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Colong Foundation, and;
Blue Mountains Conservation Society

IMPACTS FROM COAL MINING AT SPRINGVALE COLLIERY ON THE TEMPERATE HIGHLAND PEAT SWAMPS OF THE NEWNES PLATEAU

Carne Creek

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Authors	Steven Pells; Philip Pells
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Contact	K. Muir

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EXECUTIVE SUMMARY

This report provides a review of the Temperate Highland Peat Swamps on Sandstone (THPSS) above the Springvale mine, and assesses potential impacts on swamp-specific groundwater and surface water systems from longwall mining.

The ecology of THPSS is dependent on both surface water runoff and groundwater seepage.

Numerous and conflicting scientific opinions have been expressed about the impact of longwall mining on the THPSS above the Springvale mine due to changes to these surface water and groundwater resources. The reasons for differing opinions are because the issues are political and emotive, and because they are technically complex. We consider only the technical facets of these opinions in this report.

We have undertaken our own site inspections and have undertaken generic analyses. However, we rely substantially on data collected and collated by others, and on groundwater modelling and subsidence predictions made by specialists on behalf of Centennial Coal.

Albert Einstein is widely credited with saying "*everything should be made as simple as possible, but not simpler*". This report represents our efforts to communicate the issues as simply as possible, but unfortunately, in this case, the problem is not simple. This report describes mining effects which will impact on swamps, and describes the limits of scientific prediction and measurement of these effects.

The impacts are technically complex because there are a number of mechanisms through which impacts can occur. These mechanisms are difficult to predict, difficult to measure and also sometimes difficult to understand. Such mechanisms include the following:

1. Subsidence from mining causing cracking of swamp beds, leading to drainage of water from the swamps through these cracks (e.g. as seen at East Wolgan swamp).
2. Subsidence from mining causing cracking of near-surface geology, interrupting groundwater flow upon which the swamps depend.
3. Subsidence from mining causing cracking of the ground surface throughout the catchment (i.e. away from the swamps) intercepting rainfall runoff, thus reducing runoff to the swamps.
4. Ongoing seepage of groundwater into the mining works causing changes to groundwater flow directions and groundwater potentials which are sufficient to impact on swamp baseflows without drawing down the phreatic surface.

In this report, we describe how these mechanisms work, and review previous studies that have attempted to predict and measure them.

Subsidence impacts (Points 1. to 3. above) cannot be predicted at a local scale (i.e. at the swamp scale). While it is clear that the regional magnitude of subsidence expected at Springvale mine will be associated with surface cracking, prediction techniques cannot say exactly where this cracking will occur, and how severe it will be. It follows, then, that we cannot predict which swamps will be directly impacted by cracking (e.g. Point 1 above). We can state, however, that the possibility of cracking of further swamp beds cannot be ruled out.

Similarly we know that mining subsidence will induce cracking of the near-surface geology (Point 2 above). Again, the exact form of this cracking, with respect to any particular swamp, cannot be predicted. The impacts to the swamp from subsurface cracking are even more difficult to know, because the nature of detailed groundwater flow paths, and the extent and nature of the important shale layers, is unknown, and the presence of cracking is not adequately measureable.

Seepage from groundwater into the mine causes a reduction in water pressure at the mine. This pressure reduction propagates as a wave through the geology and will, eventually, arrive at the surface. When it does arrive at the surface, it will reduce groundwater flow toward the swamps. However, the rate at which the pressure wave propagates through the formation, and the amount it is attenuated, depends upon geological characteristics which are not known with accuracy. Hence, it is known that mine dewatering will ultimately affect swamps, but it is not known when, and by how much.

The removal of some water from a swamp, be this from reduction of surface water runoff, or reduction of groundwater seepage, will slowly change the swamp. It will become statistically drier, which, ultimately, will be reflected in a changed swamp ecology. This is an effect that takes time, and is difficult to measure. Measurements must be sufficient to: distinguish from natural variability; characterise pre-mining (baseline) conditions, and; characterise post-mining conditions. A fundamental problem is that the measurements must differentiate small changes in a system where large changes are controlled by climatic variability and bushfires.

It is shown in this report that the available measurements do not achieve these criteria. Hence, swamp monitoring undertaken by Centennial Coal is inconclusive.

Predictions made by Centennial Coal are underpinned by a conceptualisation whereby the geology is perceived to comprise demarcated, disconnected regions. Subject to this assumption of ‘separation’, the studies of Centennial Coal predict minor impacts to the swamps from mining activities. However, we show in this report that this conceptualisation of ‘separation’ is poorly defined and is not supported by measurement.

The situation for the swamps is therefore as follows:

- Dramatic impacts, such as sudden slumping / draining of the swamp from severe cracking (i.e. as per East Wolgan swamp), are possible. But they are not predictable. If such impacts occur, they will be clearly observed as a mining impact. Such impacts are not repairable.

- Changes to runoff from subsidence cracking, or to the localised groundwater regimes from subsurface cracking, or from regional depressurisation from mine dewatering, are certain. It is the prediction of the severity and timing of these effects which is uncertain. The effects on swamps from these mechanisms may be subtle and occur over a longer time. A resulting statistical shift to drier conditions will affect swamp ecology and flora. Indications of such effects may well be observed by a long term observer / bushwalker, particularly if these effects are pronounced. However, formal

> claims of such impacts require comprehensive and long term monitoring to measure and prove. Ecological recovery from such impacts is uncertain, and in our view, has a low probability.

If the swamps were man made entities such as buildings, roads, gas pipelines or optic fibre cables, the subsidence impacts would be the subject of risk assessments. However, the risk level cannot currently be defined because Australian society has not established any consistent criteria for the values of entities of the natural environment (cliffs, swamps, rivers etc.).

1 THE PROBLEM

Across the Newnes Plateau, west of Sydney, a series of unique swamps are found. Collectively, these swamps are Federally listed as the Temperate Highland Peat Swamp on Sandstone (THPSS). Within this categorisation, following types of swamps are classified:

1. Newnes Plateau Shrub Swamps (NPSS)
2. Newnes Plateau Hanging Swamps (NPHS)
3. Newnes Plateau Rush Sedge Snow Gum Wooden Heath Grassy Woodland (NPRSSG)

Centennial Coal EIS (2015) notes that "the swamps are listed endangered ecological communities under the TSC Act, and important habitat for a range of plants and animals" (pg. 275). A regional map, showing selected swamps is shown in Figure 1.

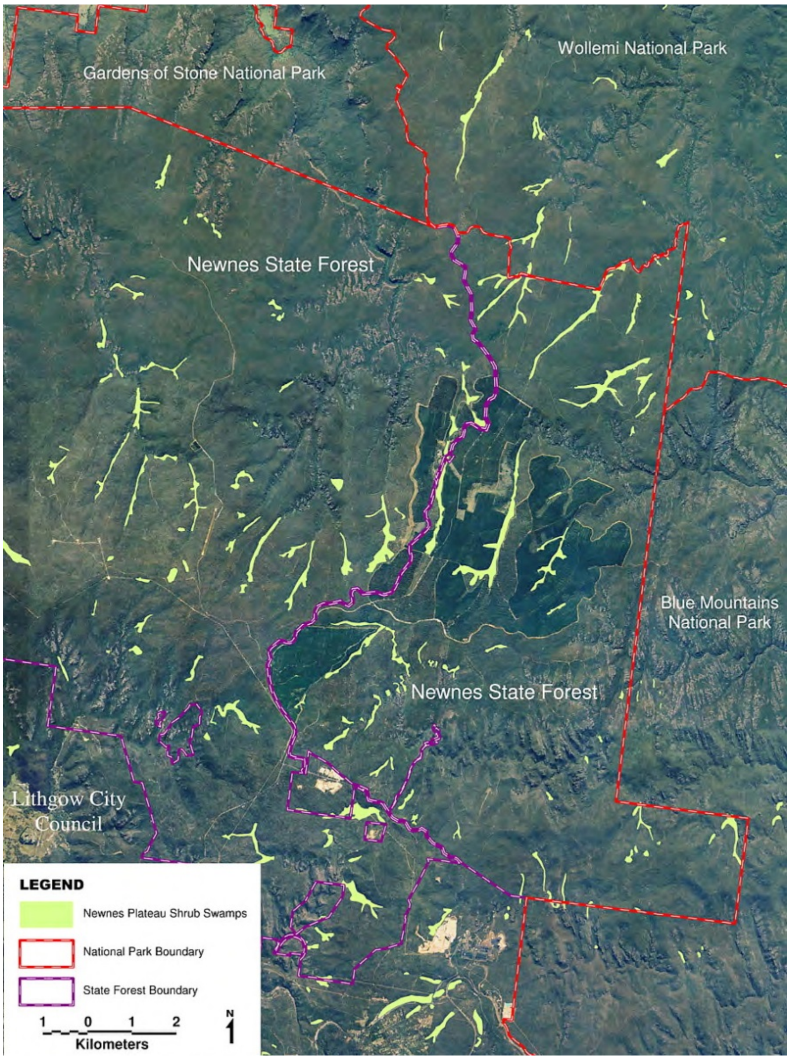

Figure 1 – Regional map showing selected swamps, f*rom Benson and Baird, 2012*

The ecology of THPSS is dependent on both surface water runoff and groundwater seepage[1].

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[1] Benson, D and Baird I R C. *Vegetation, fauna, groundwater interrelations in low nutrient temperate montane peat swamps in the upper Blue Mountains, New South Wales.* Cunninghamia, Journal of Plant Ecology for eastern Australia, 24 October 2012

Beneath these swamps, coal mining at the Springvale Colliery has been undertaken since 1995, providing thermal coal for power production. The planned expansion of the Springvale mine will provide further thermal coal, won from ongoing longwall operations, and will undermine further swamps.

The locations of swamps and existing and proposed mining are shown in Figure 2

Subsidence and mine water discharges from at the Springvale colliery significantly impacted East Wolgan swamp. While mechanisms are debated, the fact of impact is not.

However, there has been ongoing difference of opinion regarding the impacts of coal mining activities upon adjacent swamps, *due to changes in the hydro-geological regime*.

Proponents for the colliery have argued that there has been negligible such impact on the swamps, with statements such as the following:

> “West Wolgan, Junction, Sunnyside West and Sunnyside swamps, all subject to long walling, display no indications of mining-induced effects” (McHugh, 2013)
>
> “Analysis … indicates that there is negligible to minimal impact on THPSS ecosystems on the Newnes Plateau due to depressurisation of the Illawarra Coal Measures.” (Centennial Coal EIS, 2015, pg. 308)
>
> “The depressurisation of aquifers in strata overlying the coal seam has been shown to have minimal impact on the swamps on the Newnes Plateau and the surface drainage network of the water supply catchments” (Centennial Coal EIS, 2015, pg. 324)
>
> “it is accurate to say that mining at Springvale has not led to any identifiable water level impacts on the monitored swamps” (Centennial Coal EIS, 2015, Appendix E pg. 34)

Others have argued that significant impacts on the swamps have occurred, and will continue to occur, due to the changes in the hydro-geological regime:

> “analyses indicate that Carne West Swamp has lost its perched aquifer … this represents a significant impact to the Carne West Swamp “(undated letter from OEH to PAC)
>
> “Sunnyside East Swamp was fed from surface water and groundwater sources … recent monitoring data suggests that this link to groundwater has now largely disappeared” (undated letter from OEH to PAC)
>
> “Impacts to undermined THPSS have historically been severe, resulting in changes to the hydrological and hydrogeological regimes, vegetation composition and structure, and large reductions in THPSS extent …
>
> … It is highly likely that impacts to THPSS and dependent threatened species will be severe and potentially irreparable. Further, there is no scientific literature currently available to demonstrate the effectiveness of potential mitigation or remediation measures.” (IESC 2014)

> “ I consider the risk to hanging swamps to be considerable … the essence of the problem is disruption to the sustained seepage of groundwater – and that process is unacknowledged by the DoPE or by Centennial” (submission to PAC by Dr Ann Young, September 2015).

This present report by Pells Consulting has been prepared in response to a request from the Colong Foundation to undertake a brief review of the opposing views, and to provide assessment of scientific evidence underpinning the conclusions drawn.

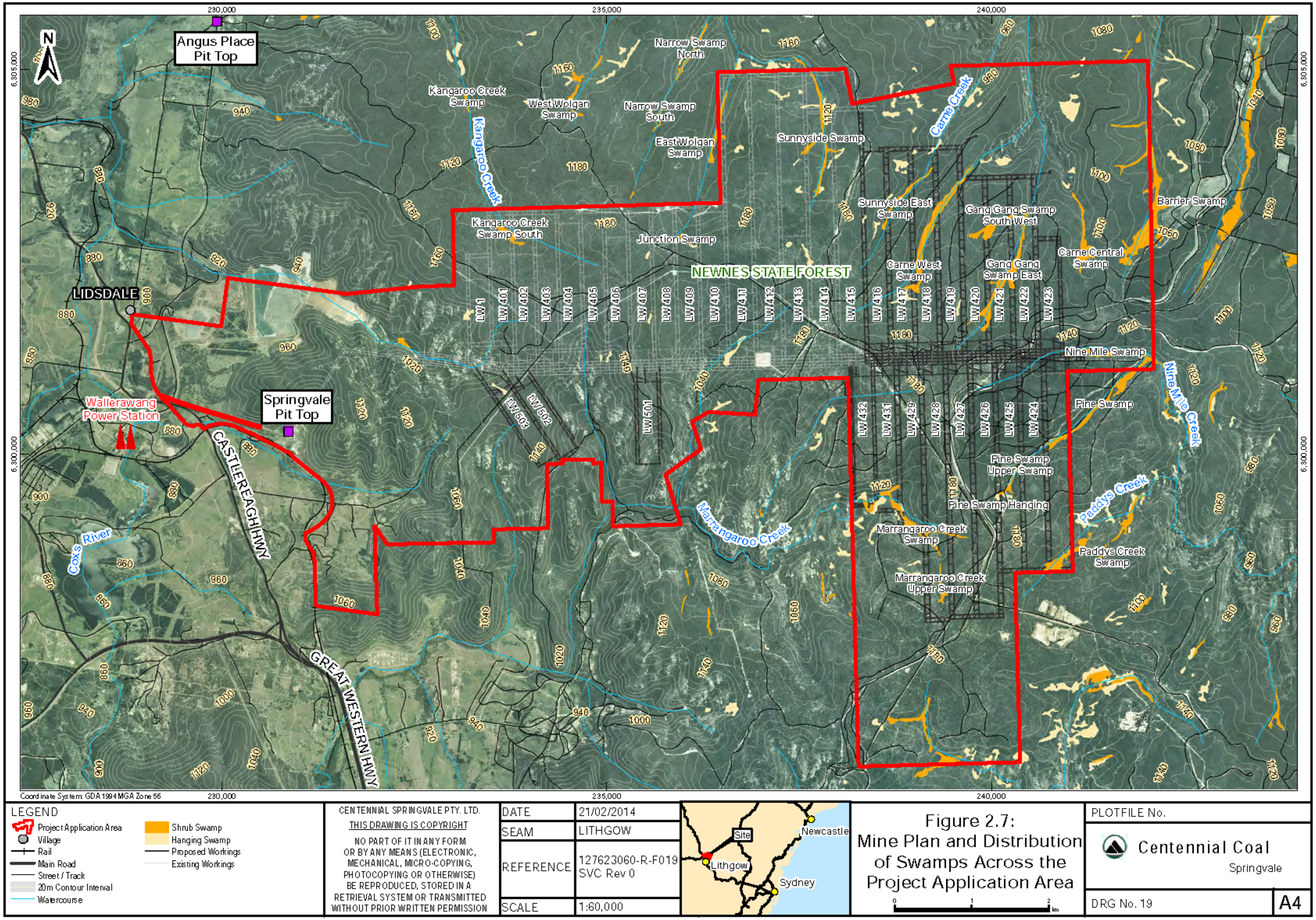

Figure 2 – Mine plan and swamp locations

Warnings to us all about Reasoning and Judgement

In presenting this report we are very aware of the limitations to rational thinking by all humans. We write with the following in mind.

Nobel Laureate Daniel Kahneman (2011):

> “you build the best possible story from the information available to you, and if it is a good story, you believe it. Paradoxically it is easier to construct a coherent story when you know little, when there are fewer pieces to fit into a puzzle. Our comforting conviction that the world makes sense rests on a secure foundation: our almost unlimited ability to ignore our ignorance”

> “Subjective confidence in a judgement is not a reasoned evaluation of the probability that this judgement is correct. Confidence is a feeling, which reflects the coherence of the information and the cognitative ease of processing it. It is wise to take admissions of uncertainty seriously, but declarations of high confidence mainly tell you that an individual has a coherent story in his mind, not necessarily that this story is true.”

> “ the illusion of validity and skill are supported by a powerful professional culture. We know people can maintain an unshakeable faith is any proposition, however absurd, when they are sustained by a community of like-minded believers”

From Jonathan Height (2001)[2]

> "… both sides believe that their positions are based on reasoning about the facts and the issues involved. Both sides present what they take to be excellent arguments in support of their positions. Both sides expect the other side to be responsive to such reasons. When the other side fails to be affected by such good reasons, each side concludes that the other side must be closed minded or insincere."

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[2] Psychological Review 108.4 (2001): 814-834

2 GEOLOGICAL SETTING AND TOPOGRAPHY

The Sydney 1:250000 Geological Sheets (Figure 3) and the Western Coalfield 1:100000 Geological sheets (Figure 4) show that the swamps above the Springvale Colliery lay upon a plateau of Triassic sandstones of the Narrabeen Group.

The Springvale mine targets underlying coal seams of the Lithgow Formation, within the Permian Illawarra Coal Measures.

More detailed, local, stratigraphy is shown in Figure 5.

The Triassic strata that overlie the Permian coal-bearing strata are dominated by sandstones with widely spaced near vertical joints, about which very little is known at the Springvale colliery in respect to spacing and continuity with depth.

Pertinent facets of the stratigraphy are set out below (Goldberry, 1969; Herbert, 1980; Corbett et al, 2014).

Caley Formation (~30m to 50m thick)

> Bedded sandstones and siltstone members, comprising Beauchamp Falls Shale (~8m) at base of the Triassic, overlain in turn by Clwydd Sandstone (10m), Victoria Pass Claystone (~2m) , Govetts Leap Sandstone (~10m) and Hartley Vale Claystone (~3m).

Burra-Moko Head Sandstone (~70m thick)

> Medium to coarse grained , quartzose to quartz-lithic, sandstones with thin lenticular siltstone beds and conglomerate layers.

Mt York Claystone (~15m to 40m thick)

> Two red-brown siltstone beds (with 5% to 25 % clay minerals) separated by a bed of quartz-lithic sandstone

Banks Wall Sandstone (~100m thick)

> Typically massive quartzose sandstone, with occasional conglomerate beds, and some lenticular shale beds.

Burralow Formation (variable according to topography)

> Fluviodeltaic deposited sandstone and conglomerate with lenticular interbeds of shale and laminite.

The major units exposed in the side of the Grose River at Mount Banks are shown in Figure 6

The interpreted stratigraphy for a E-W cross section along the Springvale lease is shown in Figure 7.

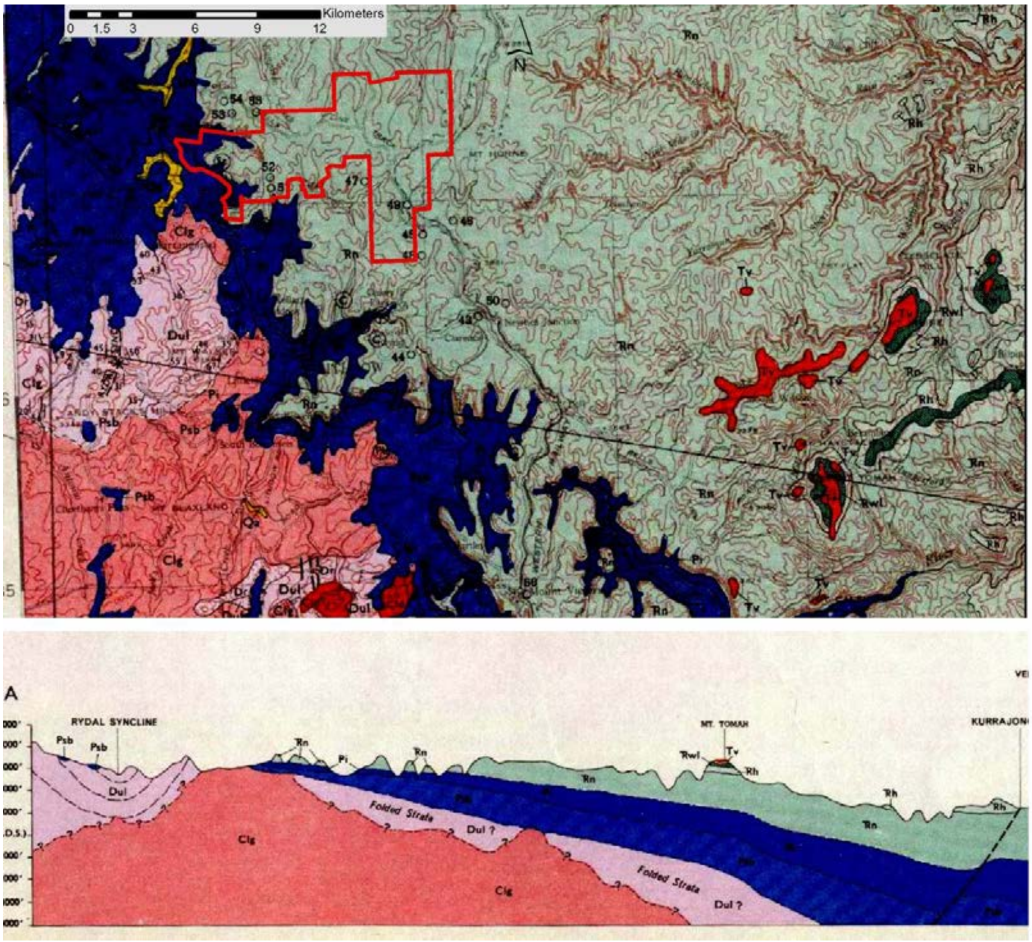


Figure 3 – Excerpts from the Sydney 1:250,000 Geological Sheet

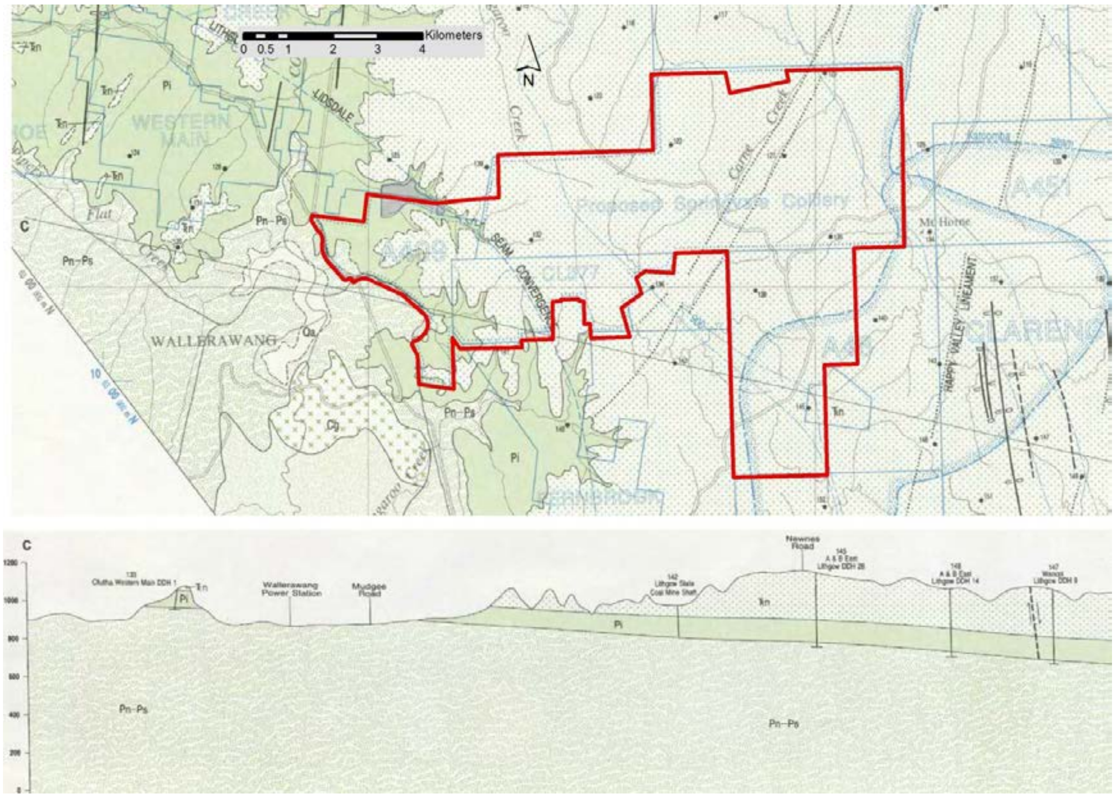
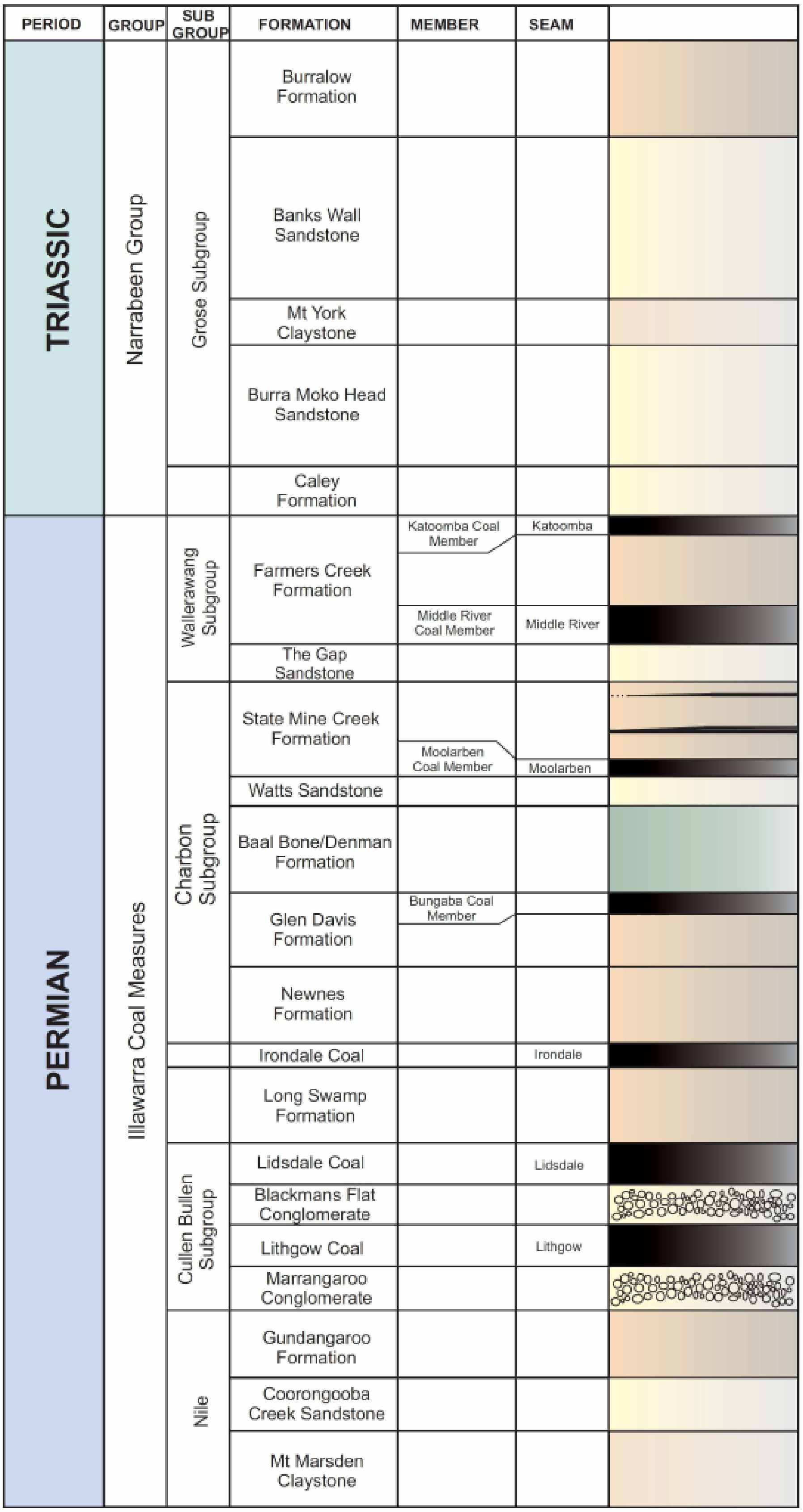


Figure 4 - Excerpts from the Western Coalfields 1:100,000 Geological Sheet



PERIOD	GROUP	SUB GROUP	FORMATION	MEMBER	SEAM
TRIASSIC	Narrabeen Group	Grose Subgroup	Burralow Formation		
			Banks Wall Sandstone		
			Mt York Claystone		
			Burra Moko Head Sandstone		
			Caley Formation		
PERMIAN	Illawarra Coal Measures	Wallerawang Subgroup	Farmers Creek Formation	Katoomba Coal Member	Katoomba
				Middle River Coal Member	Middle River
			The Gap Sandstone		
		Charbon Subgroup	State Mine Creek Formation	Moolarben Coal Member	Moolarben
			Watts Sandstone		
			Baal Bone/Denman Formation		
			Glen Davis Formation	Bungaba Coal Member	
			Newnes Formation		
			Irondale Coal		Irondale
			Long Swamp Formation		
		Cullen Bullen Subgroup	Lidsdale Coal		Lidsdale
			Blackmans Flat Conglomerate		
			Lithgow Coal		Lithgow
			Marrangaroo Conglomerate		
		Nile	Gundangaroo Formation		
			Coorongooba Creek Sandstone		
			Mt Marsden Claystone		

Figure 5 - Stratigraphic Column for Springvale (from McHugh, 2013)

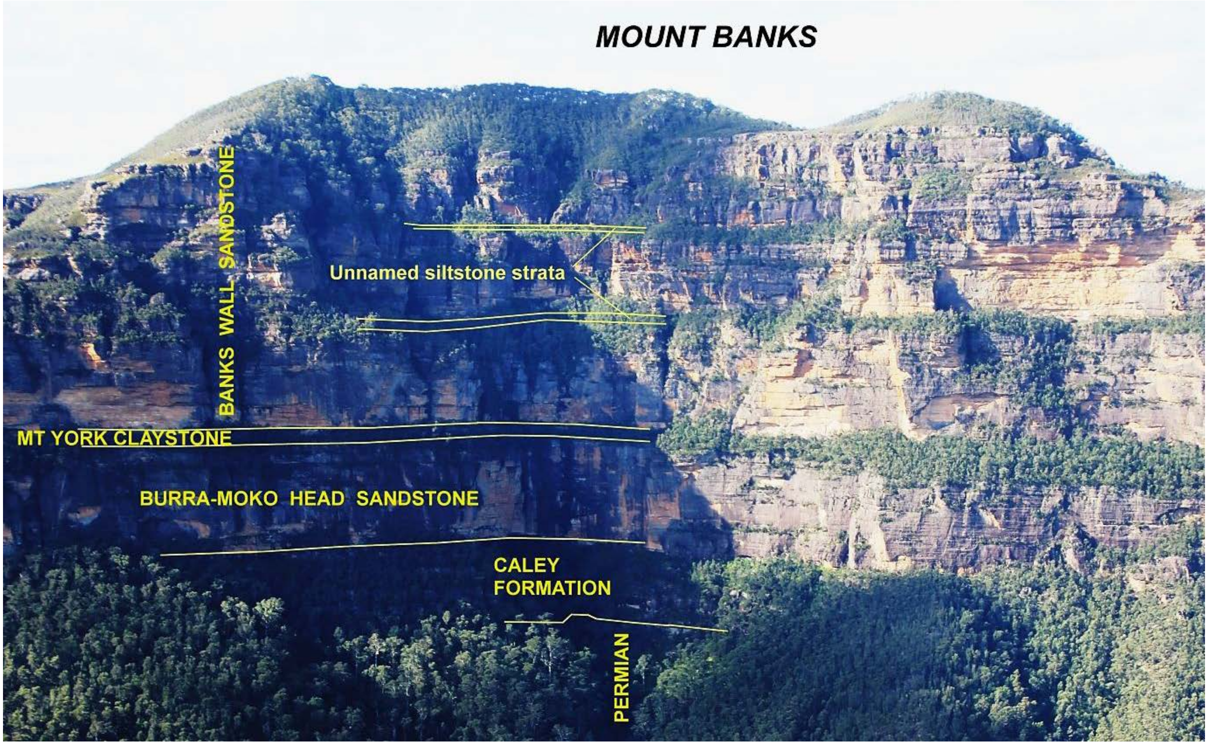


Figure 6 - The major stratigraphic units at Mt Banks

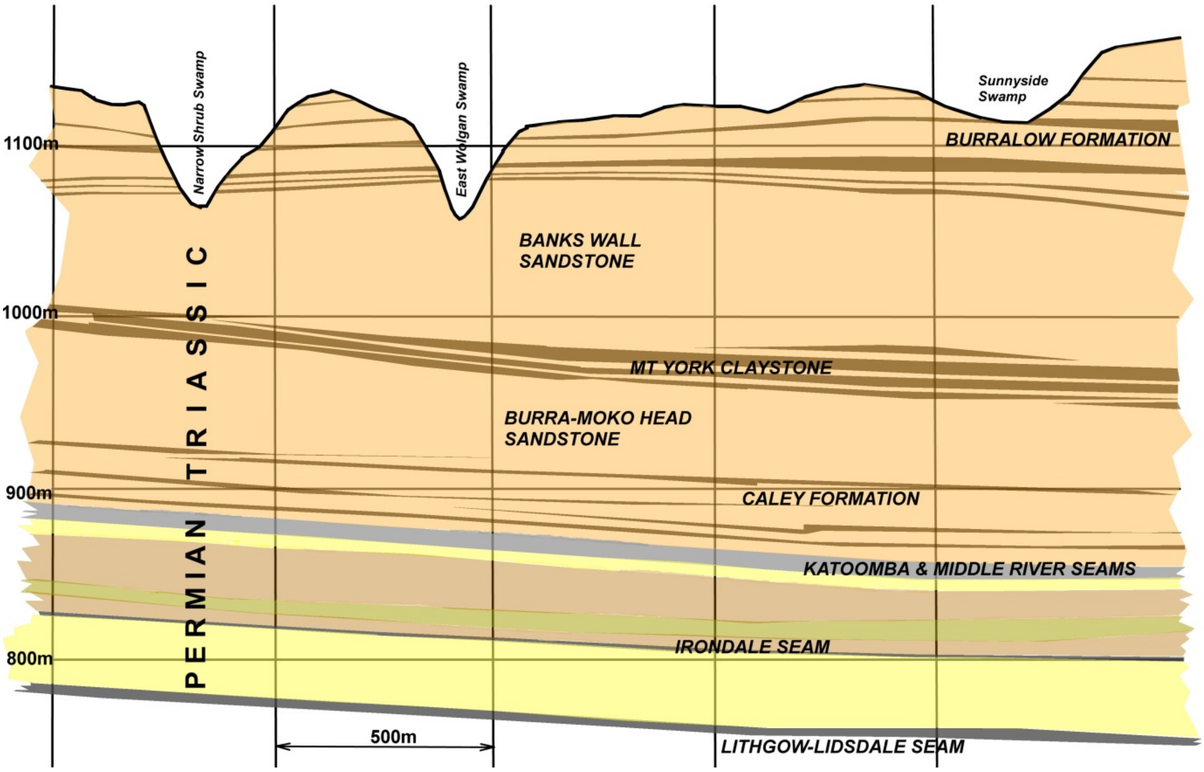


Figure 7 - Stratigraphy along E-W section through the Springvale lease

A 3D view of the topography above Springvale mine is shown in Figure 8, with the location of shrub swamps (NPSS) drawn in black. It is apparent that the shrub swamps are located on the plateau, in gullies and generally perched at the end of the gullies before they plunge off to the lower valleys.

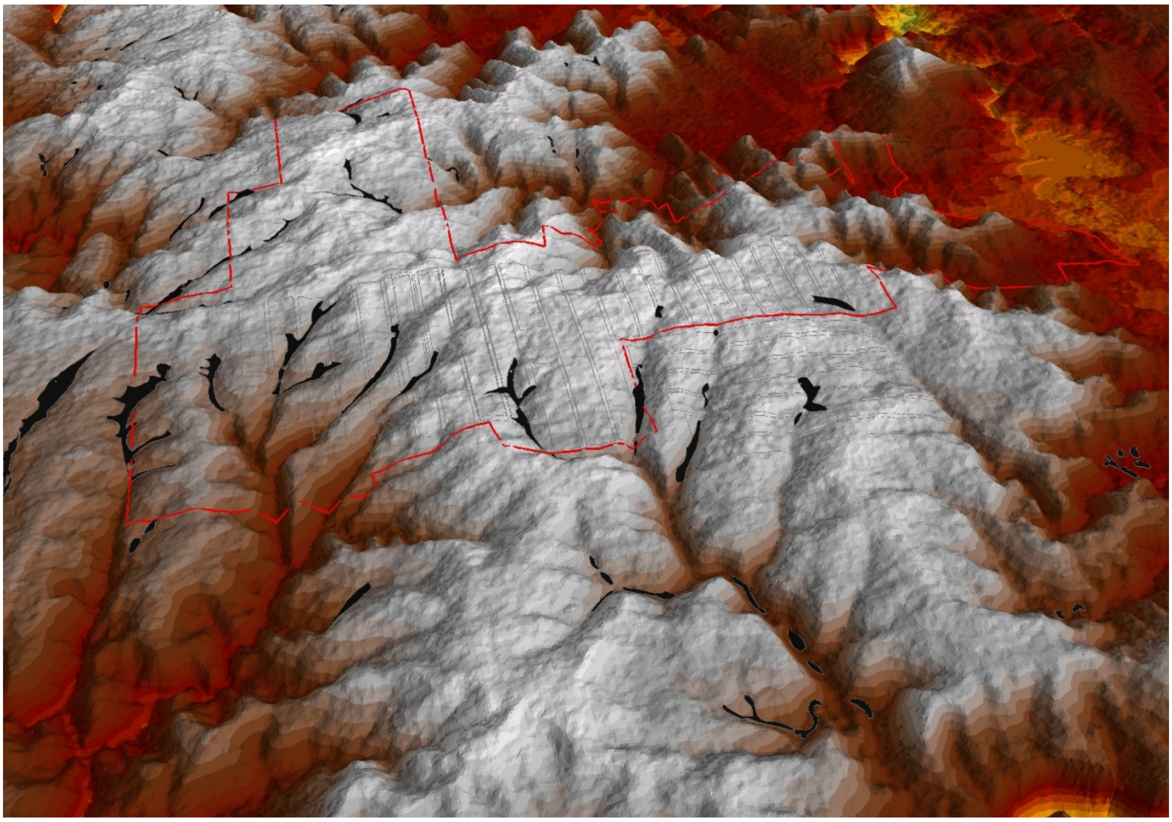


Figure 8 – 3D representation of swamps and topography

We have plotted the approximate thalwegs along six of the valley swamps, starting at about elevation RL1180m, following through the swamps, and on to the typical steeper gullies below the swamps. The computer generated thalweg lines[3] were not precisely along the lowest valley points and so, as shown in Figure 9, show some 'noise'. We have broadly averaged out the thalwegs as per Figure 10.

It is apparent from Figure 10 that there is typically a small flattening of the creek bed grades in the lengths of most of the swamps. It is also clear that the swamps are within quite a small elevation band of some 80m between ~RL1060m and ~RL 1140m.

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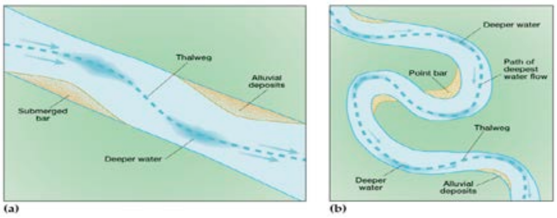
[3] **thalweg** is a line drawn to join the lowest points along the entire length of a stream bed or valley in its downward slope, defining its deepest channel



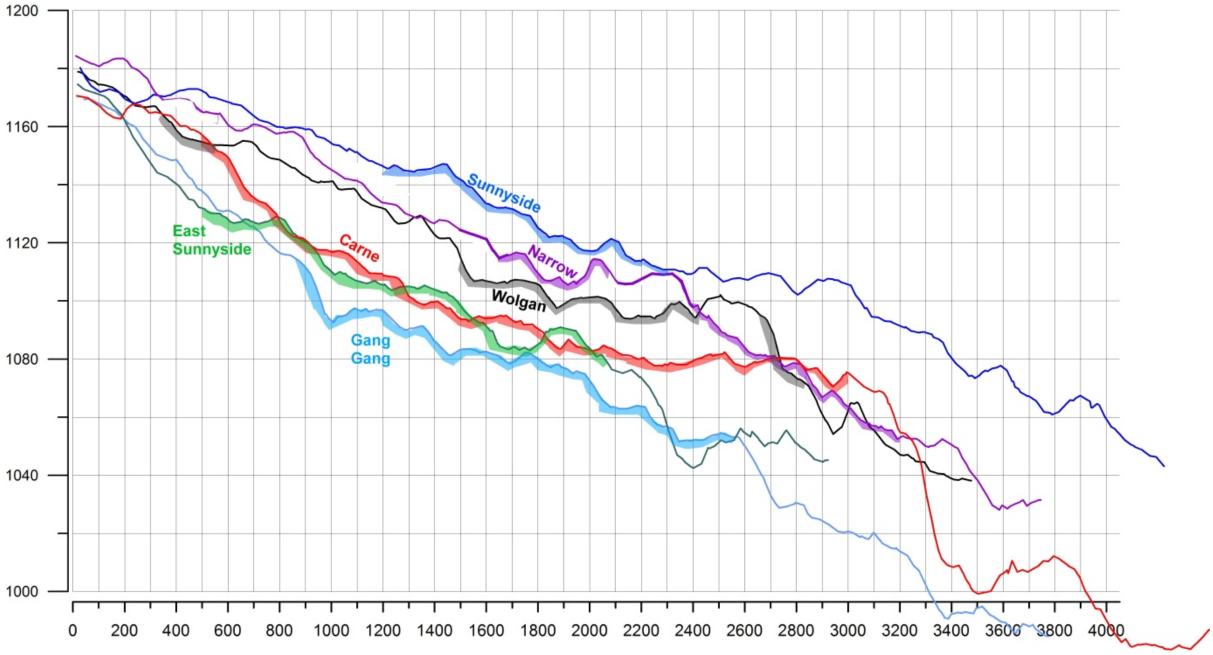


Figure 9 - Computer generated thalwegs through six selected swamps

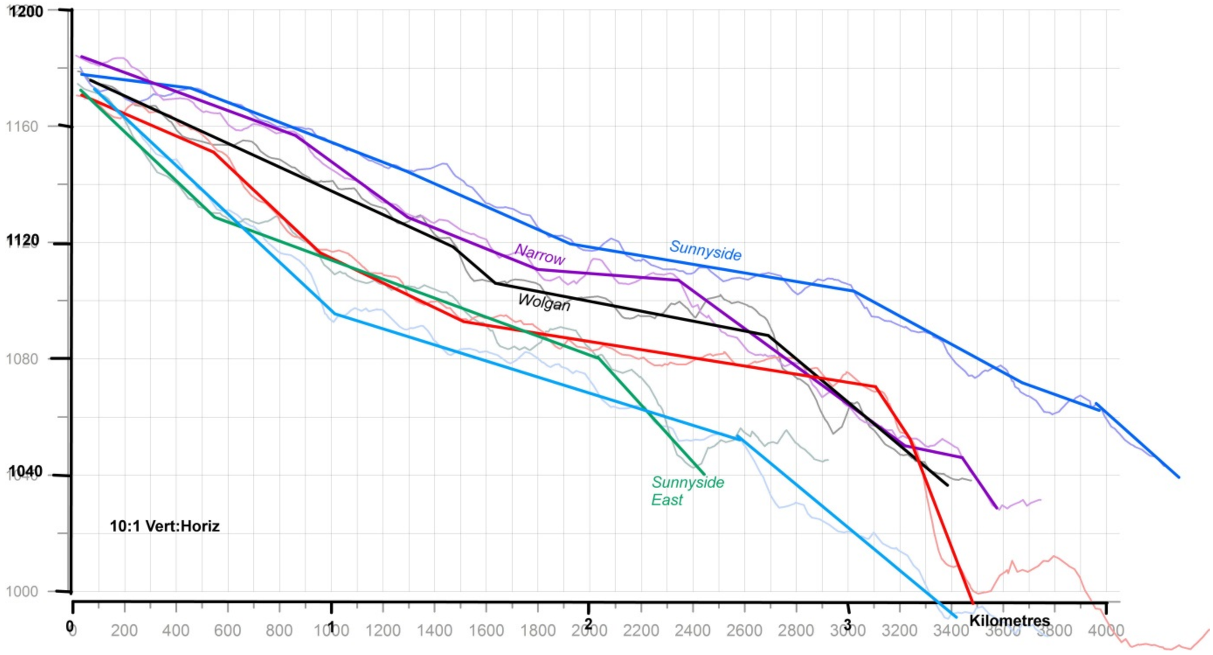


Figure 10 – Smoothed thalwegs

3 INTERPRETATIONS OF SWAMP HYDROLOGY

3.1 Generic creek / lake / swamp hydrology

When rainfall arrives at the earth surface, the water resource is divided into various paths. The process that creates water bodies, be it streams, lakes or swamps lands, is depicted generically in Figure 11. This particular representation is adapted from Starosolszky (1987), but similar schematics are published in various hydrology texts.

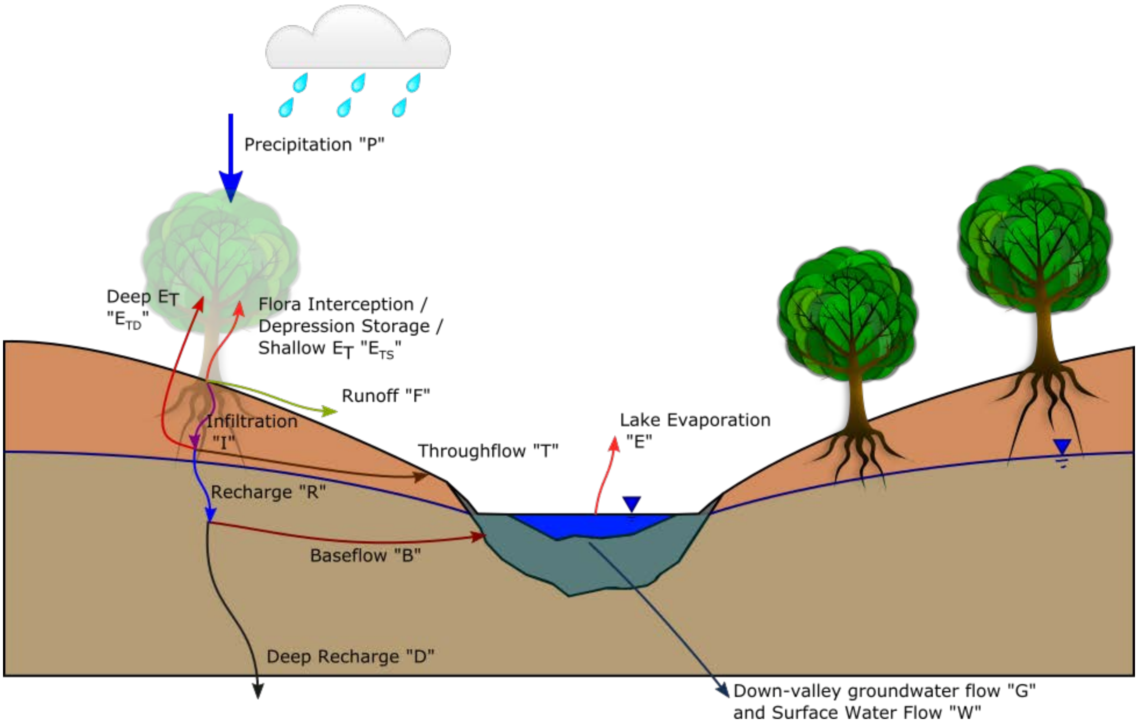


Figure 11 - Components of the land phase of the water cycle

In most of Australia, with exception of the wet tropics, the components of evaporation and transpiration from plants (E_{TD} and E_{TS}) account for ~90% of annual precipitation (Ladson, 2000). A delicate balance of the remaining ~10% of precipitation defines the nature of surface water resources, and how persistently wet they are.

The system in Figure 11 shows groundwater levels at a higher elevation to the stream, causing baseflow which is moving toward the stream. In other situations (e.g. Figure 12), where the balance of components is different, the groundwater elevation may be below the stream elevation. This “losing stream” condition has negative baseflow – i.e. seepage away from the stream.

The components have different temporal patterns (see Figure 13). Runoff in Australia is typically a very temporary condition, occurring for a short time only after *significant* rainfall (i.e. precipitation in excess of interception and depression losses) events. Persistently losing systems will only develop surface-water bodies after runoff events, and are hence typically ephemeral. As groundwater systems are slow to change, gaining conditions are often associated with perennial stream systems.

As general comment, the components making up the water cycle shown in Figure 11 and Figure 12 are notoriously difficult to measure. That is, the manner in which the “delicate 10%” is divided between F, I, T, R, B, D, E, G, and W is unknown.

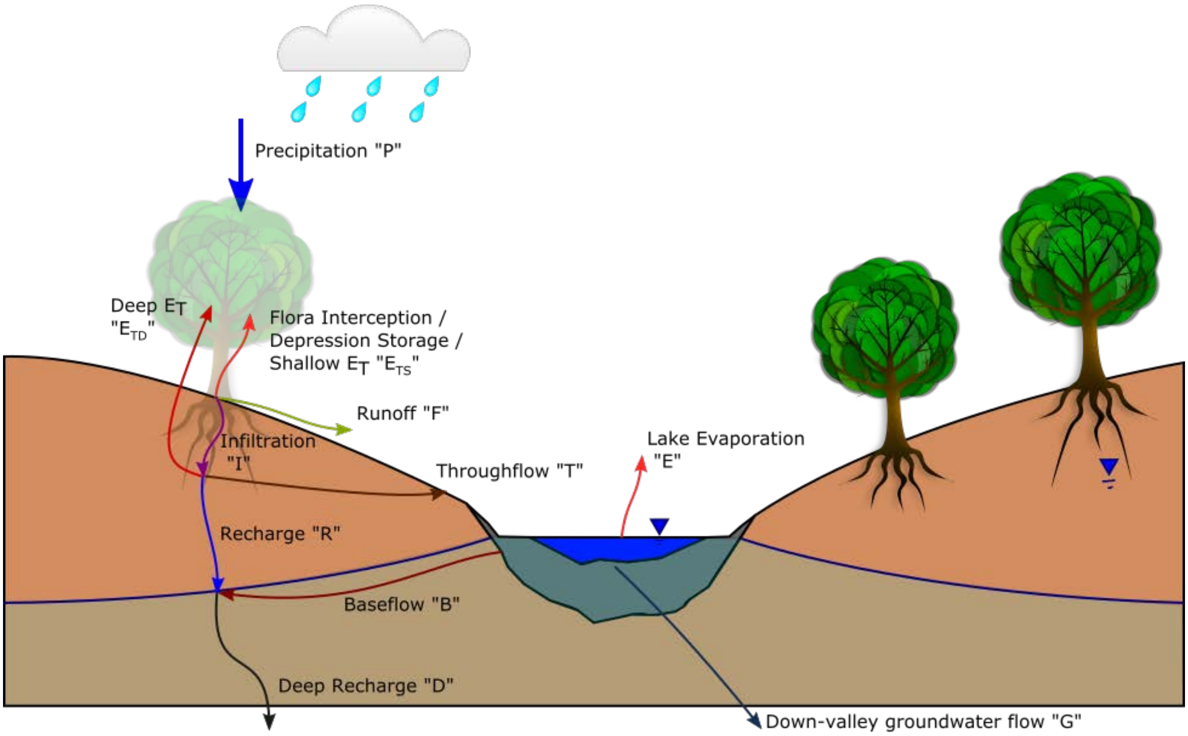


Figure 12 - Components of the land phase of the water cycle, “losing stream”

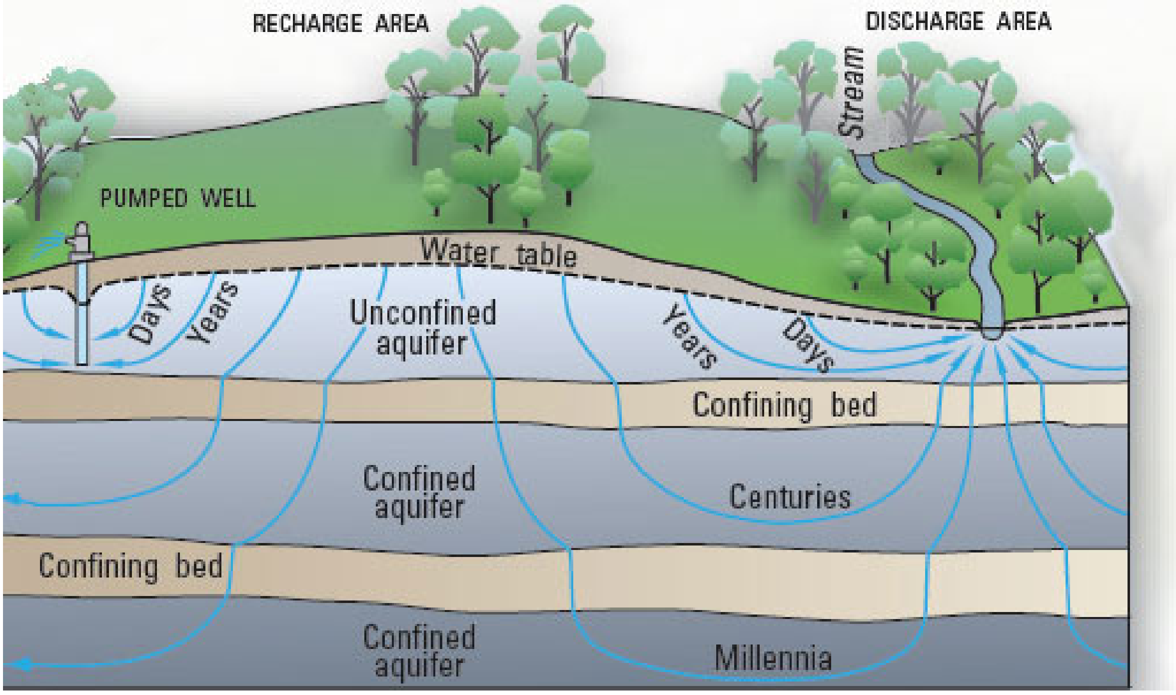


Figure 13 – Schematic of temporal movement of groundwater (USGS)

3.2 Hydrogeological interpretations for THPSS by Centennial Coal

The swamps within the Springvale lease are primarily situated within the Burralow formation (generally 20 to 100 m thickness of formation), which are “interbedded with frequent sequences of fine-grained clay-rich sandstones, siltstones, shales and claystones” (McHugh, 2013). McHugh (2013) refers to these fine-grained units as “aquitards” or “semi-permeable” layers, and argues that these “aquitards” account for the appearance of Newnes Plateau Hanging Swamps (NPHS) and “perform a vital function in the presence and persistence of the Newnes Plateau Shrub Swamps (NPSS)” (pg. 13).

The swamps are elevated on a plateau so, at depth, groundwater systems are expected to report lower in the valley, as baseflow to the Wolgan River, and tributaries, rather than rise as baseflow to the swamp systems (e.g. unlike Figure 13).

The swamps are described in Centennial Coal reports as being systems that are dependent on groundwater, and in particular, on layering of geological stratum, of various permeability. This layering is interpreted to interrupt vertical flow, and direct groundwater seepage patterns in a horizontal direction, to emerge at outcrops as baseflow, supporting swamp ecology. Also fundamental to the Centennial Coal reports is the role of the Mt York Claystone, in creating a barrier to groundwater flow.

A cross-section indicating the interpreted model for swamps, as adopted by Centennial Coal, is shown in Figure 14.

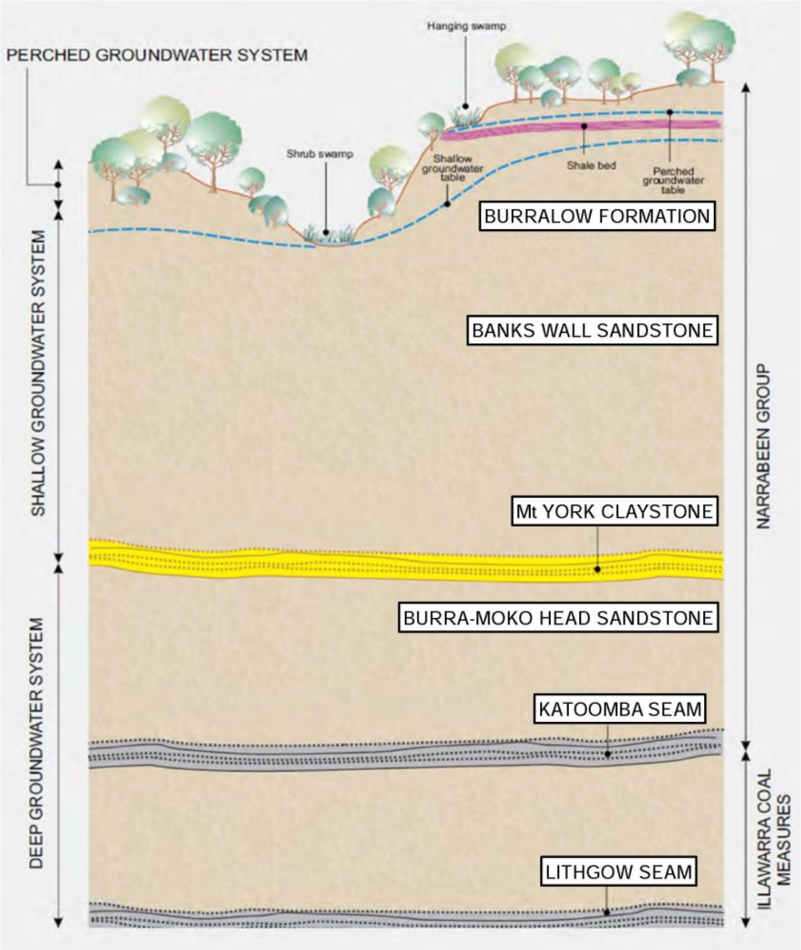
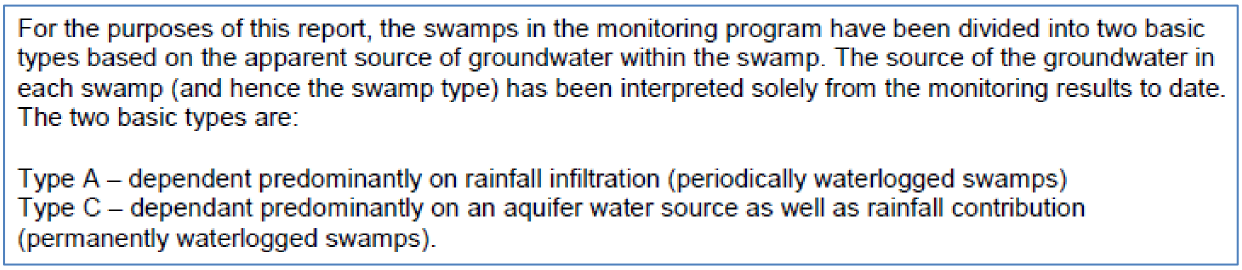


Figure 14 – Interpreted conceptual cross section adopted by Centennial Coal (2015)

Centennial Coal has adopted a categorisation of swamps as follows:

- 'Type A – periodically waterlogged', show large and reasonably rapid variations in water level in response to significant rainfall events.
- 'Type C – permanently waterlogged', display a reasonably static water level that is relatively unaffected by climatic conditions but depend largely on groundwater sources. Since the percentage of groundwater contribution to the swamp hydrogeology will vary from swamp to swamp, there may be a range of hydrogeological conditions observed for this swamp type.

This categorisation was used by consultant to Centennial Coal (Aurecon, 2010), based on monitoring of standing water levels in shallow piezometers, and limited swamps flow monitoring, to January 2010 (see excerpt below).



For the purposes of this report, the swamps in the monitoring program have been divided into two basic types based on the apparent source of groundwater within the swamp. The source of the groundwater in each swamp (and hence the swamp type) has been interpreted solely from the monitoring results to date. The two basic types are:

Type A – dependent predominantly on rainfall infiltration (periodically waterlogged swamps)
Type C – dependant predominantly on an aquifer water source as well as rainfall contribution (permanently waterlogged swamps).

This categorisation is considered by Centennial to represent a baseline (i.e. pre-mining) condition (e.g. Section 4.3 of Appendix E of the EIS).

3.3 Comments on hydrogeological interpretations for THPSS by Centennial Coal

The McHugh (2013) report, on behalf of Centennial Coal, has a wealth of valuable information and many matters of interpretation with which we agree. In essence we accept that the locations of both hanging and valley swamps are to a significant extent controlled by geological conditions – but we think that there are also hydraulic and stream energy controls on the genesis, development and sustainability of the shrub swamps. We accept that low permeability beds, and even thin beds, of argillaceous rock (siltstone and claystone, and weathered bedding plane seams in sandstone) may have an important influence on the local groundwater regime around the swamps, and on the original genesis of the swamps. We also accept the depiction of Shrub swamps as groundwater (baseflow) dependent systems, and that the swamps may each display unique patterns of 'wetness' reflecting the influence of the complex outcropping of seams.

Where we disagree substantially with McHugh (2013), based on the factual evidence, is in relation to:

- the lateral continuities of the relatively low permeability argillaceous horizons,
- the nature of 'perched' groundwater systems.

We also question the designation of "type A" and "type C" swamps adopted by Centennial Coal.

These are discussed in turn.

3.3.1 Lateral continuity of argillaceous horizons (McHugh's 'aquitards').

As shown in Figure 16 and Figure 17, McHugh (2013) interprets continuity of specific, and named[4], argillaceous beds and designates them as aquitards. In respect to Figure 17 (McHugh's Figure 13), we note interpolation between boreholes that are about 1 kilometre apart, and in cases extrapolating beds laterally up to ~0.8km. This is not consistent with the mode of formation of the thin argillaceous beds in otherwise massive sandstone, beds which are most likely the expression of over-bank flooding in a meandering deltaic environment. We acknowledge that there is evidence that major claystone beds in the Banks Wall Sandstone have substantial lateral continuity (see Figure 6), but this is unlikely to be true of the many claystone beds of ~20 to ~150 millimetre thickness.

Figure 15 shows the locations of argillaceous beds, and their thicknesses, taken from the detailed logs presented in RPS Aquaterra Appendix B (from EIS). Two points arise from these logs:

- we consider it is impossible to interpolate particular argillaceous beds between the boreholes with confidence, and;
- there is a horizon of massive sandstone at about the level of the swamps, which no doubt dips gently to the WNW, and which may have controlled the typical form of the thalweg profiles, and been a significant factor in the genesis of the swamps.

McHugh (2013) places substantial reliance on interpretation of geophysical gamma logs to interpret the existence and lateral continuity of aquitards. While gamma logs have value in discriminating between quartz dominated and feldspar/clay mineral dominated rocks, they are not sufficient to define aquitards[5], and they should not over-ride physical logging of core as per the RPS Aquaterra Appendix E to the Springvale EIS.

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[4] We quote: "With seven such identified aquitards in total (YS6, YS5, YS5a, YS4, YS3, YS2 andYS1), there is a significant retardation of water percolation through the Burralow Formation from surface to base to permit the formation not only of the Newnes Plateau Hanging Swamps, but to significantly contribute moisture at outcrop points in gullies containing the Newnes Plateau Shrub Swamps". (McHugh, pages 16 and 17)

[5] "These logs record natural gamma radiation that can be attributed mainly to sources of potassium-40 and radioactive isotopes of the uranium and thorium families. The logs are conventionally recorded in API (American Petroleum Institute) units, which, although arbitrary, do allow consistent comparisons between observation wells. The sandstones of the Dakota aquifer have fairly low radioactivity because they consist mainly of quartz and water and have only minor contents of clay, feldspars, and other accessory minerals. By contrast, the interbedded shales have moderate radioactivity caused by thorium adsorbed on the clay platelets, potassium in the composition of some clays, and variable amounts of uranium generally associated with organic matter and fixed under reducing conditions. Broad distinctions between sandstones and shales are easily made as shown by the gamma-ray log From the gamma-ray log alone it is generally not difficult to select a cut-off value and characterize a section in terms of sandstones (those below the cut-off) and shales (those above). A total thickness of aquifer sandstone can be calculated for the section by finding and measuring the cut-offs. Although this practice is applied commonly, it is only an approximation and can contain serious errors in addition to the subjectivity involved in the choice of the cut-off values. Good aquifer sandstones are characterized not only by shale content but also by significant pore volume and permeability. In practice, there are strong intercorrelations between these properties, so that it is likely that a cut-off value can be established that accommodates all these factors. However, the cut-off should be defined in an objective and consistent manner to reflect the discrimination of aquifers and aquitards indicated on additional logs of porosity and resistivity" *http://www.kgs.ku.edu/Dakota/vol3/fy91/rep04.htm*

We note that McHugh shows no borehole data in the interpretation of the continuous named aquitards beneath Carne West swamp (see Figure 18).

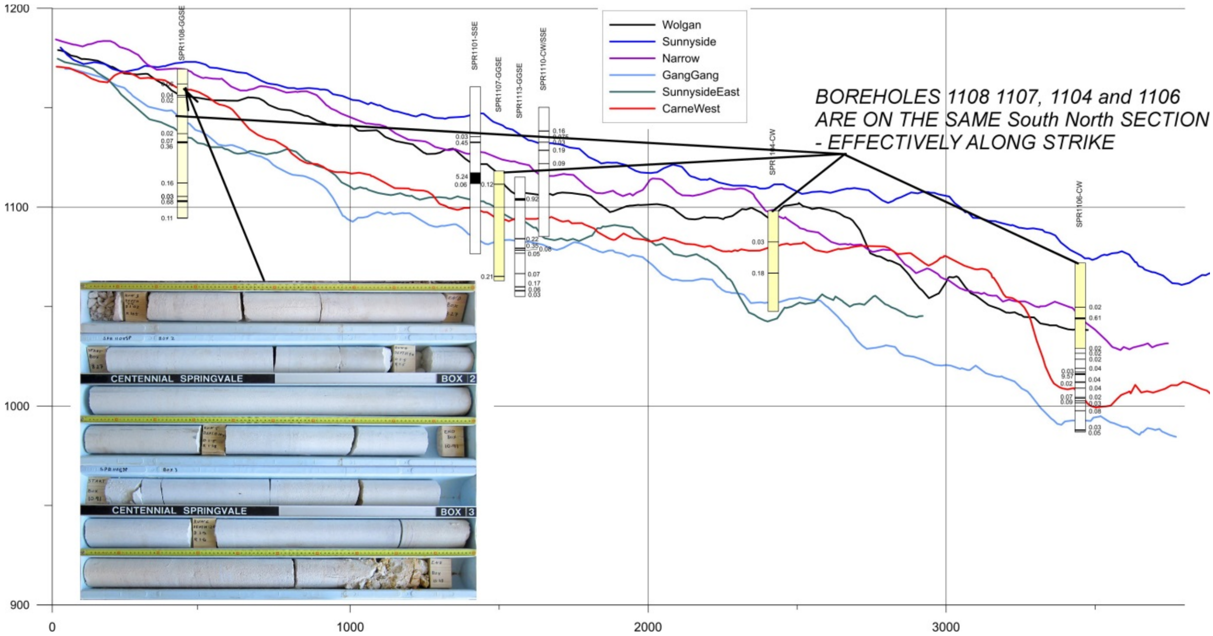


Figure 15 - Argillaceous beds and massive sandstone in the vicinity of the valley swamps

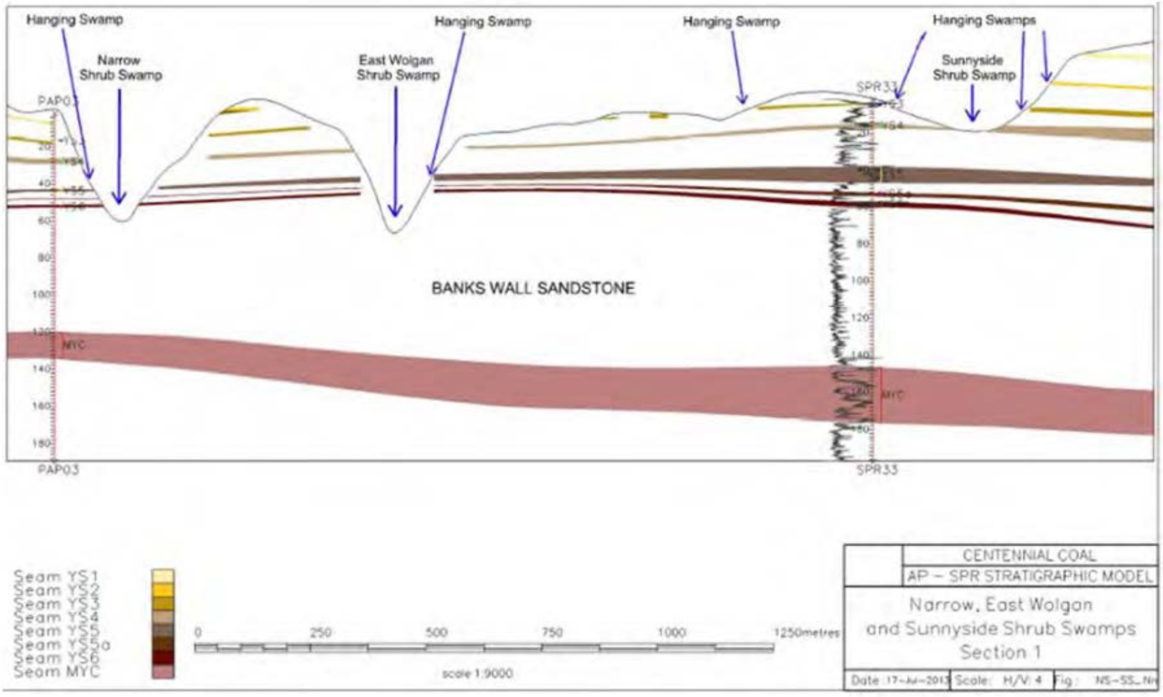


Figure 16 – Conceptual cross section through selected swamps, Centennial Coal (2015)

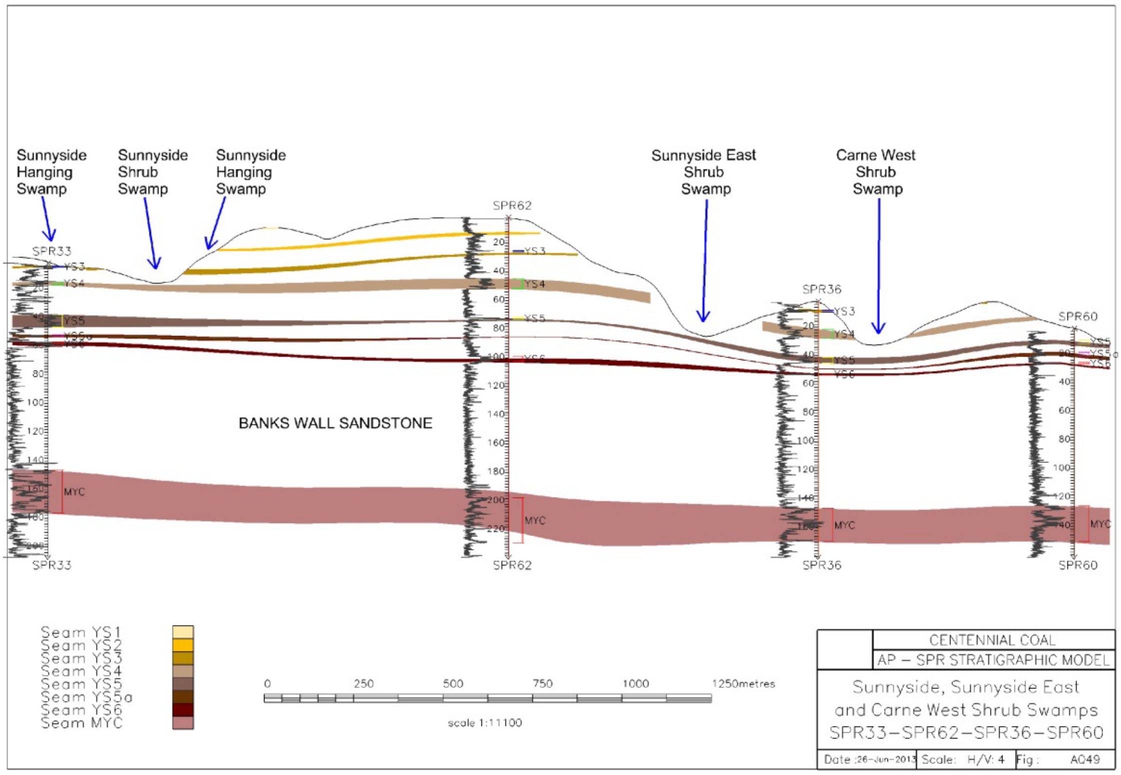


Figure 17 - Interpolation and extrapolation of lateral continuities of substantial aquitards as per McHugh (2013)

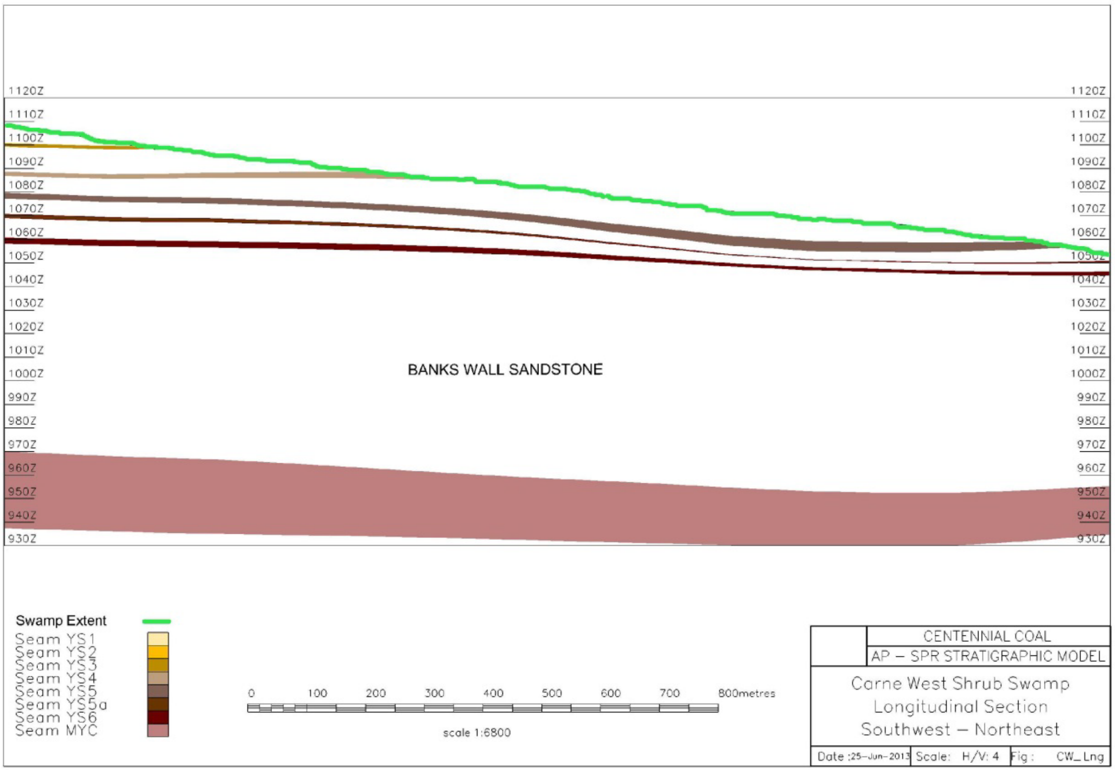
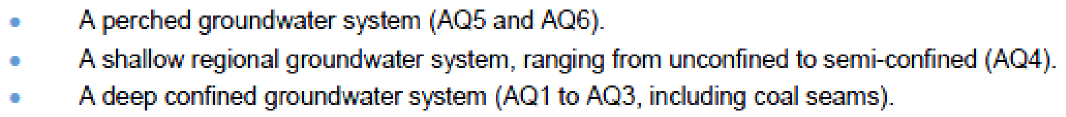


Figure 18 - McHugh interpreted continuous argillaceous beds along the alignment of Carne West valley swamp.

3.3.2 'Perched' aquifer systems

It is necessary to address the hydrogeological language of "aquifers", "aquitards" and "aquicludes" that dominates the understanding of the geology. These terms are used by hydrogeologists to describe the relative permeability of geological formations – i.e. how readily water can flow through them. They are subjective terms, and are not underpinned by any standard classification. This terminology, therefore, provides a means to impose a heuristic[6] upon the geology. The notion that follows the identification of "aquifers" and "aquitards" is that of "connectivity". "Aquitards" are perceived, within the Centennial Coal EIS, as geological formations that effectively separate groundwater into "hydraulically disconnected" systems.

The description of hydrogeology in pg. 27 of the EIS Groundwater Impact Assessment catalogues six different "aquifer" systems and stipulates which of these are deemed to either to be "hydraulically connected" or "disconnected" from adjacent formations. These six "aquifers" are then grouped further into three "systems" (as shown in Figure 14) (*ibid*, pg. 28):



- A perched groundwater system (AQ5 and AQ6).
- A shallow regional groundwater system, ranging from unconfined to semi-confined (AQ4).
- A deep confined groundwater system (AQ1 to AQ3, including coal seams).

Selections from the EIS descriptions of the hydrogeology of these "systems" are presented below:

The "perched" "system":

> "These systems comprise discontinuous, surficial systems which are *hydraulically independent* of the underlying regional groundwater system. The perched groundwater is generally located within the upper 100m where the Burralow Formation is present. It is derived from excess rainfall which is *largely prevented from infiltrating deeper down* into the regional systems due to the presence of fine grained or less permeable claystone and siltstone horizons" (emphasis ours)

The "shallow" "system":

> Most *groundwater flow in this water bearing sequence is generally horizontal* along bedding planes. The shallow groundwater system is underlain by the MYC. This horizon comprises a low permeability layer that *restricts infiltration downwards* from the shallow groundwater system to the underlying deep groundwater system.

We question the basis for this heuristic of different "systems", and query what this heuristic practically means. Are distinct groundwater systems perceived to exist because of different groundwater elevations between regions? Is it based on a notion that no (or negligible) flow moves from one "system" to the other? Is the inference that the pressure distribution in each system is entirely independent? On what evidence are "systems" decreed to be "disconnected"? As shown below, neither physics nor the available data support any of these assertions.

---

[6] Heuristics: "*simplified rules of thumb that make things simple and easy to implement. Their main advantage is that the user knows they are not perfect, just expedient, and is therefore less fooled by their powers. They become dangerous when we forget that" (Taleb, 2012).*

Consider the flow of a “perched” groundwater body horizontally upon a designated “aquitard” as shown in Figure 19.

The hydraulic gradient (i) supporting the assumed horizontal flow is approximated as $(h_2-h_1)/(x_2-x_1)$ and, using Centennial Coal’s cross sections, may have a value of 0.01 to 0.001. Using the horizontal hydraulic conductivity (K) of 1 x 10^{-7} m/s, a potential horizontal flow velocity (v_h) of 1 x 10^{-9} to 1 x 10^{-10} m/s is inferred (v=Ki). If the saturated zone is approximately 5 metres depth, a discharge of less than 5 x 10^{-9} m^3/s (0.4 litres per day) per metre width of formation is implied.

If the formation is truly “perched”, according to the conceptual model, and a zero-pressure or unsaturated zone exists underneath the “aquitard”, then the vertical hydraulic gradient is calculated as $(h_2+h_1)/(t)$ or, assuming h ~ 5 m and t ~ 5 m, approximately 2. Using the vertical hydraulic conductivity of 9 x 10^{-9} m/s for the “aquitard” (as per Centennial Coal EIS), a potential vertical flow velocity (v_v) of 1.8 x 10^{-8} m/s is inferred. That is, the potential vertical flow velocity is commensurate with the potential horizontal flow velocity. Moreover, the flow area, in the downward direction, is many times larger, meaning the potential vertical discharge, for this “perched” system, exceeds the horizontal discharge. Hence there is no “hydraulic separation” justified on the basis of flow velocity or discharge.

The data from Springvale mine also does not show that the identified “systems” are in fact separated by a zero-pressure or unsaturated zone. The data (Figure 20) show the “water head” in each “aquifer” extends into the “aquifer” above.

The implications of this, on the aquifer-aquitard heuristic adopted by Centennial Coal EIS, are shown in Figure 21. In this instance, the vertical flow hydraulic gradient is calculated as $i = \Delta H / t$. That is, the vertical flow velocity between the “aquifers” is sensitive to the pressure in adjacent “aquifers”. Hence there is no “hydraulic separation” justified on the basis of observed pressure differences.

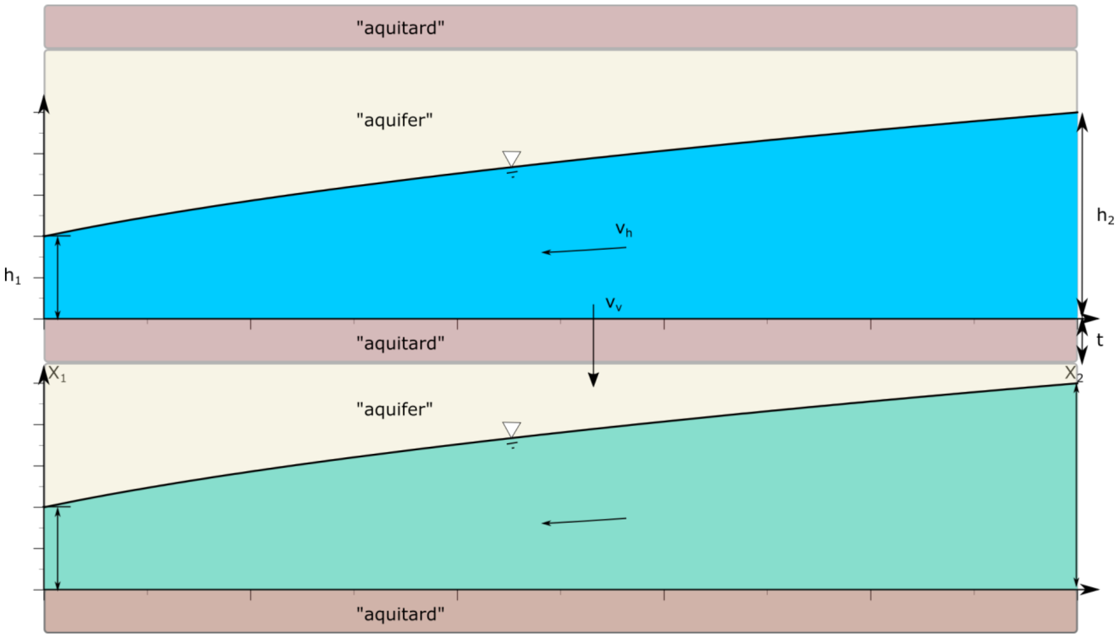


Figure 19 - Conceptual example of horizontal and vertical flow for "perched" groundwater

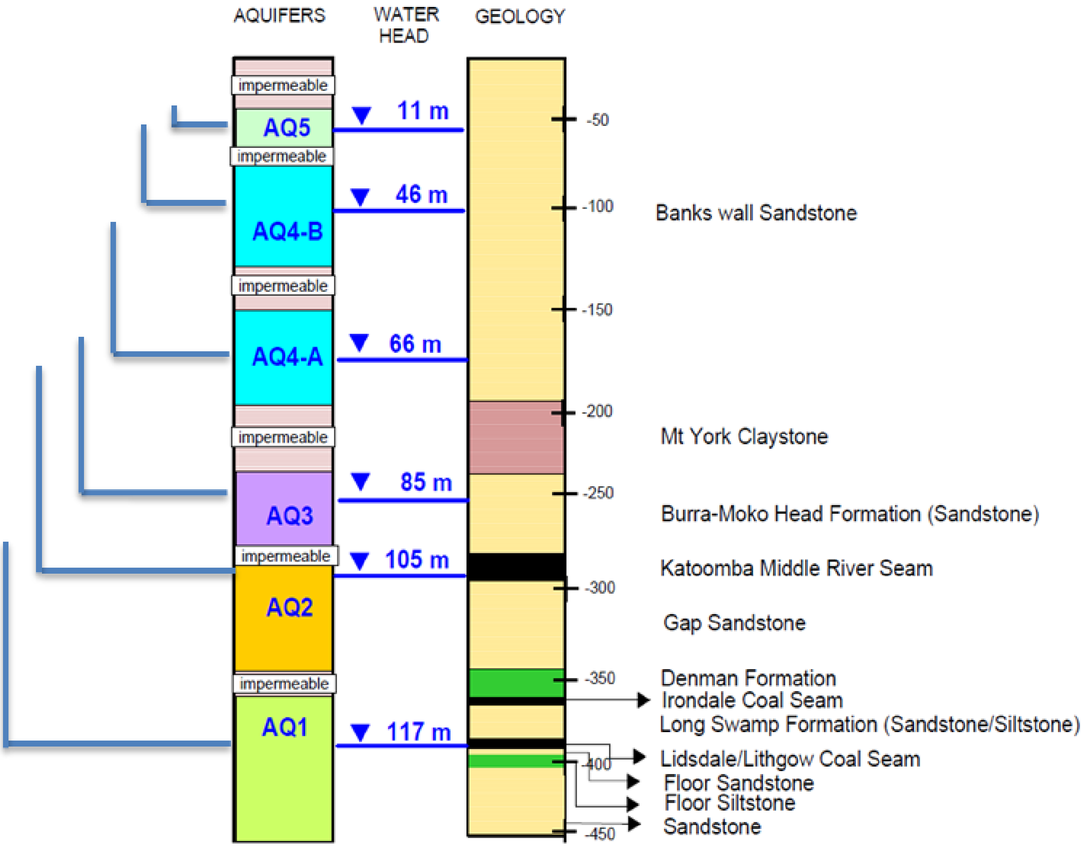


Figure 20 – VWP data at Springvale (ACARP, 2007)

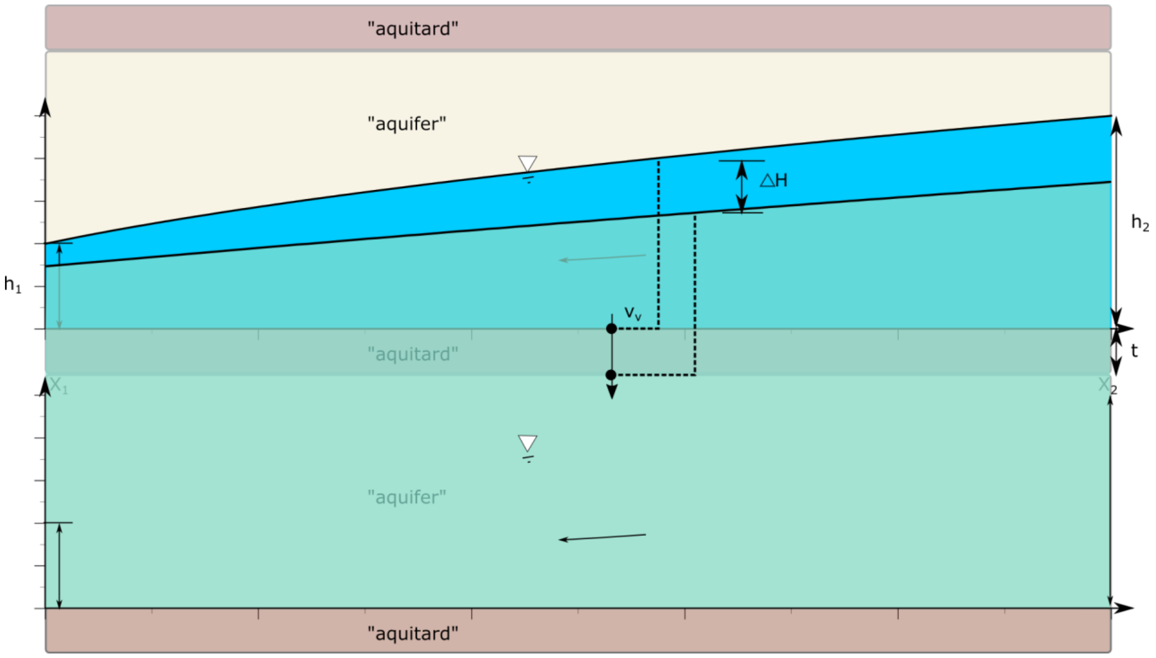


Figure 21 - Conceptual example of horizontal and vertical flow for observed groundwater levels

It is argued, therefore, that the data show that there exists a strongly vertical downward flow regime at Springvale, rather than a series of “disconnected”, “horizontally flowing” aquifers, as interpreted in the Centennial Coal EIS.

“Perching” of groundwater is a process whereby groundwater flow, moving in various directions throughout the region, goes in and out of saturation in response to variation in hydraulic conductivity of geological formations that it encounters. We reject the inference that ‘perching’ is evidence of lack of vertical ‘connectivity’ (or as offering immunity to effects from below).

It is difficult to say if the vertical flow field at Springvale is a baseline (pre-mining) condition, as in most instances, monitoring did not precede mining. Downward flow may represent natural flow from the plateau towards the adjacent valleys. Alternatively, it may be indicative of mining effects – such a pattern, due to mining effects, has been viewed to develop above numerous longwall mines in the Sydney Basin, as presented in Pells and Pells (2012).

3.3.3 Swamp categorisation – “Type A” and “Type C”

The designation of “Type A” and “Type C” swamps as a baseline condition, as adopted by Centennial Coal, has important implications to interpretation of mining effects. As discussed below, the potential impacts of mining on swamps is for those swamps to shift from perennially wet to intermittently wet conditions – i.e. from a ‘Type C’ to a ‘Type A’.

A significant period of monitoring is required to establish such hydrologic characterisations, and to discern against other climatic variables. Such characterisation should also have the support of a vegetation analysis.

In many cases, swamp monitoring at Springvale did not precede mining by a significant margin, if at all. A summary of monitoring locations and monitoring periods is given in Table 1, and the time that mining undermined the relevant catchment is also shown. As discussed below, it is difficult to determine the timeframe of mining effects, so it is hard to know when data ceases to be “baseline”. In addition, the onset of mining effects is not necessarily marked simply as the time that the longwall passes directly under the swamp – impacts from depressurisation, including from first workings and any de-gassing, can be translated ahead of the current workings, or from adjacent mined regions. In Centennial (2014 THPSSMMP page 63) baseline data collection is considered valid up to the time until mining is within 200m of a piezometer. We are of the view that this criteria does not allow for adequate demarcation of baseline conditions.

Nonetheless, it is evident from Table 1 that, in most cases, limited baseline data exists, and in many cases, none exists.

In Figure 22, the location of various swamps and their catchments and the extent of mining, as of 2012, are shown. Also shown is Centennial Coal’s swamp classification. It is evident that Type A swamps (intermittently wet) correspond with mined catchments. Without sufficient baseline data, it is evident that this classification could potentially obscure the interpretation of mining effects. Indeed, an alternative interpretation from Figure 22 is that the characterisation of ‘Type A’ swamps, may in fact be a documentation of mining effects, rather than a baseline condition.

In summary, it is our view that insufficient baseline data is available to support a baseline characterisation of “Type A” and “Type C” swamps, as adopted by Centennial, and this characterisation thus obfuscates the investigation of mining effects.

Table 1 – Summary of Flow and Piezometric Monitoring at Swamps, as of 2012

Swamp Catchment	Sub-catchment	Flow Monitoring			Swamp Piezometric Monitoring		Date catchment undermined	Swamp Type[1]
		Type	ID	Period	ID	Period		
Kangaroo Swamp	Upper	Fortnightly	?	?		-	Prior to 2003	-
	Mid	Continuous	KWH, KW2	Nov ‘08 to Feb ‘10	KC2	Since Dec-08	from Jan 2010	A
	Low	Fortnightly	?	?	KC1	Since May-05	from June 2008	C
Narrow Creek	Upper	Fortnightly	?	?	-	-	Partially, prior to 2003	-
	Mid	Continuous	NSW1	?	NS1, NS2	Since May-05	Mar-07	A
	Lower	Continuous	NSW2	?	NS3, NS4	Since Mar-08	Late 2006?	A
East Wolgan	Upper (Junction Swamp)	Continuous	?	Since May-02	D1, D2, D3	Since May-02	Prior to 2003	A
	Mid	Fortnightly	EW-US	Since May-05	-	-	Partially, between 2003 and 2005	-
	Lower	Fortnightly	EW-DS	Since Mar-06	WE1, WE2	Since May-05[2]	Early - Mid 2006	A
Sunnyside	Upper	-	-	-	-	-	-	-
	Upper Mid	Fortnightly	SS-US	Since Dec-04	SS1, SS2, SS3	Since May-05	since Feb 2011	C
	Lower Mid	Continuous	SS-DS	18-Mar-10 to 25 Nov 10	SS4, SS5	Since Feb-10	since Feb 2011	C
	Lower	Fortnightly	WT-DS	Since Jan-04	-	-	-	-
Sunnyside East	Upper	-	-	-	-	-	Not yet	-
	Lower	-	-	-	SSE1, SSE2, SSE3	Since Feb-10	Not yet	C
Carne West	Upper	-	-	-	-	-	Not yet	-
	Mid	Fortnightly	CW-US	?	-	-	Not yet	C
	Lower	Fortnightly	CW-DS	Since Dec-04	CW1, CW2	Since May-05	Not yet	C

[1] As classified by Aurecon, 2010

[2]. Measurement of natural flows was masked by continuous mine discharge from 2002 to March 2006

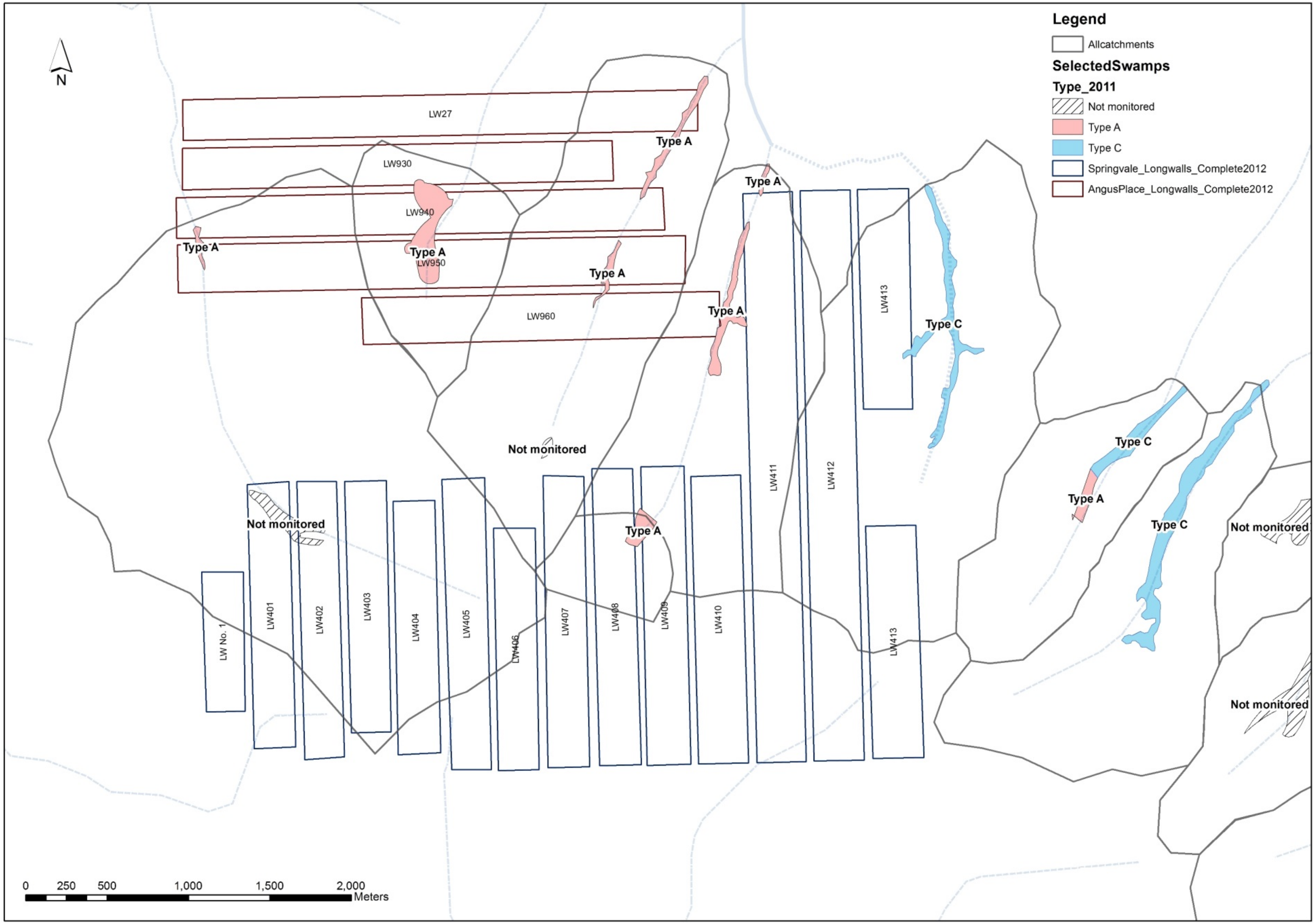


Figure 22 – Swamp types, after Aurecon (2011), showing correlation between swamp types and undermining of catchment in 2012

4 POTENTIAL EFFECTS OF MINING ON SWAMPS

Some of the potential effects that longwall mining could have on swamps are described below.

4.1 Cracking of the stream / swamp beds

The removal of the coal seam due to longwall mining causes collapse of formations above it, and propagation of cracking of throughout the formation. Various models of the nature and geometry of cracking have been published, and many publications describe clearly demarcated zones, such as the caved / fractured zone, constrained zone and surface zones, as adopted by Centennial Coal. It was argued in Pells and Pells (2012) that there was limited evidence to support such clear zones, and the cracking scheme depicted in Figure 23 was postulated.

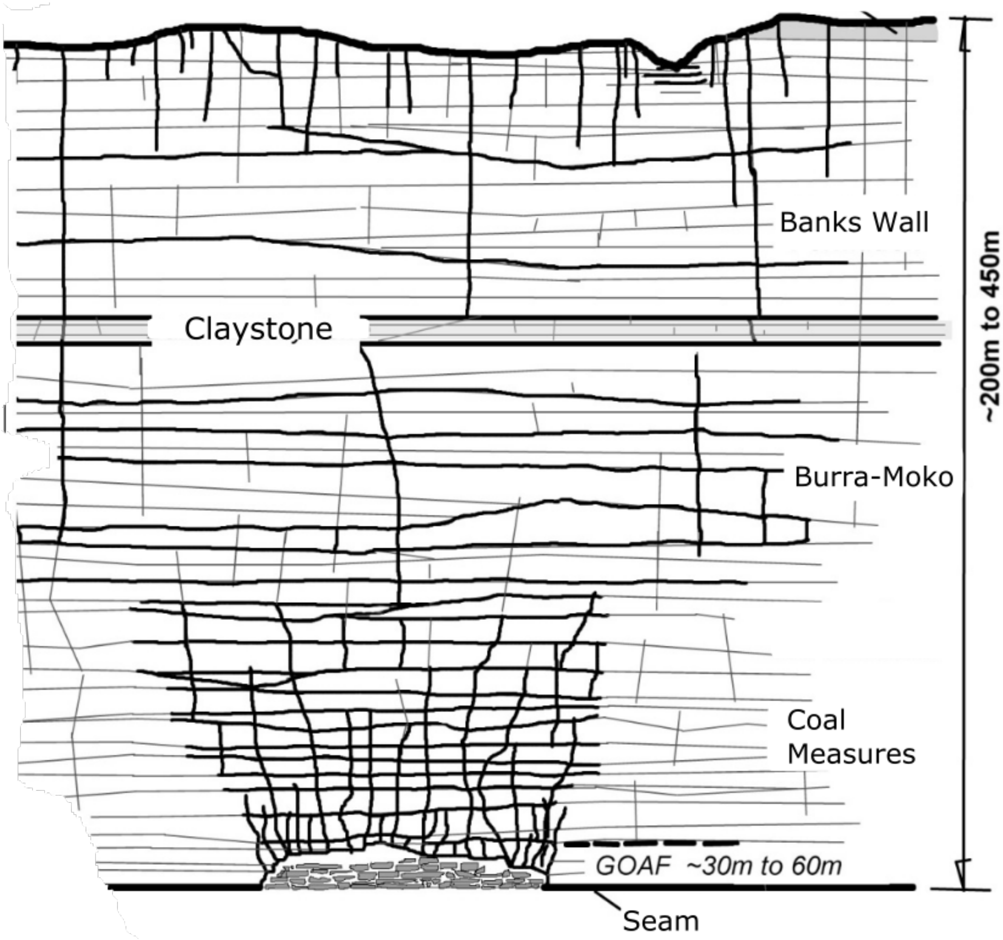


Figure 23 – Schematic of postulated impact of longwall mining

There have been various documented instances from longwall mining in the Sydney Basin where surface cracking has ruptured the beds of creeks, causing dramatic impacts on surface water bodies. Examples include the Waratah Rivulet, in the Southern Coalfields, and the East Wolgan swamp – which is at Springvale. In this latter instance, cracking devastated the swamp, with large surface openings shown to be capable of capturing large surface water discharges, and transmission of this flow, via cracks, to an apparently unknown location.

The cracking incident at East Wolgan was subject to various specific studies, and a review of the geological conditions and mining effects that led to this event is beyond the scope of this study. It is considered suffice to say that the risk of such cracking remains present, and its occurrence is difficult to predict.

4.2 Cracking through ‘aquitards’

Following from the discussion above, it is clear that cracking can result in a significant increase in permeability of geological formations.

At Springvale, various “aquitards” identified in McHugh (2013) that are stated to be the reason for the swamp existence. If swamp existence is dependent upon these argillaceous horizons, it follows that cracking and increased vertical permeability of these horizons will impact upon swamp hydrology.

4.3 Alterations to catchment hydrology

4.3.1 Interception losses

The generalised overview of swamp hydrology presented in Figure 11 illustrates that surface water bodies are dependent upon a balance of inflows from runoff, throughflow and baseflow.

Surface cracking throughout a catchment can creates additional “depression storage”. These cracks can effectively intercept runoff that may otherwise recharge swamps, and either direct it to report at another location, or hold it in the cracks, to be eventually lost to evaporation.

4.3.2 Changes to topography

Differential settlement due to subsidence has the potential to re-align existing flow channels and watershed boundaries. Changes to such flow patterns would primarily affect the manner in which swamps receive runoff.

4.4 Regional depressurisation

Potential impacts to surface water resources from longwall mining are not constrained to subsidence and cracking. The longwall mining operation must maintain ongoing removal of seepage from the mine. This creates a drop in pressure at the mine location, and this pressure drop propagates over time through the formation, towards the surface (Pells and Pells, 2012).

An illustration of the propagation of depressurisation is shown in Figure 24.

4.4.1 Reduced or reversed baseflow

The reduction of pressure at the mine causes an increased vertical hydraulic gradient (i.e. flow vertically downwards towards the mine). Once this effect propagates to the surface, increased vertical hydraulic gradient diverts flows from baseflow, redirecting it toward the mine, as shown in Figure 25. The extent of impacts to baseflow depends upon the extent of depressurisation. A smaller reduction in pressure causes a minor reduction in baseflow. A large pressure reduction, such that groundwater adjacent to the stream is lowered below the stream level, can cause reversal of baseflow – i.e. rather than feeding the stream, flow is lost from the stream.

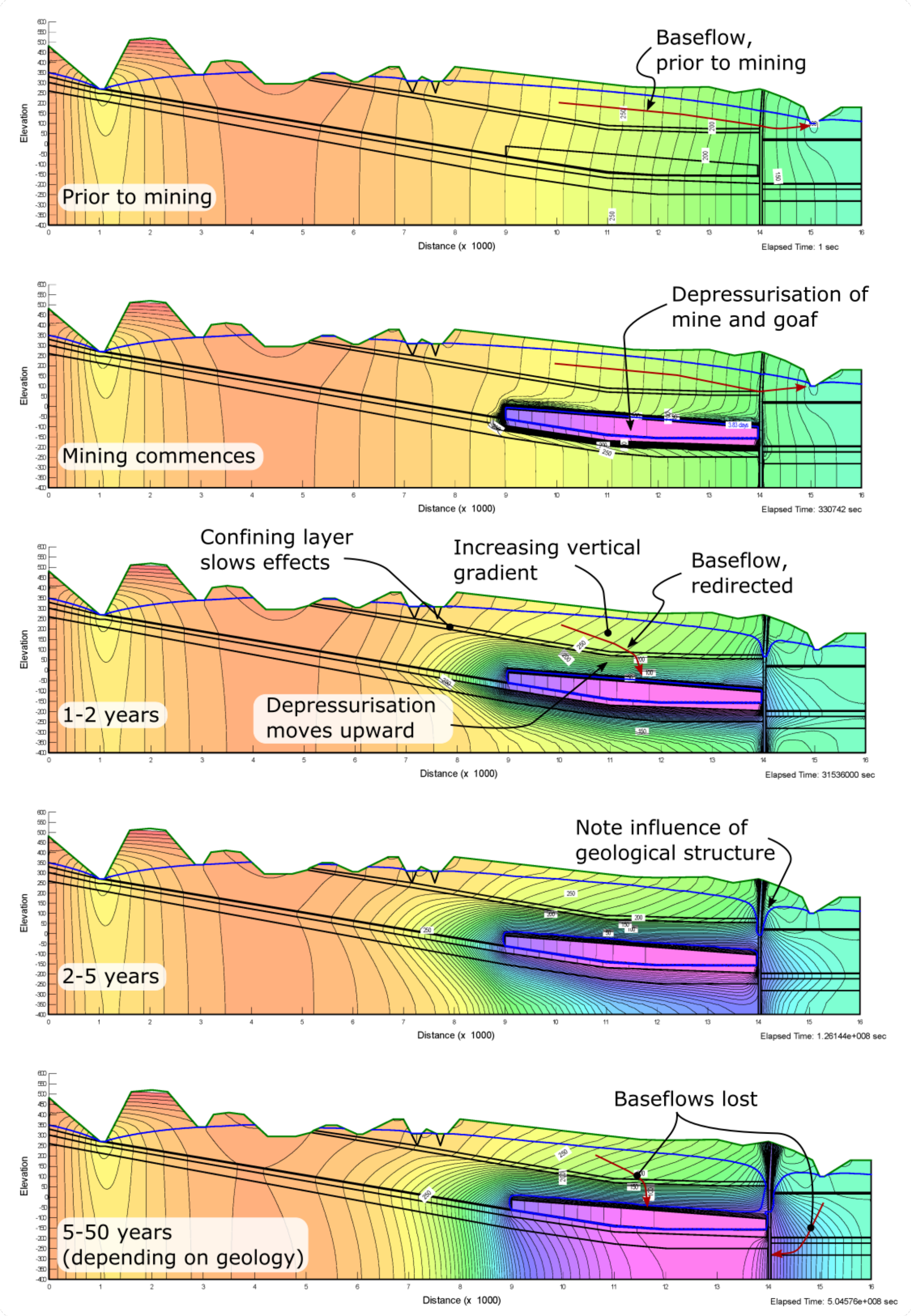


Figure 24 – Illustration of depressurisation from underground mining

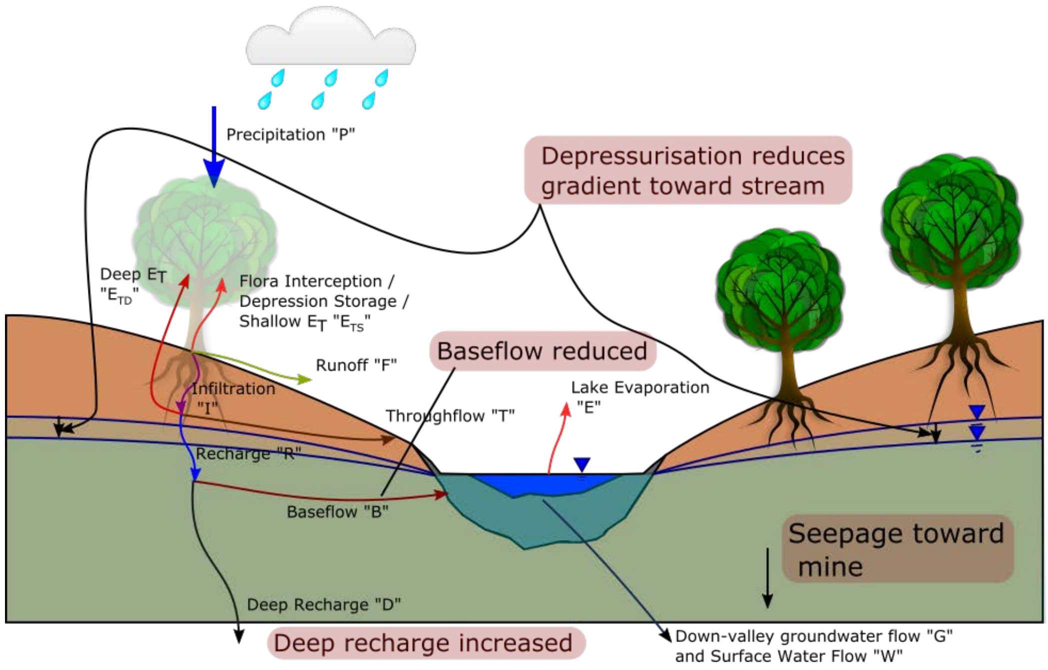


Figure 25 - Schematic of effects of depressurisation on baseflow

4.4.2 A comment on time-scale of drawdown impacts

The rate at which depressurisation effects from mining propagate is related directly to the geological conditions. The equation for groundwater flow is given as:

$$\alpha \nabla h^2 = \frac{\partial h}{\partial t}$$

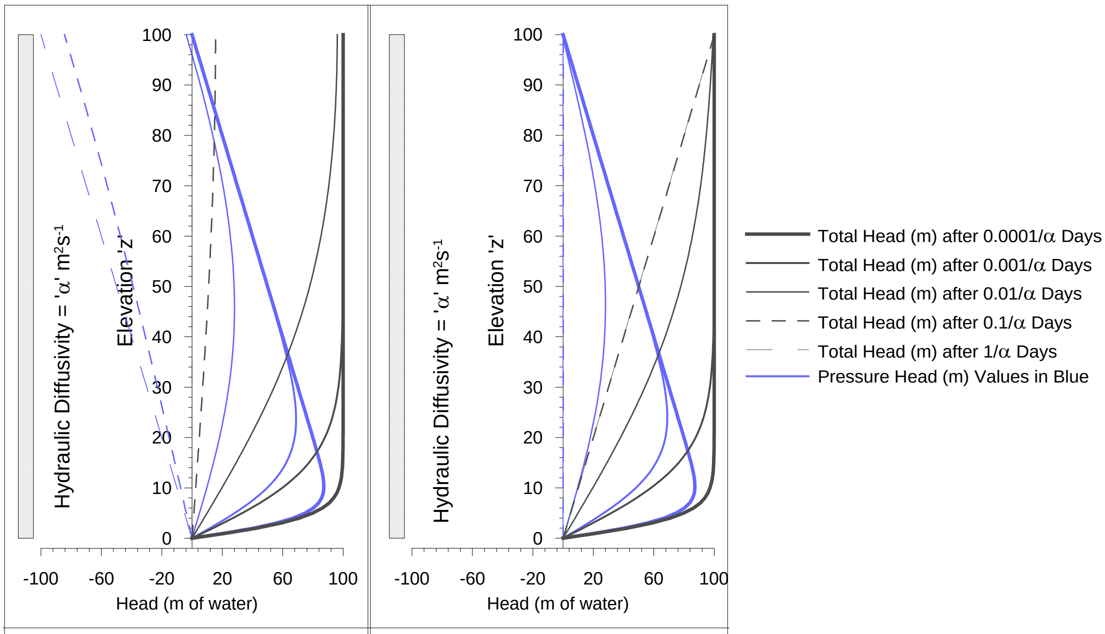
where ‘α’ is the diffusivity, defined as the ratio of hydraulic conductivity to specific storage:

$$\alpha = \frac{k}{S_s} = \text{“diffusivity”}$$

That is, the rate of depressurisation is directly related to the diffusivity of the geological formation.

The diffusivity is never known with confidence, and varies widely between different geological formations, and geological structures. This is why prediction of impacts from underground mining is fraught with uncertainty.

As an example, analysis on Pells and Pells (2012) showed that depressurisation, in a homogenous formation, is expected travel 100m above the mine over a period of 1/α days (see Figure 26). This value is calculated for two hypothetical situations, as shown in Table 2. It is seen that wide ranging predictions occur. The range in predictions becomes even wider when layering is present (Pells and Pells 2012).



Homogeneous, Saturated
No Recharge
Full Depressurisation at Base

Homogeneous, Unsaturated
No Recharge
Full Depressurisation at Base

Figure 26 - Propagation of depressurisation through a column (Pells and Pells, 2012)

Table 2 – Illustration of uncertainty in predicting rate of depressurisation

Hydraulic conductivity K (m/s)	Young's Modulus E (MPa)	Specific Storage S_S (1/m)	Diffusivity D (m^2/s)	Time to propagate 100 m
1×10^{-8}	20000	9.4×10^{-7}	1×10^{-2}	90 days
1×10^{-9}	10000	1.4×10^{-6}	7×10^{-4}	4 years

4.5 Summary: Impacts to swamps from the above mining effects

The impacts to swamps from the above effects would be a reduction in baseflows, leading the swamp to be more dependent on runoff events. Impacts would thus be evidenced as a subtle to large (depending on the swamp and nature of the effect) compromise of the persistence of wetness of the swamp - i.e. a statistical trend away from perennial conditions and towards ephemeral conditions. Excepting dramatic events, such as the East Wolgan example, these impacts are not immediately evident, and need to be discerned, over time, from natural climate variability.

To be clear, swamps that are impacted by mining will still be inundated or generally wet from time to time. The impacts will just mean that, statistically, the frequency and/or duration of wetness decreases. This trend will, over time, impact on swamp ecology.

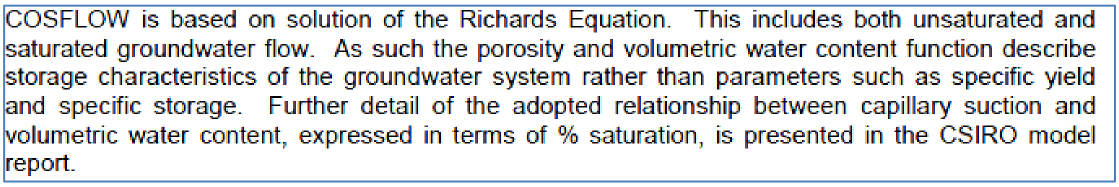
5 PREDICTED AND MEASURED IMPACTS AT SPRINGVALE

5.1 Depressurisation and groundwater modelling

A detailed study of groundwater impacts of the mining was undertaken by the Australian Commonwealth Scientific and Industrial Organisation (CSIRO). CSIRO originally presented modelling in 2007 (ACARP, 2007), but updated the analysis for the 2014 EIS.

The model by CSIRO adopted a proprietary code “COSFLOW”, which is a complex model that aspires to couple a structural model of subsidence with 3D groundwater flow modelling. Being proprietary makes the model difficult to review. We cannot, within the scope of this engagement, provide a full review of the COSFLOW code, and comment on its numerical scheme, and its suitability and performance for this application.

One of the key aspects in reviewing groundwater models is consideration of the parameters used to represent the geology – the hydraulic conductivity and specific storage. Reports by CSIRO and Aquaterra in the EIS do present the hydraulic conductivity values adopted in modelling. However, specific storage values are absent, with CSIRO stating the following:



COSFLOW is based on solution of the Richards Equation. This includes both unsaturated and saturated groundwater flow. As such the porosity and volumetric water content function describe storage characteristics of the groundwater system rather than parameters such as specific yield and specific storage. Further detail of the adopted relationship between capillary suction and volumetric water content, expressed in terms of % saturation, is presented in the CSIRO model report.

The manner in which the formation storage and compressibility is represented in the numerical model impacts directly on the time-frame of impacts predicted (see Section 4.4.2 above). We do not have the scope, within this document, to review the unique representation of storage and formation compressibility adopted by CSIRO. As such, we cannot comment on the appropriateness of the modelling of timing of impacts from mining. It is suffice to note that numerical models are sensitive to the parameters, and the parameters are not known with confidence, and hence the timing of impacts is not predicted with confidence.

Notwithstanding the complexity of the CSIRO model, we hold the view that *“numerical modelling solves the problem that you perceive”.* That is, numerical modelling tends to reflect the conceptualisation imposed by the modeller. This is considered to be true in the case of Springvale, as discussed below.

The CSIRO 3D numerical groundwater model of Springvale mine was originally documented in 2007 (ACARP, 2007). At this time Longwall 411 was being extracted. Piezometer positions along a section line are shown at natural scale in Figure 27.

By inspection it can be seen that the piezometer locations are far too widely spaced, horizontally, for any meaningful construction of flow directions in two dimensions. A reasonable interpretation of the piezometer data is that they showed downward flow to the depressurised Lithgow/Lidsdale seam, at least below the level of the Mt York Claystone.

Despite the paucity of data, the CSIRO report developed a hydrogeological model composed of aquifers and aquicludes as reproduced in Figure 28 and shown superimposed on the stratigraphy in Figure 29.

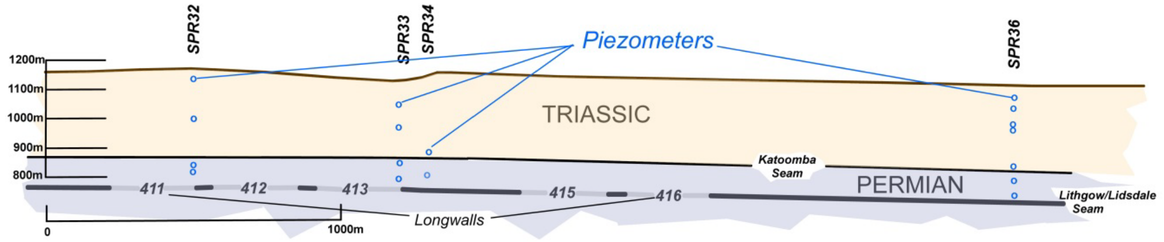


Figure 27 - Piezometer locations along section line given in Figure 5.

It is self-evident that analyses using the model presented in Figure 28 and Figure 29 will show horizontal flow in the designated aquifers, with mining only influencing where it is deemed that subsidence fracturing has breached designated aquicludes. Many similar models from longwall mining and CSG extraction in the coalfields of the Sydney Basin can be cited that contain the same heuristic, as set out above for the Springvale area.

A reasonable conclusion is that the hydrogeological heuristics discussed above, when applied to assessing depressurisation, will not properly address likely impacts.

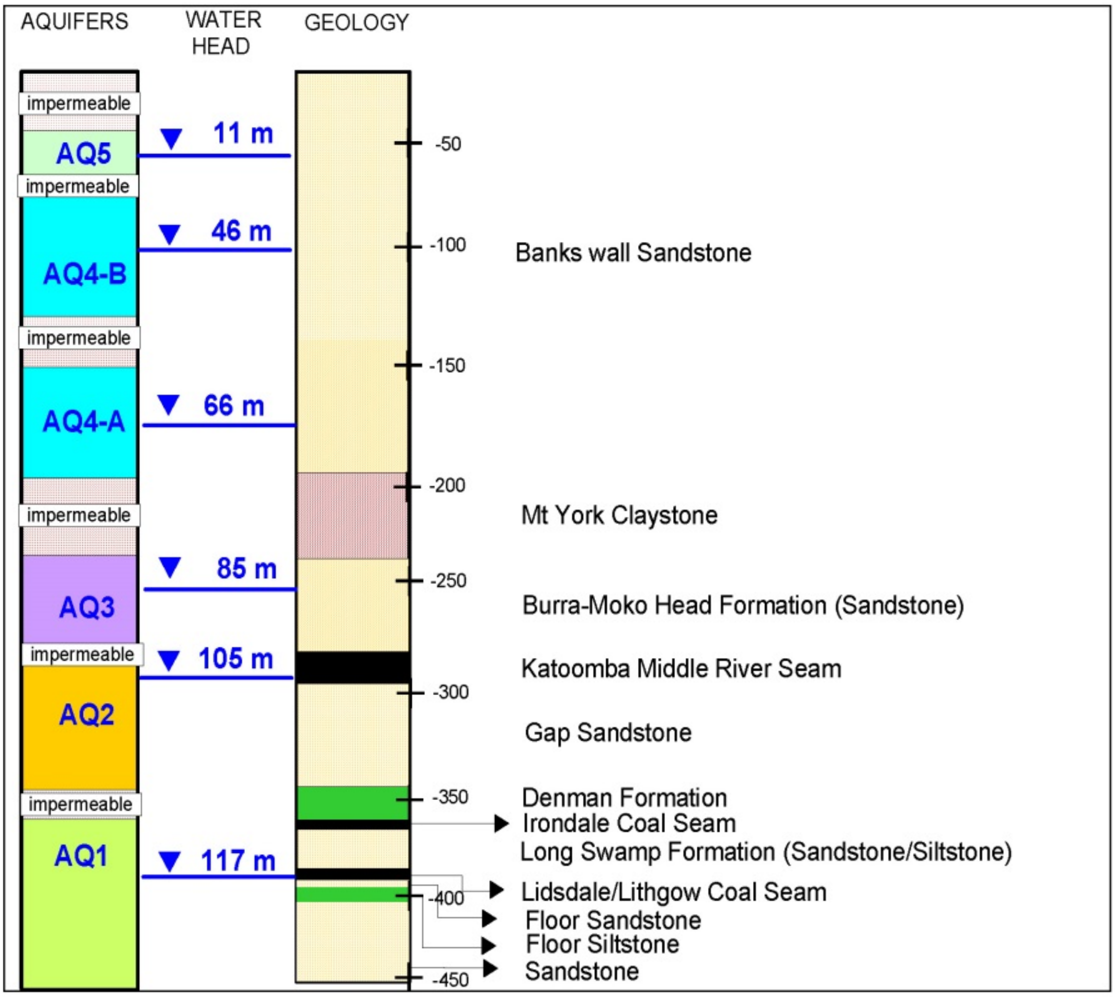


Figure 28 - CSIRO representative hydrogeological model developed for Springvale colliery (ACARP 2006)

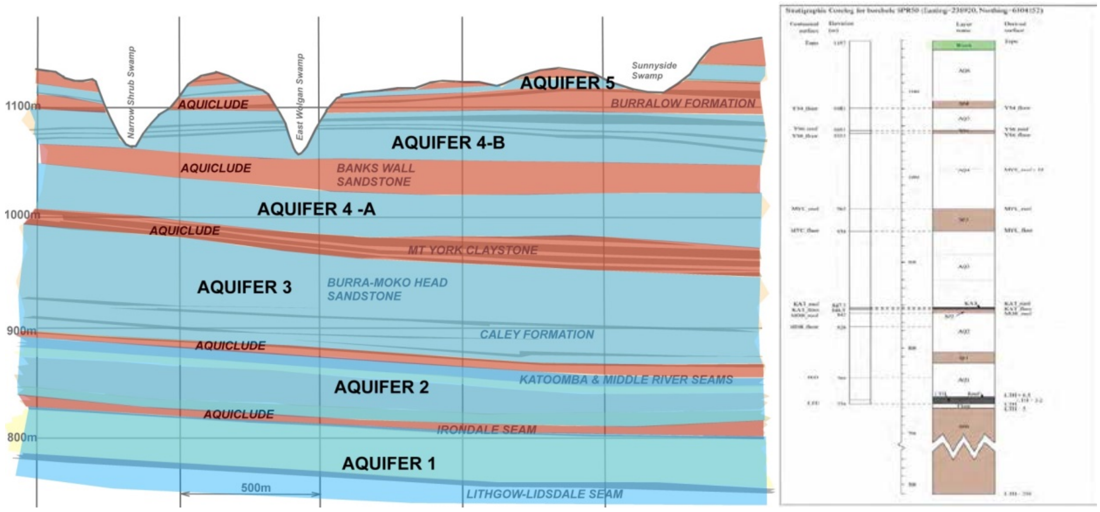


Figure 29 - CSIRO model of Figure 9 superimposed on the stratigraphy

It is understood that the model was revised for the EIS. The basis of the conceptual model was illustrated in the EIS as per Figure 30. The annotations made by the writer illustrate that the designated “aquitards” are interpreted as being completely persistent throughout the Burralow formation, as postulated by McHugh (2013).

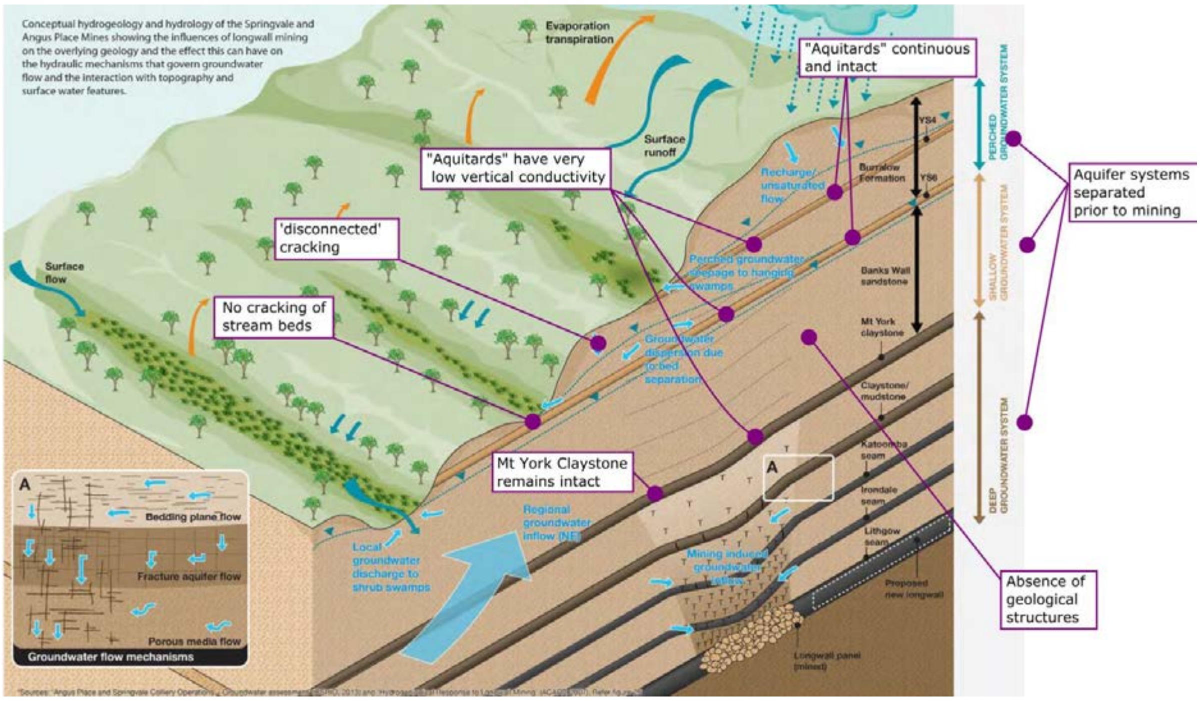
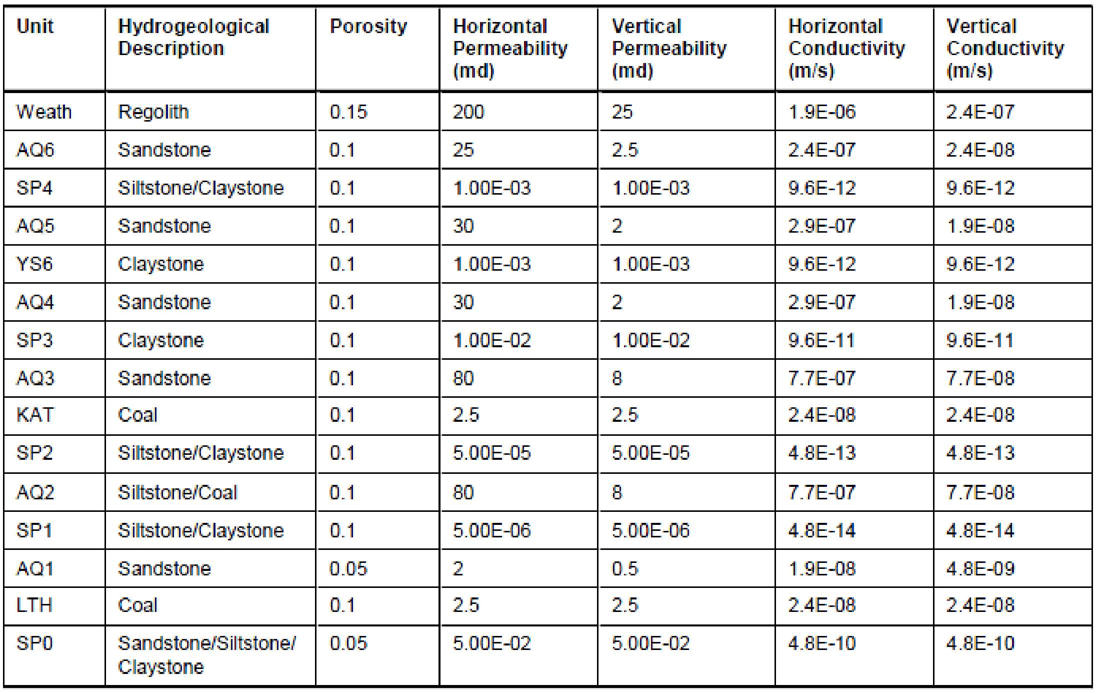


Figure 30 - Conceptual hydrogeological model represented in the numerical model (annotations ours)

The values of hydraulic conductivity adopted by CSIRO are presented in Table 3. It is seen that the values of vertical hydraulic conductivity of the “aquitards” is very low – ranging from 9.6 x 10^{-12} m/s down to 4.8 x 10^{-14} m/s. These values reflect the heuristic of separated “aquifers” and “aquicludes” in the conceptual model.

It is self-evident that such a conceptualisation will show very limited effects of deep mining on surface water resources.

Table 3 – Hydraulic conductivity values adopted by CSIRO



Unit	Hydrogeological Description	Porosity	Horizontal Permeability (md)	Vertical Permeability (md)	Horizontal Conductivity (m/s)	Vertical Conductivity (m/s)
Weath	Regolith	0.15	200	25	1.9E-06	2.4E-07
AQ6	Sandstone	0.1	25	2.5	2.4E-07	2.4E-08
SP4	Siltstone/Claystone	0.1	1.00E-03	1.00E-03	9.6E-12	9.6E-12
AQ5	Sandstone	0.1	30	2	2.9E-07	1.9E-08
YS6	Claystone	0.1	1.00E-03	1.00E-03	9.6E-12	9.6E-12
AQ4	Sandstone	0.1	30	2	2.9E-07	1.9E-08
SP3	Claystone	0.1	1.00E-02	1.00E-02	9.6E-11	9.6E-11
AQ3	Sandstone	0.1	80	8	7.7E-07	7.7E-08
KAT	Coal	0.1	2.5	2.5	2.4E-08	2.4E-08
SP2	Siltstone/Claystone	0.1	5.00E-05	5.00E-05	4.8E-13	4.8E-13
AQ2	Siltstone/Coal	0.1	80	8	7.7E-07	7.7E-08
SP1	Siltstone/Claystone	0.1	5.00E-06	5.00E-06	4.8E-14	4.8E-14
AQ1	Sandstone	0.05	2	0.5	1.9E-08	4.8E-09
LTH	Coal	0.1	2.5	2.5	2.4E-08	2.4E-08
SP0	Sandstone/Siltstone/ Claystone	0.05	5.00E-02	5.00E-02	4.8E-10	4.8E-10

We don’t accept that ‘calibration’ of the numerical model validates this conceptual model. The non-uniqueness of groundwater modelling can allow adequate calibration to be achieved for many assumed conceptual models.

We would argue that a more helpful usage of the modelling would be to undertake alternative model runs with alternative conceptualisations, such as examining the risks / effects if “aquitards” are: discontinuous; are disturbed by mining, or; are simply not as impermeable as imagined. Such an approach is appropriate, given the uncertainties in the geological formation and the hydrogeological parameters, and would allow the model to be effectively used to examine risk to swamps.

5.2 Subsidence and cracking

Subsidence settlement above longwall 415 (depth of cover 380m to 420m) was measured, in routine surveys, as achieving a maximum of 618mm. As of the March 2014 report, maximum subsidence above LW416 was 446mm. These settlements and the depth of cover, are comparable to the 700-series longwalls at Appin Colliery near Picton. Surprisingly the Springvale Subsidence Management Status reports of 2012, 2013 and 2014 do not give plots of subsidence, surface strains and tilts, so we cannot compare the data with the well-known and well-understood data from Appin.

It is reported at Springvale[7] that at least the following surface observations have been made since 2007:

> “During the retreat of Longwall 411, minor surface cracking was observed along a forestry track known as Campbell’s Rd. The visual inspection program completed on the Newnes Plateau ……During the extraction of LW411, cracking was observed within the rock bars in the

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[7] Springvale Subsidence management Status Report, March 2014

> drainage line north of the East Wolgan Swamp. The affected area has rock formations which are oriented in various directions indicating that it is a faulted zone."

Useful subsidence information, and a detailed discussion of likely ground movements in the swamp-valleys are given by Ditton Geotechnical Services (July 2013). We quote as follows:

> The measured and predicted subsidence and strain profiles (EWS-Line) across East Wolgan Swamp to-date are shown in **Figures 6a** and **6b** *(not reproduced herein)*.
>
> The profiles indicate irregularities in both subsidence and strain has occurred above the barrier pillar between LWs 411 and 950. It would normally be expected that the subsidence profile would be convex (hogging curvature) and develop tensile strains outside of the mining limits. However, the influence of the valley above the pillar can be clearly seen whereby compressive strains have developed at the base of the valley of up to 12 mm/m. The subsidence profile indicates near surface strata has moved upwards and downwards locally, which suggests the presence of near surface voids and buckling failures have occurred due to subsidence of 0.9 m above LW411 initially. The buckling is commonly seen in valley floors that have been rotated on one side by a subsidence trough, resulting in a direct increase of compressive stress across the floor of the valley. Similar stress increases can occur if the valley is directly undermined and subject to concave curvatures (see **Figure 6c**) *(not reproduced herein)*. Similar behaviour can also occur outside the angle of draw (i.e. the limit of vertical subsidence) to longwall panels due to differential displacements or rotation of near surface strata in the horizontal plane from far-field, horizontal stress relief effects (see **Figure 6d**) *(not reproduced herein)*. Both mechanisms can generate both valley closure and opening movements, which can result in apparent strain anomalies when compared to normal subsidence trough development in flat terrain (i.e. plateaus)……..
>
> Based on a review of measured subsidence effects at Springvale and Angus Place Mines, the prediction of valley closure and uplift needs to consider the influence of valley shape (depth, width and side slopes) and its location and orientation relative to the developing mine subsidence troughs. As discussed in **ACARP, 2002** and **DgS, 2010**, when creeks and river valleys are subsided, "the observed subsidence in the base of the creek or river is generally less than would normally be expected in flat terrain. This reduced subsidence is due to the floor rocks of a valley buckling upwards when subject to compressive stresses generated by surface deformation. In most cases in the Newcastle and Southern NSW Coalfields, the observed uplift has extended for several hundred metres outside of steep sided valleys.

Ditton (2013) goes on to say:

> The impact to valley floors has been greatest to valleys directly undermined by longwall panels. The results in **Table 2***(not reproduced herein)* indicate that the East Wolgan Creek Valley is likely to have had the highest closure and buckling movement of 363 mm and 112 mm. The next highest closure and buckling predicted was 275 mm and 106 mm respectively for Narrow Creek. The impacts measured above both valleys have been the highest detected for the two mines respectively. The rest of the valleys assessed have had predicted buckling and uplift movements ranging from 70 mm to 219 mm (closure) and from 15 to 82 mm (uplift). The measured impacts to all valleys have ranged from 30 to 100 mm of buckling of rock bars, 10 mm to 110 mm wide tension cracks to side slopes or no impact. The predictions and observations indicate that 15 mm to 112 mm of near surface void due to buckling may have occurred beneath the floor of the valleys due to mine subsidence.

And finally:

> …. higher valley closure and buckling predictions for the proposed longwalls 416 to 417,

The predicted subsidence and strain contours above the longwalls are reproduced in Figure 31 and Figure 32.

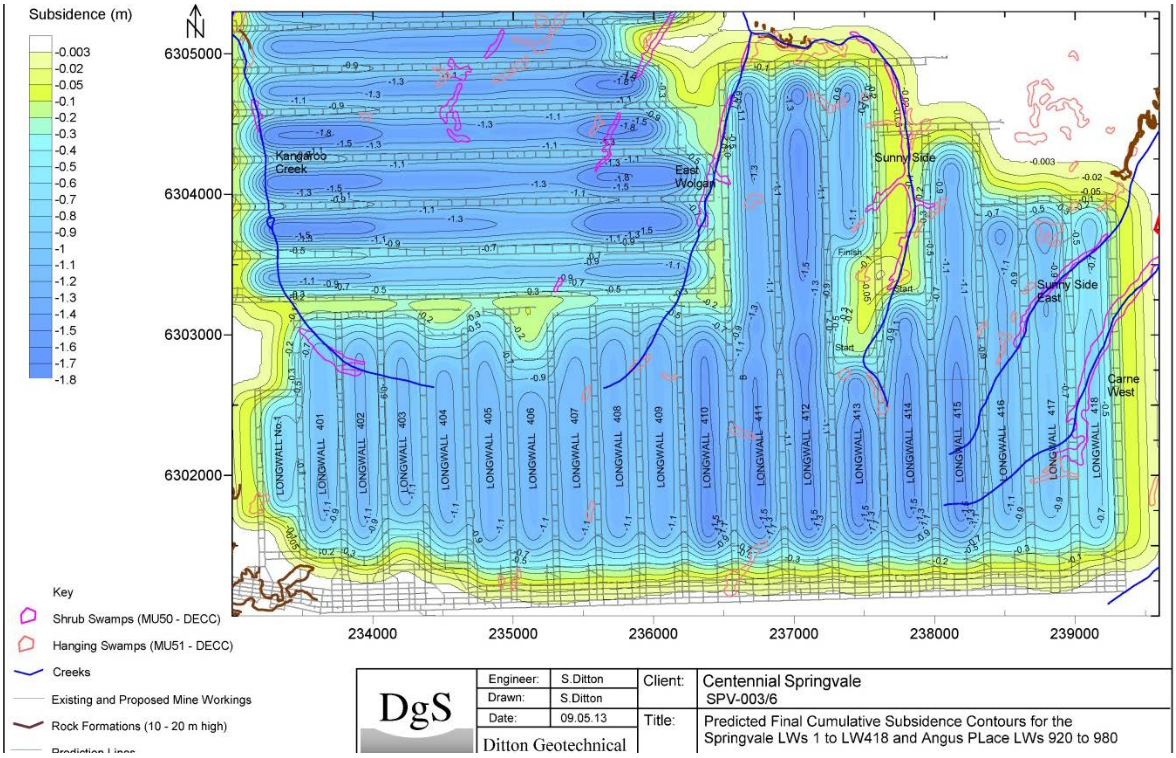


Figure 31 - Predicted surface settlement

Figure 32- Predicted surface strains

There are numerous examples from the Sydney basin coalfields where ground movements of the magnitude described above have caused cracking in creek beds, and disruption to the groundwater systems around creeks and rivers. In a recent example, considerable cracking occurred in an unnamed creek near Picton (Figure 33), as a consequence of longwall mining (not beneath the creek), with similar subsidence predictions to those at Springvale. This damage was unexpected.

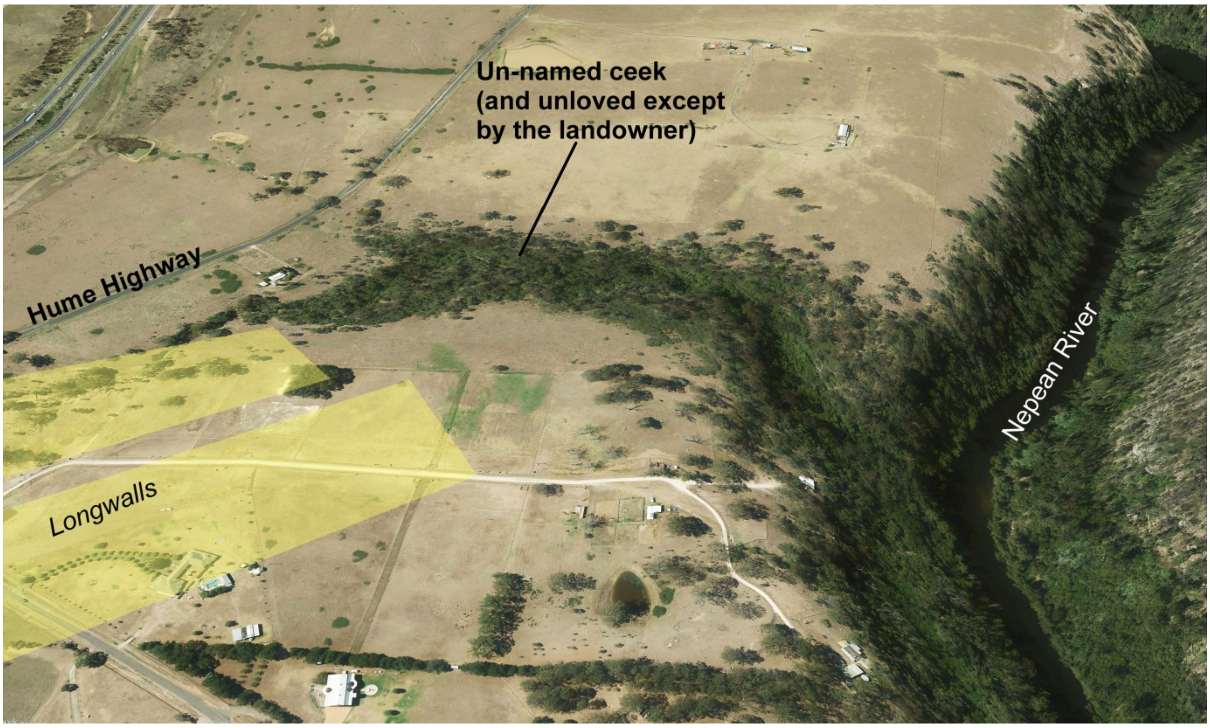


Figure 33 Un-named creek unexpectedly damaged by subsidence near Picton; ground movements and strains similar to those at Springvale.

It is certain that there will be induced tensile and compressive ground strains beneath undermined valleys and associated valley-swamps in the Newnes plateau above Springvale Mine. The nature of impacts arising from these strains will depend, subtly, on valley geometry and valley geology, and may not be observable to the eye because of the soil and vegetation cover in the swamps. This makes specific prediction and measurement of subsidence impacts difficult, if not impossible. On the basis of precedent, and with recognition of the mechanics of subsidence, subsidence studies can only reasonably conclude that some swamps may be significantly impacted and others may appear unaffected. To predict specific subsidence impacts to individual swamps is, we believe, delusional.

5.3 Measurements of swamp hydrology

Surface water and groundwater monitoring locations above Springvale mine are shown in Figure 34.

Springvale mine has produced regular reporting showing measured groundwater levels in piezometers along selected swamps.

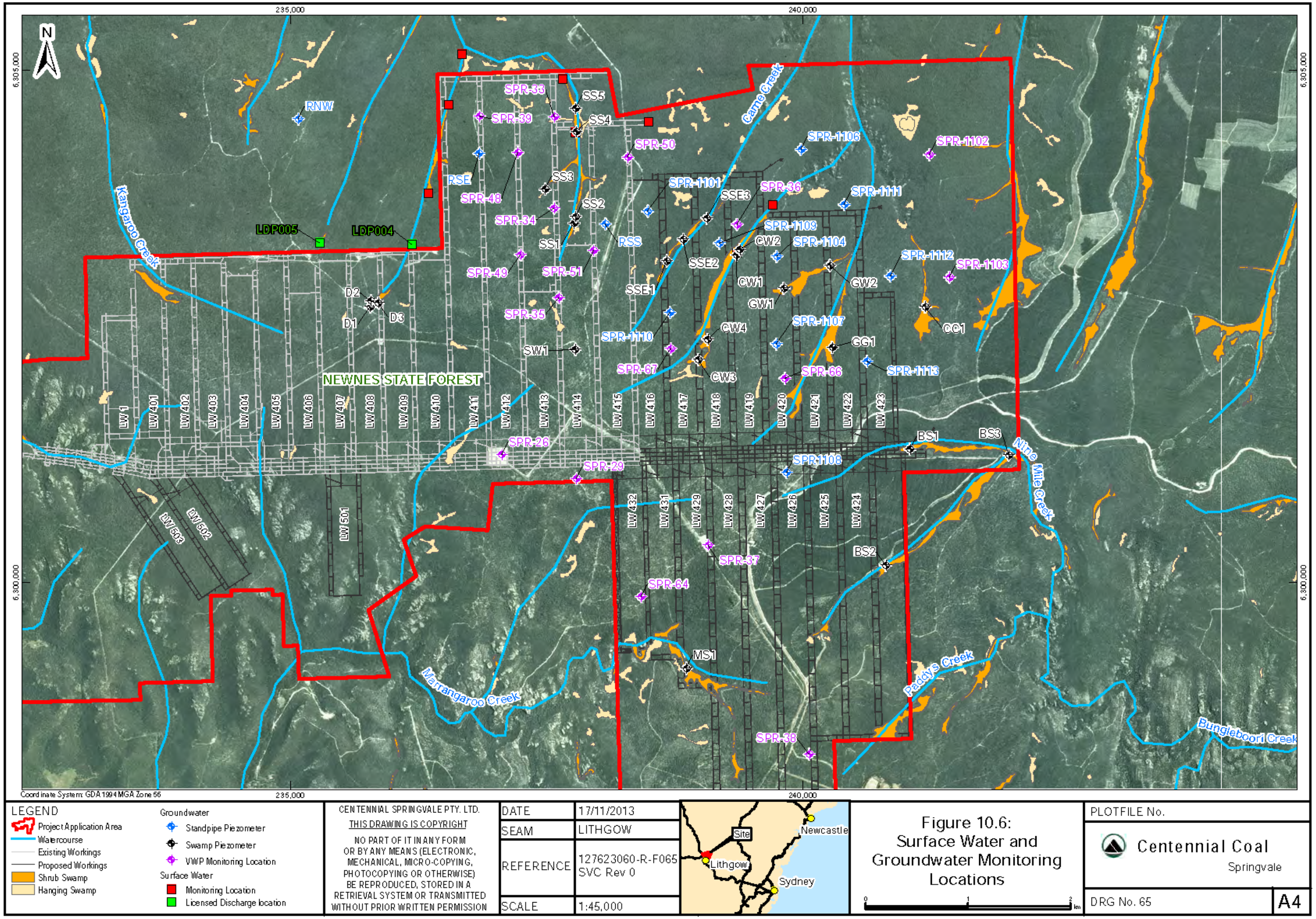
As stated in Section 3.3.3, we argue that monitoring up until 2002 was insufficient to confidently support baseline characteristics, as an insufficient period of monitoring was gained prior to mining. In addition, monitoring presented in the EIS extends generally only to 2012 – any effects that may have become apparent since that time have either not been measured or presented.

As stated above, with the exception of dramatic effect such as large bed cracking, impacts to swamps from mining is a reduction in baseflow, and an ensuing *trend* towards dryer conditions. A significant period of monitoring is required to be able to distinguish these trends from climatic variability.

These facts mean that the data, as presented in the EIS, provides an insufficient basis to discern long-term mining impacts to swamps.

In contrast to our view, in Appendix B of Appendix E of the EIS, a study was presented which demonstrated, based on review of monitoring data, that swamps had not been impacted. The basis for our questioning of their findings is demonstrated by annotations on the plots as shown in Figure 35, Figure 36 and Figure 37 below.

It is noted that the authors undertook a site inspection in October 2015, and during this time, observed that the swamp piezometer SS3 (in Sunnyside Swamp) was dry - it contained no water, and therefore was indicative of standing water levels lower than 1.25 m BGL. This is significantly lower that levels reported up to 2012, and requires further investigation.



LEGEND

- 🟥 Project Application Area
- Watercourse
- Existing Workings
- Proposed Workings
- 🟧 Shrub Swamp
- 🟨 Hanging Swamp

Groundwater

- ◆ Standpipe Piezometer
- ◆ Swamp Piezometer
- ◆ VWP Monitoring Location

Surface Water

- 🟥 Monitoring Location
- 🟩 Licensed Discharge location

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DATE	17/11/2013
SEAM	LITHGOW
REFERENCE	127623060-R-F065 SVC Rev 0
SCALE	1:45,000

Figure 10.6:
Surface Water and
Groundwater Monitoring
Locations

PLOTFILE No.

Centennial Coal
Springvale

DRG No. 65

A4

Figure 34 - Surface and groundwater monitoring locations

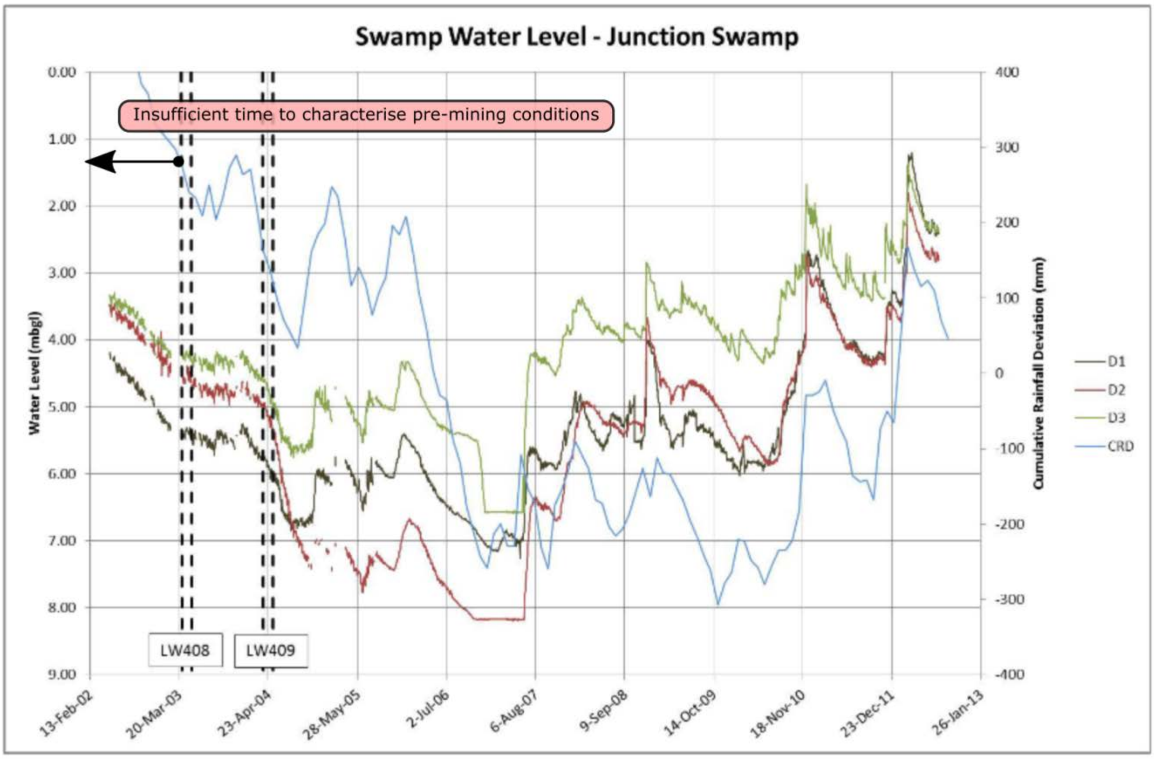


Figure 35 - Piezometer measurements, Junction Swamp

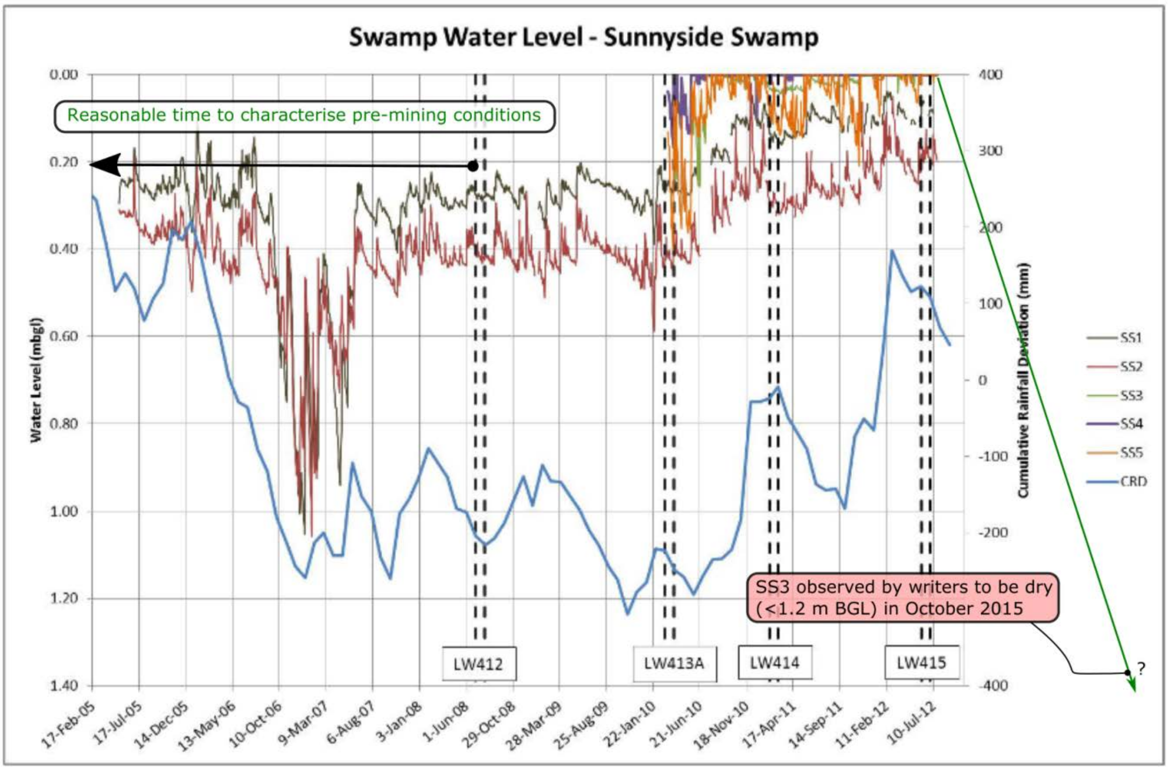
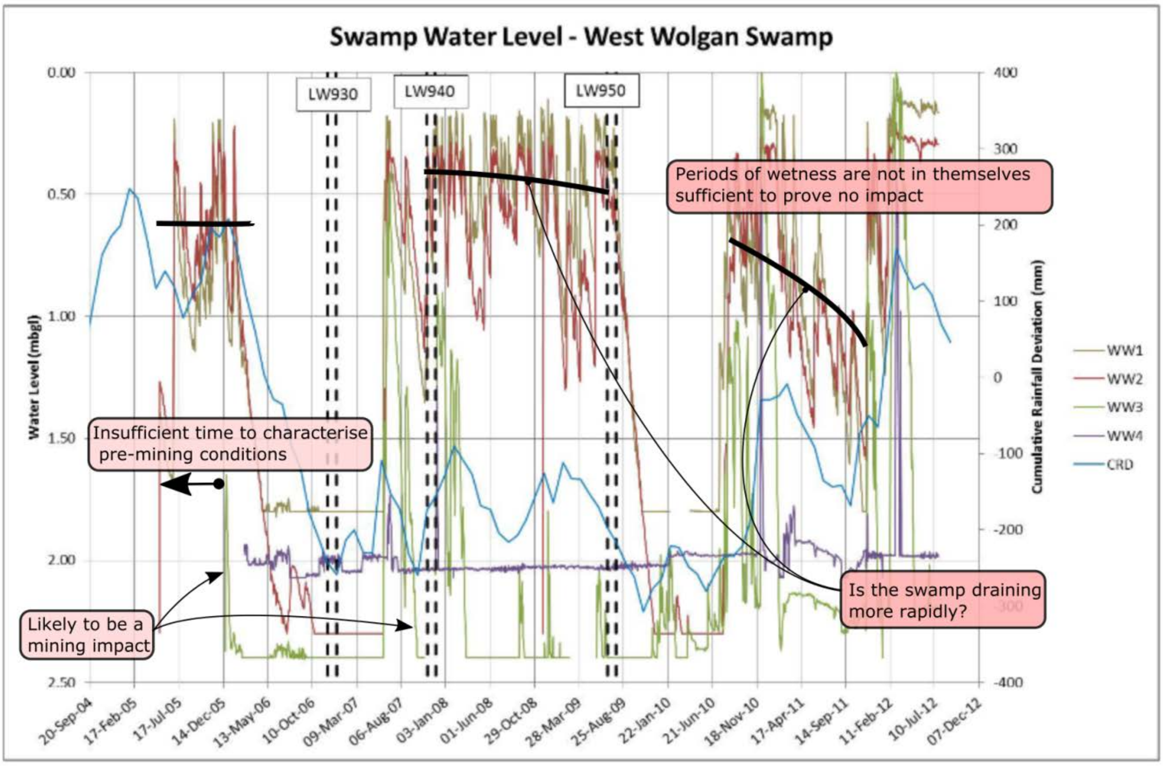


Figure 36 - Piezometer measurements, Sunnyside Swamp



Periods of wetness are not in themselves sufficient to prove no impact

Insufficient time to characterise pre-mining conditions

Likely to be a mining impact

Is the swamp draining more rapidly?

Figure 37 - Piezometer measurements, West Wolgan Swamp

6 CONCLUSIONS

The hydrology supporting the unique hanging and shrub swamps on the Newnes plateau is complex. The evidence suggests that both the hanging swamps and the valley swamps rely upon groundwater, which has complex interactions with the swamps through the adjacent sandstone formations and multiple thin and potentially discontinuous argillaceous shale beds.

The available evidence is that the valley swamps had their genesis in lengths of stream where the thalweg levelled due to the presence of erosion resistant sandstone (causing significant decrease in flow velocity) and where, at places along such lengths, relatively thin beds of argillaceous rock inhibited downwards groundwater seepage and created spring-like conditions. Low velocities allowed deposition of some gravels and coarse sand, and groundwater baseflows sustained vegetation, which in turn generated organic debris (compost) and the development of swamp vegetation, and peaty deposits.

Subsidence from longwall mining has the potential to upset this fragile pattern, through differential settlements, and cracking of the surface and of the shale beds.

Due to the complexity of the system, and given that subsidence induced tensile ground strains vary subtly according to terrain shape and near surface geology, it is not possible to predict exactly and specifically where subsidence related effects will occur around swamps, and how severe the resulting impacts will be.

Nonetheless, it is clear that there is a fragile, complex system, and that subsidence will occur, which is clearly associated with mechanisms that could cause impacts.

Ongoing dewatering of the mining operations, at depth, will continue to propagate a depressurisation 'wave' throughout the formation. This creates (or increases) a vertical flow profile. Once the 'wave' arrives at the near surface, it will remove some groundwater from the systems which interact with the swamps. This mechanism is a physical certainty. What is uncertain, is the timing of the arrival of this wave, and the amount of attenuation of this wave – i.e. how great the impacts will be. This timing and attenuation will be affected by layering of the formation, including the presence of claystone and argillaceous shale beds. Groundwater modelling attempts to numerically predict this depressurisation wave, but depends upon the hydrogeological characteristics of the formation, which are not known with certainty. Hence, while depressurisation impacts are ultimately a certainty, the timing and extent of impacts are not known with confidence.

The conceptualisation of the geology used by Centennial is such that the effects of depressurisation are stated to be small to negligible. We argue that the conceptualisation of Centennial may overstate the impermeability and continuity of shale and claystone beds, and thus under-predict impacts to swamps from depressurisation. It is possible, with alternative but equally plausible characterisations, to show that depressurisation has already arrived at the near-surface (as evidenced by the existing vertical flow profile), and has already been responsible for substantial drying of swamps (as evidenced by observed 'intermittently dry' swamp conditions above longwalls).

In summary, we cannot support assertions that further swamps will not be impacted by subsidence. This cannot be known, and on the basis of precedent, and consideration of the mechanics of subsidence, it is considered likely that further swamps will be dramatically impacted by subsidence, whereas others may suffer only subtle to imperceptible impacts.

We also cannot support assertions that dewatering from the mine has not and will not impact on swamp hydrology. Dewatering categorically will affect swamp hydrology - this is a physical certainty - it is just the timing and extent of such impacts that is uncertain. The nature of swamp hydrological monitoring undertaken by Centennial is, in our view, insufficient to provide definitive conclusions as to how much swamps have or have not been impacted through loss of baseflow. This is because the period of baseline monitoring is insufficient. Predictive modelling is also unable to definitively rule out future impacts from dewatering, due to parameter uncertainty. If, for example, an ‘alternative’ conceptualisation of the geology (with discontinuous and more permeable claystone and shale layers) is true, and the correlation between ‘intermittently wet’ swamps and longwall proximity is indeed a mining effect, we would expect to see all swamps becoming ‘intermittently wet’, rather that permanently wet, over time.

Steven Pells
Associate

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