NATIONAL PARKS ASSOCIATION OF NSW
protecting nature through community action

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[redacted]

Committee Secretary,
State Development, Natural Resources and
Agricultural Industry Development Committee,
Queensland Parliament.

4/2/19

Re: Submission for the Mineral Resources (Galilee Basin) Amendment Bill 2018

Dear Dr. Dewar,

Please find attached a submission on behalf of the National Parks Association to the committee for consideration with respect to the Mineral Resources (Galilee Basin) Amendment Bill 2018. While the amendment's primary concern is to limit climate change, the attached submission addresses the related and important consideration of mining impacts to water arsing from mining in the Galilee Basin. Reflecting flawed calculations, optimistic assumptions and limited knowledge, groundwater and surface water impact modelling for the underground coal extractions planned for the Adani Carmichael coal mine is likely to have underestimated the both volumes of water that will be lost and the rate of that loss. Impacts to the water table and watercourses in the mine area, including the Carmichael River, to nearby springs and the GAB areas to the west of the mine will then be underestimated.

Please note the submission has not been properly proof read and may contain typographical errors. Thank you for your consideration of this submission.

Yours sincerely

Dr. Peter Turner
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National Parks Association of NSW

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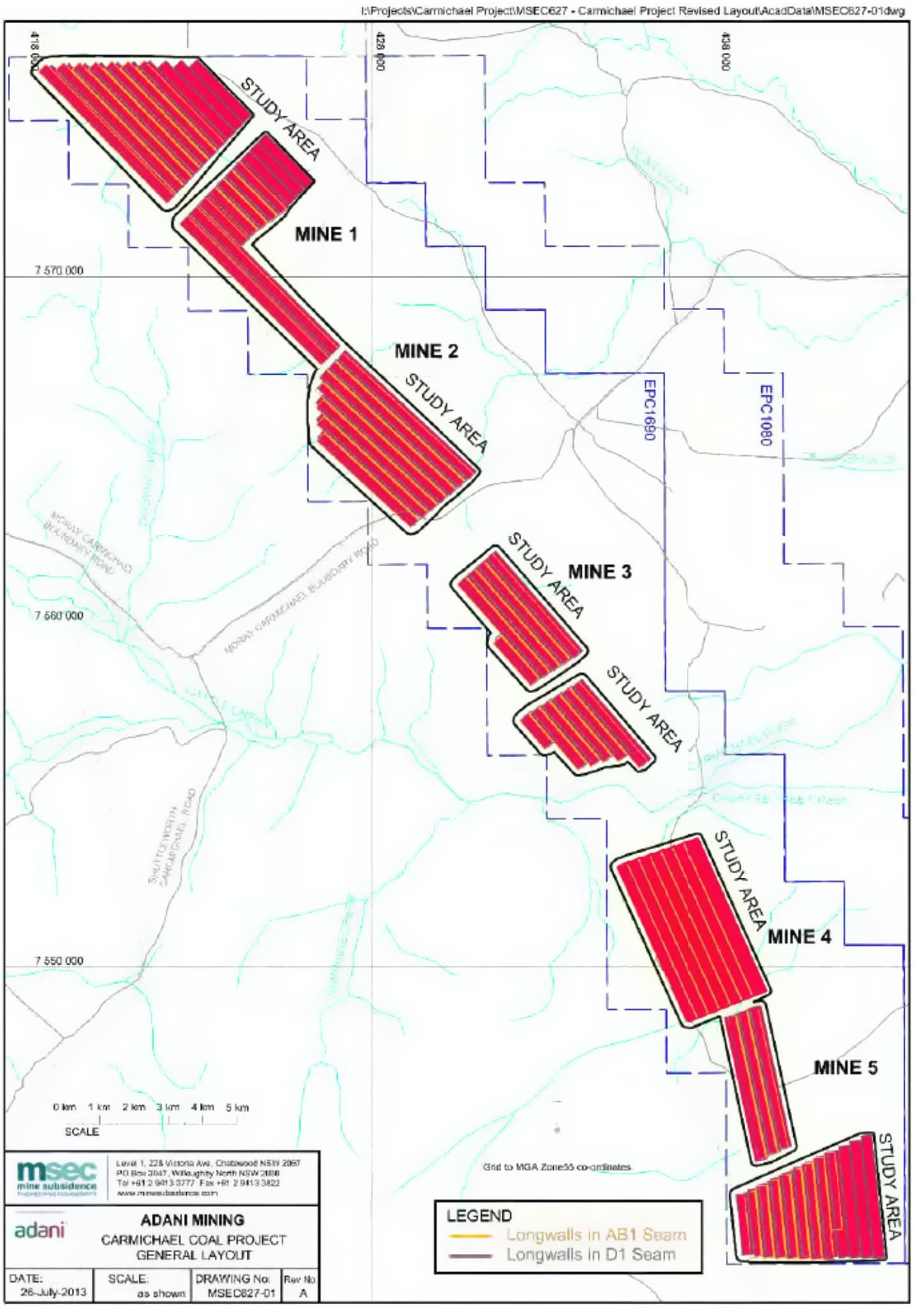
Some concerns regarding the assessment of potential water impacts of planned longwall mining at the Carmichael coal mine



Cover image: Figure 13 within, depicting the intersection of the drainage zone over all of the planned Carmichael mine longwall extractions.

General Disclaimer

Citation: *Some concerns regarding the assessment of potential water impacts of planned longwall mining at the Carmichael coal mine*, P. Turner, NSW National Parks Association, February 2019.

Summary

- Reflecting flawed calculations, optimistic assumptions and limited knowledge, groundwater and surface water impact modelling for the underground coal extractions planned for the Adani Carmichael coal mine is likely to have underestimated the both volumes of water that will be lost and the rate of that loss. Impacts to the water table and watercourses in the mine area, including the Carmichael River, to nearby springs and the GAB areas to the west of the mine will then be underestimated.
- Vital in reliably assessing water losses from an underground coal extraction is a reliable predictive estimate of the likely height of the drainage zone that will form over the extraction. The drainage zone is a fractured rock zone formed over an underground extraction where water drains relatively rapidly downward towards the mine. Within this zone water pressure measuring instruments (piezometers) report no significant pressure. The zone is also referred to as the depressurised zone or the desaturated zone.
- The groundwater impact advice provided by Dr Noel Merrick to Adani and the Queensland Land Court used an equation known as the Ditton geology equation, to estimate the likely height of the drainage zones that will form over the underground extractions planned for the Carmichael coal mine.
- In July 2015 the National Parks Association of NSW wrote the NSW Minister for Planning raising concern that the Ditton equation was obtained from an ill-suited database and accordingly fundamentally flawed. The letter raised several other concerns and made several recommendations, including a recommendation that an alternative equation known as the Tammetta equation should be used to estimate the height of the drainage zone.
- In part an outcome of the concerns raised in July 2015, in late 2017 the NSW government established an Independent Panel for Mining in the Catchment (IEPMC), to examine matters related to mining in the core areas of the Greater Sydney drinking water catchment. Known as the Special Areas, these areas are intended to protect Sydney's water storage reservoirs.
- The first IEPMC report was released on the 20th of December 2018 and among its recommendations is that the Tammetta equation be used for estimating the height of the drainage zone.
- Drainage zone height estimates provided by the Tammetta equation are greater than those from the Ditton equation. For example, the Tammetta equation estimates for the Dendrobium mine are approximately twice those of the Ditton equation. Past assessments by Dr Merrick significantly underestimated the impacts at the Dendrobium mine. In part the establishment of the IEPMC followed confirmation of concerns that the drainage zone reached the surface over the mine, contrary to advice provided by Dr Merrick and his associates.
- The AB seam extractions overlie D seam extractions. There is currently no means of reliably estimating the likely height of the drainage zone formed over double seam extractions, or multi-seam extractions more generally.
- Providing few details, Dr Merrick used an unpublished and unverified means of obtaining an effective extraction thickness, in order to treat the double extractions as single extractions.

- The assumption underlying this means is fundamentally incorrect and the drainage zone height estimates for the double seam extractions are, accordingly, unrealistically low.
- Whereas Dr Merrick finds that the drainage zone will reach the surface over 40% of the planned longwall extractions, application of the Tammetta equation suggests the drainage zone will reach the surface over all of the planned extractions.
- Dr Merrick is dismissive of concerns arising from the prospect of the drainage zone reaching the surface, providing assurances that the drainage zone will seal where it passes through the Rewan formation. Most of the D seam extractions, however, do not appear to be overlain by the Rewan formation and while most of the AB extractions are beneath this formation, the thickness appears to vary considerably.
- The hydraulic conductivity of the Rewan formation varies considerably and overlaps with that of the sandstone formations. This has been attributed to weathering, but may be a manifestation of other (or additional) natural defects, together with composition variation.
- Where the drainage zone passes through the Rewan formation, it is unrealistic to expect the material within to seal and act as an 'aquiclude'. The collapsed and fractured material within the drainage zone is separated from the surrounding strata and is, accordingly, horizontally 'destressed'. Of note, the Rewan does not appear to reach the surface over the planned extractions.
- The intersection of the drainage zone with the surface would result in water that might otherwise have contributed to runoff draining relatively rapidly downward towards the mine. In effect, this would result in a form of enhanced and extended weathering.
- Where streamflow crosses over the extractions, flow dependent volumes will be diverted towards the mine.
- Irrespective of whether or not the surface is intersected and irrespective of whether the surrounding medium is regarded an aquifer or aquitard, groundwater will enter the drainage zone from all sides and, as a consequence, the greater the height of the drainage the greater the surface area over which this happens. That is, the greater the height of the drainage zone the greater the rate of water table drawdown and mine inflow.
- Should mining proceed, a reliable assessment of the height of the drainage zone requires pre- and post-mining installation of piezometer bores over the centreline of planned extractions. The first IEPMC report recommends the use of centreline piezometer bores for the assessment of the height of the drainage zone. This should be partnered with the assessment of lithology and hydraulic conductivity over the centreline.

Contents

1. Introduction and background

Groundwater impact advice provided to Adani and the Queensland Land Court in 2014 and 2015 by Dr Noel Merrick was underpinned by the use of an empirically determined equation known as the Ditton geology equation. This equation offers an estimate of the height of the zone formed over an underground coal extraction where water drains relatively freely and quickly towards the mine (see Figs. 1 and 2). This zone is known as the drainage zone and its height is a key determinant of the groundwater impact of a coal mine. The zone has been found[1] to essentially coincide with the collapsed zone, which is a zone of large downward movement of rock towards the void created by the extraction of coal.

Together with a related equation known as the geometry equation, the geology equation was introduced in 2014 by mining company consultant Mr Steven Ditton, in collaboration with Dr Merrick. Dr Merrick and Mr Ditton have since used these equations for a number of groundwater impact assessments for coal mining project proposals in NSW and Queensland.

In July 2015 the National Parks Association of NSW (NPA-NSW) wrote to the then NSW Minister for Planning raising a number of concerns regarding groundwater impact assessments, including a concern that the Ditton equations were obtained with respect to an ill-suited database. The data used by Ditton do not appear to provide a reliable measure of the drainage zone height. The equations are then fundamentally flawed and unable to provide a reliable predictive estimate of the drainage zone height over an underground extraction (see Figs. 3 to 5 below).

Among a number of recommendations, a key recommendation in the letter of July 2015 was to instead use an alternative equation known as the Tammetta equation. This equation was introduced in October 2012 by hydrologist Paul Tammetta in providing an impact assessment on behalf of Coffey Geotechnics, a consultancy engaged by the operators of the Dendrobium mine near Wollongong. Distinguishing it from the Ditton equations, the underpinning database for the Tammetta equation is carefully constructed and comprised of data suitable for determining an equation for the height of the drainage zone. The Tammetta equation was published in the discipline leading journal Groundwater in 2013 and two subsequent publications by Tammetta in the same journal provided further support from different perspectives. Though not accepted by many in the coal mining community in NSW, Tammetta's work has not been scientifically refuted. Though presented at a conference in 2014, the Ditton equations have not been published in a peer reviewed science journal.

Where coal extraction geometries are aggressive, such as at the Dendrobium and planned for the Carmichael mine, the drainage zone height estimates provided by the Tammetta equation are considerably greater than provided by the Ditton equations. An important concern raised in the July 2015 NPA-NSW letter was that the Tammetta equation suggested that the drainage zone would reach the surface above the Dendrobium mine. The mine is located between the Avon and Cordeaux reservoirs, in an area known as the Metropolitan Special Area. The Special Areas are intended to protect Greater Sydney's water storages.

A significant problem in comparatively assessing the Ditton and Tammetta equations is that the source data for their respective databases is either not readily available or is not publicly available at all. A detailed NPA-NSW report[2] sent to the NSW Minister for Planning in December 2016 finds that the data that is available is consistent with the Tammetta equation. This report includes a detailed review of the publicly available piezometer data from the Dendrobium mine. The report can be obtained at the following link:

https://drive.google.com/file/d/1VLY6dMAZEiQpfGHLVSE227wBQyDESvps/view?usp=sharing

A notable finding[1] 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 centreline 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*". Tammetta later comments "*Despite a thorough search of the literature, no other published data could be found to show significant deviations from the equation*".[3] In developing his equation, Tammetta makes the following observation[1]; "*The strength of the relationship is remarkable given the diverse range of lithologies and void geometries present.*"

Partly an outcome of the concerns raised by the July 2015 NPA-NSW letter, the late 2017 the NSW government established an Independent Expert Panel for Mining in the Catchment (Sydney's catchment). One of the first tasks of the IEPMC was to review the Ditton and Tammetta equations. The panel's first report[4] was released on December 20th 2018 and, with some reluctance, recommends use of the Tammetta equation as a means of estimating the height of the drainage zone. Of note and importance, the IEPMC incorrectly suggest the Tammetta is dimensionally inconsistent; it is not. This and other concerns regarding the IEPMC's comments are being addressed in a follow-up submission to be sent to the panel.

2. Application of the Ditton and Tammetta equations to the proposed Carmichael longwall extractions

2.1 Single seam extractions

Ditton's geology equation is distinguished from his geometry equation in having an additional parameter characterised[5] as an 'effective strata thickness' (Dr. Merrick refers to it as a 'beam thickness'). There is however no substantiated, to science journal standard, evidence to support this characterisation of the additional term and no reliable means of knowing, a priori, what value should be adopted for a greenfield project or for existing extractions for which centreline bore data have not been obtained. The additional parameter is then an arbitrarily adjustable term that in practice amounts to a 'fudge' factor. Tammetta's work indicates that, to within 10%, a local geology adjustment term is not needed.

In providing advice to Adani, Merrick adopts a notably small value of 10 metres for the adjustment term. As Figure 3 below illustrates, with a small value of the adjustment term (t'=10) the Ditton geology equation returns drainage zone height estimates that are similar to those provided by the Tammetta equation and the measured (centreline piezometer) heights of Tammetta's database, where the represented mining geometry parameters (extraction depth, width and height) are relatively large.

Reflecting its flawed nature however, the Ditton geology equation agreement with the measured heights is then poor for other mining geometries in the database. Figures 4 compares the height estimates from the Tammetta equation and the Ditton geology equation, with respect to the

Tammetta database, using the larger (t'=30) adjustment term value used by HydroSimulations for the Dendrobium mine below Sydney's drinking water catchment. Figure 5 compares the estimates provided by the Tammetta equation and the Ditton geometry equation with respect to Tammetta's database.

The geometrical parameters of the proposed Carmichael longwall extractions are large, Where there are only single seam extractions (D seam only) the drainage zone height estimates returned by the Ditton geology equation, with an adjustment term of 10 metres, are some 20 to 30% lower than those of the Tammetta equation (see Fig 6). The Tammetta equation indicates the drainage zones formed over the single seam extractions will reach the surface.

2.2 Double seam extractions

There is additionally considerable cause for concern in the manner in which drainage zone height estimates are obtained by Dr Merrick for the double seam extractions (overlapping AB and D seam extractions). Currently there is insufficient data available from which to develop an equation for multi-seam extractions. In estimating the drainage zone heights over the Carmichael double-seam extractions, Merrick follows unpublished advice provided by Ditton in a 2014 personal communication, for which the following summary is provided in the advice[6] to Adani:

> "*the mining height (T) in the above formulas is replaced by an effective mining height (T') for the upper mined seam that accounts for the additional subsidence caused by mining other seams. This relies on theoretical estimates of subsidence for single or multiple seams. The ratio of the increase in subsidence (due to mining another seam) to the subsidence for a single seam is taken to apply also to the increase in the effective mining height*[4]"

The superscript that terminates the above quote is a reference to a footnote that advises that the method, has only been tested against an unpublished case study for which no reference is provided. That is, the method has not been scientifically validated:

> "*The fractured zone height estimates are considerably uncertain, as there is not yet any rigorously verified method of estimation. The method applied here (as developed by Ditton) rests on only one calibration point.*"[6]

Nor, it appears, has the method been published.

Though only limited information is provided, the description provided by Dr Merrick indicates that the method employed assigns an 'effective mining height' for a notional single seam extraction that would result in the same surface subsidence predicted to occur over a double seam extraction. How the single and double seam subsidence estimates are obtained is not explained and no reference is provided. The method rests on two assumptions:

(i) Subsidence can be reliably predicted.

(ii) The drainage zone height is coupled and directly related to surface subsidence. That is, the drainage zone height has the same dependence on mining geometry (extraction width, extraction height and depth of cover) as that found for surface subsidence.

Both assumptions are problematic.

2.2.1 Subsidence prediction uncertainty

Dr Merricks implicit assumption that subsidence can be reliably predicted is unsound.

The 2011 Pells Consulting report for the then draft Environmental Assessment for the Gujarat NRE 1 expansion provides[7] the following examples of subsidence prediction errors:

- *Appin Colliery LW703 – 33% to 52% over prediction.*
- *Westcliff Colliery LW34 – 10% under prediction.*
- *Tahmoor Colliery LW24A – 290% under prediction.*
- *Tahmoor Colliery LW26 – 100% under prediction*

The 2010 NSW Planning Assessment Commission (PAC; now known as the Independent Planning Commission) panel report for the Bulli Seams Operations proposal notes[8] that the otherwise highly regarded Incremental Profile Method (IPM) under-predicted subsidence over Longwalls 1 to 14 at Metropolitan Colliery by up to 50%.; Waratah Rivulet was badly damaged by the unexpected subsidence.

Longwall 4 in the eastern domain of the Russell Vale Colliery introduced triple seam extraction into the Special Areas of Greater Sydney's drinking water catchment. Prior to the commencement of Longwall 4, the subsidence above the extraction void was originally predicted to be 0.9 metres.[9], [10] In June 2014 SCT reported[11] the Longwall 4 subsidence to be 1.8 metres, following completion of the adjacent Longwall 5; twice that predicted. The June 2014 reported subsidence for Longwall 5 was also 1.8 metres, whereas it was predicted to be 1.2 metres.

In another context, proponent consultant Ross Seedsman comments;

> "*Importantly, there must be a fundamental concern if a worst-case prediction is subsequently found to be lower than what is measured. Both the Holla and MSEC methods claim to be biased towards "worst case" but there are now numerous examples where they have significantly under-predicted*'.[12]

Predicting the impacts arising from subsidence is even more problematic.

In their revised subsidence assessment[13] for the Carmichael project MSEC provide the following caution; "… *the geological setting for the Carmichael project is significantly different from the geological settings in almost all the published literature on subsidence, likely height of fracturing and height of hydraulic connectivity in Australia*".

3. Drainage zone formation and surface subsidence do not have the same dependence on mining parameters

Implicit in Merrick and Ditton's use of an 'effective mining height' is an assumption that the height of the drainage zone and the extent of surface (sag) subsidence have the same dependence on mining geometry; mining depth, width and extraction height. The assumption is ill-considered and contradicted by the available evidence.

While the formation of the drainage zone and surface subsidence are both a consequence of collapse towards the void formed by coal extraction, the two impacts do not proceed in the same way and do not have the same dependency on mining parameters. This is manifested, for example, in the differing dependence on mining depth observed for the two impacts. While the extent of surface subsidence decreases with increasing mining depth, for a given extraction width and thickness, the height of the drainage zone increases with mining depth (this reflected in both the Tammetta equation and the Ditton equations; see Fig. 8).

A further manifestation of differing geomechanical processes, surface subsidence is sensitive to the nature of the underlying rock (see Fig. 7), whereas the height of the drainage zone has been found[1] to be relatively indifferent to lithology (Section X).

Merrick and Ditton may have been unaware of observations made by Tammetta in reviews commissioned by the NSW Department of Planning, of groundwater impact assessments undertaken by GeoTerra for the proposed expansion of the Russell Vale Colliery beneath the Metropolitan Special Area of Sydney's drinking water catchment.

Commenting[14] in December 2013 on considerably greater than expected subsidence over double and triple seam extractions at the Russell Vale Colliery, up to 100% of the extracted height, Tammetta cautions:

> *"Surface subsidence results presented in the PPR indicate that the accrued surface subsidence from multiple seam operations is more than an addition of estimated single seam subsidences. Although a relationship between surface subsidence and the height of desaturation (H) is unavailable (due to the significantly greater dependence of surface subsidence on overburden depth compared to H), the surface subsidence results would suggest that the accrued height of the collapsed zone for multiple seam operations also may be more than an addition of estimated single-seam H values (Tammetta, 2012)"* (PPR is a reference to the proponents then preferred mining proposal).

In his 2013 Groundwater paper[1] Tammetta finds that the collapsed zone, the zone of significant downward strata movement immediately above an extraction, corresponds to the drainage zone.

4. Merrick and Ditton's effective mining height does not provide a means of reliably estimating the height of the drainage over multi-seam extractions

Figure 8 below graphs the drainage zone estimates provided by the Ditton equations and the Tammetta equation with respect to depth of cover and this shows that in each case the drainage height slowly increases with depth. There would appear to be no reason to expect this would not also be the case for multi-seam extractions. On the contrary, Tammetta suggests the drainage zone height increase with depth may be greater than found for single seam extractions.

Troublingly, given the central importance of this parameter, Dr. Merrick doesn't provide the effective mining height values obtained by Ditton's unpublished procedure and used in calculating the drainage zone heights listed in Table 3 of his advice[6] to Adani. There is sufficient information in that table, however, to be to able determine the values that were used, by 'back calculation'. As Figure 6 illustrates, Merrick's effective mining heights decrease with increasing depth, declining from 7.6 to 3.4 to metres.

Drainage zone height estimates calculated using Merrick's effective mining heights are accordingly lowered or suppressed with increasing depth (see Fig. 6). However, this is contradicted by the available data (Fig. 8) and the current understanding of the geomechanics of the formation of the drainage zone. Reflecting the flawed underlying assumption, the Merrick and Ditton effective mining heights are not suitable for use in estimating the height of the drainage zone over multi-seam extractions.

5. Comparison of drainage zone height estimates

Figure 6 below contrasts the very different drainage zone height estimates for the Mine 1 double seam extractions provided by the Ditton geology equation (with an adjustment term, t', of 10 metres) with those provided by the Tammetta equation, using the effective mining heights inferred from Table 3 of Dr Merrick's advice to Adani. Figure 6 includes a trace depicting the effective mining heights inferred from Table 3 of the advice to Adani. The large differences in the drainage zone height estimates for the double seam extractions provided by the Ditton equation and those of the Tammetta equation, reflect the implausible insensitivity of the former to variations in extraction height (or thickness).

The Tammetta equation suggests the drainage zone would reach the surface for all but the AB+DLW107N, AB+DLW106S and AB+DLW107S double seam extractions (labelled here with respect to the overlying AB longwall). These are the deepest Mine 1 extractions and have the smallest 'effective mining heights', being 3.95, 3.78 and 3.38 metres respectively. Noting the extraction height of the D seam alone is 3.35 metres, these depth determined heights point to the implausibility of the Ditton 'effective mining height' method.

As discussed above, Merrick and Ditton's 'effective mining height' is not suitable for the calculation of drainage heights over multi-seam coal extractions. In the absence of an equation for multiple seam extractions, in June 2014 Dr Ken Mills of consultancy Strata Control Technology (SCT) added together the extraction heights of each overlapping extraction and used Tammetta's equation to then estimate the drainage heights over the multi-seam extractions of the proposed expansion of the Russell Vale Colliery.[11] Figure 9 below shows the drainage zone heights returned by the Ditton geology equation and the Tammetta equation using the summed AB and D mining heights (5.95 metres) proposed for Mine 1. The Tammetta equation again suggests the drainage zone would reach the surface over all of the proposed longwall extractions.

Figure 10 contrasts the drainage zone height estimates from the Ditton geology equation using an adjustment term of 10 metres and the effective mining heights that appear to have been used by Merrick for Mine 1, with the heights obtained using the summation of the proposed Mine 1 AB and D seam mining heights. The Tammetta equation is used to provide the same comparison in Figure 11.

Figure 12 compares the estimated drainage zone height obtained from the Tammetta equation using the summed AB and D seam mining heights, with the summation of the drainage zone height estimate for the AB seam and the drainage zone height estimate for the D seam. The latter drainage zone height estimate is approximately 15% lower than the former; Tammetta suggests (see quote above) the latter is likely to be an underestimate. The drainage zone height estimate obtained by adding together the height estimates returned by the Tammetta equation, using the average cover depths listed in Table 3 of Merrick's advice to Adani, for the AB seam extraction and that for the D seam extraction again suggests that the drainage zone would reach the surface over all of the proposed longwall extractions. This is depicted in Figure 13. Figure 14 is Dr Merrick's depiction of the longwalls where the drainage zone reaches the surface, based on his calculations.

6. Intersection of the drainage zone with the surface and the role of the Rewan formation

Commenting in advice[15] to the Queensland Land Court in February 2015 on the implications of the drainage zone reaching the surface over the proposed underground mining, Dr Merrick suggests:

> "*This is not of major concern, as the extra near-surface fracturing would allow more rainfall infiltration (until the cracks in the ground are sealed) than would occur naturally, thus offsetting potential lowering of the water table*."

In making this statement Dr Merrick evidently assumes (no calculations are provided or referenced) that an increased 'recharge' rate arising from runoff and stream flow being diverted into subsidence cracks would equal the rate of water drawdown towards the depressurised void created by coal extraction. This would appear to be an optimistic expectation.

Experience in the Sydney basin is that even if no fracturing takes place, the rate of pressure loss and drainage towards the 'sink' of the extraction void is typically higher that the available rate of recharge. Dr Merrick evidently assumes that, within the Rewan formation, the drainage zone will 'self-heal' and so limit water drainage from above, creating a 'perched' water table. Merrick suggests the following in his advice to the Queensland Land Court:

> "*As most of the fractured zone would lie within the Rewan Formation, there would be negligible enhanced vertical hydraulic conductivity in this part of the fractured zone because the fine materials in this formation would tend to close the fractures.*"

Bearing in mind that the drainage zone would extend vertically, the revised geological interpretation by Xenith in October 2012 suggests (see Fig. 15) that most of the D seam extractions would not be overlain by the Rewan formation. Figure 15 also suggests that while it appears that the AB seam extractions would largely be overlain by the Rewan formation, the thickness of cover would vary considerably. The Rewan does not reach the surface over the proposed extractions. It's not known how representative this cross-section is of the lithography over the planned extractions. Nor is it known if the lithography has been determined over the centre of the proposed extractions.

6.1 The Rewan Formation

Dr Merrick's assumption of 'self-healing' of the Rewan formation echoes that often put forward by mining company consultants in providing groundwater assessments in support of proposed mining beneath the Special Areas of Sydney's drinking water catchment. The argument made in the context of Sydney's catchment is that a layer varying in thickness from 10 to 15 metres and typically 100 to 150 metres below the surface known as the Bald Hill Claystone, (BHC) acts as an aquitard that hinders drawdown and near surface water loss. Recent work[16] highlights, however, that this layer has a complex and variable composition and, accordingly, character. Though regarded as an aquitard, the BHC has a location dependent range of vertical conductivities similar to and overlapping those of the adjoining (above and below) sandstone formations. This also appears to be the case for the Rewan formation.

In a 2012 groundwater assessment for the Dendrobium coal mine, located in the Metropolitan Special Area, Tammetta reviews a comprehensive (unmined) local area data set and finds that:

> *"This suggests that in the top 200m of an unmined rock profile in the mine area, the bulk hydraulic conductivity of a large rock volume is controlled mostly by open defects and fracture flow. Below 200m, the hydraulic conductivity is controlled mainly by the rock matrix. This is not to say that defect apertures will all be closed below 200m depth. In fact, it will be highly likely that some defects will be open below 200m depth, but not in the same numbers nor aperture widths as at shallower depths, unless significant structures exist such as large igneous intrusions".*

Consultants Parsons Brinckerhoff confirm this finding in a 2014 study[17] of mining impacts at Dendrobium. That is, irrespective of lithology and contradicting aquitard assumptions, vertical hydraulic conductivity over the first 200 metres below ground is determined by natural fractures and joints.

The Bald Hill Claystone would appear to be, typically, ten to twenty times thinner than the Rewan formation, however there would appear to be no reason to assume that defects would not play a similar role in the conductivity characteristics of the Rewan formation. Consistent with this, the SVK acid mine drainage assessment[18] finds that 'weathering' effects persist to a depth of 200 metres.

Showing little discrimination across sandstone, siltstone, mudstone and claystone, the hydraulic conductivities given in Tables 6, 7 and 9 of the November 2013 Carmichael mine hydrology report[19] provided by consultants GHD show an overlapping range of values between $3x10^{-0}$ (i.e. 3) and $5x10^{-5}$ metres/day across the listed formations. The Rewan formation over the Carmichael underground mining project area appears to be complex in character and is reported to be weathered to varying extents. In reviewing GHD's groundwater modelling in October 2013 consultants URS observe[20] the following:

> "*It is noted that the hydraulic conductivity values for the Rewan Group ranged over 4 orders of magnitude, 9.5 x 10^{-5} to 2.9 x 10^{-1} m/day. This indicates the variation in permeability in the shallow weathered outcrop and the pristine Rewan Group sediments at depth.*"

And:

> "*It is considered that the Rewan Group (comprising layers of sandstone, mudstone and conglomerate) is the basal aquitard for the GAB. Aquifer tests indicate high variability within this unit, indicating interbeds of sandier lithology within the claystone and mudstone of this unit on site.*"

As a comparison, the calibrated horizontal pre-mining conductivities reported[21] by Tammetta for the uppermost formation (Hawkesbury Sandstone) over the Dendrobium mine to the base of that below the Bald Hill Claystone (Bulgo Sandstone; above the mine) range from $1.2x10^{-1}$ metres/day in the upper formation to $1.7x10^{-3}$ metres/day in the lower, while the vertical conductivities range from $7.5x10^{-4}$ to $1.4x10^{-4}$ metres/day. Typical Bald Hill Claystone horizontal and vertical conductivities are 'mid-range' in being respectively $1.2x10^{-2}$ and $3.6x10^{-4}$ metres/day.

In his advice[22] to the Queensland Land Court Dr Merrick suggested self-sealing of the Rewan formation was assured because "*90% of the Rewan Formation comprises low permeable fine grain materials*". GHD attribute the areas of high conductivity in Rewan the formation, found to depths of 200 metres[18], to weathering associated with outcropping. Relatively high conductivities are found in the Bald Hill Claystone, in the absence of outcropping. Irrespective of the reason for the higher conductivity measurements, Dr Merrick's comments would suggest any naturally occurring defects should have rapidly self-sealed' and areas of relatively high conductivity should not persist. Dr Merrick's suggestion of self-healing, presumably forming an aquiclude, are contradicted by the overlapping ranges of hydraulic conductivities in the Rewan formation.

In testimony to the Queensland Land Court on behalf of Adani, Mr John Bradley advised that bore holes narrowed and could close within one or two drilling shifts due to the presence of swelling clays. The tendency to closure will be a consequence of horizontal stress within the surrounding strata driving extrusion into the bore. This process would not, however, be expected to seal the drainage zone formed over a 310 metre wide coal extraction.

The collapsed and fractured material within the drainage zone is separated from the surrounding strata and is, accordingly, free of the horizontal stresses within those surrounds. Given the complex nature of the Rewan formation and noting pre-mining areas of relatively high conductivity to depths of 200 metres, it would be unsafe to assume that the drainage zones formed across the Rewan formation and reaching the surface over the planned mining will self-seal. The effect of the drainage zone passing through the Rewan formation to reach the surface could reasonably be regarded as a form of enhanced seam to surface weathering.

In considering seam to surface connected fracturing in their revised subsidence assessment[13] of July 2013 for Adani, MSEC point to a mine operating below the Isaac River as an example where aquitard material prevents significant inflows. Unfortunately, other than noting the mine is in a different geological setting, the mine is not identified and no further details or references are given. The consultants point out the following, however:

> "*The difficulty in assessing the likely height of fracturing and height of hydraulic connectivity at this project is that the geological setting for the Carmichael project is significantly different from the geological settings in almost all the published literature on subsidence, likely height of fracturing and height of hydraulic connectivity in Australia.*"

MSEC look to the Cook Colliery for guidance, but note:

> "*There is no data available from Cook Colliery however, in relation to fracture height assessments or permeability changes in the overburden.*"

Of relevance, contrary to past assessments provided by Dr Merrick, the 310 metre wide extractions at the Dendrobium mine have resulted in seam to surface depressurisation[4], [23] across the Wombarra Shale, Stanwell Park Claystone and Bald Hill Claystone strata over the extractions. The presence of these 'aquitards' has not prevented seam to surface drainage and large 'off-panel' near surface drawdowns.[2] There is no indication of self-sealing. Also contrary to past advice provided by Dr Merrick, the impacts are consistent with Tammetta equation predictions of the drainage zone reaching the surface over the mining.[2]

In providing groundwater impact advice to Waratah Coal in 2013[24] and Adani in 2014[6], Dr Merrick provides the following comments:

> "*The strata movements and deformation that accompany subsidence will alter the hydraulic and storage characteristics of aquifers and aquitards. As there will be an overall increase in rock permeability, groundwater levels will be reduced either due to actual drainage of water into the goaf or by a flattening of the hydraulic gradient without drainage of water (in accordance with Darcy's Law).*"

While the puzzling reference to flattening of the hydraulic gradient without water loss is not explained in either report, the comment acknowledges that the planned mining will lower groundwater levels. The drawdown appears likely to be significantly greater, more rapid and more extensive than Dr Merrick's assessment would suggest.

7. Erroneous assessment of the drawdown at Doongmabulla Springs

Compounding the concern of drawdown underestimation as a consequence of drainage zone underestimation, Dr Merrick makes two fundamental mistakes in his assessment[25] of the drawdown impact at Doongmabulla Springs:

(i) Defining of the water pressure head 'driving' the springs with respect to the water table instead of the surface discharge point. As a consequence of this fundamental mistake, the pressure supporting the springs is significantly overestimated by Dr Merrick.

(ii) Misunderstanding the implications of his application of Darcy's equation in assessing the consequences of drawdown at Doongmabulla Springs.

These mistakes are clearly explained[26] by Prof. Adrian Werner in his advice to the Land Court and are the subject of a 2017 Journal of Hydrology publication.[27] Dr Merrick effectively acknowledges the mistakes in answering subsequent questions during the Land Court hearing. The driving pressure head is low with respect to the discharge point and the springs are accordingly likely to be vulnerable to even the relatively minor drawdown suggested by GHD and Dr Merrick. The higher and more extensive the drainage zone, the greater, more rapid and more extensive the surface water, near-surface water and deeper groundwater impacts.

8. Conclusion

The available information and evidence suggest that key assumptions and calculations made by Merrick in providing advice on the potential groundwater and surface water impacts of the underground mining proposed as part of the Carmichael project, are ill-founded. Drawdown, baseflow loss and mine inflow rate estimates based on their assumptions and calculations are accordingly likely to have been underestimated. Impacts to the watercourses in the mine area, including the Carmichael River, nearby springs and on the GAB areas to the west of the mine will be underestimated.

In their November 2013 hydrogeology report, consultants GHD provide the following advice:

> "*Predicted maximum water table impacts in the underground mining area (i.e. towards the west of the Mine Area) and outside of the proposed open cut areas are less pronounced since the near surface units will not be drained directly. Maximum water table impacts outside of the proposed open cut areas are typically between 20 and 50 m.*"

This conclusion was based on their assessment of fracturing, which assumed that seam to surface fracturing would occur for only 20% of the longwall extractions.[15] Dr Merrick's flawed assessment in the advice to Adani of December 2014[6], found that the drainage zone would reach the surface for 42% of the longwall extractions. The Tammetta equation based assessment provided here finds the surface will be intersected over each of the longwalls. At approximately 87 square kilometres (calculated using a width of 311 for each extraction and the average longwall length for each mine), the total surface footprint of the longwall extractions of the five underground mines is substantial. The near surface groundwater units will be directly drained.

As noted above, MSEC advise[22] that if "*less permeable materials are only present in the collapsed zone and highly fractured zone then these layers do not provide a seal against downward flowing water towards the mine void.*" The Rewan formation does not appear to reach the surface over any of the planned extractions (Fig. 15). Irrespective of the presence or otherwise of the Rewan formation and irrespective of whether or not the drainage zone reaches the surface, void formation ensures the water table will be lowered. Unknown is the rate, magnitude and lateral extent of water table lowering.

The intersection of the drainage zone with the surface would result in water that might otherwise have contributed to runoff draining relatively rapidly downward towards the mine. Where streamflow crosses over the extractions, flow dependent volumes will be diverted towards the mine. Additionally, irrespective of whether or not the surface is intersected and irrespective of whether the surrounding medium is an aquifer or aquitard, groundwater will enter the drainage zone from all sides and, as a consequence, the greater the height of the drainage the greater the surface area over which this happens. That is, the greater the height of the drainage zone the greater the rate of drawdown and mine inflow.

Of note, water quality is degraded by passage over fresh rock fractures, which results in the dissolution of metal salts.[28]

Of relevance, the December 2016 NPA review[2] finds a number of problematic aspects of the groundwater impact and fracture zone assessments undertaken by HydroSimulations for the Dendrobium mine. Under-evaluated and misrepresented by the consultants, the evidence points to a significant decline of the groundwater regime between the Avon and Cordeaux reservoirs. Significant surface water losses also appear likely to be occurring. An estimate by the Independent Expert Scientific Committee suggests 40% of the inflow to the Dendrobium mine will be surface water. Of note, though the Dendrobium mine has an extensive groundwater monitoring (piezometer) network, the placement of instruments is such that it provides limited information on the height of the drainage zone over the mining and the extent to which groundwater interaction with the reservoirs and streams has changed.

Reliable knowledge of the height of the drainage zone is an essential prerequisite in assessing the likely ground and surface water impacts of underground mining. Should the planned mining proceed, in the absence of a reliable means of predictively estimating the height of the drainage zones that will form over the multi-seam longwall extractions of the Carmichael mine, in would be necessary to install pre and post-mining centreline piezometer bores over several representative extractions, both single and double. The interval between instruments should be no more than 25 metres. The need for before and after mining installations arises because piezometers installed in bores over proposed extractions typically do not survive subsequent undermining.

In its first report the IEPMC recommends pre- and post-mining installation of centreline piezometers to assess the height of the drainage zones at the Dendrobium and Metropolitan coal mines in Sydney's drinking water catchment. The NPA recommended the use of centreline piezometers in the letter sent to the NSW Planning Minister in July 2015.

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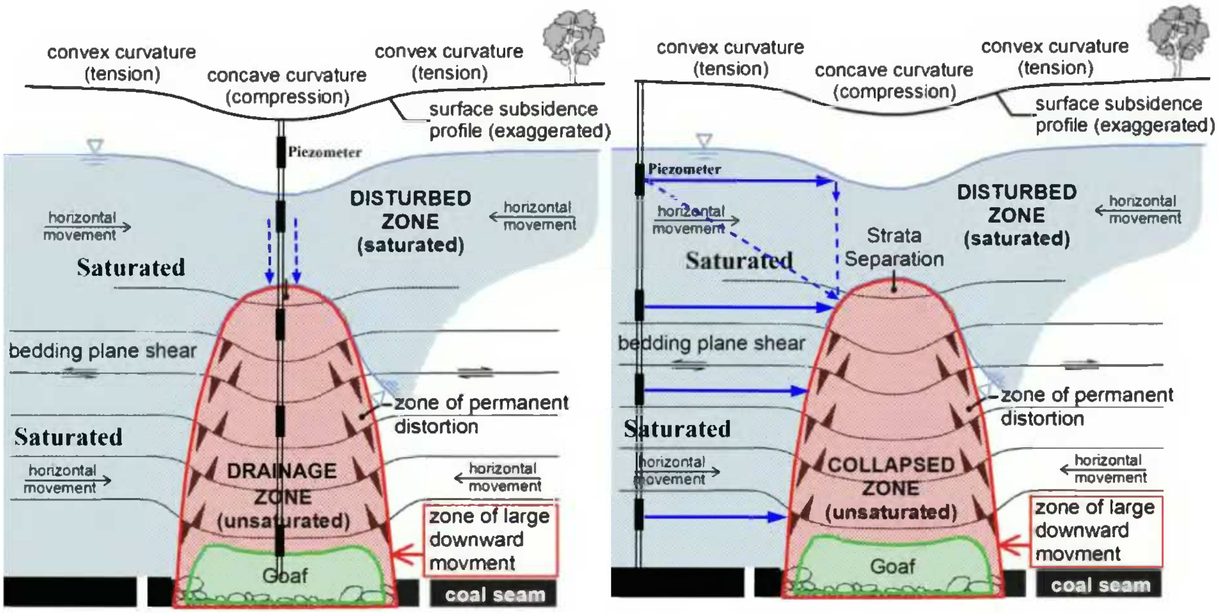
Figures



(a) (b)

Figure 1. Depiction of the cross-section profile of a drainage zone

Depiction of the cross-section profile of the drainage zone formed over an underground coal extraction. The drainage zone is a zone of connected rock fractures within which water drains relatively freely towards the void (goaf) created by coal extraction. The zone is also known as the depressurised zone and desaturated zone, and has been found[1] to correspond the collapsed zone. The collapsed zone is a zone of significant downward movement of strata towards the void. Given differences in horizontal and vertical hydraulic conductivities in the rock beyond the drainage zone of one to two or more orders of magnitude, water enters the drainage zone more rapidly and extensively from the side than from above (unless the zone has reached the surface or the surface fracture network caused by subsidence). Figure 1(a) shows a ‘centreline’ piezometer bore, while Figure 1(b) shows an ‘off-panel’ piezometer bore.

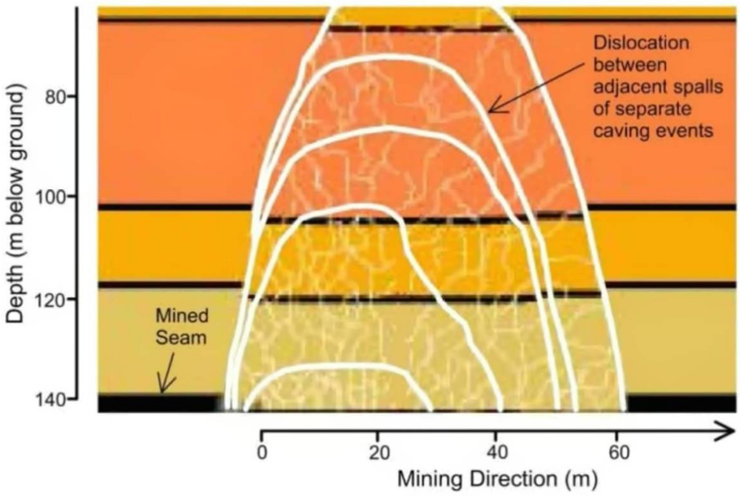


Figure 2(a). Development of the drainage (collapsed) zone

Development of the drainage (collapsed) zone across formations as a longwall extraction progresses.[29] With an underpinning database representing "*claystones, coarse-to-fine sandstones (lithic and quartzose), and limestones, in widely varying strengths, grain sizes, compositions, layer thicknesses, and recurrence patterns down the profile.*"[1], Tammetta finds the height of the drainage zone is relatively insensitive to lithology. Where the Rewan formation is relatively thick over the planned extractions (see Fig. X), Tammetta's equation may underestimate the drainage zone height.

Figure 2(b). Cut-away view of the developing drainage zone

Cut-away view[29] 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.

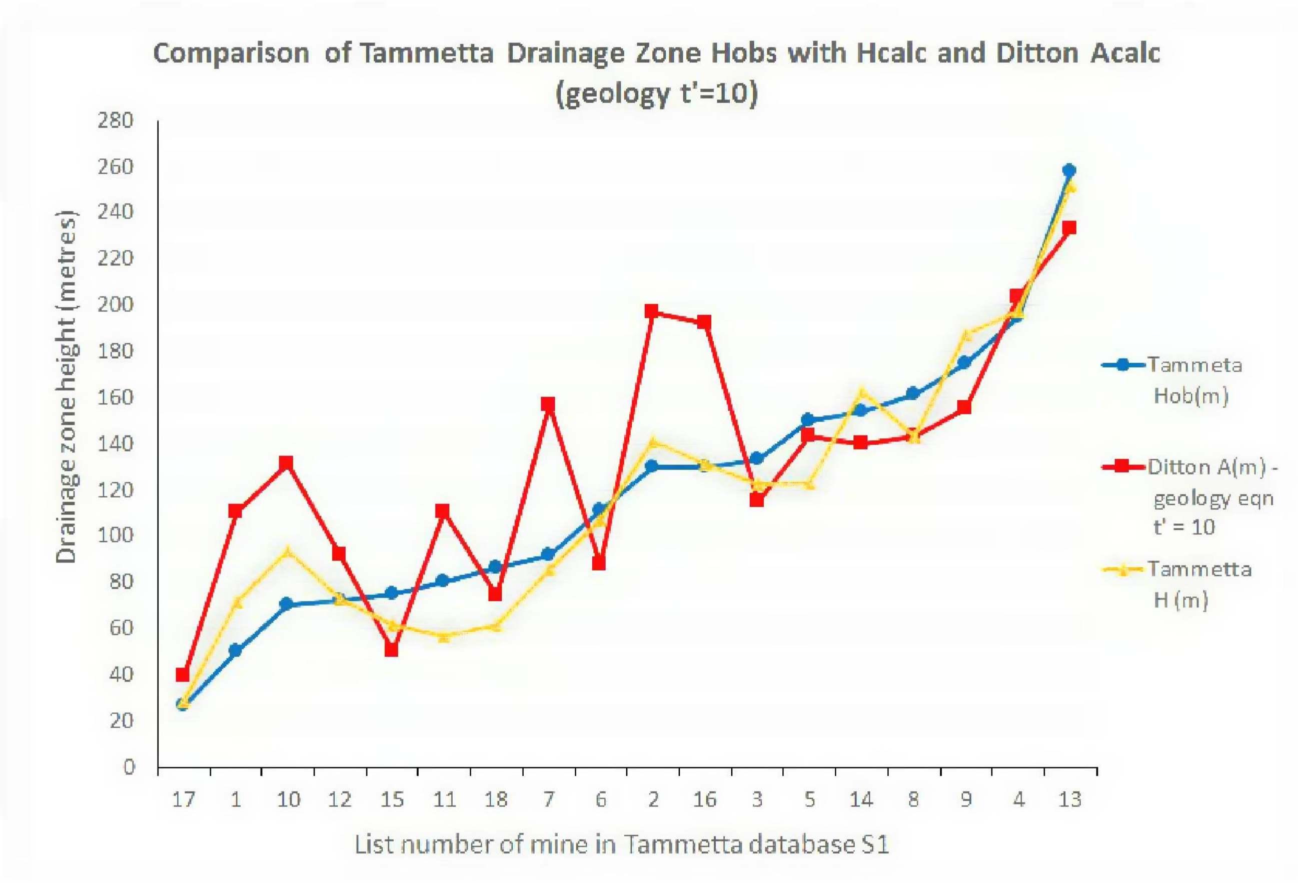


Figure 3. Comparison of drainage zone heights from Ditton geology equation with t'=10 and Tammetta's equation with respect to Tammetta's S1 database.

Providing the basis for his empirical equation, Tammetta's S1 database[30] is comprised solely of piezometer data obtained from bores sunk over the centreline of underground coal extractions. Centreline piezometer data provides the most reliable means of determining the height of the drainage zone.

Merrick's use of a relatively small value for the adjustment term of Ditton's geology equation, the drainage zone height estimates from that equation are similar to those of the Tammetta equation, where the mining geometry is relatively large. The agreement is however poor for smaller mining geometries.

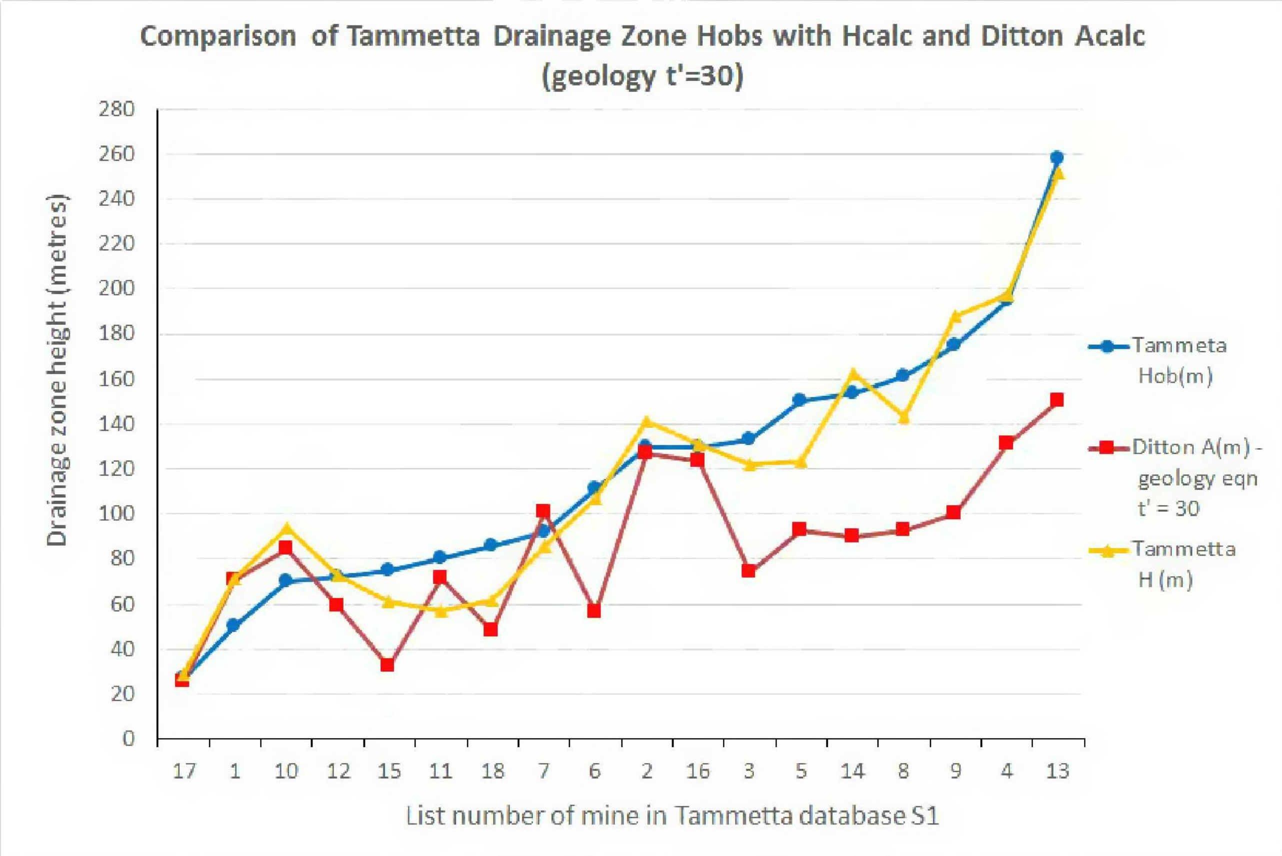


Figure 4. Comparison of drainage zone heights from Ditton's geology equation with t'=30 and Tammetta's equation with respect to Tammetta's S1 database.

Providing the basis for his empirical equation, Tammetta's S1 database[30] is comprised solely of piezometer data obtained from bores sunk over the centreline of underground coal extractions. Centreline piezometer data provides the most reliable means of determining the height of the drainage zone.

Merrick used an adjustment term of 30 in using Ditton's geology equation for recent assessments for the Dendrobium mine, located below the Metropolitan Special Area of Sydney's water catchment. The agreement between the drainage zone height estimates from the Ditton equation and those from the Tammetta equations is generally poor.

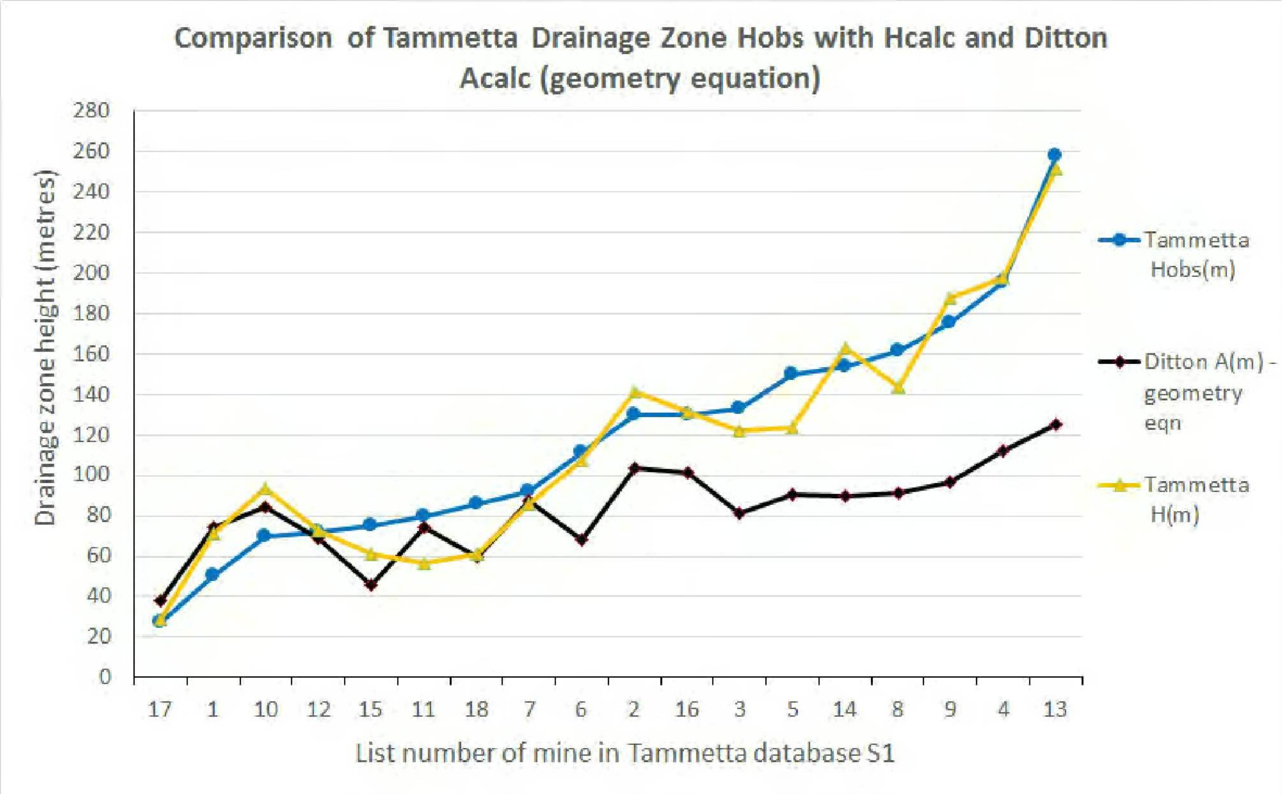


Figure 5. Comparison of drainage zone heights from Ditton's geometry equation and Tammetta's equation with respect to Tammetta's S1 database.

Providing the basis for his empirical equation, Tammetta's S1 database[30] is comprised solely of piezometer data obtained from bores sunk over the centreline of underground coal extractions. Centreline piezometer data provides the most reliable means of determining the height of the drainage zone.

The agreement between the drainage zone height estimates from the Ditton geometry equation and those from the Tammetta equations is generally poor and the disparity becomes more pronounced for larger mining geometries.

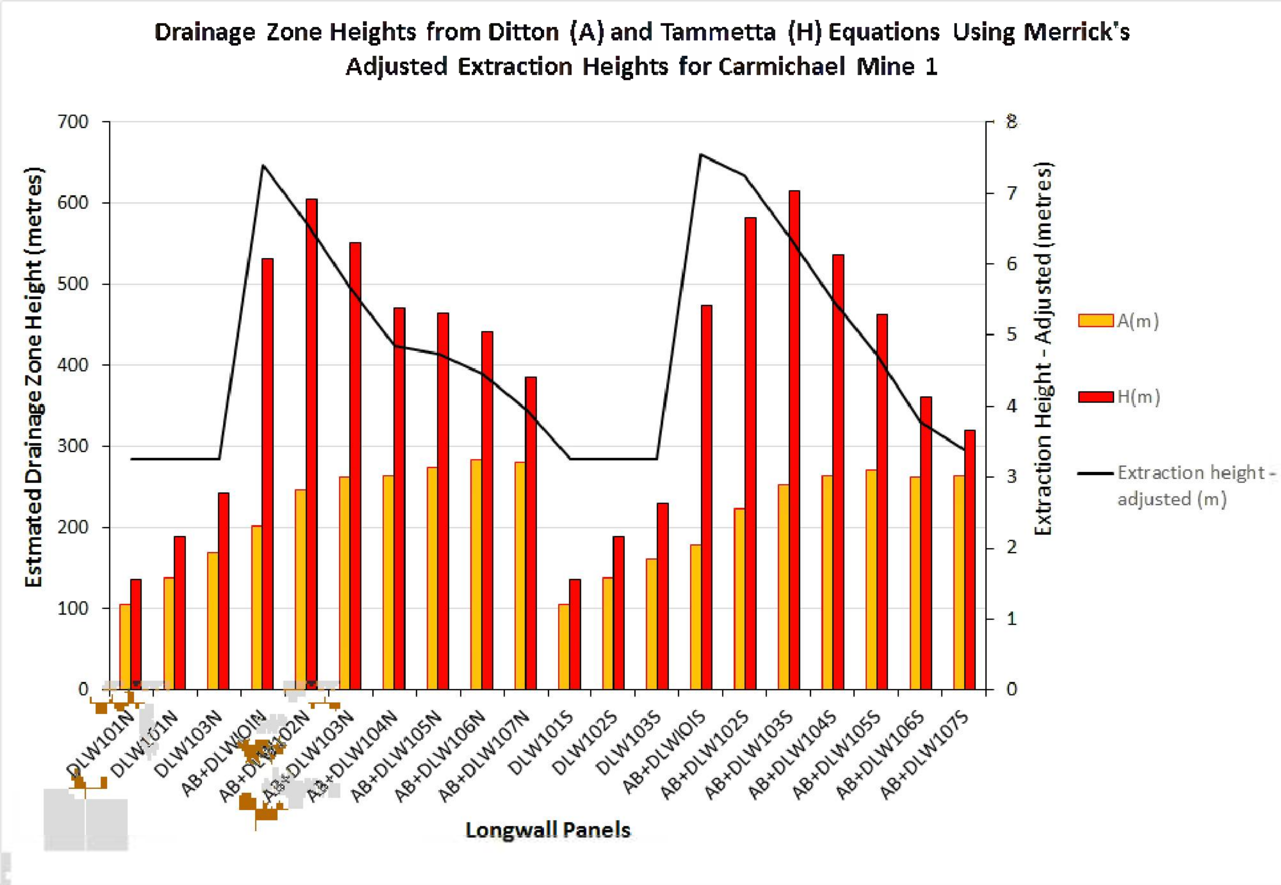


Figure 6. Comparison of Mine 1 drainage zone heights obtained from the Ditton equation (A) and the Tammetta equation (H), using Merrick's adjusted extraction thickness for the double extractions.

Shown as a black line in the graph, with respect to the right hand axis, are the adjusted extraction thicknesses (cutting heights) for the double seam extractions (AB seam extractions over the D seam extractions labelled with respect to the AB seam) that appear to have been used by Merrick in advice given to Adani in December 2014.[6] Implausibly, Merrick's 'effective mining heights', or adjusted extraction thicknesses, decrease with depth. The horizontal sections of the line mark the 3.25 metre D seam extractions proposed for Mine 1.

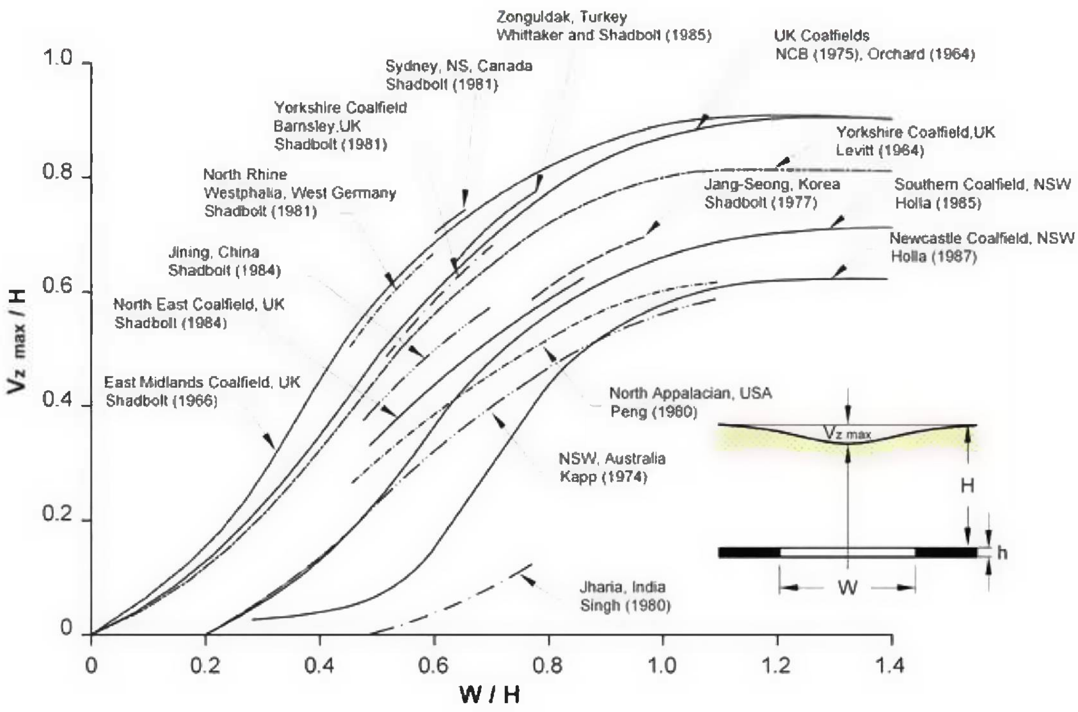


Figure 7. Characteristic surface subsidence curve

The characteristic surface subsidence curve is obtained from the ratio of surface subsidence to mining height and the extraction panel width to depth ratio, for isolated extractions at various locations. The graph reflects the sensitivity of surface (sag) subsidence to the nature of the underlying strata. Originally from a 1989 book by Whittaker and Reddish[31], the figure appears as Figure 3.14 in Prof. Jim Galvin's 2016 book[32] on coal mine engineering.

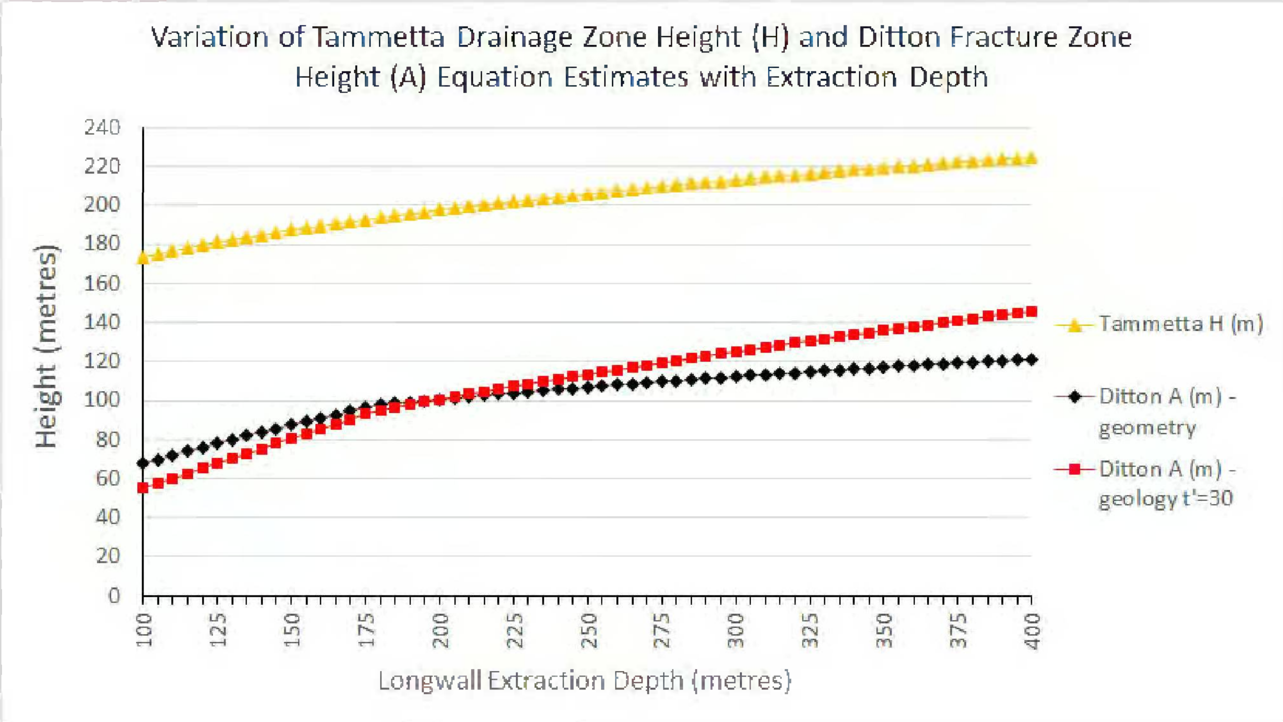


Figure 8. Dependence of the Ditton equation estimates and the Tammetta equation estimates with depth below ground.

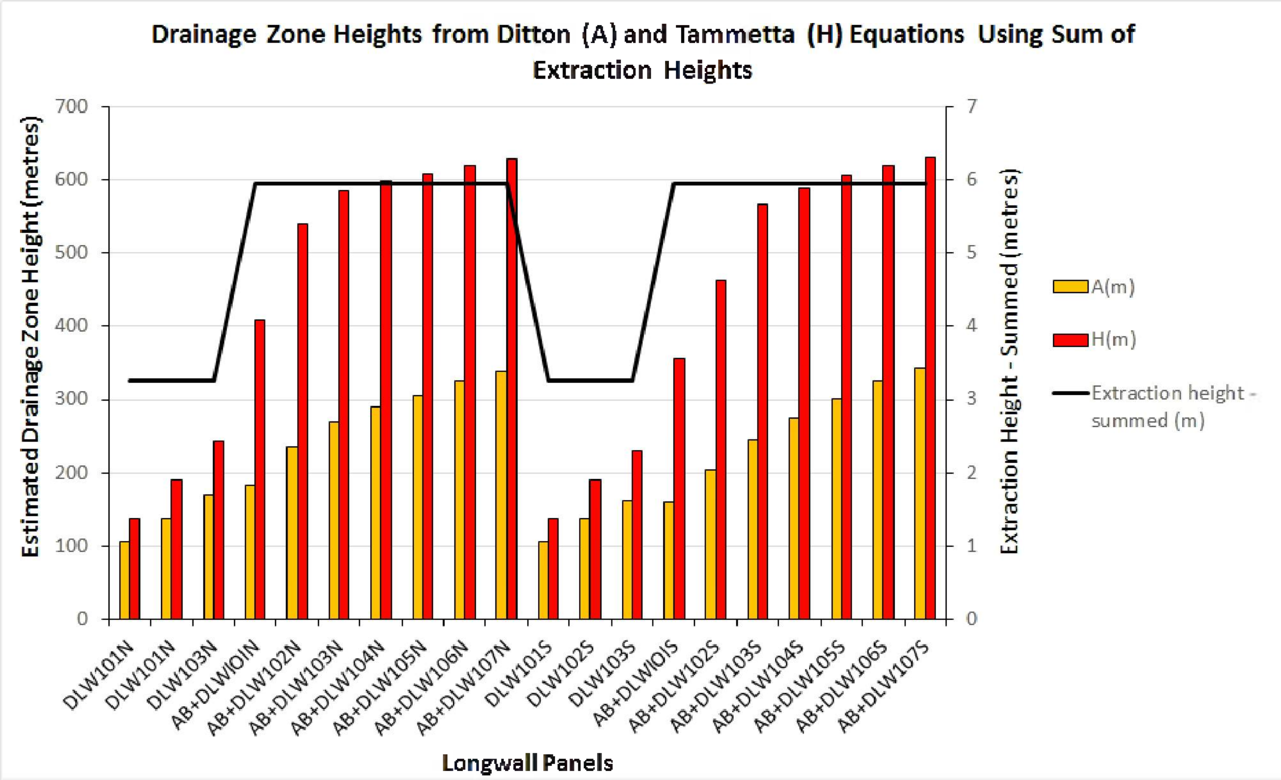


Figure 9. Comparison of Mine 1 drainage zone heights obtained from the Ditton equation (A) and the Tammetta equation (H), using the summation of the individual heights for the double extractions.

Shown as a black line in the graph, the effective extraction thickness (cutting height) for the Mine 1 double seam extractions (AB seam extractions over the D seam extractions labelled with respect to the AB seam) is taken to be the 5.95 metres sum of the individual seam extraction thickness (cutting height) of 2.7 metres for the AB seam and 3.25 metres for the D seam.

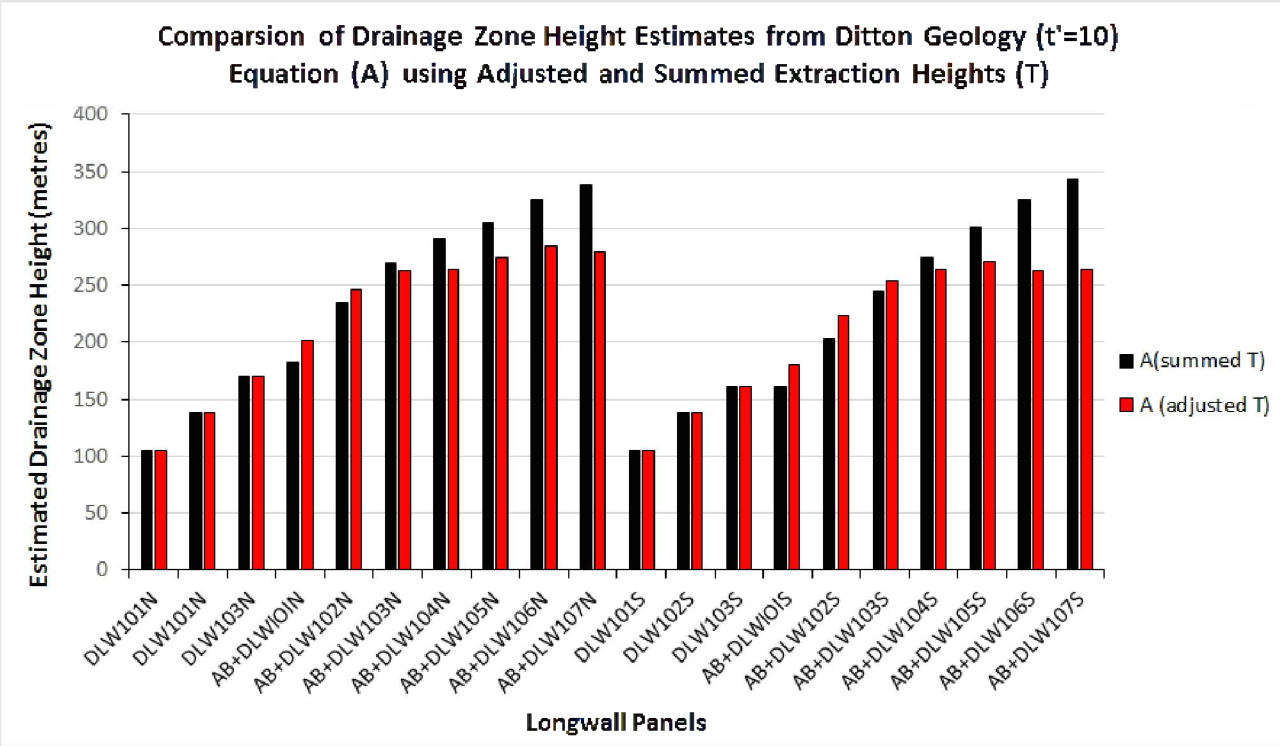


Figure 10. Comparison of Mine 1 drainage zone heights returned by the Ditton geology equation (t'=10) using summed mining heights and Merrick's adjusted mining height.

The graph compares estimates returned by the Ditton geology equation, with an adjustment term of 10 metres, using an 'effective' extraction thickness (cutting height) for the double seam extractions of 5.95 metres, this being the sum of the average thickness of the individual seam extractions (2.7 for the AB seam and 3.25 metres for the D seam), with the drainage zone heights returned by the Ditton equation using the effective extraction thickness evidently used by Merrick in December 2014 advice to Adani.[6]

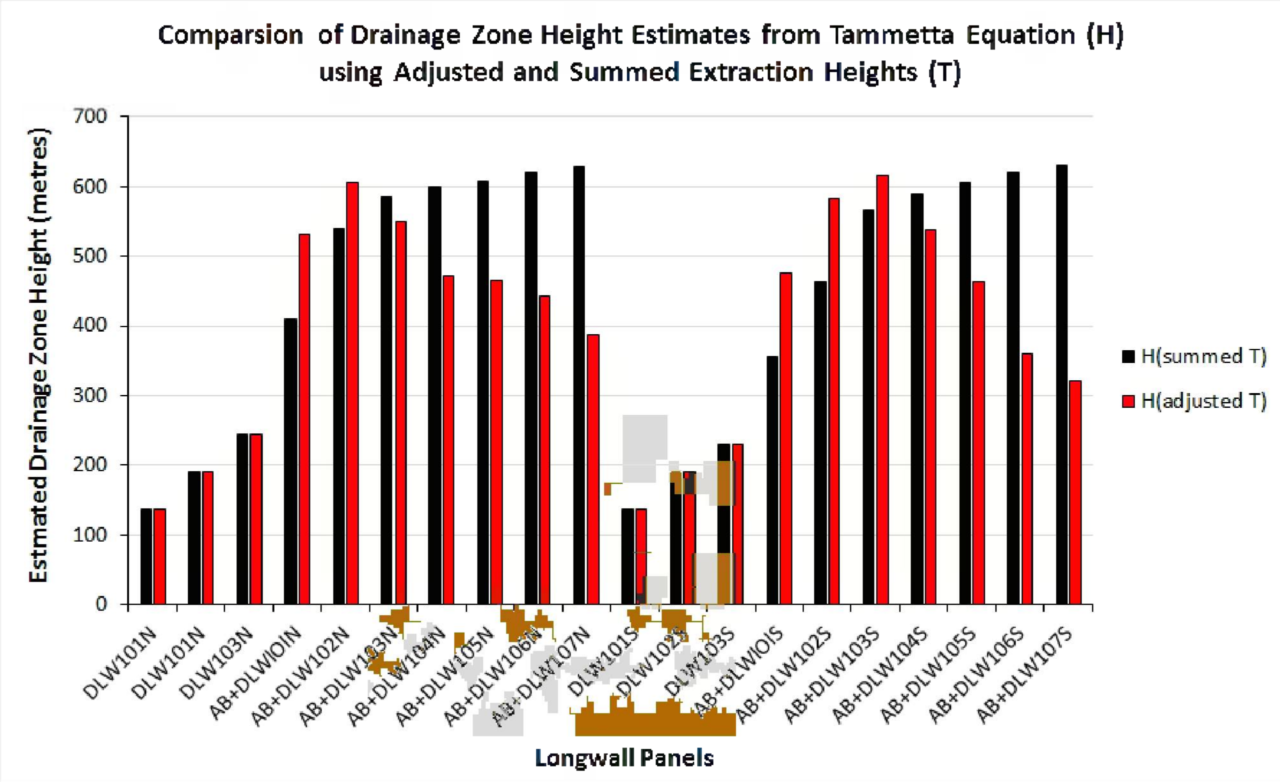


Figure 11. Comparison of Mine 1 drainage zone heights returned by the Tammetta equation using summed mining heights and Merrick's adjusted mining height.

The graph compares estimates returned by the Tammetta equation using an 'effective' extraction thickness (cutting height) for the double seam extractions (AB+D; labelled with respect to the AB seam) of 5.95 metres, this being the sum of the average thickness of the individual seam extractions (2.7 for the AB seam and 3.25 metres for the D seam), compared with the drainage zone heights returned by the Tammetta equation using the effective extraction thickness evidently used by Merrick in December 2014 advice to Adani.[6]

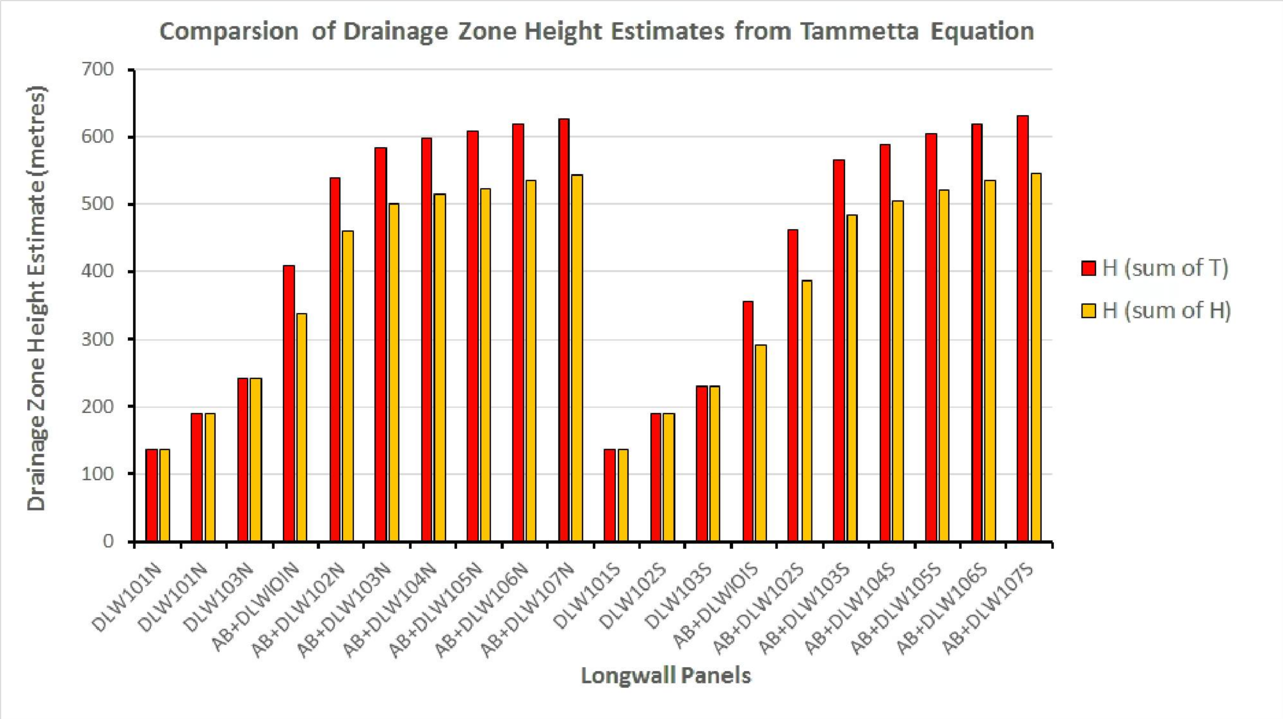


Figure 12. Comparison of drainage zone height estimates from Tammetta equation obtained by summing individual seam thicknesses and summing individual seam height estimates.

A graphical comparison of drainage zone height estimates from the Tammetta equation obtained for the double seam extractions (AB+D; labelled with respect to the AB seam); (i) by summing individual seam thicknesses ($T_{AB}+T_D = 5.95$ metres) and (ii) summing height estimates for individual seams ($H_{AB}+H_D$). The latter height estimate is about 15% less than the estimate obtained from the summed seam thickness.

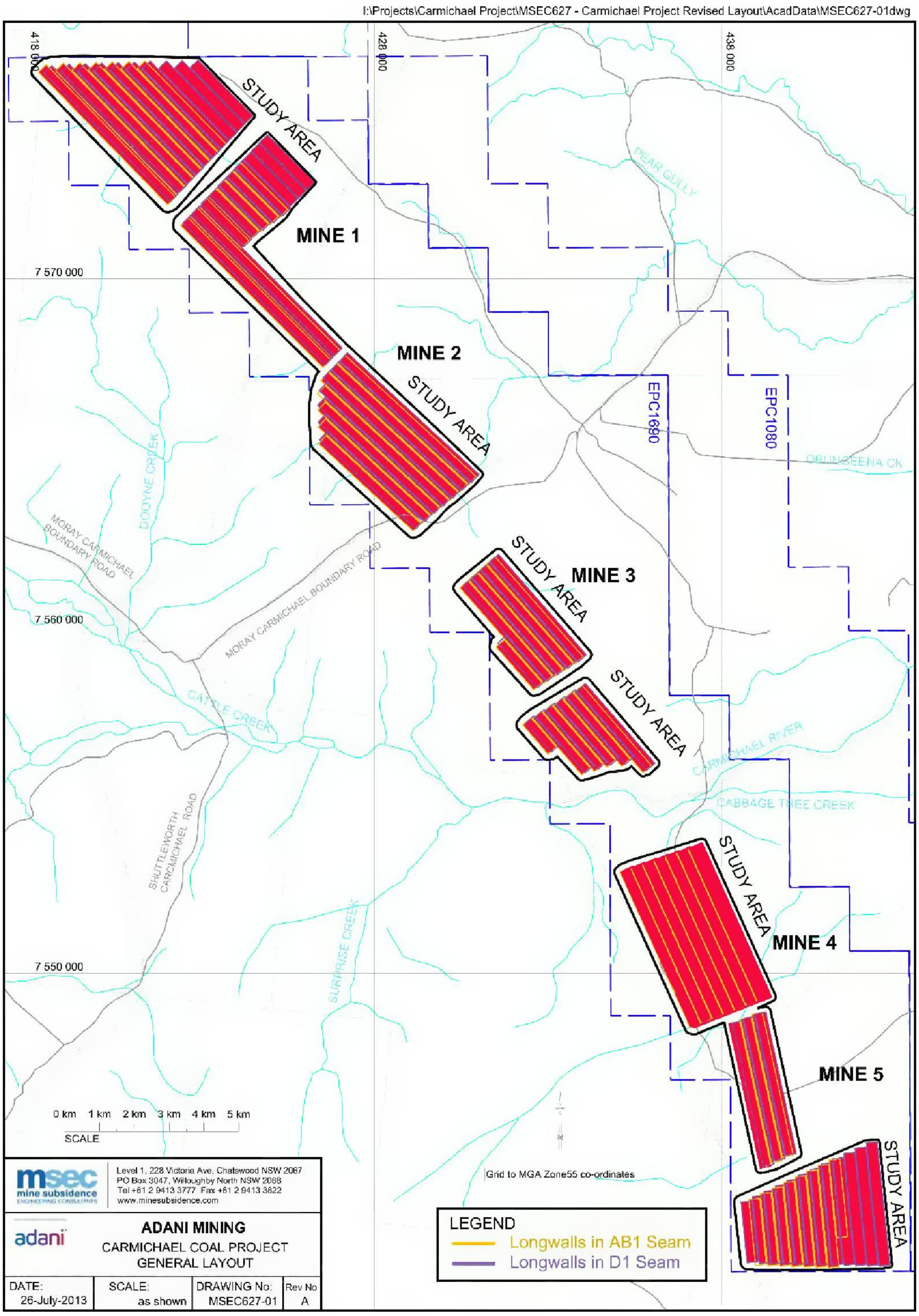


Figure 13. Depiction of the drainage zone reaching the surface over the proposed Carmichael longwall extractions.

The Tammetta equation, using the average cover depths listed in Table 3 of Merrick's advice to Adani[6], suggests the drainage zone will reach the surface over all of the proposed longwall extractions of the Carmichael project. This is indicated by the red colouration; the orange lines outline the AB seam extractions and the grey lines outline the lower D seam extractions. Most of the AB extractions overlie D seam extractions.

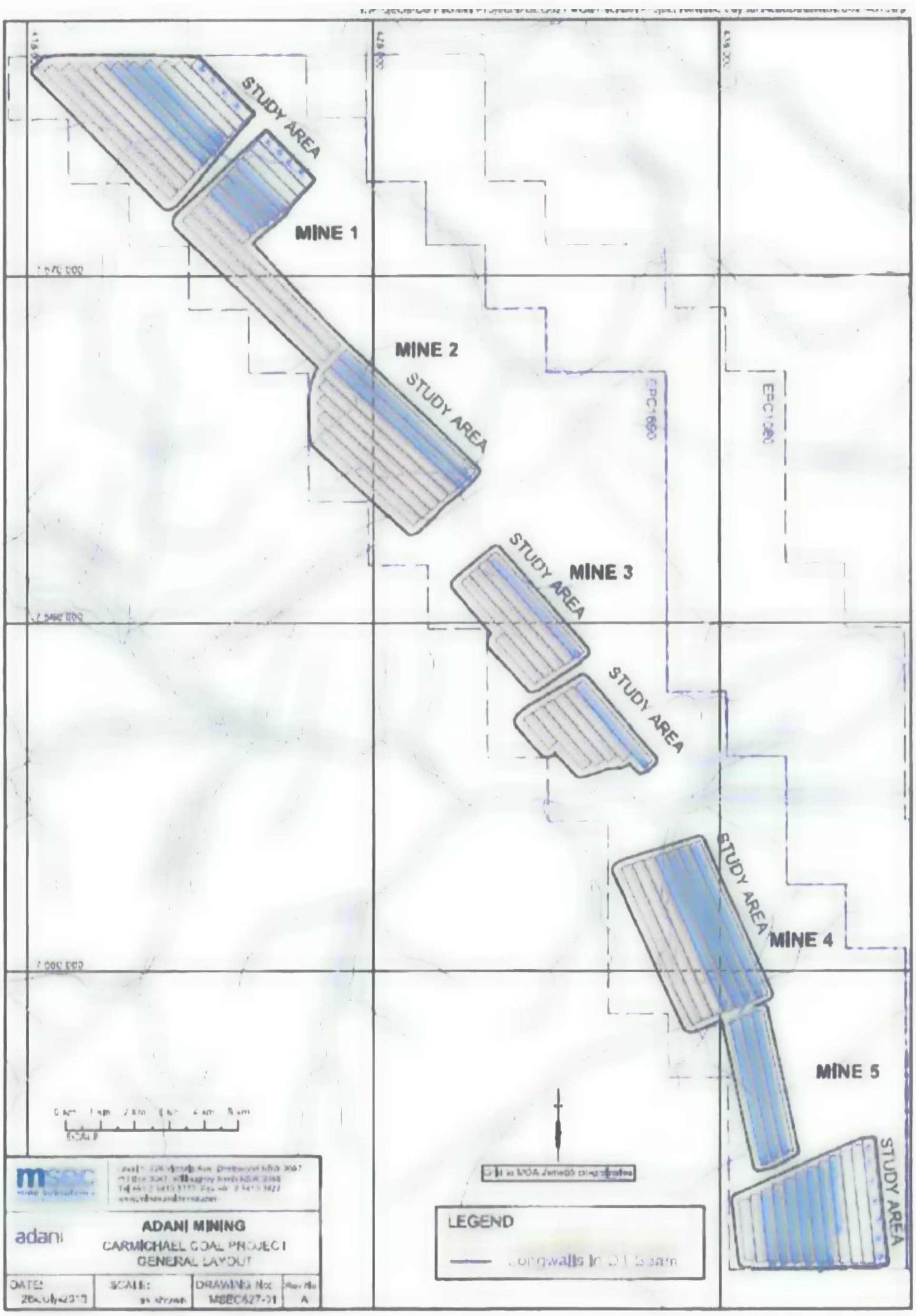


Figure 14. Dr Merrick's depiction of areas where the drainage zone reaches the surface**[6]**

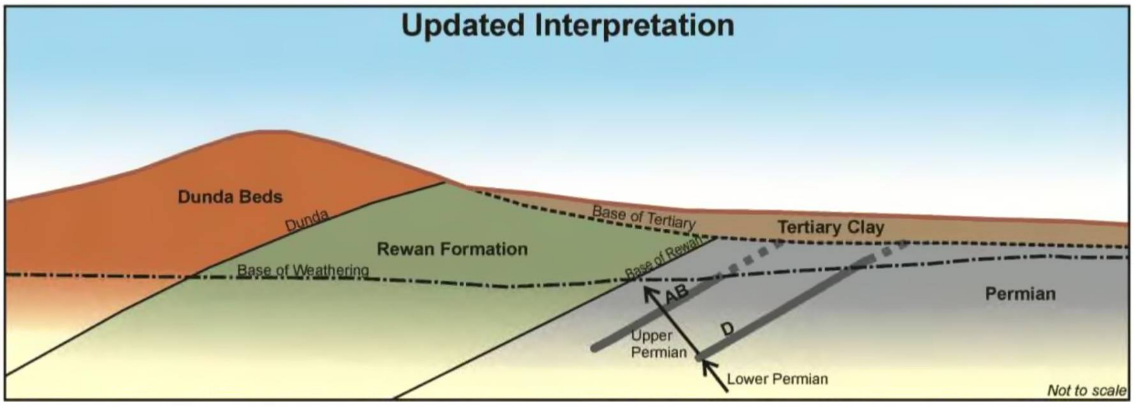


Figure 15. Xenith's revised depiction of the local area geology**[33]**

The depiction suggests that most of the D seam extractions would not be overlain by the Rewan formation. It also suggests that while it appears that the AB seam extractions would largely be overlain by the Rewan formation, the thickness of cover would vary considerably. The Rewan does not reach the surface over the proposed extractions. It's not known how representative this cross-section is of the lithography over the planned extractions. Nor is it known if the lithography has been determined over the centre of the proposed extractions.

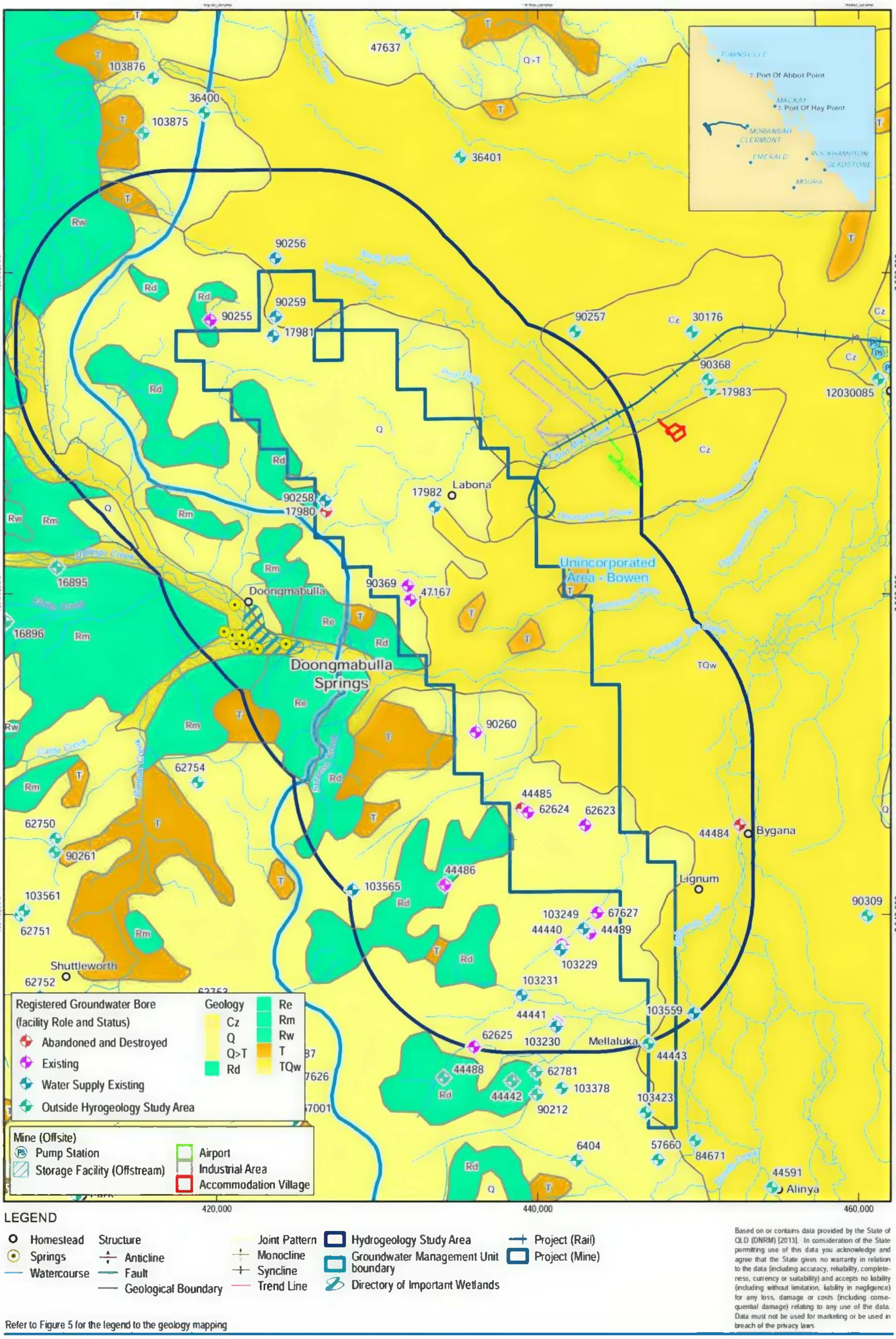


Figure 16. Surface geology in the Carmichael coal project area[19]