located on a gentle slope to the west, so the reduced pressure head could reflect increased discharge, as a result of increased horizontal conductivity, to the sloping surface to the west of the bore. Alternatively the response may reflect eastward horizontal discharge to a Longwall 5 drainage zone having an equivalent or greater height above the seam that the piezometer. Noting the bore is located over the western pillars of Longwall 5, the lateral distance from the piezometer to the sloping surface to the west appears is greater than to the edge of the extraction. Additionally, the horizontal conductivity between would seem more likely to be greater to the east than to the west.

A third possibility is that the pressure head loss reflects primarily vertical leakage into the surface fracture zone to a depth where the enhanced vertical conductivity (secondary porosity) is diminished and primarily horizontal leakage to the drainage zone is favoured.

Vertical drainage is unlikely to be significant at the piezometer 83 metres below the surface. Accordingly the DDH117/S1953 piezometers indicate that the drainage zone over Longwall 5 has a height equivalent to somewhere between 83 metres below the surface and the surface at DDH117/S1953. Providing a lower bound for the height of the drainage zone above Longwall 5, the elevation of the instrument 83 metres below the surface appears to correspond to a height over the longwall floor centreline of approximately 177 metres. That of the shallow instrument appears to correspond to a height of 250 metres.

In the November 2012 Coffey data analysis report[3] Tammetta provides extensometer data from a bore over Longwall 5 that's close to DDH117. The data from this bore, DDH116, indicate a collapsed zone height of between 200 and 220 metres.

As noted above, Ditton's tabulation[26] records a measured A zone height of 123 metres for Longwall 5. This height is clearly not consistent with the data provided by the DDH117/S1953 and DDH116 instruments.

Assuming the maximum cutting height of 3.75 metres was used in the vicinity of DDH117/S1953, Ditton's geometry equation estimates an A zone height of 117 metres, while the geology equations provides estimates of 125 metres with an adjustment parameter of 32 and 128 metres with an adjustment parameter of 30. Using the same mining parameters the Tammetta equation returns an estimate of 272 metres (an adjustment term is not needed for the Tammetta equation).

If the average extraction height of 3.4 metres has instead been used in the in the vicinity of DDH117/S1953, Ditton's geometry equation estimates an a zone height of 113 metre, while the geology equations provides estimates of 120 metres with an adjustment parameter of 32 and 123 metres with an adjustment parameter of 30. Using the same mining parameters the Tammetta equation returns an estimate of 240 metres.

While the Tammetta equation estimates are consistent with the DDH117 and DDH116 data, those of the Ditton equation are not. Successful modelling of piezometer data that sensitively reflect an underlying or nearby extraction would demand a reliable estimate of the drainage zone height. As Figure 32 below shows, the October 2012 Coffey modelling captures the DD117 behaviour.

15.1.9. Longwalls 6 and 8 – DDH97/S1889 and DDH92/S1879

Joint consideration of DDH97 and DDH92 is prompted by a September 2012 Pells and Pells paper[4] discussing the propagation of mining induced redirection and loss of groundwater. The paper includes a comparative assessment of data from the two bores. Referring to a 2011 report by Merrick and Akhter, the paper incorrectly located the bores as being "*just adjacent to the first two longwalls in Area 3A*". As detailed below, the bores have significantly different distances to the Area 3A extractions and the Pells and Pells interpretation of the piezometer data is correspondingly compromised. The paper was written during the extraction of Longwall 8 and is then not informed by the groundwater impact of that extraction.

Longwall 6 was mined between the 9th February 2010 and the 28th March 2011, with a void width of 250 metres and a maximum extraction height of 3.9 metres[69]; the cutting height profile is not available. Longwall 7 was mined with the same width and maximum height between the 4th of May 2011 and the 23rd January 2012. The void width was increased to 305 metres for Longwall 8; extraction commenced on the 24th of February 2012 and was completed on the 29th of December 2013.

Bore DDH97, also known as S1889, is located nearly half way along the length of Longwall 7, around 80 metres north of the northern edge of its southern pillars and 217 metres south of the southern edge of the Longwall 6 goaf and 318 metres south of the centre of the Longwall 6 goaf.

Also known as S1879 and DEN92, the DDH92 bore is laterally (essentially south) approximately 710 metres from the centreline of Longwall 8, about 400 metres longitudinally along the 2,214 metre long panel and approximately 810 metres from the western end of the extraction's centreline (see Fig. 28). The bore is about 820 metres to the east of the yet to be extracted Longwall 13 in Area 3B.

Hydrographs are not provided for the data from DDH97/S1889 in either the 2014 or the 2016 HydroSimulations groundwater assessments, however they are provided in the Area 3A end of panel reports. The DDH97/S1889 hydrographs period in the November 2012 Coffey data analysis terminate before the extraction of Longwall 6.

Table C2 in the November 2012 Coffey data analysis report lists eight piezometers for the DDH97/S1889 bore, and hydrographs for seven of these are provided in the Longwall 7 end of panel report. Missing is representation for a piezometer at 347 metres below the surface. The deepest instrument is in the Wongawilli coal seam.

Presumably reflecting failure, the hydrographs provided in the HydroSimulations groundwater assessment for the Longwall 8 end of panel report for the DDHH97/S1889 instruments at 10, 123 and 159 metres below the surface terminate around July 2011. The hydrographs for the four deeper instruments terminate in November 2011. The DDH97/S1889 data terminates before showing a response to the extraction of Longwall 7. The instrument in the coal seam shows a pressure loss to zero pressure head during the extraction of Longwall 5, while the near surface instrument appears to be dry throughout the recording period. Remarkably the instrument at 159 metres below the surface, in the upper Bulgo Sandstone, appears to respond to the extraction of Longwall 4.

All five of the piezometers between the deepest and the shallowest show a clear response to the mining of Longwall 6, including the lower Hawkesbury Sandstone instrument placed at 123 metres below the surface (see Figs 33 and 34). Though this instrument appears to undergo a significant pressure head loss of more than 50%, it is not highlighted in Figure 21 of the 2016 HydroSimulations area 3B assessment and may not be represented in Figure 21 (Fig. 24 below).

Pells and Pells refer to the DDH97 piezometer data, commenting that it "*shows a significant, and upward expanding depressurisation through the whole profile*". The description suggests a sequential upward progression, however hydrographs show that the depressurisation reported by the functioning instruments occurs at much the same time. The lower Hawkesbury Sandstone instrument appears to lead slightly, while the upper Bulgo Sandstone instrument lags somewhat.

The authors contrast the relatively rapid depressurisation reported by DDH97 with what they assess as being limited vertical depressurisation reported by piezometers in bore DDH92. In contrasting the two data sets the authors mistakenly place the two bores at similar distances with respect to Longwalls 6 and 7. While DDH97 is approximately 318 metres south of the centre of Longwall 6, DDH92 bore is approximately 1,318 metres from the centreline of Longwall 6, 1,027 metres from the centreline of Longwall 7 and 710 metres from the centreline of Longwall 8. The significant difference between the location of DDH97 and DDH92 would account for the instrument response differences that Pells and Pells, unaware of the difference, assume reflects the presence of unusual geological structures in the vicinity of DDH97.

Preceding the extraction of Longwall 8, the Pells and Pells paper discusses DDH97 and DDH92 in the context of the Longwall 6 and 7 extractions. As noted above, the DDH97 instruments evidently fail before responding to the mining of Longwall 7.

Hydrographs for DDH92/S1879 provided in the November 2012 Coffey data analysis report cover the period from first recordings in mid-2007 through to early 2010. Hydrographs provided in the March 2016 HydroSimulations groundwater assessment extend that coverage to September 2015 and the hydrographs in the Longwall 11 end of panel report extend to March 2016. Remarkably, given a distance of approximately 3.5 kilometres, the data show steady pressure loss of around 35 metres a year in the upper Scarborough Sandstone that commences in mid-2008, during the extraction of Longwall 4 in Area 2. This suggests a principally horizontal draw, moderated by distance.

Of note, DDH92 is approximately 2.5 kilometres north east of the eastern end of the northern most Elouera domain extraction; Longwall 8. The available hydrographs however don’t include the period of the earlier Elouera extractions. In their contribution to the Longwall 7 end of panel report, HydroSimulations advise “*there is no significant prior depressurisation caused by these workings*”. Provision of hydrographs for the period of the extraction of at least Elouera Longwall 8 would allow an assessment of the rate, timing and significance of the groundwater impacts arising from the Elouera mining.

Pressure loss in the available hydrographs for DDH92/S1879 commences in the upper Bulgo Sandstone, at a depth of 97 metres, in mid-2010 during the extraction of Longwall 6. HydroSimulations characterise[24] the pressure loss in the Bulgo Sandstone as “*Step-declines in pressure following Longwalls 6, 7 and 8*”. Longwall 8 triggered a pressure loss of 8 metres[24] in the lower Hawkesbury Sandstone piezometer from the second quarter of 2012. The reporting instrument is at a depth of 43 metres according to the HydroSimulations report and 48 metres according to the Coffey report. A relatively rapid and near simultaneous pressure reduction in the lower Hawkesbury Sandstone and in the Bulgo Sandstone reported by the DDH92/S1879 instruments, suggests the decline principally reflects significantly increased horizontal conductivity associated with the extraction of Longwall 8.

The response of the DDH97/S1889 instrument at 123 metres below the surface points to a drainage zone reaching somewhere between 264 metres above the Longwall 6 floor and the surface. The surface is approximately is 361 metres above the seam. Assuming the extraction height was 3.9 metres, the maximum used for Longwall 6, the Ditton geology equation provides a most likely A zone height estimate of 154 metres, while the Tammetta equation returns a most likely drainage zone height estimate of 307 metres. Assuming the extraction height was 3.4 metres, the average used[62] for Longwall 6, the Ditton geology equation provides a most likely A zone height estimate of 145 metres, while the Tammetta equation returns a most likely drainage zone height estimate of 258 metres. The S1889 data are not in accord with the Ditton equation.

The response of the DDH92/S1879 instrument at 48 metres below the seam suggests a drainage zone reaching somewhere between 284 metres above the Longwall 8 floor and the surface; the height of the surface above the seam is approximately 353 metres. Assuming the extraction height was 3.9 metres, the maximum used for Longwall 8, the Ditton geology equation provides a most likely A zone height estimate (A50) of 165 metres, while the Tammetta equation returns a most likely drainage zone height estimate of 366 metres. Assuming the extraction height was 3.6 metres, the average used[62] for Longwall 8, the Ditton geology equation provides a most likely A zone height estimate of 159 metres, while the Tammetta equation returns a most likely drainage zone height estimate of 331 metres. The DDH92/S1879 data are not in accord with the Ditton equation

15.1.10. Longwall 6 – DDH86/S1871

The DDH86/S1871 site is located over the northern first workings of Longwall 6, laterally approximately 50 metres from the eastern (completion) end, approximately 109 metres north of the longwall goaf edge and 210 metres north of the centreline. Hosting 12 piezometers, the bore is then beyond the desaturated zone above Longwall 6. In being in a saturated medium (see Fig. 3) the bore’s piezometers would not ordinarily be expected to become dry as a consequence of the extraction of Longwall 6.

Hydrographs for the bore’s piezometers are not provided in either the 2014 or the 2016 HydroSimulations groundwater impact assessments for Area 3B, but are provided in the Area 3A end of panel reports. The DDH86/S1871 hydrographs in the Longwall 8 end of panel report show that all of the DDH86/S1871 piezometers respond to the extraction of Longwall 6 as it approaches and reaches completion on the 28th of March 2011. The near surface instruments located 10, 31.3 and 40 metres below the surface show a sharp response in falling and equilibrating at a reduced pressure head in response to Longwall 6. The piezometers at 253, 275, 285.2 and 321.9 metres below ground additionally return a clear response to the extraction of Longwall 5.

The instrument at 88 metres below the surface reports a sharp but small initial fall followed by a steady loss of pressure head, taking some 21 months to fall from approximately 30 metres to zero or close to zero; a loss rate of approximately 17 metres a year.

In contrast the next deepest piezometer, located 134 metres below the surface, responds relatively sharply with fall of approximately 30 metres in about six weeks. The pressure head then continues to drain at a rate similar to that of the instrument at 88 metres below the surface.

There appear to be two possibilities for the response of the instrument at 88 metres below the surface:

(i) The drainage zone extends to height greater than that of this piezometer and the slow response reflects relatively modest horizontal conductivity between the bore and the collapsed zone than reflected in the instrument at 134 metres below the surface.
(ii) The drainage zone peak is just below the elevation of the piezometer and its pressure loss response is accordingly being controlled by primary porosity limited vertical conductivity.

The response of the instruments in bores DDH97, DDH84 and DDH85 circumstantially favours the first possibility. The DDH86/S1871 data then point to a drainage zone somewhere between 228 metres above the coal seam immediately below the bore and the surface. The surface is approximately 333 metres above the coal seam.

The maximum extraction height used for Longwall 6 is reported to have been 3.9 metres, however the cutting height profile along its length isn’t available. In estimating the drainage zone height of past extractions for the November 2012 Coffey groundwater assessment for Area 3B, Tammetta used[62] an average height of 3.4 metres for this extraction. In the absence of the extraction height profile information, the 3.9 maximum and 3.4 metre average suggest a minimum cutting height of 2.9 metres. The Ditton A zone (t’ = 30) and Tammetta drainage zone height estimates for these extraction heights, with a depth of cover of 330 metres and void width of 250 metres, are given in Table 4. Of note, the slope of the collapsed zone, and hence drainage zone, slopes inward toward the panel centre more from the completion end than from the commencement end. That is, the peak height of the drainage zone over the eastern section of Longwall 6 will occur some distance before the completion line. A distance of 200 metres is assumed is identifying the parameters needed for the calculation of drainage zone height estimates.

In contrast to the Ditton equation, the Tammetta equation is not challenged by the DDH86/S1871 data.

15.1.11 Longwalls 6 and 7 and 8 – TARP bore DDH84/S1867

Also referred to as S1867 and DEN84, the piezometers in bore DDH84 respond to all three of the Area 3A extractions. The bore is approximately 280 metres east of the eastern end of the Longwall 6 centreline, 380 metres from that of Longwall 7 and 630 metres from that of Longwall 8. The distances to the peaks of the eastern section of the drainage zones above each extraction will be greater. The bore is approximately 35 metres north of the pillars separating Longwalls 6 and 7.

The DDH84/S1867 bore is one of four piezometer bores used as groundwater TARP (Trigger Action Response Plan) reference sites for the current Dendrobium mining. The others are DDH85/S1870 (Section 15.1.12), DDH119/S1992 (Section 5.1.12) and DDH120/S1994 (this section). The TARP bores are further discussed in Section 15.1.20.

The March 2016 HydroSimulations groundwater assessment incorrectly states the bore is "*Over Longwall 6 in Area 3A*" (see Fig. 49). In being approximately 127 metres west of Cordeaux Reservoir, the bore is closer to the reservoir than it is to the completion end of Longwall 6. The bore is approximately 144 metres from Sandy Creek waterfall.

The following description provided by HydroSimulations in their March 2016 groundwater assessment only partly captures the response of the DDH84/S1867 instruments and incorrectly suggests the longwall passed by the bore:

> ***"HBSS**: No response during Area 2 mining; ~ 1 m decline in groundwater level at end of longwall 6; gradual decline of 3 m during Longwalls 7 and 8; ~2 m decline in lower BGSS at the end of Longwall 8; no response to Area 3B mining. **BGSS & SBSS:** Gradual depressurisation due to mining at Area 2 prior to 2010; Increase in pore pressures as Longwall 6 passed beneath piezometer (compression), then depressurisation as successive panels passed the piezometer.*"

The hydrographs provided in the end of panel report for Longwall 11 show the near surface piezometers report small but sharp pressure head loss in response to Longwalls 6, followed by slow drainage. The drainage flattens out after the completion of Longwall 8, from when fluctuations presumably associated with increased rainfall sensitivity are evident. The most likely place of discharge would appear to be the sloping surface to the east of the bore site.

The piezometer at 88 metres below the surface shows a sharp response to each of Longwalls 6, 7 and 8. Puzzlingly, between the relatively rapid reductions over some four to six weeks near longwall completion, the pressure head then slowly rises over the course of the following year or so and completion of the next extraction and subsequent pressure loss. The rapid fall associated with Longwall 7 is large at about 20 metres. Between the fall associated with Longwall 6 and that of Longwall 7, the pressure head appears to rise approximately seven metres over 10 months. Following the December 2012 completion of Longwall 8, the subsequent slow pressure head rise begins to flatten midway through 2013. The net loss in pressure head from the commencement of Longwall 6 in February 2010 appears to be approximately 10 metres.

The DDH84/S1867 instrument at 100 metres below the surface shows a relatively sharp pressure head rise of approximately 20 metres towards the end of the extraction of Longwall 6. This rise flattens out with the completion of the extraction and is then followed by a relatively small but sharp drop on the completion of Longwall 7 and again on completion of Longwall 8. The pressure head reported by this instrument then slowly declines though to the end of the period covered by the hydrograph in January 2016. The net loss over the period from the initial pressure head rise in August 2010 to January 2016 appears to be about 30 metres.

In the quote above HydroSimulations attribute the pressure rise to compression associated with the extraction of Longwall 6. A similar response is reported by the piezometer at 99 metres below the surface in nearby TARP bore DDH120/S1994. The instrument at 55 metres below the surface appears to be faulty and all become increasingly unreliable from 2013. Located approximately mid-way between the northern and southern Longwall 6 pillars, DDH120 is approximately 100 metres from the edge of the reservoir and so slightly further from the end of Longwall 6 than is DDH84/S1867. DDH120 is approximately 95 metres north east of DDH84.

Given relief would require passage of the longwall face and that this is not possible for piezometers beyond the completion end of an extraction, persistent compression effects may well account for the response of the DDH84/S1867 and DDH120/S1994 instruments respectively at 100 and 99 metres below the surface. While it may be correct, the suggested (quote above) compression effect persisting until the completion of Longwalls 7 and 8 doesn’t seem to be an entirely satisfactory explanation. The effect is not seen in the instruments of DDH85/S1870 (Section 5.1.12), which is approximately 190 metres to the east of the eastern end of Longwall 7 and close to the pillars separating Longwall 7 from Longwall 8. DDH85/S1870 is closer to Longwall 7 than it is to the reservoir, whereas the converse is the case for DDH84/S1867. The effect is not seen in the DDH85/S1870 piezometers.

Compression doesn’t seem to account for the behaviour of the DDH84/S1867 instrument at 88 metres below the surface. The behaviour of this instrument suggests a change in the hydrogeology at this level that results in a degree of recharge sufficient to slightly more than counter both the Area 2 drainage influence evident before the commencement of Longwall 6 and the increased drainage arising from the Area 3A extractions. If so, the change is not reflected in the behaviour of the near surface instruments. The behaviour might be related to the close proximity of the reservoir, but is not seen in the DDH120/S1994 instrument at 55 metres below the surface, which corresponds to an elevation of 291 mAHD and would appear to be close to the low water level of the reservoir.

The DDH120/S1994 instrument at 55 metres below the surface doesn’t show a clear response to the Area 3A mining, though there is a pressure head decline of about 5 metres over the course of the extraction of Longwall 6. The behaviour of this instrument contrasts the clear mining response of the DDH85/S1870 instrument at 55 metres below the surface and having an elevation of 296 mAHD. Though the DDH120/S1994 instrument is much closer to the reservoir than is the DDH85/S1870 instrument, there is no obvious pressure head correlation with the reservoir water level. Perhaps correlation is masked by the depressurisation.

Of note, the November 2012 Coffey data analysis report[62] characterises DDH120/S1994 as returning “*BAD DATA*”. This is reflected in the very patchy hydrographs provided in Figure 2.19 of the groundwater assessment for the Longwall 11 end of panel report. The hydrographs suggest that the pressure head reported by the instrument at 99 metres below the surface had fallen to the level of Cordeaux Reservoir by January 2016.

The DDH84/S1867 piezometers in the Bulgo Sandstone at 100 and 150 metres below the surface and the DDH120/S1994 Bulgo Sandstone instrument at 99 and 148 metres below the surface both report a pressure head decline to below the stored water level of Cordeaux Reservoir and, accordingly a Level 2 TARP alert has been triggered.

Also of note and triggering a Level 2 alert, the Bulgo Sandstone piezometers at 93 and 142 metres below the surface in TARP bore DDH119/S1992 also fell below the Cordeaux Reservoir level as a consequence of the Area 3A mining. This bore is approximately 150 metres north east of the fourth of the Dendrobium TARP bores, piezometer bore DDH85/S1870. All three instruments in this bore fall below the water level of Cordeaux Reservoir as a consequence of the Area 3A mining, triggering a Level 3 TARP alert. DDH85/S1870 is discussed in Section 15.1.12. The TARP bores are also discussed in Section 15.1.20X.

The sharp responses of the DDH84/S1867 piezometer 88 metres below the surface provides a lower bound, from this bore, for the heights of the drainage zones above Longwalls 6, 7 and 8 respectively of 196, 196 and 191 metres. The DDH85 instrument at 55 metres below the surface provides lower bounds of 236, 234 and 229 metres respectively for the drainage zone heights of Longwalls 6, 7 and 8 (discussed in Section 15.1.12).

As discussed in Section 15.1.9, the DDH97/S1889 instrument at 123 metres below the surface provides a lower bound of 264 metres for the drainage zone height of Longwall 6. The DDH92/S1879 instrument at 48 metres below the surface provides a lower bound of 284 metres for the drainage zone height of Longwall 8; see Section 15.1.9.

The drainage zone height estimates provided by the Ditton and Tammetta equations for the Area 3A Longwalls are included in Table 4, together with the lower bounds suggested by the instruments in DDH84/S1867, DDH85/S1870, DDH86/S1871, DDH97/S1889 and DDH92/S1879. The estimates provided by the Ditton equation are challenged by the piezometer data.

15.1.12. Longwalls 6, 7 and 8 – TARP bore DDH85/S1870

HydroSimulations incorrectly list[24] the bore as being located over Longwall 7 in their 2016 Area 3B groundwater assessment. The bore appears to be located approximately 10 metres north of the pillars that separate Longwall 7 from its southern neighbour, Longwall 8 (see Fig. 49). The bore is approximately 300 metres from the eastern end of the Longwall 8 centreline. DDH85 hosts 12 piezometers and serves as one of four groundwater impact TARP trigger bores for the current Area 3B mining.

Longwall 7 was extracted between the 4th of May 2011 and the 23rd of January 2012, while Longwall 8 commenced on the 24th of February 2012 and was completed on the 29th of December 2013.

15.1.12.1. HydroSimulations expectation of piezometer drainage

Referring to the 2007 GHD hydrogeological assessment[57] for Area 3A, a 2011 Heritage Computing (now HydroSimulations) groundwater assessment for Dendrobium that's not publically available, the 2015 Parsons Brinckerhoff height of fracture assessment for Area 3B Longwall 9 and the Heritage Computing and HydroSimulations end of panel reports for Dendrobium, HydroSimulations provide the following problematic assessment[21] of the DDH85/S1870 piezometer data in their 2015 connected fracture zone report:

> “*While these studies report significant depressurisation in strata closely overlying the mined seam, with significant decreases in head often seen in the Bulgo Sandstone, complete groundwater drainage, as was conceptualised in Coffey (2012b), is not observed. Data from bore S1870, located on the eastern edge of Area 3A near Sandy Creek and 100 m east of Longwall 7 and 40 m North of Longwall 8, is assessed in HydroSimulations (2015). At this location, the Tammetta (2013) ‘Collapsed Zone’ was predicted to reach the surface, however the groundwater levels in shallow piezometers in S1870 do not show complete groundwater drainage. Instead, a decrease in head up to 80 m is observed in units below the Stanwell Park Claystone; a decrease in head of approximately 30 m in the Bulgo Sandstone; while heads in the overlying Hawkesbury Sandstone are very close to pre-mining conditions.*”

Where “*HydroSimulations (2015)*” refers to their end of panel groundwater assessment[70] for Dendrobium Longwall 10. The above comments from HydroSimulations give cause for concern.

As noted above, DDH85/S1870 appears to be about 190 metres beyond the eastern end of the Longwall 7 extraction; not 100 metres as the quote suggests. The consultants may not have taken into account the completion of Longwall 7 at maingate cut through 10, some 100 metres short of the planned finishing line.[71] The bore is located immediately to the north of the 40 metre wide southern pillars that separate Longwalls 7 and 8. As noted above, the consultants incorrectly and misleadingly list the bore as being over Longwall 7 in their 2016 Area 3B groundwater assessment. The bore is also approximately 220 metres east of the northern corner of the Longwall 8 void and 300 metres from the eastern end of the extraction centreline.

The location of bore DDH85/S1870 places the instruments beyond the collapsed/drainage zones of Longwalls 7 and 8. Of significance, the collapsed zone arcs away from the end of an extraction (see Fig. 4(b)) and this increases the distance between bore and the eastern peak of the Longwall 7 and 8 collapsed/drainage zones.

The medium around the piezometers of DDH85/S1870 would then be expected to be saturated (see Fig. 3). Whether or not the drainage zones of Longwalls 6, 7 and 8 intersected the surface above these extractions, in the absence of other factors the DDH85/S1870 piezometers located at 10, 15 and 23 metres below the surface[42] would not be expected to show complete groundwater drainage. It’s puzzling that HydroSimulations suggest otherwise and it may be that they do not understand Tammetta’s work.

15.1.12.2. HydroSimulations suggestion of Tammetta equation expectation of surface intersection by the drainage zone

In the quote given above HydroSimulations state: *At this location, the Tammetta (2013) ‘Collapsed Zone’ was predicted to reach the surface*”. The comment doesn’t specify where this prediction is made, though it appears to suggest the prediction came from Tammetta. The “*Tammetta (2013)*” reference refers to Tammetta’s 2013 Groundwater paper[16], which describes the origin of his collapsed zone height equation but doesn’t consider extractions at Dendrobium. The quote in Section 15.1.12.1 also refers to the November 2012 Coffey data analysis report[62]; “*Coffey (2012b)”*. This assessment accompanied and underpinned the numerical analysis[36] that BHP-Billiton and South32 have refused to make available to the agencies and public. As discussed in Section 19, the important November 2012 numerical analysis report, which will contain impact assessments, and its partner were not made available in the lead up to the 2013 approval for the mining now underway in Area 3B. The data analysis report has however recently been made available, following a request for assistance in obtaining a copy of the numerical analysis report made to the Department of Planning and their consequential request to South32.

Figure 41 (see Figure 23 below) in the November 2012 Coffey data analysis report depicts the relationship of the Tammetta equation estimated height of the drainage zone for all of the Dendrobium longwall extractions, with respect to the surface projection of those extractions. Presumably intended to be indicative rather than detailed, given it covers all of the Dendrobium domains, the average cutting height of each extraction (Table 10 in the Coffey report) was used in applying the Tammetta equation for the report's Figure 41 depiction.

The figure shows that the Tammetta equation estimates that the drainage zone would have intersected the surface at the eastern (completion) end of Longwall 8. This then seems likely to be the 'prediction' referred to by HydroSimulations in the quote given above. If so, HydroSimulations overlook the context and intent of Figure 41 (Fig. 23 below), which was not provided in the context an assessment of Longwall 8 or the response of the piezometers in bore DDH85/S1870.

Importantly, Figure 41 in the Coffey report doesn't suggest that the Longwall 8 drainage zone extends northwards from the extraction to reach the surface at DDH85/S1870; as noted above, DDH85/S1870 is some distance from both the Longwall 7 and 8 drainage zones.

A proper assessment of the response of the DDH85/S1870 piezometers with respect to the drainage height estimates from the Tammetta equation and the A zone height estimates from the Ditton equations, would utilise the cutting height profile for at least the final quarter of Longwall 8. This information would presumably have been made available to HydroSimulations on request, if not otherwise provided, and it's then puzzling that this information hasn't informed the DDH85/S1870 comments made by HydroSimulations.

As a consequence of this significant shortcoming in the HydroSimulations assessment, the comments made by HydroSimulations are misleading. It's not possible to determine whether or not the Tammetta equation estimates that the drainage zone would intersect the surface at the eastern end of Longwall 8 without knowledge of the cutting height profile. The mining company has not responded to a request for the cutting height profiles used at the mine.

Though compromised by data loss during the extraction of Longwall 8, some insight is provided by the DDH85/S1870 piezometers.

15.1.12.3. Implications of the DDH85/S1870 piezometer responses

Noting the collapsed zone arcs inwards away from the completion end (see Fig. 4(b)) of an extraction, the responses of the DDH85/S1870 piezometer to Longwall 7 and 8 will be tempered by the distance from the bore site to the peak height of the drainage zones above the eastern ends of these extractions. The DDH85/S1870 site is approximately 190 metres from the end of the Longwall 7 extraction surface footprint and is likely to be at least 300 metres and possibly more than 400 metres laterally from the eastern drainage zone peak.

The HydroSimulations comments of 2015 quoted in Section 15.1.12.1 above appear to be detached from the following account of the behaviour of the DDH85/S1870 piezometers, given in their 2016 groundwater impact assessment for Area 3B:

“*Middle and upper HBSS: ~ 1.5 m decline in groundwater level at end of Longwall 6; ~3 m decline at the end of longwall 8;* ***Increase in rainfall response*** *range from 1.5 m to 3 m after longwall 8; No response in Lower HBSS; no response to Area 3B mining. BGSS & SBSS: Increase in pore pressures towards the end of longwall 3 (compression);* ***step-declines in pressure following Longwalls 6, 7 and 8****, beneath piezometer (compression), then depressurisation as successive panels passed the piezometer*.”; (bold emphasis added here).

Of note, contrary to the puzzling suggestion in the quote, no Area 3 extractions pass the bore site; the bore is located to the east of the completion end of the extractions (see Fig. 49). It’s also misleading to suggest no response in the lower Hawkesbury Sandstone. As Figure 35 indicates, the depth of the Hawkesbury Sandstone appears to be about 30 metres and the bore has piezometers at 10, 15 and 23 metres below the surface. Though muted, the response of the instrument at 23 metres below the surface largely mirrors that of the instruments above, which show increasing rainfall sensitivity from the completion of Longwall 6.

The 2016 HydroSimulations groundwater assessment provides three figures showing hydrographs for DDH85/S1870; Figure 11 and 23, and an additional figure in Appendix C. Figure 11 in the report provides the clearest representation of the piezometer data. Figure 2.17 from the Longwall 11 end of panel report presents the hydrographs with respect to the strata sequence (provided as Fig.35 below).

While showing a response to Longwall 6, data recording from the DDH85/S1870 piezometers underlying the instrument placed at 204 metres below the surface appears to have failed before providing a response to the Longwall 7 extraction. Recording from the instruments between 204 and 55 metres below the surface fails as they report a relatively sharp but modest pressure head fall in response to this extraction. Data collection resumed from July 2013, during the extraction of Longwall 9. It would appear that data were either not collected from DDH85/S1870 during the extraction of Longwall 8, or the data has been lost.

Figure 36 below was obtained by digitising Figure 11 from the 2016 HydroSimulations report and MSEC contours maps were then used to obtain the pressure heads represented in the figure. The pressure heads in particular add insight to the comments from HydroSimulations.

Figures 35 and 36 reflect an initially slow decline in the pressure recorded by the DDH85/S1870 piezometer at 55 metres below the surface (Piezometer 4) that commences with the start of Longwall 4.

Reflecting its location to the east of the Area 3A longwalls, the decline steepens slightly in response to the completion of Longwall 6, again on completion of Longwall 7 and continues into early 2016 - the end of the period covered by the hydrographs provided in Figure 11 of the 2016 HydroSimulations groundwater impact assessment.[70] As Figure 36 indicates, between July 2009 and July 2015 this piezometer recorded an approximately 83% pressure head decline from approximately 35 metres to approximately 6 metres. The hydraulic head is by then approximately at the level of Cordeaux Reservoir. The elevation of this piezometer, Piezometer 4, is 296 metres (mAHD), in line with Cordeaux Reservoir. The instrument does not appear to be represented in Figure 21 of the 2015 HydroSimulations height of fracture report (Fig. 24 below). The loss of pressure reported by this relatively shallow piezometer would seem to signal a more than negligible loss of groundwater support for Sandy Creek and the storage reservoir.

The piezometer shows a relatively sharp rise and fall in pressure head as Longwall 6 nears completion and the rate of pressure loss then steepens slightly. The response to Longwall 7 is much the same, albeit with a sharper subsequent rate of pressure loss. The instrument's response is consistent with the approximately horizontal influence of the Longwall 6 and 7 drainage zones compounding that of the more distant Area 2 extractions.

Piezometer 4 records a larger pressure loss in response to Longwall 8 and slight reduction in the subsequent rate of pressure loss, reflecting the lower pressure head. The decline appears to flatten out as the pressure head approaches five metres.

The completion of Longwall 7 results in a marked decline in the pressure head reported by the Hawkesbury Sandstone instruments at 10 and 15 metres below the surface. This decline is not evident in the data from the instrument at 23 metres below the surface. As noted by HydroSimulations, all three Hawkesbury Sandstone piezometers report significant rainfall sensitivity following the completion of Longwall 8, rising and falling quickly by up to five metres (see Fig. 36). The piezometer at 10 metres below ground effectively became dry in January 2013, something that had not happened in the period from the start date of the hydrographs in October 2006. That is, the instrument did not become dry during the Millennium drought, but did so on the completion of Longwall 8.

The rise and fall in response to rain signals joint dilation and/or vertical fracturing and horizontal leakage to a sink. The sloping surface would be the closest sink to the piezometers at 10 and 15 metres below the surface. That may also be the case for the instrument at 23 metres below the surface, which has an elevation of the 328 metres. The nearest corresponding surface location would appear to be approximately 265 metres to the north east, not far from the Sandy Creek arm of Cordeaux Reservoir. The eastern end of the Longwall 8 centreline is approximately 300 metres away and the eastern peak of the drainage zone would be significantly more distant. Some of the water seeping out to the surface may still enter Cordeaux Reservoir, though with diminished quality.

The DDH85/S1870 piezometer data accordingly suggest the drainage zone height over the eastern section of Longwall 8 is somewhere between that of the piezometer 55 metres below the surface and the surface. That is, a height somewhere between approximately 229 and 273 metres above the extraction floor centreline in the eastern part of Longwall 8. The data do not appear to exclude the possibility of the drainage zone reaching the surface.

In the absence of knowledge of the cutting height profiles for Longwalls 6, 7 and 8, it's not possible to determine whether or not the DDH85/S1870 and S1871 data support or contradict the suggestion from HydroSimulations, that the Tammetta equation overestimates the height of the drainage zones over the Area 3A extractions. The DDH85/S1870 data do appear however to pose a significant challenge for the Ditton geology equation.

The Longwall 10 end of panel report has the following disturbing observation:

> *Bulgo Sandstone heads on the western side of Sandy Creek (adjacent to Area 2) have been reducing steadily since 2011, and in recent times some of these have fallen below the Cordeaux Reservoir water level. Based on the criteria set in the Avon and Cordeaux Reservoirs Management Plans for Dendrobium Mine, TARP Level 2 has been reached in four bores monitoring the Bulgo Sandstone near to where Sandy Creek flows into Lake Cordeaux. Further*

monitoring and some additional actions regarding data capture and review have been recommended.

The Longwall 11 end of panel report advises:

"*trigger Level 3 has been reached in S1870, with all Bulgo Sandstone piezometers recording groundwater levels lower than Cordeaux Reservoir lake level*"

The elevation of the 55 metres deep instrument is 296 metres (mAHD); the surface of Cordeaux Reservoir fluctuates between approximately 305 and 295 metres during the period of the hydrographs provided in the groundwater assessment for the Longwall 11 end of panel report.

TARP bore DDH119/S1992 is located approximately 150 metres north east of DDH85/S1870, approximately 86 metre west of Sandy Creek and approximately 146 metres south west of the Sandy Creek entrance to Cordeaux Reservoir; bore DDH119 is closer to the reservoir than is DDH85. Triggering a Level 2 alert, two of the three piezometers in DDH119/S1992 fell below the stored water level of the reservoir during the extraction of Longwall 10. The rate of pressure head decline reported by the shallowest of the three piezometers, that at 46 metres below the surface, is slower than returned by the other two instruments. The elevation of this piezometers is 291 metres (mAHD), placing it in line with the reservoir. The lower rate of pressure loss may reflect compression effects or perhaps a degree of support from the reservoir countering the depressurisation associated with the drainage zone. The DDH119/S1992 bore is closer to the reservoir than is DDH85/S1870, while the latter is closer to the nearest drainage zone that is DDH119/S1992. The DDH85/S1870 instruments do not record the pressure increase reported by the DDH119/S1992, which would seem to suggest the DDH119/S1992 response does not reflect compression effects. Proximity to the reservoir might also explain the behaviour of the Bulgo Sandstone piezometers in DDH84/S1867 and DDH120/S1994.

Figure 36 indicates that the pressure head recorded by the DDH85/S1870 instrument at 55 metres underground has been declining since at least 2008, with the extraction of Longwall 4 in Area 2. The Area 2 extractions are on the opposite side of Sandy Creek and its arm of the Cordeaux Reservoir. The comments from HydroSimulations quoted above don't incorporate or recognise the behaviour and implications of the DDH85/S1870 instruments at 10, 15, 23 and 55 metres below the surface. The Area 2 and Area 3A longwalls appear to have caused a significant diversion of groundwater that would otherwise be expected to contribute to Sandy Creek and Cordeaux Reservoir.

The TARP bores and trigger conditions are discussed further in Section 15.1.20.

15.1.12.4. Ditton and Tammetta equation estimates

The centreline depth of cover at the eastern end of the Longwall 7 extraction appears[72] to be approximately 310 metres. The extraction void width is 250 metres and the maximum extraction height was 3.9 metres. The extraction width of the adjacent Longwall 8 was 305 metres and again the maximum extraction height employed was 3.9 metres. As noted above, the extraction height profiles are not publically available.

With a distance of approximately 220 metres to the northern eastern corner of the Longwall 8 goaf, the distance from DDH85/S1870 to the drainage zone peak at the eastern section of Longwall 8 would seem likely to be least 350 metres and, depending on the slope of the collapsed zone slope at the completion end of the extraction, possibly more than 450 metres.

The lack of knowledge of the cutting height profiles for Longwall 6, 7 and 8 greatly compounds the interpretation limitations imposed by the off-panel nature of the DDH85/S1870 instruments. It’s accordingly only possible to make an indicative assessment of the piezometer response with respect to drainage and A zone height estimates respectively provided by the Tammetta and Ditton equations. Table 4 lists the Ditton geology equation and Tammetta equation height estimates for Longwalls 7 and 8, for the maximum extraction height of 3.9 metres, the 3.6 metres average extraction height and an assumed minimum extraction height of 3.3 metres. In the absence of cutting profiles for the longwalls, the minimum height actually used for each extraction is not known.

Assuming the eastern most peak of the collapsed zone, at the point it begins to drop towards the completion point, is 200 metres from the extraction’s completion line, the corresponding depth of cover over Longwall 7 and 8 is respectively 310 and 270 metres. These depths were used in obtaining the results given in Table 4.

The DDH85/S1870 piezometer at 55 metres below the surface corresponds to a height over the seam at the eastern end of the centrelines of Longwalls 7 and 8 of approximately 228 metres. This is approximately the same height as that of the S1871 piezometer at 88 metres below the surface, with respect to Longwall 6. As suggested in Section 15.1.12.3, the response of the DDH85/S1870 piezometer at 55 metres below the surface suggests it’s above but close to the height of the eastern sections of the drainage zones over Longwalls 6 and 7.

The piezometer’s response to Longwall 8 suggests the height of the Longwall 8 drainage zone is equal to or greater than the piezometer’s approximately 228 metre height above the seam floor. The Tammetta equation estimates given in Table 4 are all above this height, while the Ditton equation estimates are below. The height of the surface over the Longwall 8 centreline appears to be approximately 273 metres. The DDH85/S1870 data do not exclude the possibility that the drainage zone reaches the surface over the eastern part of Longwall 8.

The Tammetta equation estimates that a cutting height of 3.15 metres would result in a drainage zone height of 228 metres over Longwall 7, while a cutting height of 2.79 metres would give that height over the wider Longwall 8.

The Ditton geology equations estimate, with t’=30, estimates that an extraction height of 10.6 metres would result in an A zone height of 228 metres over the eastern end of Longwall 7 and an extraction height of 10.4 metres would return this height over Longwall 8. Alternatively, reducing t’ to 8.78 would return an A zone height estimate of 228 metres for a 3.6 metre high Longwall 8 extraction, while using t’ = 8.66 would provide the same A zone height estimate for a 3.6 metre high Longwall 7 extraction. There are no indications of unusual geology over the eastern end of Area 3A; HydroSimulations have used t’=32 and 30 in their considerations of Longwall 5, which is not far from the eastern ends of the Area 3A extractions.

The Ditton geology equation appears to be contradicted by the data from DDH85/S1870.

15.1.13. Longwall 9 - DDH105/S1910

Longwall 9 was extracted with a void width of 305 metres and a maximum cutting height of 3.7 metres between the 9^{th} of February 2013 and the 2nd June 2014. The total extracted length of the longwall was 2186 metres. Mining was suspended between late July and September 2013 when difficult mining conditions arising from anomalous horizontal stress conditions were encountered (see Sections 15.1.14 and 16).

Also referred to as S1910 and DEN105, this bore is approximately 127 metres north of the northern edge of the Longwall 9 void, approximately 279 metres from its centreline and approximately 1090 metres longitudinally from the western (commencement) end of the panel. The first longwall to be extracted in Area 3B extraction, the northern pillars of Longwall 9 mark the northern extent of the Area 3B mining domain (see Fig. 28).

Piezometer data from DDH105 are represented in Figure 21 of the 2016 HydroSimulations groundwater assessment (Fig. 24 below). Though not discussed in that report, the data are discussed in the groundwater impact assessments prepared by HydroSimulations for the end of panel reports for Area 3B Longwalls 9, 10 and 11. The Longwall 9 and 10 reports state: "*The Ditton (2012) height of connective cracking ('A') estimate appears to be in agreement with the observed drawdowns in Bore S1910.*". However the data would appear to challenge the Ditton equation and appear to be in accord with the Tammetta equation.

Hydrographs with instrument depths are provided in the 2016 HydroSimulations groundwater assessment and in the Longwall 9, 10 and 11 end of panel reports for Dendrobium. Depths and elevations are provided in the November 2012 Coffey data analysis report, however there are significant differences between these depths and those given by HydroSimulations. In the absence of clarifying information, the more recent depths are assumed here to be correct, though this may not be the case.

In being beyond the Longwall 9 extraction void and collapsed zone the DDH105/S1910 bore is located over coal that has not been extracted and in strata that have not been undermined. Figure 3(a) depicts an off-panel bore with a piezometer above the collapsed zone height and others piezometers horizontally in line with the collapse zone of an extraction with a single adjacent extraction and which is on the opposite side to that of the bore. Given there is no northern adjoining longwall, Tammetta's work finds that the Longwall 9 drainage zone would not be expected to extend beyond the northern pillars of Longwall 9.[2] The bore will then be in saturated surroundings and complete depressurisation at the DDH105/S1910 piezometers as a consequence of the extraction of Longwall 9 would not ordinarily be expected.

Figures 37 and 38 below provide pressure head hydrographs for some (six and four respectively) of the eight piezometers in bore DDH105/S1910, with respect to date and with respect to the point of shortest distance between the northern pillars of Longwall 9 and the bore. The hydrographs were generated by digitising Figure 2.2 in the end of panel groundwater report[73] for Longwall 11 (Fig. 39 below) and subtracting the elevation head from the heads given in that figure. The Longwall 11 groundwater report provides better quality hydrographs than provided in Figure 2.6 of the Longwall 9 (Figure 40 below) end of panel report and Figure 2,2 of the Longwall 10 report, which provide only monthly datum intervals. As a consequence, details of change of pressure head recorded by the DDH105/S1910 piezometers are obscured to some extent in the hydrographs of the Longwall 9 and

10 reports. The pressure heads obtained from the Longwall 9 end of panel report are slightly lower than from the Longwall 11 report (see Figs. 37 and 39).

Puzzlingly, the hydrograph for Piezometer 2 provided in the Longwall 11 report terminates in October 2013, whereas in the Longwall 9 and 10 reports the period of the hydrographs continues until the completion of Longwall 9 in June 2014.

The two deepest DDH105/S1910 piezometers are in installed within the Bulli and Wongawilli Coal seams and depressurisation at these depths commences in 2010, presumably reflecting mining in Area 3A and possibly the Elouera workings. A pressure loss of one metre reported by a piezometer 10 metres below the surface (Piezometer 1) is attributed[42] by HydroSimulations to the surface fracture zone. The instrument appears to have become dry or very close to dry, having been nearly dry prior to the commencement of Longwall 9.

According to HydroSimulations the five instruments between the near surface piezometer and the two in the coal seam are located 125 , 169, 247, 273 and 313 metres below the surface (Piezometers 2, 3, 4, 5,and 6). These piezometers all show a marked and sharp pressure head reduction (Figs. 37 and 38) as the extraction progresses and all but Piezometer 2 fail soon after the pressure loss. Of these instruments, all but the instrument at 247 metres below the surface fail at some point during a period when the longwall machine retreat was suspended from late July to early September 2013 (see Sections 15.1.14 and 16). At this time the longwall face appears to have been approximately 270 metres past the point of shortest lateral distance between the longwall and bore location. The instrument at 247 metres below the surface failed at some point between mid-June and mid-July, when the machine was somewhere between the point of shortest lateral distance to the bore and 170 metres past this point.

The loss of the instruments as a result of horizontal shear indicates that the formation and growth of the collapsed zone in the vicinity of the point of shortest distance to DDH105/S1910 continued during the period the mining was suspended.

The Longwall 9 and 10 reports indicate that the piezometer 125 metres below the surface, Piezometer 2, continued to function throughout the extraction of Longwall 9 and most of the mining of Longwall 10. Puzzlingly the hydrograph in the Longwall 11 report extends only to October 2013. This instrument records a pressure head loss at its location of approximately 40 metres before equilibration with respect to the pressure gradient and changed horizontal conductivity arising from the growth of the collapsed zone over the longwall void. As Figure 37 indicates, this loss corresponds to about 50% of the pre-extraction head pressure. There’s no subsequent recovery over the period for which data are represented in the Longwall 9 and 10 end of panel reports. The pressure loss recorded by Piezometer 2 is interrupted by a relatively brief rise that presumably reflects an intermittent collapse process, settlement and associated compression effects. The net loss rate corresponds to approximately 120 metres a year.

Of note and cause for concern, the hydraulic pressure reported by Piezometer 2 falls from being approximately 5 metres above the water level of Avon Reservoir to about 35 metres below, as a consequence of the extraction of Longwall 9.

As noted above, HydroSimulations’ interpretation of the DDH105/S1910 data finds it consistent with the connected fracture zone (A zone) height estimate provided by Ditton’s geology equation and inconsistent with the height estimate from Tammetta’s equation.

If not provided to them as part their engagement, the extraction heights used for Longwall 9 (see Table 3) would presumably have been made available to the consultants if requested. HydroSimulations appear however to have instead used the proposed extraction height of 3.9 metres in applying the Ditton and Tammetta equations for their Longwall 9 and 10 end of panel report assessments of the DDH105/S1910 data. The estimates provided by the equations are then higher than if the actual cutting heights had been used.

The Longwall 9 void width is reported[74] to be 305 metres and MSEC contour maps[64] indicate that the centreline depth of cover at the point closest to DDH105/S1910 is approximately 410 metres. Using the t' adjustment term of 32 used in the 2014 HydroSimulations Area 3B groundwater assessment[23] the Ditton equation estimates a most likely A zone height of 176 metres for a 3.9 metre high extraction and 181 metres using a t' adjustment term of 30 as used in their 2015 height of connected fracturing report. Tammetta's equation returns a drainage zone height estimate of 377 metres for a 3.9 metre high extraction and the given longwall geometry and depth.

Reference to MSEC surface and seam elevation contour maps[64] indicates that, for 3.9 metre high extractions, the 181 metre Ditton height estimate places the peak of the A zone at approximately 236 metres below the surface, in the Bulgo Sandstone. In contrast the Tammetta equation puts the 377 metre peak of the drainage zone at about 40 metres below the surface, in the upper Hawkesbury Sandstone.

Reflecting this difference, HydroSimulations conclude that the DDH105/S1910 hydrographs (Figs 39 and 40) support the Ditton equation:

> "*The Ditton (2012) height of connective cracking ('A') estimate appears to be in agreement with the observed drawdowns in Bore S1910. The lagged and attenuated drawdowns in the Hawkesbury Sandstone are likely to result from responses to the depressurisation of underlying strata, and/or from increased horizontal permeability and storativity due to disconnected 'B' zone cracking and/or surface cracking*."

The quoted comments evidently refer to the DDH105/S1910 piezometer placed at 125 metres below the surface (Piezometer 2).

The suggestion that the response at least in part reflects storativity changes and/or surface cracking lacks foundation. Storativity changes in the vicinity of DDH105/S1910, if any, would be expected to be minor and not cause or contribute significantly to the 40 metres drop in hydraulic head logged by the piezometer. Table 1 in Tammetta's recent assessment[19] of storage changes caused by longwall extraction indicates that on average only 2.6% of the mined volume is distributed into the upper part of the disturbed zone (see Fig. 41) and surface cracking would not be expected to extend to a depth of 125 metres in the vicinity of DDH105/S1910. Further, the piezometer does not report any recovery over the recording period of the available hydrographs, from August 2013 to September 2014.

The consultants suggest that there is "*not only a time lag in depressurisation effects up through the strata, but also vertical attenuation, due to relatively low vertical hydraulic conductivity*." Not noted is the magnitude of a pressure head change will depend on the initial pressure head and this declines with increasing elevation.

The magnitude and rate of pressure head loss measured by a piezometer will depend on its vertical and horizontal distance from the causal drainage zone and the diffusivity determining vertical and horizontal conductivity between the piezometer and the drainage zone.

The quoted comments recognise that low vertical hydraulic conductivity would limit the rate of depressurisation at Piezometer 2 caused by pressure loss in the strata below, assuming the piezometer is above the peak of the drainage zone, and this is because it will determine the vertical hydraulic diffusivity (see Section 1). However HydroSimulations don't appear to have considered whether the pressure head loss reported by Piezometer 2 could actually occur at the observed sharp rate, if it was caused by the vertical propagation of pressure loss occurring in the underlying strata. Noting that the vertical diffusivity would not be expected to be greatly changed in the saturated constrained/disturbed zone, reference to Figure 1 below (see Section 1) suggests this is unlikely.

The groundwater response reported by Piezometer 2 is not what would be expected at a location significantly above the drainage zone height and below the surface fracture zone.

The separation between Piezometer 2 and Piezometer 3 is 44 metres and the interval between the commencement of the sharp fall recorded by Piezometers 3, 4 and 5 and that recorded by Piezometer 2 appears to be approximately 45 days. Given the close proximity of Piezometer 2 to Piezometer 3, a delay of 45 days would seem unlikely to reflect vertical diffusion of the pressure loss. The Piezometer 2 hydrograph in the Longwall 11 end of panel report (see Figs 38 and 39 below) suggests instead that the apparent delay reflects the interruption of a decline that commences at about the same time as recorded by the lower piezometers, by a sharp pressure rise presumably associated with evidently temporary compression effects over the northern edge of the extraction. The subsequent relatively precipitous fall recorded by Piezometer 2 is very similar to that reported by the lower instruments. The fall is again followed by a rise and then slowed decline that suggests persistent compression effects. Obtained by digitising the Longwall 11 end pf panel report hydrographs from DDH105/S1910, Figure 38 indicates that Piezometers 2 and 3 convey a relatively complex collapse process.

That the magnitude of the fall reported by Piezometer 2 is smaller than that of the lower instruments, in part would seem likely to be a consequence of the lower initial pressure head at the elevation of Piezometer 2. Given their failure, the post-collapse equilibrated pressure head at the location of the DDH105/S1910 piezometers isn't known.

The similarity of the nature of the pressure loses recorded by the instruments above the coal seam argues against Piezometer 2 reflecting vertical rather than a largely horizontal propagation of pressure loss. It's highly unlikely that all of these piezometers are above the height of the drainage zone.

Unless there is a significant level of vertical defects (joints, fractures) between Piezometers 2 and 3, the pressure loss reported by Piezometer 2 would seem unlikely to primarily reflect vertical depressurisation. There does not appear to be any reason to expect an unusual concentration of vertical defects in the Hawkesbury Sandstone in the vicinity of DDH105/S1910. While the location of DDH105/S1910 is well within the thirty five degree 'angle of draw' subsidence zone, surface fracturing at this location would not be expected to be significant and extend to the depth necessary to give the responses recorded by the piezometers at 125 metres and 169 metres below the surface, to the extraction of Longwall 9.

If pressure head loss propagated upwards from the drainage zone to the surface, through the saturated zone below the surface fracture zone, at the rate reported by the DDH105/S1910 piezometers, catchment impacts and mine inflows would be expected to be considerably greater than have been reported.

Tammetta reports[2] that within the collapse zone the ratio of pre-mining to post-mining hydraulic conductivity (denoted by R and primarily reflecting horizontal conductivity) decreases with increasing height above the mined seam, as a result of desaturation effects: "*the effect of unsaturated conditions in the collapsed zone is calculated to reduce R by 54% at y = 0 (the top of the collapsed zone), and by 66% at 0.57H below the top of the collapsed zone, according to a slightly non-linear function*." In part the rate of discharge from the saturated surrounds into the depressurised (to approximately atmospheric pressure) collapsed zone at its boundary may also depend on heightened vertical compression effects at the boundary.

The DDH105/S1910 hydrographs appear to be consistent with a drainage zone that reaches a height above the floor of Longwall 9 equivalent to somewhere between Piezometer 2 at 125 metres below the surface and either Piezometer 1 at 9.6 metres below the surface or the surface. That is the hydrographs are consistent with a drainage zone height of between approximately 271 metres and at least 383 metres above Longwall 9 in the vicinity of the point of shortest distance between the longwall and DDH105/S1910.

At the centre-line point laterally in-line with DDH105/S1910, with an extraction height of 3.4 metres, the Ditton geology equation with an adjustment term of 30 metres estimates a most likely A zone height of 167 metres, while the Tammetta equation estimates a most likely drainage zone height of 317 metres. The Tammetta equation drainage zone height estimate is consistent with the data from DDH105/S1910, whereas the Ditton equation A zone height estimate is contradicted by that data.

15.1.14. Longwall 9 - S2192

Hosting six vibrating wore piezometers, bore S2192 is located above the centre-line of Longwall 9 approximately 620 metres, nearly a quarter of the extraction length, from the eastern (completion) end of the extraction.

The longwall retreat halted between the last week of July and the first week of September 2013, when complications arising from anomalous horizontal stress were encountered (see also Section 16).[75], [76] As a consequence of the unusual stress conditions, the extraction of Longwall 9 took some five months longer than anticipated, commencing on the 9th of February 2013 and finishing on the 2nd June 2014 (see Section 16.2).

The Parsons Brinckerhoff connected fracturing report of March 2015 advises that the longwall face passed below S2192 on the 3rd of October 2013. Effectively in agreement, digitising the longwall progress trace included with the hydrographs provided in the groundwater assessments for the Longwall 9 and 10 end of panel reports, but not the Longwall 11 report, indicates the passage occurred on the 4th of October.

Hydrographs are provided in the HydroSimulations groundwater impact assessments for the end of panel reports for Longwalls 9, 10 and 11 (Figs 2.7, 2.3 and 2.5 respectively in those reports).

Pressure head graphs are also provided for the three shallowest S2192 instruments in the 2015 Parsons Brinckerhoff connected fracturing report (Figure 52(a) below).[13] The hydrographs provided in the Longwall 9 and 10 reports only provide monthly data points, whereas the Longwall 11 report hydrographs appear to provide at least daily data points. The Parsons Brinckerhoff report also appears to present at least daily data points, though over a more limited time period. The Parsons Brinckerhoff hydrographs present data recorded between April and July 2013, while the Longwall 9 and 10 reports appear to present data from the 14th of March 2013 to the 15th of September 2013, based on data obtained by digitising the hydrographs. The period provided in the Longwall 11 assessment hydrographs appears to commence on the 25th of March 2013 and apparently finishes with a loss of data recording on different dates for each instrument. Piezometers 1 to 4 appear to fail in early October, while Piezometer 5 fails in early September and Piezometer 6 fails in late September.

Of note, the hydraulic heads reported by the S2192 instruments at 95 and 140 metres below the surface fall below that of Avon Reservoir before they apparently fail in October 2013.

The hydrographs in Figures 43, 44 and 45 below were obtained by digitising those provided in the Longwall 11 end of panel report (Fig. 42(a) below) and subtracting piezometer elevations to obtain pressure head data. Piezometer 1 is 50 metres below the surface and the data recording commences with a notably low pressure head, relative to the depth of the instrument, of six metres. Following a steady decline to two metres a pressure head rise commences on the 25th of September 2013 when the longwall face is approximately 85 metres west of S2192 (See Fig. 44). The pressure head rise appears to reach a peak of five metres on the 3rd of October and then falls rapidly to approximately minus three metres, effectively zero, when the data terminate on the 7th of October 2013. It is disturbing that a piezometer at this depth reports such a low initial pressure head and this would appear to indicate significant depressurisation of the Hawkesbury Sandstone prior to the commencement of Longwall 9.

The piezometer's terminal response presumably reflects subsidence related compression (pressure rise) and then tension (pressure loss) impacts, with the longwall face passing below the bore between the 3rd and 4th of October. The behaviour of Piezometer 1 is consistent with Booth's account[77] of the response of relatively shallow groundwater piezometers located over the centreline of a longwall extraction, to the development of the surface fracture zone. The behaviour reported by Piezometer 1 contradicts advice, primarily from mining company consultants, that the surface facture zone does not extend to more than 30 metres below the surface[21] and would typically extend no further than 15 metres below the surface.[52] The data from 'twin' bore S2220 suggests the surface fracture zone can extend further than 50 metres from the surface (Section 16.7).

In their groundwater assessment for the Longwall 11 end of panel report HydroSimulations make the following comment:

> "*there is no clear evidence of mining effects in the Hawkesbury Sandstone at 50 m depth from either Longwall 9 or 10 (**Figure 2.5**).*"

This is incorrect and the consultants make no comment on the behaviour of the Hawkesbury Sandstone instruments at 95 and 140 metres below ground, both of which report heads that fall below that of Avon Reservoir.

The slow decline towards a zero pressure head reported by Piezometer 1 prior to the 25th of September would seem likely to reflect seepage to the approaching Longwall 9 drainage zone or into deeper groundwater flows. At 50 metres below the surface and with an elevation of approximately 335 metres (mAHD) the piezometer appears to be below the base of Donalds Castle Creek, at least to the northern limit of the MSEC surface elevation contour maps.

The cumulative residual rainfall trace in Figure 13 of the 2016 HydroSimulations groundwater assessment indicates lower than average rainfall between March and June 2013 and between July and September 2013, and above average rain in June-July 2013. The Parsons Brinckerhoff report indicates there was no rain between late April and late May 2013. The periods of little or no rain don't however explain the steady pressure head decline reported by Piezometer 1, which shows no response to the above average rain of June 2013.

Piezometer 2 is located 95 metres below the surface and its hydrograph data commence with a steady decline from an initial pressure head of 28 metres. The instrument reports a sharp pressure head rise from 17 metres that appears to commence on the 13th of June, much earlier than that reported by Piezometer 1, with the longwall face approximately 425 metres west of S2192. Of note, the longwall face passed the point of shortest distance to bore DDH105/S1910 on the 9th of June 2013. The pressure head recorded by S2192 Piezometer 2 peaked at 31 metres on the 16th of June and then steadily declined to 17 metres by the time the data reporting terminated on the 7th of October 2013. The pressure head declined by 40% from data recording commencement to termination. The instrument's behaviour suggests it responded to a collapse process at some distance west of S2192 and the gradual decline following the sharp pressure rise suggests persistent compression effects as the subsidence trough approached the piezometer. The pressure head appears to be about to commence a relatively sharp decline at the time the instrument fails. The loss of the data reporting occurs during or shortly after the longwall face had passed below (see Figs. 43-45).

Though the piezometer at 95 metres below the surface reports a significant net pressure head loss, it does not appear to be included in Figure 21 of the 2016 HydroSimulations groundwater assessment for Area 3B (Fig. 24 below).

Piezometer 3 is located 140 metres below the surface and the hydrograph data commence with a pressure head of 83 metres that, after a relatively rapid initial decline, steadily falls towards a relatively complex and drawn-out period of compression effects that appears to peak with the longwall face approximately 207 metres to the west on the 27th of July, with a pressure head of 81 metres. This appears to coincide with the start of the period over which the extraction was suspended because of mining difficulties associated with high levels of horizontal stress (see Section 16.2). The pressure head declines from the July 27th peak of 81 metres to 64 metres before a sharp pressure rise commences on the 16th of September and peaks on the 27th of September at 83 metres. A precipitous pressure head fall follows, with the hydrograph data terminating at 51 metres on the 6th of October (see Fig 45).

At a depth of 175 metres Piezometer 4 reports an initial pressure head of 127 metres that slowly rises to a sharp rise that commences on the 8th of July and peaks at 135 metres on the 11th of July. A rapid fall follows, reaching 111 metres on the 21st of July 2013. The pressure then decline slowly before a mild and drawn out rise that starts on the 4th of September, peaks on the 19th at 108 meters and then slowly falls to 102 metres and data loss on the 5th of October.

None of the S2192 piezometers survive the passage below of the longwall face for any length of time and this precludes a direct assessment of the height of the drainage zone below this bore. The early July behaviour of Piezometer 4 indicates a response to an approaching drainage zone that reaches at least 175 metres below the surface. Piezometers 3 and 2 fail before establishing post undermining pressure heads and though the pressure head recorded by Piezometer 1 falls to zero, it does so from a low initial pressure of approximately six metres. The slow decline reported by Piezometer 2 indicates either that the drainage zone to the west doesn't reach to 95 metres below the surface or that compression effects arising from the advance of the subsidence trough directly towards the bore hinder horizontal drawdown. The response of piezometers in bores beyond the surface projection of Longwall 9 would appear to favour the latter possibility. The lowest lower bound for the drainage zone height indicated by the piezometers in bores DDH105/S1910, DDH104/S1908. DDH109/S1926 and DDH111/S1929 is 264 metres and the highest lower bound is 280 metres.

The hydrographs for the three uppermost S2192 piezometers additionally include post Longwall 9 data from between approximately the 11th of November and the 19th of November 2014. Given the interval following reporting loss in October 2013, these data are unlikely to be reliable. Providing confirmation, data recording from the instruments at the same depth in nearby bore S2220 appears to have commenced on the 11th of November 2014 and the data are not in accord with the November 2014 data from S2192.

Section 16.7 discusses the data from piezometer bore S2220, which is approximately 17 metres south of S2192. Piezometers were installed in S2220 in late 2014, following the June 2014 completion of Longwall 9, as part of project undertaken by Parsons Brinckerhoff to determine the height of the extraction's drainage zone. The bore hosts the same number of vibrating wire piezometers, placed at the same depth, as hosted by S2192. The lower three instruments were lost shortly after installation as a result of ongoing collapse. The Parsons Brinckerhoff project's findings were inconclusive and it seems likely the project was stymied by the stress conditions that had halted Longwall 9 from late July to early September 2013 (see Section 16.2). Paradoxically, the unusual horizontal stress conditions over the eastern end of Longwall 9 may have contributed to the survival of the S2192 instruments in the immediate lead-up and passage of the longwall machine below the bore. Data were collected from the three remaining S2220 instruments for only the short period between the 11th of November 2014 and the 23rd of February 2015. The data may have been truncated by further instrument loss. The limited S2220 data are included in the pressure head hydrographs of Figure 45 below.

Discussed in Sections 16.2 and 16.7, the S2220 piezometers provide some insight into the post undermining pressure heads that would have been recorded by the S2192 instruments, had they survived the post-passage retreat of the longwall face. Of note, the S2192 and S2220 data indicate a pressure head loss in the lower Hawkesbury Sandstone, at a depth of 140 metres, of approximately 67 metres by the 20th of February 2015. This corresponds to a pressure head loss of approximately 82% over the centreline of Longwall 9 as a consequence its extraction. Also of note, the S2220 data suggest the possibility of a horizontal connection between a notably deep surface fracture zone, extending to a depth of at least 95 metres, and the longwall's drainage zone.

15.1.15. Longwall 9 - DDH104/S1908

Hosting seven instruments and located near the centreline of Longwall 10 approximately a third of its length from the eastern (commencement) end, DDH104/S1904 offered a notably informative piezometer bore. The bore is approximately 345 metres south of the Longwall 9 centreline.

The hydrographs provided in the March 2016 HydroSimulations SMP groundwater assessment don't include elevations for the bore's piezometers. Depths and elevations are however provided in the November 2012 Coffey data analysis report.

Though Figure 21 in the HydroSimulations assessment (Fig. 24 below) associates the bore with Longwall 10, the period of the provided hydrographs ends in March 2014 and, accordingly, they don't show how the instruments respond to Longwall 10. This longwall was extracted between the 1st of January 2014 and the 1st of January 2015. Almost certainly most if not all of the S1908 piezometers will have failed as the face of Longwall 10 approached; it would have been helpful if a period beyond the failure point had been included in the hydrographs. The Figure 21 association of the bore with Longwall 10 may give the impression the response indicated in the graphic reflects the extraction of Longwall 10.

Though the HydroSimulations hydrographs are not provided with instrument elevations, Figure 21 in the 2016 groundwater assessment (Fig. 24 below) indicates that an instrument at a depth of 154.9 metres records a pressure loss that HydroSimulations identify as significant. Consistent with the depth given by HydroSimulations for this instrument, the November 2012 Coffey data analysis report lists a DDH104 instrument, Piezometer 2, at a depth of 155 metres.

The Piezometer 2 hydrograph provided in the March 2016 groundwater impact assessment indicates a pressure head loss of approximately 60 metres as a consequence of the extraction of Longwall 9. The hydraulic head will have fallen below that of Avon Reservoir. Puzzlingly this significant loss does not appear to be noted in the Longwall 9, 10 and 11 end of panel reports and DDH104/S1908 hydrographs are not provided in these reports.

Located in the lower Hawkesbury Sandstone and the closest to the near surface instrument, which is 10 metres below the surface and which would appear to be dry, Piezometer 2 provides an indicative lower bound for the height of the Longwall 9 drainage zone. Reference to the MSEC contour maps indicates that the elevation of Piezometer 2 corresponds to a height above the longwall floor centreline of approximately 257 metres.

The bore would appear to be laterally in-line with the relatively short section of Longwall 9 that was extracted with a height of 3.7 metres, the rest being extracted at 3.4 metres. The Ditton equation A zone height estimate is 171 metres, while the Tammetta equation drainage zone height estimate is 352 metres. The Ditton equation estimate is below the lower bound of 257 metres provided by Piezometer 2 at 155 metres below the surface. The data again argue against the conclusion reached by HydroSimulations, that the Ditton equation is more consistent with the piezometer data from Dendrobium than is that of Tammetta.

15.1.16. Longwall 9 – DDH109/S1926

Also hosting seven instruments, DDH109/S1926 is approximately halfway between the southern pillars and centreline of Longwall 10 and a relatively short distance past the half way point of the extraction. The bore is some 395 metres from the centreline of Longwall 9 and 285 metres from the southern edge of its void.

Like DDH104/S1908, DDH109/S1926 is associated with Longwall 10 in Figure 21 of the March 2016 HydroSimulations SMP report (Fig. 24 below) and, like DDH104/S1908, the time period of the hydrographs provided by HydroSimulations excludes the responses of the bores piezometers to the extraction of Longwall 10. The bore's instruments would almost certainly have responded to the approaching longwall before failing and provided insight into the Longwall 10 collapsed zone height; the upper instruments may have survived. There would seem to be no reason that the hydrographs could not have been provided with a time period that included the point of failure and no reason is given in the report.

Again the hydrographs provided in the HydroSimulations report do not provide elevations for the instruments. Figure 21 in the 2016 groundwater assessment however provides the depth for an instrument that HydroSimulations identify as recording a significant pressure loss. Unless HydroSimulations are referring to data not included in the hydrographs provided in their report, this loss will have been caused by the extraction of Longwall 9, not Longwall 10. The bore is some 270 metres from the southern edge of Longwall 9.

The depth of the instrument, evidently Piezometer 3, is given as 192 metres and this depth places it in the mid to upper Bulgo Sandstone. The hydrographs show that the instrument above it in the lower Hawkesbury Sandstone also records a significant response to Longwall 9, yet this piezometer is not included in Figure 21 (Fig. 24 below). The absence of this instrument, Piezometer 2, highlights the need for HydroSimulations to define the applied categories of pressure loss. Noting the CSIRO Springvale study, any response greater than a loss of 5 metres is significant for an off-panel response by a piezometer at some distance from the causal extraction. The bore site is approximately 405 metres from the centreline of Longwall 9.

Consistent with the depth given by HydroSimulations, the November 2012 Coffey data analysis report gives the depth of Piezometer 3 as 192 metres and gives depths and elevations for the rest of the bore's instruments. Piezometer 2 is listed in the Coffey report as being in in the lower Hawkesbury Sandstone with a depth of 139 metres. The instrument in the Hawkesbury Sandstone again provides a lower bound for the height of the drainage zone. The instrument reports a significant pressure loss of approximately 20 metres and provides a lower bound of 266 metres for the height of the Longwall 9 drainage zone.

The eastern half of Longwall 9 was extracted with a cutting height of 3.4 metres. The Ditton geology equation, with an adjustment parameter of 30, estimates an A zone height of 164 metres, while the Tammetta equation provides a drainage zone height estimate of 317 metres. Again the lower bound argues against the Ditton equation providing A zone height estimates in accord with Dendrobium piezometer data. In contrast, the lower bound for the height of the Longwall 9 drainage zone provided by the piezometer data does not contradict the Tammetta equation.

15.1.17. Longwall 9 – DDH111/S1929

Like DDH109/S1926, piezometer bore DDH111/S1929 is about midway between the southern pillars and centreline of Longwall 10, but about a 1/4 of the extraction length from its eastern end. The bore is some 410 metres from the centre-line of Longwall 9 and 265 metres from the southern edge of the Longwall 9 void.

Again the hydrographs provided in the March 2016 HydroSimulations groundwater assessment do not provide elevations for the bore's instruments and the period covered excludes their responses to Longwall 10. Piezometer depths and elevations are provided in the November 2012 Coffey data analysis report and in the Longwall 11 end of panel report.

Of note, the bore's piezometer in the lower Hawkesbury Sandstone, Piezometer 2 at 76 metres below ground, reports small but discernible pressure head losses in responses to the Area 3A extractions and a slow subsequent pressure head decline, before responding to the extraction of Longwall 9 (see Fig. 46). The instruments in the Bulgo and Scarborough Sandstone relay a slightly steeper decline commencing with the extraction of Longwall 6.

HydroSimulations follow their October 2015 comments on the data from DDH85/S1870 (see Section 15.1.12) with the following comments with respect to data from DDH111/S1929:

> "*Similarly, the passing of Longwall 9 did not cause complete groundwater drainage at bore S1929 in Area 3B (200 m south of Longwall 9 and above the path of Longwall 10). Decreases in observed head of approximately 20 m were seen in the upper and lower Scarborough and Bulgo Sandstones, with the Hawkesbury Sandstone again maintaining premining head conditions*."

Desaturation, complete groundwater drainage, would not be expected to occur at the piezometers in DDH111/S1929 until undermined by Longwall 10. The period covered by the hydrographs provided by HydroSimulations terminates before the piezometers record a response to the approaching collapsed zone as Longwall 10 is extracted.

Contradicting the statement quoted above, the DDH111/S1929 piezometer in the lower Hawkesbury Sandstone (Piezometer 2) reports a significant response to Longwall 9, with the pressure head falling approximately 30 metres (see Figure 47). Most of the pressure head is lost relatively rapidly, with a fall of approximately 25 metres between the 9th of November 2013 and the 1st of February 2014, corresponding to a loss rate of approximately108 metres a year. Following this rapid fall, the pressure head continues to decline to the end of the period covered by the hydrograph in August 2014, with the net pressure head fall by then being approximately 30 metres.

In contrast to the lower Hawkesbury Sandstone piezometer in the DDH105/S1910 bore, the DDH111/S1929 instrument does not report post pressure head fall compaction/compression effects. Intriguingly, the pressure head reported by Piezometer 3 in the upper Bulgo Sandstone effectively mirrors the progress of the approaching longwall face (see Fig. 47).

Of note and concern, the hydraulic pressure reported by the piezometer in the lower Hawkesbury Sandstone had fallen below the water level of Avon Reservoir before the instrument responded to the extraction of Longwall 9.

Like the DDH109/S1926 instrument in the lower Hawkesbury Sandstone, this piezometer does not appear to be highlighted in Figure 21 of the 2016 HydroSimulations assessment (Fig. 24 below) and may not be represented in this graphic.

At a depth of 76 metres this instrument, Piezometer 2, provides a lower bound of 269 metres for the height of the Longwall 9 drainage zone above the seam floor. The Ditton equation provides a most likely A zone height of 155 metres, while the Tammetta equation provides a drainage zone height estimate of 308 metres. The Ditton equation appears to be challenged by the data, in being below the lower bound indicated by DDH111/S1929 Piezometer 2.

15.1.18. Longwall 11 – DDH108/S1925

Associated with Longwall 11 in Figure 21 of the March 2016 HydroSimulations groundwater assessment, this bore is located mid-way along from the western (commencement) end of the panel, directly over the southern pillars separating it from Longwall 12. In being located over pillars, the bore location is similar to that of DDH89 and DDH117/S1953. The bore hosts eight piezometers, with one in the Wongawilli seam and one in the Bulli seam. Hydrographs with depths are provided in Figure 14 of the 2016 HydroSimulations groundwater assessment and in the groundwater assessment for the Longwall 11 end of panel report. Depths and elevations are provided in Table C2 of the November 2012 Coffey data analysis report. The instrument depths given by HydroSimulations and Coffey are in agreement.

All of the instruments respond to the extraction of Longwalls 9 and 10, and all but two appear to be lost as the extraction of Longwall 11 progresses (see Fig. 48 below). The instruments at 10 and 144 metres below the surface evidently survive the passage of the longwall machine; the near surface instrument appears to have been essentially dry throughout.

Tammetta's work indicates that prior to the extraction of Longwall 12 the shallow piezometers in DDH108/S1925 would expected to be in the saturated zone around the collapsed zone of Longwall 11. These instruments would then not be expected to report complete depressurisation.

As mentioned Piezometer 1, 10 metres below the surface, appears to have been dry throughout the period of the hydrographs provided by HydroSimulations. Reflecting the effect of distance (see Section 1), the hydrograph from Piezometer 2 in the lower Hawkesbury Sandstone at 144 metres below the surface, shows increasingly sharp responses to Longwalls 9, 10 and 11. The DDH108/S1925 bore is approximately 825 metres from the centreline of Longwall 9 and 522 metres from that of Longwall 10.

The pressure head sequentially drops a total of approximately 50 metres and appears to fall to zero or close to zero as a result of the extraction of Longwall 11. This instrument is highlighted in Figure 21 of the 2016 HydroSimulations groundwater assessment for Area 3B (see Fig. 24 below).

Of note, the hydraulic head reported by Piezometer 2. In the Hawkesbury Sandstone at a depth of 144 metres, falls below that of Avon Reservoir during the extraction of Longwall 9.

Reference to the MSEC elevation contour maps[64] indicates that the piezometer data provide a lower bound of 271 metres for the height of the Longwall 11 drainage zone. Given the immediate proximity to the Longwall 11 collapsed zone, this is likely to be a reliable lower bound measurement. The Longwall 11 drainage zone is likely to be somewhere between 271 metres above the seam floor and the surface. The height of the surface above the seam appears to be 413 metres.

In the approach to DDH108/S1925 Longwall 11 was extracted with a cutting height of 3.95 metre. The Ditton geology equation then provides an A zone height estimate of 181 metres, or 224 metres below the surface, while the Tammetta equation provides a drainage zone height estimate of 382 metres, or 23 metres below the surface. The lower bound provided by the Piezometer 2 data again argues against the height estimate provided by the Ditton geology equation. The data do not contradict the Tammetta equation.

15.1.19. Longwall 11 - DHH131/S2009

This bore is located near the centreline of Longwall 12, approximately 145 metres from the commencement end pillars. The extraction of Longwall 12 had not commenced at the time of completion of the 2016 HydroSimulations groundwater impact assessment report. DDH131/S2009 is approximately 310 metres from the western end of the longwall's centreline and is likely to be some 400 metres or more metres from the eastern peak of the Longwall 11 collapsed zone. The extraction height for Longwall 11 was 3.95 metres.

Commencing in September 2009, the DDH131/S2009 hydrographs provided in the March 2016 HydroSimulations groundwater assessment are puzzling in that no data are represented from mid-2010 to late 2014, a period that includes the extraction of Longwalls 9 and 10. The extraction of Longwall 11 commenced on the 18th of February 2015.

Though elevations are not provided with the hydrographs provided by HydroSimulations, Figure 21 of their report (Fig. 24 below) highlights two of the seven piezometers for which hydrographs are provided. Located in the Bulgo Sandstone, the highlighted instruments are respectively 220 and 185 metres below the surface. Figure 21 of the HydroSimulations report does not highlight significant responses evident in the hydrographs for two piezometers in the lower Hawkesbury Sandstone. The pressure loss reported by this instrument is slightly greater than that of the instrument at 185 metres below the surface.

Table C2 in the November 2012 Coffey data analysis report lists depths and elevations for 10 DDH131/S2009 piezometers, indicating three instruments are not represented in the hydrographs provided by HydroSimulations in their 2016 groundwater assessment. The Coffey table lists three instruments in the Hawkesbury Sandstone, with depths of 69, 100 and 132 metres and elevations of 334, 303 and 271 metres (AHD).

The hydrographs are provided for ten DDH131/S2009 instruments in the May 2016 groundwater impact assessment for the Longwall 11 end of panel report and the depths given for these instruments match those given in the November 2012 Coffey data analysis assessment. The representation of the DDH131/S2009 piezometers provided in the March 2016 assessment would appear to be misleading.

The hydrograph provided for the Longwall 11 end of panel report for the shallowest instrument, 69 metres below the surface, appears to steadily fall to become dry or close to dry.

The instruments at 100 and 132 metres below the surface both show similar pressures head loss rates and magnitudes. Piezometer 2 at 100 metres below the surface appears to become dry or close to as a consequence of the extraction of Longwall 11. Though the data is interrupted for much of the period covered by the provided hydrographs, prior to responding to Longwall 11 the instrument reports a pressure head fall from approximately 25 metres to approximately 7 metres between mid-

2009 and the start of 2015. The low pressure head in 2009 is disturbing. Over this period, before the extraction of Longwall 11, the hydraulic head reported by Piezometer 2 falls below the level of Avon Reservoir.

The response of Piezometer 2 suggest the Longwall 11 drainage zone reaches to somewhere between 100 metres below the surface and the surface. The lower bound height challenges the Ditton geology equation A zone height estimate of 181 metres, which corresponds to 229 metres below the surface and would place it in the Bulgo Sandstone above the centreline of Longwall 11. The Tammetta equation drainage zone height estimate for the 3.95 metre high Longwall 11 extraction is 382 metres, placing it in the upper Hawkesbury Sandstone 28 metres from the surface. At this height the drainage zone would be likely to join the surface fracture zone.

15.1.20. The TARP bores

As noted earlier, the Department of Planning approved the mining currently underway in Area 3B in February 2013 without a groundwater impact assessment that matched the planned mining. The mining was also approved[78] without specific groundwater impact performance measures, other than with respect to Avon Reservoir:

> "*Negligible environmental consequences including:*
> - *negligible reduction in the quality or quantity of surface water inflows to the reservoir;*
> - *negligible reduction in the quality or quantity of groundwater inflows to the reservoir; and*
> - *negligible leakage from the reservoir to underground mine workings*"

No performance measures were specified in the current Area 3B approval with respect to baseflow for Cordeaux Reservoir or the Area 3B watercourses. Evidently referring to the Hawkesbury Sandstone and upper Bulgo Sandstone, the Department's December 2015 Area 3B inspection report states "*The only performance measure in the relevant approvals which refers to groundwater losses relates to losses from shallow aquifers supplying baseflow to reservoirs and streams.*" The report doesn't specify which approvals are being referred to as relevant, however the December 2008 notice of approval[79] for a modification (see Section 19) to the 2001 consent for mining in Area 3 states:

> "*The Applicant shall ensure the development does not result in reduction (other than negligible reduction) in the quality or quantity of surface water or groundwater inflows to Lake Cordeaux or Lake Avon or surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek, to the satisfaction of the Director-General.*"

This condition would apply to the Area 3B mining. The Department provides the following advice in the December 2015 inspection report:

> "*To date, no significant groundwater losses in these shallow aquifers have been reported. Nonetheless, WaterNSW recommends expanding the shallow groundwater monitoring system to provide additional confidence in this conclusion.*"

Hydrographs provided in Appendix A of the May 2015 HydroSimulations groundwater assessment[70] for the Longwall 10 end of panel report suggest this advice is mistaken.

The hydrographs represent data from piezometers in four bores located between the completion (eastern) ends of Longwalls 6 and 7 and Cordeaux Reservoir and Sandy Creek, that the groundwater assessment advises are used as Trigger Action Response Plan (TARP) reference sites. The four bores are DDH84/S1867 (see Section 15.1.11), DDH85/S1870 (see Section 15.1.12), DDH119/S1992 (see Section 15.1.12) and DDH120/S1994 (see Section 15.1.11). It's not clear when these bores began to be used as TARP reference sites; the Longwall 10 report appears to be the first end of panel groundwater assessment that refers to TARP provisions for the assessment of groundwater impacts in Area 3.

Groundwater TARP conditions are tabulated for secondary control TARP 4 in the current version (Revision 3 dated 9/10/15) of the Avon and Cordeaux Reservoirs DSC Notification Area Management Plans document[80], which shows a revision history dating to June 2005. The document advises:

> "*Groundwater monitoring is a Secondary Monitoring Control undertaken to determine and assess hydrogeological conditions within the rock mass between the Reservoirs and the Wongawilli Seam in Areas 1, 2, 3A and 3B. This monitoring aims to detect the impacts of mining on groundwater, assess groundwater flow from stored water and provide verification of the results of hydrological modelling.*"

The management document further advises:

> "*Groundwater monitoring at Dendrobium consists of both 'shallow' and 'deep' monitoring. The 'shallow' groundwater monitoring is primarily used to assess impacts on surface flows, swamps and ecology, the deep' groundwater monitoring is used to understand inflows into the mine. In Areas 1 and 2 'deep' groundwater monitoring was heavily focused on the area between the extraction and the Reservoir. The monitoring in Area 3 has been designed to provide regional groundwater data in addition to increased monitoring near the reservoir where access is available. Groundwater Monitoring details are shown in Plans 3 – 5.*"

Plan 5, provided below as Figure 49, locates the Area 3 groundwater bores with respect to the domain's longwall extractions, water courses and reservoirs. Puzzlingly, given the document has been made available as part of the SMP material for the proposed extraction of Longwalls 14 to 18, the management document specifies the TARP 4 alert levels only with respect to Cordeaux Reservoir and only with respect to DDH84/S1867, DDH85/S1870, DDH119/S1992 and DDH120/S1994.

Figure 28 below is from the October 2012 Coffey assessment and shows the locations of bores DDH84, 85 and 119. The DDH120 bore is not shown and this is presumably because Tammetta found[62] the data to be unreliable and accordingly unsuitable for groundwater calibration.

The TARP bore hydrographs provided in the May 2015 Longwall 10 groundwater assessment show significant depressurisation that commences with the completion of Longwall 4 and leads to a Level 2 TARP alert being flagged for all four bore sites during the extraction of Longwall 10. Appendix A of the Longwall 10 groundwater report tabulates the conditions under which each TARP alert is flagged. Level 2 is prompted when at least one TARP bore piezometer in the Bulgo Sandstone falls below the standing water level (SWL) of Cordeaux Reservoir. The same Level 2 condition is given in the October 2015 DSC Notification Area Management Plans document. Two of the three Bulgo Sandstone piezometers in each of bores DDH85/S1870 and DDH119/S1992 and one of the three is each of DDH84/S1867 and DDH120/S1994 had fallen below the Cordeaux trigger level by late 2015.

The HydroSimulations groundwater assessment for the Longwall 10 end of panel report doesn't refer to the TARP alert level above Level 2 as Level 3, but instead distinguishes it as "*unacceptable*". This level, the highest groundwater TARP level, is flagged when all Bulgo Sandstone piezometers in a reference bore fall below the level of Cordeaux Reservoir. In contrast, this trigger condition is classified as Level 3 in the October 2015 DSC Notification Area Management Plans document and the May 2016 HydroSimulations groundwater assessment for the Longwall 11 end of panel report. The change does not appear to be explained in either document.

Hydrographs provided in the groundwater assessment[73] for the Longwall 11 end of panel report show that the third of the three Bulgo Sandstone piezometers in bore DDH85/S1870 fell below the Cordeaux Reservoir level during the first half of 2015 (see Fig. 35). The report accordingly flags a Level 3 TARP alert. As noted in Section 15.1.12, Figure 36 reveals that between July 2009 and July 2015 this piezometer, at 55 metres below the surface, recorded an approximately 83% pressure head decline from approximately 35 metres to approximately 6 metres. The hydraulic head is by then approximately at the level of Cordeaux Reservoir. The elevation of this piezometer is 296 metres (mAHD), in line with Cordeaux Reservoir.

TARP bore DDH119/S1992 is located approximately 150 metres north east of DDH85/S1870, approximately 86 metre west of Sandy Creek and approximately 146 metres south west of the Sandy Creek entrance to Cordeaux Reservoir; bore DDH119 is closer to the reservoir than is DDH85. Triggering a Level 2 alert, two of the three piezometers in DDH119/S1992 fell below the stored water level of the reservoir during the extraction of Longwall 10.

As noted in Section 15.1.12.3, the rate of pressure head decline reported by the shallowest of the three piezometers, that at 46 metres below the surface, is slower than returned by the two other Bulgo Sandstone instruments. The elevation of this piezometer is 291 metres (mAHD), placing it essentially in line with the reservoir. The slower rate of depressurisation may reflect compression effects or perhaps a degree of support from the reservoir countering the depressurisation associated with the drainage zone. The DDH119/S1992 bore is closer to the reservoir than is DDH85/S1870 and, conversely, DDH85/S1870 is closer to the nearest collapsed zone than is DDH119/S1992 (see Fig. 49). Compression effects are not evident in the DDH85/S1870 Bulgo Sandstone hydrographs. Proximity to the reservoir might also explain the behaviour of the Bulgo Sandstone piezometers in TARP bores DDH84/S1867 and DDH120/S1994 (see Section 15.1.11).

Table 5 lists large drawdowns recorded by Dendrobium piezometers located in the upper Bulgo Sandstone and lower Hawkesbury Sandstone, at elevations similar to Avon and Cordeaux Reservoirs. The table notes hydraulic (piezometric) heads that have fallen below storage reservoir level. A weakness in the Dendrobium groundwater piezometer network is that there is a paucity of instruments installed between depths of around 100 metres and 10 metres below the surface – typically corresponding to the interval between lower Hawkesbury Sandstone and the near surface. It's then not possible to know how high the significant depressurisation of the shallow Area 3 aquifers that's signalled in Table 5 reaches above the level of the reservoirs. Similarly it's not possible to determine if the depressurisation reflected in Table 5 reaches the elevation of the Area 3 water courses, or if it joins the surface fracture network.

Only two of the piezometers represented in Table 5 are groundwater TARP reference instruments, however several are included in the set of bores identified as groundwater monitoring bores in the Avon and Cordeaux DSC Notification Area Management Plans document (see Fig. 49 below). Table 5 would seem to signal significant shallow aquifer depressurisation in Area 3, contrary to the advice given in the Department of Planning's December 2015 Area 3B inspection report. Given the magnitude of the drawdowns, it would seem unlikely that the Area 3 mining has resulted in no more than negligible loss of groundwater support for the Avon and Cordeaux Reservoirs. This may also be the case for the watercourses of Area 3.

As the DDH108/S1925 piezometers demonstrate, the influence of the drainage zone can extend a considerable distance horizontally beyond the underlying extraction.

15.1.21. Concluding comments

Misunderstanding, misrepresentation and exaggeration is evident in comments made in the October 2015 HydroSimulations height of connected fracturing report. As noted in Section 15.1, the HydroSimulations' report comments:

> "*There are numerous 'little or no depressurisation' points below the calculated Tammetta H level, which is conceptualised as the height of complete groundwater drainage. This suggests that the Tammetta (2013) method overestimates the height of complete drainage at Dendrobium (discussion of the reasons is presented below).*"

The report also comments:

> "*Modelling of the fractured zone extending to the Hawkesbury Sandstone and above, as seen in Coffey (2012a, 2012b), indicates a greater risk of surface desaturation than modelled in HydroSimulations (2014). However, monitoring shows partial recovery in shallow groundwater levels in some boreholes, which does not support the conceptualisation of total desaturation extending to these upper units*."

The *Coffey (2012a)* reference in the quote refers to the October 2012 groundwater impact assessment report and *Coffey (2012b)* refers to the November 2012 data analysis report. The nature, significance and availability of these reports, both of which had partner reports, is discussed in Sections 3, 7, 13, 14, 15.1, 18 and 19.

Compounding the propagation of the impact exaggeration arising from the use of the maximum rather than actual extraction height in contrasting the Tammetta equation estimates with those of the Ditton equation, in making their comments HydroSimulations don't identify which piezometers contradict the "*total desaturation*" predicted by their use of the Tammetta equation. It's then not possible to determine if the piezometers being referred to are over an area where the cutting height was less than the maximum used for the relevant extraction and/or the Tammetta equation does not predict the drainage zone would reach the surface, or if they're side-panel or off-panel piezometers that accordingly would not be expected to report 'total' desaturation.

The Dendrobium domain has only one centreline piezometer bore site able to provide post-undermining hydrological data. Located a quarter of the longwall length from the end of the panel, bore S2220 was installed after the completion of the extraction of Longwall 9. Discussed in Section 16.2, data were collected from the bore's instruments for only 15 weeks and did not provide a determination of the height of the underlying drainage zone. The Longwall 9 mining height in the vicinity of the bore was 3.4 metres for which the Tammetta equation estimates a drainage height of 315 metres, corresponding to a depth below the surface of approximately 80 metres. That is, the instruments in this unique bore would not be expected to report a drainage zone reaching the surface.

The short period of time over which data were evidently recorded from S2220 has not been explained and the most likely explanation would appear to be instrument loss associated with ongoing development of the collapsed zone over Longwall 9 (Section 16).

Discussed in Sections 15.1.1 and 15.1.15, piezometer bores DDH39 and DDH104 are also installed over the centre line of the underlying longwall extraction. Unlike S2220, the piezometers in these bores were installed prior to their host sites being undermined and all but the shallow instrument in DDH104 fail before being undermined. The shallow bore in DDH104, 10 metres below the surface above Longwall 10, is dry and unresponsive throughout the recording period. In the recoding period before failure, the medium around all of the instruments in the two bores would be expected to be saturated and the piezometers would not be expected to report ‘total’ desaturation. Further, the mining height used was such that the Tammetta equation does not predict the drainage zone would reach the surface.

There are a number of off-centre or side-panel piezometer bores with deeper instruments that the Tammetta equation predicts would be drained following undermining. Of those for which there is sufficient information available, none appear to have survived the passage of the longwall face. That is, these instrument do not appear to have survived being undermined and would be unable to provide data that contradicts the Tammetta equation.

As mentioned, Tammetta finds[16] that in the absence of an adjacent extraction the collapsed zone extends over an extraction’s pillars to a height of up to 30% of its centre-panel height and up to 60% of that height where there is an adjacent extraction. DDH42 is a piezometer bore located over the southwestern pillars of Longwall 1 in Area 1. The Tammetta equation estimates a centreline drainage height of 242 metres for Longwall 1 and this then suggests a drainage zone height over the pillars beneath the DDH42 site of up to 73 metres. The Tammetta equation ‘u’ value for the Longwall 1 is 3,363 and Figure 4 in his 2013 paper[16] on the height of the drainage zone suggests that the drainage zone height over the Longwall 1 pillars would be approximately 50 metres. Tammetta gives[36] the Longwall 1 roof elevation as 179 metres (mAHD) and, assuming a floor elevation of 175 metres, the Tammetta equation then suggests a drainage zone peak elevation over the centre of the pillars below DDH42 of 225 metres (mAHD). The piezometer elevations given in Table C2 of the November 2012 Coffey data analysis report suggest that Piezometers 1 might be within the drainage zone over the pillars of Longwall 1. While the instrument reports a large pressure head fall of approximately 30 metres, the hydrographs provided in the November 2012 Coffey data analysis report suggests it has not been drained. The bore site appears to be close to being over the ‘external roads on the south-eastern side of the pillars. If so, the drainage zone height would be approaching zero and Piezometer 1 would not be drained. That is, DDH42 does not appear to provide evidence that challenges the Tammetta equation. The Ditton equation doesn’t provide A-zone estimates for special locations.

With the exception of S2220 over the centre of Longwall 9, from which the data collection appears likely to have been prematurely terminated (presumably reflecting instrument loss; see Section 16.2), the publically available information indicates that there are no piezometer bores in locations that would place their instruments within the Tammetta equation estimated drainage zones of the Dendrobium extractions. The available data is consistent with the Tammetta equation and does not contradict or challenge the Tammetta equation as suggested by HydroSimulations.

The HydroSimulations groundwater assessment for the 2016 SMP submission comments; "*Drawdown in the upper Hawkesbury Sandstone (HBSS) is typically minor*". Again this comment is uninformative and unhelpful, providing no details and making no distinctions between piezometer bores and their placement relative to the relevant longwall extraction(s). The near surface instruments are typically at a depth of 10 metres or less and, subject to location, will consequentially have a small to negligible pressure head gradient and correspondingly limited drawdown. Additionally, some of the shallow piezometers are dry or close to dry throughout the logging period provided in the publically assessment reports. Dendrobium does not appear to have any shallow piezometers at locations where the Tammetta equation predicts the drainage zone would reach the surface.

A notable deficit in the Dendrobium piezometer network is a scarcity of instruments between depths of around 100 metres and 10 metres below the surface. As Table 5 indicates, the instruments that are between 55 and 155 metres show significant drawdowns.

Being dependent on the topography in the vicinity of a given bore site, whether or not a piezometer reporting a significant drawdown is or is not located in the Hawkesbury Sandstone is of less importance than its depth below the surface. Table 5 provides examples of significant drawdowns at Hawkesbury Sandstone depths below the surface.

Illustrating the need for specific information, piezometer bore DDH105/S1910 (see Section 15.1.13) is located approximately127 metres from the northern edge of the surface projection of the Longwall 9 void and some 279 metres from the surface projection of its centreline (see Fig. 28). The pressure head reported by the piezometer at 125 metres below the surface, in the Hawkesbury Sandstone, dropped by approximately 40 metres with the passage of Longwall 9 - about 50% of its pre-extraction head pressure. This would not be regarded as a minor drawdown.

Data from key piezometer bore in Areas 2, 3A and 3B, including the TARP bores, show significant pressure loss occurring at depths between 55 and 155 metres below the surface (Table 5 below), resulting in hydraulic heads falling from being above to being at or below that of the adjacent storage reservoirs (indicated in Table 5). A significant number of shallow instruments appear to be dry or close to dry, including those in TARP bores DDH84/S1867 and DDH85/S1870. It's clear that the Dendrobium mining has caused considerable disruption to the groundwater regime between Avon and Cordeaux Reservoirs. Given that horizontal pressure loss can extend rapidly for considerable distances, as demonstrated by DDH108/S1925, the highest drainage zone peak in a mining domain can have a significant adverse impact well beyond the surface footprint of the underlying longwall panel. That is, the highest drainage zone peak for a set of extractions can determine the height at which significant adverse groundwater impacts occur for a significant area beyond the causal longwall.

Contrary to the suggestion otherwise by HydroSimulations, the available piezometer data appears to be consistent with the Tammetta equation and contradicts the Ditton equations. The comments made by HydroSimulations suggest that they have either misunderstood Tammetta's work or have been unable to accept the message it would seem is being delivered by the piezometer data from the Dendrobium bores.

15.2. Mine inflow

15.2.1. Inflows to the Dendrobium mine

Like Springvale, the Dendrobium mine is a notably 'wet' mine, with rain dependent peak inflow of up to 13 million litres a day - the equivalent of five Olympic swimming pools. The mine is the wettest of the mines currently and recently operating in the Schedule 1 Special Areas of Sydney's drinking water catchment. It may be the wettest of all mines to have operated in the Special Areas.

Figure 50 below shows the inflows recorded by the Dendrobium mine's reticulated water system, which may not capture all inflows to the mine. That this may be so is suggested in the 2007 GHD assessment for a then proposed modification to the mining approved in 2001. The modification significantly expanded the mining footprint of the Area 3 domain, largest of the mine's domains, from some 1,890 hectares to 3,350 hectares. The GHD report[57] suggests a degree of drainage from Dendrobium into the neighbouring Elouera mine workings:

> "*BHP Billiton have advised that inundation of the workings by minewater has reached the main heading servicing Elouera Longwalls 7 & 8 (see Figure HG320). The long-term scenario may change, but this current water level does not preclude drainage into Elouera from Dendrobium Area 3A and thereby provides an explanation for the current hydraulic control apparent in the type-section through Longwall 6 of Area 3.*"

As Figure 51 indicates, a nepheline syenite sill bridges the Dendrobium and Elouera workings and GHD have suggested it may act as a conduit for drainage into Elouera. That is, water that would otherwise have entered the Dendrobium workings drains into the adjacent workings of the former BHP-Billiton mine. A significant body of water is accumulating in the closed workings of the old Elouera mine (see Fig. 51; this depiction is nearly a decade old).

Following the recent completion of Longwall 10 the average inflow to the Dendrobium mine, as captured by its reticulated system, has reached 8 million litres a day.[73] The inflows display a relatively short time-lag rainfall dependency[81][3] consistent the drainage zone approaching and reaching the surface above parts of the mine. A three week time lag reported[81] in a 2011 study of Dendrobium inflows by the Dams Safety Committee (DSC) is notably short. Tammetta finds an overall lag for combined inflow to Areas 1, 2 and 3 of seven weeks and this is dominated by the influence of rainfall on Area 2 inflows.

Tammetta comments[3] "*Inflows to Area 1 in Figure 9 were similar to inflows to Area 2 at first, but have become more subdued and less influenced by meteorological variations. This may be related to the presence of Bulli Seam workings directly above Longwalls 1 and 2 (which were drained prior to mining but may now be intercepting a component of vertical recharge from above), or to the presence of full extraction mining in the Wongawilli Seam (the Kemira longwalls) adjacent to Longwalls 1 and 2. The Kemira workings are currently being used as a water storage for excess mine water.*" That is, the Area 1 inflows may not be being fully captured in the mine's reticulated water system and reported inflow volumes.

The 2011 DSC study finds that modern water makes up to 20% of the Area 1 and 2 mine water;

> "*Tritium values are elevated for mine waters relative to the formations from which they are presumably sourced and are consistent with contributions of around 20% of modern water/surface water to the mine.*"

Hindering their analysis, the DSC note that "*LW1 and LW3 goafs were sealed in 2008*".[81] This may be reflected in the changed Area 1 inflow behaviour noted by Tammetta.

Heavy rain in June 2007 resulted in a prolonged inflow event in Area 2's Longwall 3, with a total inflow of 50.5 million litres by the end of the month, with an inflow rate of just over 5 Ml/day on June 18 and 19. The peak rate was just over 7.5 Ml/day.

Consultants GHD provide the following account[82] for the end of panel report for the Longwall 3 extraction:

> "*It appears that the inflow event was coincident with heavy rainfall, with the inflow commencing on 14 June during a rainfall event that produced 227mm over 3 days and a total rainfall depth of almost 400mm over 16 days – see Figures IF-02 and IF-03. Furthermore, an influence from subsequent rainfall events is identifiable as a response in the water balance. For example, with reference to Figure IF-03, the water balance response to rainfall events becomes apparent, with a peak in water balance outflow from Maingate 3 several days (between 6 and 8 days) after rainfall. There has typically been a recession of the water balance following a peak outflow from Maingate 3 over a period of several weeks, though the recession has been routinely interrupted by subsequent rainfall events during the mining of Longwall 3. The style of response observable in 6 events during the retreat of Longwall 3 following the June 2007 inflow event*".

The rainfall data provided with the end of panel report provide a total rainfall of 435 mm during June, commencing with 34.5 mm on June 9 and finishing with 54.5 on June 17, following a peak of 89.5 on June 16 and 79.5 mm on June 15. In contrast the rainfall in July totalled 62.5 mm, almost all comprised of 26.5 mm on July 9 and 33 mm on July 10. At the time the elevated inflow commenced the mining had passed beneath almost all of the length of Greenfields Creek, its tributaries and catchment across the surface over the southern end of the longwall panel. All of the overlying sections of these watercourses were undermined by the end of June 2007. The end of panel surface and groundwater impact assessment[83] for Longwall 3 has the following comments:

> "*In June 2007 a large inflow of water of the order of 50.5 ML occurred underground in Longwall 3, while mining under the catchment of Greenfields Creek (Creek 11).*"

And:

> "*It is noted that the upper catchment of Greenfields Creek was the area in which cracking of soil and rock materials in the slopes over Longwall 3 was most evident*."

As noted above, the Tammetta equation predicts the drainage zone reaches the surface over this part of Longwall 3.

Two similar inflow events occurred in 2008 during the extraction of Longwall 4, one in February and one in June. The peak inflow in February 2008 was 9.5 Ml/day. Though the inflows were in Longwall 3, the mining company consultants attribute the inflow to caving in Longwall 4. This remarkable suggestion is qualified with the statement "*Whilst the inflow events are associated with rainfall events (with lag), the mechanics of the linkage to the mining intervals have yet to be established*."[84] Nor have they since been established. As mentioned, Longwall 3 was sealed in 2008.

Without elaboration or justification, the subsequent end of panel reports for Longwalls 5[56], 6[85], 7[86], 8[87], 9[42] and 10[70] suggest "*episodic caving can account of the magnitude of the* *observed inflow events*". The suggestion is implausible and no explanation is given for the observed rainfall dependence or the presence of modern water.

Referring to a large inflow event that peaked at just over 13 million litres a day, BHP-Billiton comments recorded in the minutes of the February 2013 meeting of the Community Consultative Committee advise "*The inflow event occurred in late February 2012 in Dendrobium Area 2. Inflows have been occurring since 2005 following large rainfall events*". Again, episodic caving is an implausible explanation for the repeated rainfall related inflows in Area 2. The inflow would presumably have been much larger if Longwall 3 had not been sealed in 2008.

Referring to the calculation of inflow from mine records, Tammetta makes the following comment in the October 2012 Coffey groundwater assessment[3] for Area 3B:

> "*The match between modelled and calculated groundwater inflows is influenced by the effects of rainfall recharge, during severe rainfall events, through collapsed zones that have reached the surface. This is supported by the analysis of rainfall and inflow residuals in Ziegler and Middleton (2011) and in the current study (see above), and results from tritium analysis (Ecoengineers, 2012). Based on water chemistry data, PB (2012) suggests that the proportion of modern water increases during inflow events (where an event is an occurrence where sudden increases in inflow to the workings are sustained, usually during high rainfall events, with decrease in inflows occurring soon after*)".

This is demonstrated by the inflow behaviour of Longwall 3 in Area 2 and Longwall 1 in Area 1 is reported to have behaved in a similar manner. As noted above, both longwalls were sealed in 2008. The inflow events in Longwalls 1 and 3 occurred during the Millennium drought.

15.2.2. HydroSimulations' comments on inflow

HydroSimulations suggest inflows that are higher than a nominal baseline are driven by elevated piezometric heads, which in turn are caused by high net recharge compared with long term discharge from the aquifer systems. A difficulty with this suggestion is that it would apply to other mines operating in the Special Areas and beyond, yet the inflow volumes and comparatively short lag between rain and inflow distinguish Dendrobium from other mines. Beyond the collapse zone vertical conductivity does not differ greatly from its pre-mining character, with the exception of the surface fracture network. The highly implausible suggestion offered by HydroSimulations would also require ponding.

Intersection of the drainage zone with the surface or surface fracture networks above parts of some of the longwall extractions would more readily account for the inflow behaviour at Dendrobium. Estimating where this would occur requires an extraction height profile for the mining and this information only appears to be have been made publically available for Longwall 3.[65] The 2015 Dendrobium inspection report[20] tabulates extraction heights for Longwalls 9 to 11 (see Table 3). This information should be made available for all underground mining as a matter of routine.

15.3. Mine water chemistry

HydroSimulations argue that chemical and conductivity analysis of the mine waters indicates that mine inflows do not contain a significant surface water component and, accordingly, that high inflows cannot simply be explained as a proportional increase in surface water ingress. The consultants note a surface water component of 10% or less may not be apparent given the limits of measurement precision and the natural range in source compositions.

Other than through watercourse floors, surface water can only enter a mine during and following periods of rainfall and in areas where a connecting fracture and/or the drainage zone intersects the overlying surface. The extent and rate at which surface water reaches mine workings will depend on the intensity and duration of the rainfall. Surface water reaching an underlying mine will be heavily diluted by groundwater entering the drainage zone from its sides, as has been observed[13] over Longwall 9 by Parsons Brinckerhoff. Additionally, the chemical character of the surface water will be increasingly modified through fracture surface chemistry as it descends towards the mine.

HydroSimulations don't mention a 2011 Dams Safety Committee paper that assesses the origin of modern water found in Area 1 and Area 2. The paper notes "*it can be difficult to determine the provenance of any modern waters present using water chemistry alone*." and comment in their Dendrobium study "*available water chemistry is unable to discriminate between the various potential sources of modern water*". As noted above, the study concludes that the tritium data indicated the mine water contained approximately 20% of modern water and contained algae that pointed to a reservoir or watercourse component. The DSC study was hindered by the sealing of Longwalls 1 and 3 in 2008.

Contrary to the suggestion made by HydroSimulations, the inflow water chemistry does not preclude intersection of the drainage zone with the surface over all or parts of some of the Dendrobium longwalls. See also Section 21.

15.4. Database coverage

In their 2015 height of fracture report, submitted as part of the 2016 SMP application for the extraction of Longwalls 14 to 18, HydroSimulations state:

> "*HydroSimulations (2014) highlights that much of the existing and proposed mined areas at Dendrobium have longwall geometries beyond the limits of the database upon which the Tammetta (2013) regression is based. Specifically, that database does not cover mined heights of greater than 4.1 m (4.5m mined height in Area 3B) or panel widths of greater than 260 m (305 m void widths in Areas 3A and 3B).*"

Not mentioned is that the mining geometry represented in Tammetta's database spans the range of sub-critical, critical and supercritical; it's unlikely that his equation will fail in its application to Area 3B.

Discussed in Section 16, the 2014 Parsons Brinckerhoff attempt to directly measure the height of the drainage zone over the eastern end of Longwall 9 was limited and inconclusive. Nonetheless the evidence currently available from Dendrobium is in accord with drainage height estimates from the Tammetta equation. In order to provide verification a bore should be placed over the centreline of the western quarter of Longwall 10 or 11, where horizontal stress effects appear to have been minimal.

15.5. Elouera

The distance from the centre of Area 3B Longwall 14 to Elouera Longwall 7 is approximately 2.5 kilometres, while that to Area 2 Longwall 5 is approximately 5 kilometres; the proximity of Longwall 7 (LW7) in the Elouera domain of the Wongawilli mine to Area 3B of the Dendrobium mine is shown in Figure 10.

Likewise extracting coal from the Wongawilli seam, Area 3B of the former BHP-B owned Dendrobium mine amounts to an extension of the former BHP-B owned Elouera mine, which is now part of Wollongong Coal's Wongawilli mine. Reflecting this, the current HydroSimulations groundwater model for Area 3B includes use of a bore in the Elouera domain, shown as bore S1709 in Figure 7 of the 2016 HydroSimulations assessment report and as DDH8 in the Drawing 2 map in Tammetta's October 2012 Area 3B assessment and in the Drawing 3 map in Tammetta's November 2012 Area 3B data analysis report.

Figure 6 from the Tammetta assessment (see Fig. 28 below) shows bore DDH8 is located to the side of Elouera Longwall 8, the Elouera longwall closest to Area 3B. The figure also shows that the adjacent longwall, Longwall 7, has a centre-line piezometer bore, labelled DDH9. Puzzlingly, as noted above, this bore is not mentioned in either the 2014 or the 2016 HydroSimulations groundwater assessments for Area 3B. Nor is it mentioned in the 2015 Parsons Brinckerhoff assessment for Longwall 9 in Area 3B. As S1710 it appears to be shown as a side panel bore in the end of panel report[73] for Dendrobium Longwall 11 (see Fig. 31(a)).

As discussed in Sections 12 and 15.2.1, in their 2015 height of fracture assessment[21] HydroSimulations present a summary of the 2007 GHD hydrogeologic assessment for Area 3. The GHD assessment includes consideration of an SCT analysis of extensometer data from a bore over the centreline and another over the adjacent rib at of a longwall extraction at the adjacent Elouera mine. HydroSimulations however fail to point out that SCT find the zone of large downward movement, which they characterise as movements of 0.2 to 0.5 metres, above the longwall has a height equivalent to the longwall width. Nor does the HydroSimulations report note that SCT found likewise at Clarence Colliery.

In their assessment GHD effectively suggest that the zone of large downward movement found by SCT would not result in depressurisation. In doing so they attempt to reconcile the SCT results with Forster and Enever's earlier classification of fractured and constrained zones formed over a longwall extraction and accordingly place the upper 60% of the zone of large downward movement in the Forster and Enever constrained zone (the definition is quoted in Section 12). The stark contradiction in locating most of the zone of large downward movement in the constrained zone is either overlooked or not recognised by GHD. As discussed in Sections 3 and 7, contradicting GHD's proposed reconciliation, in 2013 Tammetta published an analysis that finds the zone of significant downward movement identified by extensometer data coincides with the depressurised zone identified by piezometer data.

HydroSimulations nonetheless accept the self-contradictory GHD interpretation in their 2015 height connected of fracturing assessment for Dendrobium. Also puzzling, the Elouera Longwall 7 piezometer data considered in Section 12 are not considered or mentioned by HydroSimulations, yet the piezometers in the bore adjacent to Longwall 8 are included in their piezometer data modelling for Area 3B.

While Parsons Brinckerhoff note that the 2011 overview paper[59] by Mills concludes that the zone of large downward movement following coal extraction occurs to a height approximately equivalent to the panel width, they don’t point out that extensometer data from Elouera support this finding. Like the 2014 and 20016 HydroSimulations groundwater impact assessments, the Parsons Brinckerhoff report lacks mention of the Elouera study, which was requested by the NSW Dams Safety Committee in assessing the then proposed mining for Area 1. Nor does the Parsons Brinckerhoff report consider the piezometer data from the bore over the centreline of Elouera Longwall 7.

16. Dendrobium Area 3B - Parsons Brinckerhoff report for Longwall 9

The approval conditions for the mining currently underway in Area 3B requires a determination of the drainage zone heights for Longwalls 6 to 10 and reliable estimates for the height of the zones formed by the extraction of Longwalls 11 to 12, as a precondition for an approval of further mining (see Section 24). Presumably toward this end, in March 2015 Parsons Brinckerhoff completed a report[13] on a project commissioned by then mine owners BHP-Billiton to determine groundwater impacts arising from the extraction of Longwall 9 of Area 3B; the ‘height of fracture’ project. The report presented and assessed results from several bores over or close to being over the centreline of Longwall 9, very close to pre-mining piezometer bore S2192 and approximately one quarter of the Longwall 9 length from its eastern (completion) end.

16.1. Puzzling use of Ditton’s geology equation

Using a mining depth of 400 metres, width of 310 metres, extraction height of 3.7 metres and adjustment parameter of 30 metres, the Parsons Brinckerhoff report gives (Table 3.4) the likely Longwall 9 fracture zone height (A50) estimated by the Ditton geology equation as 255 metres. However, using the parameters given in the report, application of the geology equation (given in Table 3.3 of the report) returns an A zone height of 175 metres, which is 33 metres higher than returned by the Ditton geometry equation and 80 metres lower than given in the Parsons Brinkerhoff report.

An adjustment parameter of 11.67 metres would be required for the height of 255 metres Parsons Brinkerhoff suggest is returned by the Ditton geology equation. At a mining depth of 400 metres Ditton suggests[26] a minimum parameter of 40 for the Southern Coalfield, though 32 and, more recently, 30 are used for Dendrobium (see the quote from HydroSimulations in Section 15.1.7). Parsons Brinkerhoff appear to have made a mistake. Figure 8 below shows how the height estimate varies with varying adjustment parameter.

It may be that the consultants have listed the geology equation height estimate with the addition of twice its expected error, equivalent to the 95% confidence limit. That is, the Ditton equation estimate listed in the Parsons Brinckerhoff report may be the upper bound estimate for which there is a 95% expectation that that the measured A zone height with be equal to or less this estimate (the

A95%/5% estimate) and a 5% probability that it will be greater than this value. However the A95 estimate returned by the equation would appear to be 222 metres.

The report suggests the Ditton geometry equation (mining geometry only, no adjustment parameter) "*may underestimate the height of connective fracturing*" at S2220. The difference between the heights returned by the geometry and geology equations is however relatively small; if the geometry equation provides an underestimate, then so does the geology equation.

Incorrectly giving the Longwall 9 extraction height as 3.7 metres, Parsons Brinckerhoff are evidently unware that, other than for 340 metres, the extraction height for most of Longwall 9, including all of the second half of the extraction, was 3.4 metres (Table 3). Using an extraction height of 3.4 metres, an adjustment term of 30, depth of cover of 395 metres and the void with of 305 metres given by MSEC, Ditton's geometry equation estimates a likely A zone height of 136 metres, 244 metres below the surface, and the geology equation estimates a likely height of 166 metres, 214 metres below the surface.

As part of the study, six months the completion of Longwall 9 an array of six piezometers was installed in a centreline bore labelled S2220. The Ditton geology equation estimate of the likely A zone height would put the zone's peak between S2220 piezometer 4 at 175 metres below the surface and piezometer 5 at 260 metres below surface. Both of these instruments failed shortly after installation.

16.2. Insufficient piezometer data

The piezometers in bore S2220 were installed over the centreline of Longwall 9 in October 2014, approximately a year after the longwall face had passed below nearby centreline bore S2192 in October 2013 and four months after the extraction was completed in June 2014. Of note, Parsons Brinckerhoff incorrectly give the completion date as being in January 2014. This is contradicted by the end of panel report and its component reports. The subsidence report[74] for Longwall 9 states for example: "*The extraction of Longwall 9 commenced on the 9th February 2013 and was completed on the 2nd June 2014*" and Figure 42(b) below, from the Longwall 9 groundwater report[42], includes a longwall progress trace that shows completion in June 2014. As explained below, the discrepancy is of some significance.

Bore S2220 is 18 metres south of bore S2192 and its piezometers are located at the same depths as those in S2192. As discussed in Section 15.1.14, the S2192 instruments failed with the approach of and passage of the longwall face in October 2013.

Data were collected from the S2220 piezometer array between the 12th of November 2015 and the 23rd of February 2015, a period of just under 15 weeks. Hydrographs for the upper three piezometers over this short period are shown in Figure 5.7 of the Parsons Brinckerhoff report. As mentioned, the lower three piezometers failed shortly after installation and, of significance, this is attributed to ongoing subsidence.

The Parsons Brinckerhoff report acknowledges that the data collected from centreline piezometer bore S2220 were insufficient to allow a determination of the drainage zone height: "*current observations do not allow a precise measurement of the height of intense fracturing using any criteria*". The consultants also suggest however that the "*likely height of connected fracturing is* *best represented by the Ditton and Merrick (2014) "geology" formula*". As discussed in Section 16.1, their use of the Ditton equation is unclear and appears to be erroneous.

Parsons Brinckerhoff also appear to have been unware that the extraction of the eastern half of Longwall 9, in particular its final third, was considerably hindered by unusually high horizontal stress conditions.[75], [76], [88] The problematic conditions halted mining between the end of July and early September 2013. Following the resumption of mining, it took 9 of the 18 months needed to complete the extraction of Longwall 9, to finish the last 500 metres or so of the longwall (see Fig. 42(b)). That is, reflecting the stress conditions, the extraction of the final quarter of Longwall 9 required as much time as the extraction of the rest of the longwall.

Steep terrain is often associated with anomalous stress conditions. Figures 10 and 27 below depict the steep topography in the east of Area 3B, with notably steep terrain immediately to the east of the location of the centre-line piezometer bores over Longwall 9.

Difficulties encountered with the extraction of the eastern end of Longwalls 10 and 11 demonstrate that, contrary to expectations[89] [88], the stress conditions first encountered in the mining of the eastern half of Longwall 9 have not yet been released. Stress release can be spontaneous, or a result of nearby mining or earth tremor.

In their 2007 hydrogeological assessment for Dendrobium Area 3 GHD comment;

> "*In common with the rest of the Southern Coalfield, the in-situ horizontal stresses at the Dendrobium Mine are relatively high. SCT Operations has reported that the maximum horizontal stress (σ_H max) is 14 MPa to 16 MPa at 200 metres depth of cover and 20 MPa to 24 MPa at 450 metres depth of cover. The maximum principal stress direction, based on borehole breakout data, is NE to SW (032°– 065° relative to True North). The rocks of the Hawkesbury Sandstone and the Narrabeen Group are of relatively low permeability at depth and have a limited capacity to facilitate migration of water from the surface into the proposed mine workings. This capacity is further reduced by the relatively high level of in situ horizontal stress*."

The difficulties encountered in the eastern part of Area 3B suggest the horizontal stress is anomalously higher than reported by GHD.

As noted in Section 7, Tammetta observes that anomalous horizontal stress can result in a delayed and unpredictably intermittent development of the drainage zone.[49] Tammetta makes this observation on examining piezometer data for Longwall 9 at the Mandalong mine, following a mining consultant's suggestion that the data did not support the Tammetta equation.[49] The consultant was evidently unaware that following the delayed and intermittent development of the Longwall9 drainage zone over the course of a year, with completion of the adjacent longwall and part of the next, the drainage zone height was in good agreement with that estimated by the Tammetta equation. Tammetta accordingly cautions:

> "*The example of the Mandalong water level database highlights the necessity of undertaking adequate review of estimates made by proponents of heights of desaturation for underground mining projects, so that unrepresentative or erroneous results are not incorporated into impact assessments*."

The Mandalong Longwall 9 experience suggests the possibility that the development of the collapsed zone over Dendrobium Longwall 9 had not completed before the termination of the collection of data from the piezometers in the centre-line bore S2220. Whereas extraction of Longwall 9 was expected to dissipate the stress[89], similar conditions were encountered in the eastern part of Longwall 10[88] and are understood to have hindered Longwall 11. The principal horizontal stress direction noted by GHD in their 2007 Area 3 assessment[57] is consistent with anomalously high horizontal stress delaying post coal extraction overburden collapse.

The loss of the three lower S2220 instruments a year after the longwall face passed below nearby bore S2192 and some five months after the completion of Longwall 9, is consistent with a delayed collapsed zone development. That is, a year after passing below the bore site, the collapsed zone height increased to a height between Piezometer 4, located at approximately 220 metres above the seam, and Piezometer 3 at approximately 255 metres above the seam.

In order to have confidence of a reliable determination of the drainage zone height, data from S2220 should then have been collected for at least a year after the completion of Longwall 9 and, given evidence that the stress had not been released, it should have continued until the completion of Longwall11 - or until the remaining sensors failed as the developing collapsed zone reached their location.

It’s not known whether the limited data collection period reported for S2220 reflects a project management decision or instrument failure. As noted, data collection from S2220 was halted on February 23 2015, just under 15 weeks after data collection commenced on November 12 2014, following installation of the piezometers in October 2014.[13] In May 2016 the mining company was asked by email if the data collection from the instruments in S2220 could be resumed, but has not replied. Given the considerable expense of installing a piezometer bore and the benefit it would provide in monitoring at least the impacts of Longwall 11, it seems more likely that the limited data collection period reflects instrument failure than a management decision. This possibility is supported by the S2192 hydrographs provided in the groundwater assessment for the Longwall 11 end of panel report which, in contrast to those provided in the Longwall 9 and 10 reports, show a small number of additional data recorded in November 2014, more than a year after the instruments had apparently failed. Though the additional S2192 data are unreliable, their provision suggests that if additional S2220 data were available, it would have been provided.

16.3. Insufficient extensometer data

An extensometer array installed in the nearby bore S2191 (AQ2) before the extraction passed beneath enabled monitoring of overburden strain at depths between 20 and 280 metres during undermining of the site. Extensometers anchored within the Hawkesbury Sandstone, Garie Formation, Bald Hill Claystone and Bulgo Sandstone responded within 3 to 8 days of undermining, with a response within the deeper units first. The post undermining data appears to be limited to just eight days.

Ditton associates[26] the connected fracture zone, the A zone, with vertical strain greater than 8 mm/m. Parsons Brinkerhoff report that the average vertical strain in the Bulgo Sandstone was approximately 11 mm/m. Vertical strain above the base of the Bulgo Sandstone is reported to be highest across the Bald Hill Claystone at approximately 7.2 mm/m, while within the Bulgo and Hawkesbury Sandstones it’s reported to be approximately 3.3 mm/m and 2.4 mm/m. Accepting Ditton’s strain characterisation suggests that at the time of the last data collection, the collapsed zone below S2191 had not extended into the Bulgo Sandstone.

Parsons Brinckerhoff don't explain why the post undermining extensometer data is limited to eight days. Perhaps the data became erratic and the instruments failed as the collapsed zone developed. If so, the pre-failure data would have provided some insight and should have been provided.

It's disappointing that the eight day summary isn't supported graphically and that displacements are not provided. Tammetta more appropriately characterises[16] the collapsed zone with respect to a clear change in the extent of downward anchor displacement with respect to anchor depth. Doing so avoids characterisation with respect to an arbitrary strain that may or may not be associated significant downward movement.

In the absence of a substantially longer data collection period, reliable conclusions about the height of the collapsed zone cannot be drawn from the S2220 and S2191 data. However, as mentioned, centreline piezometer and extensometer data from the nearby Elouera mine provide data indicating a drainage and collapsed zone height that's in accord with the estimate provided by the Tammetta equation.

Data provided by piezometers in off-panel bores in the vicinity of Longwall 9 are consistent with the Tammetta equation, but challenge the Ditton equations (see Table 4 and Sections 15.1).

16.4. Tracer studies

The Parsons Brinckerhoff study included the use of fluorescein and rhodamine dyes and a salt (potassium chloride) tracer to assess the following:

(i) Horizontal flow changes.
(ii) Connectivity between groundwater and the mine and nearby streams.
(iii) Integrity of the Bald Hill Claystone below the text site.

The latter test involved injecting approximately 30,000 litres of a 40 milligram per litre (40 mg/l) solution of rhodamine over a 7.5 hour period into a bore (AQ8) above the Bald Hill Claystone, with monitoring for 25 hours at a second bore (AQ7) at a depth below the Bald Hill Claystone.

In accord with the piezometer data, the dye was not detected at the monitoring bore. Detection of the dye was compromised by greater water outflow than inflow to the bore, such that it appears the detector was only infrequently submerged. No dye was found in carbon bags that were used as a backup. The test provides confirmation that, at the time of the test, the collapsed zone below the bore site had not reached beyond the Bald Hill Claystone.

The second test involved injecting fluorescein at intervals at depths between 163.1 and 298.6 metres below the bore site AQ5 (which later became piezometer bore S2220) between July the 8th and July the 16th 2014. Monitoring was carried out in the mine workings directly below the AQ5 site and additionally at one point on Wongawilli Creek, two points on tributary WC21, one point on Donalds Castle Creek and a tributary DC13. The Wongawilli Creek site are to the north east of the bore site, at distances of approximately 430, 900 and 960 metres away; the prevailing groundwater flow direction is to the northwest. The Donalds Castle Creek are to the North West at distances of approximately 630 and 770 metres.

As of November 2014, no dye and been detected at any of the stream monitoring sites. Parsons Brinckerhoff report that groundwater flowed northwest prior to the extraction of Longwall 9, presumably reflecting the gentle down dip of the strata in this direction evident in the MSEC coal seam elevation contour map.[64]

The MSEC contour maps suggest a reason for the failure to detect dye at the Donalds Creek and Wongawilli monitoring sites. The injection at shallowest injection depth 163.1 metres below the ground is significantly below the elevation of the streams at the monitoring site locations. The shallowest injection depth corresponds to an elevation of 225 mAHD and the MSEC maps indicate the elevations at the monitoring sites are 345 and 350 metres for the two Donalds Castle Creek sites and 280, 284 and 320 metres for the Wongawilli Creek sites.

That is, the Donalds Castle Creek sites are approximately 120 and 125 metres above the shallowest injection point, while the Wongawilli Creek sites are 55, 59 and 95 metres above the shallowest injection point. Given low vertical hydraulic conductivity, there would seem little prospect of the dye being detected, whether or not the watercourses were gaining streams at the monitoring sites.

Parsons Brinckerhoff report however report detection of low dye levels in the mine at the monitoring site below the bore. Discussed below in Section 16.7, an explanation for the detection of limited dye quantities in the mine may be found in considering the piezometer data provided from bores S2192 and S2220.

16.5. Conductivity and rock defect assessment

In their March 2015 Longwall 9 height of fracturing report Parsons Brinckerhoff make the following observation:

> "*Hydraulic conductivity (horizontal) in these three intervals after mining is approximately two to three orders of magnitude higher than before mining This indicates that increases in horizontal hydraulic conductivity associated with dilation of strata is not distributed evenly above the longwall, but is influenced by geology and, in particular, appears to be correlated with the density of pre-existing bedding plane defects.*".

The comments refer to post-mining bore AQ5 hydraulic conductivity (packer) conductivity measurement results for the lower Bulgo Sandstone (below a depth of approximately 240 metres), lower Hawkesbury Sandstone (120 m to around 180 m below ground level) and the Bald Hill Claystone grouping, and the upper Hawkesbury Sandstone group (to a depth of around 110 metres). Located over the Longwall 9 centreline nearly three quarters along the length of the extraction, AQ5 later became bore S2220 following the installation of six vibrating wire piezometers in November 2014.

Pre-mining conductivity measurements found:

> "*There was a marked decrease in average hydraulic conductivity by almost two orders of magnitude below approximately 120 m depth (lower Hawkesbury Sandstone). This is consistent with findings reported in Coffey (2012), where a break in slope in a curve of a number of packer tests in the Dendrobium area and wider Southern Coalfield occurs at approximately 100 m depth, indicating a shift in hydraulic conductivity control at this depth. At approximately 200 m depth, permeability of the bulk rock mass, as estimated from packer tests, starts to converge with the matrix permeability as estimated from core permeability tests. These converging depth trends suggest that the bulk hydraulic conductivity in the upper 200 m is dominated by open defects and fracture flow, whereas below this depth, the bulk permeability is controlled primarily by the rock matrix (Coffey, 2012).*"

Of note, the results confirm that the Bald Hill Claystone does not act as an aquitard controlling vertical flow between Hawkesbury and Bulgo Sandstone. The conductivity changed markedly following mining;

> "*Average values (arithmetic mean) of horizontal hydraulic conductivity are one to three orders of magnitude higher than the pre-mining conditions. Increases in hydraulic conductivity are observed in every geological unit, but are greatest below the base of the Hawkesbury Sandstone*."

The investigations reported by Parsons Brinckerhoff were not sufficiently sensitive to be able to measure any significant changes to vertical conductivity following mining;

> "*Although the tracer tests used in this study do not allow precise estimates of Kv, observations of groundwater levels after the passing of Longwall 9 indicates that Kv increases to much less of an extent within the constrained zone (Figure 6.5).*"

Pre-mining investigation found no significant numbers of vertical defects in the rock below the study site;

> "*Very little natural fracturing was observed in the intersected strata. Rock defects were dominated by bedding planes with little associated open fracturing, with relatively few identified joints*."

Inspection by a BHP-Billiton geologist of the core obtained from the post undermining sinking of AQ5/S2220 found 777 rock defects of which 524 were attributed to mining impacts. Parsons Brinckerhoff did not inspect the core and there has been no independent assessment. Based on the electronic records and photographs provided by BHP-Billiton, Parsons Brinkerhoff report that of the 524 mining defects reported by the BHP Billiton geologist; "*the vast majority are related to bedding planes and subhorizontal joints*". They also observe; "*Sub-vertical fractures are apparent throughout the core but are more prevalent towards the base of the Bulgo Sandstone and in the Stanwell Park Claystone (e.g. 286.2 m, 287.2 m).*" That is, the centreline core inspection finds no indication of significant change to the number and character of the vertical defect population above the height of the collapsed zone, suggesting little change to the vertical conductivity above this height.

16.6. Storativity

Parsons Brinckerhoff use the data from extensometer bore S2191 to estimate the increase in storativity above Longwall 9 as a consequence of fracturing and dilation. Compromising the assessment, the bore evidently provided data for only eight days. Puzzlingly the consultants use an extraction length of 3000 metres and an extraction height of 3.7 metres, whereas the extraction length was 2,186 metres[74] and most of Longwall 9 was cut with a height of 3.4 metres. The assessment endeavours to estimate a time for groundwater levels to recover; within the drainage zone this won't occur until the dilated seam floor and goaf fill with water, which will take many years.

Tammetta's recent assessment of storativity changes arising from longwall coal extractions finds that on average 34% of the extraction volume is distributed into the goaf, 32% into the collapsed zone, 18% into the surface trough formed by subsidence, 12% into the dilated seam floor, 2.6% into the upper disturbed zone (including the surface fracture zone) and 0.9% into the lower constrained zone. That is, 70% of the extraction volume is distributed into the subsurface zones, which includes 66% in the collapsed and goaf zones; this assumes the collapsed zone doesn't intersect the surface.

As noted above, Longwall 9 was extracted over a length of 2.186 kilometres, with a width of 305 metres and an average cutting height of 3.5 metres, corresponding to an approximate volume of 2.3 gigalitres (Gl; 1000,000,000 litres). This is essentially the same volume estimated by Parsons Brinckerhoff using the strain data from bore S2192. Tammetta's work suggests the collapsed zone will absorb 747 million litres of the extraction volume and the goaf volume will be a 793 million litres. That is, in addition to pre-existing defect volumes, a total of 1.54 gigalitres would be required to fill the void space distributed into the goaf and collapsed zones, once mine dewatering stops.

16.7. Rationalizing the S2192 and S2220 data

The S2192 hydrograph provided in the HydroSimulations groundwater assessment for the Longwall 11 end of panel report (Fig. 42(a) below) shows that the piezometer at 50 metres below the surface (Piezometer 1; see also Section 15.1.14 and Figs. 42-45 below) slowly loses water pressure before a sharp rise and then a precipitous fall that terminates with a zero pressure head (actually slightly negative) and instrument failure. The piezometer doesn't respond to rainfall or recharge over the period covered by the hydrograph (Fig. 52 (a) below). Indicating no post-subsidence settlement recovery, which might have been expected[77] for a relatively shallow centreline instrument[77], the corresponding S2220 instrument installed in November 2014 is dry and shows no recharge or rainfall response (Fig. 52 (b) below).

As indicated in Figs 42 to 45, the S2192 instrument at 95 metres below the surface, Piezometer 2, records a gradual decline from April 2013 before responding to the compression effects of the 'head-on' approaching longwall face in the second half of June. The instrument shows no response to rain over the period covered by the hydrograph. Parsons Brinckerhoff comment:

> "*The variations seen from the S2192 hydrographs are larger than in S2220, however those variations are not correlated to rainfall events and are instead interpreted as far-field changes to the rockmass and pore pressure as the longwall approached the position of the site (approximately 350 m away from the site at the end of June 2013).*"

Though the period covered in the Parsons Brinckerhoff hydrograph ends in July 2013, the instrument didn't fail until during or shortly after the longwall had passed below the bore site in early October 2013; see Figure 43. Of note, at the time the compression response reported by S2192 Piezometer 2 peaks in mid-June, the longwall face was approximately 73 metres past the point of shortest distance to off-panel bore DDH105/S1910 (Section 15.1.13).

In contrast to the corresponding S2192 instrument, and as noted by Parsons Brinckerhoff, at 95 metres below the ground S2220 Piezometer 2 records a clear sensitivity to the moderate rainfall intervals over the limited time period covered by the hydrograph; reported to be from the 11th of November 2014 to the 23rd of February 2015. Notwithstanding the rainfall response, over this period the initial pressure head of approximately 17.3 metres falls to 15.5 metres. In contrast, while similarly reporting a decline from approximately 15.5 to 13.7 metres, S2220 Piezometer 3 at 140 metres below the surface does not report a response to rainfall.

Of note, the underlying rate of pressure loss recorded by Piezometer 2 at 95 metres below the surface appears to be similar to that of Piezometer 3 at 140 metres below ground. Though the piezometers are vertically separated by 45 metres, the pressure head difference is just two metres. Also of note, reference to the initial pressure head reported by S2192 Piezometer 3 of approximately 83 metres and the last reported pressure head reported by S2220 Piezometer 3, indicates the pressure head in the lower Hawkesbury Sandstone had fallen approximately 67 metres by the 20th of February 2015. This corresponds to a pressure head loss of approximately 82% at a depth of 140 metres, over the centreline of Longwall 9. The loss at 95 metres below the surface by this time corresponds to approximately 50% of the initial pressure head of 29 metres reported by S2192 Piezometer 2.

The S2220 instrument at 50 metres below the surface, Piezometer 1, reports that water drained freely at this depth over the recording interval. At 95 metres below the surface, the post-extraction behaviour of S2220 Piezometer 2 reflects considerably increased vertical hydraulic conductivity and suggests a significantly deeper surface fracture network than might have been anticipated. The lack of sensitivity to rainfall demonstrated by Piezometer 3 indicates that the greatly enhanced vertical hydraulic conductivity demonstrated by the instruments above, doesn't reach its depth of 140 metres below the surface. That is, over the short S2220 recording period there is no evidence of significant vertical hydraulic connectivity spanning the interval between 95 and 140 metres below the surface.

There would appear to be two possibilities for reconciling the differing rainfall behaviour with the similar magnitudes and rates of pressure loss displayed by the 95 and 140 metre instruments:

(i) The underlying pressure loss recorded by the 95 metre instrument primarily reflects horizontal draw to a sink, while the pressure loss recorded by the 140 metre piezometer reflects vertical pressure loss to a sink at a relatively short distance below. That is, at the time the data were collected, the 140 metre instrument is close to the collapsed zone over this section of Longwall 9.

(ii) Both piezometers primarily reflect horizontal pressure loss to the same sink.

The similar magnitude of the net pressure loss reported by the two piezometers over the limited S2220 recording period perhaps favours the second possibility. That S2220 Piezometers 2 and 3 do not report a complete loss of pressure head seems to contradict the implications of the instruments in the off-panel bores that respond to the mining of Longwall 9. The lowest lower bound for the Longwall 9 drainage zone height indicated by the piezometers in bores DDH105/S1910, DDH104/S1908, DDH109/S1926, DDH111/S1929 and DDH108/S1925 is 264 metres and the highest lower bound is 280 metres.

Figure 53 below depicts a reconciliation of the apparent contradiction; the collapsed zone in the western section of Longwall 9 essentially reached full height, while the development of the collapsed zone underlying S2192/S2220 hadn't finished by the end of the short recording period of the hydrographs provided for S2220. The western section of the Longwall 9 collapsed zone could then provide the sink responsible for pressure loss recorded by the S2220 instruments at 95 and, perhaps, 140 metres below the surface; corresponding to approximately 255 and 300 metres above the floor of Longwall 9. This would account for the failure to detect fluorescein below S2220 in July 2014.

The lack of water retention at 50 metres below ground and rainfall sensitivity evident at 95 metres below the surface points to a surface fracture network penetrating considerably deeper than the maximum depth of 30 metres expected by HydroSimulations.[21] Consultants assessments typically suggest the surface fracture network extends no more than 20 metres below the surface. In their 2008 assessment for the then proposed new longwall extractions in the Elouera domain of the Wongawilli mine, consultants MSEC advise:

> “*The depth of cracking and dilation of strata have been measured in the past at other collieries, and in each case the depth of cracking and dilation have extended downwards to depths of approximately 5 to 10 metres and a maximum depth of approximately 14 me*tres.”

The 2007 review by McNally and Evans, of consultancy Sinclair Knight Merz, advises that the surface fracture network typically extends no further than 15 metres below the surface.[52]

Though the limited data provided by the height of fracture project assessed and reported by Parsons Brinckerhoff precludes a clear measure of the height of the collapsed zone below S2220, the available evidence, including that of the Dendrobium piezometers and centreline piezometers over Elouera Longwall 7, Springvale Longwall 409, Longwall 10 at Tahmoor and Longwall 9 at Mandalong, suggests that the Ditton geometry and geology equations will significantly underestimate the final drainage zone height at S2220, following stress discharge. The Tammetta equation provides an estimate of 315 metres for the final height of the drainage zone at S2220. The surface is approximately 395 metres above the seam at the bore location. Given the behaviour of S2220 Piezometer 2, the Tammetta equation suggests the drainage zone would join the fracture zone above Longwall 9 at this location.

17. Dendrobium Area 3B - modelling

The 2012 Coffey assessments introduced the use of a regional scale groundwater model that WaterNSW (then the SCA) has described as an important step forward:

> “*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*.”[47]

Though the details are held in reports that are not publically available, the limited available information indicates that the earlier modelling for Dendrobium, undertaken by HydroSimulations (then trading as Heritage Computing), was significantly more limited in scope and rigour. Without explanation, the groundwater impact assessments for the Longwall 6, 7 and 8 end of panel reports advise that the fractured zone (assumed to be effectively equivalent to the drainage zone) height incorporated in the model underpinning the groundwater assessments was set at the base of the Bulgo sandstone. Fixing the drainage zone at the base of the Bulgo Sandstone does not appear to be consistent with the available piezometer evidence. Hydrographs from key piezometer bores are discussed in Section 15.

While the March 2014 HydroSimulations groundwater impact assessment that replaced the 2012 Coffey assessments retained much of the 2012 model, it was fundamentally different in replacing the Tammetta equation with use of the Ditton equation. Though presented by HydroSimulations as a step forward, the accumulating evidence suggests this change was instead a significant step backwards.

The model underpinning the March 2014 HydroSimulations assessment is also used for the groundwater impact assessments for the Longwall 9, 10 and 11 end of panel reports. As discussed in Section 15.1.13, the groundwater assessment reports for Longwall 9 and 10 present data from piezometer bore DDH105/S1910 as a test of the Ditton and Tammetta equations and find in favour of the Ditton equation. The data from DDH105 and other Area 3B piezometer bores appear however to be consistent with the drainage zone height estimates provided by the Tammetta equation.

Figure 1 depicts rates of pressure loss for hydraulic diffusivities of 0.0001, 0.001, 0.01 and 0.1 m^2/sec, using the solution to the one dimensional diffusion equation (see Section 1). The commercial software used by HydroSimulations and Tammetta embodies numerical solutions (finite difference) to the three dimensional form of the equation. Pressure head change with time and distance from the causal sink depends on the hydraulic diffusivity over the path between sink and measurement point (see Section 1). Table 1 compares the diffusivities (as conductivity divided by specific storage) for the 2012 modelling undertaken by Coffey and the 2016 modelling by HydroSimulations. While Coffey and HydroSimulations report the same specific storage values, there are significant differences in their conductivity values. Tammetta obtained his conductivities by calibration against field data. Table 2 lists the ratios of the corresponding hydraulic conductivities from the Coffey and HydroSimulations assessments. The significant differences in their conductivity values are consequentially reflected in their respective diffusivity values. A notable example, the upper Bulgo Sandstone vertical diffusivity from the Coffey data is 250 times that of HydroSimulations. While the vertical diffusivity from the Coffey work is typical of sandstone, that from the HydroSimulations report would appear to be more like that of shale.[10]

HydroSimulations use a relatively new software module that models fractures as ‘Connected Linear Networks’ (CLNs) for their 2016 Dendrobium assessment. The consultants are surprised to find that the mine inflow estimates returned via the use of CLNs shows little sensitivity to the height of the fracture zone:

> “*The results of the sensitivity run assuming that the connected fracturing extends to the Tammetta (2013) ‘H’ are also plotted on Figure 38. Surprisingly, the results of that model show very little difference to the base case (using the Ditton A95). This may be because the CLNs are limiting the vertical flow rate, or (less likely) because the strata is limiting the rate of flow into the CLNs, no matter how high they extend into the overburden. In fact, the simulated flow into the mine is not predictably higher or lower with the higher fracture zone CLNs*.”

This highly implausible finding contradicts the sensitivity found in the 2014 modelling undertaken by HydroSimulations, which did not use CLNs; “*Simulated future Dendrobium mine inflows are highly sensitive to the assumptions made regarding the height of the fractured zone above longwalls*”.[23] The Area 3B drainage zone heights returned by the Tammetta equation are about twice the 95% level A zone heights (height plus twice the estimated uncertainty; A95) returned by the Ditton equation. The CLN based modelling is evidently insensitive to the drainage zone intersecting the surface. The insensitivity of the CLN based inflow estimates with respect to drainage zone heights is not physically credible. The current implementation of CLNs are not suitable for modelling non-Darcian flow through fractures in unsaturated media and it’s surprising that the consultants have used this package in this context. The 2016 modelling does not appear to be credible.

The Coffey report of October 2012 tabulates calibration against Dendrobium and other regional mines. In contrast HydroSimulations present calibration with respect to the Dendrobium inflows, but not other regional mines. Tammetta states the following in the October 2012 assessment:

“*A regional numerical groundwater flow model has been simultaneously calibrated to the observed hydraulic conductivity distribution, hydraulic heads, baseflow to rivers (surface discharges), inflow to Dendrobium Mine (deep discharges in the mine area), and inflows to other mines (deep discharges in the regional area). This has considerably reduced the uncertainty in model outputs*.”

The equivalent is not provided in the HydroSimulations report; that is, the HydroSimulations assessments do not demonstrate simultaneous calibration to field conductivities, hydraulic heads and regional mine inflows. This is effectively acknowledged in the report; “*Calibration has focussed on replicating observed groundwater levels and mine inflow*”. Its puzzling that HydroSimulations have not calibrated against field conductivities; Tammetta notes[3] “*the hydraulic conductivity database for the Dendrobium Mine area is substantial (being complemented by numerous published packer test results for the Southern Coalfield) and a good representation of the hydraulic conductivity field in the regional area.*” The lack of constraint in the modelling undertaken by HydroSimulations may contribute to its lack of sensitivity of inflow to drainage zone height.

The end of panel report for Area 3B Longwall 10 suggests good agreement between modelled and observed inflows, commenting “*Modelled inflows are generally slightly lower than observed inflows, by less than 0.1 ML/d on average*”.[70] The HydroSimulations modelling used[23] for the report is based on A zone heights from Ditton’s geology equation with twice the estimated uncertainty of the calculation added to the height estimate (95% confidence level; A95).

The report evidently overlooks a discrepancy between the mining heights used in the modelling, which appear to be those of Tammetta’s rejected November 2014 assessment, as given in Table 3 of the HydroSimulations report, and the employed mining heights. As Table 3 indicates, the mining heights used to date have been significantly less than planned; the mining height used and, hence, the observed mine inflows do not correspond to the modelling undertaken by HydroSimulations. That is, the end of panel report’s finding that the modelled and observed inflows are in accord suggests that the Ditton equation A zone height estimate for 4.5 metres high extractions is an underestimate. Of importance, that HydroSimulations add twice the uncertainty estimate to the A zone height returned by the Ditton equation, referred to as the A95 base case, reinforces this suggestion.

Figure 54 below is Figure 10 from the 2014 HydroSimulations assessment, which comments; “*Figure 10 presents the model calibration to the observed mine water inflows. Modelled inflows are lower than those of Coffey (2012a), but they broadly replicate the observed inflows*”. The figure has an inflow trace that the reference to Coffey (2012a) suggests is taken from the October 2012 Coffey assessment. A comparison of Figure 54 with Figure 55 , which is Figure 19 from the October 2012 Coffey assessment, suggests this is not the case. The trace might instead represent an application of the Tammetta equation by HydroSimulations, using the same extraction heights used in the November 2012 Coffey assessment and not the 3.4 metres used for the October Coffey assessment. Alternatively an error may have been made in the application of the Tammetta equation by HydroSimulations.

Table 3 in the March 2014 HydroSimulations assessment advises that a 4.5 metre mining height was been used for their Area 3B calculations. That the Tammetta equation based model inflow shown in Figure 54 (below) is higher than the observed inflow from July 2012 onwards may at least partly reflect that the mining of Longwalls 9, 10 and 11 used extraction heights lower than the heights used for the modelling (see Table 3). This is likely to also be the case for Longwall 8, which is distinguished from the previous Dendrobium longwalls in having the same planned mining dimensions as Longwall 9 and which commenced in February 2012. Additionally, as noted above, GHD suggested a degree of drainage from Dendrobium into the neighbouring Elouera mine workings. Further, current modelling methods are limited to indicative predictions and, as mentioned, the accuracy of the mine's reticulated water management system as a gauge of inflow is not known.

As noted in Section 14, the March 2016 HydroSimulations assessment states that that the cutting heights used for the calculation of drainage zone heights are "*Actuals for Longwall 1-11*". While this appears to be the case for Area 3B Longwalls 9 to 11, Table 3 in the report suggests the planned or maximum extraction heights have instead been used for Longwalls 1 to 8.

Figure 55 below shows that the modelled inflows of the October 2012 Tammetta assessment are in agreement with the observed inflows, yet the modelled extraction height of 3.4 metres is in general lower than used in the mining. The limited information available suggests 3.7 metres would be closer to the average Dendrobium extraction height and this is the average of the set of heights given in Table 10 of the November 2012 Coffey data analysis report.[62] Regrettably the inflow assessments for the November 2012 Coffey assessment are not publically available and there would appear to be little prospect of Tammetta having opportunity to update that modelling.

In addition to not requiring simultaneous calibration to field conductivities, hydraulic heads and regional mine inflows, the 2016 HydroSimulations modelling is compromised by the use of CLNs. The March 2014 modelling undertaken by HydroSimulations used the mining heights planned for Area 3B, 3.9 metres for Longwall 9 and 4.5 metres for Longwalls 10 to 18, whereas the October 2012 Coffey modelling assumed an extraction height of 3.4 metres for all of the Dendrobium longwalls. As Figures 53 and 54 indicate, the HydroSimulations and Coffey inflow estimates are nonetheless similar. This is also the case for the March 2016 modelling, which uses the cutting heights actually employed for Longwalls 9, 10 and 11. The similarity of the 2012 Coffey and the 2014 HydroSimulations inflow modelling further suggests that the Ditton equation underestimates the height of the drainage zone. The modelling undertaken by HydroSimulations is not of the same calibre as that of Tammetta.

18. Dendrobium Area 3B – unanswered and denied information requests

The October and November 2012 Coffey groundwater impact assessments for Dendrobium were each partnered by data analysis reports. Of the four Coffey reports provided to BHP-Billiton in 2012, only the October impact assessment appears to have been provided to the Department of Planning and only this report was made available to the agencies and public in the lead up to the approval of the mining in February 2013 (see Section 19). The October 2012 data analysis report is referred to in the publicly available assessment report and OEH accordingly sought a copy; the request was refused.[90]

Though the Department of Planning was aware of the November reports and was briefed on their content (see Section 19), the agencies and public were not made aware their existence in the lead up to the Department's approval of the Dendrobium Area 3B mining currently underway in February

2013. Given it includes groundwater impact assessments for up to 4.5 metre high extractions, in accord with the mining actually planned, the November groundwater impact assessment is of considerable importance.

Demonstrating its pivotal importance, the November 2012 Coffey assessment is frequently directly or indirectly referred to in the March 2014 HydroSimulations groundwater impact assessment (which replaced the rejected Coffey assessments), the October 2015 HydroSimulations height of connected fracturing report for Area 3B, the March 2016 HydroSimulations Area 3B groundwater impact assessment report and the groundwater impact assessments by HydroSimulations for the end of panel reports for Longwalls 9, 10 and 11. The November 2012 Coffey assessment is of considerable importance in gauging both Dendrobium impacts to date and the potential impacts of the second set of longwall extractions currently being proposed for Area 3B.

Following belated recognition of the discrepancy between the 3.4 metre high extractions considered in the publically available October 2012 Coffey groundwater impact assessment for Area 3B and the planned mining, and advice (see Section 19) of Coffey's provision of a revised assessment in November 2012, requests were made in 2015 to BHP-Billiton for copies of the October 2012 Coffey data analysis report and the November 2012 impact assessment report. These requests have received no response. Likewise spin off company South32 have not replied to a further request in May 2016 for a copy of the November 2012 impact assessment.

In order to provide comments on the SMP for the second set of longwalls planned for Area 3B, Longwalls 14 to 18, assistance was sought from the Department of Planning in seeking a copy of the November 2012 Coffey impact assessment report. South32 have however refused to provide the Department with the November 2012 Coffey assessment, arguing that it was provided by Coffey as a draft report.

Whether or not it was provided as a draft or is regarded by the mining company as a draft, the revised assessment will have been provided to BHP-Billiton for inclusion in the Department's assessment of the 2012 mining plans for Area 3B. Coffey has publically defended its impact assessment.[91] The 2014, 2015 and 2016 HydroSimulations reports that refer to the November 2012 Coffey impact assessment give no indication of it being a draft awaiting further revision and the document is not referenced as a draft in the reference details given in the HydroSimulations reports.

Further contradicting South32's reason given for refusing to provide the November 2012 Coffey impact assessment to the Department, in responding to the Department's request the company instead provided a copy of the November 2012 data analysis report, which underpinned the withheld impact assessment. The data analysis report lacks the estimates for impacts such as mine inflow and groundwater diversion arising as consequence of the proposed mining that will be included in the withheld assessment report. The report does however confirm that in preparing the November 2012 assessment for Coffey Tammetta found that his equation predicted that the drainage zone would interest the surface above 4.5 metre extractions in Area 3B (see Figs. 21 and 23). That the mining company released the data analysis report but not the impact assessment report suggests the latter may contain grave impact estimates.

In the context of the 2016 SMP proposal, requests have also been made to South32 for Dendrobium longwall cutting height profiles, extensometer and piezometer information and clarification of statements made in reports provided to BHP-Billiton and South32 by HydroSimulations. For example, as mentioned, clarification was sought regarding the source of the piezometer data associated with Longwall 5 that HydroSimulations describe as near perfectly matched with drainage zone (A zone) height estimates provided by the Ditton equation. The mining company was asked if it would be possible to resume the collection of data from bore S2220 over the centreline of Longwall 9. All requests made to the mining company have had no reply. An earlier request made to HydroSimulations for clarification of the source of the Longwall 5 related data received the following response[92]:

> "*Unfortunately, Dr Merrick is unable to respond to your enquiries at this time and requests that you follow proper protocol and submit a formal enquiry to Illawarra Coal who can then pass it on to him if they see fit*."

19. Dendrobium Area 3B - the Department of Planning's assessment of the Area 3B mining

Then mine owners BHP-Billiton were given in-principle approval to mine in Area 3B as part of the outcome of a 2001 Commission of Inquiry.[93] In December 2008 the mining company gained[94] approval[79] for a modification to the original approval that increased the mining footprint of Area 3, the largest of the mine's domains, from some 1,890 hectares to 3,350 hectares. The Minister for Planning was the consent authority for the original development approval in November 2001 and was accordingly the consent authority for the 2008 modification. The modification was approved under section 75W of Part 3A of the Environmental Planning and Assessment Act 1979. Part3A was repealed in 2011, however it continues to have application for mining approved before the repeal.

In October 2012 BHP-Billiton submitted mining plans and associated impact assessments (Subsidence Management Plan; SMP) for the extraction of ten longwalls in Area 3B, to the Department of Planning. On the 6th of February 2013 the Department approved[78] the SMP for the first five of the ten proposed. In the lead up to the February 2013 approval assurances were given that the assessment would be rigorous, open to public scrutiny, fully assessed by government departments and agencies and would not be determined by BHP-Billiton's mining schedule. This is not what transpired however; the assessment was far from rigorous, important information was withheld and the timetable was dictated by BHP-Billiton.

As noted in Section 14, the October 2012 Coffey groundwater impact assessment submitted by BHP-Billiton to the NSW Department of Planning as part of the then proposed Subsidence Management Plan (SMP) for the commencement of longwall mining in Area 3B, was based on modelling that assumed a 3.4 metre cutting height for all of the existing and proposed Dendrobium longwalls. Yet only Longwalls 1 and 2 in Area 1 had been planned with a maximum height of 3.4 metres and were subsequently extracted at a height of 3.3 to 3.4 metres.[63] Longwalls 3 to 18, were all planned with greater heights and by October 2012 Longwalls 1 to 7 and most of Longwall 8 had been extracted, with average cutting heights greater than 3.4 metres. The September 2012 MSEC subsidence assessment[61] provided with the Area 3B SMP submission material was based on planned extractions heights of 3.9 metres for Longwall 9 and 4.6 metres for Longwall 10 to 18.

The discrepancy between the 3.4 metre cutting height used for the October 2012 Coffey groundwater assessment and the past and planned Area 3B mining presumably reflects a communication or briefing error. The difference went unnoticed by members of the public and the agencies in the lead up to the February 2013 approval of the mining plans. The discrepancy is of considerable significance; the potential impacts arising from 4.6 metre high extractions at Dendrobium are much greater than those of 3.4 metre high extractions (compare Figs. 19 and 21).

The cutting height differences were belatedly noticed in April 2015 and, prompted by the discrepancy, an application of the Tammetta equation with the cutting heights and other details given in the September 2012 MSEC subsidence assessment returned height estimates predicting that the drainage zone would intersect the surface above the 4.6 metre extractions planned for Longwalls 10 to 18 (see Fig. 21).[95]

When asked[96] about the discrepancy the Department of Planning initially advised[97] that BHP-Billiton had provided a second Coffey assessment report in November 2012 and that this report included an assessment of 4.5 metre high extractions. The Department subsequently advised[98] that it did not hold a copy of the November 2012 report and was unable to confirm that it had not been provided with a copy of the report in the lead up to the approval of the mining in February 2013. The Department advised that BHP-Billiton briefed the Department on both the October and November 2012 Coffey assessments reports at a meeting in the lead up to the approval of the SMP. The Department was unable to advise if the briefing included advice that the November 2012 Coffey assessment predicted that the drainage zone would interest the surface above 4.5 metre extractions.[99] The question is of considerable importance, given the implications of the drainage zone intersecting the surface.

Evidently reflecting advice from the mining company, the Department subsequently suggested[20] that the November 2012 assessment was undertaken as a sensitivity analysis. HydroSimulations similarly offer the following remarkable account in their May 2015 groundwater and modelling plan report[100] for Illawarra Coal (then owned by BHP-Billiton and now South32):

> "*The Coffey model was developed to support the Subsidence Management Plan (SMP) application for mining of Area 3B (Coffey, 2012a). A second report and supporting model was developed by Coffey, after the SMP application was submitted, to assess the sensitivity of model assumptions with regard to the height of the fractured zone above Longwall panels (Coffey, 2012b). The later model assessed the sensitivity of raising the height of the fractured zone to the upper Hawkesbury Sandstone instead of the lower Hawkesbury Sandstone, as might be expected for a greater mined seam thickness using the Tammetta (2013) formulas for fractured zone height*."

Contradicting this account, the September 2012 MSEC subsidence impact assessment[61] for 4.6 metre high extractions and the October 2012 Coffey assessment for 3.4 metre high extractions were both submitted as part the original SMP documentation. It would appear that, rather than a sensitivity analysis, the subsequent November 2012 Coffey assessment for 4.5 metre extractions was a revision undertaken to align the groundwater impact modelling with the planned mining. The title of the November 2012 Coffey report[36] is "*Groundwater Study Area 3B Dendrobium Coal Mine Revised Numerical Modelling*".

Its puzzling that Coffey were, evidently, commissioned to assess groundwater impacts for 3.4 metre high extractions, while MSEC were commissioned to undertake subsidence impact assessments for 4.6 metre extractions (3.9 metres for Longwall 9). Clearly the mining company did not intend to limit cutting heights to no more than 3.4 metres.

As noted in Section 18, both the October and November 2012 Coffey groundwater impact assessment reports were partnered by data analysis reports. Of the four Coffey reports, only the October groundwater impact report was made publically available in the lead up to the Department of Planning's determination in February 2013. Unaware of the November 2012 Coffey reports, public and agency submissions to the Department regarding the mining plans were based on the October groundwater impact assessment.

Following receipt of the November reports BHP-Billiton rejected all of the Coffey assessments. Without consulting the agencies or seeking independent expert (no financial dependency on coal mining) opinion, Planning accepted BHP-Billiton's rejection of the Coffey assessments and withholding of the November impact assessment. As indicated above, the agencies and community were not made aware of the existence of the November assessment reports; nor were they advised of BHP's rejection of the Coffey assessments. Agency and community comments on the groundwater impacts of the proposed mining were made with respect to an assessment that did not correspond to the proposed mining and that had been rejected by the mining company because of the findings a subsequent assessment that did correspond to the planned mining.

No scientific basis has been put forward for BHP-Billiton's rejection of the Coffey assessments. As mentioned, the rejected work was subsequently published in the highly regarded and demanding journal Groundwater. The publically available Coffey report of October 2012 is detailed and clearly describes the determination of the Tammetta equation and the data analysis document[101] that partnered the October 2012 report would have provided further information and insight. The Department has advised[98] that they do not appear to have been provided with a copy of this report; it's not known if the Department sought a copy of the report. As mentioned OEH, did seek a copy and were denied.[90]

Given the absence of a replacement assessment for the rejected assessments, the Department's decision to approve Longwalls 9 to 13 in February 2013 was made without a groundwater assessment that matched the proposed mining. A draft replacement groundwater impact assessment was provided by HydroSimulations in October 2013, at much the same time that the work rejected by BHP-Billiton was published in the journal Groundwater. HydroSimulations completed their replacement for the Coffey assessment in March 2014, more than a year after the Department approved the current Area 3B mining.

Evidently uncritically accepting advice from the mining company, the Department of Planning has suggested[98] the 2012 Coffey assessments were inconsistent with earlier assessments, such as the groundwater assessments undertaken by HydroSimulations (as Heritage Computing) for the end of panel reports for the Dendrobium mine. The possibility that the earlier assessments were flawed (see Section 15) seems not to have been considered by the Department. The piezometer data considered here suggests the earlier assessments were flawed.

Echoing the mining company (see Section 21), Planning has also suggested[98] that the Coffey assessment "*predictions were not in line with the actual mine water inflows and surface dewatering that had been observed to date at Dendrobium*". This suggestion is contradicted by the notably high and rainfall dependent Dendrobium inflows.

As noted in Section 15.2, the Dendrobium mine is distinguished in being the 'wettest' mine currently and recently operating in the Schedule 1 Special Areas, with rainfall dependent peak inflows of up to 13 million litres day; an Olympic swimming pool holds 2.5 million litres. The average daily rainfall onto Areas 1, 2 and 3A is 6.2 million litres a day. A relatively short time-lag rainfall dependence has been noted by Tammetta[3] in 2012 and the Dams Safety Committee in 2011.[81] Inflows to the Dendrobium mine, as measured by its reticulated water system, are consistent with the drainage zone approaching and, in some locations, intersecting the surface above earlier extraction voids. A comparison of Figures 53 and 54 below further contradicts the Department's suggestion.

The approved and planned Area 3B mining is markedly more aggressive than the earlier Dendrobium mining. In explaining its acceptance of BHP-Billiton's rejection of the Coffey assessments, the Department of Planning characterised the work of Tammetta as "*novel*", yet standard methods were used. As noted above, the same approach was subsequently used by Ditton. Tammetta's work was novel in the sense it used data able to directly determine the height of the drainage zone. That is, it was scientifically appropriate.

As noted in Sections 7 and 17, in its 2012 submission on the then planned Area 3B mining the SCA, now a part of WaterNSW, endorsed the Tammetta's modelling. Tammetta's work appears to be of a high scientific calibre.

The assessment and approval of the then proposed Are 3B mining was dictated by BHP-Billiton's mining schedule. The Department of Planning accepted BHP-Billiton's rejection of good quality science and approved mining while waiting for a replacement groundwater impact assessment acceptable to BHP-Billiton. That is, BHP-Billiton decided what material was acceptable for the assessment process.

The approval conditions for the mining currently underway in Area 3B requires a determination of the drainage zone heights for Longwalls 6 to 10 and reliable estimates for the height of the zones formed by the extraction of Longwalls 11 to 12, as a precondition for an approval of the second set of five longwalls of the ten proposed in 2012. The approval conditions have allowed Longwalls 9, 10, 11 and 12 to be extracted before the results of that determination are to be reported. Longwall 12 is currently being extracted (see Section 24).

There has yet to be a reliable direct determination of the drainage height for any of the Area 3B longwalls (see Sections 12, 15 and 16). The truncated nature of the data from centreline bore S2220, likely a result of further instrument loss (Section 16.2), has precluded a reliable determination of the Longwall 9 drainage zone height. The October 2015 HydroSimulations connected fracture report for Area 3B is presumably provided with the 2016 SMP material in order to, in part, satisfy the prerequisite for the approval of further mining. This assessment, like the March 2016 groundwater impact assessment, appears to be deeply flawed and misleading.

As noted earlier, the approval of the current Area 3B mining in 2013 allowed what appears to be the largest extraction height to have been used beneath the Special Areas and amongst the very widest, if not the widest, set of longwall extractions beneath the Special Areas. The 2013 approval is inconsistent with the 2008 advice of the Director General's environmental assessment for the in-principal approval for mining in Area 3: "*Future assessment of these SMPs would allow the Director-General to impose additional conditions requiring particular subsidence impact limits or subsidence management measures and processes, should predicted impacts make this advisable*". The equation underpinning the work rejected by BHP-Billiton finds the drainage zone of the approved mining will intersect the surface across Longwall 10 to 13. Neither this possibility nor the aggressive character of the Area 3B extractions would have been anticipated in 2008, or in 2001.

20. Dendrobium Area 3B - compounding the contentious

As discussed in Section 19, agency and community submissions to the Department of Planning providing pre-approval comment on the then proposed Area 3B mining were made without knowledge of the November 2012 Coffey assessment for extractions with cutting heights of 4.5 metres. Even without this knowledge, the February 2013 approval of the mining now well underway in Dendrobium Area 3B caused deep community concern and dissatisfaction with the actions of the Department of Planning.

The SMP approval requirements are not in accord with the protection considerations, advice and recommendations of the 2001 Commission of Inquiry[93], the 2008 Director General's Assessment for Area 3[102], the 2009 and 2010 PAC reports for the Metropolitan Coal Project[103] and the Bulli Seam Operations Project[39] and the requirements of the OEH's 2012 draft swamp guidelines.[104] The OEH's guidelines embodied and elaborated the PAC recommendations.

The Area 3B mining is notably aggressive, with the largest extraction height and amongst the very widest, if not the widest, set of longwalls to have been extracted from below the Special Areas and possibly anywhere in NSW. Yet Area 3B is an area that the 2001 Commission of Inquiry identified as the most sensitive ecological area within the Dendrobium mine domain, which is located in the Schedule 1 Metropolitan Special Area.

The Commission of Inquiry specified that the swamps of the Donalds Creek catchment merited protection from mining - this being well before the PAC's introduction of the recognition of swamps of Special Significance in their reports for the Metropolitan Coal and the Bulli Seam Operations projects.[39], [103] The five longwalls approved by Planning in 2013 undermine four particularly large swamps (see Fig. 56), at least three of which meet the criteria of Special Significance. Less than 10% of swamps on the Woronora Plateau have an area greater than 9.3 ha; the area of Swamp 1a in Area 3B is 12.8 ha, Swamp 5 is 9.65 ha and the area of Swamp 8 is 10 ha. The Department of Planning nonetheless made the following statement in its 11th of February 2013 media release announcing the Area 3B mining approval:

> "*While there are expected to be impacts on the eight upland swamps situated above the first five longwalls, there are around 1,000 similar swamps situated across the Woronora Plateau.*"

This is incorrect.

The swamps have long been recognised as being important because of their high level of biodiversity and significant contribution to water quality and quantity. This is reflected the recommendations of the 2001 Commission of Inquiry, the 2009 PAC report for the expansion of the Metropolitan Colliery, the 2010 PAC report for the Bulli Seam Operations project and OEH's 2012 draft swamp guidelines. As noted above, the OEH's guidelines embody the recommendations of the PAC reports. The Department of Planning however opposed their being adopted as Government policy and as a consequence provision for the Coastal Upland Swamps has been 'shoe-horned' into the OEH's contentious Biodiversity Offset Policy. This policy does not recognise the contribution to water quality and quantity made by the swamps.

In March 2012 the swamps were listed as Endangered Ecological Communities under the NSW Threatened Species Conservation Act of 1995.[105] In May of 2013 they were listed on the IUCN Red List as endangered/critically endangered.[106] In July 2014 they were listed[107] as Endangered Ecological Communities under the Commonwealth Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act).

Approximately 83% of these swamps are found on the Woronora Plateau and most are located in the Special Areas of Sydney's catchment. Neither their State nor Commonwealth EEC listings, listing on the IUCN Red List or their location in the Special Areas ensures their protection, as the Department's approval of February 2013 demonstrates. Section 23 provides a summary of mining impacts to data in Area 3B.

In their 2012 submissions the community, OEH and SCA urged changes to the Area 3B longwall layout. The Department of Planning however accepted BHP-Billiton's advice that this was not possible because the underground roadways and other infrastructure were already in place and the mining layout was accordingly 'locked-in'. The Department's report states:

> "*The decision makers were satisfied that full avoidance or substantial reduction of the predicted swamp impacts in the early years of the mining was not economically feasible given that the layout for the initial longwall panels had already been established. In particular, the proposed width of the longwalls had already been established by first workings undertaken by Illawarra Coal to define the longwall layout*."

In effect, Planning accepted responsibility for the commercial risk undertaken by BHP-Billiton in preparing establishing infrastructure prior to the mining being assessed and approved.

In a statement explaining the February 2013 approval of Longwall 9 to 13 the Director General notes that BHP-Billiton, as Illawarra Coal, had advised "*if the SMP is not approved shortly, there could be significant economic consequences for both the company and the wider region*".[108] No changes were made to the planned mining layout and geometry.

21. Dendrobium - Illawarra Coal comments on Tammetta equation estimates

Illawarra Coal, owned by BHP-Billiton until mid-2015 and now owned by their spin-off company South32, argues that their inflow monitoring at the Dendrobium mine is not consistent with the implications of the drainage zone height estimates provided by the Tammetta equation.

Referring to the work undertaken by Tammetta for then BHP-Billiton consultant's Coffey Geotechnics, Illawarra Coal state the following[88]:

> "*Coffey maintain water de-saturation to the surface. If this was the case we would not expect to see water resurface downstream of creeks in the catchment. Coffey modelling shows in Area 1 and 2 that surface is cracked through to the mine. This is not consistent with what we see in mine water make*."

This statement is incorrect and misleading for the following reasons:

(i) Extraction height profiles are only publically available for Longwalls 3 and 9 to 11, accordingly it's not possible to reliably estimate where the drainage zone would reach the surface or join the surface fracture network. The 2015 HydroSimulations height of connected fracture report includes a depiction indicating where the Tammetta equation estimates suggest that the drainage zone would intersect the surface above the Dendrobium goaves. It appears however that, though the cutting heights actually used would have been available to the consultants, the application of the Tammetta equation for Areas 1 to 3A was based on either planned or maximum extraction heights. For instance, Table 3 in the report gives the Longwall 3 extraction height as a 3.8 metres, whereas the end of panel subsidence report tabulates a range of heights from 3.2 to 3.7 metres.

(ii) Surface flow would be expected to persist under high flow conditions.

(iii) There does not appear to be any scientifically credible demonstration that all water lost from streams into cracks subsequently returns to the surface - whether or not the Tammetta equation predicts the surface cracks connect to a drainage zone.

It's puzzling that the comments focus on Areas 1 and 2. As discussed in Section 15.2, inflows to both Area 1 and Area 2 are notably correlated with rainfall[3][81], with relatively short time-lags between rainfall and inflow. That is, the inflows are consistent with the drainage zone reaching the surface fracture network or the surface over parts of the mine.

The minutes of the February 2013 meeting of the Community Consultative Committee (CCC) for the mine quote EcoEngineers in stating[109] "*there has not been any recent sudden ingress of ultra-low salinity surface water*". This statement ignores the observations noted above (Section 15.3) and incorrectly suggests that surface water entering the drainage zone would make its way downwards to arrive in the mine without water-rock chemistry occurring and any without mixing with groundwater inflow to the drainage zone.

The same minutes indicate that BHP-Billiton had made the following comment on the Coffey/Tammetta modelling: "*this extensive and 3D model would provide a much better understanding of groundwater than the earlier, smaller 2D Merrick model*". Presumably this advice to the CCC was given before the company was provided with the November 2012 assessment from Coffey/Tammetta. Though it clearly regarded the earlier work by Merrick as inadequate, BHP-Billiton rejected the work of Tammetta when it found that the drainage zone formed by the planned extraction of Longwalls 10 to 18 would intersect the surface.

The minutes of the February 2015 meeting of the Community Consultative Committee include the following misleadingly statement by Illawarra Coal: "*The Coffey conceptual model was developed using data dominated by narrow LWs, there was no data with high extraction heights and wide longwalls. The conceptual model did not take into account the non-linear limits of fracturing*." As noted in Section 15.4, Tammetta's database[41] of centre-panel observations of the drainage zone height spans the range from sub-critical, to critical to super-critical mining, where the spanning capacity of the overlying strata is exceeded. The equation derived from this data accommodates this range. Currently no examples of reliably measured centre-panel drainage zone heights have been reported that are not in accord with the Tammetta equation.

In being empirically determined directly from the data, the Tammetta equation is a 'best fit' representation of the data and is not the outcome of a conceptual modelling process.

As noted in Sections 7 and 17, WaterNSW/SCA endorsed the October 2012 Coffey/Tammetta Area 3B assessment. Consultants SCT describe the analysis reflected in the rejected assessment as "*very good work*".[46]

22. Dendrobium Area 3B – cutting height limits to protect ground and surface water

The October 2012 Coffey Geotechnics groundwater impact assessment[3] for mining then proposed for Area 3B of the Dendrobium mine suggests that where mining takes place in the Special Areas, up to 66% of the groundwater flow that would otherwise contribute to watercourse and reservoir storage volumes may be diverted towards an underlying or nearby mining void:

> "*Rainfall infiltration is typically about 6% of rainfall. Based on the data analysis, it is assessed that in virgin catchments, about half of this recharge (about 3% of rainfall) would report to drainage channels for transport out of the system. The remainder (about 3%) would be consumed by evapotranspiration, ocean discharge, escarpment discharge (mostly evapotranspiration anyway), and downgradient lateral groundwater flow out of the model area.*
>
> *At present, the model area is located in a catchment where the groundwater recharge reporting to lakes and drainage channels is assessed to be a maximum of about 1% of rainfall (probably about 0.7% to 0.8% most of the time). Most of the remaining recharge of about 2% or more of rainfall is probably being diverted towards the mine voids*".[3]

Some may be lost into regional groundwater flows and/or some into the mine. Indicating the importance of groundwater inflow to the reservoirs in the Special Areas, groundwater is reported to contribute up to 35% of the inflow to Cataract Reservoir.[110] The figure for Cordeaux appears to be approximately 25%. The quantity diverted as a consequence of coal mining in the Special Areas each year is unknown; not all finds its way into the reticulated water systems of the mines. Nor is there knowledge of the quantity of surface water diverted into surface fracture networks and that then deeper flows that escape storage.

The October 2012 Coffey groundwater impact assessment includes in its flow budget an estimate of baseflow diversion as a consequence of mining. The estimate is however for 3.4 metre high extractions. The cutting height has often been higher and extractions to 4.6 metres are proposed for the next set of Area 3B longwalls. Baseflow diversion, compounding that of existing extractions, from the drainage zone of 4.6 metre high extractions will be significantly greater than arising from 3.4 metre high panels. The November 2012 Coffey impact assessment will have included baseflow diversion estimates for mining to a cutting height of 4.6 metres.

Consultants GeoTerra indirectly advise that the drainage zone doesn't need to reach the surface to exert an adverse influence[111], [112]:

> "*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.*"

Illustrating the reach of the surface fracture zone, data from post-mining piezometer bore S2220 reveals rainfall sensitivity to a depth of 95 metres over Dendrobium Longwall 9. This suggests restricting the extraction height such that the drainage zone does not reach to within 245 metres of the surface.

In order to provide the 150 metres separation margin suggested by GeoTerra between the drainage zone and the surface fracture zone, the height of the drainage zone would need to be restricted to being no more than 200 metres. This assumes a surface elevation of 400 metres (mAHD) and a seam elevation of 50 metres (mAHD) for Area 3B Longwalls 14 to 18. The Tammetta equation then suggests that, for 305 metre wide extractions and depth of cover of 341 metres, the extraction height should be no more than 2.4 metres.

In the absence of the consideration of local and regional cumulative impacts, mining of the second set of Dendrobium Area 3B longwalls might reasonably be approved if the extraction height was restricted such that the drainage zone did not reach within 150 metres of the groundwater regime that provides baseflow to the storage reservoirs. This should also reduce stream baseflow impacts.

The elevation of the base of Cordeaux Reservoir appears to be about 270 metres (mAHD). In the absence of information otherwise, the elevation of the base of the Avon Reservoir is assumed to be the same. While MSEC coal seam elevation contour maps indicate that Cordeaux is ‘down dip’ from Avon, the presence of the voids in the Dendrobium and Wongawilli mine will have markedly altered the original groundwater flow regime.

Assuming a surface elevation of 400 metres and seam elevation of 50 metres, the Tammetta equation suggests the cutting height of 305 metre wide longwalls would need to be restricted to 1.1 metres to prevent the drainage zone reaching within 150 metres of the elevation of the Cordeaux Reservoir base.

A cutting height of 2.6 metres would allow the drainage zone to reach the 270 metre (mAHD) elevation of the base of the reservoir. Assuming an average surface elevation of 400 metres, this would allow the drainage zone of the new longwalls to reach 130 metres from the surface.

The cumulative local and regional impacts to date however appear to be such that no further mining should be approved.

23. Dendrobium - some surface impacts observed in Area 3B

In August 2012 Krogh compiled[113] a detailed tally of 340 impacts in Areas 1, 2 and 3 of the Dendrobium mine. More recent impacts in Area 3B are included in the December 2015 report[20] of the September 2015 inter-agency Area 3B inspection led by the Department of Planning. As noted in Section 2.1, this inspection was prompted by concerns raised in July 2015 by the NPA regarding the 2012-13 assessment of the then proposed mining currently underway in Area 3B and its potential groundwater impacts. The September inspection found a total of 89 impacts as a consequence of the extraction of Area 3B Longwalls 9, 10 and 11. Of these impacts 52% were to watercourses, 18% to swamps and 30% to other features.

The NPA wrote to the NSW Minister for Planning in February 2016 expressing concern at the flawed nature of the report prepared by the Department of Planning. In places unquestioningly repeating industry statements and assertions, the Department’s report contains errors of importance and misleading statements, and there are omissions of significance.

The Department’s report finds that the impacts are generally in accord with the predictions made by the mining company’s consultants and of minimal environmental consequence, with the exception of impacts to a tributary to Wongawilli Creek known as WC21. The severe impacts to this stream are described by the Department as significant and exceeding the predictions of the mining company’s consultants.

23.1 Watercourses

The Department's report records that impacts along Donalds Castle Creek and Wongawilli Creek tributary WC21 have exceeded predictions:

> "*Of the 16 Level 2 watercourse impacts recorded within the catchment of Wongawilli Creek for Longwalls 9 - 11, 10 have occurred within WC21. These impacts involved significant rock fracturing, reduction in water levels in pools and an absence of surface flows (see cover photo). Level 2 fracturing in rockbars has been observed in WC21. Since undermining of Longwalls 9 and 10, complete loss of flow has been observed in this watercourse in the area overlying the mined panels, this length being some 600 m during wet periods and longer in dry periods. The bed of the stream is sufficiently cracked that it seems incapable of containing significant runoff flows for more than a few days*."

And:

> *The impacts within WC21 remain a particular concern to WaterNSW and other agencies, given that the proposed Longwalls 12 – 15 are likely to extend these impacts. Close attention will be paid to the ongoing monitoring of flows and pool levels as additional longwalls are mined*."

The Department's report goes on to comment:

> "*Whilst noting that the impacts at WC21 are greater than predicted, they are not considered by DPE to be a breach of the mine's performance measures. The performance measures specifically relate to Wongawilli Creek and Donalds Castle Creek, rather than their associated tributaries, including WC21. DPE assigned performance measures to Wongawilli Creek and Donalds Castle Creek in its conditional approval for the Area 3B SMP because they are the most significant watercourses within Area 3B. The Southern Coalfield Inquiry and also subsequent Planning Assessment Commission reviews of both the Bulli Seam Operations Project and the Metropolitan Coal Project all recommended protection of third and higher order streams, which is the nature of these two streams. WC21 is variously a first and second order stream*."

Though correct the information provided in the quoted statement is incomplete. The 2010 PAC report for the Bulli Seam Operations project[39] finds 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.*
>
> *First and second order streams also provide the connectivity between upland swamps and the larger streams. The upland swamps provide baseflow to these lower order connecting streams and that maintains both continuity of flow and water of the highest quality. If the larger stream is considered significant, and water quality is one of the important values, then it makes no sense whatsoever to compromise both the flow pathway and the quality of the water emanating from the swamp by allowing subsidence-induced damage to these connecting sections of lower order streams.*"

The November 2008 Director General's report[102] for the approval of changes to Area 3A includes the following advice with respect to the then future assessments for Areas 3B and 3C:

> "*Preparation of the SMPs would be subject to requirements which reflect contemporary subsidence impact assessment practice and the recommendations of the Southern Coalfield Inquiry*."

The Area 3B approval conditions for Wongawilli Creek and its tributaries do not reflect the subsidence impact assessment practice reflected in the 2010 PAC report for the Bulli Seam Operations project.

The Area 3B approval requirements for Wongawilli and Donalds Castle creeks require that mining is to cause no more than "*minor fracturing, gas release and iron staining; and minor impacts on water flows, water levels and water quality*". These are the same conditions given in the 2008 Area 3 modification approval for Sandy Creek and Wongawilli Creek:

> "*The Applicant shall ensure that underground mining operations do not cause subsidence impacts at Sandy Creek and Wongawilli Creek other than "minor impacts" (such as minor fracturing, gas release, iron staining and minor impacts on water flows, water levels and water quality) to the satisfaction of the Director-General.*"

The approval conditions for the Area 3B mining do not recognise the importance of 1st and 2nd order streams, which are recognised in the 2010 PAC report for the Bulli Seam Operations project.

The Department's report notes that "*WaterNSW considers that some loss of flows from Wongawilli Creek may be occurring, but that the sensitivity of Illawarra Coal's monitoring has not been able to identify such losses.*" The Department acknowledges this may also be the case for Donalds Castle Creek

> "*it is possible that environmental consequences in terms of loss of flows and catchment yield from the Donalds Castle Creek catchment may be occurring without having been recognised by field inspections or in downstream flow gauging results*."

The Department recognises that the mining company's monitoring network may be inadequate:

> "*methodologies for defining, measuring and assessing impacts may need to be improved and expanded to determine their extent and significance, particularly in respect of baseflow reductions and streamflow diversions to underlying aquifers*"

Nonetheless the Department concludes:

> "*satisfied that there have been no unacceptable impacts on Wongawilli Creek and that the relevant performance measure of 'minor environmental consequences including, minor fracturing, gas release and iron staining; and minor impacts on water flows, water levels and water quality' has not been breached*."

The Department's position would appear to be that if the mining company's monitoring provisions, irrespective of their adequacy, are unable to measure the impact then the mining approval conditions will not have been breached.

Table 15 of the 2010 PAC report for the Bulli Seam Operations project lists watercourses that the PAC identifies as being of Special Significance with respect to a set of criteria. Given its location in a Schedule 1 Special Area, connection to swamps and association with threatened species and endangered ecological communities, Wongawilli Creek would accordingly seem to merit recognition as being of Special Significance. The PAC report for the Bulli Seam Operations required a performance criterion of "*negligible subsidence-related impact*" for natural features of Special Significance. The requirement for watercourses then being; "*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 Department of Planning's Area 3B inspection report notes:

> *"The impacts within WC21 remain a particular concern to WaterNSW and other agencies, given that the proposed Longwalls 12 – 15 are likely to extend and exacerbate these impacts. Similar impacts may also occur on other creeks like WC15, WC11 and creeks draining to Lake Avon by the mining of Longwalls 12 – 18. Close attention will be paid to the ongoing monitoring of flows and pool levels as additional longwalls are mined."*

It would appear that the Department's perspective is that impacts of the kind identified to date in Area 3B will continue to be acceptable until such time as they can be shown to be of greater significance than, in the Department's judgement, minor.

The 2010 PAC report for the Bulli Seam Operations project advises:

> "*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*."

23.2 Swamps

Swamps 1a, 1b, 5 and 8 are exceptional swamps that meet the OEH's criteria[104] for recognition as being of Special Significance and that would merit protection from other than negligible mining impacts. The approval for the current Area 3B mining include the following 'performance measures' for Swamps 1a, 1b, 5, 8, 11, 14 and 23:

> "*Minor environmental consequences including:*
> - *negligible erosion of the surface of the swamps;*
> - *minor changes in the size of the swamps;*
> - *minor changes in the ecosystem functionality of the swamp;*
> - *no significant change to the composition or distribution of species within the swamp; and*
> - *maintenance or restoration of the structural integrity of the bedrock base of any significant permanent pool or controlling rockbar within the swamp*"

It's been widely recognised for several years that changes to swamp size, ecosystem functionality and species composition and distribution as a consequence if mining take time to become undeniably evident and that these impact measures are accordingly inadequate.

Reflecting this knowledge, the 2010 PAC report for the Bulli Seam Operations comments:

> "*the bottom line appears to be if mine subsidence has the potential to impact on near surface formations to an extent that could cause changes in the hydrology of a swamp, then the swamp is at risk of serious negative environmental consequences in whole or in part*".

The PAC report recommended protection for swamps of Special Significance from other than negligible impacts and defined their protection with respect to hydrology. In its December 2012 submission to the Department of Planning regarding the then proposed Area 3B mining, the OEH advised "*performance measures, including 'negative environmental outcomes', for all swamps need to be defined in terms of a statistically significant decrease in water levels within the swamp that is* *directly attributable to subsidence*".[114] The Department did not accept this advice and does not recognise swamps of Special Significance.

The Department of Planning's report[20] on the Area 3B inspection that took place in September 2015 states:

> "*A total of 16 swamp impacts have been reported, including five Level 3 impacts and two Level 2 impacts in Swamp 5, one Level 1 impact in Swamp 8 and eight Level 2 impacts in Swamps 1a and 1b.2 These impacts mostly relate to increases in groundwater recession rates and/or significant changes in the shallow groundwater regimes.* ***All undermined piezometers within swamps have exhibited an increase in groundwater recession rates and/or water levels lower than before mining, suggesting that the hydrological characteristics have been temporarily or possibly permanently altered.*** *The monitoring results show that mining of Longwalls 9 – 11 has impacted on every swamp that has been directly undermined or is immediately adjacent to mining*." [Bold text emphasis added here]

A lack of evidence of recovery suggests that the water recession does not reflect increased storativity associated with surface fracturing.

The Department notes:

> "*OEH has assessed the data presented for the boreholes in these swamps and concluded that greater than 80% of the swamp piezometers in each swamp either have groundwater levels below the lowest recorded baseline period and/or exceedance of the groundwater level recession rate recorded before mining. OEH equate such impacts to a Level 3 impact for each swamp. OEH also raised concerns regarding the availability of adequate baseline data.*"

The water retention impacts are consistent with the drainage zone having reached a sufficient height to interact with the surface fracture zone. For instance, the Longwall 10 extraction height beneath Swamp 5 was 3.9 metres, for which the Tammetta equation predicts the drainage zone will be 25 metres or less from the surface in this area. If this is the case, the drainage zone will have joined the surface fracture network and, in effect, reached the surface.

If the drainage zone has not reached the surface, then water will instead be being lost into subsurface groundwater flows. Some of all of this water may nonetheless enter storage but, if so, its quality will have been significantly degraded by passage over the surfaces of rock fractures.

The Department notes:

> "*OEH estimates a loss of 0.3 – 0.4 ML/day at the basal end of Swamp 1b and proposes that this has led to an increase in the number of cease to flow periods in Donalds Castle Creek downstream of this swamp. This is contrasted to the two reference swamps where the drainage lines downstream of the swamps have continuously flowed.*"

OEH has set-up a water loss monitoring system at Swamp 1b's stream exit. Pristine water will be being lost from the other impacted swamps.

Effectively recognising that the performance measures for the current mining are inadequate, the Department comments:

> "*To date, no triggers have been exceeded which relate to the performance measures for erosion, swamp size, ecosystem functionality, composition or distribution of species and maintenance or restoration of the structural integrity of the bedrock base of permanent pools or rockbars*

associated with the swamps. At this point, the possibility that some or all of these performance measures would eventually be breached as the swamps dry out as a consequence of the fractured basements cannot be ruled out."

The Department further comments:

"*Nonetheless, DPE, which has responsibility for enforcing the conditions of the Area 3B SMP approval, does not consider that these impacts are breaches of the mine's performance measures relating to upland swamps. The performance measures in the approval do not directly consider shallow groundwater, but specifically relate to erosion, swamp size, ecosystem functionality, composition or distribution of species and maintenance or restoration of the structural integrity of the bedrock base of permanent pools or rockbars*."

The Department also set the approval conditions, which are out of step with current knowledge and standards. The Department's perspective contradicts the advice of the OEH and the recommendations of the 2010 PAC report for the Bulli Seam Operations project.

23.4 September 2016 community inspection of Area 3B

Coincidentally exactly a year after the Department of Planning's inspection, a visit to Area 3B on the 8th September2016 organised by the community group Protect Sydney's Water Alliance (PSWA) included representatives of the NSW NPA, Lock the Gate, the Colong Foundation, the EDO, and the Department of Planning, with guidance by catchment management staff of WaterNSW. The inspection commenced just below the confluence of WC21A with WC21, and followed WC21 across Longwalls 11, 10 and 9 to the edge of the angle of draw boundary beyond Longwall 9. Significant damage to WC21 extends the full length of the creek across the extracted panels.

Swamp 1b (see Fig. 56) was also inspected and, not withstanding substantial recent rain, was found to be drying and in decline. Dr Ann Young, a representative for the NPA and a member of the Dendrobium Community Consultative Committee, notes the impact of progressive dehydration, with dry vegetation and many of the sedges having fallen over. Dr Young comments:

"*Sediments which four years ago were very dark brown or black in colour, wet and sticky with decayed organic matter and compressible are now dry, brown, friable and firm to step on. Even in the valley axis where flow is concentrated, the surface is barely moist*.

Casuarinas and broad-leafed geebungs have invaded from the swamp margins and the Banksia robur leaves are drier and more yellowed and more insect-predated than expected even for a late winter period. The vigour of the vegetation is markedly less than pre-mining.

There is zero flow from the exit stream. The swamp sediments are now dry enough to burn if there is a fire, and lose even more of the organic matter that binds the sandy sediment. This means that the swamp will be gullied easily by subsequent rainfall, and the sandy fill will be eroded from the swamp and washed downstream."

The Tammetta equation suggests that over the centre of the western quarter of Longwall 9, where the cutting height was 3.4 metres, the drainage zone would reach to between 100 and 50 metres below the swamp. The same cutting height was used for most of Longwall 9, including the eastern half where piezometer bore S2220 suggests a surface fracture network penetrating to 95 metres below the surface (Section 16.7).

Of significance, as noted in Section 15.1.15, the near surface instrument in piezometer bore DDH104/S1908, located 10 metres below the surface and having an elevation of 396 metres (mAHD), appears to be dry throughout the period of the hydrographs provided in the March 2016 HydroSimulations groundwater assessment. This bore is approximately 613 metres from Area 3B Swamp 1b and 230 metres from Area 3B Swamp 1a.

As noted above, the Longwall 10 extraction height beneath Swamp 5 was 3.9 metres, for which the Tammetta equation predicts the drainage zone will be 25 metres or less from the surface in this area. If this is the case, the drainage zone will have joined the surface fracture network and, in effect, reached the surface.

Swamps 12 and 15b partly overlie Longwall 8 in Area 3A. Like Longwall 9, Longwall 8 was extracted with a void width of 305 metres and a maximum cutting height of 3.9 metres. It would seem likely that the decline of these swamps will also reflect the approach of the drainage to within 150 metres of the substrate supporting the swamps. Adverse impacts to these swamps are detailed in Krogh's 2012 assessment.[113]

24. Dendrobium - Compliance

The Department of Planning's (DPE) December 2015 Area 3B inspection report concludes:

> "*Based on all available information, DPE is satisfied that so far there have been no unacceptable or material impacts from mining in Area 3B on Sydney's and Wollongong's water supply*."

The statement is troublesome in at least four respects:

(i) As is the case elsewhere in the Special Areas, current Area 3B monitoring provisions are not able to measure the volume of surface water (streams, swamps, runoff) being lost into groundwater flows that leave the catchment.
(ii) The statement indicates the Department will continue to approve mining until there is a clear and irrefutable demonstration that unacceptable impacts have occurred; by then it's too late.
(iii) The statement treats Area 3B in isolation, without recognition of the cumulative impacts of the mines in the Metropolitan Special Area, such as the volume of water entering the mines (see Section 26).
(iv) The statement has no recognition of post mine closure seepage of contaminated mine water where the drainage zone reaches either the surface or the surface fracture network.

As discussed in Section 15.1.20, the approval conditions for the current Dendrobium mining require no more than negligible changes to the groundwater support for the Avon and Cordeaux reservoirs, and the Area 3 watercourses. The available evidence suggests that it's unlikely that the Area 3 mining undertaken to date has had no more that negligible impact on baseflow support for the reservoirs – Cordeaux in particular.

The Tammetta equation suggests this would also be the case for the watercourses. A weakness in the Dendrobium piezometer network is a paucity of suitably located bores with piezometers installed at depths between around 100 metres and 20 metres below the surface. The Department of Planning evidently holds the view that, in effect, unless an impact can be shown unequivocally to have occurred, then the impact has not occurred. This is reflected in the following comment from the Department's December 2015 Area 3B report:

"*DPE generally considers that the performance measures relating to watercourses and water bodies have been met. However, methodologies for defining, measuring and assessing impacts may need to be improved and expanded to determine their extent and significance, particularly in respect of baseflow reductions and streamflow diversions to underlying aquifers. An expanded monitoring network in the shallow bedrock aquifer would also provide additional confidence in determining the extent and significance of impacts, particularly in respect of baseflow losses.*"

The approval conditions for the mining currently underway in Area 3B require the following:

"*14. Prior to the extraction of longwall 12, the Applicant shall:*

(a) undertake detailed geotechnical and hydrological investigations of the height of cracking in Longwalls 6 to 10; and

(b) submit a report to the Department, including:

- *a model describing the measured height of cracking across Longwalls 6 to 1O; and*
- *detailed predictions of the height of cracking for Longwalls 11 to 19;*

to the satisfaction of the Director General."

The attempt by Parsons Brinckerhoff to determine the height of the drainage zone over Longwall 9 was unsuccessful, most likely having been thwarted by the unusual horizontal stress conditions over the eastern part of Area 3B (see Section 16). The modelling and predictions undertaken by HydroSimulations appear to be deeply flawed, erroneous and highly misleading. Longwall 12 is currently being extracted and the Department of Planning is currently assessing the mining plans for the next set of longwall extractions proposed for Area 3B, Longwalls 14 to 18. The investigations and modelling undertaken to date do not provide a sound basis for gauging the impact of Longwalls 13 to 18.

25. Russell Vale

Like the publically available assessments undertaken by Tammetta for Coffey and provided to BHP-Billiton for the Dendrobium mine, the four Tammetta reviews[115][116][117][49] commissioned by the Department of Planning for the proposed expansion of the Russell Vale colliery are rich in information of significance. In recommending approval for the proposed mining to the PAC, the Department of Planning evidently overlooked, discounted or perhaps misunderstood important information provided in these assessments.

Of note, the Department accepted and endorsed the groundwater impact assessment provided by GeoTerra: "*The Groundwater Assessment uses the latest available data from the mine's piezometer network, has been peer reviewed and been endorsed as 'fit for purpose'*."[118] In endorsing the groundwater assessment, the Department set aside the concerns of WaterNSW:

"*WaterNSW continues to express its dissatisfaction with the surface and groundwater modelling, particularly in respect of predicted baseflow losses (see* ***Section 3.2.6*** *below).*"

The peer review[119] that found the groundwater impact assessment was fit-for-purpose was provided by Merrick on behalf of HydroSimulations. Tammetta, on behalf of Coffey, found serious shortcomings[117] in the GeoTerra assessment:

"*The current model is considered uncalibrated and model results cannot be used for impact assessment. If the proponent wishes to assess impacts using model results, the model will require simultaneous transient calibration to measured hydraulic heads (throughout the depth profile),* *estimated baseflow to water courses, and measured void discharges, as has been undertaken for other mines in the Southern Coalfield. Sufficient data are available for this to be undertaken, and to significantly reduce uncertainty and improve the reliability of model results. In conjunction with hydraulic heads, simultaneous calibration of surface discharges and deep discharges is a vital way of attempting to calibrate the crucial vertical hydraulic conductivity distribution of the subsurface, and the degree of insulation afforded by this distribution between shallow and deep flow processes*."

The Tammetta reports provide a more insightful assessment of the potential impacts of the proposed mining. The HydroSimulations review was funded by the mining company, while the Coffey assessments were commissioned by the Department.

The Russell Vale colliery introduced triple seam mining to the Special Areas, with extractions in a seam below two previously mined seams resulting in areas of overlapping double and triple seam extractions. The application[115] of Tammetta's equation indicates that there are areas above existing and proposed overlapping triple seam extractions at Russell Vale, where the drainage zone will intersect the surface (see Fig. 57 below). The equation was developed from data obtained over single seam extractions. Currently there are insufficient piezometer data available from bores installed above overlapping multi-seam extractions to provide a basis for the development of an equation for the estimation of drainage zone heights above overlapping multi-seam mining. Tammetta cautions[116] that the drainage zone height estimates returned by his equation when applied to multi-seam extractions are likely to be underestimates.

In their March 2014 hydrology report[120] for the proposed expansion of the Russell vale Colliery consultants SCT report "*very strong correlation*" between water levels at a monitoring bore in the eastern domain of the mine referred to as NRE-D and the level of Cataract Reservoir. Located in the eastern domain of the mine, the monitoring site is located approximately 540m from the nearest edge of Cataract. The data are graphed in Figure 8(b) of the SCT report and the correlation is most evident in the data obtained at a depth of 110 metres. SCT suggest the data reflect a lateral connection to the reservoir through a shear plane with an upper boundary about 70 metres below the surface: "*The correlation with the changes in water level in Cataract Reservoir indicates there is a connection between NRE D and the reservoir even at a distance of 540m*." There is a downward hydraulic gradient towards the mine and the circumstantial evidence suggests the shear plane is associated with past mining.

The surface height at NRE-D is approximately 348 metres[45] and accordingly a depth of 110 metres would correspond to a reduced level (RL) Australian Height Datum (AHD) elevation of approximately 238 metres. Given the southern end of proposed Longwall 7 in the Wongawilli seam is reported to have an RL elevation of 5 to 20mAHD (Fig.8 in [46]) , the correlation observed at 110 metres below the NRE-D site would be 218 to 233 metres above the floor of the southern end of Longwall 7. A depth of 70 metres below the NRE-D site would be equivalent to about 258 to 273 metres above the level of the southern end of Longwall 7.

The southern end of Longwall 7 of the proposed expansion would be extracted below old bord and pillar extractions, with pillar removal, in the Bulli seam. SCT's application of the Tammetta provides a drainage zone height estimate of 260 metres above the overlapping extractions at the southern end of Longwall 7. Noting Tammetta's caution that his equation is likely to underestimate drainage zone heights over multi-seam extractions, the NRE-D data warn of the possibility of a shear plane bearing water from Cataract reservoir being intersected by the drainage zone above the overlapping Bulli and Wongawilli extractions. This possibility is depicted in Figure 58 below.

To date no bores appear to have been sunk to determine the height of the drainage zone over the overlapping extractions at Russell Vale. Characterising the drainage zone above the existing overlapping double and triple seam extractions should be a prerequisite for the assessment of the proposed expansion of the mine.

26. Estimates of water lost into mines within and adjacent to the Metropolitan and Woronora Special Areas

Estimating how much water is being lost into the mines in and around the Special Areas is challenged by limited publically available information and, in some cases, the information that is available lacks clarity. It’s likely the mining companies, particularly BHP-Billiton/South32, hold information that would be of considerable assistance.

Mine inflows are ultimately expressed at the catchment surface and near surface groundwater flows at a rate and over an area that depends on the extraction characteristics. Where mine inflows are comparatively high, as is the case in the Dendrobium and the old Elouera mine (an amalgamation of the Nebo and old Wongawilli mines), draw from the surface evidently occurs relatively rapidly. These mines are reported to have relatively short lag-time correlations between rainfall and inflow volumes, indicating a significant portion of the inflow is likely to be drawn from the catchment area above and in the area around the mine. There may be other mines, not being monitored and for which there is no publically available information, within or adjacent to the Special Areas with inflows that have a local area rainfall dependence.

Estimates of current water levels in closed or decommissioned mines do not appear to be publicly available and inflows into the mines that are no longer operating do not appear to be reported to Government or otherwise tracked by Government agencies. It’s likely that the mining companies, such as BHP-Billiton/South32, hold information that would be of considerable assistance in assessing inflows. The reporting of inflows into operating mines commenced relatively recently; for instance inflows during the extraction of the first set of longwalls at Metropolitan Colliery, between 1995 and 2010, do not appear to have been recorded and reported. Inflows to the large bodies of water known (discussed below) to be accumulating in the workings of the mines operating in and around the Special Areas (see Figs. 51 and 57 to 61) may not be included in reported assessments. Inflow volumes reported by mining companies are not independently verified.

Reported inflow volumes will depend on the period over which the inflow was assessed and the rainfall levels over that period.

Table 6 below uses the limited publically 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.

There don’t appear to be accessible inflow reports for five of the Metropolitan Special Area mines listed in Table 6 and for two of the three Woronora Special Area mines included in Table 6. Estimate-1 in Table 6 accordingly assumes an inflow of 0.1 million litres a day (Ml/day) for the two Woronora mines, while Estimate-2 assumes an inflow of 1.0 Ml/day for the two Woronora mines. The two estimates also differ in the inflow figures for the Wongawilli mine. The approach used to include the five Metropolitan Special Area mines with unknown inflows in the summation, uses the respective medians of the Table 6 Estimate-1 and Estimate-2 inflow figures as an inflow estimate for each of the five mines.

Adding together the Table 6 entries for mines in and around the Metropolitan and Woronora Special Areas for which figures are available gives an Estimate-1 total of 23 Ml/day and an Estimate-2 total of 31 Ml/day. Including the Estimate-1 and Estimate-2 medians of the Metropolitan mines for the five mines for which figures are not available gives an Estimate-1 total of 29 Ml/day and an Estimate-2 total of 40 Ml/day.

Given the wide range of the inflow estimates, adopting a figure of 34 Ml/day, comprised of 33 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.

The inflow estimate given here amounts to a variation of a 2012 summation reported by Tammetta[3] in modelling the impacts of Area 3B of the Dendrobium mine. Using available data, Tammetta finds an average total inflow of 35 Ml/day, with a range of 30 to 40 Ml/day, for the mines in and around the Metropolitan Special Area that are relevant to modelling the groundwater impacts of the Dendrobium mine (reflecting the mine’s development at that time, the 35 Ml/day total includes 5Ml/day for the Dendrobium mine). His summation for the Dendrobium modelling includes inflows for mines to the west of the Metropolitan Special Area, such as Tahmoor, but doesn’t include mines to the north of Cataract reservoir such as the Metropolitan and Darkes Forest coal mines.

Determining a reasonable estimate of water inflow to the whole of the current Wongawilli mine is challenged by the complexity of the mine and a lack of clarity in the limited publically available information The environmental assessment material provided by Gujarat NRE (now Wollongong Coal) for the 2010 proposal for longwall extractions in the Nebo domain of the Wongawilli mine provides apparently conflicting inflow figures. The groundwater assessment[121] provides an estimate equivalent to 5.0 ML/day. The assessment also provides a tabulation (Table 1 in the report) of recent and historical inflows that evidently reflect seasonal and climate (e.g. La Niña, El Niño) variability. The table appears to give a BHP-Billiton inflow figure equivalent to 10.4 ML/day specifically for the longwalls BHP-Billiton and Delta SBD extracted in the Elouera domain of the mine, but also appears to give the same figure as a peak inflow figure specifically for the longwalls Gujarat NRE has since extracted in this part of the Wongawilli mine (given as panels 11 to 19 in the table). The table also gives a “background’ inflow figure for the new longwall extractions that corresponds to 4.3 Ml/day.

Of note, the 2010 Nebo groundwater assessment attributes the 5.0 ML/day (as 1,824 Ml/year) to the proposal’s surface water management report[122], however the referenced report does not appear to provide this figure. Tammetta evidently refers to Section 6.3 of the surface water management report in giving an inflow figure of 4.16 Ml/day (provided as 1,518 Ml/year in the Nebo report) for the Wongawilli mine, in the October 2012 Coffey assessment[3] for Dendrobium. Figure 5.2 in

Section 5.3 of 2010 Nebo the surface water management report gives an average inflow between January 2005 and October 2009 of 4.2 Ml/day. This figure is used for Estimate-1 in Table 6 below.

Indirectly providing some insight into the inflow figures given in the groundwater report for the 2010 Nebo proposal, the May 2012 end of panel report for Longwall 19[123] and the August 2012 end of panel report for Longwall 20[124] both state "*no observable increased inflow to the Wongawilli mine workings following extraction of Longwall 11, 12, 19 and 20*". The current Wongawilli mine is an amalgam of the Elouera and Avondale mines and part of the Huntley mine. The Elouera mine was established by BHP-Billiton as an amalgam of the old Wongawilli and Nebo bord and pillar mines.

Given no additional inflows were reported as a consequence of the new (Gujarat) Elouera area longwalls, the inflow discrepancies in the Nebo groundwater report noted above may be rationalised if, rather than the specified longwalls, they're effectively for the same set of mine workings (old Elouera longwalls and old Wongawilli, Nebo and Avondale bord and pillar) recorded over periods with differing rainfall patterns. This is supported by figures given in Table 2 of a May 1989 review[125] by the NSW Dams Safety Committee, which gives inflow figures for the old Wongawilli and Nebo mines that total 7.6 Ml/day during "*Normal*" periods and 15.4 Ml/day during "*Wet Season*" periods. These figures highlight the rainfall sensitivity of mine inflows in the Metropolitan Special Area.

Reflecting the evident variability, the Estimate-1 summation in Table 6 below uses a Wongawilli inflow figure of 4.2 ML/day, as given in the May 2010 Surface Water Management report[122] for the then proposed Nebo area longwalls panels, and the Estimate-2 summation uses the inflow of 10.4 Ml/day. The Surface Water Management report inflow figure is for the period January 2005 to October 2009 and will accordingly reflect the impact of the Millennium drought; that is, the inflow figure reflects a drought period. The Elouera longwalls extracted by BHP-Billiton and Delta SBD were mined between 1993 and 2007[126]; a period that also includes the Millennium drought.

Table 6 also assumes that Avon, Avondale and Huntley inflows are not included in the inflow figures given in the 2010 Nebo panel assessments. This assumption seems reasonable given the BHP-Billiton and peak Gujarat inflow figures given in the groundwater assessment (Table 1 of the assessment) are the same. Avon, Avondale and Huntley don't appear to have been part of the BHP-Billiton Elouera domain and Avon doesn't appear to be part of the Gujarat (now Wollongong Coal) Wongawilli domain.

Of note, depending on the extent of the area over which pillars are removed, bord and pillar extractions can be at least as damaging as longwall extractions. For example, extractions of up to 385 metres wide and 765 metres long are reported[121] to have been carried out in the Nebo area. Again, the available information is limited.

Table 2 of the 1989 DSC review provides a 1978 inflow figure of 2.16 Ml/day for what is now the eastern domain of the Russell Vale Colliery. The date of this inflow figure precedes the longwall mining in the western domain of the mine, which commenced in 1979.[127] The 1978 inflow is accordingly used as an upper estimate base for inflows into the eastern domain of Russell Vale Colliery prior to the extraction of Longwalls 4 and 5. The SCT assessment[128] that the extraction of Longwalls 4 and 5 resulted in a further eastern domain inflow of 0.6 Ml/day then suggests an upper inflow estimate of 2.76 Ml/day for Russell Vale east.

The March 2014 SCT inflow estimate[120] of 1.1 Ml/day for Russell Vale east is used for Estimate-1 in Table 6 below.

In the absence of a breakdown of the inflows accumulating in the western domain of Russell Vale Colliery, an upper estimate of 1.0 Ml/day is adopted on the assumption of an inflow rate similar to that of the adjacent Cordeaux Colliery. A lower estimate assumes 0.4 Ml/day of the 0.8 Ml/day Russell Vale inflow reported[120] by SCT is inflow arising from the western domain legacy mining.

As noted above, compounding the problem of limited data and information, the extent to which reported inflow figures capture the true extent of mine inflow is uncertain. The Dendrobium mine uses the old Kemira mine workings to hold water (see Fig. 59), reportedly to act as a sediment pond ahead of pumping to the surface.[57] Inflows are reported as the difference between known mine inflows (reticulated water into the mine, moisture in the downcast ventilation, 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 ROM coal). Unless subsequently pumped to the surface, water stored underground would not otherwise be included in reported inflow volumes

The Wongawilli mine is accumulating a substantial body of water in an area of the Elouera workings (see Fig. 51) that until relatively recently had also been used to provide water for mining operations. An unknown amount of water from the Dendrobium mine is understood to also drain into this pool. This area is no longer accessible because of relatively recent mining activity and, accordingly, inflow into this part of the mine is no longer included in reported mine inflow volumes; "*The significant drop off in water pumped out in the last few months is due to access to underground water storages being blocked due to panel development for LW19*".[123] Wollongong Coal has advised[129] that inflows in excess of the 4.52 Ml/day allowed under the mines current groundwater licence (Groundwater Licence 10BL602990) are held underground. In being granted a licence for 4.5 Ml/day (1650 a year) in January 2013, the mining company had sought approval for 10.14 Ml/day (3,700 Ml/year).

An underground area in the western domain of the Russell Vale Colliery known as X-main, at the lowest point in the mine's Bulli seam workings, is reported[130] to have a large reservoir of water (see Figs. 60 and 61). Some of the water is used in mine operations and excess is then pumped back to the reservoir and this may mean that not all of the inflow is recorded. Some of the water in this area of the mine is thought to be seepage form the neighbouring Cordeaux Colliery. Cordeaux is closed[57] and holds a significant body of water estimated to be accumulating at a rate of 1.47 Ml/day.[130]

Cordeaux Colliery mined the Bulli seam, using longwall extraction, immediately to the south of the western domain of Russell Vale Colliery, while bord and pillar extraction was used by the mine in the same seam to the north of Mt Kembla Colliery. Just as water may be leaking into Russell Vale from Cordeaux, water may enter Cordeaux and/or the adjoining Corrimal mine from the Kemira mine. Kemira is connected to Mt Kembla, which overlies Dendrobium. Mine closures may then, over several decades, ultimately result in a very large body of underground water.

A net inflow of 34 Ml/day into the mines in and around the Metropolitan and Woronora Special Areas would correspond to 13.6 Olympic swimming pools of water being lost each day. Most of the loss occurs in and around the Metropolitan Special Area. As noted above, several of these mines show correlation with rainfall and, in some cases, relatively short lag times between rain and inflow. Whether or not other mines in the Metropolitan Special Area and Woronora Special Area behaviour similarly isn't known.

Providing some context, the long term average daily supply from the Avon, Cataract, Cordeaux, and Woronora Reservoirs totals approximately 334 Ml/day. A loss of 34 Ml/day would then be numerically equivalent to 10.2% of the daily supply from these dams. How much of the lost water would otherwise have entered storage isn't known.

Modelling by consultants suggests the Dendrobium Area 3B mining and the approved expansion of the Metropolitan Colliery will respectively add a further 2.74 Ml/day and up to 3.4 Ml/day to mine inflows in the Metropolitan and Woronora Special Areas - approximately 6 Ml/day. Inflow estimates for the prop0sed expansion of the Russell Vale mine are uncertain and, accordingly, an additional inflow of 2 ML/day is assumed. The indicative net inflow would then be 42 Ml/day, equivalent to 12.6% of the daily supply from the Avon, Cataract, Cordeaux, and Woronora Reservoirs.

In addition to the loss of water into the mines, an unknown amount of water is being diverted and lost into groundwater flows that leave the storage reservoir catchment areas.

27. Water licence anomalies

Licence allocations are would appear to be unable to take into account the unknown inflows accumulating in old mine workings (Section 26), such as the large pool accumulating in the Elouera domain of the Wongawilli mine. Water flows into this pool from both the Wongawilli mine and the Dendrobium mine.

As noted in Section 26, Wollongong Coal has advised[125] that inflows in excess of the 4.5 Ml/day (1,650 Ml/year) allowed under the mines current groundwater licence for its Wongawilli mine, which adjoins the Dendrobium mine, are held underground. This fails to recognise that the diversion of water into the mine constitutes 'take' from the groundwater system above, whether or not it's held in the mine workings. The mine had sought a licence allowing 10.14 Ml/day (3,700 Ml/year). The mine doesn't appear to be able to operate in compliance with its water licence and this may be the case for the Dendrobium mine.

The Department of Planning's December 2015 report[20] on the September 2015 inspection of impacts in Dendrobium Area 3B advises:

> "*The extraction of water from rivers or aquifers to use for commercial purposes requires a water licence or other approval from DPI-Water under either the Water Management Act 2000 or the Water Act 1912.*
>
> *The current total mine inflows were reported to be about 6.2 ML/d (2263 ML/year) following the completion of Longwall 10. Illawarra Coal presently holds a groundwater entitlement of 1537 ML/year. Illawarra Coal has confirmed that in September 2014 it acquired the rights to an additional 2500 ML/year through a controlled allocations release. However, the entitlement has not been registered by Illawarra Coal with Land and Property Information and therefore to date a water access licence has not been issued.*

Reporting by Illawarra Coal indicates that surface water may be being diverted (ie 'taken' under the water legislation) which is not being properly accounted for. This matter needs to be further examined as Illawarra Coal is required to hold a water access licence with sufficient allocation to account for this water take. These issues are to be resolved between Illawarra Coal and DPI-Water separately."

Average inflows have since increased to 8 Ml/day. That the issue is problematic is highlighted by the following remarkable, given the problematic nature of the modelling provided by HydroSimulations, commitment[100] from the March 2015 HydroSimulations groundwater assessment and modelling plan report:

"*In addition, the current groundwater licence held by Illawarra Coal for the Dendrobium Mine is assigned to the Sydney Basin South Groundwater Source (see Section 2.3). A key output of future modelling is going to be the partitioning of 'groundwater take' by the Dendrobium Mine from the local Groundwater Sources, notably between the Sydney Basin South and Sydney Basin Nepean Groundwater Sources.*"

The rainfall sensitivity of inflows indicates that much of the water entering the Dendrobium and Wongawilli mines will, directly or indirectly, be drawn from the Metropolitan Special Area.

28. Recommendations of the NSW Chief Scientist

The May 2014 recommendations[131] of the NSW Chief Scientist addressed the need for a whole of catchment approach to the assessment and prediction of cumulative impacts, including the establishment of a whole of catchment data repository:

Recommendation 1
That Government create a whole-of-Catchment data repository.

Recommendation 2
That Government develop a whole-of-Catchment environmental monitoring system.

Recommendation 3
That Government commission computational models which can be used to assess the impacts on quantity and quality of surface water and groundwater.

Recommendation 4
That Government encourage the use of data visualisation tools for examining 3D representations of the Catchment.

Recommendation 5
That Government establish an expert group to provide ongoing advice on cumulative impacts in the Catchment

The Government doesn't appear to have acted on any of these recommendations.

References

[1] P. Hannam, ‘Coalminers accused of “playing Russian roulette” in Sydney’s water catchment’, *Sydney Morning Herald*, 21-Dec-2015.

[2] P. Tammetta, ‘Estimation of the Change in Hydraulic Conductivity Above Mined Longwall Panels. Supporting Information.’, *Groundwater*, vol. 53, no. 1, pp. 122–129, 2015.

[3] P. Tammetta, ‘Groundwater Study Area 3B Dendrobium Coal Mine - Numerical Modelling’, Coffey Geotechnics Pty Ltd, Groundwater assessment prepared for BHP Billiton GEOTLCOV24507AA-AB2, Oct. 2012.

[4] S. E. Pells and P. J. N. Pells, ‘Impacts of Longwall Mining and Coal Seam Gas Extraction on Groundwater Regimes in the Sydney Basin Part 2 – Practical Applications’, *Aust. Geomech. J.*, vol. Vol 47, no. No. 3, p. 51, Sep. 2012.

[5] D. Lees, D. Edwards, and B. Grant, ‘Recent Experiences in Grouting Sydney Sandstone’, in *Geotechnical Aspects of Tunnelling For Infrastructure Projects*, 2005.

[6] D. Banks, ‘From Fourier to Darcy, from Carslaw to Theis: the analogies between the subsurface behaviour of water and heat’, *Ital. J. Groundw.*, vol. 1, no. 3, pp. 9–19, Dec. 2012.

[7] R. W. Zimmerman, ‘Flow in Porous Media’, M.Sc. in Petroleum Engineering, Imperial College, 2002.

[8] D. Yang, Q. Li, and L. Zhang, ‘Propagation of pore pressure diffusion waves in saturated porous media’, *J. Appl. Phys.*, vol. 117, no. 134902, pp. 1–5, Apr. 2015.

[9] N. Kresic, *Hydrogeology and Groundwater Modeling, Second Edition*. CRC Press, 2006.

[10] S. E. Pells and P. J. N. Pells, ‘Impacts of Longwall Mining and Coal Seam Gas Extraction on Groundwater Regimes in the Sydney Basin Part 1 – Theory’, *Aust. Geomech. J.*, vol. Vol 47, no. No. 3, p. 35, Sep. 2012.

[11] D. Hillel, *Fundamentals of Soil Physics*. Academic Press, 1980.

[12] P. Tammetta, ‘Estimation of the Height of Complete Groundwater Drainage above Mined Longwall Panels - authors reply to comments’, *Groundwater*, vol. 52, no. . 3, pp. 339–342, Jun. 2014.

[13] S. Brown, A. Madden, and R. Leslie, ‘Connected fracturing above longwall mining operations, Part 2: Post-longwall investigation’, Parsons Brinckerhoff Australia on behalf of BHP Billiton Illawarra Coal, 2172268F-WAT–REP–002 RevB, Mar. 2015.

[14] A. Waddington and D. Kay, ‘The Impacts of Mine Subsidence on Creeks, River Valleys and Gorges Due to Underground Coal Mining Operations’, in *Aziz, N. (ed), Coal 2003: Coal Operators’ Conference*, 2003, pp. 101–116.

[15] P. Eade and J. Wood, ‘Longwalling and Its Impact in the Southern Coalfield – Recent BHP Experiences’, in *Aziz, N (ed), Coal 2001: Coal Operators’ Geotechnology Colloquium*, 2001, pp. 85–92.

[16] P. Tammetta, ‘Estimation of the height of complete groundwater drainage above mined longwall panels’, *Ground Water*, vol. 5, pp. 723–34, Oct. 2013.

[17] F. Smith, ‘Dendrobium Area 38 - Application for Approval to Extract Longwalls 14-18’, WaterNSW, 02016/32556, Apr. 2016.

[18] P. Tammetta, ‘Estimation of the Change in Hydraulic Conductivity Above Mined Longwall Panels’, *Groundwater*, vol. 53, no. 1, pp. 122–129, 2015.

[19] P. Tammetta, ‘Estimation of the Change in Storage Capacity above Mined Longwall Panels’, *Ground Water*, vol. Epub ahead of print, p. Online, Jan. 2016.

[20] NSW Department of Planning, ‘Mining Impacts at Dendrobium Coal Mine Area 3B’, Report to Government, Dec. 2015.

[21] A. Skorulis and W. Minchin, ‘Estimated Height of Connected Fracturing above Dendrobium longwalls’, HydroSimulations, Report for Illawarra Coal / South32 BHP008-HC2015-27f, Oct. 2015.

[22] S. Ditton and N. Merrick, ‘A New Sub-Surface Fracture Height Prediction Model for Longwall Mines in the NSW Coalfields’, in *Abstract Proceedings of Australian Earth Sciences Convention*, Newcastle., NSW, Australia, 2014, vol. 136.

[23] C. N. Nicol and N. P. Merrick, ‘Dendrobium Area 3B Groundwater Model Revision: Swamps, Stream Flows and Shallow Groundwater Data’, HydroSimulations, HC2014/4, Mar. 2014.

[24] W. Minchin, S. Brown, and C. Turvey, ‘Dendrobium Area 3B Groundwater Assessment’, HydroSimulations, Dendrobium LW14 - LW18 Groundwater Assessment for Illawarra Coal - South32 HC2016/02, Mar. 2016.

[25] S. Ditton, ‘RE: further query re Springvale RTS’. Reply to email from Peter Turner, 19-May-2015.

[26] S. Ditton, ‘Subsurface Fracture Zone Assessment above the Proposed Springvale and Angus Place Mine Extension Project Area Longwalls’, Ditton Geotechnical Services Pty Ltd, SPV-003/7b, Sep. 2014.

[27] N. P. Merrick and M. Alkhatib, ‘Moolarben Underground Mine UG1 Optimisation Modification Groundwater Modelling Assessment’, Hydrosimulations for Moolarben Coal, HC2014/034, May 2015.

[28] S. Ditton, ‘Mine Subsidence Assessment on the Proposed 75W Modification to the Stage 2 Mining Layout at the Narrabri Mine’, Ditton Geotechnical Services Pty Ltd, NAR-004/1, Aug. 2015.

[29] N. P. Merrick, ‘Adanl - Carmichael Coal Project: Assessment of Fracturing In the Groundwater Model’, Heritage Computing trading as HydroSimulations, HC2014/33, Dec. 2014.

[30] N. P. Merrick, ‘Expert Report to the Land Court by Dr Noel Patrick Merrick: Land Services of Coast and Country Inc. v Adani Mining Pty Ltd’, HC2015/6, Feb. 2015.

[31] K. Wardell and P. Eynon, ‘Structural concept of strata control and mine design’, *Trans. Inst. Inst. Min. Metall.*, vol. 77, no. Section A, pp. A125–A150, 1968.

[32] K. Mills and P. O’Grady, ‘Impact of longwall width on overburden behaviour’, presented at the Coal 98 Conference, Wollongong, 1998.

[33] W. Gale, ‘Water Inflow Issues above Longwall Panels’, in *Aziz, N (ed), Coal 2006: Coal Operators’ Conference*, 2006, pp. 175–179.

[34] W. Gale, ‘Aquifer Inflow Prediction Above Longwall Panels’, ACARP Project C13013, 2008.

[35] L. Holla and E. Barclay, ‘Mine Subsidence in the Southern Coalfield, NSW, Australia’. New South Wales Department of Mineral Resources, Jun-2000.

[36] P. Tammetta, ‘Groundwater Study Area 3B Dendrobium Coal Mine Revised Numerical Modelling.’, Coffey Geotechnics Pty Ltd, Groundwater assessment prepared for BHP Billiton GEOTLCOV24507AB-AB2, Nov. 2012.

[37] S. Ditton, ‘Sub-Surface Fracture Height Review and Predictions for the Proposed Longwalls 42 to 47, 51 and 52 at West Wallsend Colliery, Killingworth’, Ditton Geotechnical Services Pty Ltd, WWD-012/8b, Aug. 2013.

[38] S. Ditton, ‘Subsidence Predictions and General Impact Assessment for the Tasman Extension Project’, Ditton Geotechnical Services Pty Ltd, DGS Report No. TAS-005/1, Jun. 2012.

[39] N. Shepherd, J. Bennett, J. Galvin, C. Mackie, and J. Tilleard, ‘Review of the Bulli Seam Operations Project’. NSW Planning Assessment Commission (PAC), Jul-2010.

[40] H. Guo, D. P. Adhikary, and D. Gaveva, ‘Hydrogeological Response to Longwall Mining’, CSIRO Exploration & Mining, Australian Coal Industry Research Program (ACARP) C14033, Oct. 2007.

[41] P. Tammetta, ‘Estimation of the height of complete groundwater drainage above mined longwall panels - Supplementary Material’, *Ground Water*, vol. 5, pp. 723–34, Oct. 2013.

[42] C. N. Nicol, N. P. Merrick, and N. Akhter, ‘End-of-Panel Groundwater Assessment for Dendrobium Longwall 9, (Area 3B)’, Heritage Computing Pty Ltd trading as HydroSimulations, Report: HC2014/015, Aug. 2014.

[43] R. N. Singh and M. Jakeman, ‘Longwall Mining Under the Cataract Reservoir’, in *IMWA Proceedings 1999*, Sevilla, Spain, 1999.

[44] R. N. Singh and M. Jakeman, ‘Strata Monitoring Investigations Around Longwall Panels Beneath the Cataract Reservoir’, *Mine Water Environ.*, vol. 20, pp. 55–64, 2001.

[45] GeoTerra Pty Ltd, ‘Russell Vale Colliery Underground Expansion Project Preferred Project Report Wonga East Groundwater Assessment’, Appendix C of the Underground Expansion Project Residual Matters Report NRE8 R1C GW, Jun. 2014.

[46] K. Mills, ‘Update to Subsidence Assessment of Wollongong Coal Preferred Project Report Russell Vale No 1 Colliery - Appendix B of the Underground Expansion Project Residual Matters Report’, Strata Control Technology (SCT) Pty, WCRV4263, Jun. 2014.

[47] R. Young, ‘Dendrobium Mine Area 38 Subsidence Management Plan’, Sydney Catchment Authority, Submission to Dept. Planning D2012/111778, Dec. 2012.

[48] R. Howard, D. Kitto, and M. Ray, ‘Major Project Assessment: Russell Vale Colliery Underground Expansion Project (MP 09_0013) - Secretary’s Environmental Assessment Report Section 75I of the Environmental Planning and Assessment Act 1979’. NSW Department of Planning, 12-Nov-2014.

[49] P. Tammetta, ‘Russell Vale Colliery (formerly the NRE No. 1 Mine) Underground Expansion Project Groundwater Review’, Coffey Geotechnics Pty Ltd for the NSW Department of Planning, GEOTLCOV24840AC-AB, Sep. 2014.

[50] J. Sheppard, ‘Advice to the June 12th 2014 Tahmoor Community Consultative Committee Meeting’, *Pers. Commun.*

[51] ‘Metropolitan Coal 2013 Annual Review and Annual Environmental Management Report’, Peabody Energy, 581658, Mar. 2014.

[52] G. McNally and R. Evans, ‘Impacts of longwall mining on surface water and groundwater, Southern Coalfield NSW’, Sinclair Knight Merz Pty Ltd, Report prepared for NSW Department of Environment and Climate Change., Sep. 2007.

[53] D. P. Adhikary, ‘Reply to query re 2007 Springvale assessment report’, *Email March 30 2016*.

[54] ‘Springvale Colliery Subsidence Management Status Report’, Centennial Coal, Four Monthly Update, Nov. 2009.

[55] Australasian Groundwater and Environmental Consultants Pty Ltd (AGE), ‘Mandalong Longwall Coal Mine Groundwater Monitoring Review for AEMR 2014’, G1455C, Feb. 2015.

[56] Comur Consulting Pty Ltd, ‘End of Panel Report for Longwall 5 at Dendrobium Colliery’, Report prepared for BHP Billiton, Apr. 2010.

[57] GHD Geotechnics, ‘Dendrobium Area 3 - Predicted Hydrogeologic Performance’. GHD Pty Ltd 2007, Nov-2007.

[58] K. W. Mills, ‘Interpretation of results from Boreholes DSC12 and DSC13 at Elouera Colliery’, Prepared for BHP Billiton DEN2947, Dec. 2005.

[59] K. W. Mills, ‘Developments in Understanding Subsidence with Improved Monitoring’, in *Proceedings of the 8th Triennial Conference on Mine Subsidence, 2011*, Pokolbin, N.S.W, 2011.

[60] I. Forster, ‘Impact of Underground Coal Mining on the Hydrogeological Regime’, in *Editors: Sloan, S.W, Allman, M.A.; Australian Geomechanics Society (AGS) Conference Proceedings*, University of Newcastle, 1995.

[61] Mine Subsidence Engineering Consultants (MSEC), ‘Dendrobium Area 3B – Longwalls 9 to 18 Subsidence Predictions and Impact Assessments for Natural Features and Surface Infrastructure in Support of the SMP Application’, Mine Subsidence Engineering Consultants Pty Ltd (MSEC), MSEC459 Revision B, Sep. 2012.

[62] P. Tammetta, ‘Groundwater Study, Area 3B Dendrobium Coal Mine, Data Analysis (2nd Edition)’, Coffey Geotechnics Pty Ltd, Prepared for BHP Billiton GEOTLCOV24507AB-AB1, Nov. 2012.

[63] A. Madden, J. Ross, and J. Jankowski, ‘Longwall Mining Effects on Deep Groundwater in a Southern Coalfield Catchment, Australia’, in *Adapting to Change*, Newcastle., NSW, Australia, 2009, pp. 86–97.

[64] Mine Subsidence Engineering Consultants (MSEC), ‘Dendrobium Area 3B – Longwalls 12 to 18: Review of the Subsidence Predictions and Impact Assessments for Natural and Built Features in Dendrobium Area 3B based on Observed Movements and Impacts during Longwalls 9 and 10’, Mine Subsidence Engineering Consultants Pty Ltd (MSEC), MSEC459 Revision C, Dec. 2015.

[65] Mine Subsidence Engineering Consultants (MSEC), ‘Dendrobium Mine, End of Panel Subsidence Monitoring Report for Longwall 3 in Dendrobium Area 2. Attachment C Subsidence Monitoring.’, MSEC346, Feb. 2008.

[66] J. Cairns and S. A. Short, ‘End of Panel Surface and Shallow Groundwater Impacts Assessment Dendrobium Area 2 Longwall 4’, Ecoengineers Pty Ltd for BHP Billiton, Report for BHP Billiton Illawarra Coal 2008/11A Revision 4, Aug. 2008.

[67] Mine Subsidence Engineering Consultants (MSEC), ‘Dendrobium Mine, End of Panel Subsidence Monitoring Report for Longwall 4 in Dendrobium Area 2’, Revision D MSEC377, Dec. 2008.

[68] Mine Subsidence Engineering Consultants (MSEC), ‘The prediction of subsidence parameters and the assessment of mine subsidence impacts on natural features and surface infrastructure resulting from the extraction of proposed Longwalls 6 to 10 in area 3A and future longwalls in Areas 3B and 3C at Dendrobium mine’, MSEC311 Revision D, Oct. 2007.

[69] Comur Consulting Pty Ltd, ‘End of Panel Report for Longwall 6 at Dendrobium Colliery’, Report prepared for BHP Billiton, Jul. 2011.

[70] N. Akhter, W. Minchin, and N. P. Merrick, ‘Dendrobium Mine End of Panel Groundwater Assessment: Longwall 10 (Area 3B)’, Heritage Computing Pty Ltd trading as HydroSimulations, Project number: BHP007 Report: HC2015/015, May 2015.

[71] Mine Subsidence Engineering Consultants (MSEC), ‘Dendrobium – Area 3A – Longwall 7. End of Panel Subsidence Monitoring Report for Dendrobium Longwall 7.’, Report for BHP Billiton Illawarra Coal MSEC545 RevA., Mar. 2012.

[72] Mine Subsidence Engineering Consultants (MSEC), ‘End of Panel Subsidence Monitoring Review Report for Dendrobium Longwall 8 - Revision B’, Report prepared for BHP Billiton MSEC607, Apr. 2013.

[73] A. Skorulis and N. Akhter, ‘End of Panel Groundwater Assessment: Longwall 11 (Area 3B)’, Heritage Computing trading as HydroSimulations, Prepared for South32 HC2016/21, May 2016.

[74] Mine Subsidence Engineering Consultants (MSEC), ‘End of Panel Subsidence Monitoring Review Report for Dendrobium Longwall 9’, MSEC670, Jun. 2014.

[75] BHP Billiton, ‘Minutes for the August 2013 Meeting of the Dendrobium Community Consultative Committee’. 15-Aug-2013.

[76] BHP Billiton, ‘Minutes for the November 2013 Meeting of the Dendrobium Community Consultative Committee’. 21-Nov-2013.

[77] C. J. Booth, ‘The effects of longwall coal mining on overlying aquifers’, in *Mine Water Hydrogeology and Geochemistry. Younger PL and Robins NS (eds.)*, Special Publications., vol. 198, The Geological Society of London, 2002, pp. 17–45.

[78] NSW Department of Planning, ‘Area 3B Subsidence Management Plan Approval February 2013’. [Online]. Available: http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=2010. [Accessed: 09-Mar-2016].

[79] ‘Notice of Modification: Dendrobium Underground Coal Mine (Area 3)’, NSW Department of Planning, Section 75W of the Environmental Planning and Assessment Act 1979, Dec. 2008.

[80] South 32, ‘Dendrobium Mine Avon and Cordeaux Reservoirs DSC Notification Area Management Plans’, Sep. 2015.

[81] W. Ziegler and H. Middleton, ‘Analysis of mine water origins using geochemistry, Tritium isotopes and algae’, in *Proceedings 11th International Mine Water Association Congress*, Aachen, Germany.

[82] GHD Geotechnics, ‘Dendrobium Area 2, End of Panel Report for Longwall 3, Hydrogeological Response of Rockmass to the Mining of Longwall 3.’, 21/11716/02/AY412, Mar. 2008.

[83] S. A. Short, ‘End of Panel Surface Water and Groundwater Impact Assessment Dendrobium Longwall 3.’, Ecoengineers Pty Ltd for BHP Billiton., Prepared for BHP Billiton Illawarra Coal. 2008/03A, Feb. 2008.

[84] GHD Geotechnics, ‘Dendrobium Area 2, End of Panel Report for Longwall 4, Hydrogeological Response of Rockmass to the Mining of Longwall 4.’, 21/11716/02/AZ057_R1, Dec. 2008.

[85] N. P. Merrick and N. Akhter, ‘End-of-Panel Groundwater Assessment for Dendrobium Longwall 6 (Area 3A)’, Heritage Computing Report HC2011/9, Jul. 2011.

[86] N. P. Merrick and N. Akhter, ‘End-of-Panel Groundwater Assessment for Dendrobium Longwall 7 (Area 3A)’, Heritage Computing Report HC2012/9, Apr. 2012.

[87] N. P. Merrick and N. Akhter, ‘End-of-Panel Groundwater Assessment for Dendrobium Longwall 8 (Area 3A)’, Report HC2013/10, Mar. 2013.

[88] BHP Billiton, ‘Minutes for the February 2015 Meeting of the Dendrobium Community Consultative Committee’. 19-Feb-2015.

[89] BHP Billiton, ‘Minutes for the February 2014 Meeting of the Dendrobium Community Consultative Committee’. 20-Feb-2014.

[90] Office of Environment and Heritage, ‘RE: query re discrepancy between subsidence and groundwater docs for Area 3B of Dendrobium’, Email to Peter Turner May 21 2015.

[91] P. Hannam, ‘BHP’s coal mine approved in Sydney’s catchment without groundwater assessment’, *Sydney Morning Herald*, 31-Jul-2015.

[92] M. Merrick, ‘Re query re groundwater modelling for Dendrobium - Reply to Peter Turner’, *Email May 28 2015*.

[93] K. Cleland and M. Carleton, ‘Dendrobium underground coal mine project. Report of Commissioners of Inquiry to the Minister for Urban Affairs and Planning’, 2001.

[94] NSW Department of Planning, ‘Dendrobium underground coal mine - modification of consent to expand Area 3 and obtain approval for mining in Area C’. [Online]. Available: http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=1403. [Accessed: 09-Mar-2016].

[95] P. Turner, ‘Concerns arising from flawed groundwater impact assessments in NSW’, NSW National Parks Association, Letter to NSW Minister for Planning July 14 2015.

[96] P. Turner, ‘Query re Dendrobium’, Email to Howard Reed April 22 2015.

[97] NSW Department of Planning, 'RE: groundwater assessment for Dendrobium Area 3B', Email to Peter Turner May 8 2015.

[98] NSW Department of Planning, 'RE: groundwater assessment for Dendrobium Area 3B', Email to Peter Turner June 5 2015.

[99] H. Reed, 'Re Coffey Groundwater Assessment for Area 3B Dendrobium Coal Mine - Revised Numerical Modelling November 2012', NSW Department of Planning, Personal Communication June 25 2015.

[100] HydroSimulations, 'Dendrobium Coal Mine Groundwater Monitoring and Modelling Plan', May 2015.

[101] P. Tammetta, 'Groundwater Study, Area 3B Dendrobium Coal Mine, Data Analysis', Coffey Geotechnics Pty Ltd, Groundwater assessment prepared for BHP Billiton GEOTLCOV24507AA-AB1, Oct. 2012.

[102] 'Environmental Assessment: Dendrobium Coal Mine - Modification of Consent (Area 3)', NSW Department of Planning, Director-General's Environmental Assessment Report, Section 75W of the Environmental Planning and Assessment Act 1979, Nov. 2008.

[103] N. Shepherd, J. Bennett, J. Galvin, C. Mackie, and J. Tilleard, 'The Metropolitan Coal Project Review Report'. NSW Planning Assessment Commission (PAC), May-2009.

[104] NSW Office of Environment and Heritage, 'Upland Swamp Environmental Assessment Guidelines - Guidance for the underground mining industry operating in the southern coalfield'. NSW Government, Aug-2012.

[105] NSW Scientific Committee, 'Coastal Upland Swamp in the Sydney Basin Bioregion - endangered ecological community listing', Mar-2012. [Online]. Available: http://www.environment.nsw.gov.au/determinations/coastaluplandswampfd.htm. [Accessed: 03-Sep-2016].

[106] D. A. Keith, J. P. Rodriguez, K. M. Rodriguez-Clark, E. Nicholson, and K. Aapala, 'Scientific Foundations for an IUCN Red List of Ecosystems', *PLoS ONE*, vol. 8, no. 5, p. e62111, 2013.

[107] Commonwealth Department of the Environment, 'EPBC Act status for the Coastal Upland Swamps in the Sydney Basin Bioregion', 17-Jul-2014. [Online]. Available: http://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=140&status=Endangered. [Accessed: 03-Sep-2016].

[108] S. Haddad, 'Dendrobium Area 3B Subsidence Management Plan Approval - Reasons for Approval'. NSW Department of Planning, Feb-2013.

[109] BHP Billiton, 'Minutes for the February 2013 Meeting of the Dendrobium Community Consultative Committee'. 21-Feb-2013.

[110] Sydney Catchment Authority, 'Environmental Assessment NRE No.1 Colliery Stage 2 Underground Expansion Project Application No. MP 09_0013 - submission to the NSW Department of Planning regarding the proposed expansion of the Russel Vale Colliery'. 15-Apr-2013.

[111] GeoTerra Pty Ltd, 'Gujarat NRE Coking Coal Ltd Preliminary Works Surface Water & Groundwater Assessment Bellambi, NSW', GUJ3-R1C, Sep. 2010.

[112] A. Dawkins, 'Appin Area 7 Longwalls 705 to 710 Groundwater Assessment', Geoterra Pty Ltd on behalf of BHP-Billiton Illawarra Coal Pty Ltd, BHP41-R1B, Jun. 2008.

[113] M. Krogh, 'Assessment of Impacts over Dendrobium Mine'. NSW Office of Environment & Heritage, 31-Aug-2012.

[114] Office of Environment and Heritage, 'Submission to the Department of Planning Regarding the Swamp Impact, Monitoring, Management and Contingency Plan for Area 3B of the Dendrobium Mine - Attachment 1', DOC12/51816, Dec. 2012.

[115] P. Tammetta, 'Gujarat NRE No.1 Colliery Major Expansion Project Part 3A Application: Review of the Groundwater Component of the Preferred Project Report - June 2013', Coffey Geotechnics Pty Ltd for the NSW Department of Planning, GEOTLCOV24840AB-AB, Jun. 2013.

[116] P. Tammetta, ‘Gujarat NRE No.1 Colliery Major Expansion Project Part 3A Application: Review of the Groundwater Component of the Preferred Project Report - December 2013’, Coffey Geotechnics Pty Ltd for the NSW Department of Planning, GEOTLCOV24840AA-AB, Dec. 2013.

[117] P. Tammetta, ‘Gujarat NRE No.1 Colliery Major Expansion Project Part 3A Application: Review of the Groundwater Component of the Preferred Project Report - November 2013’. Coffey Geotechnics Pty Ltd for the NSW Department of Planning, 26-Nov-2013.

[118] H. Reed and D. Kitto, ‘Addendum Report: Major Project Assessment Russell Vale Colliery Underground Expansion Project (MP 09_0013)’, NSW Department of Planning, Nov. 2015.

[119] N. P. Merrick, ‘Peer Review – Russell Vale Colliery Groundwater Impact Assessment’, HydroSimulations, Review on behalf of Wollongong Coal HS2014/12, Jun. 2014.

[120] K. Mills, ‘Assessment of Groundwater Data for Russell Vale Colliery and Implications for Further Mining in the Wonga East Area’, Strata Control Technology (SCT) Pty, Appendix C of the Russell Vale Colliery Underground Expansion Project Preliminary Residual Matters Report and Appendix D of Environmental Assessment Russell Vale Colliery Commencement of Long Wall 6 WCRV4209, Mar. 2014.

[121] GeoTerra Pty Ltd, ‘Wongawilli Colliery Nebo Longwall Panels 1 To 6 Groundwater Assessment’, GUJ4-GWR1B, Jun. 2010.

[122] WRM Water & Environment Pty Ltd, ‘Gujarat NRE FCGL Pty Ltd Wongawilli Colliery Surface Water Management’, 0637–02–A[Rev2], May 2010.

[123] C. Irving, ‘Wongawilli Colliery LW19 End of Panel Report’. Gujarat NRE FCGL Pty Ltd, 04-May-2012.

[124] C. Irving, ‘NRE Wongawilli Colliery Longwall 20 End of Panel Report’. Gujarat NRE FCGL Pty Ltd, 24-Aug-2012.

[125] D. Anderson, D. H. . S. Stapledon, and N. S. Mattes, ‘Coal Mining Beneath Reservoirs New South Wales Australia 1979 - 1989’, Dams Safety Committee, 407/JG/JENNY.AA9/MASS, May 1989.

[126] ‘Prediction of Subsidence Parameters and the Assessment of Mine Subsidence Impacts on Natural Features and Surface Infrastructure Resulting from the Proposed Extraction of Longwalls N1 to N6 in the Nebo Area in Support of a Part 3a Application’, Mine Subsidence Engineering Consultants Pty Ltd (MSEC), MSEC412 Revision B, Jun. 2010.

[127] ‘NRE No.1 Colliery Major Expansion Stream Assessment’, Geoterra Pty Ltd on behalf of Gujarat NRE Coking Coal Ltd, GUJ1-SWR1D, Nov. 2012.

[128] Wollongong Coal Limited, ‘Russell Vale Colliery Longwall 5 End of Panel Report’. May-2014.

[129] Wollongong Coal Limited, ‘Minutes for Meeting No. 8 Wongawilli Colliery Community Consultative Committee’. 18-Mar-2014.

[130] P. J. N. Pells and S. E. Pells, ‘Review of Subsidence and Related Facets of the NRE No 1 Colliery Underground Expansion Project Draft Environmental Assessment: Appendix C - Site Inspection’, Consultants report by Pells Consulting for Gujarat NRE P043.R2, Oct. 2011.

[131] NSW Chief Scientist and Engineer, ‘On measuring the cumulative impacts of activities which impact ground and surface water in the Sydney Water Catchment’. May-2014.

[132] D. P. Olsen, ‘Environmental Assessment Illawarra Coal Seam Gas Exploration Drilling & Gas Monitoring Program’, Olsen Consulting Group Pty Ltd, for APEX Energy NL, Mar. 2009.

[133] P. Whittall, ‘Dendrobium Mine: From Paper to Production’, presented at the Coal 2004: Coal Operators’ Conference, Aziz, N (ed), 2004, pp. 21–39.

Tables

Table 1. Coffey and HydroSimulations Horizontal and Vertical Hydraulic Diffusivities[1]

	Coffey 2012[3]		**HydroSimulations 2016**[24]	
Stratum	Kh/Ss (m^2/s)	Kv/Ss (m^2/s)	Kh/Ss (m^2/s)	Kv/Ss (m^2/s)
Upper Hawkesbury Sandstone	1.39	1.39E-03	0.23	1.93E-03
Lower Hawkesbury Sandstone	0.29	8.68E-03	0.14	8.68E-04
Bald Hill Claystone	0.14	4.17E-03	0.02	9.26E-05
Upper Bulgo Sandstone	0.06	3.22E-03	0.05	1.29E-05
Lower Bulgo Sandstone	0.02	1.97E-03	0.02	1.01E-03
Stanwell Park Claystone	0.02	9.92E-04	0.01	2.48E-04
Scarborough Sandstone	0.02	1.85E-03	0.05	9.65E-04

[1]The diffusivities were obtained by dividing the hydraulic conductivity by the specific storage data tabulated in the respective assessments.

Table 2. Ratio of Hydraulic Conductivities from Coffey and HydroSimulations

Stratum	Kh(C[1])/Kh(Hyd[2])[3]	Kv(C)/Kv(Hyd)[4]
Upper Hawkesbury Sandstone	6.00	0.72
Lower Hawkesbury Sandstone	2.08	10.00
Bald Hill Claystone	8.00	45.00
Upper Bulgo Sandstone	1.25	250.00
Lower Bulgo Sandstone	1.00	1.94
Stanwell Park Claystone	1.67	4.00
Scarborough Sandstone	0.30	1.92

[1]C: Coffey
[2]Hyd: HydroSimulations
[3]Kv: vertical conductivity
[4]Kh: horizontal conductivity

Table 3. Mining heights for Area 3B Longwalls 9 to 11**[20]**

Longwall	Start Location (m)	End Location (m)	Mining Height (m)
Longwall 9	2,180	1,740	3.4
	1,740	1,400	3.7
	1,400	0	3.4
Longwall 10	2,200	1,140	3.9
	1,140	1,040	4.5
	1,040	910	3.9
	910	460	3.7
	460	0	3.9
Longwall 11	2,290	Ongoing	3.95

Table 4. Comparison of Dendrobium drainage zone height bounds indicated by piezometer data and height estimates from the Ditton and Tammetta equations

Bore	Longwall	Width to depth of cover ratio[a]	Longwall void width (metres)	Longwall cutting height[b] (metres)	Distance from centreline[c] (metres)	Drianage zone height lower bound (metres w.r.t. centreline seam elevation[d])	Drianage zone height upper bound[f]	Surface height above centreline (metres)[d]	Ditton A50 (metres)	Ditton A95 (metres)	Tammetta H (metres)	Main Text Section
DDH39/S1578	3	1.09	246	3.2	30	114[e]	Surface	236[e]	110	135	216	15.1.1
DDH50/S1652	3	1.33	246	3.7	470	113[e]	Suface	190[e]	106	124	252	15.1.2
DDH89/S1876	4	0.98	245	3.4/3.75	113	254[e]	Surface	270[e]	119/125	148/154	238/269	15.1.3
DDH38/S1577	5	0.92	245	3.4/3.75	292	215	Surface	282	123/129	153/159	240/272	15.1.5
DDH90/S1877	5	0.92	245	3.4/3.75	230	110	Surface	270	123/129	153/159	240/272	15.1.7
DDH117/S1953	5	0.93	245	3.4/3.75	145	177	Surface	280	123/128	153/158	240/272	15.1.8
DDH97/S1889	6	0.7	250	3.4/3.9	318	264	Surface	361	145/154	183/192	258/307	15.1.9
DDH86/S1871	6	0.76	250	2.9/3.4/3.9	180	223	Surface	333	129/139/149	167/177/187	207/255/303	15.1.10
DDH84/S1867	6	0.76	250	3.4/3.9	280	196	Surface	333	139/149	177/187	255/303	15.1.11
DDH85/S1870	6	0.76	250	3.4/3.9	190	236	Surface	360	139/150	177/188	255/304	15.1.12
DDH85/S1870	7	0.8	250	3.3/3.6/3.9	190	234	Surface	314	133/138/144	170//176/182	242//271/300	15.1.12
DDH84/S1867	7	0.8	250	3.6/3.9	380	196	Surface	314	133/138/144	170/176/182	242/271/300	15.1.11
DDH84/S1867	8	1.13	305	3.3/3.6/3.9	617	191	Surface	273	134/139/144	164/169/174	283/316/350	15.1.11
DDH85/S1870	8	1.13	305	3.3/3.6/3.9	300	229	Surface	273	134/139/145	164/169/170	283/316/350	15.1.12
DDH92/S1879	8	0.87	305	3.6/3.9	700	284	Surface	351	159/165	198/204	331/366	15.1.13
DDH105/S1910	9	0.74	305	3.4/3.7	279	267	Surface	417	169/176	215/222	317/353	15.1.14
DEN104/S1908	9	0.76	305	3.4/3.7	345	264	Surface	404	167/174	213/220	316/351	15.1.16
DDH109/S1926	9	0.78	305	3.4/3.7	395	280	Surface	393	165/172	211/218	315/350	15.1.17
DDH111/S1929	9	0.88	305	3.4/3.7	410	269	Surface	347	155/161	194/200	308/342	15.1.18
DDH108/S1925	9	0.77	305	3.4/3.7	850	278	Surface	394	166/173	212/219	315/350	15.1.19
DDH108/S1925	10	0.78	305	3.9/4.5	540	278	Surface	395	176/188	222/234	373/444	15.1.19
DDH108/S1925	11	0.75	305	3.95	155	273	Surface	412	181	227	382	15.1.19
DHH131/S2009	11	0.75	305	3.95	310	306	Surface	410	181	227	382	15.1.20

Table 4 continued - Footnotes

[a]Less than 0.9 is sub-critical, between 0.9 and 1.4 is critical and greater than 1.4 is super-critical.

[b]Single numbers are from available profile information; the first of a forward slash separated pair is the average and the second is the maximum; where there are three numbers the first is additionally an estimated minimum value.

[c]See relevant section in the main text for a description of the bore location with respect to the extraction.

[d]Unless otherwise indicated, elevations (mAHD) were taken from MSEC contour maps.

[e]Seam elevation obtained from an unsourced contour map of unknown accuracy.

[f]Piezometers located between that providing a lower bound and the surface were not suitable for identifying an upper bound; see main text.

Table 5. Examples of significant drawdowns recorded by piezometers at the Dendrobium mine

Piezometer Bore	Drawdown (metres)	Depth below surface (metres)	Stratum	Text Section
S2192+S2220[a]	67	140	L. Hawkesbury S.	15.1.14 & 16.7
DDH104/S1908[a]	60	155	L. Hawkesbury S.	15.1.15
DDH108/S1925[a]	50	144	L. Hawkesbury S.	15.1.18
DDH105/S1910[a]	40	125	L. Hawkesbury S	15.1.13
DDH111/S1929[a]	30	76	L. Hawkesbury S.	15.1.17
DDH97/S1889	21	123	L. Hawkesbury S.	15.1.9
DDH90/S1877[b]	70	136	Bulgo S.	15.1.7
DDH88/S1875	50	130	Bulgo S.	15.1.6
DDH86/S1871[b]	40	88	Bulgo S.	15.1.10
DDH119/S1992[b,c]	53	92	Bulgo S.	1.15.12
DDH85/S1870[b,c]	31	55	Bulgo S.	15.1.12
DDH117/S1953	21	83	Bulgo S.	15.1.8
DDH39/S1578[b]	20	122	Stanwell Park C.	15.1.1
DDH42/S1588	15	116	Stanwell Park C.	15.1.20

[a]Falls below Avon

[b]Falls below Cordeaux

[c]TARP bore

Table 6. 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)
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			
Appin[3]	Bulli	1.20	1.20
Bulli[125]	Bulli	0.24	0.24
Cordeaux[130]	Bulli	1.47	1.47
Corrimal[125]	Bulli	1.30	1.30
Dendrobium[73]	Wongawilli	8.0	8.0
Huntley 1 and 2[125]	Wonga and Tongarra	3.93	3.93
Kemira[125]	Bulli and Wongawilli	0.80	0.80
Russell Vale - East (South Bulli)	Bulli, Balgownie, Wongawilli	1.1[120]	2.76[125][128]
Russell Vale - West (Bellambi West)	Bulli and Balgownie	0.4	1.0
Wongawilli - all of mine		4.20[122]	10.37[121]
Avon	Wongawilli	?	?
Avondale	Wongawilli and Tongarra	?	?
Mt Kembla	Bulli	?	?
North Bulli	Bulli	?	?
South Clifton	Bulli	?	?
Mean (Ml/day)		**2.26**	**3.11**
Median (ML/day)		**1.25**	**1.38**
Total (Ml/day)		**22.64**	**31.07**
Total (Gl/year: 1 Gl = 1000 Ml)		**8.26**	**11.34**

Figures

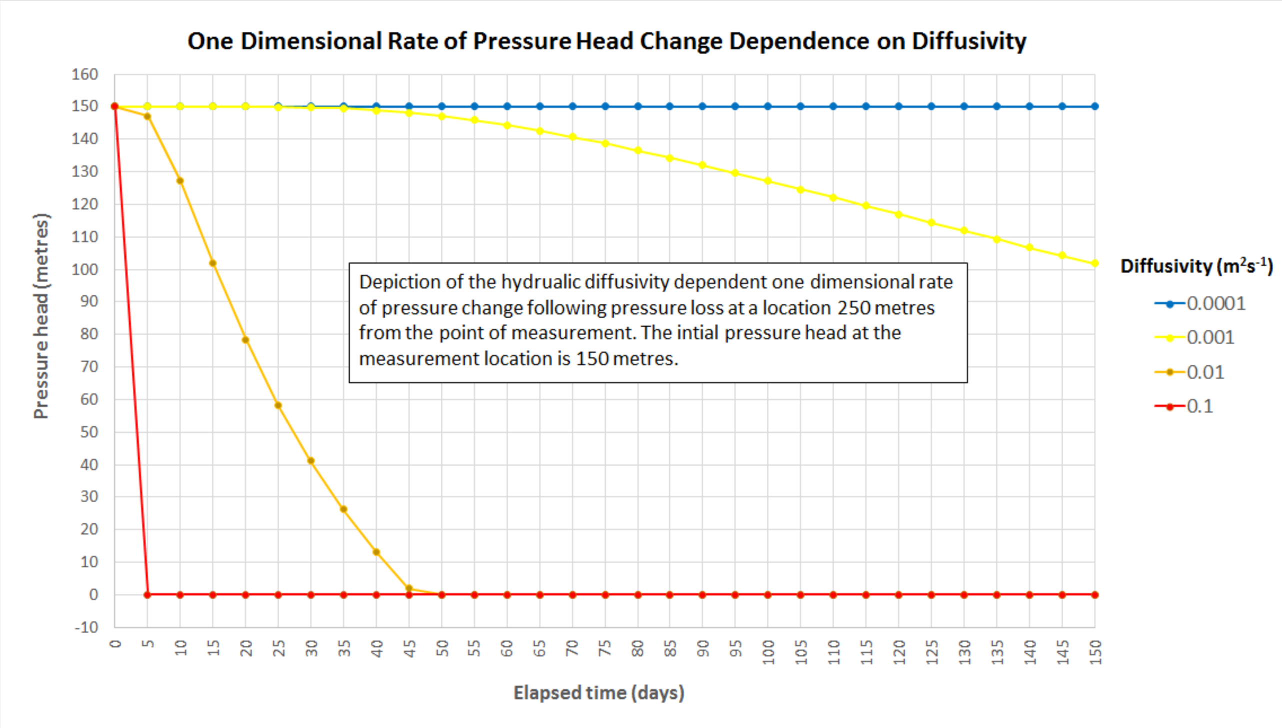
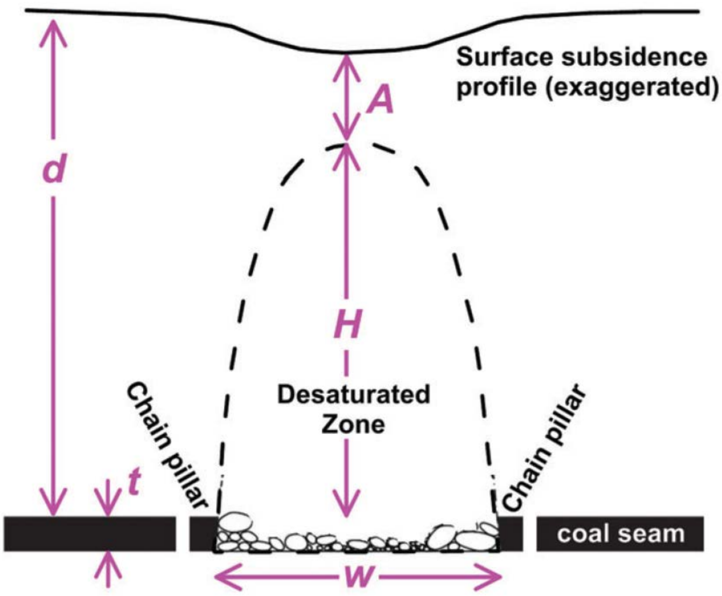


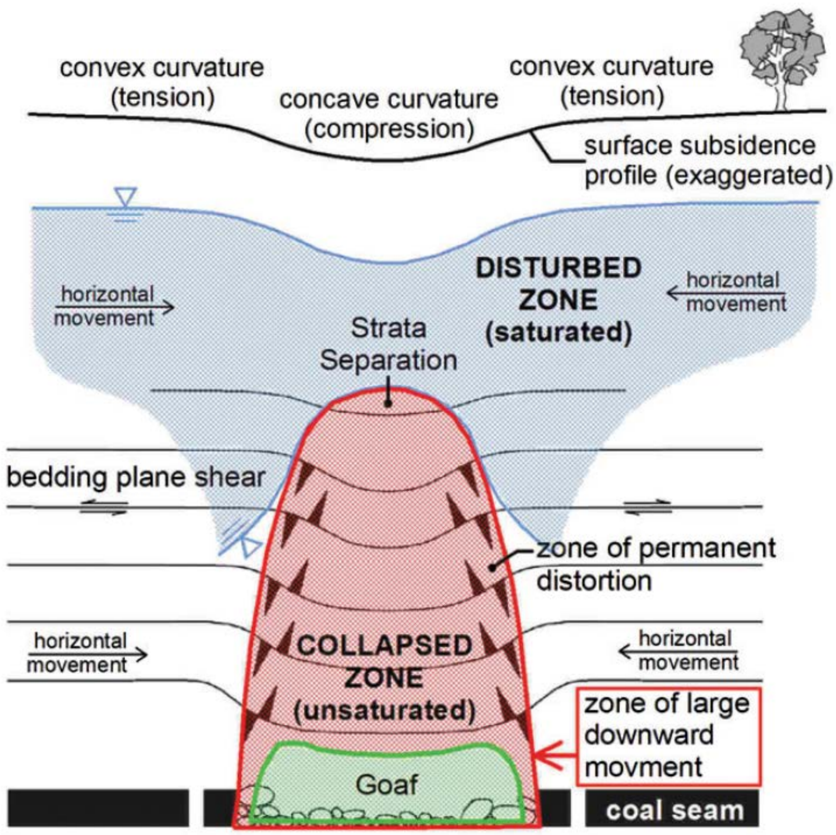
Figure 1. Pressure change with time dependence on hydraulic diffusivity

Using the solution for the one dimensional diffusion equation[8][9][10], the above graph depicts the hydraulic diffusivity dependence of the change in pressure at a location with an initial pressure head of 150 metres and is 250 metres from a point where the pressure head falls abruptly from 400 to 0 metres. This corresponds to a measurement point 150 metres below a surface point that is 400 metres above the point of sudden pressure loss. It could also correspond to a point 250 metres laterally distant from a point of sudden pressure loss.

The vertical diffusivity of sandstone that has not been impacted by mining is typically 0.001 m^2s^{-1}.[10] The sandstone hydraulic parameters used in the 2012 Coffey groundwater impact assessment[3] modelling provide typical diffusivities, whereas those of 2016 HydroSimulations assessment[24] are generally smaller. This is notably so for the upper Bulgo Sandstone, for which the parameters listed in the 2016 HydroSimulations groundwater impact assessment give a vertical diffusivity of 0.000013 m^2s^{-1}, a value more typical of shale than sandstone. Puzzlingly then, the upper Bulgo Sandstone and Hawkesbury Sandstone piezometer mining response modelling given in the HydroSimulations assessment shows rates of change consistent with much greater vertical diffusivity values. The relatively rapid rates of pressure head change reported by the piezometers discussed in Section 15 do not appear to be consistent with the hydraulic diffusivities that appear to have been used by HydroSimulations in their 2016 groundwater modelling for Dendrobium.



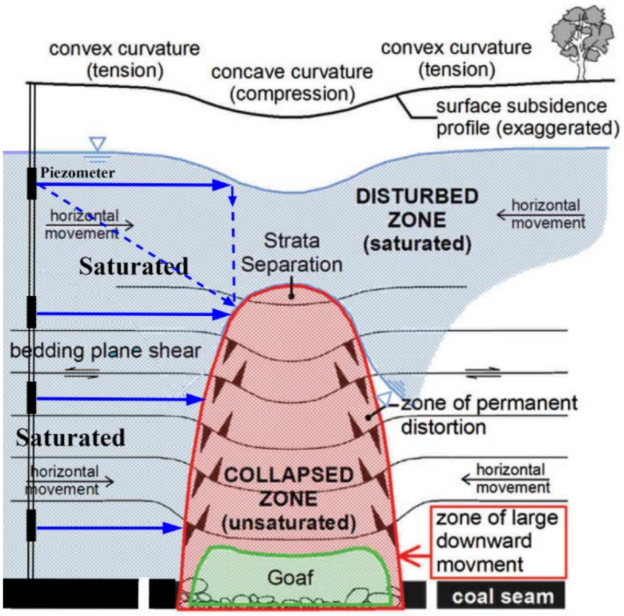
(a)



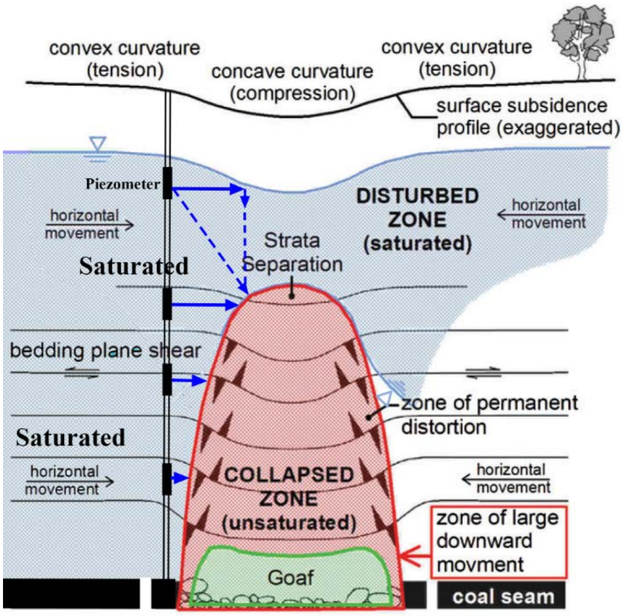
(b)

Figure 2. Tammetta depiction of (a) the drainage zone and (b) the collapsed zone.

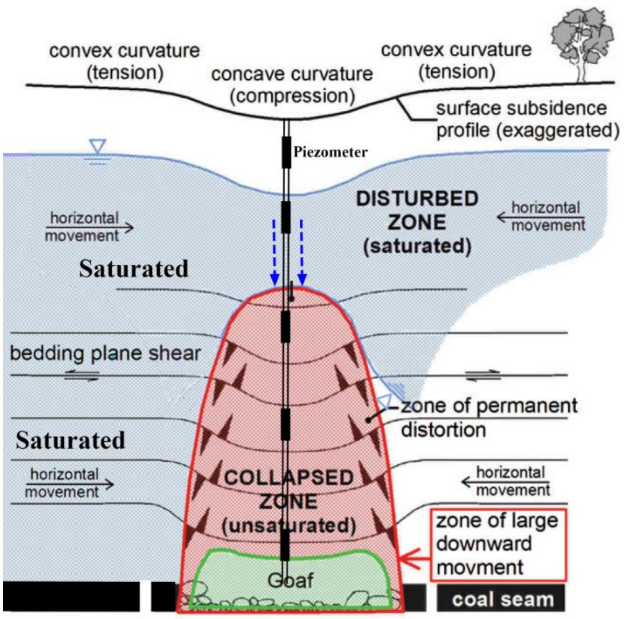
Tammetta finds the boundary of the drainage zone, identified with hydrological (piezometer) data, coincides with the collapsed zone identified with geotechnical (extensometer) data.[16], [18]



(a) Off-panel piezometer bore



(b) Pillar bore with single adjacent extraction



(c) Centre-panel bore

Figure 3. Depiction of (a) off-panel, (b) pillar and (c) centre-panel piezometer bores

These depictions are adapted from that given by Tammetta[2], 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.

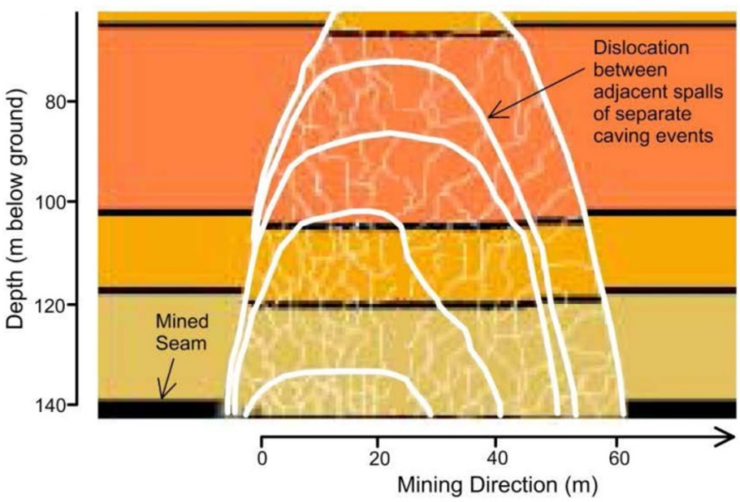


Figure 4(a). Development of the drainage zone as a longwall extraction progresses.**[2]**

Figure 4(b). Cut-away view of the developing drainage zone

Cut-away view[2] of the developing drainage zone over a completed longwall extraction and over the early stage of a second extraction, in which the rock surrounding the drainage zone is not shown.

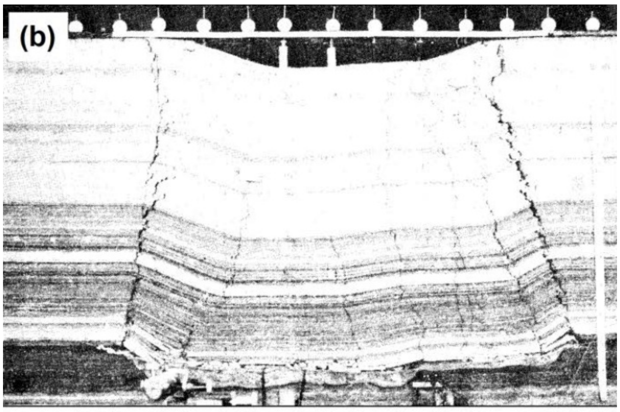


Figure 4(c). Physical model of the drainage zone intersecting with surface.

Physical model of a drainage zone that has reached and extended over the surface above a coal extraction where the extraction width is greater than the critical width.[2]

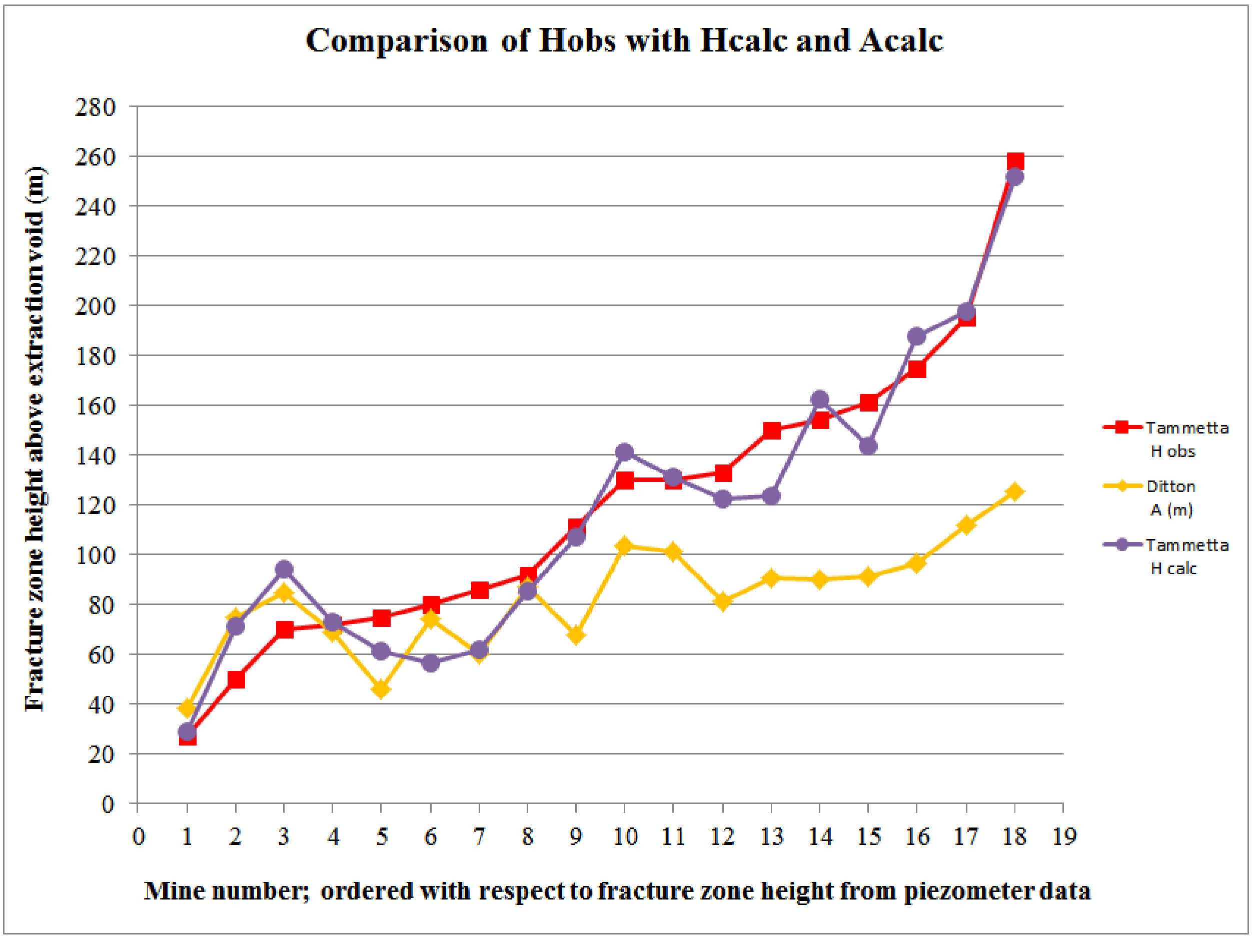


Figure 5. Comparison of Hcalc and Acalc with respect to Tammetta's database

Height of the drainage zone (Hobs) from centre-panel piezometer instruments above longwall extractions at various mines around the world, graphed with respect to height estimates obtained from the Tammetta equation[16] (Hcalc) and the A zone height from the Ditton geometry equation[26] (Acalc). The piezometer data are from the database[41] used to determine the Tammetta equation, ordered with respect to increasing Hobs. The data points are connected by lines in order to provide clarity.

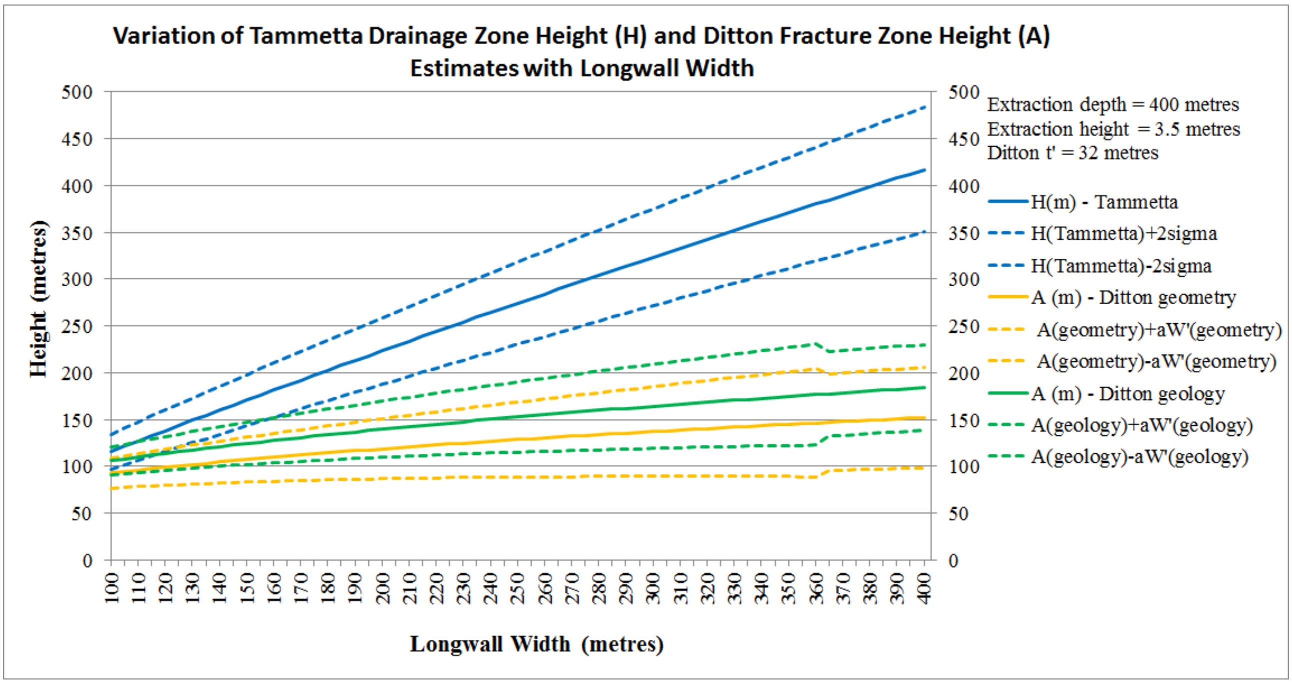


Figure 6. Tammetta and Ditton equation height estimate variation with longwall width.

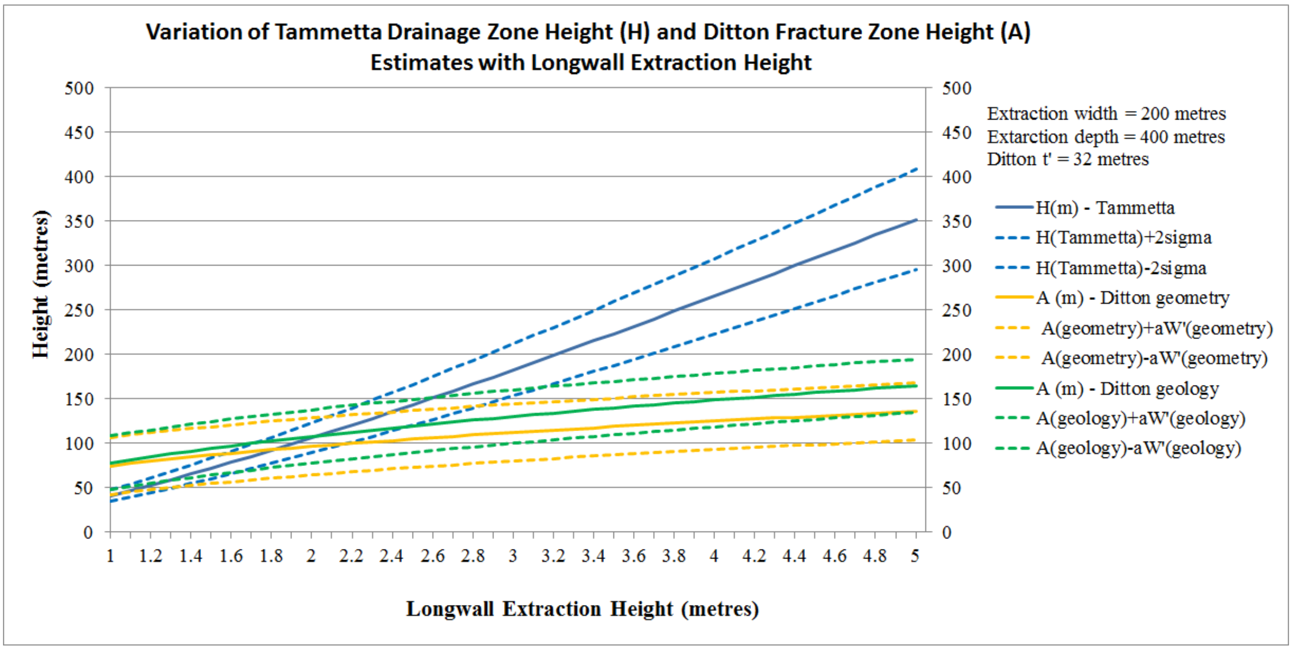


Figure 7. Tammetta and Ditton equation height estimate variations with extraction height.

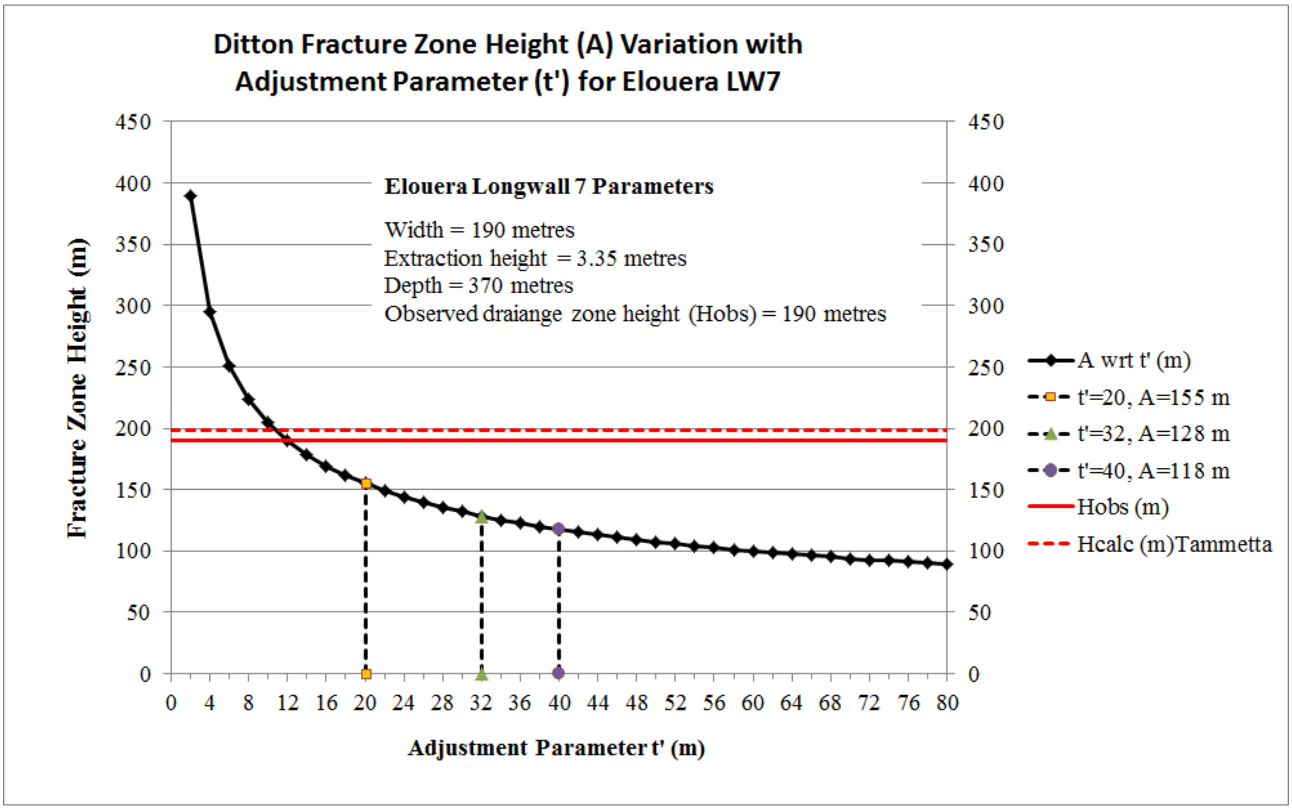


Figure 8. Variation of Ditton fracture zone height estimate with adjustment parameter t'

The graph depicts the variation of the fracture zone (A zone) height estimate returned by Ditton's 'geology' equation with varying adjustment parameter t'. The equation has been used here with respect to the mining geometry of Elouera Longwall 7 (see Fig. 10 and Sections 12 and 15.5). Ditton describes this parameter as an 'effective strata thickness' parameter, in practice it acts as 'fudge' factor (see main text above).[26]

Hobs is the drainage zone height obtained by Tammetta from the piezometers in the centre-panel bore over Elouera Longwall 7 (Fig. 10) and given in the supplementary data of his 2013 Groundwater paper.[41] A t' value of 12 metres is needed for Ditton's geology equation to return an estimate that matches Hobs. Yet Ditton suggests a t' of 32 for Dendrobium and a minimum value of 20 for the Southern Coalfield. A t' value of 32 is used in the March 2014 groundwater modelling by HydroSimulations.[26]

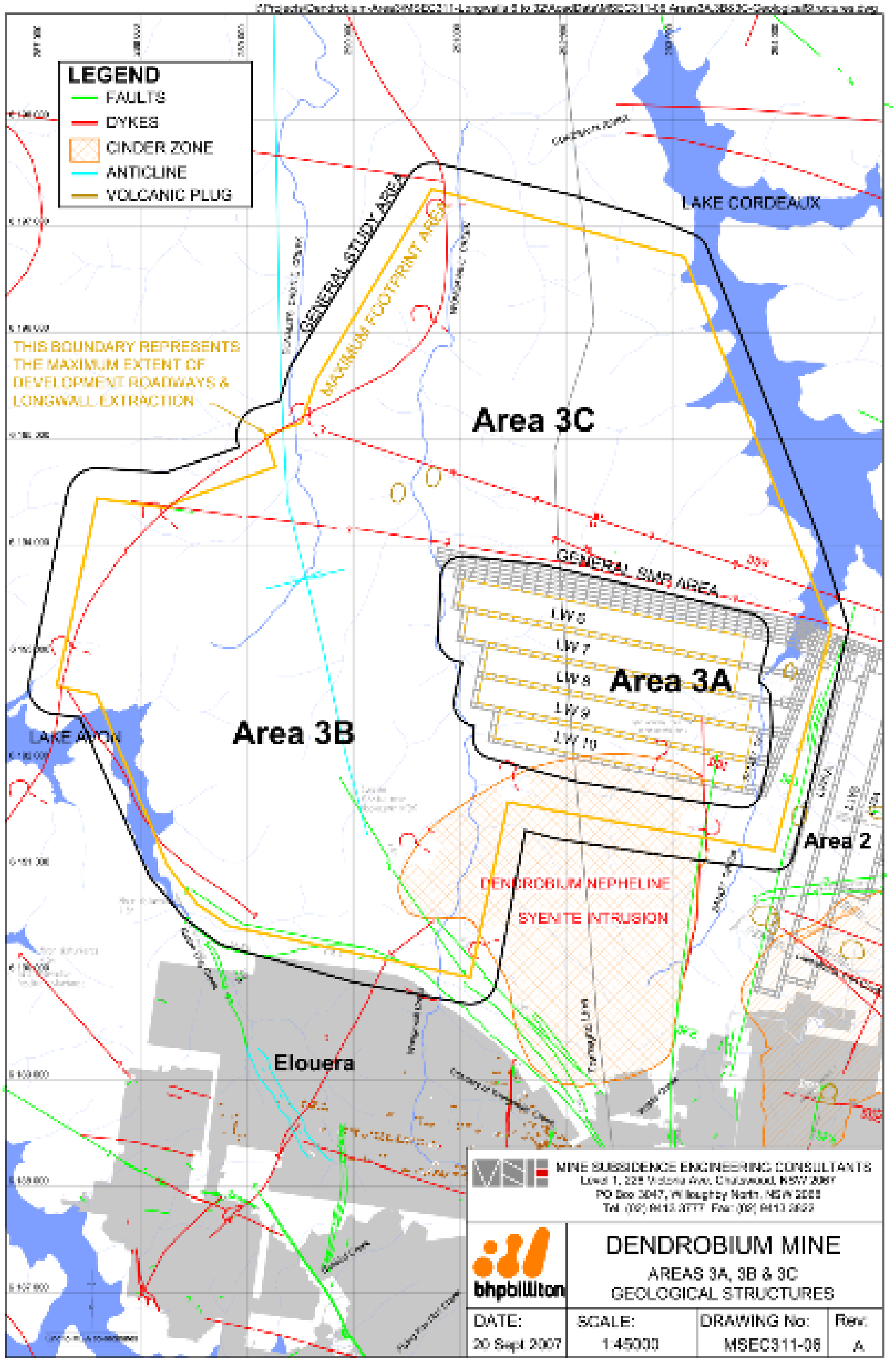


Figure 9. Geological structures in the vicinity of the Elouera domain and Dendrobium Area 3B

MSEC[61] depiction of geological structures over the Elouera domain and Dendrobium Area 3B domain. An unusual nephaline syenite formation slightly intrudes in to the south eastern corner of Area 3B. See also Figs. 10, which shows the layout of the Area 3B longwalls, and 48.

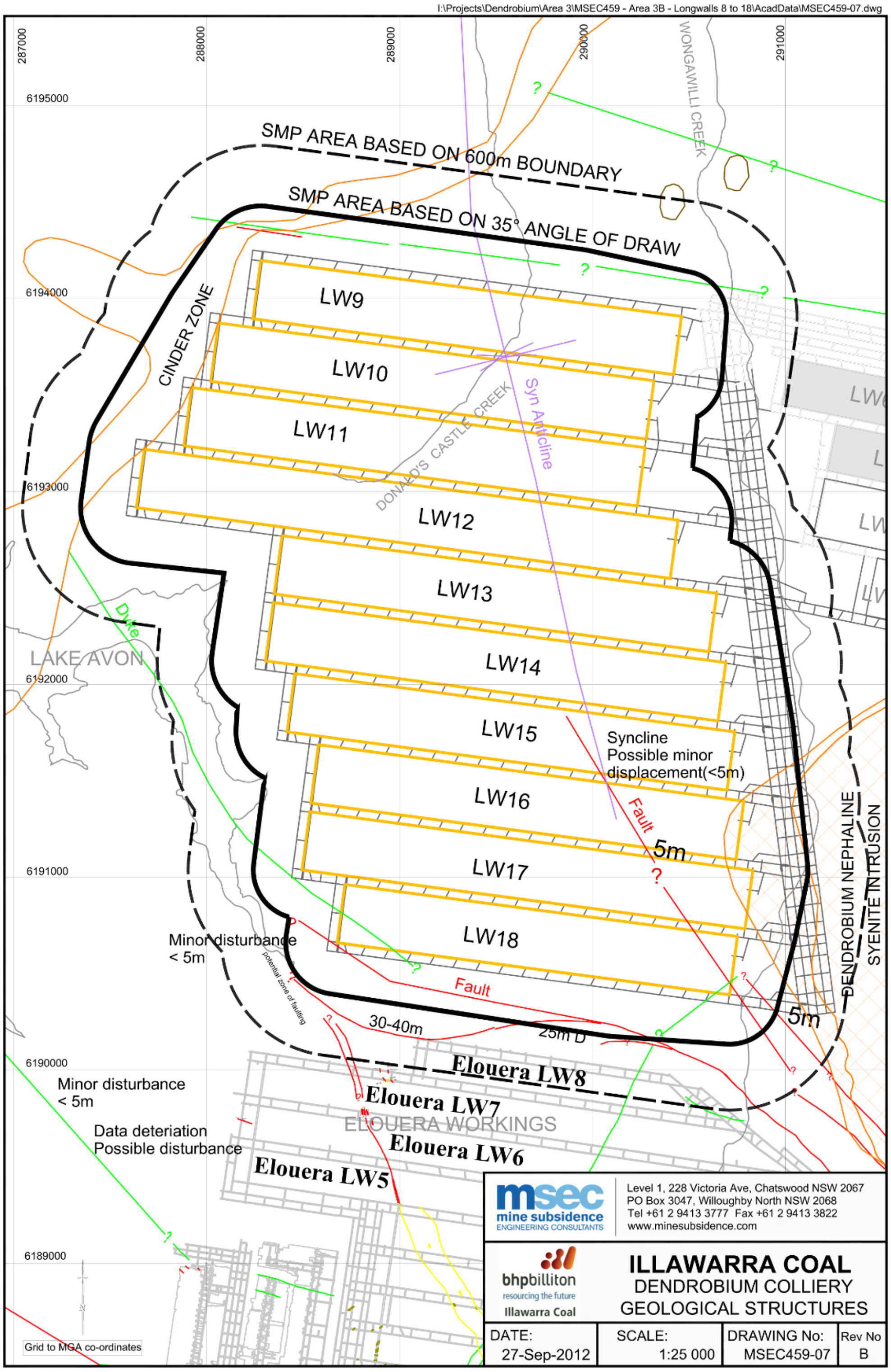


Figure 10. Proximity of Elouera Longwalls and geological structures over the Area 3B longwalls

MSEC[61] depiction of geological structures over the Area 3B longwalls. An unusual nephaline syenite formation slightly intrudes in to the south eastern corner of Area 3B. There are no other noteworthy Area 3B deviations from the stratigraphy typical of the Woronora Plateau (see Fig. 11). Labels for the Elouera longwalls adjacent to Area 3B have been added to the MSEC map.

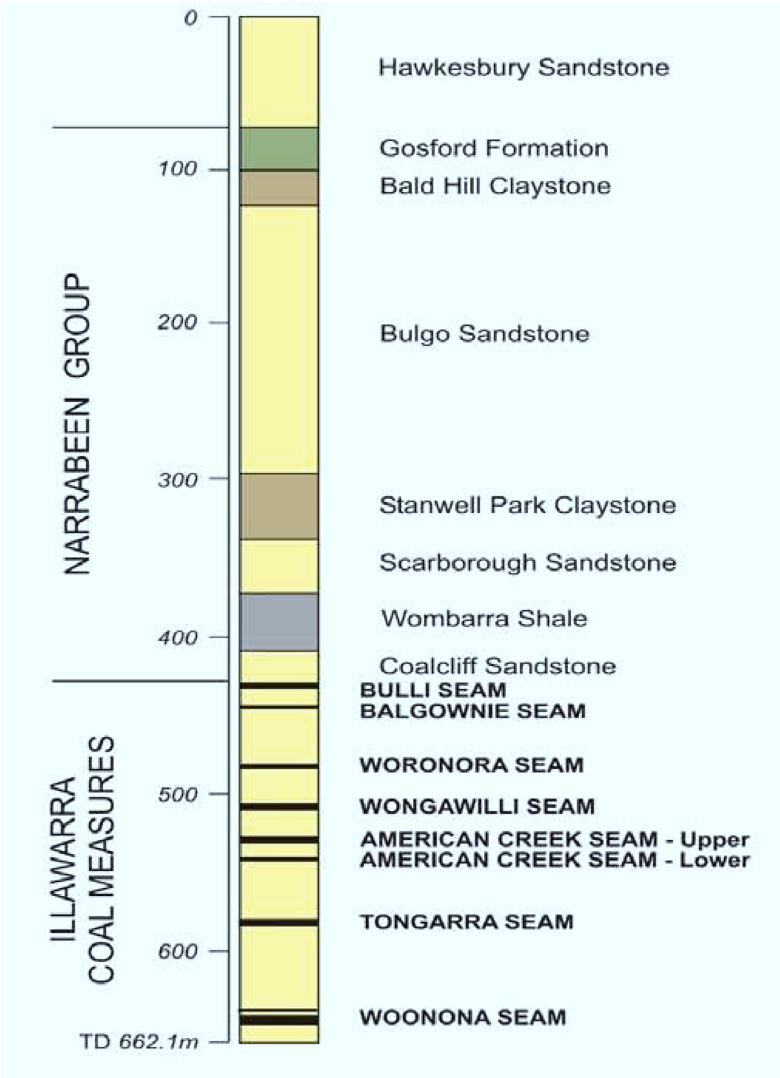


Figure 11. Representative stratigraphy of the Woronora Plateau**[132]**

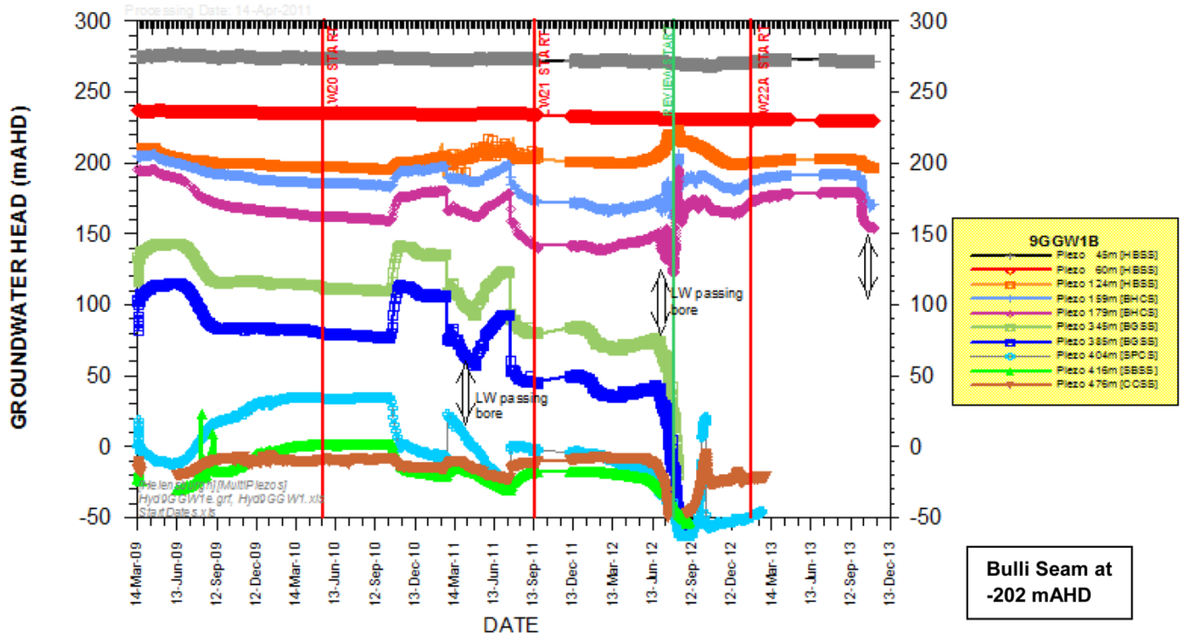


Chart 16 Time Variations in Potentiometric Heads at Site 9GGW1B

Figure 12. Piezometer readings from over the centre of Longwall 22B of the Metropolitan Colliery

Graph of recordings from piezometer instruments in bore 9GGW1B over the centre of Longwall 22B of the Metropolitan Colliery.[51] The passage of Longwall 20 in 2011 and that of Longwall 21 in 2012 is marked on the graph. The chart provides an example of the differing responses of groundwater piezometers above and below the height of the drainage zone. The drainage zone over Longwall 21 would appear to reach somewhere the piezometer at metres 179 and 354 metres below the surface. Persistent depressurisation is not evident in the piezometers above that at 354 metres below ground prior to the evidently terminal responses to the extraction of Longwall 22B.

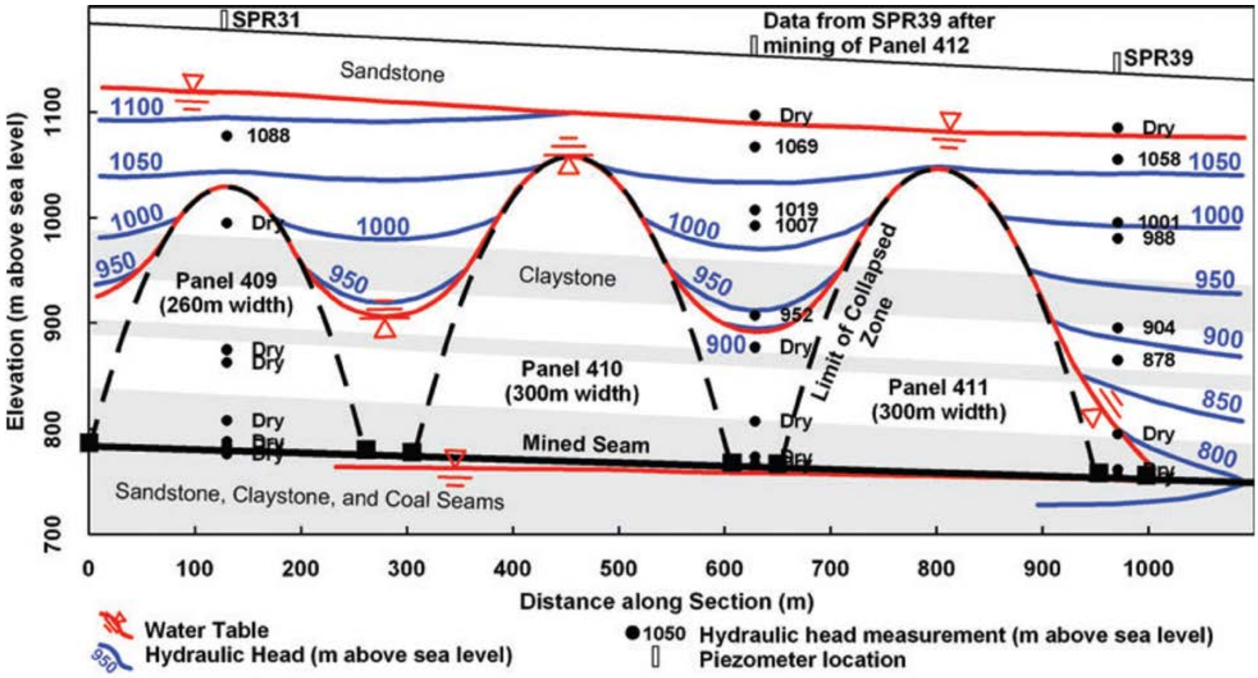


Figure 13. Hydraulic head measurements and Tammetta**[16]** interpreted contours for Springvale

Tammetta finds[16], [41] that the piezometer data indicate the height of the drainage zone above Longwall 409 is 258 metres and notes[49] that this is consistent with the earlier work of Guo.[40]

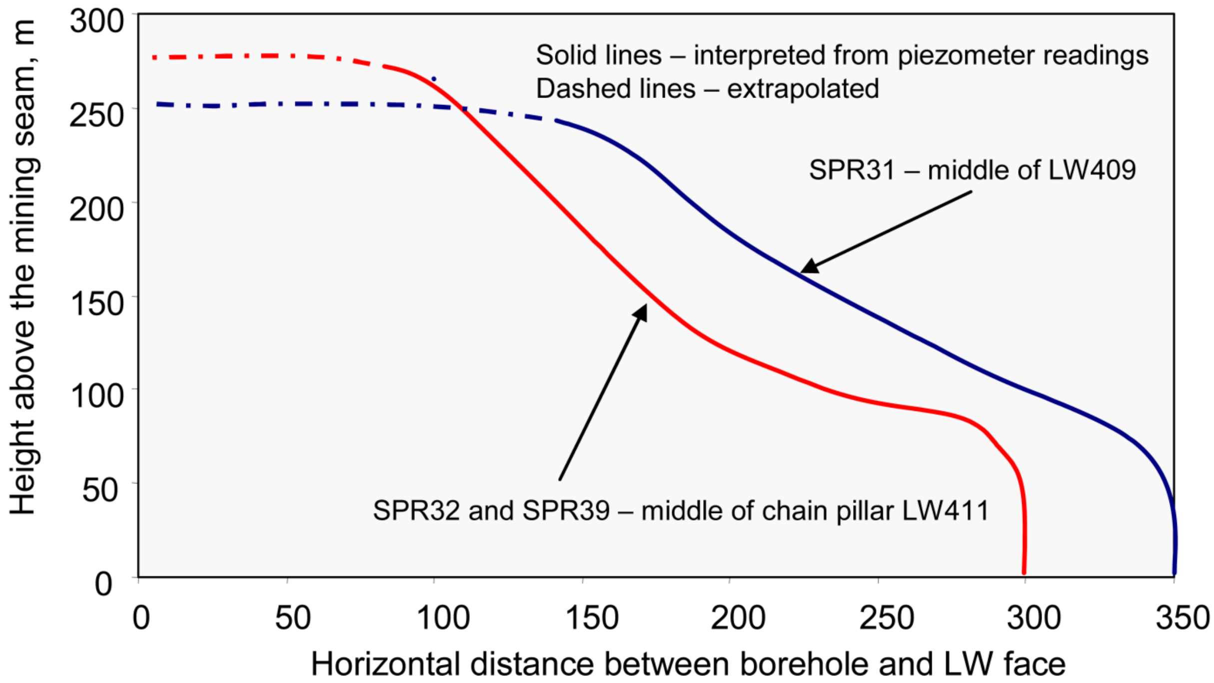


Figure 14. Hydrological zone of influence of Springvale Longwalls 409 and 411

The CSIRO determined the zone of influence of the extractions by monitoring piezometers as the longwall machine approached and plotting the distance at which a piezometer at a given height first registered a clear response (pressure head loss of 5 metres[53]) to the approaching drainage zone. Longwall 409 has a centreline piezometer bore while Longwall 411 has a bore over its pillars. The above graph is Figure 62 from a 2007 CSIRO assessment[40] of longwall at the Springvale Colliery.

Of significance, both graphs evidently approach a plateau with decreasing distance, suggesting that the response is primarily determined by horizontal conductivity/diffusivity changes in-line with the developing and approaching collapsed zone.

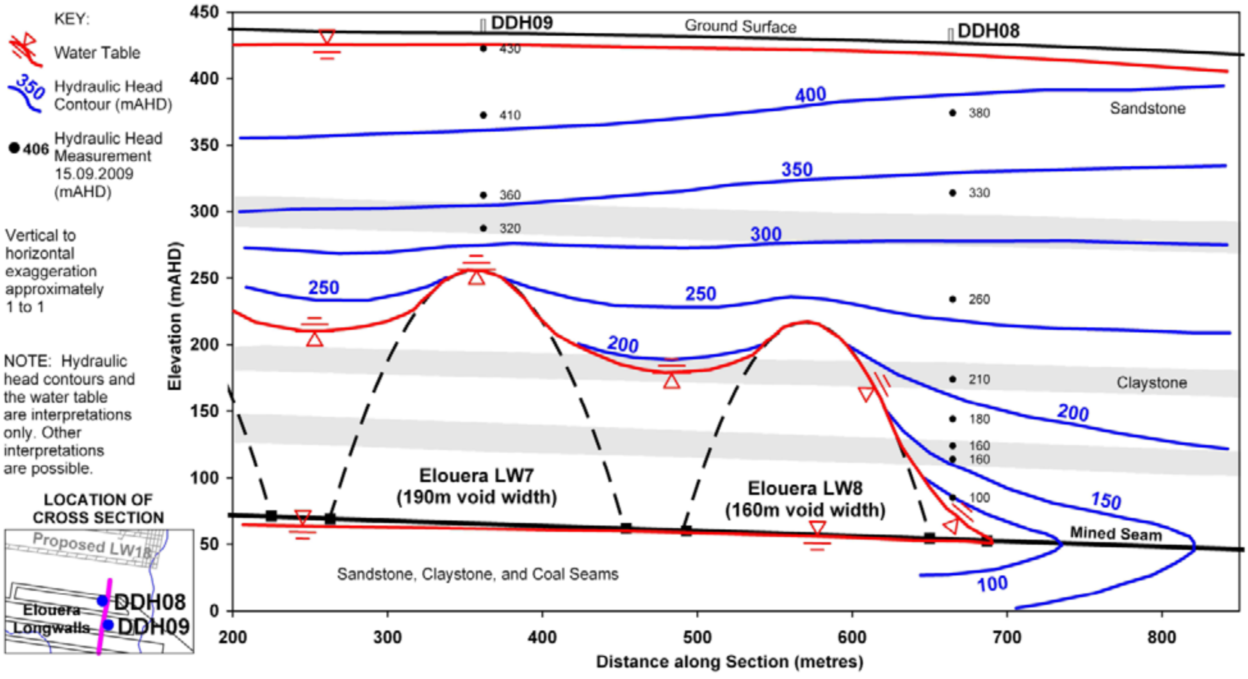


Figure 15. Hydraulic head measurements and Tammetta interpreted contours for Elouera LW 7

Figure 14 is Figure 6 from the October 2012 Coffey/Tammetta groundwater impact assessment[3] for Area 3B. The data obtained by digitising this figure is used in Figure 15 below to demonstrate the determination of the drainage zone height above Elouera Longwall 7 (LW7) from the piezometer data.

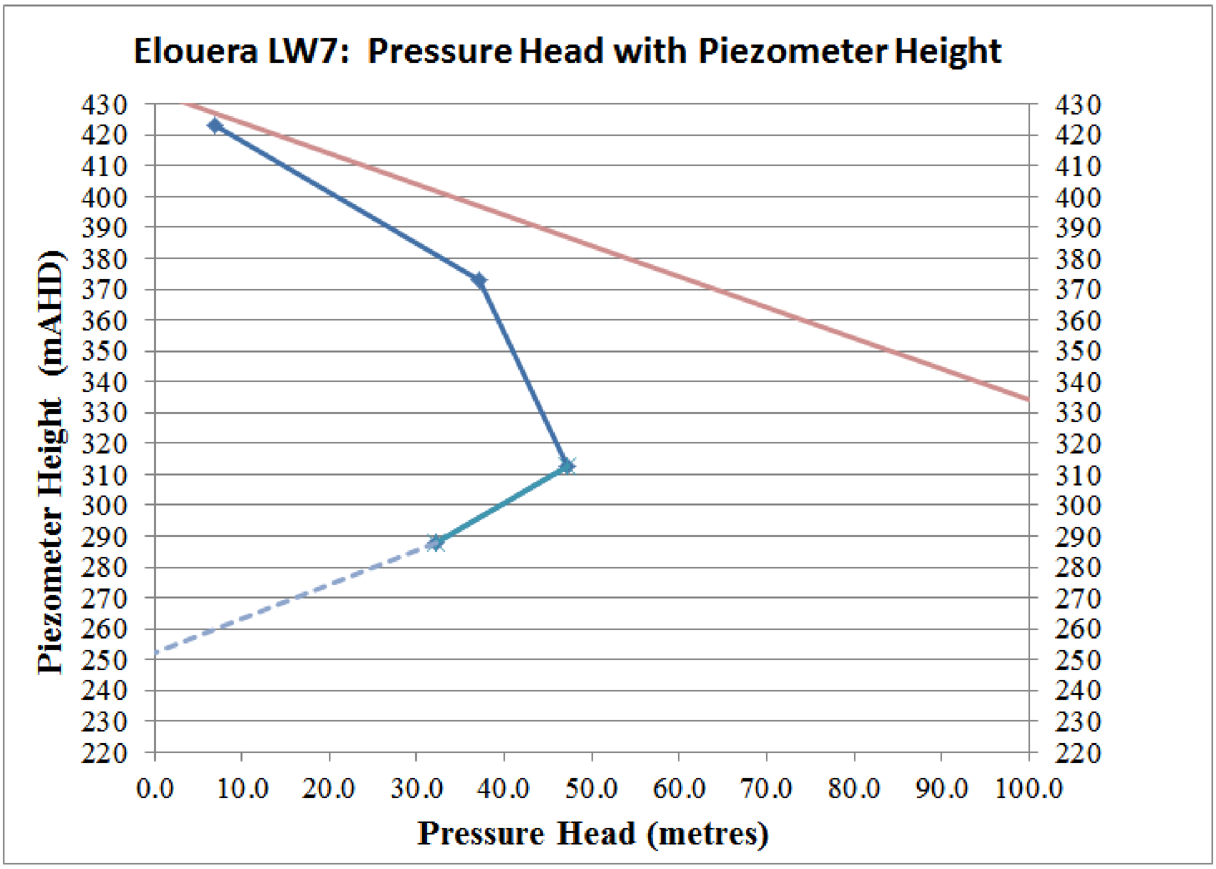


Figure 16. Height of the drainage zone obtained from Elouera LW7 piezometer data

The data in Figure 16 were obtained by digitising Figure 15, which is Figure 6 from the October 2012 Coffey/Tammetta groundwater impact assessment.[3] The blue line links the pressure heads at each piezometer in the centre-line bore over Elouera Longwall 7 (LW7). In each case the pressure head was obtained by subtracting the piezometer height given in Fig.15 from the hydraulic pressure given in Fig. 15.

The grey line in the above figure depicts the change in groundwater pressure head with depth that would be expected under 'artesian' conditions in the absence of mining impacts (hydrostatic pressure). The pressure recorded by the piezometers deviates from this hydrostatic pressure as the distance between a piezometer and the drainage zone decreases.

The height of the drainage zone is obtained extrapolating to a pressure head of zero, conservatively assuming a 'hydrostatic' (1:1) rate of change of pressure between the deepest piezometer and the top of the drainage zone, which identified in having no measureable water pressure. The height of zero pressure head is accordingly estimated to be 252 mAHD (Australian Height Datum in metres; effectively the height above sea level). Figure 15 suggests the coal seam is 66 mAHD and the peak height of zero pressure head, the height of the drainage zone, above the coal seam is then 186 metres. Given the conservative nature of the extrapolation, the height is likely to be slightly underestimated. The profile is seen above longwall extractions at other locations in the Southern Coalfield, such as Russell Vale.

The height estimate returned by the Tammetta equation is 198 metres. The height estimate returned by the Ditton geometry equation is 112 metres, while that from the Ditton geology equation, with t'=32 (as suggested by Ditton[26] and used by HydroSimulations[23]), is 128 metres.

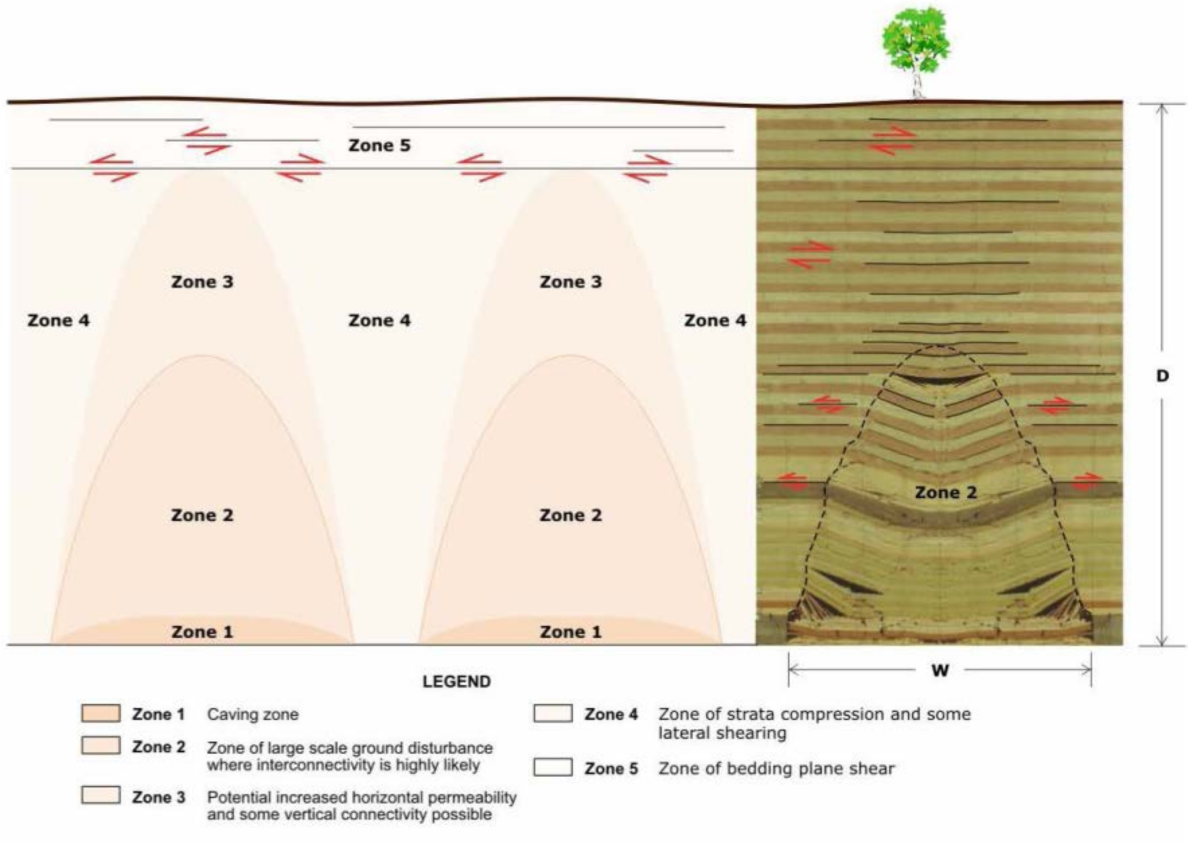


Figure 17. SCT representation of Elouera longwall subsidence impact zones

SCT representation[57], [58] of subsidence zones determined from extensometer bores DSC12 and DSC13 sunk over Longwall 7 and beside Longwall 8 of the decommissioned Elouera mine, immediately south of the Dendrobium mine. For the extraction height and width used, the height of the zone of large downward movement, zone 2, is found to be approximately equal to the panel width. SCT defines this zone by a change in the magnitude of downward movement from about 0.2 to 0.5 m.

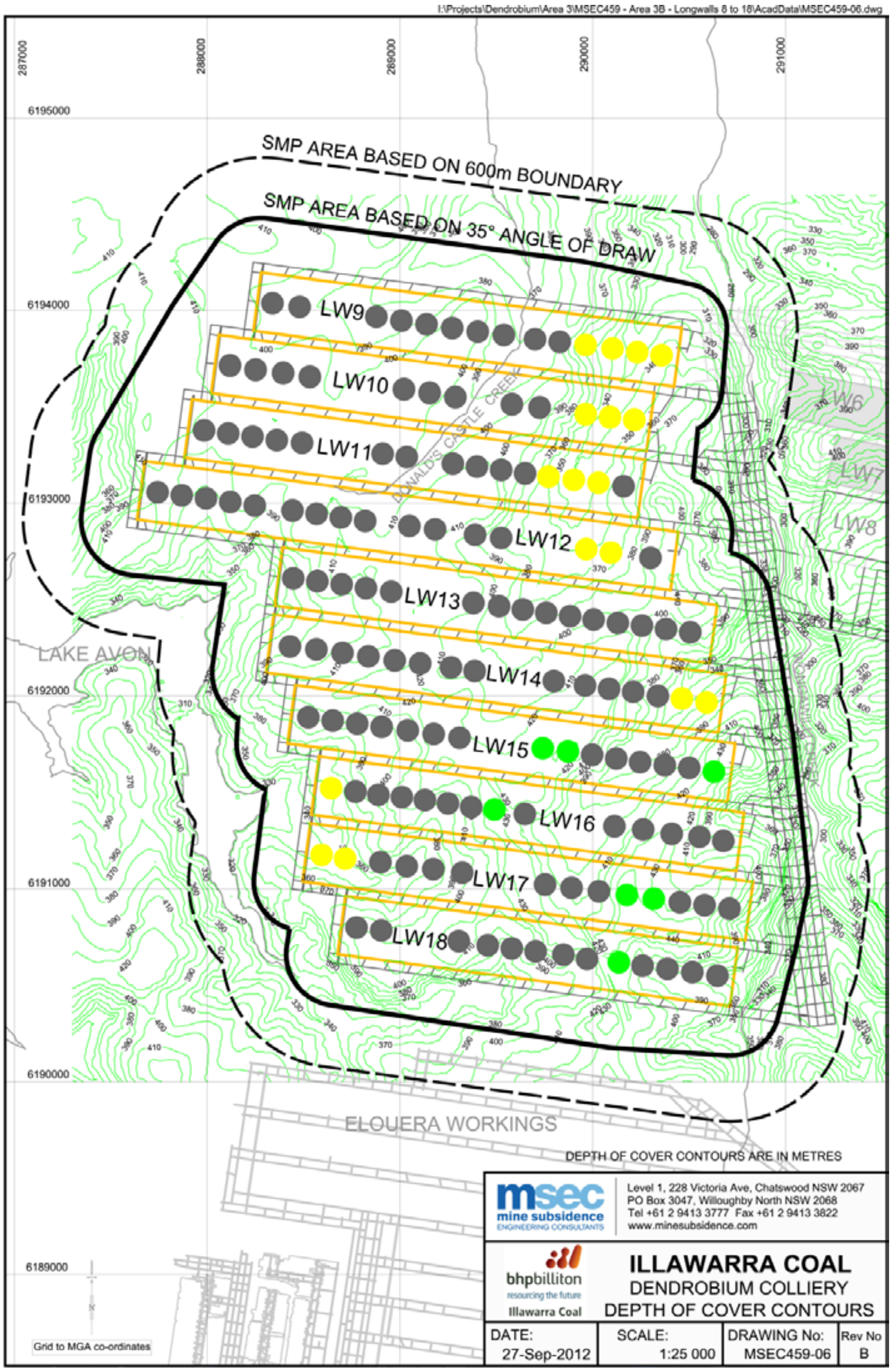


Figure 18. Depiction of the height of the drainage zone for 3.0m high extractions in Area 3B

Coloured circles have been added to the MSEC representation[61] of the depth of cover over the Area 3B longwalls, to indicate the Tammetta equation[16] estimate of the height of the drainage zone. Green indicates the drainage zone is at least 150 metres from the surface; grey indicates between 150 and 100 metres and yellow indicates between 50 and 100 metres from the surface.

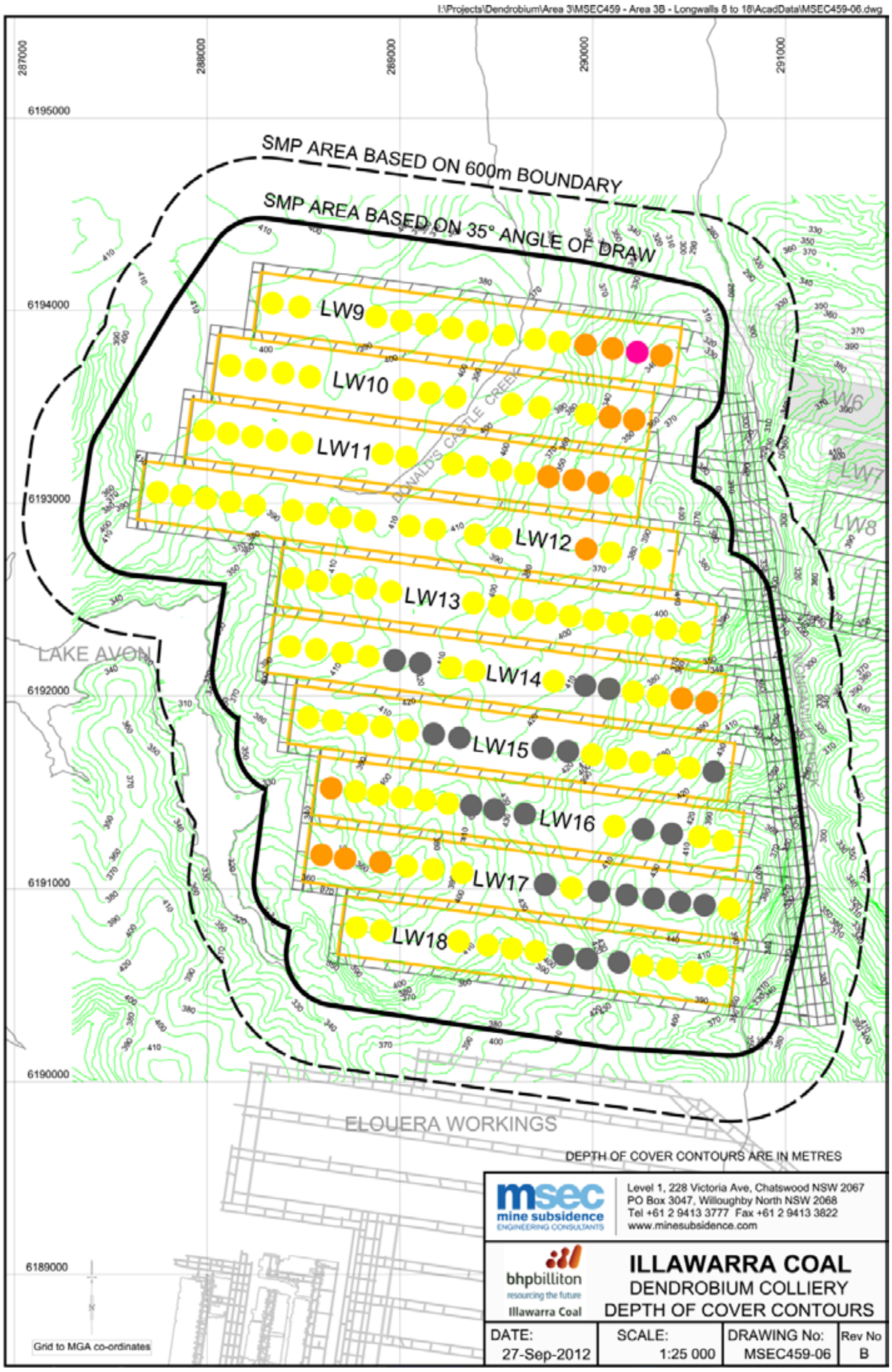


Figure 19. Depiction of the height of the drainage zone for 3.4m high extractions in Area 3B

Coloured circles have been added to the MSEC representation[61] of the depth of cover over the Area 3B longwalls, to indicate the Tammetta equation[16] estimate of the height of the drainage zone. Grey indicates the drainage zone is between 150 and 100 metres from the surface, yellow indicates between 50 and 100 metres, orange indicates between 25 and 50 metres and pink indicates between 0 and 25 metres from the surface.

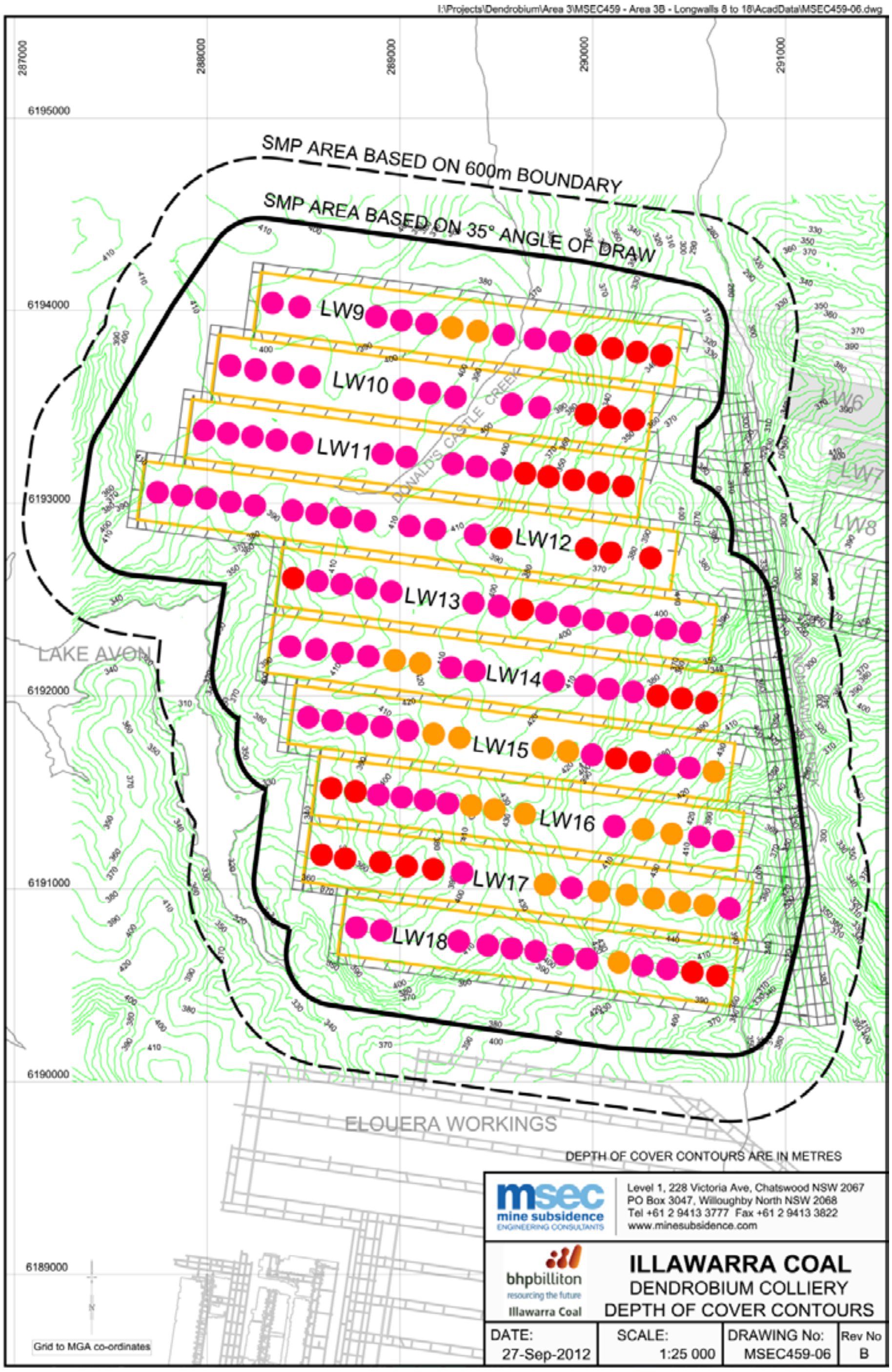


Figure 20. Depiction of the height of the drainage zone for 4.0m high extractions in Area 3B

Coloured circles have been added to the MSEC representation[61] of the depth of cover over the Area 3B longwalls, to indicate the Tammetta equation[16] estimate of the height of the drainage zone. Orange indicates the zone is between 25 and 50 metres from the surface, pink indicates between 0 and 25 metres from the surface and red indicates intersection with the surface. The height estimates for Longwall 9 are shown with respect to the planned extraction height of 3.9 metres.

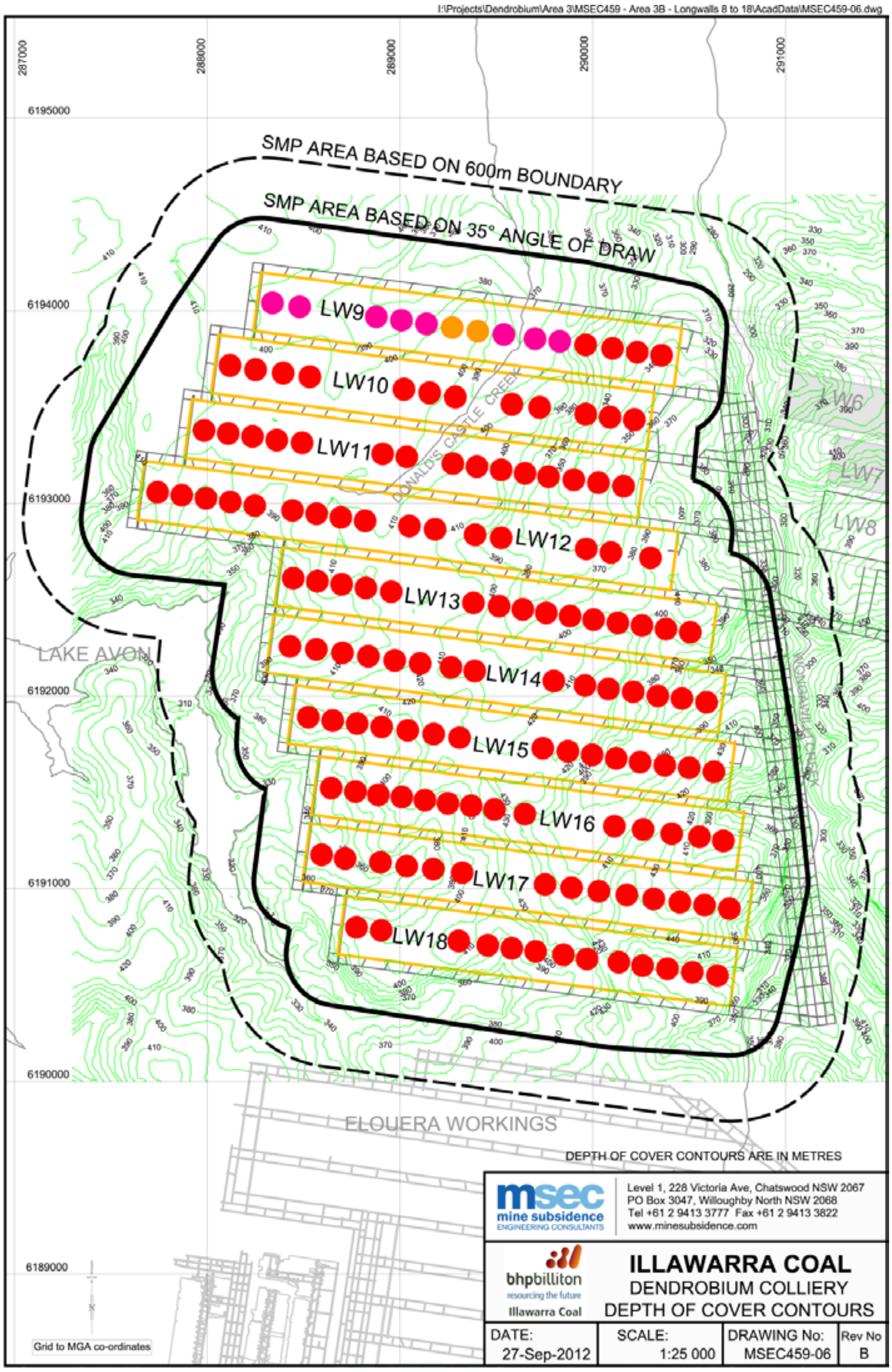


Figure 21. Depiction of the height of the drainage zone for 4.6m high extractions in Area 3B

Coloured circles have been added to the MSEC representation[61] of the depth of cover over the Area 3B longwalls, to indicate the Tammetta equation[16] estimate of the height of the drainage zone. Orange indicates the zone is between 25 and 50 metres from the surface, pink indicates between 0 and 25 metres from the surface and red indicates intersection with the surface. The height estimates for Longwall 9 are shown with respect to the planned extraction height of 3.9 metres.

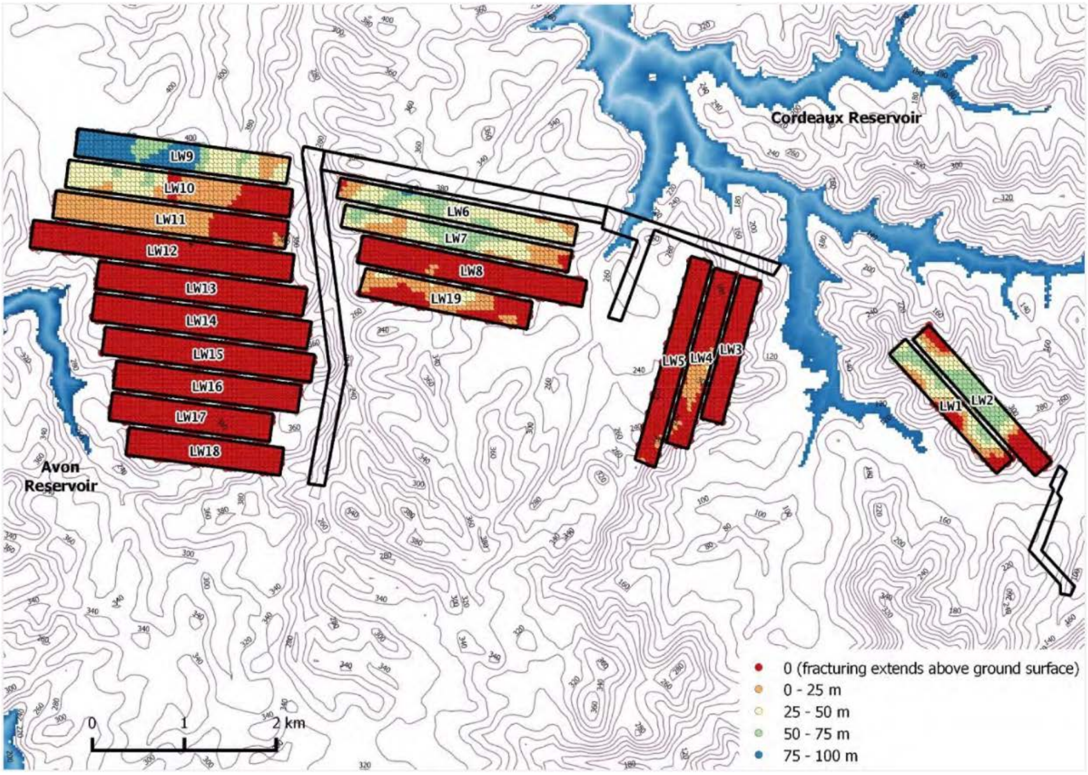


Figure 22. HydroSimulations 2015 depiction of Tammetta equation drainage zone height estimates for Area 3B of the Dendrobium mine.

The figure above is Figure 7 from the October 2015 HydroSimulations height of connected fracturing report.[21] The differences between this figure and Figure 23 below are discussed in Section 14.

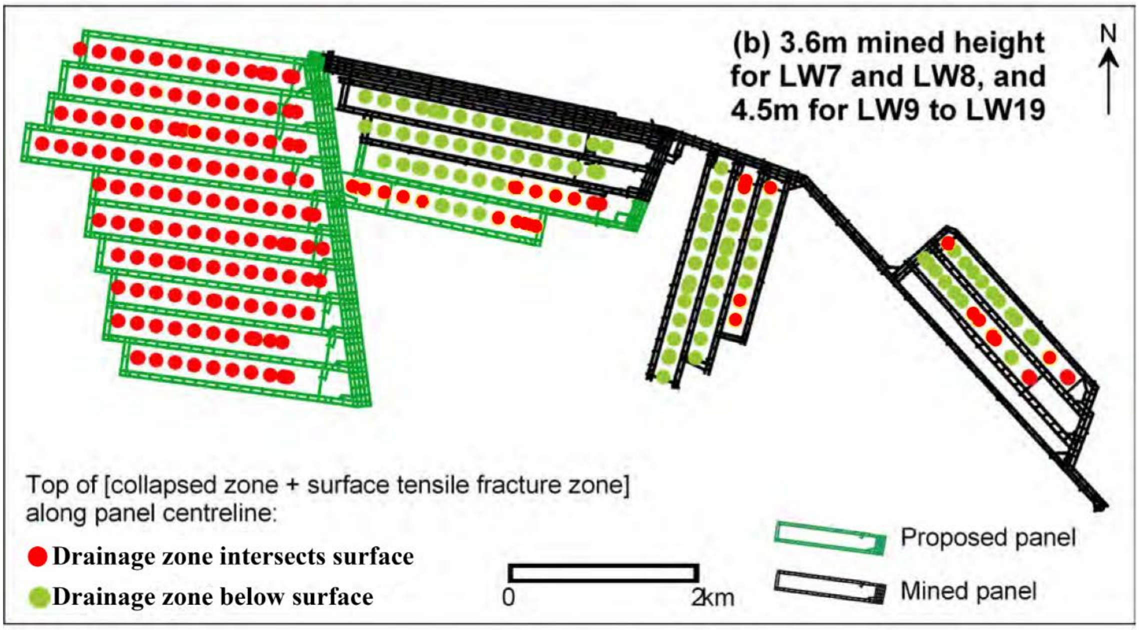


Figure 23. Tammetta depiction for Coffey Geotechnics of relationship of drainage zone height estimates with respect to the surface above the longwalls of Dendrobium Area 3B.

The above figure is Figure 41 in the November 2012 data analysis report[62] that partnered the November 2012 groundwater impact assessment for the then proposed new mining in Dendrobium Area 3B. The latter report has not been made available. The figure depicts drainage zone heights for 4.5 metre extractions. The assessment made available to the public and agencies ahead of the February 2013 approval of the mining currently underway in Area 3B was for 3.4 metre high extractions. The mining planned was for up to 4.6 metre high extractions; see Section 19. The differences between this figure and that of Figure 22 above are discussed in Section 14.

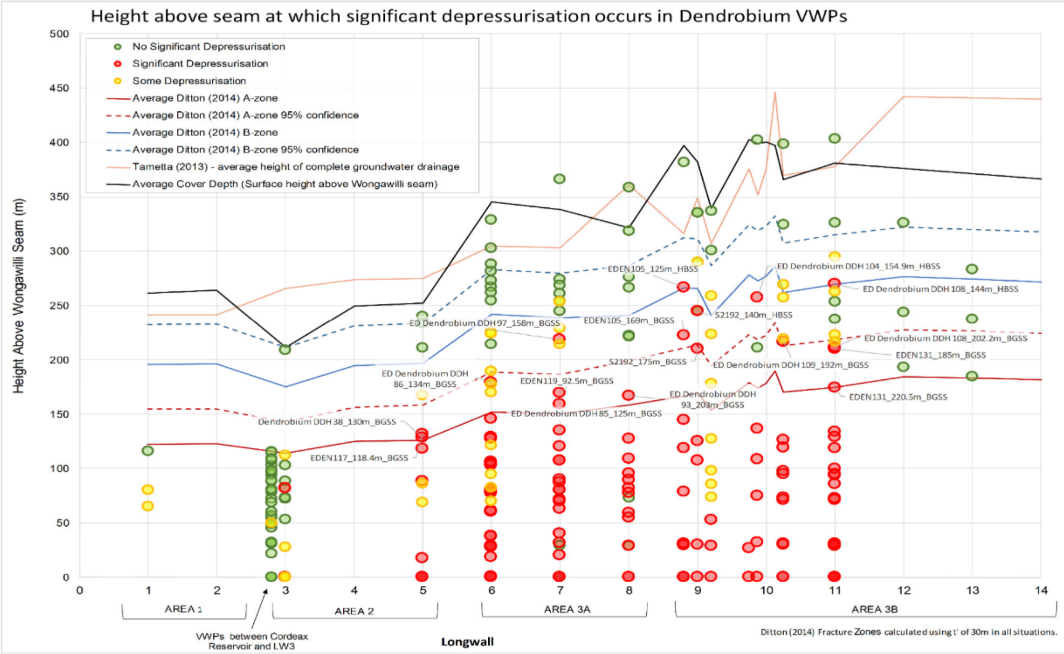


Figure 21 Summary of Groundwater Depressurisation and Estimated Height of Connected Fracturing

Figure 24. HydroSimulations representation of groundwater pressure loss recorded by piezometers in bores installed at the Dendrobium mine.

This figure is Figure 21 in the 2016 HydroSimulations groundwater impact assessment[24] for Dendrobium Area 3B.

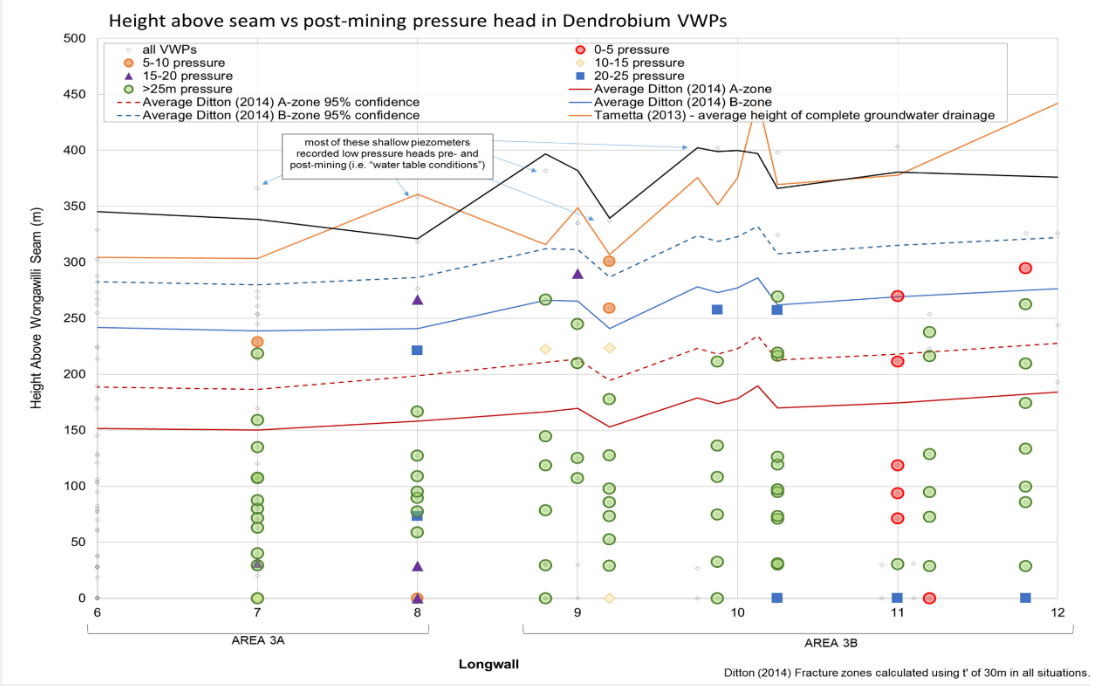


Figure 22 Summary of post-mining Groundwater Pressures near Areas 3A and 3B

Figure 25. The second HydroSimulations representation of groundwater pressure loss recorded by piezometers in bores installed at the Dendrobium mine.

This figure is Figure 22 in the 2016 HydroSimulations groundwater impact assessment[12] for Dendrobium Area 3B.

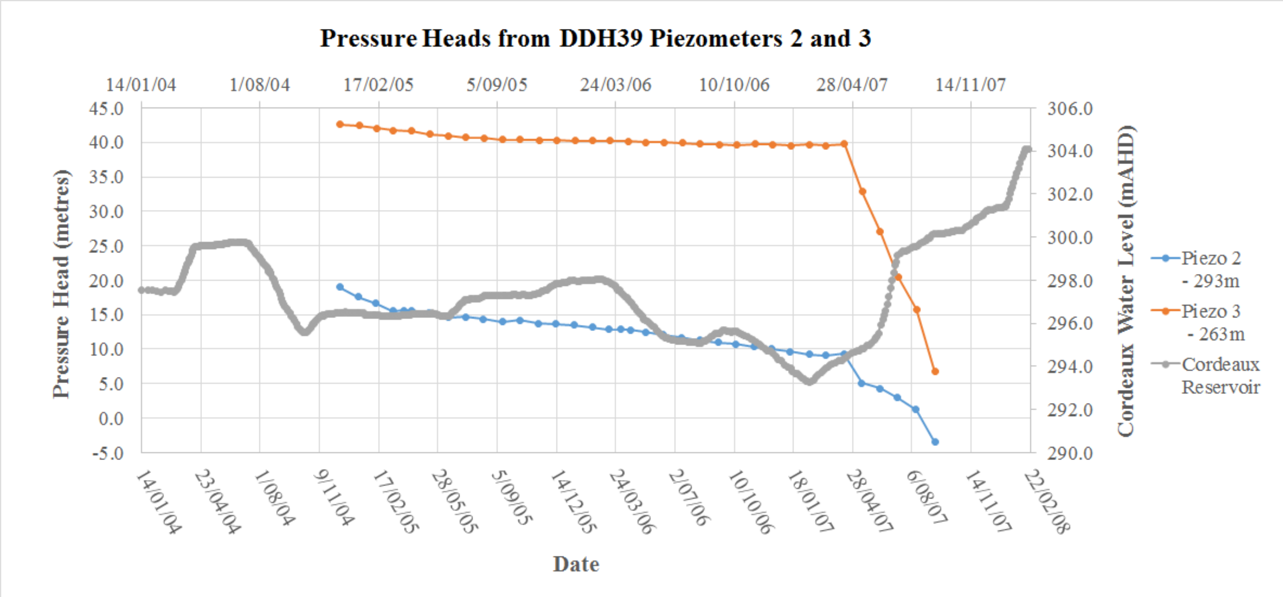


Figure 26. Pressure heads recorded by Piezometers 2 and 3 in bore DDH39 over Longwall 3 in Area 2 of the Dendrobium mine.

Figure 26 was obtained by digitising the hydrographs given on page 5 of Appendix E of the November 2012 Coffey data analysis report[62] for Dendrobium area 3B. Pressure heads were obtained by subtracting the given piezometer elevations from the hydraulic heads.

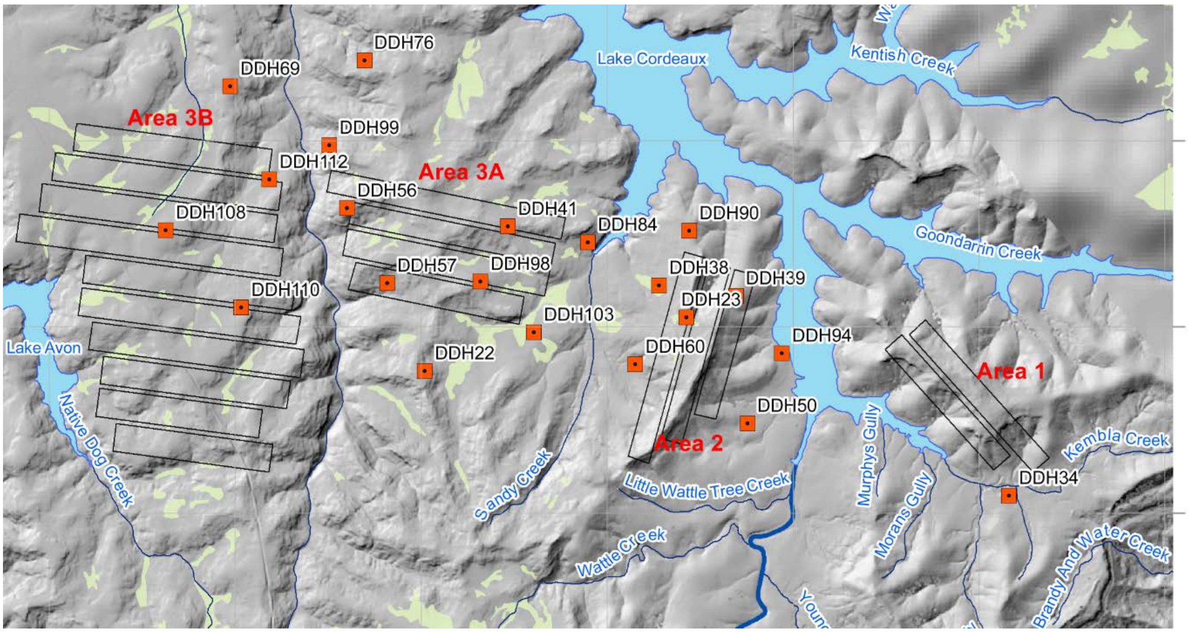


Figure 27. HydroSimulations piezometer location map from the March 2014 Dendrobium groundwater assessment.**[23]**

As discussed in Sections 15.1.4 and 15.1.8, the March 2014 assessment map does not show DDH117. This important site is shown in Dendrobium end of panel reports (see Fig. 31 and in the Coffey maps given in the 2012 Coffey assessments (see Fig. 28).

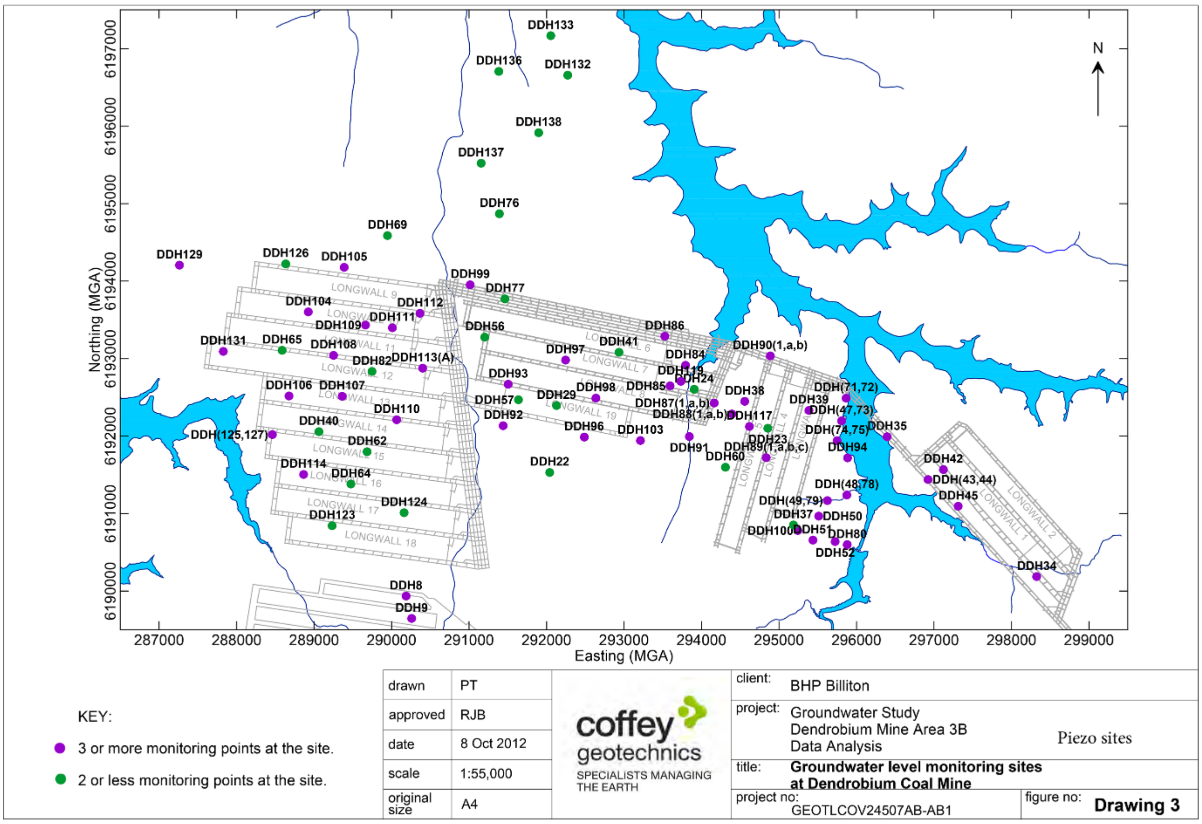


Figure 28. Coffey map showing the location of the piezometer bores used for model calibration by Tammetta.

The map is provided in Drawing 3 of the November 2012 data analysis report[62] that partnered the November 2012 groundwater impact assessment rejected by BHP-Billiton**.**

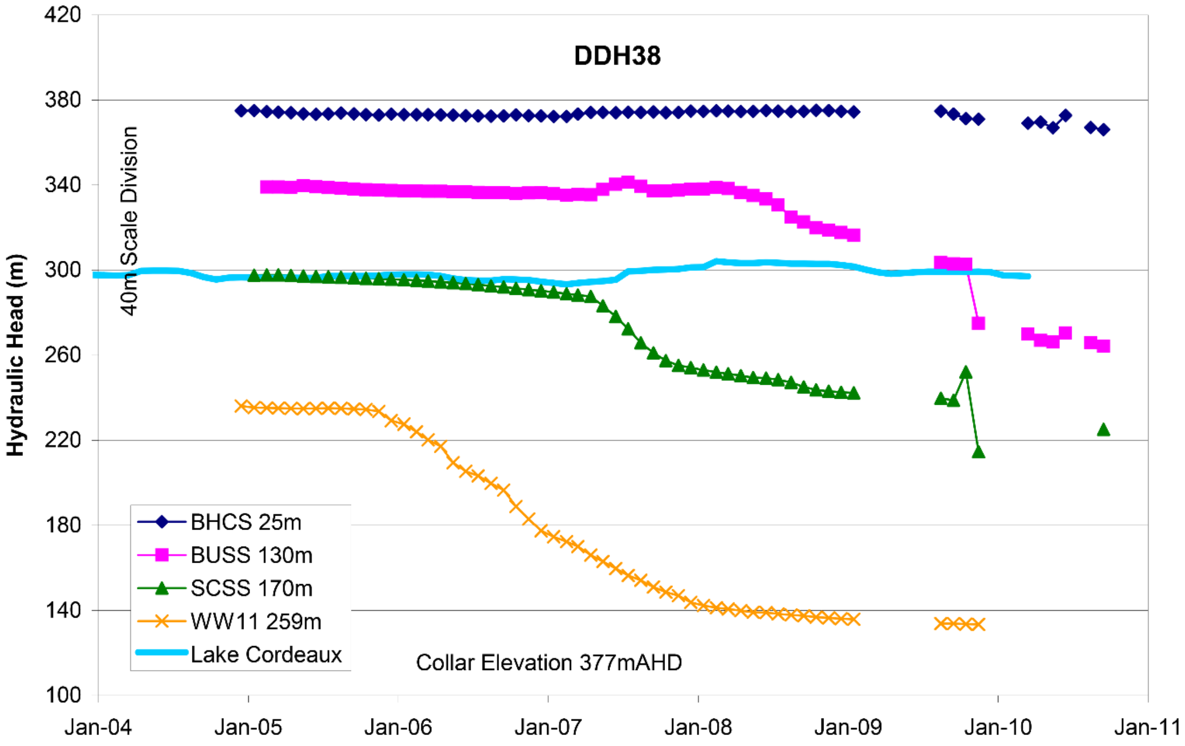


Figure 29. DDH38 piezometer hydrographs from the November 1012 Coffey data analysis report.**[62]**

See also Figure 30.

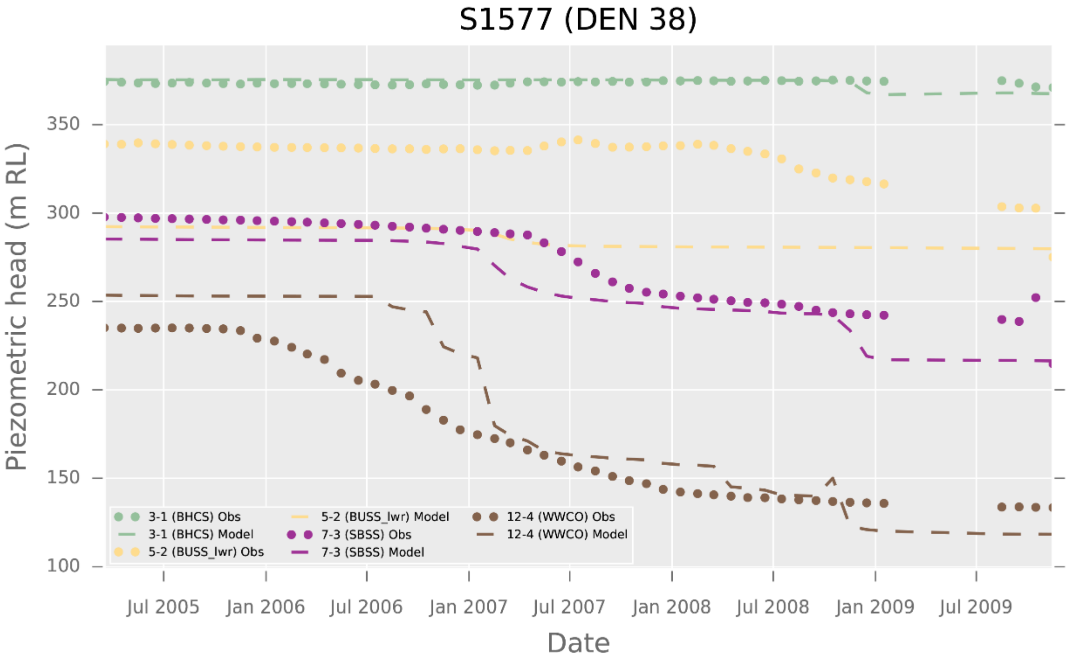


Figure 30. DDH38 piezometer hydrographs from the March 2016 HydroSimulations groundwater impact assessment**[24]** for Area 3B of the Dendrobium mine.

See also Figure 29.

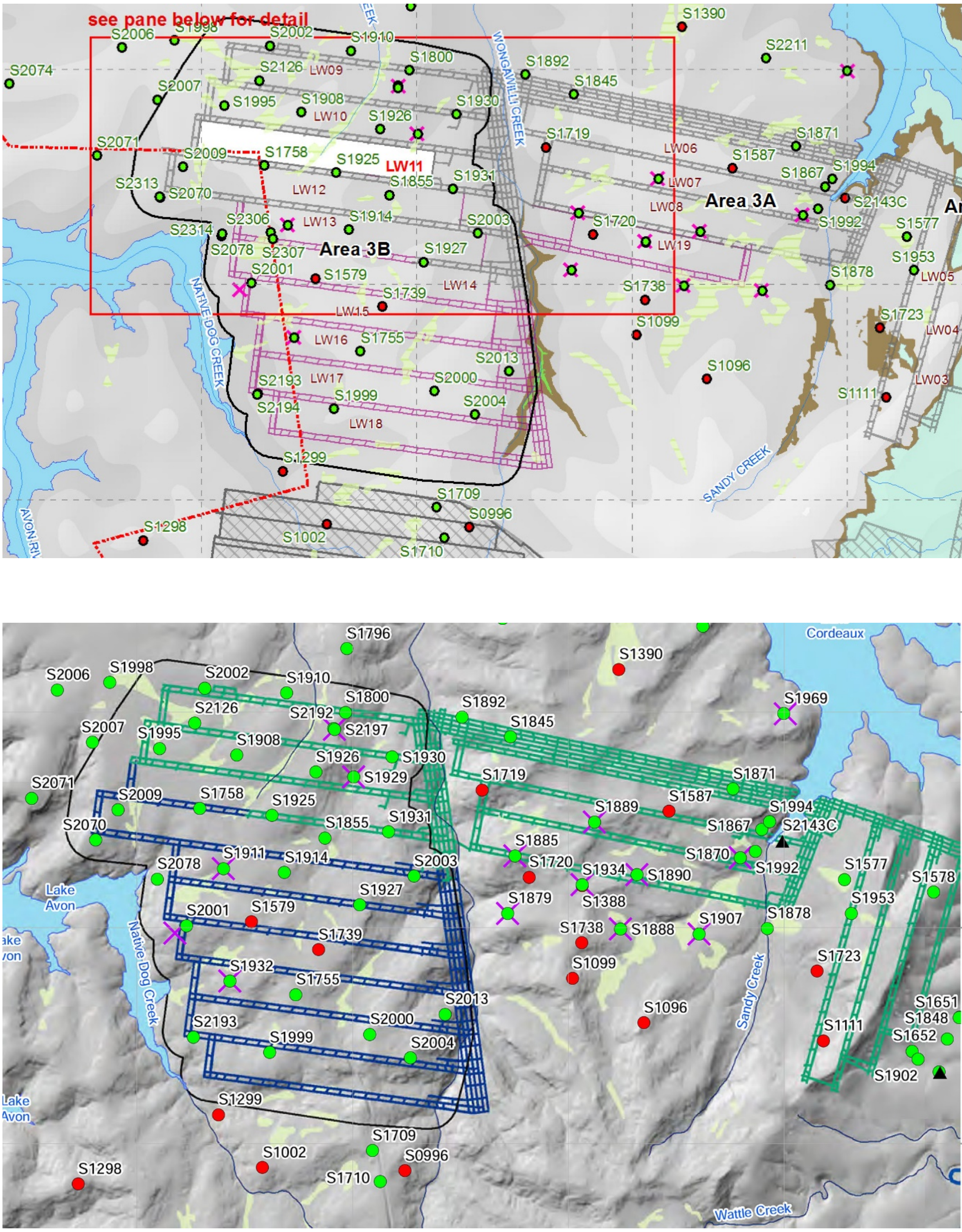
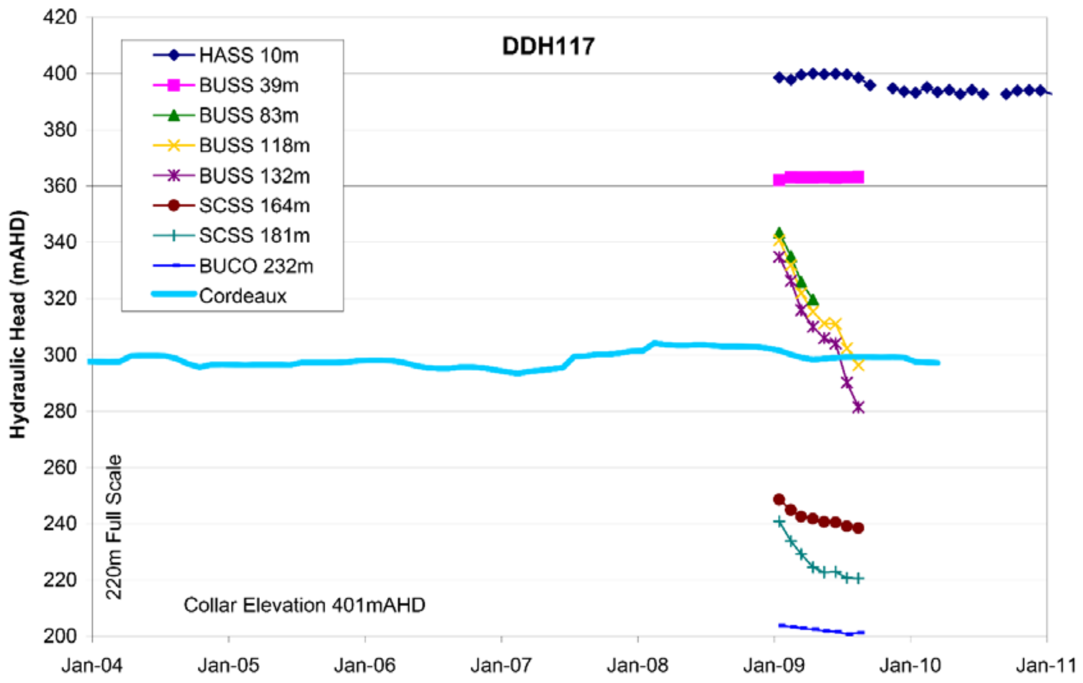
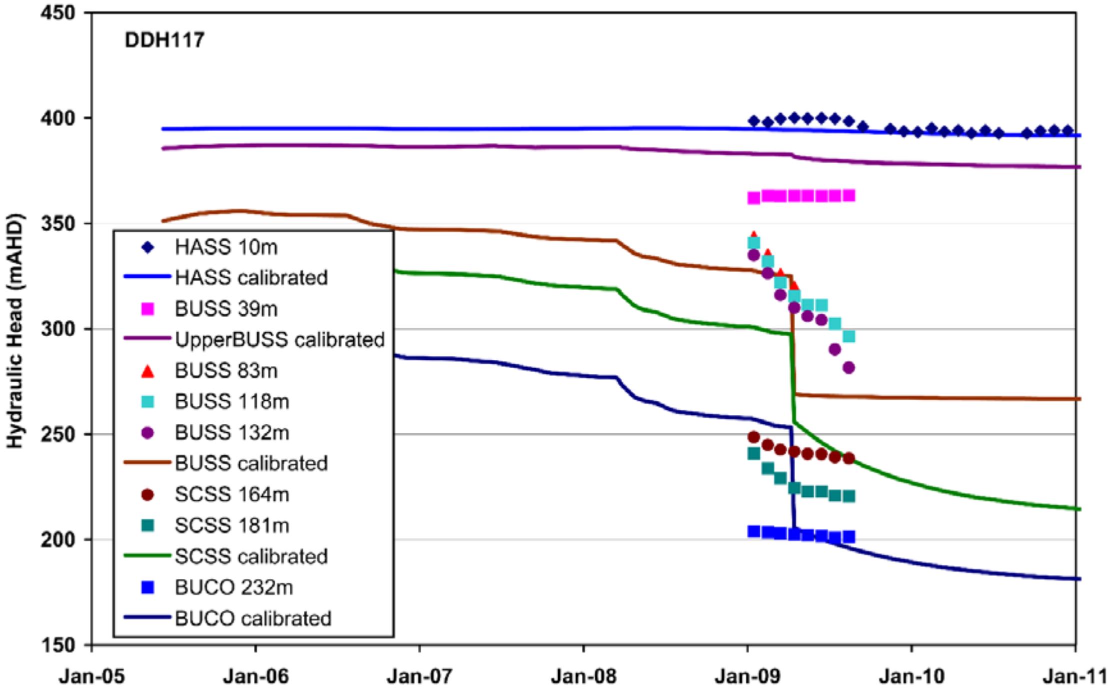


Figure 31. HydroSimulations piezometer location maps from (a) the May 2016 Longwall 11 end of panel report**[73]** and (b) the August 2014 Longwall 9 end of panel report.**[42]**

Bore DDH117/S1953 is included in both maps and also in the maps provided in the Longwall 6, 7, 8 and 10 end of panel reports, but is not included in the March 2014 and March 2016 groundwater assessments.



(a)



(b)

Figure 32. DDH117 hydrographs with respect to (a) Lake Cordeaux**[62]** and (b) Coffey model calibration.**[36]**

The hydrographs show that during the extraction of Longwall 5 the piezometers at 83, 118 and 132 metres below the surface show marked pressure loss occurring at essentially the same relatively rapid rate. The instruments at 118 and 132 metres fall below the level of Cordeaux Reservoir before failing and it’s likely that at 83 metres would have done likewise.

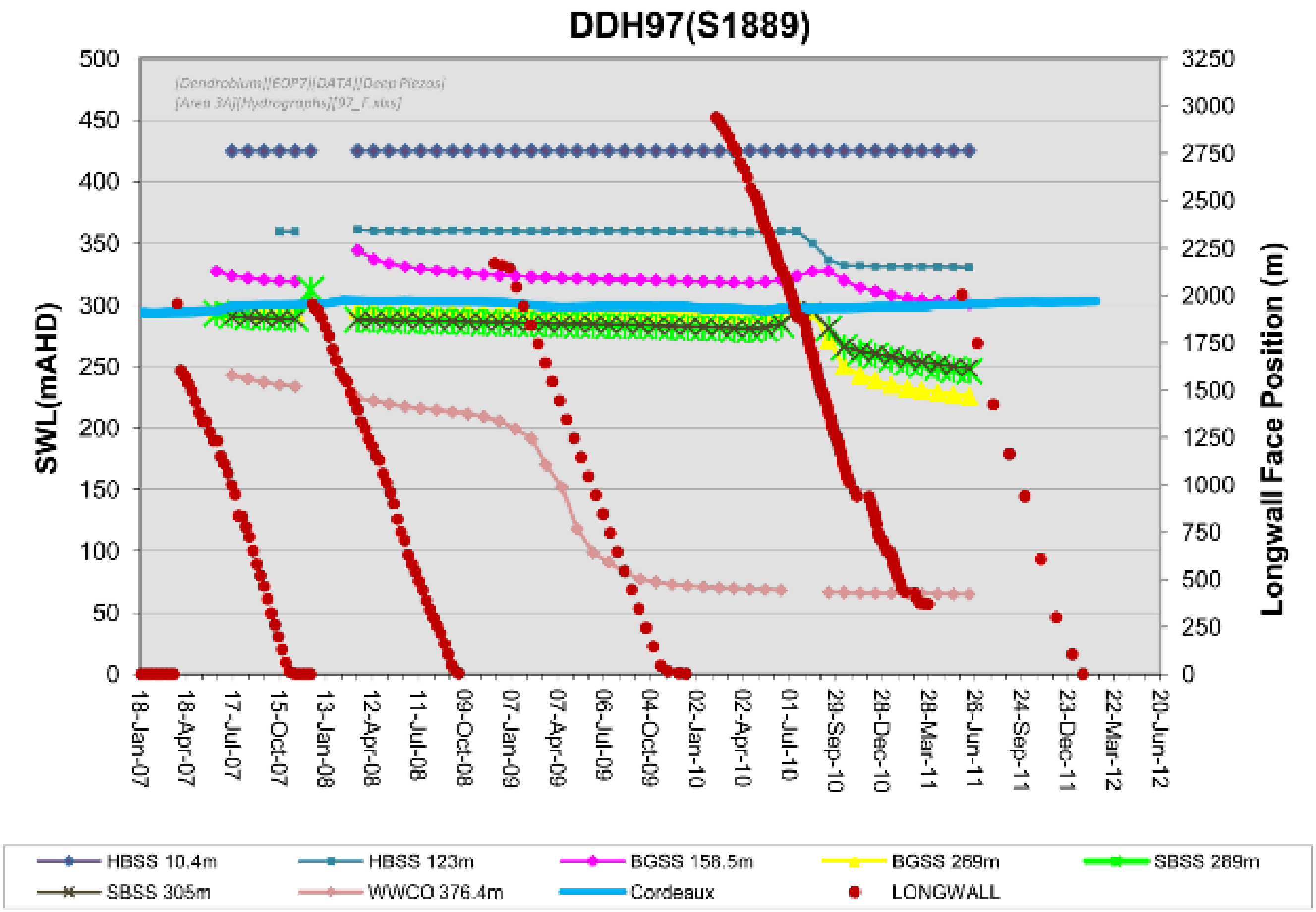


Figure 33. Hydrographs from piezometer bore DDH97/S1889

Discussed in Section 15.1.9. the above figure is from the HydroSimulations groundwater assessment for the Longwall 8 end of panel report.[87]

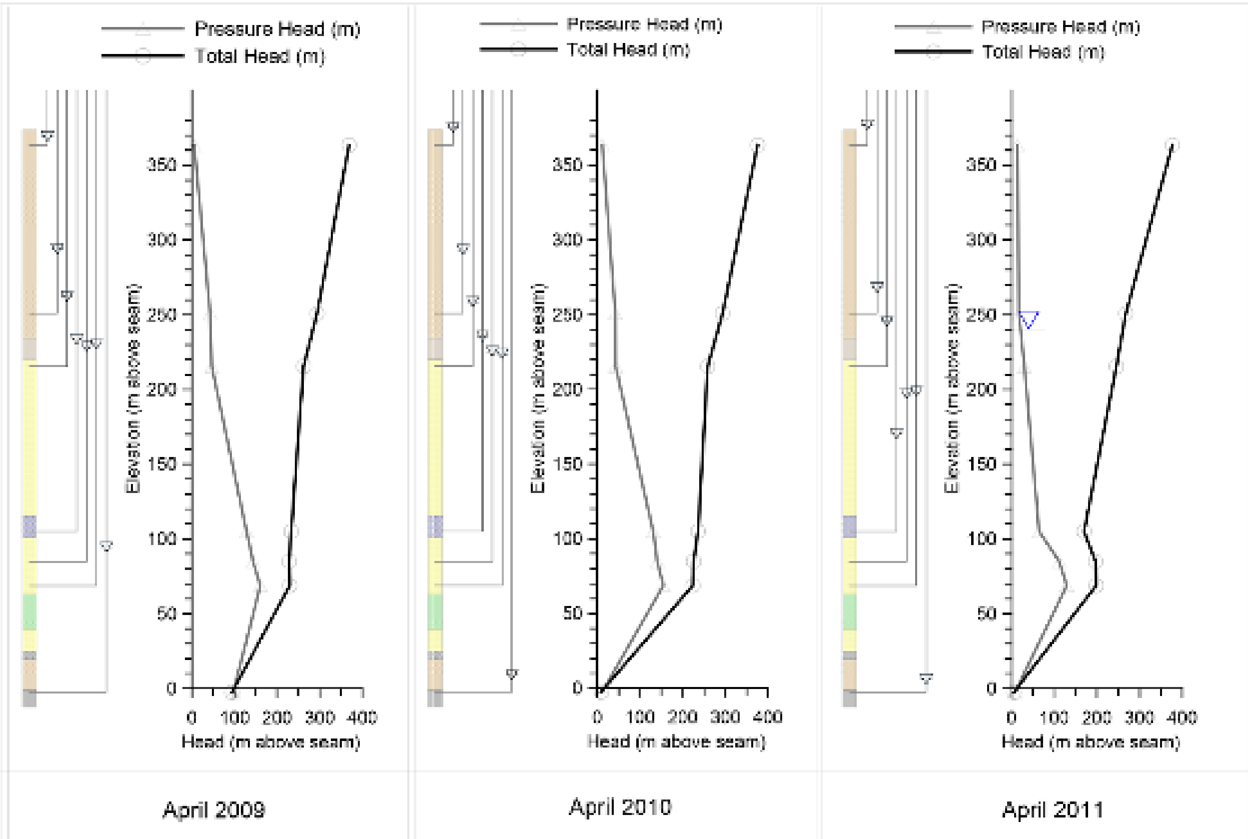


Figure 34. DDH97/S1889 piezometer pressure head profiles with respect to elevation.

Figure 34 is taken from a 2012 Pells and Pells paper[4] and shows the loss of pressure head "through the whole profile" as a consequence of the extraction of Longwall 6. The figure distinguishes strata by colour. Discussed in Section 15.1.9, Longwall 6 was mined between the 9th February 2010 and the 28th March 2011. Following the completion of Longwall 6, the pressure head profile has formed the 'half tear-drop' shape typical of a mining impact on groundwater.

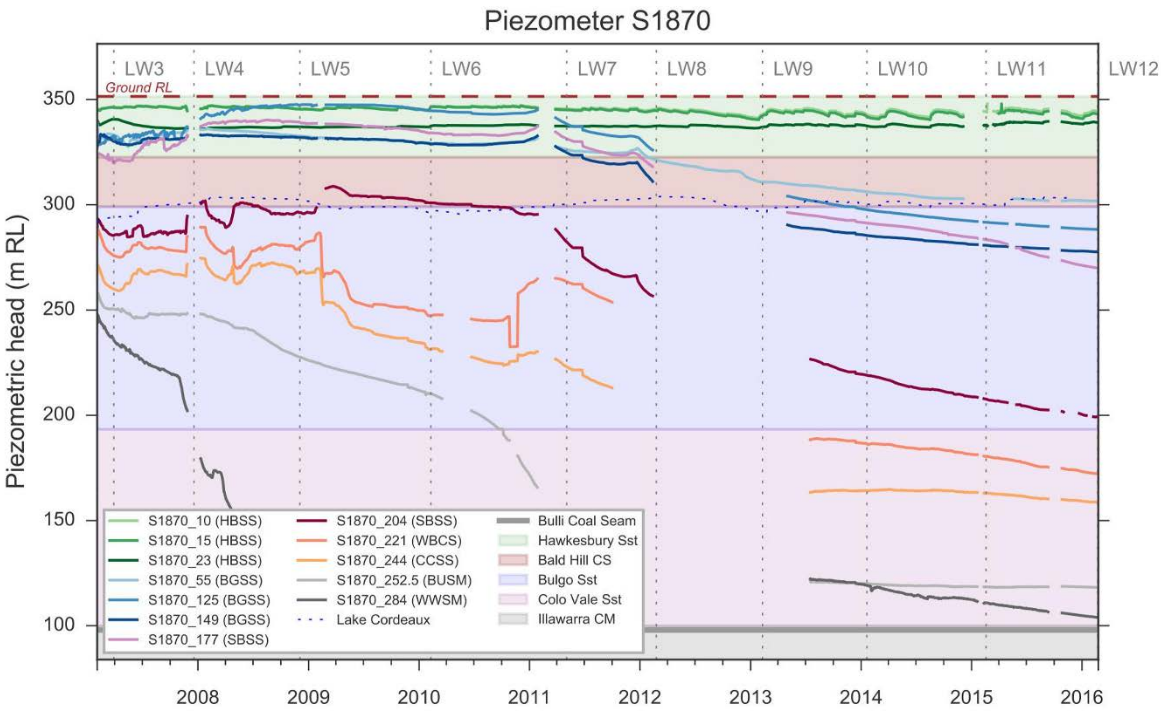


Figure 35. Hydrographs from piezometer bore DDH85/S1870

Taken from the 2016 HydroSimulations groundwater assessment for the Dendrobium Longwall 11 end of panel report.[73] The hydrographs are discussed in Section 5.1.12 and pressure head changes for Piezometers 1 to 4 are given in Figure 36. The Hydraulic head of Piezometer 4, in the upper Bulgo Sandstone, falls to the level of Cordeaux Reservoir.

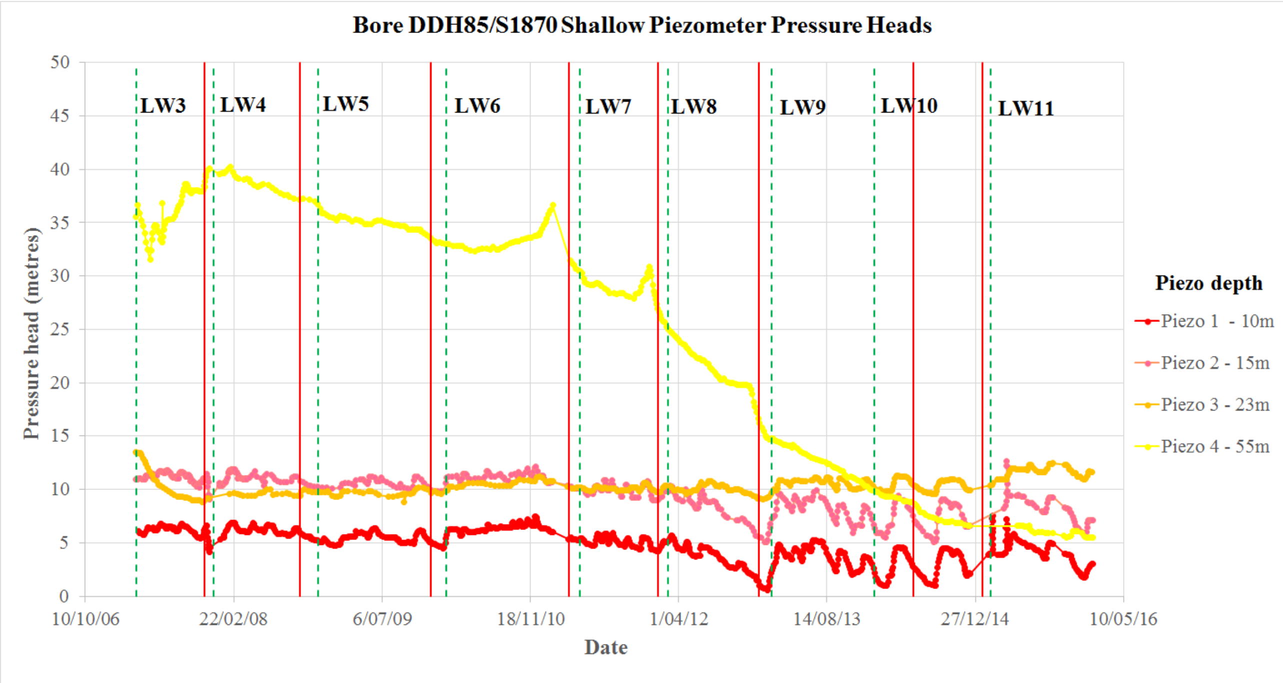


Figure 36. Pressure heads recorded by Piezometers 1 to 4 in TARP bore DDDH85/S1870**.**

The pressure heads were obtained by digitising Figure 11 in the March 2016 HydroSimulations groundwater assessment[24] and subtracting elevations from hydraulic heads.

The dashed vertical line denotes the commencement of an extraction and the sold line indicates its completion. See Section 15.1.12.

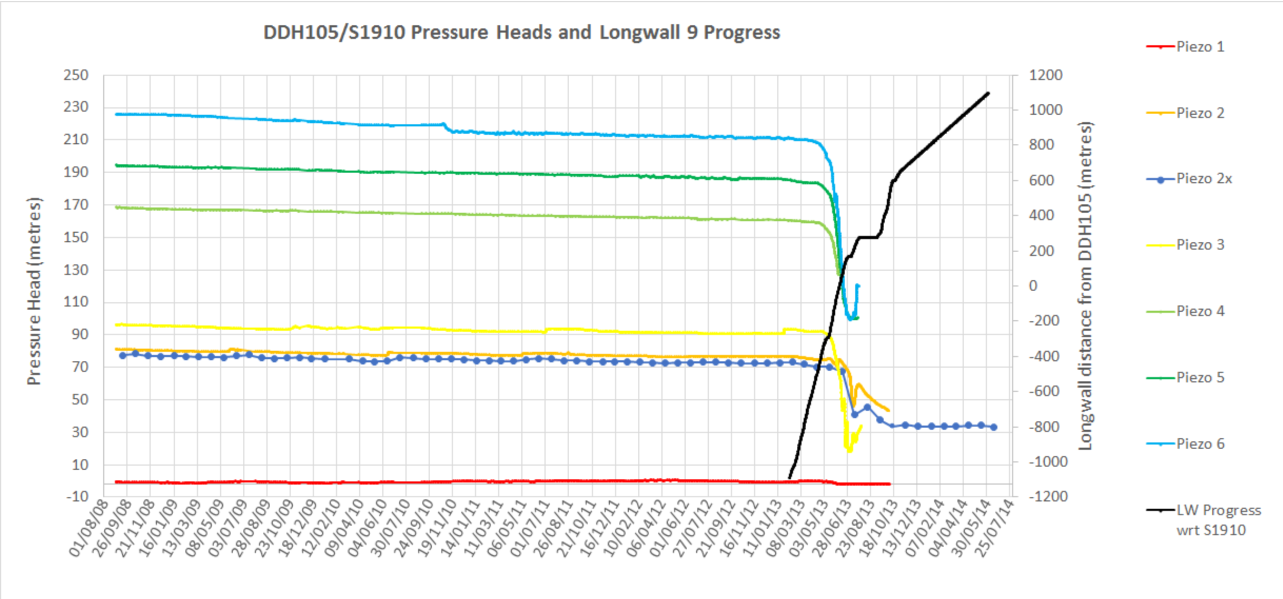


Figure 37. Pressure heads for Piezometers 2 to 6 in off-panel bore DDH105/1910 near Longwall 9 of Dendrobium Area 3B.

Discussed in Section 5.1.13, the pressure heads represented by the continuous lines (piezometers 2 to 6) were obtained by digitising the hydrographs in Figure 2.2 of the groundwater assessment for the 2016 Longwall 11 end of panel report (Fig. 39 below).[73] The Piezometer 2 hydrograph represented by the circle punctuated blue line were obtained by digitising Figure 2.6 of the August 2014 HydroSimulations groundwater impact assessment[42] for the Longwall 9 end of panel report (Fig. 40 below). Pressure heads were obtained by subtracting elevations from hydraulic heads. Provided only at monthly intervals in the report, the pressure heads obtained from the 2014 assessment are lower than obtained from the 2016 report. The hydrographs of the 2014 report continue for a longer period of time.

The figure also shows the distance of the longwall face from the point of shortest distance between DDH105 and the northern edge of Longwall 9. The bore is approximately 127 metres north of the northern edge of the Longwall 9 void, approximately 279 metres from its centreline and approximately 1090 metres longitudinally from the western (commencement) end of the panel.

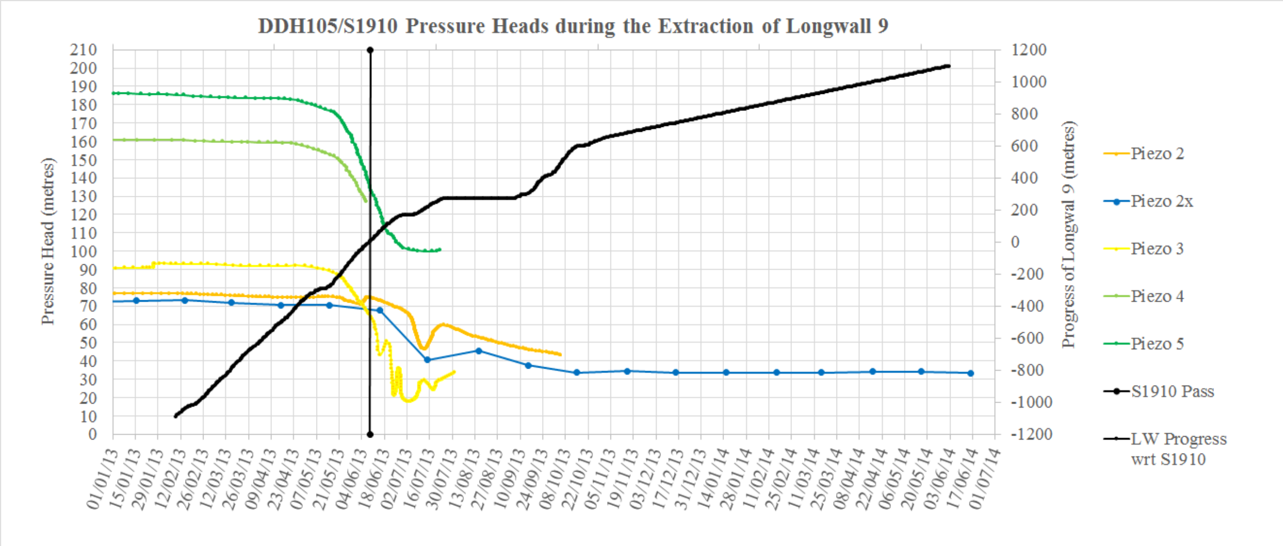


Figure 38. Pressure head hydrographs from off-panel bore DDH105/1910 during the extraction of Longwall 9.

The hydrographs are a subset of those in Figure 34, showing only the period over which Longwall 9 was extracted. The vertical line marks the date the longwall face passed the point of shortest distance between the northern edge of Longwall 9 and bore DDH105/S1910.

The figure also shows the distance of the longwall face from the point of shortest distance between DDH105 and the northern edge of Longwall 9. The bore is approximately 127 metres north of the northern edge of the Longwall 9 void, approximately 279 metres from its centreline and approximately 1090 metres longitudinally from the western (commencement) end of the panel.

The pressure heads represented by the continuous lines (piezometers 2 to 6) were obtained by digitising the hydrographs in Figure 2.2 of the groundwater assessment for the 2016 Longwall 11 end of panel report (Fig. 39 below).[73] The Piezometer 2 hydrograph represented by the circle punctuated blue line was obtained by digitising Figure 2.6 of the August 2014 HydroSimulations groundwater impact assessment[42] for the Longwall 9 end of panel report (Fig. 40 below). Pressure heads were obtained by subtracting elevations from hydraulic heads. Provided only at monthly intervals in the report, the pressure heads obtained from the 2014 assessment are lower than obtained from the 2016 report. The hydrographs of the 2014 report continue for a longer period of time. See Section 5.1.13.

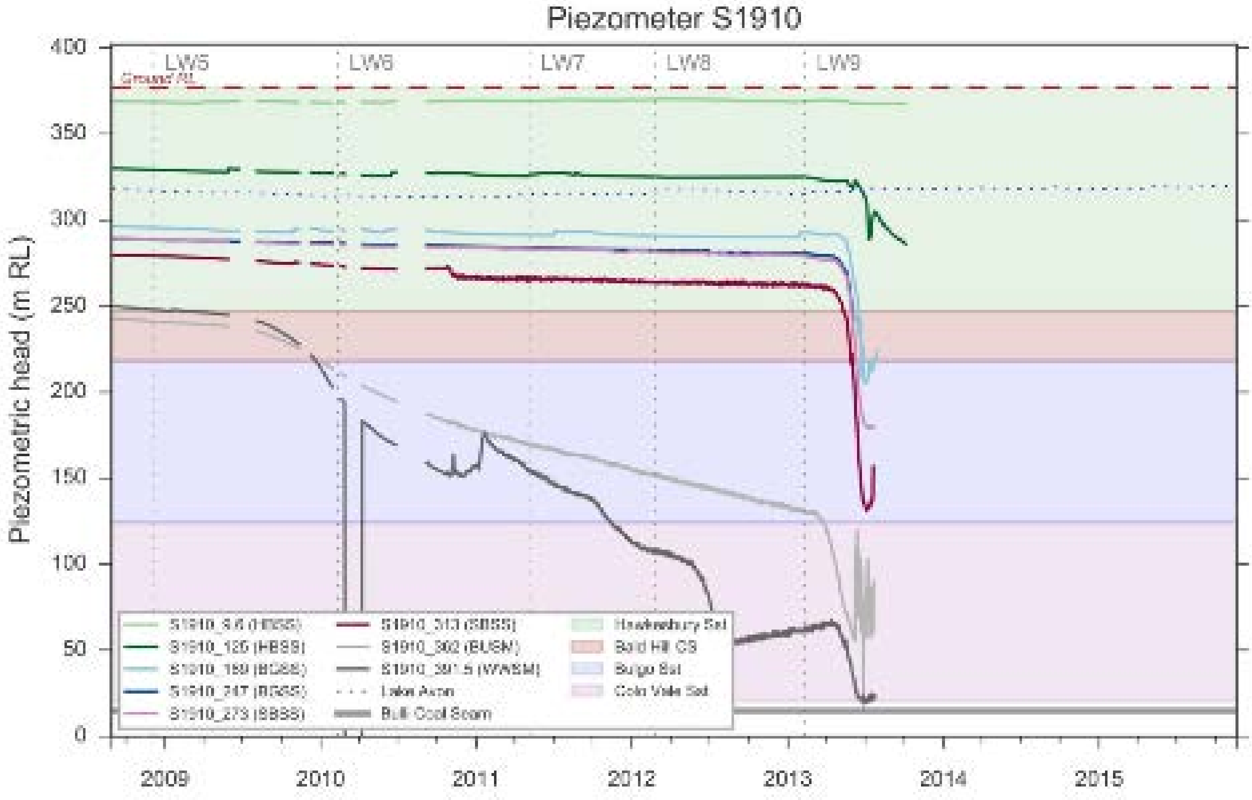


Figure 39. Response of the piezometers in bore DDH105/S1910 to the passage of Longwall 9

Hydrographs for the piezometers in bore DDH105 (S1910) showing the response to the passage of Longwall 9, the northern most longwall to be extracted in Area 3B of the Dendrobium mine. The graph is provided as Figure 2.2 in the groundwater assessment for the end of panel report[73] for the extraction of Longwall 11. Data appear to be represented at least daily intervals, in contrast to the monthly interval of the hydrographs provided in the Longwall 9 end of panel report.[42]

The bore is approximately 127 metres north of the northern edge of the Longwall 9 void, approximately 279 metres from its centreline and approximately 1090 metres longitudinally from the western (commencement) end of the panel. See Section 5.1.13.

See Figs. 37 and 38.

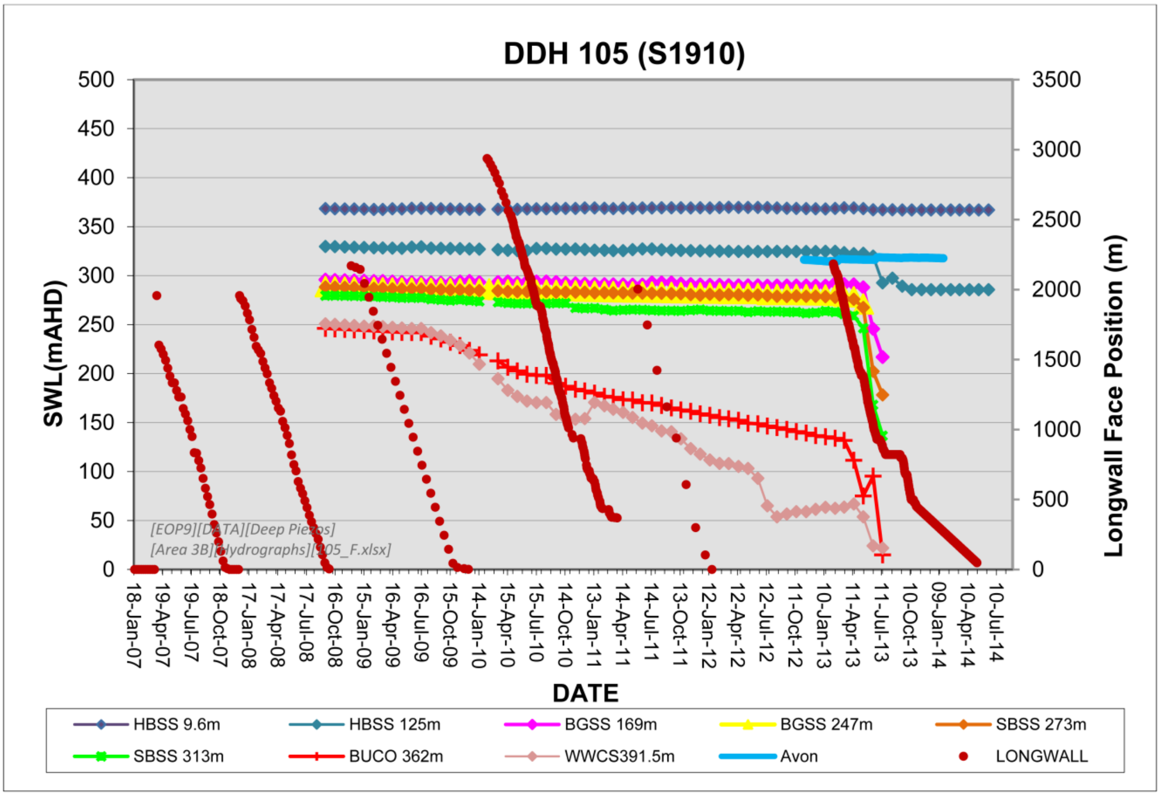


Figure 2.6 Groundwater hydrographs for Bore S1910 in Area 3B (LW9)

Figure 40. Response of the piezometers in bore DDH105/S1910 to the passage of Longwall 9

Hydrographs for the piezometers in bore DDH105 (S1910) during the passage of Longwall 9, the northern most longwall to be extracted in Area 3B of the Dendrobium mine. The graph is provided as Figure 2.6 in the groundwater assessment for the end of panel report for the extraction of Longwall 9.[42] In contrast to the hydrographs provided in the Longwall 11 end of panel report (Figure 39 above), data are only provided at monthly intervals, though for a longer period of time. See Section 5.1.13.

See also Figs. 37 and 38.

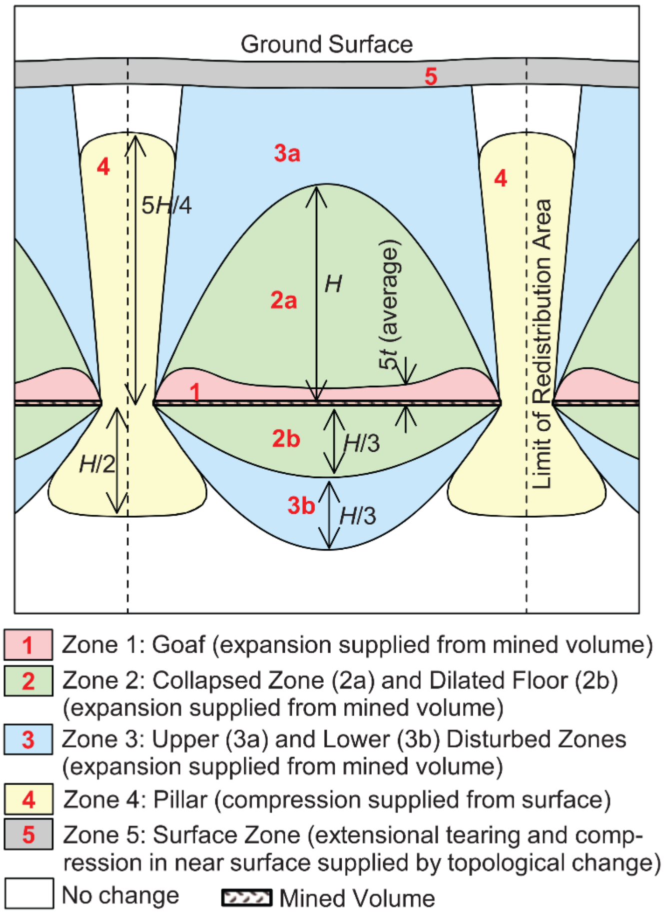
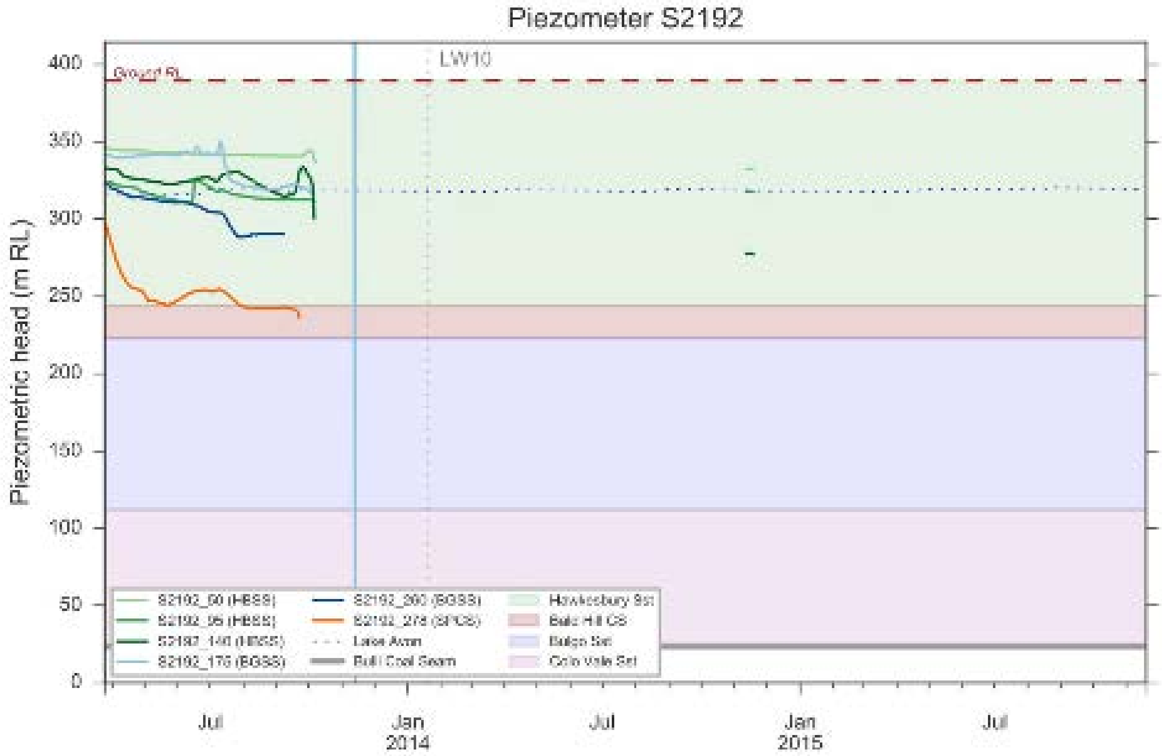
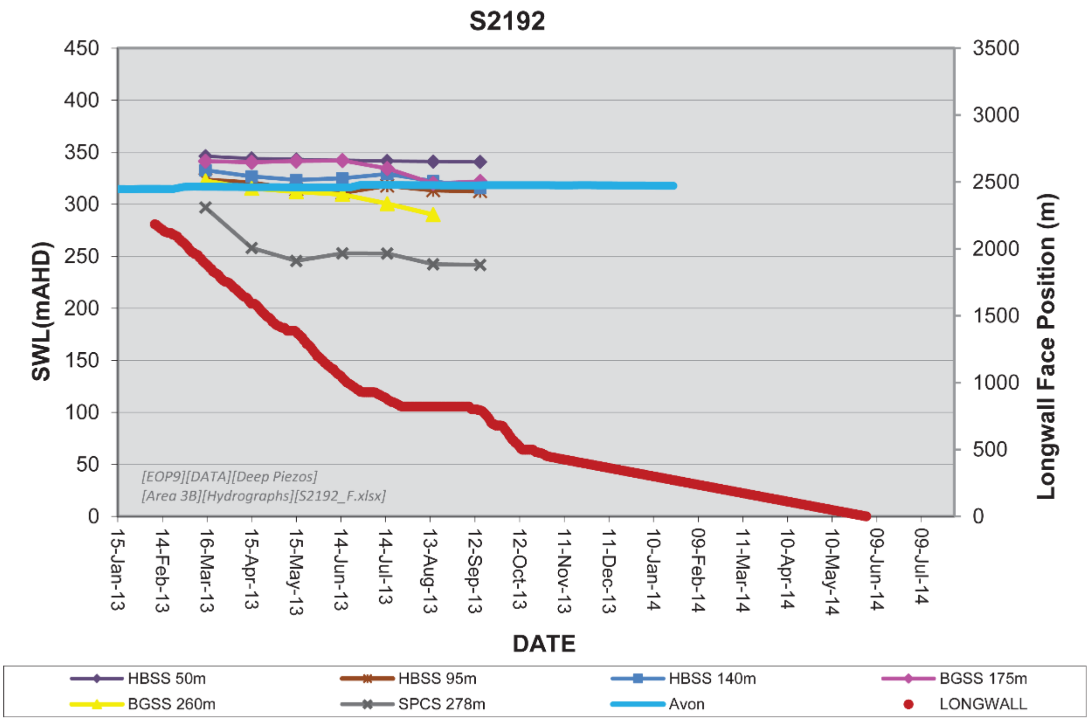


Figure 4. Subdivisions applied to the space around a caved panel, into which the mined volume is redistributed (based on Tammetta 2013, 2015).

Figure 41. Figure 4 from the 2016 Groundwater paper**[19]** by Tammetta addressing the redistribution of the mined volume**.**



(a)



(b)

Figure 42. Hydrographs from bore S2192 over Area 3B Longwall 9

Hydrographs from piezometer bore S2192 provided in the HydroSimulations groundwater assessment for (a) the Longwall 11 end of panel report[73] and (b) the Longwall 9 end of panel report.[42] See Sections 15.1.14, 16.2 and 16.7.

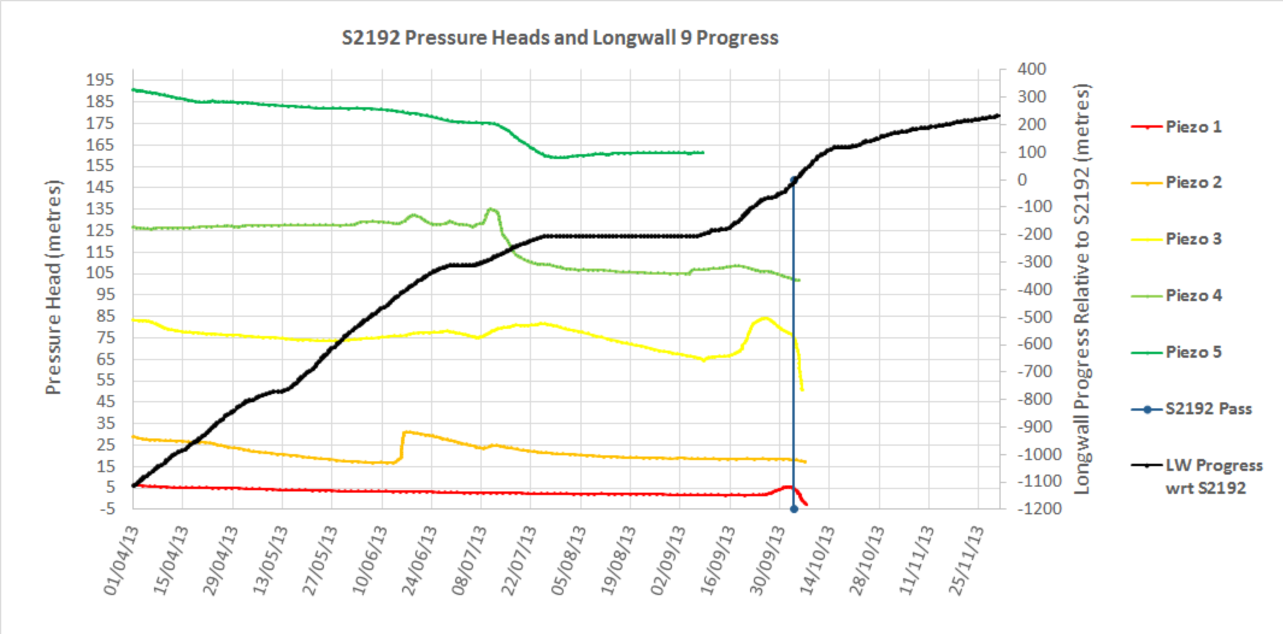


Figure 43. Pressure heads from S2192 piezometers 1 to 6 and Longwall 9 progress

The pressure heads were obtained by digitising the hydrographs in Figure 2.5 of the HydroSimulations groundwater impact assessment[73] for the Longwall 11 end of panel report (provided here as Fig. 42). Pressure heads were obtained by subtracting elevations from hydraulic heads. See Sections 15.5.15, 16.2 and 16.7.

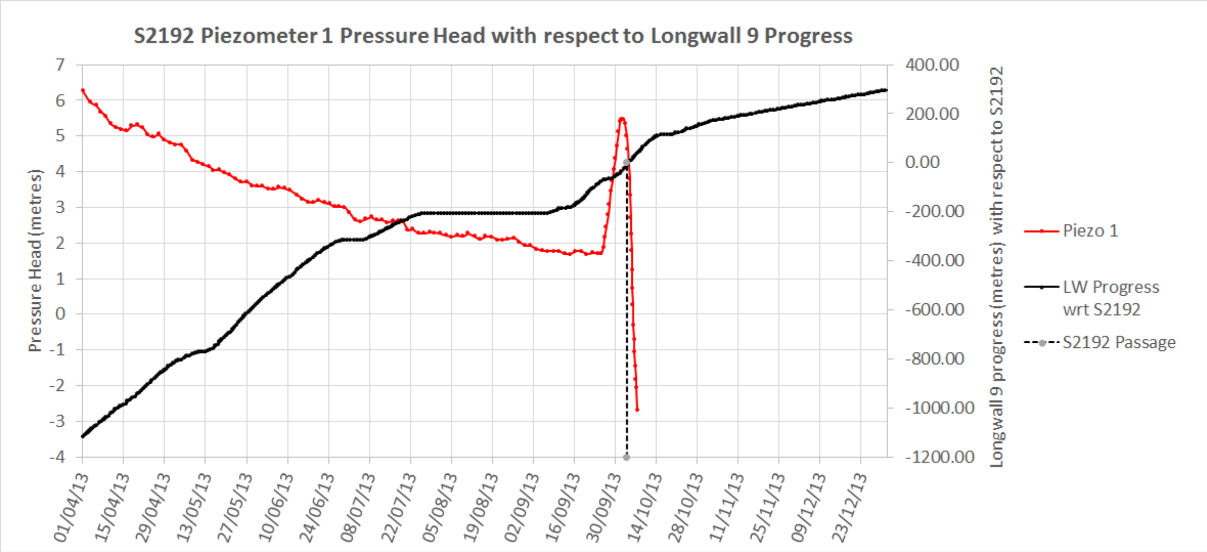


Figure 44. Pressure heads from S2192 piezometers 1 and Longwall 9 progress

The pressure heads were obtained by digitising the centreline piezometer bore S2192 hydrographs provided in Figure 2.5 (provided here as Fig. 42) of the HydroSimulations groundwater assessment[73] for the May 2016 Longwall 11 end of panel report. The longwall extraction commenced on the 9th of February 2013 and finished on the 2nd of June 2014. Piezometer 1 is located 50 metres below the surface; it's disturbing that the initial pressure head at this depth is so low. See Section 15.1.14.

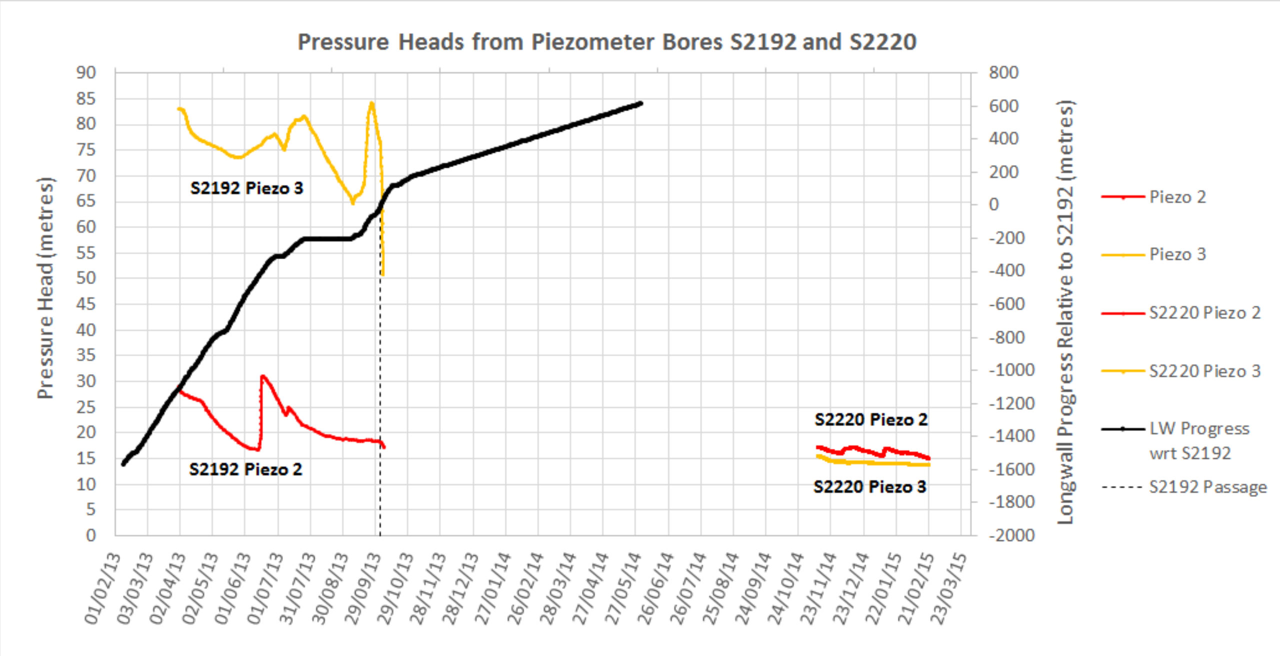


Figure 45. Pressure heads from S2192 and S2220 piezometers 2 and 3

The pressure heads were obtained by digitising the hydrographs in Figure 2.5 (provided here as Fig. 42) of the HydroSimulations groundwater impact assessment[73] 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.[13]

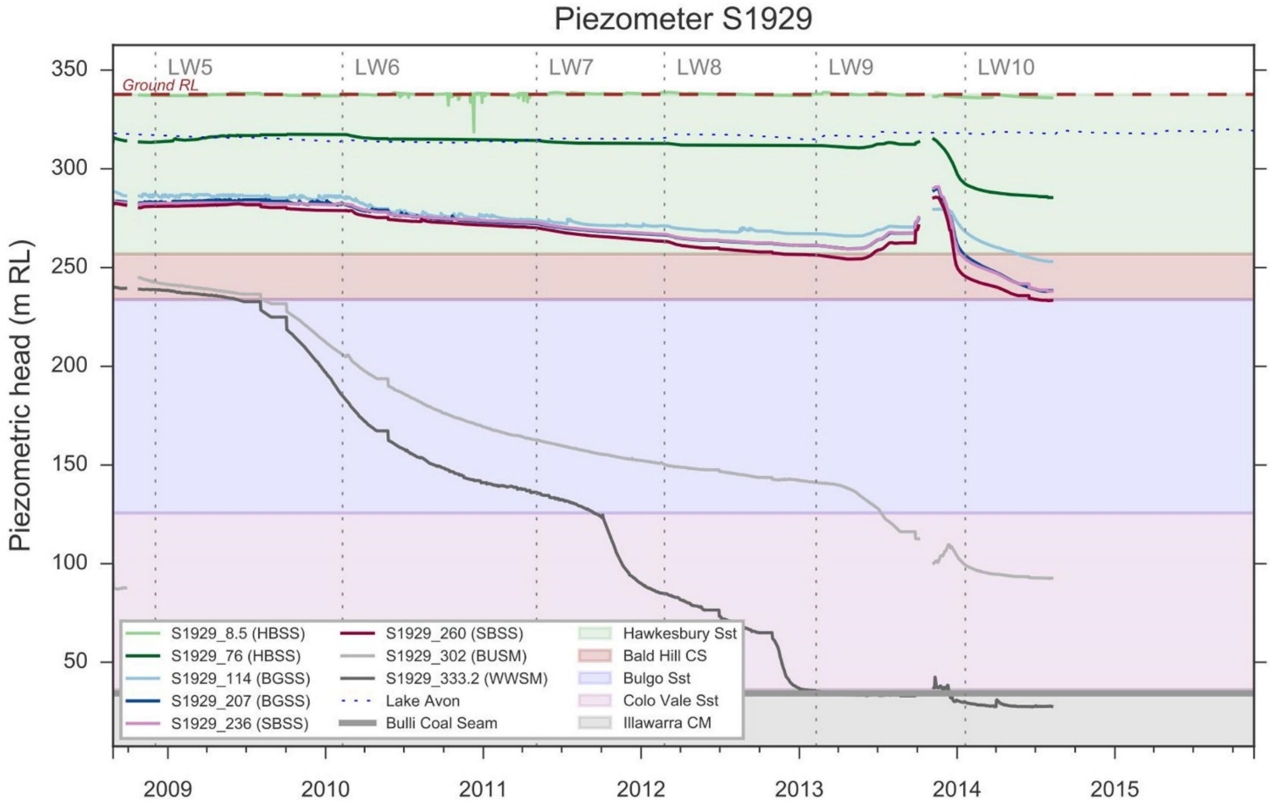


Figure 46. DDH111/S1929 hydrographs from the Longwall 11 end of panel report.**[73]**

Of note, the hydraulic head reported by the piezometer in the Hawkesbury Sandstone at 76 metres below the surface falls significantly below the level of Avon Reservoir.

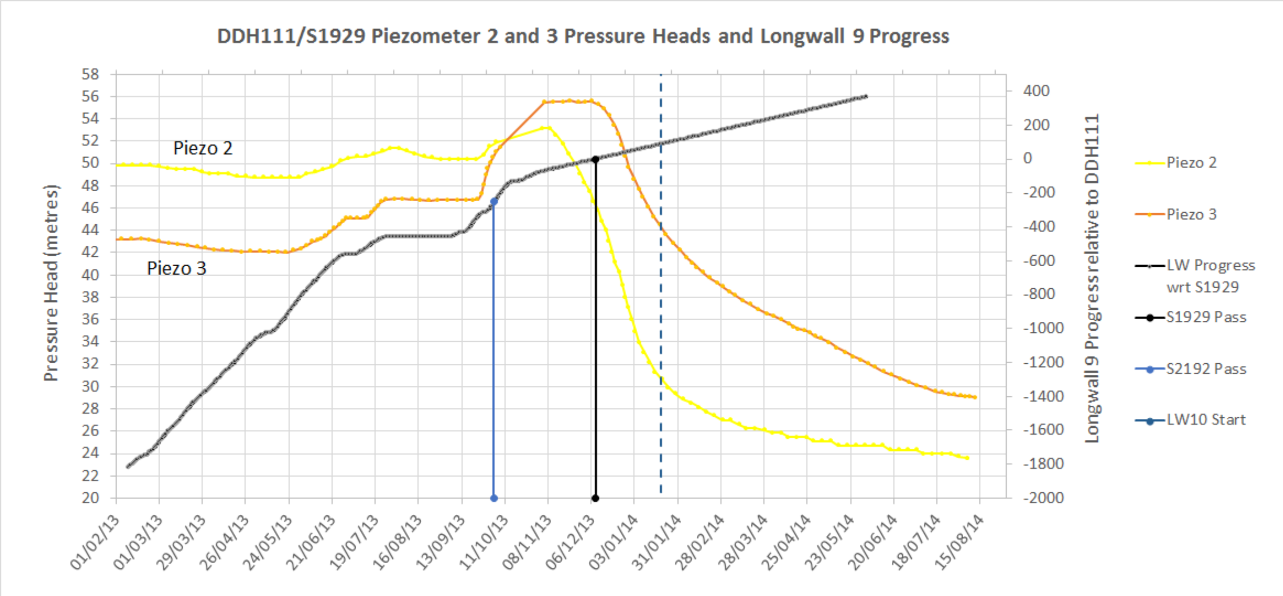


Figure 47. DDH111/S1929 Piezometer 2 and 3 pressure head profiles

Pressure head profiles obtained from the DDH111/S1929 hydrographs provided in the groundwater assessment for the Longwall 11 end of panel report.[73]

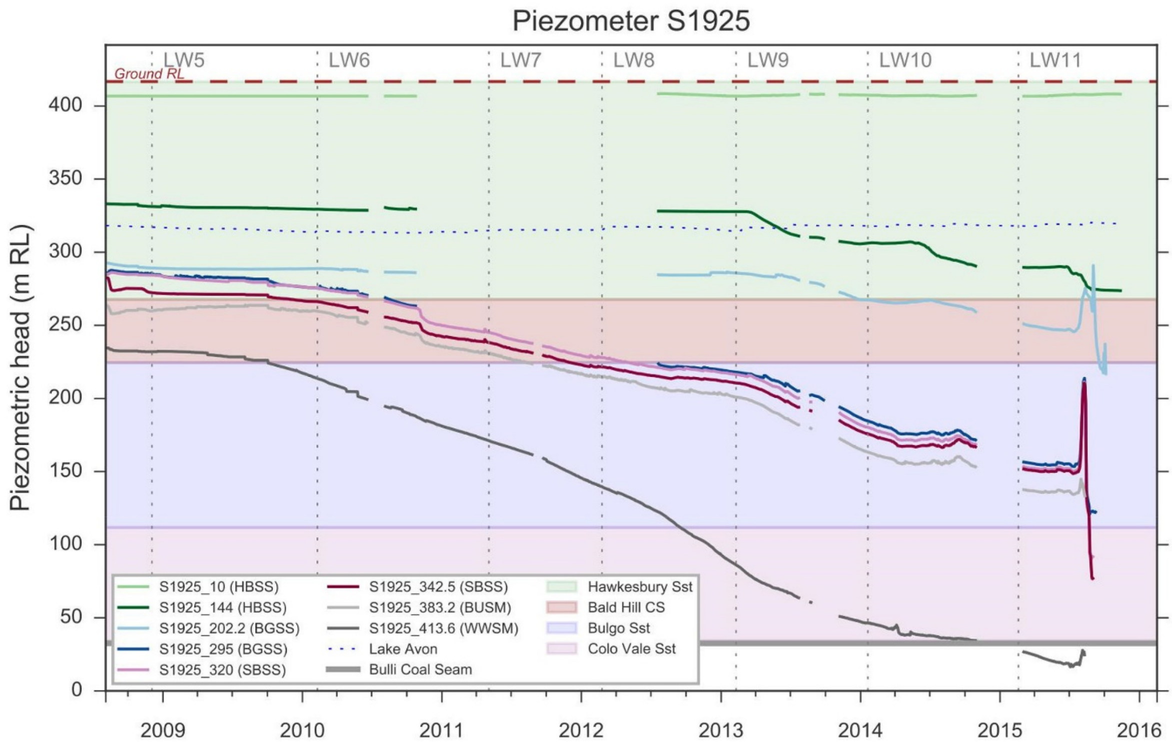


Figure 48. DDH108/S1925 hydrographs from the Dendrobium Longwall 11 end of panel report

The figure is Figure 2.3 in the HydroSimulations groundwater assessment for the Longwall 11 end of panel report.[73]

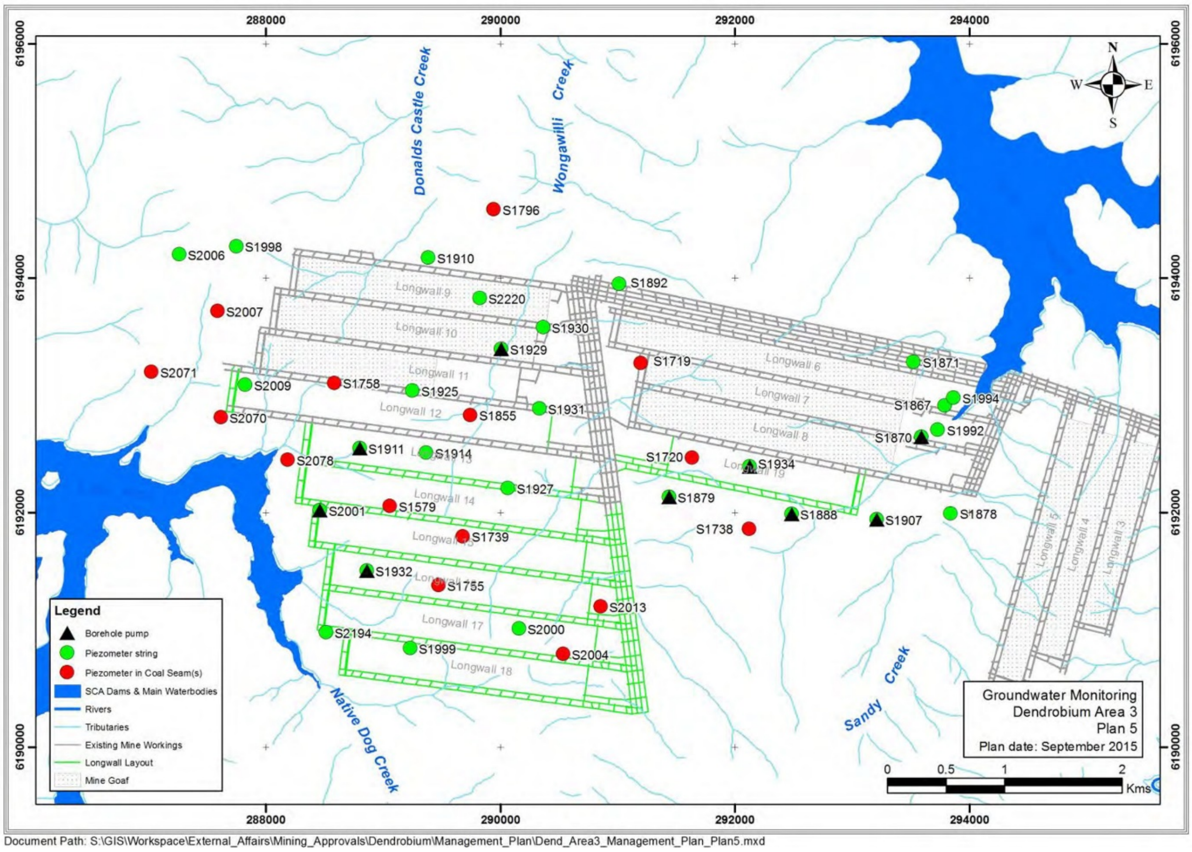


Figure 49. Groundwater monitoring bores identified in the Avon & Cordeaux Reservoirs DSC Notification Area Management Plans (see Section 15.1.20)

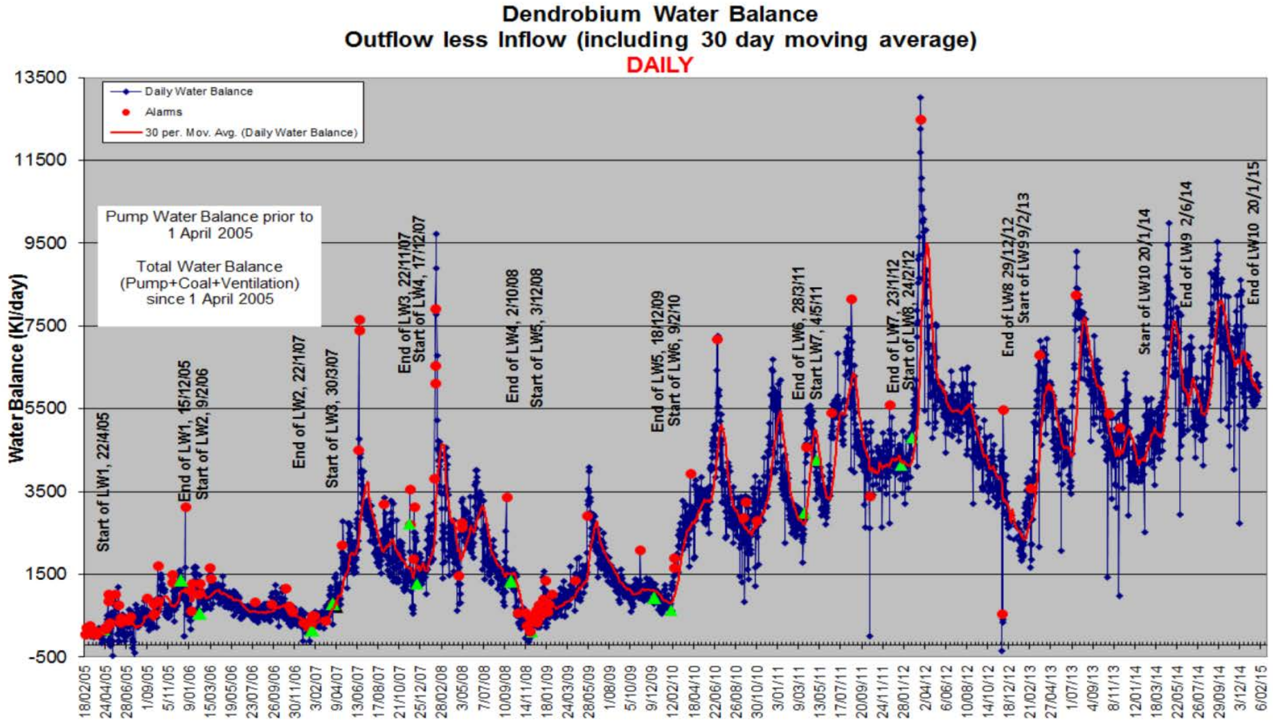


Figure 50. Water inflow to the Dendrobium mine from February 2005 to February 2015

Water inflow to the Dendrobium mine from February 2005 to February 2015, as estimated from the records of the mine's reticulated water system.[70]

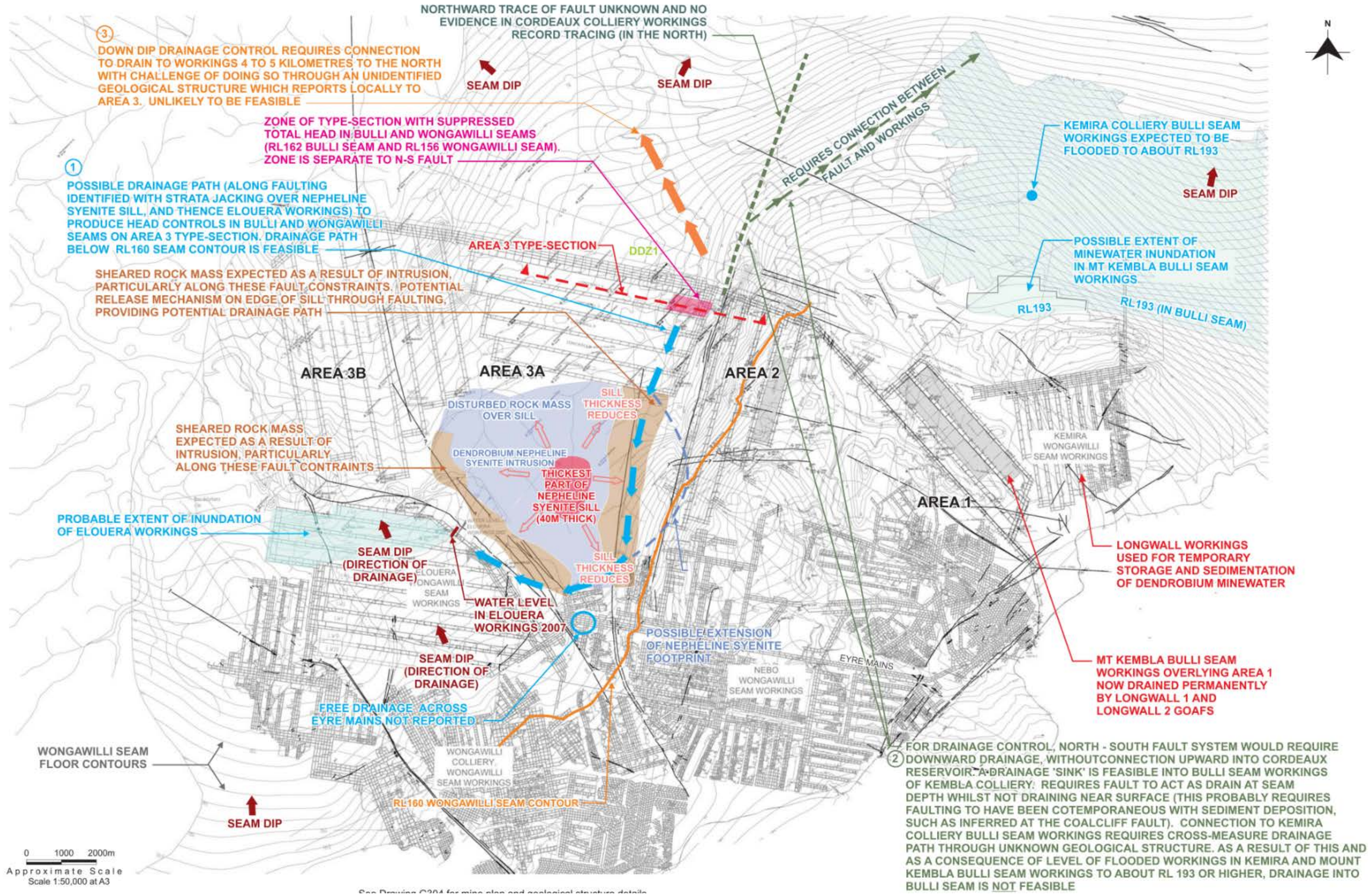
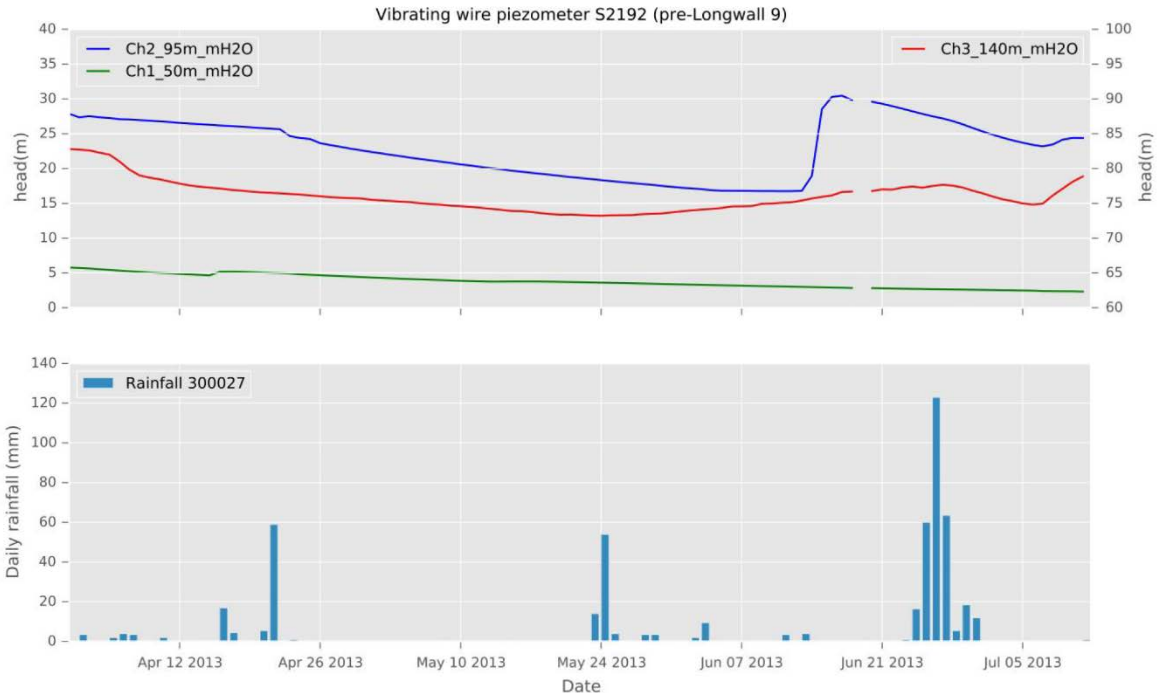
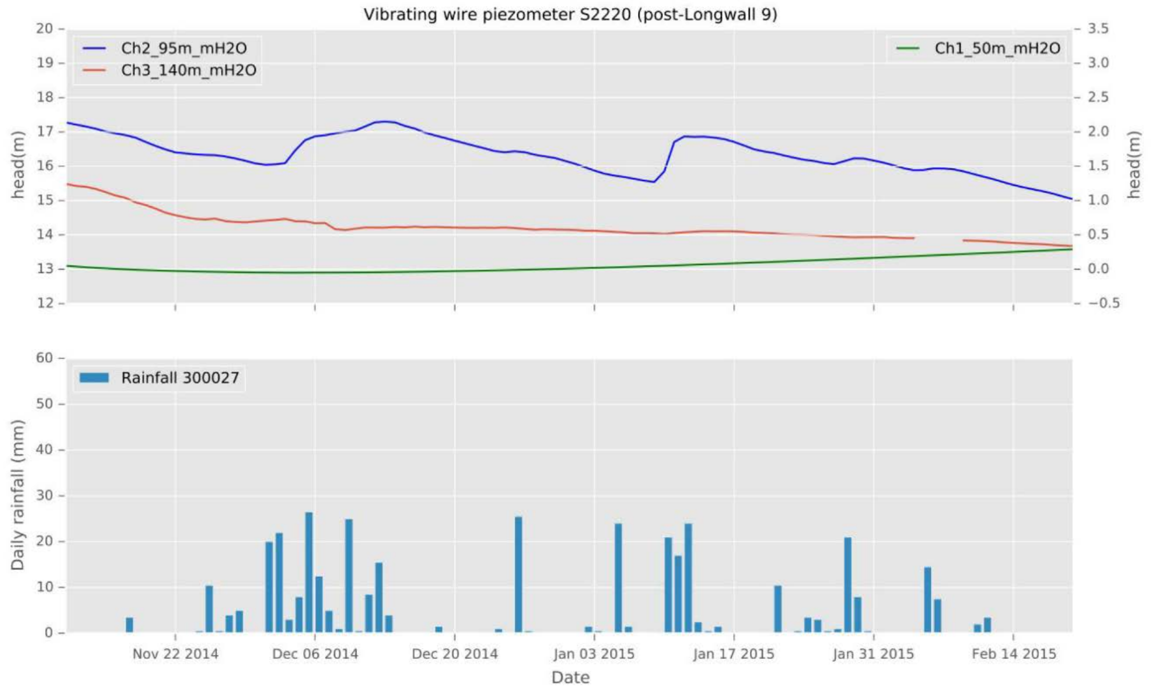


Figure 51. GHD depiction of hydrological controls at the Dendrobium and Elouera mines

The depiction shows a body of water accumulating in the decommissioned Elouera mine workings, which includes possible drainage from Dendrobium via the Nepheline Seynite sill. The depiction is nearly a decade old and the water level will have accordingly increased. The layout of the longwalls changed; see Figure 10.



(a)



(b)

Figure 52. Hydrographs from the upper most three piezometers in bores (a) S2192 and (b) S2220 over the centreline of Longwall 9 in Area 3B of the Dendrobium mine.

The depictions are taken from the March 2015 height of fracturing assessment by Parsons Brinckerhoff.[13]

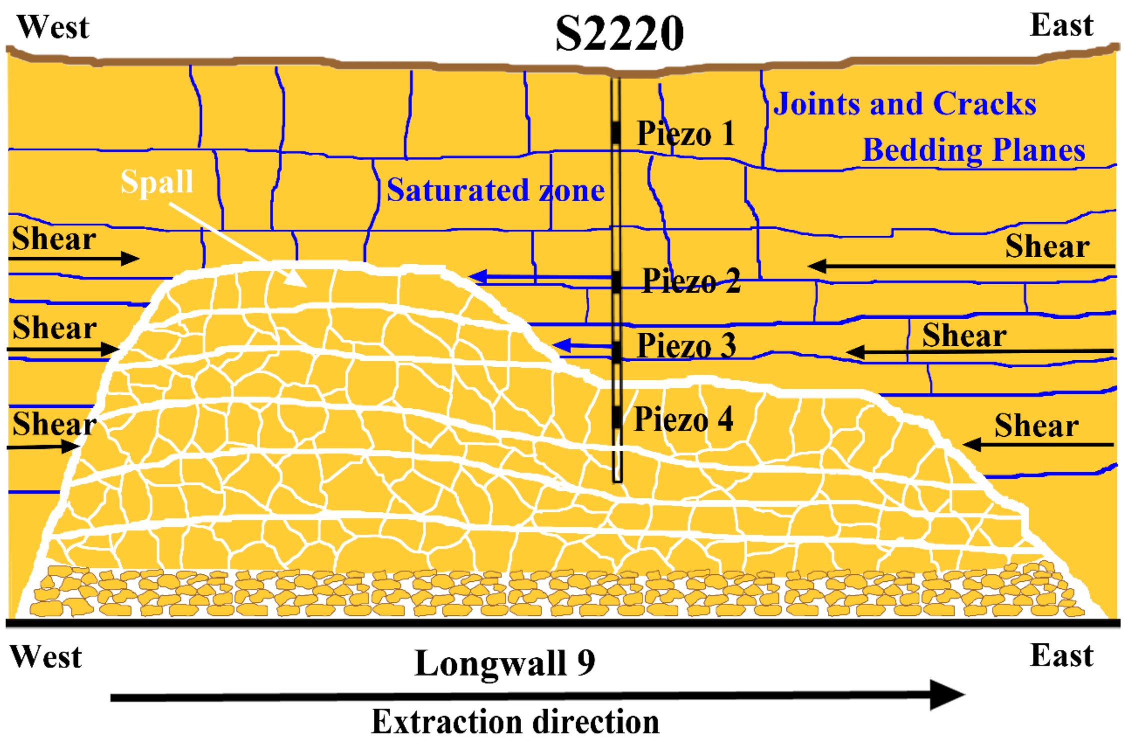


Figure 53. A west to east depiction of the drainage zone over Longwall 9 in Area 3B of the Dendrobium mine.

The depiction reconciles the differing drainage zone heights suggested by piezometers in bores S1910, S2192 and S2220. The difference in the drainage zone height between the western and eastern parts of the extraction reflects anomalous horizontal stress in the east. See Section 16.7.

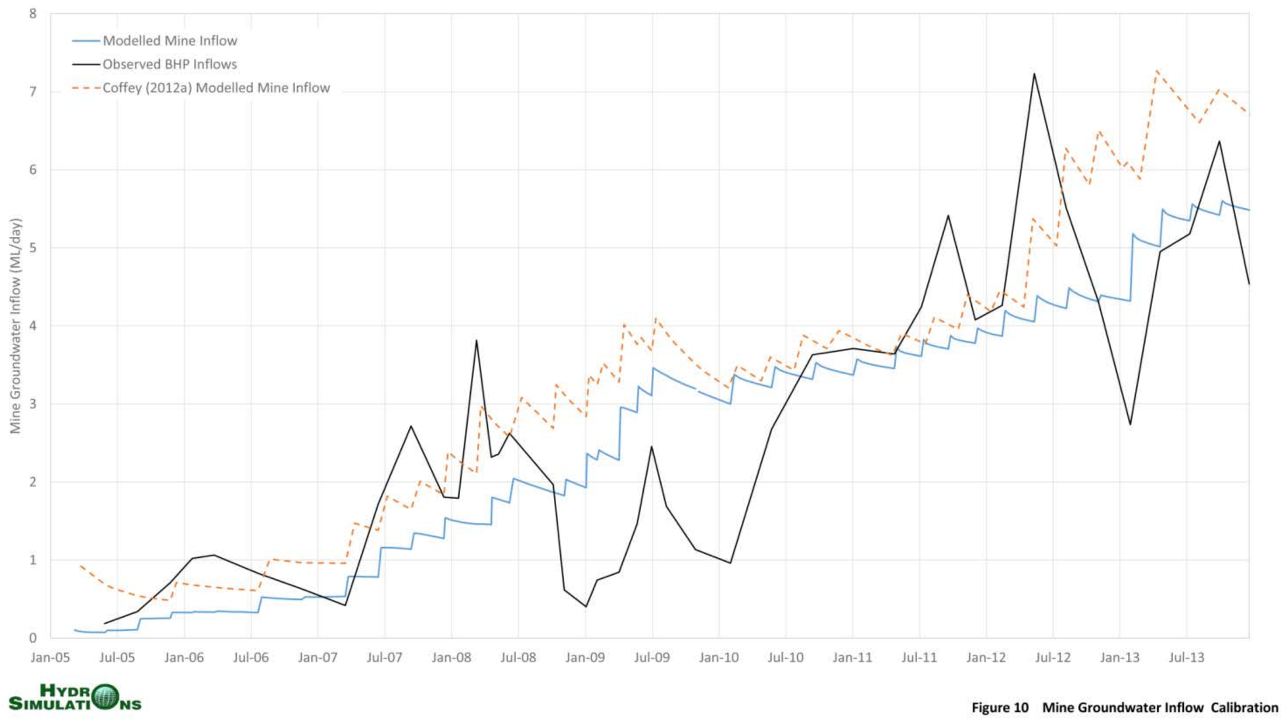


Figure 54. Modelled inflows to the Dendrobium mine from the March 2014 HydroSimulations assessment for the Dendrobium mine.

A comparison of observed and modelled inflows to the Dendrobium mine given in Figure 10 of the March 2014 groundwater assessment[23] undertaken by HydroSimulations on behalf of BHP-Billiton. The sold black line depicts the observed inflow, the blue line depicts HydroSimulations inflow modelling using the Ditton equation, with the addition of twice the estimated uncertainty, and the dashed red line depicts their application of the Tammetta equation.

The planned mining heights of 3.9 metres for LW9 and 4.6 metres for LWs 10 to 18 were used by HydroSimulations in calculating the A zone and drainage zone heights. The mining heights actually used to date have been lower than planned (see Table 1). The 2014 HydroSimulations assessment replaced the 2012 groundwater assessments[3][36] undertaken by Coffey Geotechnics on behalf of BHP-Billiton. See also Figure 45.

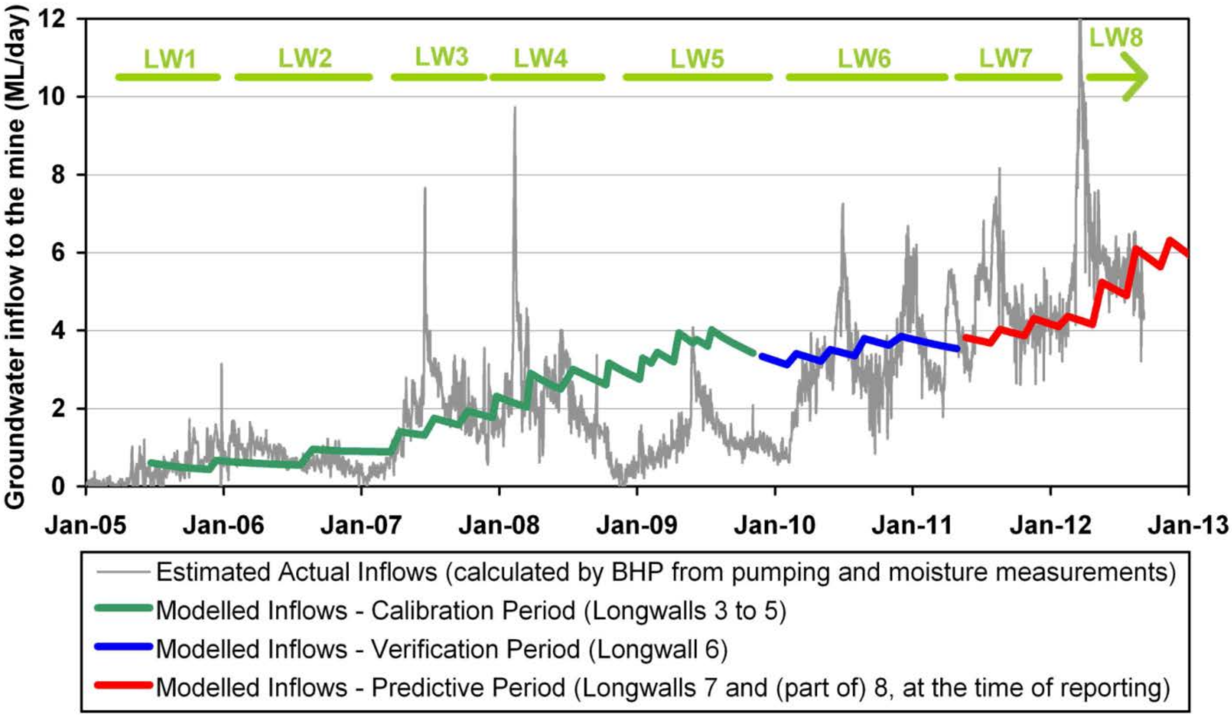


Figure 19. Calibrated groundwater inflows to the Dendrobioum mine.

Figure 55. Tammetta modelled inflows to the Dendrobium mine

A comparison of observed and modelled inflows to the Dendrobium mine from the October 2012 groundwater assessment[3] undertaken by Tammetta for Coffey Geotechnics on behalf of BHP-Billiton. This assessment used the Tammetta equation with a mining height of 3.4 metres, which is much lower than the 3.9 metres then planned for Longwall 9 and 4.6 metres for Longwalls 10 to 18. An assessment using cutting heights consistent with the mining actually planned was provided to BHP-Billiton in November 2012.[36] This report is not publically available.

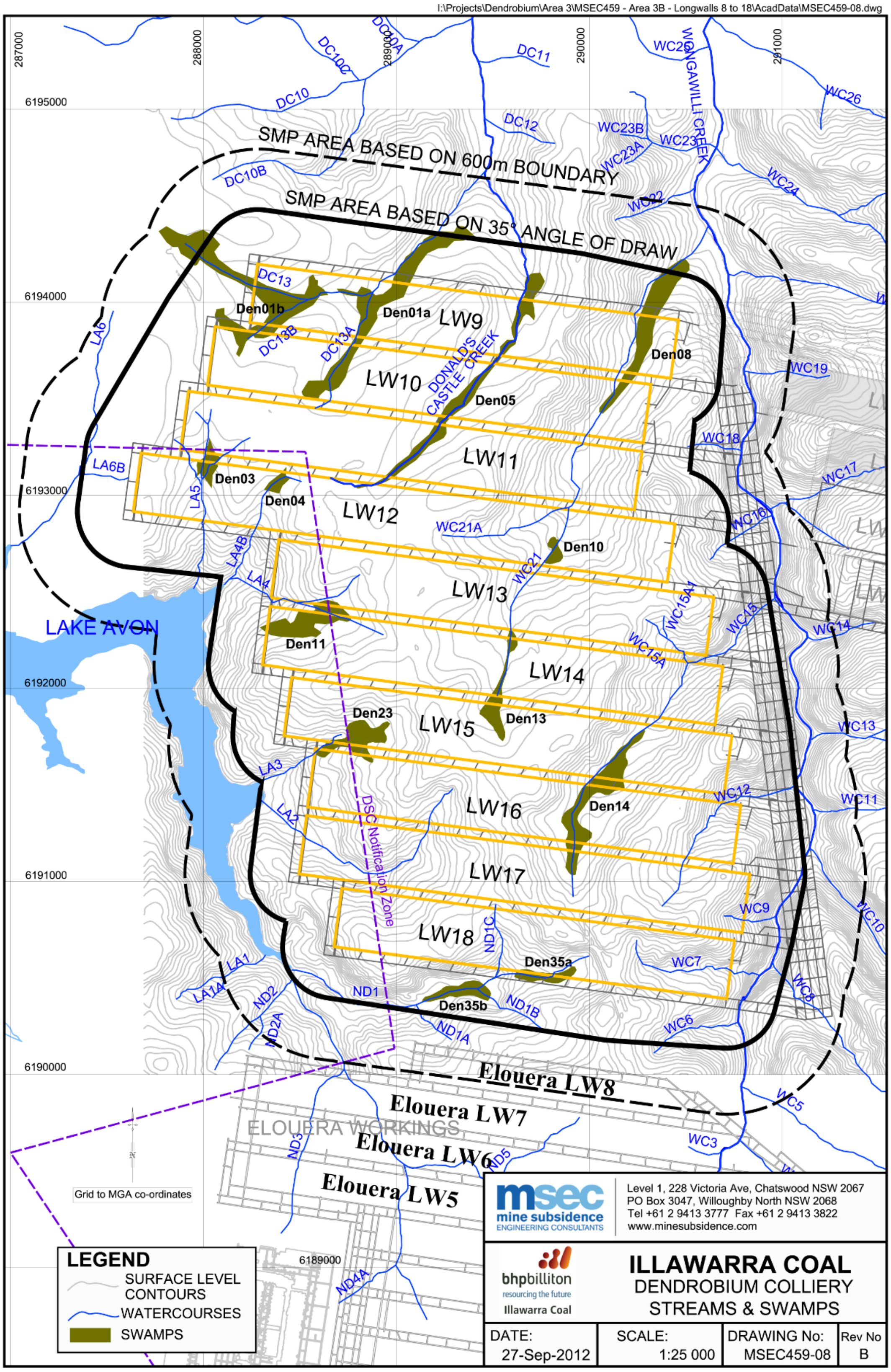


Figure 56. **S**wamps and streams over Area 3B of the Dendrobium mine.

Numbers for the longwalls in the Elouera domain immediately to the south of Area 3B have been added to the MSEC depiction of Area 3B.[61]

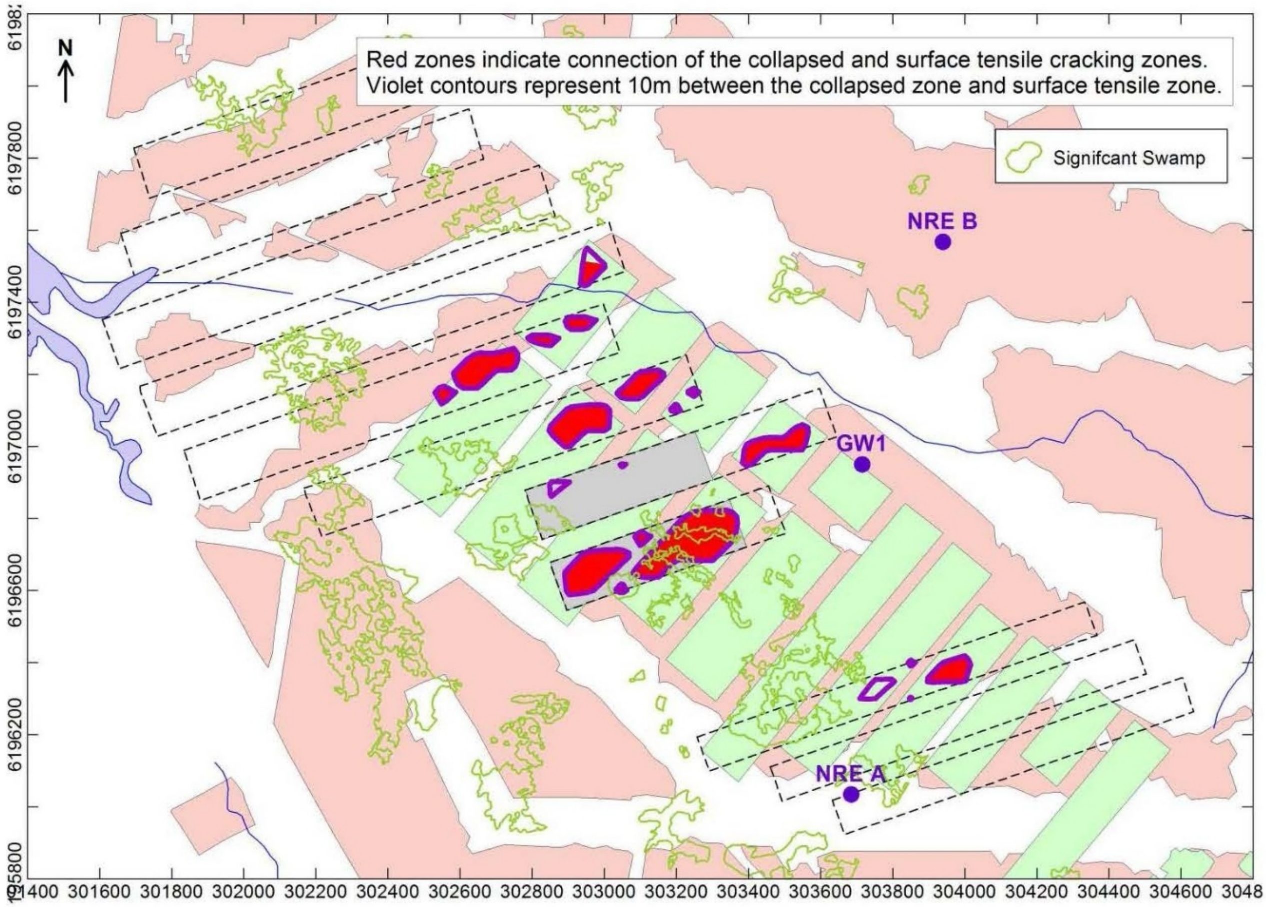


Figure 57. Tammetta's depiction of areas where the drainage zone above triple seam extractions would reach the surface at the Russell Vale Colliery**.**

The proposed mining layout was subsequently adjusted to reduce impacts to Cataract Creek, but significant areas remain where the drainage zone would be expected to reach the surface. Tammetta's equation was developed the estimation of drainage heights above single seam extractions and he cautions[116] that it's likely to underestimate the height of the zone above multi-seam extractions.

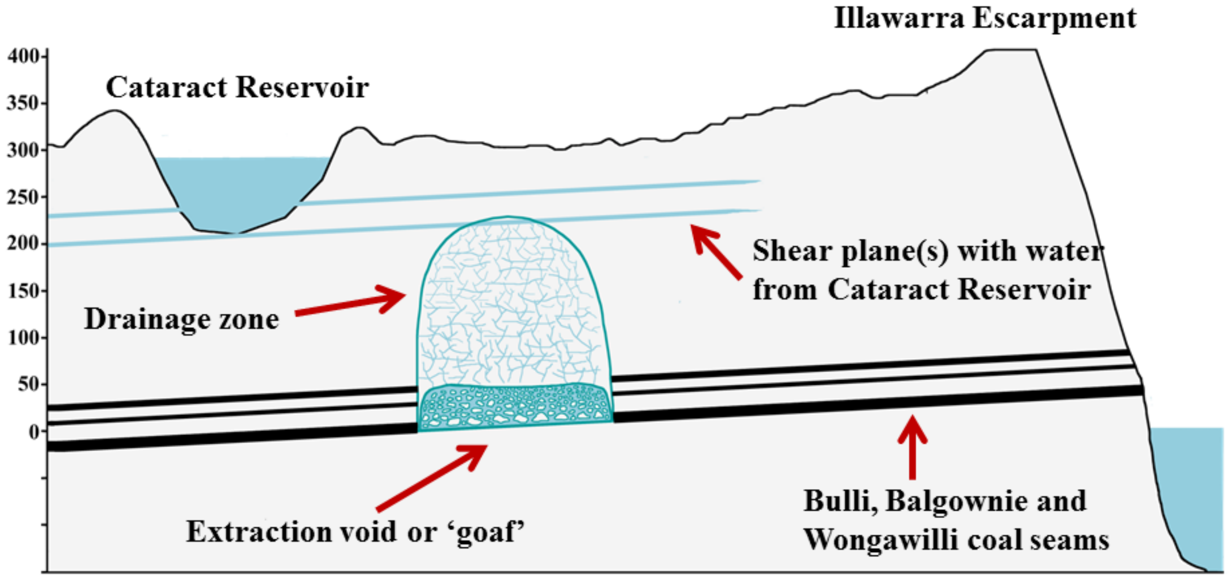


Figure 58. Depiction of the drainage zone formed above double seam extractions at the Russell Vale colliery intersecting a water bearing shear plane**.**

Application of Tammetta's single seam equation suggests that the drainage zone above two overlapping extractions at the Russell Vale coal mine could interest mining induced shear planes bearing water from nearby Cataract Reservoir. Monitoring bores at the mine have detected shear planes of this kind; see Section 25. The graphic depicts the caved and drainage zone formed by overlapping extractions in the Wongawilli (lower seam) and Balgownie seam. The area of the mine where an intersection of this kind is most likely to happen is at the southern end of proposed extractions in the Wongawilli seam below past extractions in the Bulli seam.

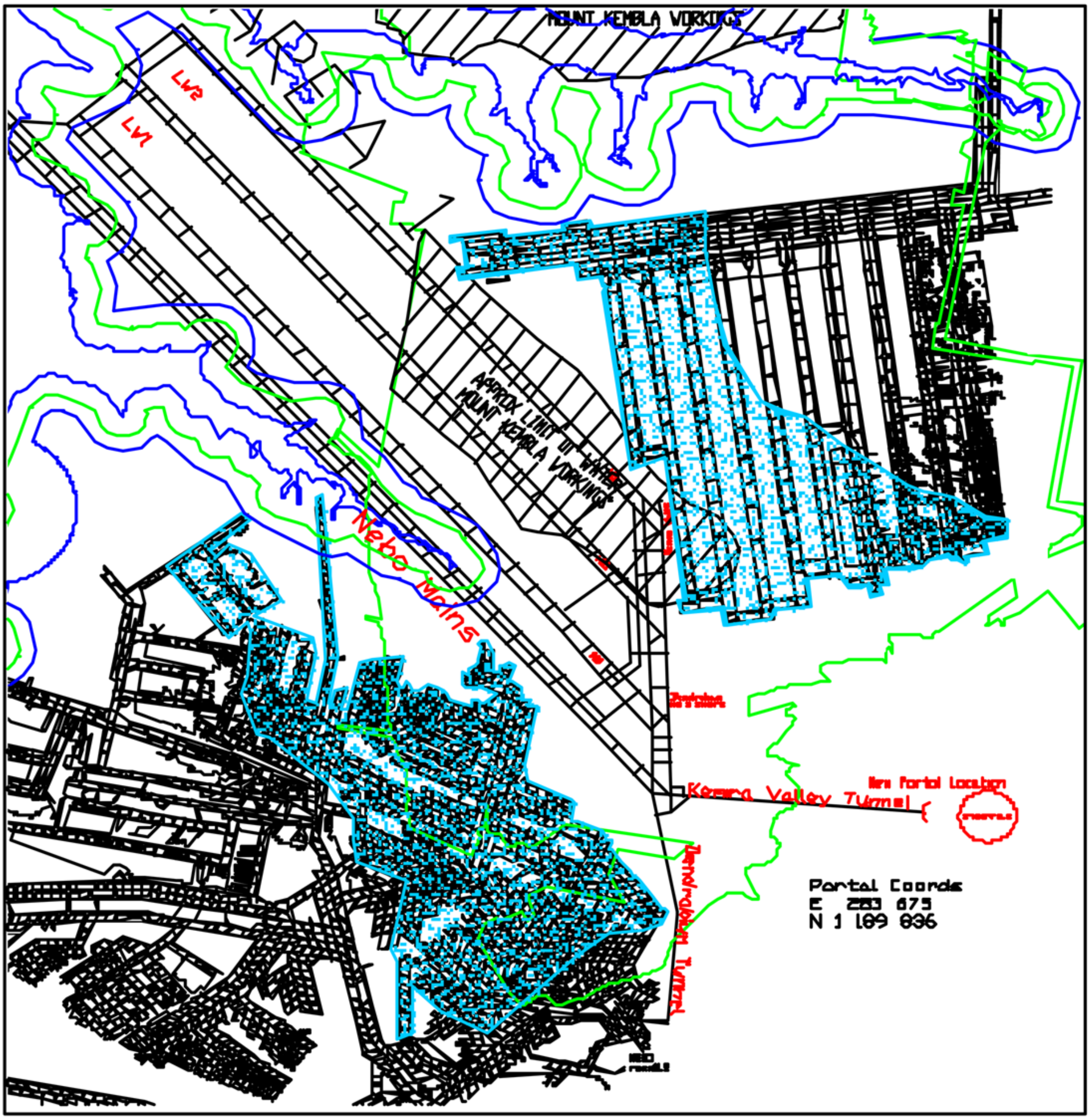


Figure 59. Depiction of the flooded areas of the Kemira Colliery (centre right) and the Nebo area of what is now the Wongawilli Colliery

Flooded areas are shaded blue. The map schematic also shows the Dendrobium Area 1 and 2 longwalls. Not shown are the partially overlying Bulli seam bord and pillar workings of Mt Kembla Colliery. The depiction is 12 years old.[133]

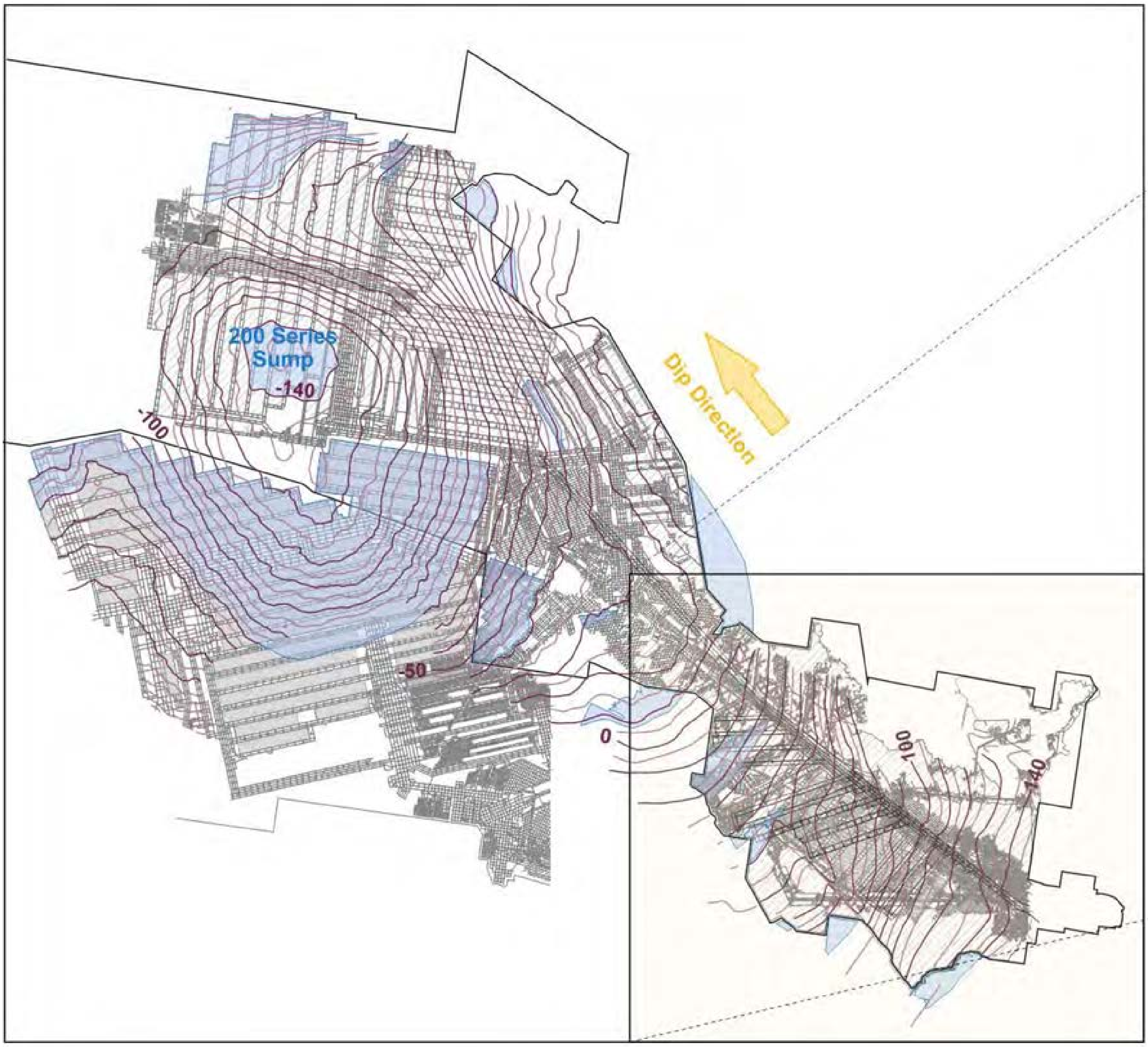


Figure 60. SCT schematic showing the flooded areas of the Russell Vale, Cordeaux-Corrimal and Bulli mines.

The flooded areas will have expanded since this SCT schematic was prepared.[120] The inset highlights the eastern domain of the Russell Vale mine, which is where new mining is proposed. The inset is expanded in Fig. 61.

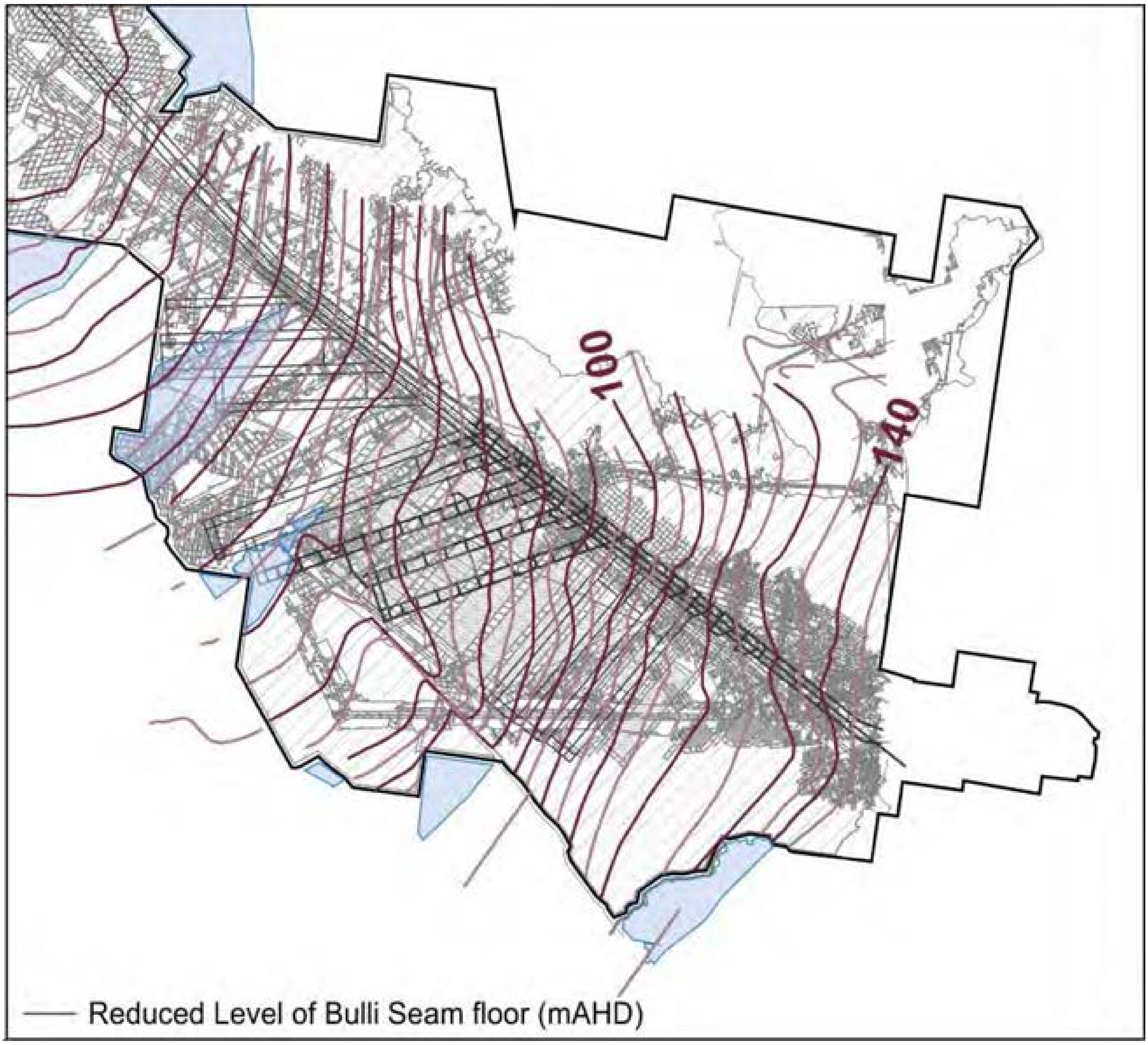


Figure 61. Expanded Fig. 60 inset showing water accumulation areas in the eastern domain of the Russell Vale Colliery**.**