Centennial Coal

Response to the Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining Knowledge Report

Temperate Highland Peat Swamps on Sandstone: Longwall Mining Engineering Design – Subsidence Predictions, Buffer Distances and Mine Design Options

September 2014

Introduction

The following is a response by Centennial Coal to the Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining Knowledge Report: Temperate Highland Peat Swamps on Sandstone: Longwall Mining Engineering Design – Subsidence Predictions, Buffer Distances and Mine Design Options (the IESC Report). In general the IESC Report:

- does not consider all of the relevant publicly available information in developing arguments about the effects of longwall mining on Temperate Highland Peat Swamps on Sandstone communities (THPSS).
- Where publicly available data has been used in the preparation of this report, certain data has been excluded where it does not support the position argued in the IESC report.
- Certain reference sources cited in the IESC report contain material which is not based on data and is biased against coal mining.

These general observations are further described in this report. For ease of reference, the structure of this report is based on the structure of the IESC report, and has been appended to the Response to Submissions to add a summary of relevant information from publicly available sources. In some areas this extends to a rebuttal of the data analysis or arguments presented in the report.

Centennial acknowledged in Chapter 2 and Chapter 8 of the Springvale Mine Extension Project Environmental Impact Statement (SVMEP EIS) and the Angus Place Colliery Mine Extension Project Environmental Impact Statement (APMEP EIS) that longwall mining has caused impacts to certain THPSS, however, as identified in these documents, this has not been the case in all instances. Chapter 2 of both the SVMEP EIS and the APMEP EIS acknowledged that subsidence impacts to swamp hydrology have been noted at two swamps (Kangaroo Creek Swamp and East Wolgan Swamp). Where impacts to certain THPSS on the Newnes Plateau have occurred, Centennial has conducted extensive research to understand the causes of the impacts. Centennial has used the findings of the research to avoid and mitigate both past and future impacts of longwall mining and related activities to THPSS on the Newnes Plateau.

Extensive research and investigation, lead primarily by work commissioned by the then DEWHA (the Goldney 2010 Report), has shown that impacts to THPSS on the Newnes Plateau have been caused primarily by:

- Licenced discharge of mine water through THPSS
- Changes to swamp hydrology caused by cracking of rock substrate beneath THPSS as a result of mine subsidence

The Goldney 2010 Report found that *the principal cause of impacts* to East Wolgan Swamp and Narrow Swamp was mine water discharge. This finding has been reinforced by research conducted by the University of Queensland. Neither these reports, nor Centennial's response to the findings, have been referenced in the IESC Report. The finding of major impacts caused by mine water discharge is not acknowledged in the IESC Report. As a result of the finding, Centennial has not discharged mine water through THPSS on the Newnes Plateau since 2010 and is committed to managing mine water through the Water Transfer Scheme (WTS), which transfers mine water off the Newnes Plateau.

Following completion of the DEWHA investigation and the Goldney 2010 Report, in November 2011, Centennial (through its Joint Venture) and the Minister for the Environment entered into an Enforceable Undertaking under section 486DA of the Environment Protection and Biodiversity Conservation Act 1999. Under this Enforceable Undertaking, the Joint Venture entered into a research agreement with the Australian National University to undertake a comprehensive research program into THPSS[1].

With the conclusion of these investigations, in 2011, Centennial made applications to the Minister for the Environment to extract coal from Springvale Mine longwall 415 to 417 (EPBC2011/5949) and from the Angus Place Colliery longwall 900W and 910. In 2012, the Minister for the Environment conditionally approved these applications. The primary condition of approval was the need to demonstrate that sub-critical longwall panel design would not result in anomalous subsidence impacts to THPSS.

To demonstrate this, changes to the mine design were are based on reduced mining void widths and increased chain pillar widths. The changes have been made in the context of cover depths in proposed future mining areas in the vicinity of THPSS and are designed to a criterion of sub-critical panel geometry. Subsidence modelling indicates that the design changes will result is very significant reductions to total subsidence and differential subsidence movements. These changes were made specifically to reduce the environmental impacts of longwall mining under the Newnes Plateau, and demonstrate Centennial's commitment to sustainable mining practices.

This mine design approach for all future longwall mining described in the SVMEP EIS and the APMEP EIS in the vicinity of THPSS is consistent with that approved for longwall mining beneath THPSS by DotE under EPBC2011/5949.

All documentation supporting this research, investigations, outcomes is available on the Centennial Coal website, www.centennialcoal.com.au.

[1] In should be noted that in this report, a reference to the federally listed endangered ecological community Temperate Highland Peat Swamps on Sandstone, includes a reference to the State listed endangered ecological communities incorporating the Newnes Plateau Shrub Swamps and Newnes Plateau Hanging Swamps. The extent to which these communities have been described under these listings is discussed further in response to the IESC Report on ecological characteristics of THPSS.

Overview and Summary

Mining and Subsidence

In 2008 and 2009, monitoring at Angus Place and Springvale Collieries detected impacts attributable to mining-related activities at two THPSS. Centennial Coal launched an extensive investigative program to determine the factors causing these impacts. Specific investigations were targeted to determine the hydrogeological characteristics of THPSS. The purpose of these investigations was to ascertain the coincident characteristics which lead to THPSS formation and to understand the sensitivity of those characteristics to mine subsidence behaviour.

These investigations include:

- Aurecon Report Ref:7049-010 Newnes Plateau Shrub Swamp Management Plan Investigation of Irregular Surface Movement in East Wolgan Swamp (2009)
- Determining Whether or not a Significant Impact has Occurred on Temperate Highland Peat Swamps on Sandstone within the Angus Place Colliery Lease on the Newnes Plateau, Goldney et at, 2010 (a report prepared for the then Department of Environment, Water, Heritage and the Arts)
- Aurecon Report Ref: 208354, Geotechnical Investigation Report East Wolgan Swamp Investigation, 2011
- Geophysical Survey Ground Penetrating Radar and Resistivity Investigation of East Wolgan Swamp on the Newnes Plateau, Speer (2011)
- DgS Report No SPV-003/6 Further Discussion on the Potential Impacts to Sunnyside East and Carne West Temperate Highland Peat Swamps on Sandstone due to the Proposed LW416 to 1418, Ditton 2013The Geology of the Shrub Swamps within Angus Place/Springvale Collieries, McHugh 2013
- Assessment of Flora Impacts Associated with Subsidence, Fletcher et at, 2013
- EPBC Approval 2011/5949 Application to Allow Longwall Mining Under Temperate Highland Peat Swamps on Sandstone on the Newnes Plateau – Supplementary Data Volume 1 to 3 and Appendices, Corbett et all, 2013
- Monitoring Surface Condition of Upland Swamps Subject to Mining Subsidence with very high resolution imagery, Fletcher et al, 2014
- DgS Report No SPV-003/7B Subsurface Fracture Zone Assessment above the Proposed Springvale and Angus Place Mine Extension Project Area Longwalls, Ditton, 2014
- Hydrogeological Characterisation of Temperate Highland Peat Swamps on Sandstone on the Newnes Plateau, Corbett et al, 2014
- Case Studies of Groundwater Response to Mine Subsidence in the Western Coalfields of NSW, Corbett et al, 2014
- Flora monitoring methods for Newnes Plateau Shrub Swamps and Hanging Swamps, Brownstein et al, 2014

The results of these investigations, described further in the SVMEP EIS, the APMEP EIS, the respective Response to Submission Reports and this report, have allowed Centennial Coal to understand the multiple co-incident factors that led to historical mining-related impacts and implement management practices to ensure mining impacts will be avoided in the future or can be appropriately mitigated.

Since the investigations were conducted, Centennial Coal has been proactive in avoiding or minimising potential subsidence impacts to the geodiversity and biodiversity of the mining area using a comprehensive multi-disciplinary risk-based approach to mine planning and mine design in conjunction with a rigorous monitoring program.

The monitoring techniques employed are wide-ranging and complementary and the combined results provide insights into the role those factors such as geology, hydrogeology and topography play in THPSS formation and the effects of mine subsidence on these.

The extensive monitoring and investigation process employed by Centennial Coal, which utilised multiple lines of evidence to support the management decisions, created the foundations for an adaptive management outcome. Mine design changes (in the form of reduced longwall void width and increased chain pillar width) were implemented in 2011 and are planned in all Mine Extension Project (MEP) areas where THPSS are present.

Based on the results of the investigation and changes implemented in response to the investigation, the Federal DotE gave approval to mine beneath THPSS under EPBC2011/5949 in October 2013.

Monitoring

There is no evidence to support the statement of limited onsite monitoring data to determine the effect of longwall mining subsidence on upland peat swamps on the Newnes Plateau. There are 36 swamp piezometers installed in Newnes Plateau shrub swamps over the Angus Place and Springvale MLs. They were installed over the period 2005-2011 (Corbett et al 2014).

Groundwater aquifer monitoring commenced at Springvale Mine in 2002. The are currently 28 open hole aquifer monitoring piezometers and 26 multi-level vibrating wire piezometers at Springvale and Angus Place.

The results of these monitoring points are described further in the SVMEP EIS, the APMEP EIS (specifically Chapters 2 and 8), the respective Response to Submission Reports and this report.

The peer reviewed THPSS Monitoring and Management Plan (THPSS MMP) which has been approved by the Federal Department of the Environment (DotE) is aligned with **Before-After/Control-Impact (BACI)** design.

Mitigation

The primary mechanism to mitigate potential impacts to THPSS is mine design. The mine design for the SVMEP and APMEP is described in detail in the respective Environmental Impact Statements (specifically, Chapter 8).

Major design changes have been made to the Springvale and Angus Place mine plan in order to reduce subsidence from longwall mining. These changes are based on the following dimensional changes:

• Void width reduced from 315m to 261m

• Pillar width increased from 45m to 58m

The changes have been made in good faith and at significant cost to the business at a time when there was no guarantee of approval for ongoing mining activities. No subsidence effects to swamp hydrology or flora communities have been identified in areas where sub-critical mine design have been used in the past (refer to Chapter 2 and Chapter 8 of the respective EIS).

The mine design approach for all future longwall mining in the Springvale and Angus Place MEP areas is consistent with that approved for longwall mining beneath THPSS by DotE under EPBC2011/5949.

Future mine dewatering systems have been designed to ensure that discharge of mine water to Newnes Plateau Shrub Swamps is avoided. No mine water discharges into Newnes Plateau THPSS have occurred since April 2010.

Remediation

To date, there has been no requirement or need to undertake hard engineering mitigation on a THPSS on the Newnes Plateau. Regardless, there are examples from other regions where hard engineering mitigation has been successful.

A specific example of where PUR grouting has been shown to successfully repair a rock substrate can be seen at Helensburgh Coal Pty Ltd (HCPL) in the NSW Southern Coalfields. Experience at HCPL has shown that grouting using PUR can be used to successfully fill cracks ranging from small sub millimetre sized cracks to open fractures greater than 100 mm.

A trial was conducted at HCPL on the WRS4 rock bar in the Waratah Rivulet and was followed by a remediation report (Waratah Rivulet Remediation Trial Activities – Completion Report (2007)). The main findings of the remediation report were:

· PUR is non-toxic.

· PUR injection can be conducted in an environmentally acceptable fashion.

· PUR injection is suitable for sealing cracking in rocks from less than 1mm to greater than 100 mm.

· Pre and post permeability testing showed that permeability was reduced by several orders of magnitude following PUR injection.

· The PUR injection process was transferrable to other areas where cracking of rock had occurred.

The HCPL PUR grouting programs are used to seal cracking in outcropping rock bars. However, it is considered that this technology is transferrable and can be used to seal cracks in swamp bases as a swamp base is analogous to a rock bar, albeit one covered with peat and sand.

The use of cementitious grouts has also been used to successfully remediate subsidence induced cracking which led to water loss in watercourses in the Southern Coalfield. Injection grouting with cementitious grouts was successfully used for rock bar rehabilitation in the Georges River.

Where alluvial material overlies sandstone, injection grouting though drill rods has also been used successfully to seal void under the alluvial material (soil / peat). This technique was also used in the Georges River, where 1-2m of loose sediment was grouted through using purpose designed grouting pipes.

2 Peat swamps

THPSS Communities in the Blue Mountains / Newnes Plateau

Centennial Coal has acknowledged the importance of the THPSS in the landscape. Research conducted over the last 5 years (2009 to 2014) by the University of Queensland has worked towards quantifying the nature and extent of the community across the Newnes Plateau. Further work undertaken through the Enforceable Undertaking has been targeted towards:

- The nature and extent of THPSS
- THPSS water balances
- Functionality of swamps
- Environmental history and origins
- Ecology/biodiversity of major structural species
- Contribution to the landscape
- Condition status/mapping
- Monitoring of selected reference sites
- Thresholds for recovery

The University of Queensland is currently conducting research on communities identified as temperate treeless palustrine swamps in a 268 square kilometre area which includes the Newnes Plateau. Based on publicly available combined mapping from the temperate zone of New South Wales and manual interpretation of the numerous vegetation classifications used, a region containing more than 1000 shrub swamp communities per degree of latitude/longitude was identified which contained the communities mapped as Newnes Plateau shrub swamps. A report based on the research will be published and finalised in 2014.

3 Geology

Newnes Plateau Geology / Hydrogeology Related to THPSS Formation

Centennnial Coal has conducted detailed studies into the geology and hydrogeology of the Newnes Plateau, as outlined in the following excerpts from Corbett et al (2014).

Detailed analysis of the lithology was undertaken and the data was incorporated into the Minex geological database to allow three-dimensional modelling of correlatable stratigraphic units (i.e. stratigraphic units that are present on a regional scale). The analysis of the near surface stratigraphy also involved the use of geophysical data from 84 exploration boreholes (i.e. a total of 101 exploration boreholes).

A key finding of the study (McHugh, 2013) was the identification and detailing of the stratigraphy of the Burralow Formation, which overlies the Banks Wall Sandstone. Most previous studies of the Angus Place Colliery and Springvale Mine areas do not typically include the presence of the Burralow Formation, and instead refer to the Banks Wall Sandstone as the uppermost outcropping unit.
At a maximum thickness of approximately 110m, the Burralow Formation above Angus Place and Springvale is thicker than previously proposed in the general Lithgow region. It is noted that CoA (2014) THPSS: Longwall Mining Engineering Design – Subsidence Predictions, Buffer Distances and Mine Design Options, Figure 3.3 identifies the Burralow Formation in the Western Sydney Basin Stratigraphy.

The Burralow Formation consists of medium- to coarse-grained sandstones interbedded with frequent sequences of fine-grained, clay-rich sandstones, siltstones, shales and claystones.
From the 101 bores, the Burralow Formation was determined to contain multiple fine-grained lithological units, which can be several metres thick: their presence differentiates the Burralow Formation from the underlying Banks Wall Sandstone. Correlation of the finer-grained units within the Burralow Formation identified at least seven units, as described in Palaris (2013). Several of the claystone horizons, together with clay-rich, fine-to-medium grained sandstones and shales, were found to be acting as aquitards, or semi-permeable layers. These aquitards retard the vertical movement of groundwater into underlying strata. Instead, much of the groundwater present within the Burralow Formation is redirected laterally down-dip to discharge points in nearby valleys (valley wall seepage), which creates a permanent water source for the formation and maintenance of the NPHS. In the case of NPSS, precipitation is supplemented by moisture from groundwater sources to form several discharge horizons along the course of the host creek in which a shrub swamp is located.

This is presented in Figure 3, whereby the brown contours show the outcropping Burralow Formation units where groundwater seepage would occur. Valley wall seepage, together with direct in-gully input of groundwater via aquitards, permits continuity of hydration for the THPSS during periods of drought. The presence of the Burralow Formation is essential to the formation and persistence of both hanging and shrub swamps (McHugh, 2013). Figure 3 presents a three-dimensional representation of the topography over the eastern area of the Springvale Mining lease. Steep changes in topography occur at the downstream of the THPSS often in the form of water falls.

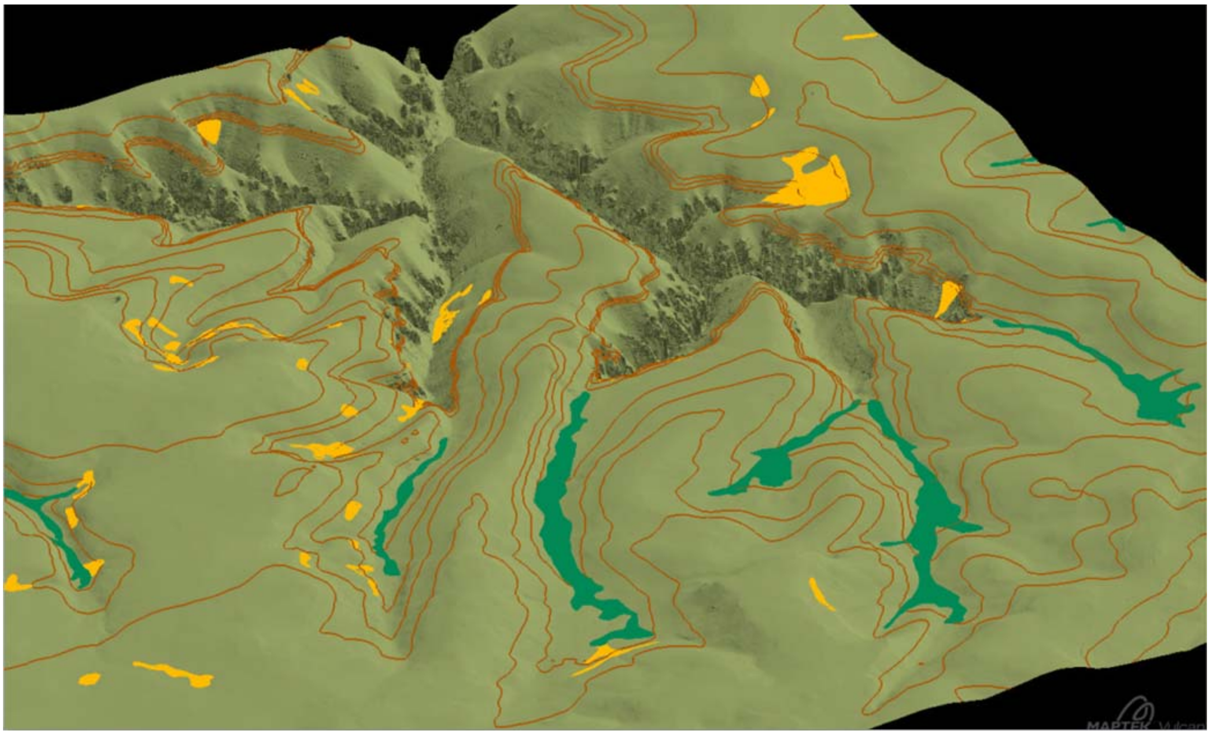


Figure 3 View of shrub swamps in headwaters of Carne Creek from 3-D geology model

Figure 4 presents the interpreted extent of the Burralow Formation in both lateral (spatial) and vertical (thickness) extent in relation to the Angus Place and Springvale Mining Leases. Figure 4 also shows the location of swamps in relation to the Burralow Formation and it can be concluded that the majority of the major swamp formations are located in this Formation. The extensive ridge system in the Springvale lease, where the Burralow Formation is at its thickest, provides both a substantial precipitation recharge zone plus an array of aquitards to promote groundwater retention in the streams which flow from this watershed area.

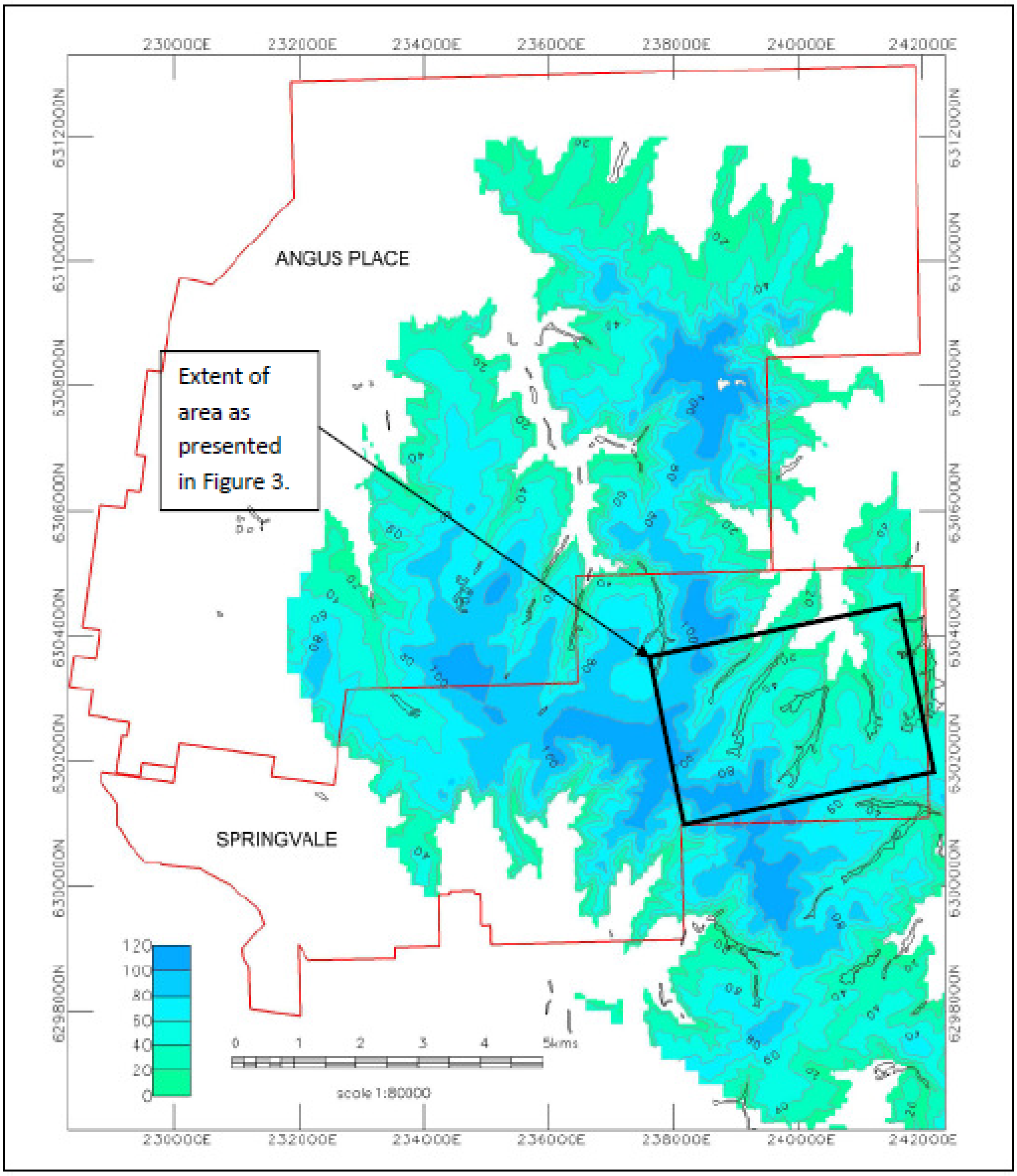


Figure 4 Isopach drawing of the Burralow Formation in the Angus Place and Springvale Mining Lease Areas together with shrub swamp locations (black outline)

Swamp hydrology

In the case of Newnes Plateau Shrub Swamps, baseline data from the piezometers indicates that swamp hydrology is variable along individual swamps, and standing water levels are typically influenced by rainfall in the upper reaches and by groundwater in the lower reaches. This demonstrates the increasing groundwater contributions from the multiple outcrops of the Burralow Formation aquitards.

The data from the swamp monitoring has shown that the hydrology of an individual swamp can be ‘periodically waterlogged’ or ‘permanently waterlogged’ or can vary along its length from ‘periodically waterlogged’ to ‘permanently waterlogged’, with transitional behaviour between (Corbett et al 2014).

Monitoring of piezometers in Sunnyside, Sunnyside East, Tri-Star and Carne West swamps indicates that variable hydrology (between periodically waterlogged in the upper reaches and permanently waterlogged in the lower reaches) occurs for swamps to the East of the Newnes Plateau in swamps previously identified as entirely permanently waterlogged.

5 Surface subsidence

At Southern Coalfield mines, where the depths of cover are greater than 400 metres, conventional horizontal movements are a small component of observed valley ground movements. However, subsidence monitoring within valleys over the Angus Place and Springvale Coal mines, where the depths of cover are less than 400 metres, has shown that systematic or conventional horizontal movements can represent a much greater proportion of the measured valley ground movements. As discussed in the latest valley closure report, sometimes the conventional horizontal movement components are additive to the valley closure movements and at other times these components reduce the valley closure movements and this is one of the reasons why there is considerable scatter in the monitored ground movements in valleys.

Hence, the new ACARP valley closure prediction models, which were developed based solely on data from the deeper Southern Coalfield mines without adjustments for conventional horizontal movement components, do not provide accurate valley closure predictions for valleys where the depths of cover are less than 400 metres and additional research work is now required to develop appropriate ground movement models for mines at these shallower depths of cover (MSEC 2014).

Measured strains at Springvale and Angus Place have been in excess of 0.5mm/m tensile and 2mm/m compressive, without causing measurable impacts to groundwater levels in THPSS. In the case of Kangaroo Creek Swamp, where changes to groundwater levels were caused by mine subsidence in 2008, measured strains were 6mm/m tensile and 26mm/m compressive. At East Wolgan Swamp, where localised cracking in the base of the swamp were caused by mine subsidence, measured strains were 13mmm tensile and 17mm/m compressive. In both of these cases the w/H ratio (longwall panel width / depth of cover) was in excess of 1.0 (critical mine design). Where mine design with lower w/H ratios has been used in the past, measured differential subsidence values have been lower and impacts to THPSS hydrology have not been measured (Corbett at al 2014). This reference is to the Southern Coalfield, where the geological and stress regime is different to the Western Coalfields. The subsidence response behaviour of the Burralow Formation claystone aquitards is measurably different to that of the Hawkesbury Sandstone(Corbett at al 2014, EPBC 2011/5949 Application to Allow Longwall Mining Beneath THPSS on the Newnes Plateau (2013) Vol. 1-3 and Appendices). (pp64)

The NSW Department of Mineral Resources (now Department of Resources and Energy) *Guideline for Application for Subsidence Management Approvals EDG17* states:

"The Application Area is defined as the surface area that is likely to be affected by the proposed underground coal mining. It should not be smaller than:

(1) A surface area defined by the cover depths, Angle of Draw of 35° and the limit of the proposed extraction area in mining leases of the Southern Coalfield, and

(2) A surface area defined by the cover depths, Angle of Draw of 26.5° and the limit of the proposed extraction area in mining leases of all other NSW Coalfields."

It is noteworthy that the Southern Coalfield is excluded from the recommended 26.5 degree design angle of draw within the Guideline, for reasons related to geology, surface topography and depth of cover (explained in more detail in Springvale Colliery's *EPBC Approval 2011/5949 Application to Allow*

Longwall Mining Under Temperate Highland Peat Swamps on Sandstone on the Newnes Plateau (March 2013)). A value of 35 degrees is recommended for the Southern Coalfield, however, the recommended value for the Western Coalfield (including Springvale and Angus Place) is 26.5 degrees.

6 Overburden caving processes

The overburden caving mechanisms identified in Section 6 are accepted by Centennial, however, it is observed that the majority of the research work has been conducted in the Southern Coalfield and that differences in geology, topography and stress regimes result in different behaviour in other coalfields. Details of the effects to groundwater systems of overburden caving caused by mine subsidence on the Newnes Plateau are discussed in Section 7 (below).

As an example of the differences in overburden caving behaviour, it is noted that at Springvale, the height of continuous fracturing / panel width has been measured at 0.81 (SPR40 extensometer), which is significantly less than the values of 1-1.6 referenced in the IESC report.

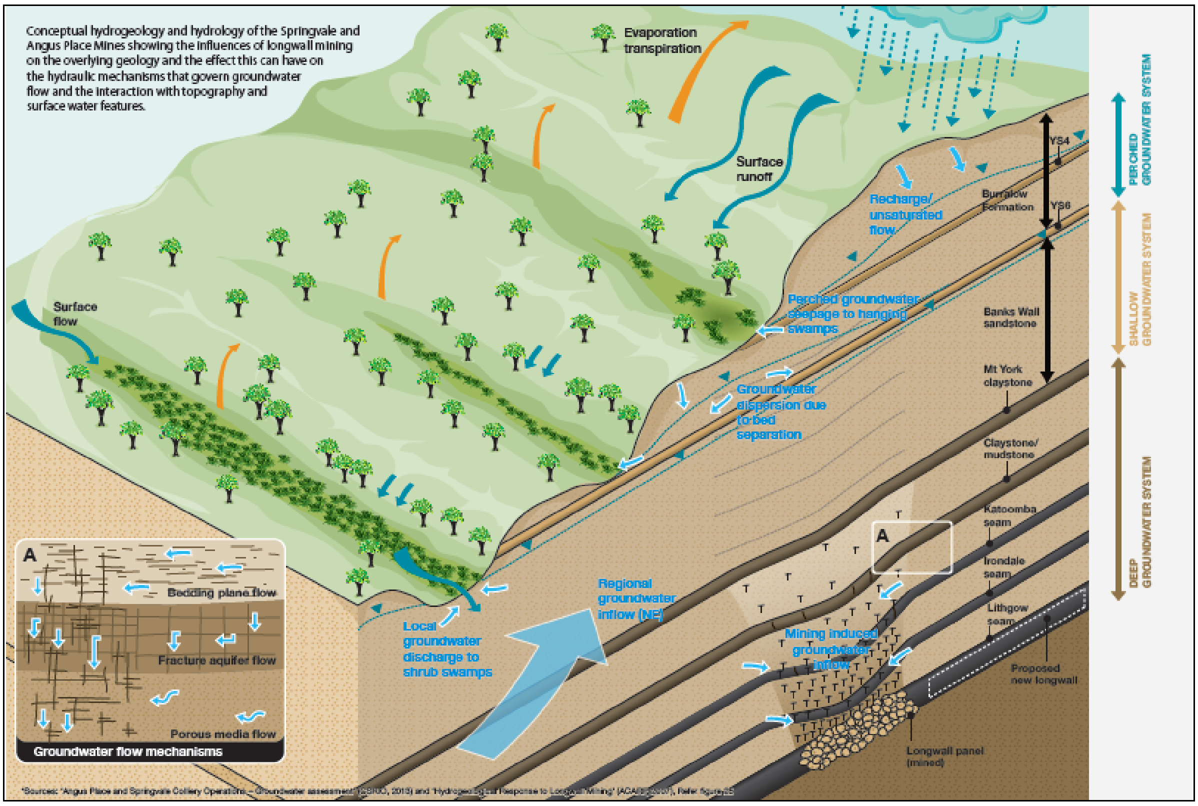
7 Groundwater

7.1 Introduction

As above, the Burralow Formation overlies the Banks Wall Sandstone in the Angus Place and Springvale Mine Extension Project area.

7.3 Examples of peat swamps and associated groundwater systems

A conceptual geological and hydrogeological model was developed for the Newnes Plateau in the Angus Place and Springvale Mine Extension Project, as shown in the figure below. As presented in the Groundwater Impact Assessment for Angus Place and Springvale (RPS, 2014ac) and the main text of the EIS, the hydrogeological system comprises stacked and segregated groundwater systems recharged by rainfall, locally with respect to shallow and perched systems and regionally with respect to the deep groundwater system. The deep groundwater system, within which the target coal seam is located, is essentially isolated from the shallow and perched groundwater systems. The perched system is supported on low permeability aquitards layers identified within the Burralow Formation. Three dimensional geological mapping of the Burralow Formation, based on analysis of 101 boreholes, establishes a clear association between occurrence of shrub swamps and presence of these aquitards plies. Recharge to the perched system is via lateral transmission of percolating infiltration, from rainfall, along contacts between these aquitards. Aquifer interference in the deep groundwater system due to subsidence-induced goaf formation does not extend above the Mount York Claystone. This is supported by the extensive network of Vibrating Wire Piezometers (VWPs) at Angus Place (12 sites) and Springvale (18 sites). The Mount York Claystone is laterally continuous across the site. Modelling indicates that depression in the Coal Seam within the deep groundwater system leads to desaturation of the bottom of the Mount York Claystone. As such there is not a continuous hydraulic connection predicted between the deep groundwater system and the shallow and perched groundwater system. This is supported through field observation.



7.4 Pre-mining aquifer properties

7.4.3 Banks Wall Sandstone

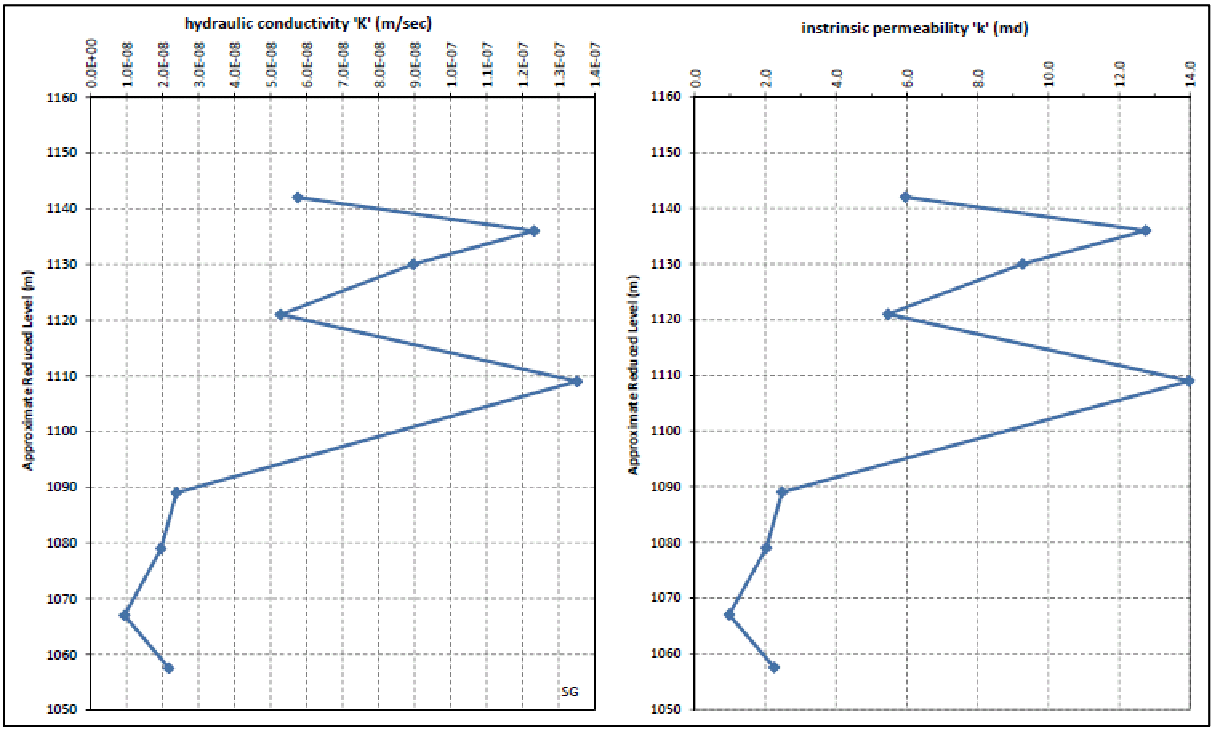
Borehole permeability testing for the Burralow Formation, which overlies the Banks Wall Sandstone on the Newnes Plateau in the Angus Place and Springvale mining areas, has been conducted in a number of holes. An example of testing conducted for bore SPR1101PT is included below.

The results of permeability testing are used as inputs into the CSIRO COSFLOW groundwater model.

Packer Testing Summary for SPR1101PT & RD

Test	Depth (m)		hydraulic conductivity (m/sec)			intrinsic permeability (md)			Lugeons (uL)	
	from	to	K range min	K range max	K (averaged)	k range min	k range max	k (averaged)		
1	12.00	18.00	4.15E-08	7.40E-08	5.76E-08	4.29	7.66	5.96	<1	
2	18.00	24.00	3.70E-08	2.18E-07	1.23E-07	3.82	22.60	12.75	1	
3	24.00	30.00	1.92E-08	1.49E-07	8.96E-08	1.99	15.42	9.28	1	
4	30.00	42.00	2.86E-08	7.22E-08	5.28E-08	2.96	7.47	5.46	<1	
5	42.00	54.00	9.79E-08	2.19E-07	1.35E-07	10.13	22.65	13.98	1	
6	64.00	72.00	1.65E-08	3.20E-08	2.39E-08	1.71	3.31	2.47	<1	RD
7	72.00	84.00	1.57E-08	2.71E-08	1.96E-08	1.62	2.80	2.03	<1	RD
8	84.00	96.00	8.10E-09	1.14E-08	9.43E-09	0.84	1.18	0.98	<1	RD
9	96.00	103.00	1.41E-08	3.06E-08	2.18E-08	1.46	3.16	2.25	<1	RD

Notes: K - hydraulic conductivity measured in units of metres per second
k - intrinsic permeability, measured in units of millidarcys
Intrinsic permeability (k) calculated assuming water at 20°C



The relationship between pre-mining and post-mining permeability at Springvale Mine has been researched by CSIRO. In ACARP report (C18016), the overburden strata were divided into separate deformation zones with distinctive hydrogeological response characteristics. Figure 28 presents a hydrogeological response model developed for Springvale Colliery.

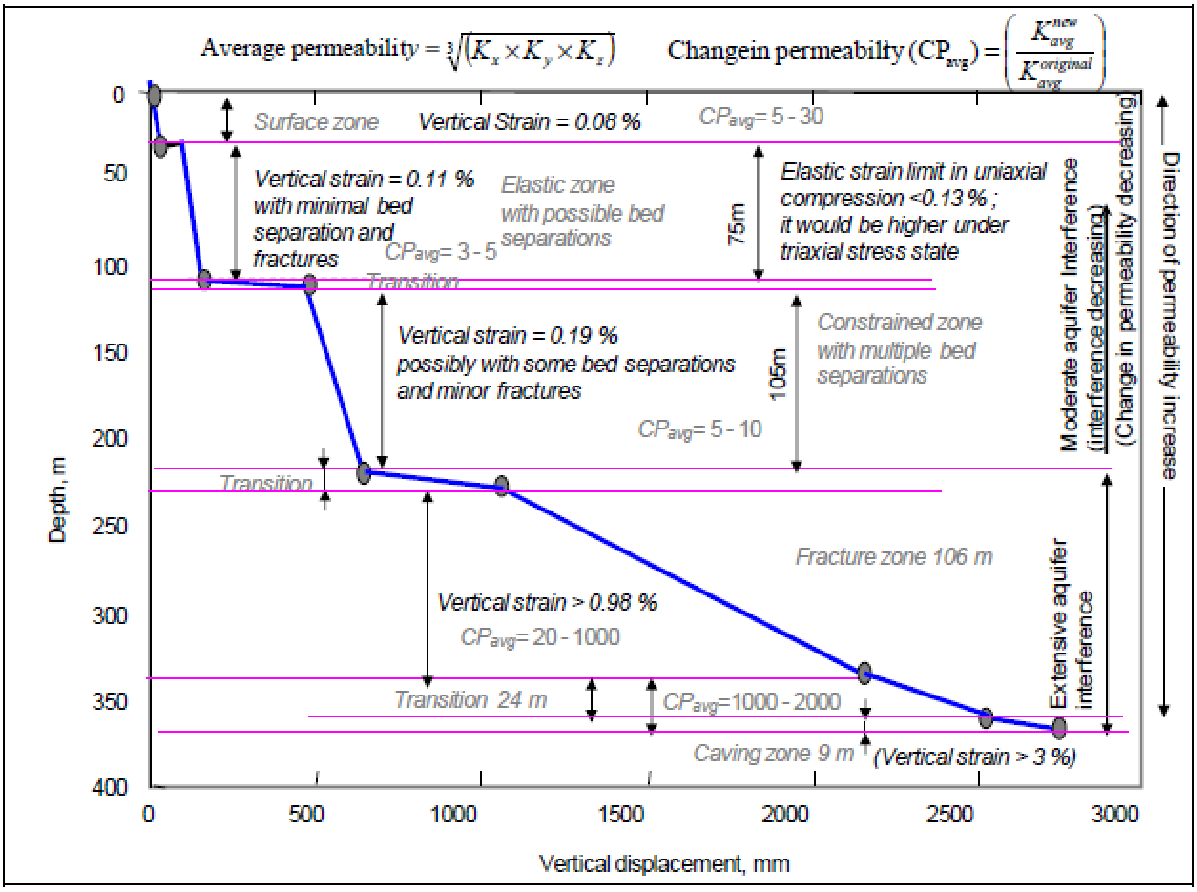


Figure 28 Hydrogeological response model for Springvale Colliery (ACARP C18016)

7.5 Impacts of longwall mining on the groundwater system

7.5.1 Models of general impacts on the groundwater system

MSEC conducted a review of estimates of the height of connected fracturing (HoCF) provided in:

- Ditton Geotechnical Services (DgS) report, titled "***Subsurface Fracture Zone Assessment above the Proposed Springvale and Angus Place Mine Extension Project Area Longwalls***", DgS Report No. SPV-003/7b, dated 9th September 2014; and
- Commonwealth Scientific and Industrial Research Organisation (CSIRO) report, titled "***Angus Place and Springvale Colliery Operations – Groundwater Assessments***", Report No. EP132799, dated May 2013.

MSEC provided the following summary on the subsidence induced HoCF.

"The primary porosity of a rock is a measure of the size of void spaces (i.e. the empty or open) between the grains within the rock as a proportion of the total rock volume. When all these void spaces are filled with water the rock is said to be saturated. The secondary porosity exists in rocks due to the presence of fractures, joints, faults and bedding plane partings that were created after the rock was originally formed. This secondary porosity is usually more important in layered sequences of typical sedimentary coalfield strata, but, the secondary porosity cannot be measured in a laboratory since it is impossible to use a large enough sample to represent the rock in situ. Measurements of porosity within a rock mass must be made by field tests to sample a large enough volume of rock. However, the existence of primary or secondary porosity in a rock does not in itself imply the existence of permeability or the ability to transmit water.

Water may flow through a rock mass depending on the size and the length of the available flow path and the available head. Whilst porosity is related to storage capacity, permeability is related to flow. Permeability of a rock is a measure of the ease with which a fluid will pass through that rock. In homogeneous rocks, such as those normally constituting uniform-grained aquifers, permeability is commonly equal in all directions. However, in many of the horizontally bedded consolidated rocks, such as shales, sandstones and claystones of sedimentary coal measures, permeability is measured to be far greater in the horizontal directions parallel to the bedding planes than in a vertical direction. It is easier and more accurate to determine permeability by direct site measurements by means of flow experiments. Henry Darcy, in 1856, was the first to experiment with the flow of water through sand, and he found that the rate of flow through sand is proportional to the hydraulic gradient (Darcy's Law). The constant of proportionality in Darcy's Law is known as the coefficient of permeability. It includes properties of the rock and the fluid and has the dimensions of velocity (i.e. metres per day). The coefficient of permeability of a rock used in the groundwater industry, where the fluid is always water, is known as the hydraulic conductivity. Hydraulic Conductivity is defined as the rate at which water can be transmitted, in cubic metres per day, through a cross sectional area of one square metre normal to the direction of flow, under a hydraulic gradient of one. The units of hydraulic conductivity are usually metres per day or centimetres per second.

A hydraulic conductivity of say 10 metres per day does not mean that water will flow through that rock at the rate of 10 metres per day; it can do so only if the hydraulic gradient is one. If the hydraulic conductivity is 1/1000 then water will flow through the rock at the rate of 0.01 metres per day. The table below provides a range of hydraulic conductivity for typical rocks with the values for highly fractured rocks can be much higher than rocks that are not fractured.

Table of saturated hydraulic conductivity (*K*) values found in nature

Values are for typical fresh groundwater conditions — using standard values of viscosity and speci permeability values.[10]

K (cm/s)	10^2	10^1	$10^0=1$	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}
K (ft/day)	10^5	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001	10^{-5}	10^{-6}	10^{-7}
Relative Permeability	Pervious				Semi-Pervious				Impervious				
Aquifer	Good					Poor				None			
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam							
Unconsolidated Clay & Organic					Peat		Layered Clay			Fat / Unweathered Clay			
Consolidated Rocks	Highly Fractured Rocks				Oil Reservoir Rocks			Fresh Sandstone		Fresh Limestone, Dolomite		Fresh Granite	

Source: modified from Bear, 1972

For water to move through rocks the head available has to overcome surface tension and frictional resistance. It is possible to have rocks of such low hydraulic conductivity that they require large differences in head to overcome the frictional resistance and therefore they only transmit negligible quantities of water except by molecular and surface tension forces; such rocks are termed impervious or impermeable despite the fact that they may process some hydraulic conductivity. Use of this knowledge is made in the design of engineering structures such as rock fill dams. The vertical flow of water through a layered sequence cannot be obtained by using the average vertical hydraulic conductivity of the layers; the prime controls being the layer of lowest vertical hydraulic conductivity and the head acting on it.

It is common for aquifers to be encountered at a number of levels within a layered sequence of horizontally bedded sedimentary rocks, each having a successively deeper standing water level (i.e. the level at which water from the aquifer concerned will stand in a bore exposed to that aquifer). The sequence in water levels is due to there being layers of lower permeabilities within the strata and these retard downward movement of water.

Longwall mining results in surface and sub-surface subsidence displacements and it creates new fractures and opens up or widens pre-existing bedding planes and natural joints within the overburden. The location of and the impacts from these mining induced fractures within the overburden depend on both the mining geometry and the geology and lithology of the strata as discussed below.

The opening of existing joints and bedding planes and the creation of new mining induced cracks within the overburden over a mined panel does increase the permeability of the existing strata layers. The height at which new mining induced fractures (HoF) may form above a mined panel has been measured to be up to 1 to 1.5 times the panel width, depending on the spanning capacity of the overlying strata and the bulking of the goafed strata. However the creation of these new fractures does not necessarily imply that a direct hydraulic connection will exist vertically up through the strata layers to each fracture. Significant volumes of mine inflow only occur from the height where the fractures form a connected continuous path or a conductive network towards the mined opening.

The height of the connected fracturing zone (HoCF) which is defined, for the purposes of this review, as the height of a zone above the seam that mining induced connected or continuous fractures can transmit water from the overlying strata to the mined void, or, the height of a zone above the seam from which water would flow freely into the mine. The HoCF is commonly much lower than the HoF, depending on many factors as is discussed below.

Unfortunately, there have been mining cases at shallow depths of cover where mine subsidence movements have caused extensive surface cracking and where surface water flows were captured and drained down into mine workings. There have also been mining cases where mine subsidence movements impacted on groundwater aquifers that were located at deep and shallow cover above the mine workings. These failures have been observed in all geological regions, especially where the depth of cover was shallow, or, the interburden thickness between the workings and the aquifer was shallow.

On the other hand, there have also been many cases where mining has been successfully carried out at very shallow depths of cover under surface waters, rivers, creeks as well as under various aquifers with negligible, minor or only small losses of water being recorded into the mines.

In 1972 Kapp and Williams advised that 80 years ago coal was successfully mined at shallow cover beneath the Hunter River and Newcastle Harbour. In the Stored Waters Inquiry Report, Reynolds (1977) advised that first workings coal was extensively and successfully mined under Newcastle Harbour and under the ocean off Newcastle with narrow bords and pillars at the following mines taking up to 50% of the coal by plan area with no reported inundations:

- The Winning or Sea Pit, where the depth of cover was more than 140 feet (43 metres);
- Newcastle Coal Mining Company's A and B Pits, where the depth of cover varied from 150 feet (46 metres) to 113 feet (35 metres);
- Burwood Colliery, where the depth of cover was more than 120 feet (36 metres);
- Dudley Colliery, where the depth of cover was more than 100 feet (31 metres);

- Redhead Colliery, where the depth of cover was more than 120 feet (36 metres); and
- John Darling Colliery, where the depth of cover was more than 120 feet (36 metres).

Additionally extensive areas of first workings, panel and pillar second workings, longwall panel extraction and total extraction has taken place under the lake areas south of Newcastle.

Hence, the impacts of mining and subsidence on surface water and groundwater resources have been found to be extremely variable and it is important to appreciate the circumstances for each of these mining cases in order to understand when water may be lost from the surface or aquifers and when mining can be undertaken safely without noticeable impacts on groundwater or surface flows.

The issue of hydraulic connections between the surface water bodies and the mine workings has been the subject of several government inquiries and reports over the past few decades by the NSW State government and more recently by the federal government. The first major inquiry was commenced in 1974 by Mr Justice Reynolds for the State Government of NSW because of the possibility that hydraulic connections between surface stored waters and deep mine workings beneath several major water dams in the Southern Coalfields of NSW could impact on Sydney's water supply. The Stored Waters Inquiry concluded in 1977 that under certain strict conditions mining could be permitted. At depths of cover greater than 120 meters, the extracted panel widths should not exceed one third of the cover depth and the panels should be separated by pillars that had a width of one fifth of the cover depth or fifteen times the height of extraction. Effectively these dimensions were proposed (and were determined to be appropriate) to prevent pillar failure and to maintain a constrained zone above the mined panels that was likely to include at least one of the less permeable layers from the Narrabeen Group.

After this Inquiry was completed a range of field, laboratory and computer simulation studies were undertaken and the results of these studies indicated that the Inquiry recommendations were overly conservative in most circumstances, especially, since a number of very low permeability claystone strata layers, such as the Bald Hill claystone, are now considered to function as aquitards or hydraulic barriers to surface water flowing into the mine workings that have remained relatively "dry" even though many panels had been extracted under the stored waters and known groundwater aquifers.

Based on these developments, mine owners have successfully petitioned, on a number of occasions, the Dam Safety Committee of NSW and other government regulators to approve less conservative mine layouts than those that were recommended by Justice Reynolds as long as they could prove that strata layers of low permeability existed above the predicted heights of interconnected fracturing.

Many engineers, surveyors, geologists and groundwater hydrologists have published reports and papers on the effects of mine subsidence on surface water and groundwater resources. Over the past decade the Australian Coal Industry's Research Program (ACARP) sought research proposals that addressed this issue as one of their key industry problems. Several ACARP research reports have now been published that provide advice on the likely impacts of mining on surface water and aquifers.

Recently some further extensive studies have been published on this issue by the Australian Government Department of Environment, on the advice of the Independent Expert Scientific Committee on Coal Seam Gas and Large Scale Mining Development. This Committee was established as a statutory committee in 2012 by the Australian Government under the *Environment Protection and Biodiversity Conservation Act 1999 (Cth)* in response to community concerns about coal seam gas and coal mining.

Despite the availability of many new reports on this issue, varying opinions have been given on: which subsidence parameter most influences the observed impacts; how best to determine the likely impacts of mining on water resources; and the choice of which computer programmes should be utilised in these studies. Fortunately, some basic concepts and understandings have developed, even though; some authors have not yet understood all the complex issues. Some authors, who only see limited data on a local perspective, rather than on a state wide basis, have assumed the influence of geology is not important, but, the presence of strong or massive strata and the presence of layers of low permeability can have a significant effect on the impact of mining on surface and aquifers and on water inflows into mines. Contrary to what one researcher recently published, i.e. "host geology appears to play a minor role", MSEC believes the impacts of mining and subsidence on surface water and groundwater resources vary significantly due to changes in the local geology and lithology.

The following review of some important research papers provides some interesting background in this field.

Holla 1987 published a paper titled "***Design of mine workings under surface waters in New South Wales***" in 1987 in which he advised; "*Guidelines for mining coal from underneath large bodies of surface water should ideally aim at achieving maximum and efficient recovery of coal resource consistent with the safety of underground mine operations and overlying surface features or improvements. The guidelines prevailing at present in New South Wales (NSW) were framed during the 19705. Even though the basic engineering concepts used for developing them are sound, the guidelines themselves are conservative and over-restrictive given the circumstances and level of available local knowledge at that time.*"

"Mining under tidal lakes, rivers, streams and the ocean in NSW is controlled in accordance with the provisions of the Coal Mines Regulation Act (NSW Government, 1982) and other regulations framed and administered by the Chief Inspector of Coal Mines. The present regulations are based on Wardell's report (Wardell, 1975) and are designed to minimise water encroachment upon surrounding lands and to contain surface and sub-surface strata movement to levels required to ensure mine safety."

"Movement at rockhead under tidal waters (outside HWMSB) is controlled by the following four guidelines.

1. *The minimum solid strata cover depth for any extraction to occur is 46 m.*
2. *The maximum horizontal tensile strain al rockhead is limited to 7.5 mm/ m.*
3. *For total extraction to occur, the minimum solid strata cover depth should be sixty times the extracted seam thickness.*
4. *Panel and pillar workings can occur with panel width restricted to O.4D and pillar width to 0.120 or eight times the extracted seam thickness, whichever is the greater."*

"Guideline 3 was obtained from Guideline 2 using the well known relationship that connects strain, subsidence and depth of cover, which is given below.

Emax = K x Smax/D where,

Emax = maximum tensile strain (non-dimensional)

Smax = maximum subsidence (m)

D = solid cover depth (m)

K = maximum tensile strain coefficient (non·dimensional)"

"Wardell (1975) assumed the following values in arriving at the minimum depth of solid strata cover D for mining a seam of thickness T.

Emax = 0.0075

Smax = 0.6 x T

K =0.75

D = K x Srnax/Ema> = 0.75 x 0.6 x T 10.0075) =60 x T"

"Equating 60 times the extracted seam thickness with the rock·head tensile strain of 7.5 mm/m is valid only for the assumed values of Smax: and K. If the input values for Smax and K are changed, the minimum depth of cover would assume a different value for the same rockhead strain of 7.5 mm/ m. In other words, the rockhead tensile strain is the independent and essential criterion, and 60 times the extracted seam thickness is the dependent and nonessential criterion. The guidelines for mining under the Pacific Ocean are assumed to be similar to those for mining under tidal waters."

Holla (1989) also published a NERRDC funded report titled "***Investigation into Sub-Surface Subsidence***" which documents research to collect information on the heights of caving above the seam and to study the variation in subsidence-surface subsidence for various panel width to depth ratios and the associated vertical strains. Holla reported that

"*During the course of this project, it was considered that the measure of the movement of strata might not adequately demonstrate the possible changes in permeability of the strata due to mining. It was therefore decided to collect additional data on fracturing and bulk permeability of strata before and after mining."*

"The investigation was carried out in four collieries reflecting different geological and mining environments. The collieries were Ellalong and Wyee collieries in the Newcastle Coalfield, Invincible colliery in the Western Coalfield and Tahmoor colliery in the Southern Coalfield."

The zone of caving and bed separation at Ellalong was observed to be 13 times the extracted seam thickness. Longwall panel 2 at the Invincible colliery was sub-critical (the extraction width to mining depth ratio being 1.24) and the zone of caving and bed separation was confined to 9 times the extracted seam thickness. At Wyee, where multi-seam mining was undertaken, the caving extended up to the previously formed goaf, which was 26 m above the extracted seam."

"These observed caving heights of 9 to 13 times are significantly larger than the caving height of two to five times the extracted seam thickness reported in the British coalfields. The difference appears to be due to the more competent seam roof strata in NSW caving with much smaller bulking factors than the weak seam roof strata generally found in the UK caving with larger bulking factors."

"At the Ellalong borehole, high vertical dilations were confined to a rectangular area behind the face and extended roughly to 50 m height above the seam roof. The average tensile strain in the overburden above the caving zone was 1.28 mm/m. In the region extending 75 m below the surface, the tensile strains were less than 1 mm/m. In the case of the Invincible borehole, high strains developed throughout the overburden which ranged between 1 and 10 mm/m. At the Tahmoor borehole, the strains in the overburden to 165 m depth below the surface were generally small, and the average tensile strain was 0.77 mm/m. Strains varied between less than 0.5 mm/m compressive strain and 4.0 mm/m tensile strain."

"The strain contours were layered in all boreholes, which indicates a correlation between strata dilation and geology. this trend was more pronounced at the Invincible borehole, where larger strains were associated with layers of sandstone, siltstone and conglomerate. Layers of mudstone, claystone and coal subsided in blocks, thereby exhibiting smaller strains. Vertical dilation in the overburden tended to be much more closely related to stratigraphy than to proximity to the extracted seam roof."

"Generalising the above observation, overburdens consisting of competent strata such as massive sandstones and conglomerates capable of accommodating large vertical strains are likely to subside less resulting in less surface subsidence. Conversely, overburdens consisting of weak mudstones and claystones are likely to develop larger surface subsidence. "

"The vertical dilation of strata in the region extending from the surface to 100 m downwards was small both at Ellalong and at Tahmoor, where the mining depths were respectively 370 m and 420 m.

Based on the criterion of rock fracture at dilations in excess of 2.5 mm/m, the strata to the depth of 100 m below the surface are expected to remain elastic and free from fracturing. The overburden in such a condition is highly unlikely to provide a continuous hydraulic connection between the surface water body and mine workings."

Holla provided that following additional comments on the influence of geology of observed subsidence in a later 1991 paper titled "*Some Aspects of Strata Movement relating to Mining under Water Bodies in New South Wales, Australia*":

"Successful mining layouts for mining coal under large water bodies should ensure that a substantial thickness of overburden strata remains undisturbed to prevent the flooding of mine workings. One of the criteria followed in many countries for controlling sub-surface strata disturbance is to specify a limit on the rockhead tensile strain. However, the generally specified rockhead strains are well in excess of the strain required to cause surface fracturing. It therefore leads to the conclusion that the composition of strata between the cracked zone on the surface and the caved zone above the extracted seam plays an important role in preventing water inflows into mine workings. Ductile beds like shales, mudstones and clay bands appear more effective than sandstone beds of the same thickness."

"Mudstones, shales and claystones absorb a large amount of strain energy before fracture. Thus, these beds in the overburden can subside significantly without fracturing and therefore are preferred to sandstones and conglomerates in providing a barrier against downward movement of surface water."

"*In a tightly constrained condition, many rocks including coal are impermeable and remain so until they are fractured and expanded. In constrained condition, shales, mudstones, siltstones and coal are impermeable, whilst sandstones and conglomerates are considered more permeable. "*

"In spite of this, most rock materials with a few exceptions have relatively low permeability when compared with the high permeability caused by the joints and fissures in the rock mass. It can be said that the water flow occurs almost entirely through the voids and fissures in the rock mass and not through the rock material. Therefore, the permeability of the rock mass will depend on the degree of jointing and fracturing and the opening and interconnection of these fractures."

The following comments on the heights of observed caving and cracking (HoF) were copied from a published paper by Mills and O'Grady in 1998 titled "*Impact of Longwall Width on Overburden Behaviour*":

"*Clarence Colliery mines the Katoomba seam, the uppermost seam in the sequence. The immediate overburden strata comprises a sequence of competent interbedded fine grained sandstones and siltstones with some weaker coarse grained sandstones. A major sandstone unit occurs at about 25 m above the seam with another major unit some 50-70 m above the seam. The sandstones in each unit are generally massive and free from bedding."*

"Four surface extensometers and two subsidence lines over Longwalls 4 and 5. The first extensometer was installed in the centre of Longwall 4 and was monitored during retreat of both panels. Three more extensometers were installed over Longwall 5 on the same cross-section, one in the centre of the panel and the other two offset 65 m toward each gateroad. Subsidence measurements were made on two cross-lines over Longwalls 4 and 5.

"Fig. 7 (below) shows the zones of large downward displacement inferred from the extensometer measurements for various distances past the longwall face. The edges of this zone are somewhat arbitrarily defined because the downward movements decrease exponentially. For the purposes of discussion, the 200 mm contour has been assumed to represent the edge of this zone. "

"The zone of large displacement was essentially dome shaped above each extracted longwall panel. The sides of the zone were steeper than the front edge. The front edges extended back from the face over the goaf at about 35° from vertical. The sides extended upward from the chain pillars at approximately 20° from vertical."

"The study showed that a zone of large downward movement (<0.5 m)—developed at a height above the mining horizon approximately equal to the panel width and the shape of the zone of large downward movement—was approximately a paraboloid, similar to the shape observed in physical model studies. The study also showed that there must be large, open voids created within the overburden strata around the sides of the zone of large downward movement and potentially also at the top of it (in the sandstone strata at this site)"

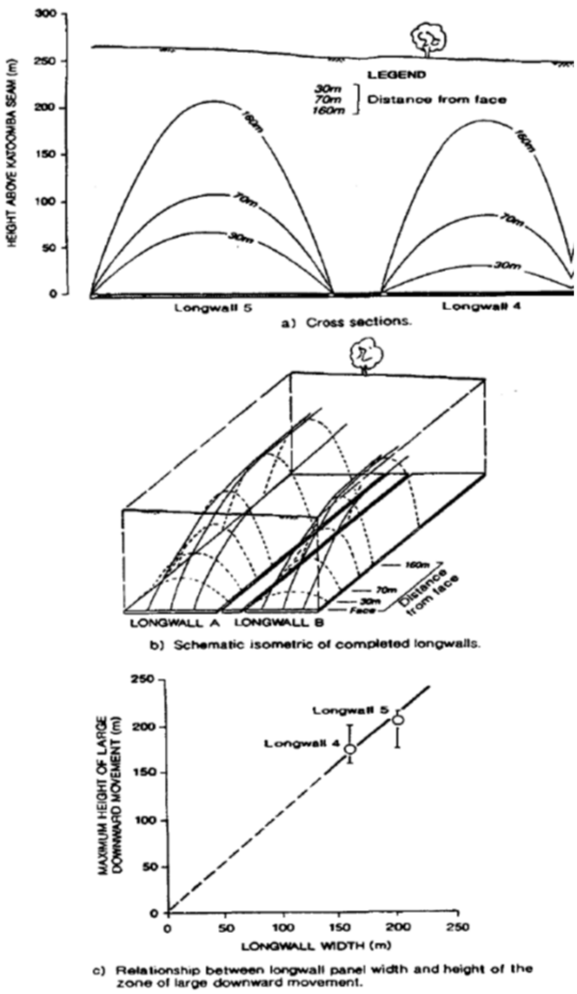


Fig. 7 - Zones of large downward displacement above two Longwall panels of different widths at Clarence Colliery

(Mills and O'Grady 1988)

The following comments on the HoF and the HoCF have been copied from the ACARP Project C13013 that titled "***Aquifer Inflow Prediction above Longwall Panels***" and dated September 2008 that was prepared by Gale.

"Water inflow into coal mines has been a design issue for many years. Guidelines as to the potential for water inflow have been developed in many countries based on local experience and the form of mining being undertaken."

"In most instances, the guidelines relate to inflows which would endanger underground personnel and operations. In more recent times, water inflow criteria for mines has been widened to include lesser inflows which may not impact on mine safety or operations, but have the potential to reduce water flow within streams and surface aquifers. For the purpose of this report the larger inflows relating to mining safety are defined as mine inflow and the lesser inflow relating to aquifer water loss as environmental inflow."

"Extraction of the coal causes caving of the immediate roof (5 to 20m, depending on the strata types) behind the supports to form a goaf. Above this goaf zone, the strata tend part along particular bedding planes and form "beams or plates". These subside onto the goaf as an interlocked but fractured network of bedding planes, pre-existing joints, mining induced fractures and bending related fractures within the beams."

"Tensile fracturing and dilation of existing jointing occurs in the upper zones of the overburden as a result of bending strains. The development of these zones is dependent on panel geometry and depth."

"Caving and cracked beam subsidence movements tend to occur up to a height of 1-1.7 times the panel width. Examples of this have been monitored by surface to seam extensometers (Mills and O'Grady 1998, Holla and Armstrong 1986, Holla and Buizen 1991, Guo et al. 2005, Hatherley et al. 2003) and predicted to occur from computer models (Gale 2006). This indicates that cracking and deflection related to such caving and cracked beam subsidence could extend to the surface for panel widths greater than 0.75-1 times depth, depending on geology."

"Longwall mining creates additional fractures and changes the conductivity of pre-existing fractures. The height that mining related fractures may form has been established from monitoring and computational studies as being 1-1.5 times the panel width.

"However, the creation of these fractures alone does not necessarily imply that a direct hydraulic connection exists over this zone. In order for mine inflow to occur, the fractures created must form a connected and conductive network to allow significant volumes of inflow.

"The flow quantity and velocity is highly dependent on the conductivity of the in situ fracture networks and those created by mining. Therefore, inflow into a mine is related to the combined insitu and mining induced fracture networks and the extent that they form a connected system to allow migration through the overburden strata.

"A review of mine inflow experience from Australia and the UK conducted found that unsafe volumes of water inflow in the UK occur for longwall mines having a rockhead less than 105m to the water source and theoretical tensile strains above 10mm/m. Longwall faces tended to be dry for strains on the strata at the water source less than 4mm/m. It was found that longwall faces were typically wet with strains at 6mm/m and high inflows may occur at strains greater than 10mm/m.

"Water inflow experience in Australia was consistent with this experience, albeit with some variance related to geology. Overall, the data suggests that mine inflow (observed inflows) can occur for theoretical strain values above approximately 6mm/m and the severity of inflow increases as the strain increases. Strains above approximately 10mm/m are likely to be associated with significant inflow.

"Overall, the results indicate that the overburden above panels having theoretical tensile strains of 4mm/m has flow networks close to the in situ conductivity. This therefore provides a reasonable estimate for the onset of enhanced conductivity of the overburden.

"As the subsidence increases the conductivity increases to the point of a highly conductive fractured mass. Average conductivity overburden for panels having a theoretical strain of 10mm/m is typically in the 10-2 to 10-3 m/s range.

"Conductivity of 10-1 to 10-2 m/s was noted for strain values greater than 10mm/m. Inflow for the highly conductive cases close to and greater than 10mm/m would be largely controlled by the aquifer properties.

"These results are summarised in Figure S1.

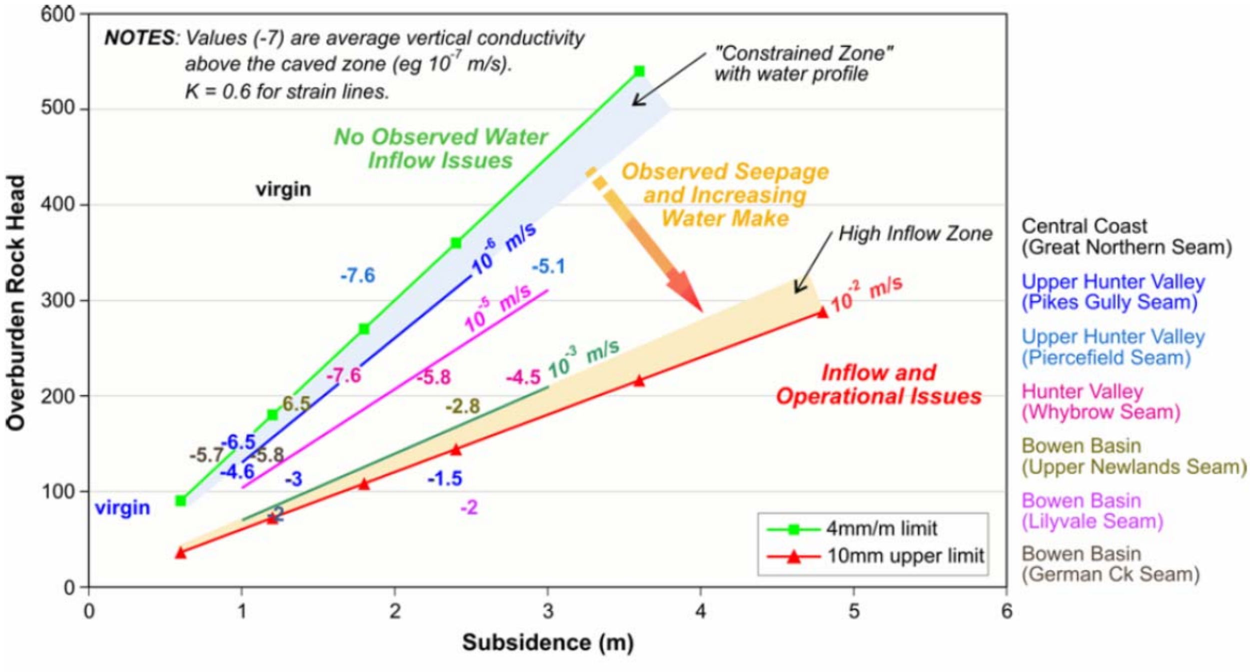


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

"In order to evaluate the potential inflow it is essential to assess the surface or aquifer conditions which would provide input into the fractured network as the nature of soils and surface topography may impact on the location and rate at which surface water may connect with the mining fractures.

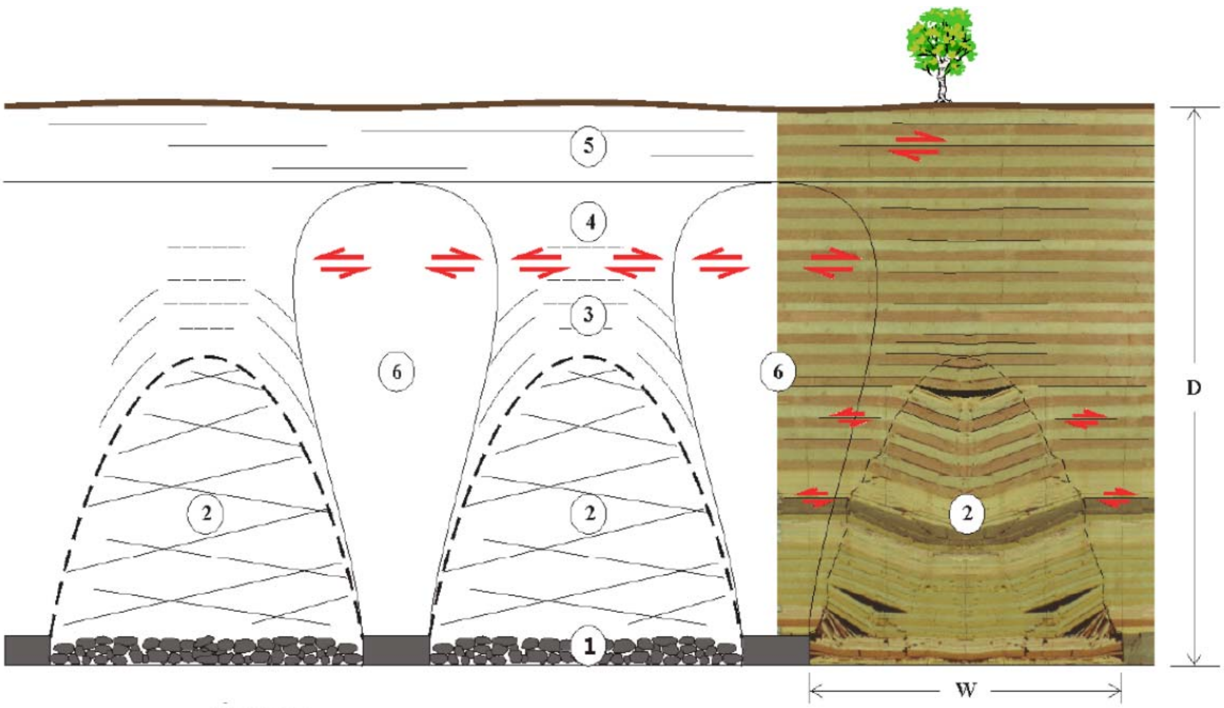
"The panel width has been found to influence the height that mining induced fractures can extend above the coal seam. However, for mine inflow to occur, the fractures must have formed a connected network to allow observable volumes of inflow. It is considered that the frequency, networking and aperture of those fractures increases with increasing overburden strain and subsidence. Therefore, whilst panel width typically controls the height of fracturing, the network connectivity and conductivity of fractures is controlled by the magnitude of strain and subsidence. Panel width, depth and seam thickness influence strain and subsidence. Therefore there are a number of inter related factors which can influence the result. If a significant thickness of clay material occurs, this may have the effect of constraining the fracture network either due to the fact that it can strain without fracturing or it is able to heal fractures by expansion of the clay."

Mills (2011) advised in a paper titled "***Developments in Understanding Subsidence with Improved Monitoring***":

"Subsidence monitoring provides an excellent view of the ground movements at the surface.

"Extensometer monitoring presented in Mills and O'Grady (1998) indicates that these zones are arch-shaped above each panel similar to the doming type roadway failures observed in an underground roof fall once all the material has been removed."

"The figure below shows a schematic of the zones of ground displacement above multiple longwall panels differentiated in subsidence monitoring and characterised using camera observations, packer testing, piezometer data, and extensometer monitoring. The upper zones shown in Figure 5 are not to scale."



LEGEND

1. Zone of chaotic disturbance immediately above mining horizon (0-20m).
2. Zone of large downward movement (→1.0 x panel width).
3. Zone of vertical dilation on bedding planes (1.0w - 1.6w)
4. Zone of vertical stress relaxation (1.6w - 3.0w).
5. Zone of no disturbance from sag subsidence (>3.0w) but shear during elastic compression subsidence of multiple panels.
6. Zone of compression above chain pillars.

"Zone 5, the uppermost zone is essentially undisturbed above single panels. However, when multiple longwall panels are mined adjacent to one another at depth, there is typically significant elastic strata compression subsidence. The broad area subsidence associated with elastic strata compression results in differential shearing on bedding planes within this upper zone. "

"The freeing up of these bedding planes contributes to the stress relief movements controlled by topography that tend to be the dominant type of ground movement whenever mining is deep enough for Zone 5 to be present."

"In Zone 4, between 1.6 and 3.0 times panel width above the mining horizon, the vertical displacements are consistent in magnitude with elastic relaxation of the pre-mining vertical stresses without the need for physical opening of bedding planes."

A number of other researchers have also investigated and commented on the likely mechanics of these mining induced strata deformations in order to assess the impact of mining on surface and aquifers. A common approach to the study of these impacts on groundwater issues, has centred on the dividing the overburden strata over a mined panel into a number of zones with different deformation characteristics. The size and nature of these overburden zones have been based on either, sub-surface borehole measurements and fracture observations, or, pore pressure and piezometer readings and permeability monitoring. However, the terminology used by different authors to describe these strata deformation zones above extracted longwalls varies considerably and caution should be taken when comparing the recommendations from differing authors. The important points to note between many of these researchers is whether they were commenting on the likely HoF or the HoCF

Singh and Kendorski (1981) in a paper titled "***Strata Disturbance Prediction for Mining Beneath Surface Water and Waste Impoundments***", proposed the following three zones that he called the fracture zone, the aquiclude zone and the zone of surface cracking.

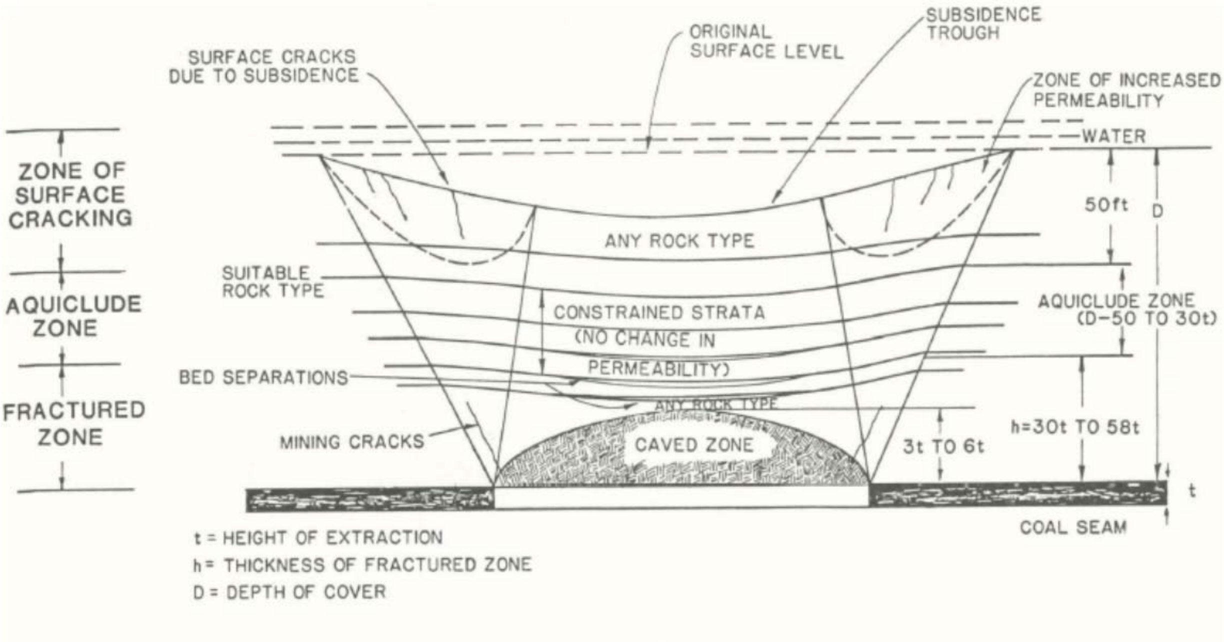
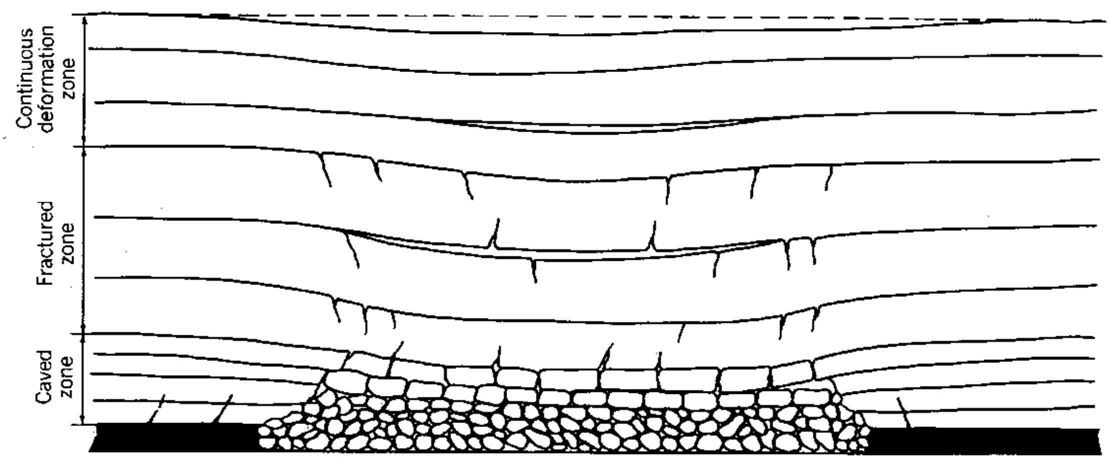


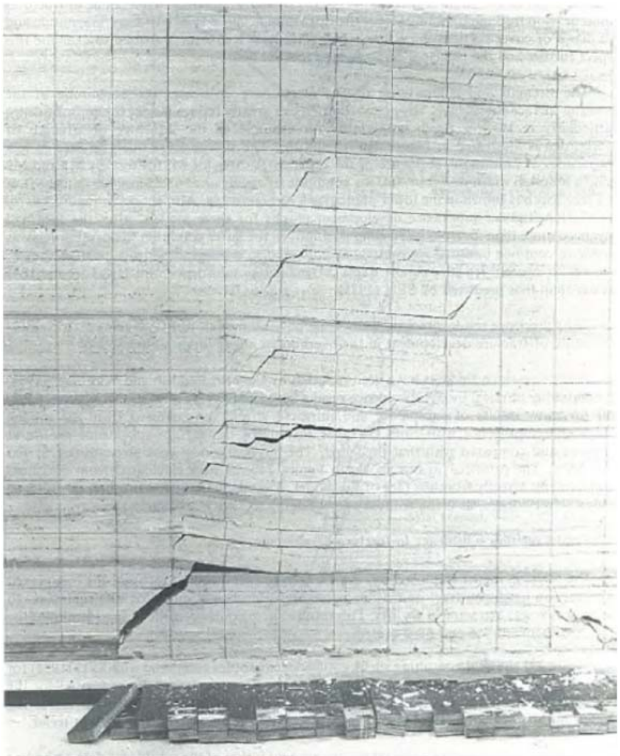
Fig. 4 - Generalized Depiction of Strata Behavior With Total Extraction Mining

Kratzsch (1983) in his text book titled "***Mining Subsidence Engineering*** ", identified four zones, but he named them the immediate roof, the main roof, the intermediate zone and the surface zone.

Peng and Chiang (1984) in his text book titled "***Coal Mine Ground Control***", recognised only three zones as reproduced below.

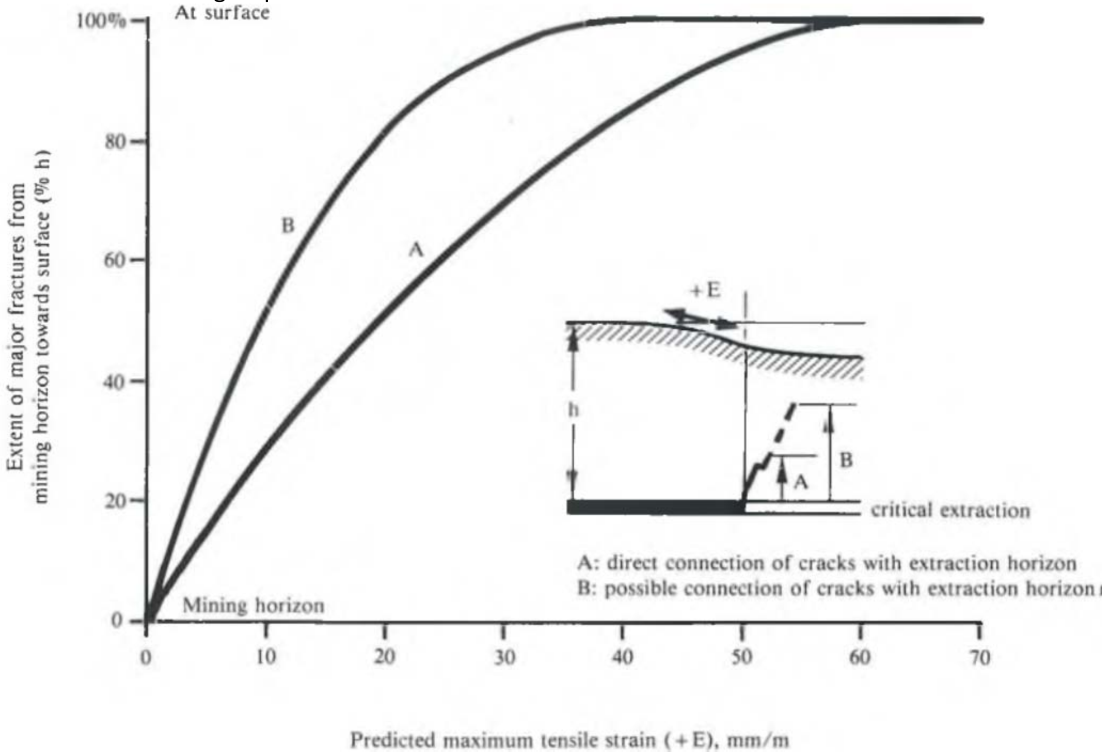


Whittaker and Reddish (1989) in their text book titled "***Subsidence - Occurrence, Prediction and Control***", used physical models built of sand/plaster/water mixes, as shown in the sketch below, that were suitably scaled in strength and size to simulate ground movement of the overburden to illustrate the development of fracture distributions and help understand the subsidence phenomena and strata mechanisms. Two fracturing types were addressed in these models, firstly the maximum height extended by those fractures which were judged to be definitely interconnected with the extraction horizon, (called zone A), and secondly the extent of any appreciable fracture even if they did not necessarily interconnect with the extraction horizon (called zone B).

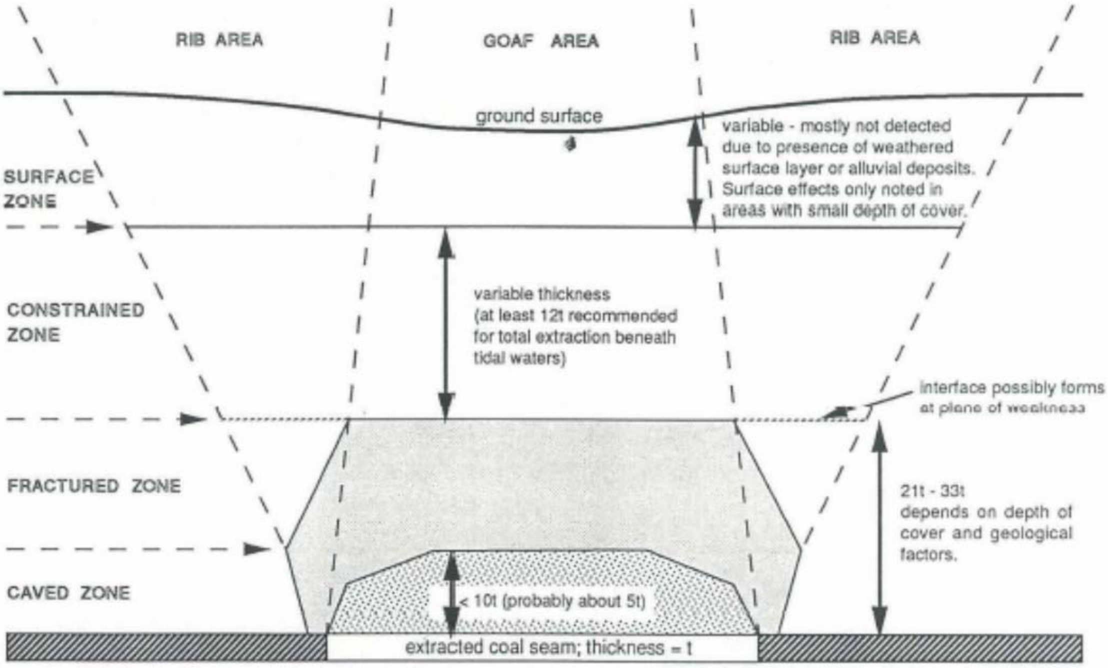


Zone A fracture development was interpreted as being indicative of where free flow from an overlying aquifer would readily occur, whilst the second could be indicative of where there might be a risk of water inflow seeping horizontally from an overlying aquifer but not necessarily flowing downwards to the mine. The second figure below shows an interpretation of these fracture development zones as a proportion of the depth of cover based on maximum tensile stresses in the overburden.

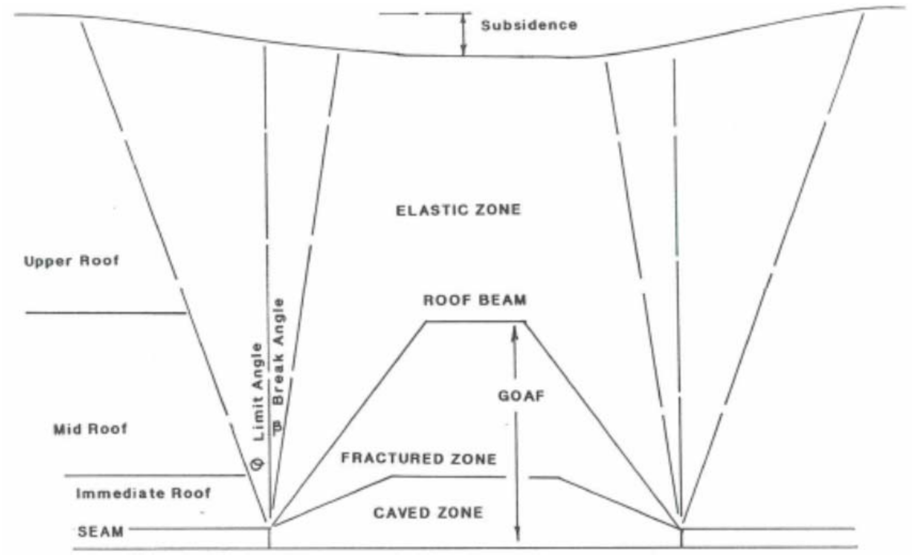
Whittaker and Reddish (1989) also recognised that local geology and depth of mining play important roles, especially in influencing the magnitude and extent of fracture development. They stated that bands of clay and aquicludes that can be located in the overburden can act as major factors in controlling water seeping from overlying horizons even though stronger fractured beds may exist above and below such pliable and impervious bands. It was also noted that the existence of pliable mudstone beds within the strata sequence would tend to inhibit the magnitude and extent of fracture development above the ribside.



Forster and Enever (1992) in their report titled "***Study of the Hydrogeological Response of Overburden Strata to Underground Mining Central Coast - New South Wales***", undertook a major groundwater investigation over supercritical extraction areas in the Central Coast of NSW and concluded that that overburden could be sub divided into four separate zones, as shown below, with some variations in the definitions of each zone. Forster and Enever noted that while the height of the caved zone over these total extraction areas were related principally to the extracted seam height, seam depth and the nature of the roof lithology, the extent of the overlying disturbed zone was dependent on the strength and deformation properties of the strata and to a lesser extent on the seam thickness, depth of cover and width of the panel.

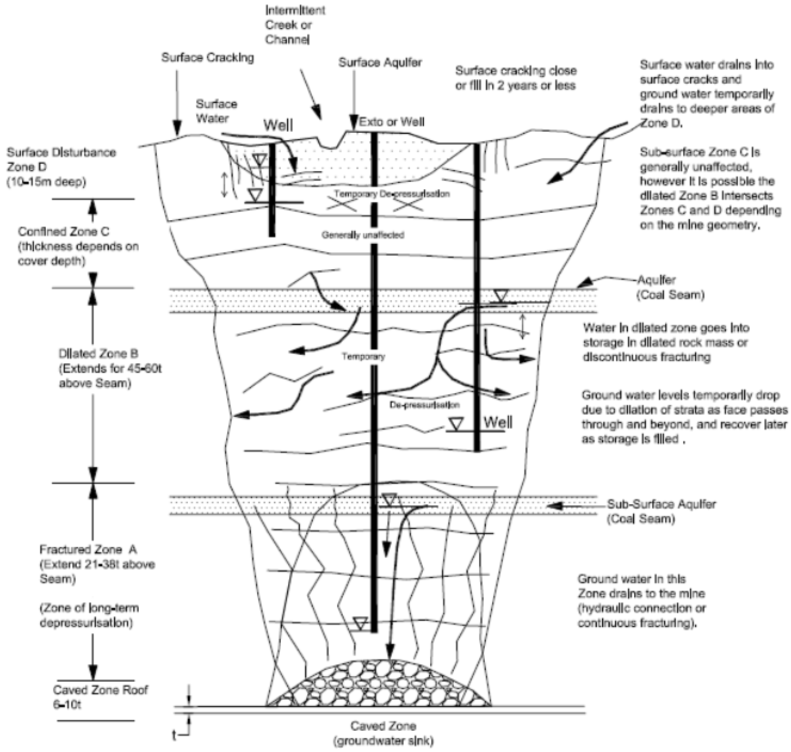


McNally et al (1996) in their paper titled "***Geological factors influencing longwall-induced subsidence***", recognised only three zones, which they referred to as the caved zone, the fractured zone and the elastic zone.

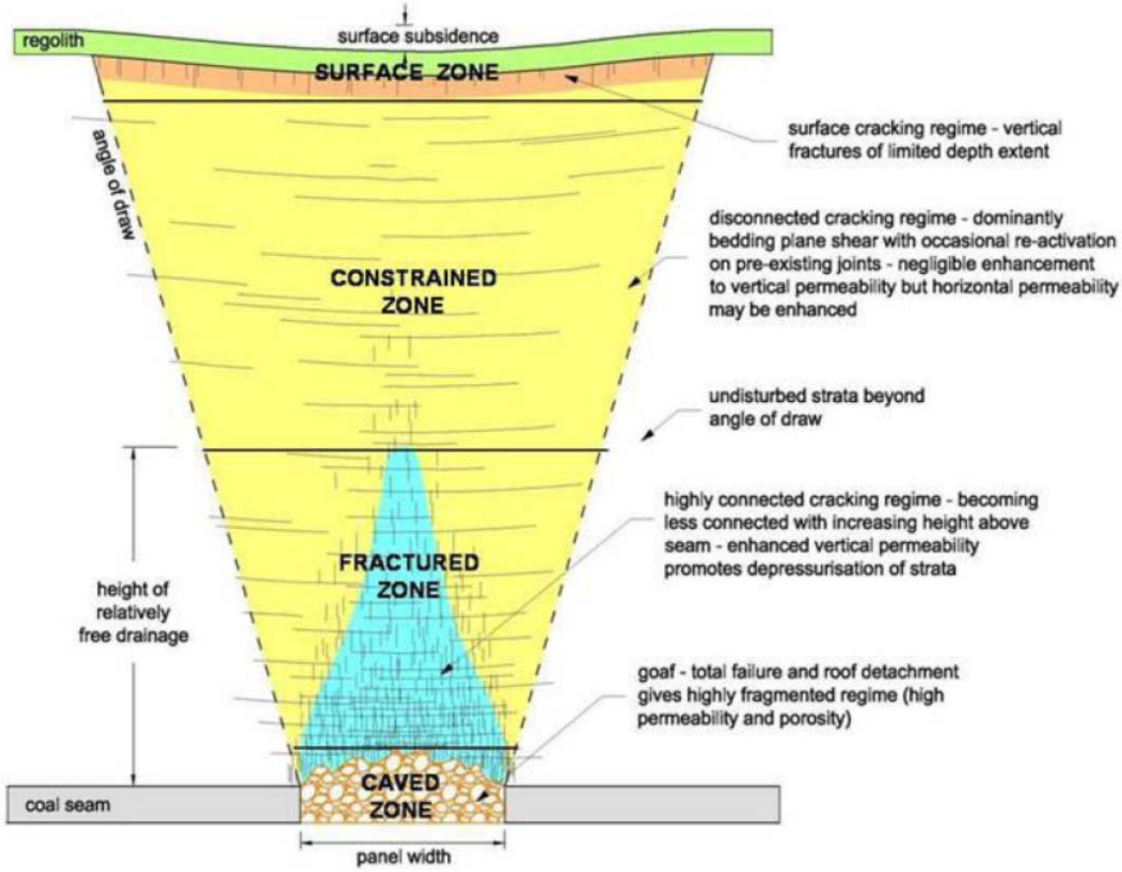


Ditton, Frith and Hill (2003) in their report titled "***Review of Industry Subsidence Data in Relation to the Influence of Overburden Lithology on Subsidence and an Initial Assessment of a Sub-Surface Fracturing Model for Groundwater Analysis***", reviewed the above Whittaker and Reddish Model plus the available borehole data in the Central Coast Region of the Newcastle Coalfield and then derived formulas for the height of continuous fracturing (HoCF), called Zone A, and the height of discontinuous fracturing zone (HoF), called Zone B as discussed by Whittaker and Reddish (1989). Ditton, Frith and Hill confirmed the definitions that the HoCF refers to the height at which a direct connection of the fractures occurs within the overburden and over the workings and represents a direct hydraulic connection for groundwater inflows. The HoF refers to the height at which the horizontal permeability increases as a result of strata de-lamination and fracturing, however, a direct connection of the fractures within this zone and the workings does not occur.

Ditton (2005) in a later report titled "***Surface and Sub-Surface Investigation and Monitoring Plan for LWs 1 to 6 at the Proposed North Wambo Mine***", expanded on these A and B zones by providing the following description of five zones in the following sketch. It can be noted that Ditton has split the constrained zoned, as described by Forster and Enever into the Dilated Zone (B) and the Confined Zone C.



Since then there have been several major government inquiries and Planning and Assessment Commission reviews that have investigated the potential effects of mining on surface and groundwater and the potential loss of water towards mined openings. Most of these reports have included the following sketch that was initially prepared by Mackie in 2007 to explain the nature of fracturing of the overburden over a coal mine. This model has four zones.



From the above discussions, it can be noted that just as the terminology used by the various researchers differs and the means of determining the extents of each of these zones also varies. Indeed some of the difficulties in establishing the heights of the various zones of disturbance above extracted longwalls stem from: the imprecise definitions of the fractured and constrained zones; the differing zone names and clarity regarding whether the discussed fractures were continuous, connected, discontinuous or not connected; the use of different extensometer borehole testing methods; the use of differing permeability or piezometer measuring methods; and differing interpretations of monitoring data.

Some authors have suggested simple equations to estimate the heights of the collapsed and fractured zones based solely on the extracted seam height, whilst others have suggested equations based solely on the widths of extraction, and then others have suggested equations should have been based on the width-to-depth ratios of the extractions. Some authors interpret the influence of geology on the height of the connected collapsed and/or fractured zones to only relate to those geotechnical strength issues that are associated with the possible presence of massive strong strata layers. Whilst others believe that the presence of layers of low permeability, (such as shales, siltstones, mudstones, and tuffs within the overburden), was a more important influencing factor.

The HoCF zone above extracted longwalls is believed to be affected by at least the following factors:

- widths of extraction, (W)
- heights of extraction, (t)
- depths of cover, (H)
- presence and proximity of previous workings, if any, near the current extractions,
- presence of pre-existing natural joints within each strata layer,
- thickness, geology and geomechanical properties of each strata layer,

- angle of break of each strata layer,
- spanning capacity of each strata layer, particularly those layers immediately above the collapsed and fractured zones,
- bulking ratios of each strata layer within the collapsed zone, and the
- groundwater factors such as the presence of and the head in aquiclude or aquitard zones within the overburden and the permeability of each strata layer.

The following listed reports from two recent ACARP funded studies provide extensive discussions on mining induced groundwater flows and computer based modelling techniques that are available to assess the heights of the various defined zones over mined panels and the potential inflows into a mine;

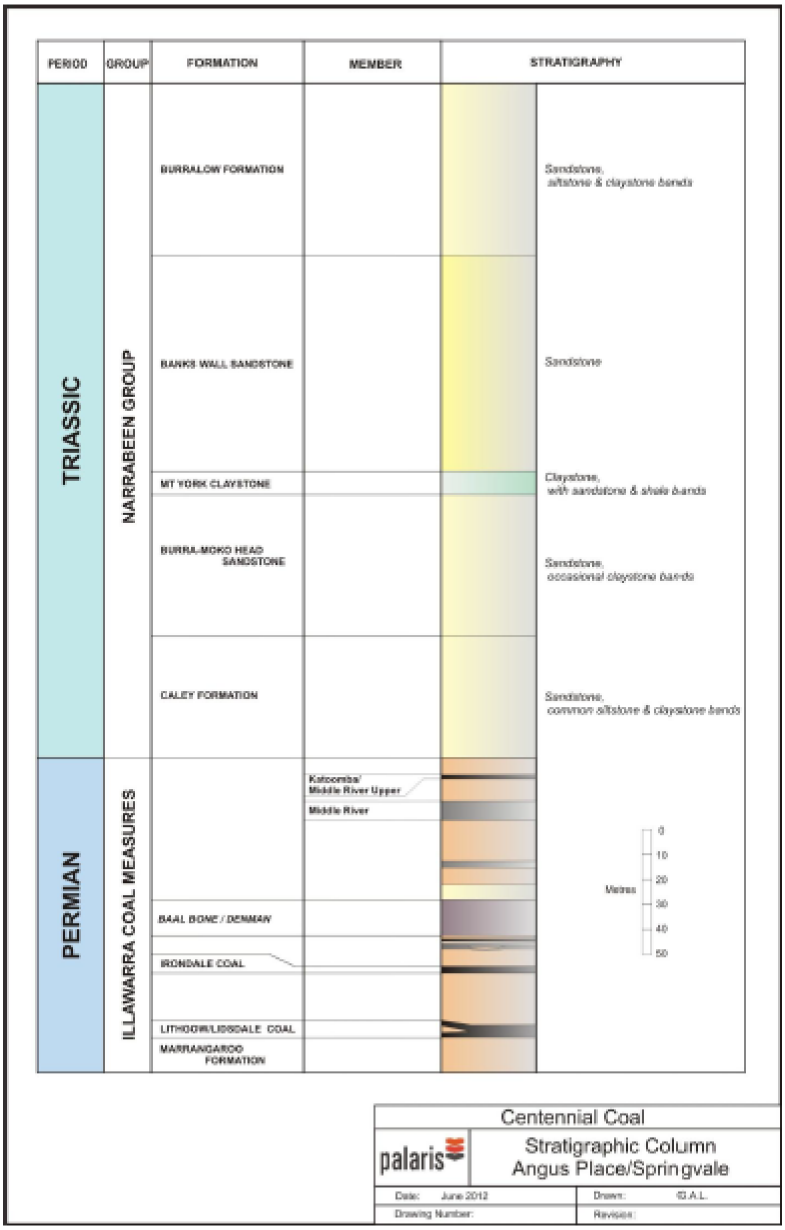
- CSIRO, Guo, Adhikary & Gaveva, (2007), ACARP C14033, "***Hydrogeological Response to Longwall Mining***", and
- SCT, Gale, (2008), ACARP C13013 "***Aquifer Inflow Prediction above Longwall Panels***".

These reports highlight that; the location of and the impact from these mining induced fractures depends on a complex combination of the mining geometry and the lithology and geology of the overburden strata.

The proposed longwalls at the Springvale and Angus Place Mine Extension Projects are located within the Illawarra Coal Measures. Above the coal measures lie the Narrabeen Group of the Triassic period. The surface geology of the terrain that is overlying these panels is located within the Burralow Formation of the upper Narrabeen Group which usually comprise sandstone, claystone and siltstone bands.

Within the Narrabeen Group of rocks, the Burralow Formation and the Mount York Claystone are key stratigraphic horizons in terms of their hydrogeological significance. The groundwater system underlying the Project Application Area has been extensively researched and has been found to be relatively complex with multi-layered units of variable permeability resulting in a number of discrete groundwater flow systems. A number of additional key hydrostratigraphic units have been identified from past investigations as shown in the stratigraphic sequence and geological cross section presented below that have been copied from a report by Palaris titled "***Stratigraphic Setting -Angus Place and Springvale Collieries***", Doc No CEY1535-01, dated March 2013.

Response to IESC Report: THPSS: Longwall Mining Engineering Design – Subsidence Predictions, Buffer Distances and Mine Design Options



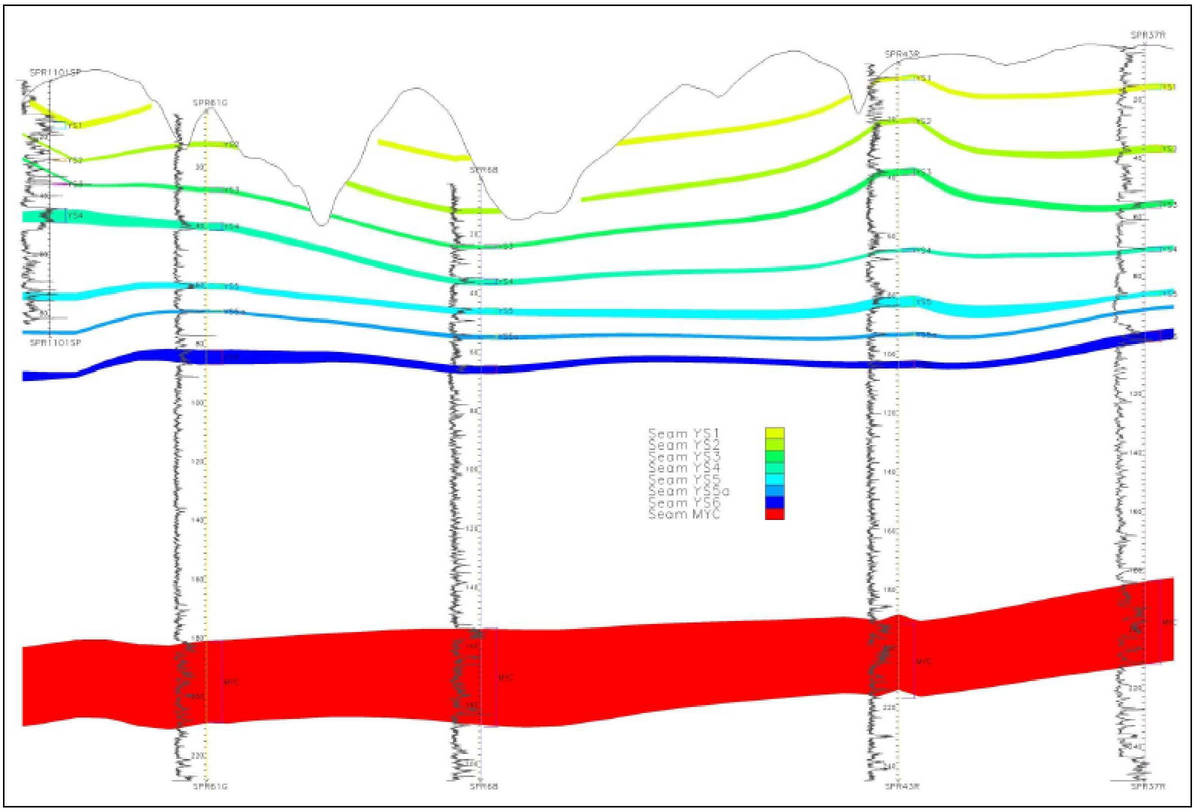


Figure 1.3 Correlated & Modelled Units in the Narrabeen Group

These plots show a series of horizontally layered and bedded, highly laminated and flat-lying sedimentary layered lithologies, which form a complex layered sequence of less-permeable and more-permeable horizons. Each layered sequence has differing grain size, lithification and strength properties which define their range in permeability. The generalised stratigraphy of this area as presented in following Table 2.5, which was copied from the a Golder and Associates report titled "Angus Place Mine Extension Project State Significant Development 5602 Environmental Impact Statement Volume 1: Report", and dated April 2014.

This table presents information on corresponding aquifer designations and less permeable horizons. The hydrostratigraphic sequences were incorporated into the hydrogeological model developed for the site by the above referenced CSIRO report (2013). The stratigraphic sequence were further subdivided into three groundwater systems, separated by the Burralow Formation (SP4) and the Mount York Claystone (SP3), and in the natural environment, are largely independent of each other. These groundwater systems are denoted as perched, shallow and deep groundwater systems respectively.

Table 2.5 Regional Hydrostratigraphic Summary and Hydrogeological Components

	Formation	Groundwater System	Aquifer Unit	Lithology	Hydraulic Properties	Importance
Narrabeen Formation (Triassic)	Burralow Formation	PERCHED	AQ6	Sandstone	Unconfined aquifer overlies YS1 claystone. Siltstone/claystone aquitards direct groundwater laterally into adjacent gullies. Burralow Formation is consistent in the region, up to 100m thick in the south.	Formation within which swamps are formed (NPSS and NPHS). Without the Burralow Formation and the aquitard layers within it, swamp communities would not exist. The thicker the Burralow Formation, the larger and more laterally extensive the swamp.
			SP4	Fine grained sandstone/siltstone/ Aquitard.	Separates AQ6 claystone units (YS4) and AQ5	
		PERCHED	AQ5	Medium to coarse grained sandstones interbedded with sandstone / siltstone / claystone	Siltstone/claystone aquitards direct groundwater laterally into adjacent gullies. Burralow Formation is consistent in the region, up to 100m thick in the south.	
			YS6	Thin semi-permeable claystone layer	Separates AQ5 and AQ4	
	Banks Wall Sandstone	SHALLOW	AQ4	Medium to coarse grained sandstone	Sandstone aquifer, consistent in nature and thickness, averaging 90m thick across the region.	Aquifer that underlies some of the swamp communities. Swamps formed in Banks Wall Sandstone have less access to seepage due to lack of Burralow Formation aquitards and are generally narrower and less extensive than those with Burralow

						Formation substrate .
	Mount York Claystone		SP3	Interbedded claystone and sandstone. Aquiclude	Separates AQ4 and AQ3. Averages 22m thick across the region	Significant regional aquitard that separates the shallow and deep groundwater systems
	Burra – Moko Head Sandstone	DEEP	AQ3	Predominantly sandstone, with several thick claystone bands	Sandstone units with consistent thickness in the region. Lowest stratigraphic unit above the coal measures.	Sandstone unit where A Zone height of fracturing terminates
	Caley Formation			Interbedded siltstone and sandstone		
Illawarra Coal Measures (Permian)	Farmers Creek Formation	DEEP	AQ3	Katoomba seam	Hydraulically connected to the overlying Caley Formation and Burra-Moko Head Sandstone	
			SP2	Sandstone, claystone, siliceous claystone. Aquiclude	Separates AQ3 and AQ2	
	Gap Sandstone	DEEP	AQ2	Sandstone with laminated siltstone		
	State Mine Creek Formation			Coal, mudstone, claystone (Middle River Seam)		
	Watts Sandstone			Sandstone		
	Denman Formation		SP1	Interbedded mudstone / sandstone, claystone, mudstone. Aquitard	Separates AQ2 and AQ1	
	Glen Davis Formation	DEEP	AQ1	Coal, claystone (Lithgow / Lidsdale / Irondale Seams)	Includes the Lithgow / Lidsdale Seam which is hydraulically connected with the Berry Siltstone and Marrangaroo Formations beneath and the Long Swamp Formation and Irondale Coal Seam above	

The extent, severity and manner of the observed impacts of coal mining on surface water resources and groundwater aquifers vary between different coal mines because every situation is different. The nature and extent of mining induced ground movements around, beneath and near these surface water resources and groundwater aquifers varies considerably due to differing size of the extraction and depth of cover and differing proximities to the water bodies. Each stream, pond or lake is unique in terms of its characteristics and each characteristic (i.e. stream flow conditions, water quality, gradients, valley depths and degree of incision, sediment and nutrient load, bedrock mineralogy, ecosystems and geomorphology) influences the observed consequences and impacts.

Hence, the specific geology of each case should be closely considered as the presence or absence of either strong channels or impermeable layers in the overburden can completely change generalised impact assessment that are only based on longwall widths or seam thicknesses.

The complexity of all these factors requires groundwater impact assessments for mining applications near streams or groundwater aquifers to be undertaken on a case by case basis.

Extensive groundwater testing programs over the years by various researchers have resulted in various hydro-geological models for subsurface behaviour zones. The first such hydro-geological model that was published for NSW conditions was one prepared by Forster and Enever in 1992 that studied various supercritical longwall panels in the Central Coast area of NSW. Several studies, since then, have suggested that the vertical extents of each of the various hydrogeological zones vary depending on many factors, including; the longwall width, extraction height, depth of cover, proximity of previous workings, local geology, overburden rock strength and the permeability and conductivity of the various strata layers in the overburden. Recently Forster wrote a groundwater report for a mine in this Central Coast area providing the following advice; "*The exact level of the top of this zone* (HoCF) *will most likely depend on the position of the numerous tuff layers located in the upper part of the formation. Previous analyses of bore cores indicated that there are up to 100 separate tuff or tuffaceous claystone horizons ranging from 1 mm to more than 3 metres thick in the overburden. Any cracks which penetrate the entire thickness of coarse-grained material in the lower section of the formation should be sealed when they reach the tuff layers, due to plastic deformation or swelling of the reactive clays contained in them. This is even more likely if the cracking results in some groundwater movement. Any one of these tuff layers therefore could form a relatively impermeable horizon that would present a barrier to vertical groundwater movement in the overburden strata, provided that it is located higher than about 65 metres above the* roof of the seam."

Similar more recent studies have highlighted that mine design recommendations should not be applied blindly based on the extracted seam thickness or the longwall panel width as some authors have recently suggested without assessment of the host geology. Careful consideration must always be given to specific site geology as "host geology" does play a significant or major role in determining the HoCF.

Experience in NSW, Queensland and around the world has indicated that, if the right type and thickness of the less permeable strata layers are present above the "fractured zone" and within a "constrained zone", then extraction may take place beneath water bodies without surface water finding its way into the workings. It is now generally recognised that where there are no low permeable layers within the overburden and above the "fractured zone", then, much higher HoCF are observed than where there are many of the lower permeable strata layers. Where there are many low permeable strata layers within the overburden, then, relatively low HoCF have been observed, even where the panels were supercritically wide.

MSEC has reviewed the above referenced CSIRO and DgS Reports and found that they provide detailed information on the existing environment, the groundwater systems, the overburden and the presence of layers of low permeability for this Western Coalfields area. The selection and use of both numerical and empirical models which have been calibrated to site data over many years and used for the Angus Place and Springvale Mine Extension Projects, are believed to represent the current "industry best practice".

MSEC has reviewed these reports and, in our opinion, we consider the assessments of the HoCF for the proposed longwalls at Angus Place and Springvale Collieries that are included in these reports are reasonable for this particular geological region.

It is noted that these reports have provided geologically adjusted and calibrated predictions and assessments of the likely HoCF over the proposed longwalls at Angus Place and Springvale Collieries, which, in our opinion, appear to be appropriate for this geological region and, hence, should provide a satisfactory estimate for the impact assessments on the groundwater systems from the proposed mining for this particular geological region. "

7.5.1.4 Tammetta (2012)

HydroSimulations provided the following review of the Tametta (2012) model: "Comments on the Tammetta conceptual model have also been made in Centennial's response to *Temperate Highland Peat Swamps on Sandstone: evaluation of mitigation and remediation techniques.* Additional comments are made in the following sections when comparing the Ditton and Tammetta conceptual models and analytical formulas.

There is agreement with the concept of an arched collapsed zone, but there is disagreement as to the height of this zone and also the requirement that it be fully unsaturated, that it "is completely drained of groundwater during caving" to the height H given by the cited formula. It is agreed that "Darcy's equation is unlikely to be obeyed" at local scale, but at the scale of numerical models an equivalent porous medium is a practical surrogate for characterising the fractured zone and accommodating the water throughput. As the fractured zone permeabilities required to match mine inflows are very much lower than would be expected for pure fracture flow, it is likely that weighted averaging with the fractured zone matrix is appropriate, or the fractures lack sufficient continuity to transmit large volumes of water. In the report extract, it is recognised that the matrix still contains water - "the matrix of rock blocks may continue draining for extended periods". Although the water pressure in the fractures is likely to be atmospheric, when combined with the water pressure in the matrix in an equivalent porous medium, it is likely that a net positive pressure would occur in the modelled representation of the upper part of a fractured zone.

HydroSimulations (2014)[2] conducted a peer review of the groundwater assessment by CSIRO (Adhikary and Wilkins, 2013)[3] for the Angus Place and Springvale Colliery Operations in which this statement was made: " Of particular interest are the resulting pressure head distributions above mined longwall panels (see Figures 62, 63, 76, 77, 78). The results show alternating zones of saturation and desaturation which significantly advances our conceptualisation of the saturation field associated with underground mining - a matter currently under debate in the hydrogeology profession". Figures 63 and 77 are reproduced below for a North-South cross-section.

[2] HydroSimulations, 2014, Peer Review - Angus Place and Springvale Colliery Operations Groundwater Assessment. Letter Report HC2014/11 prepared for Centennial Angus Place Pty Ltd.

[3] Adhikary, D. P. and Wilkins, A., 2013, Angus Place and Springvale Colliery Operations Groundwater Assessment. CSIRO Report No EP132799 for Angus Place Colliery and Springvale Colliery. May 2013.

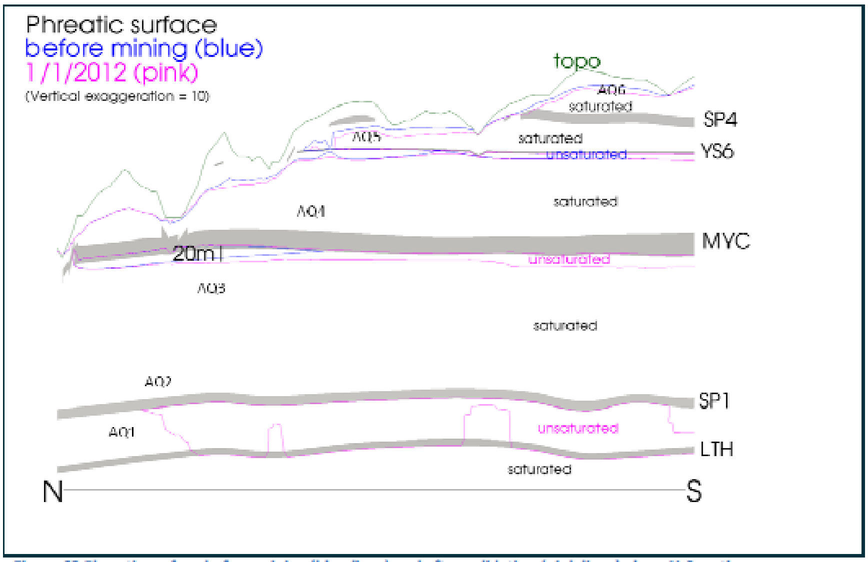


Figure 63 Phreatic surface before mining (blue lines) and after validation (pink lines) along N-S section

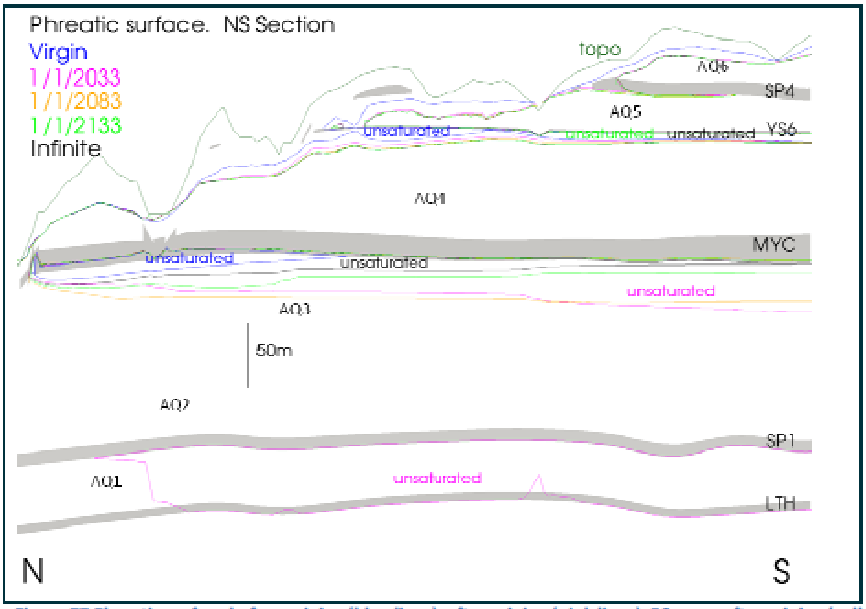


Figure 77 Phreatic surface before mining (blue lines), after mining (pink lines), 50 years after mining (yellow lines), 100 years after mining (green lines) and steady-state after mining (black lines) along N-S section

Alternative Fractured Zone Algorithms

There are only two known algorithms that aim to estimate the altitude of the deformed zone above an underground mine in terms of more than one causative factor.

The algorithms have been put forward in consulting reports by Steve Ditton of Ditton Geotechnical Services Pty Ltd (DGS) and in a journal paper by Paul Tammetta of Coffey Geosciences Pty Ltd[3]. Their formulas have been differentiated by Noel Merrick and Chris Nicol of HydroSimulations (not previously published) to reveal the sensitivity of fractured zone height to each causative factor. The two approaches have similar sensitivities for cover depth but differ for panel width and mining height. For mining height they are very different and trend in different directions.

The latest formulation of the Ditton model was presented at the Australian Earth Sciences Convention in Newcastle NSW in July 2014 (Ditton and Merrick, 2014)[4].

Both authors have found a relation between the height of some representation of the "fractured zone" and three key attributes of the mining system:

- Mining height [T (Ditton) or t (Tammetta)];
- Cover depth [H (Ditton) or h (Tammetta)]; and
- Longwall panel width [W (both authors)].

In addition, the Ditton model includes effective stratum thickness [t'] as a surrogate for roof rock integrity in one of his two developed models. The second model that uses only mining geometry, with no geology term, is directly comparable to the Tammetta model.

In this report, the underlying formulas for fractured zone height and sensitivity are presented, and then used to compare and contrast the predicted effects for varying panel width (for face widening), cover depth or mining height (for top coal caving).

Ditton Model Formulas

The Ditton conceptual model is illustrated in Figure 1.

The new Ditton model includes the key fracture height driving parameters of panel width (W), cover depth (H), mining height (T) and local geology factors to estimate the A-Zone and B-Zone horizons above a given longwall panel. Segregation between the A-Zone and B-Zone is based on a threshold vertical strain of 8 mm/m.

Formulas are offered for two models:

<u>Geometry Model</u>, which depends on W, H and T; and

<u>Geology Model</u>, which depends on W, H, T and t' (where t' is the effective thickness[4] of the stratum where the A-Zone height occurs).

The formulas for fractured zone height (A) for single-seam mining are:

<u>Geometry Model</u>: $A = 2.215\, W'^{0.357}\, H^{0.271}\, T^{0.372}$ +/- [0.16 - 0.1 W'] (metres)

<u>Geology Model</u>: $A = 1.52\, W'^{0.4}\, H^{0.535}\, T^{0.464}\, t'^{-0.4}$ +/- [0.15 - 0.1 W'] (metres)

where W' is the minimum of the panel width (W) and the critical panel width (1.4H).

The 95th percentile (maximum) A-Zone heights are estimated by adding aW' to A, where *a* varies from 0.1 for supercritical panels to 0.16 (geometry model) or 0.15 (geology model) for subcritical panels.

The models have been validated to 34 measured Australian case-studies (including West Wallsend, Mandalong, Springvale, Able, Ashton, Austar, Berrima, Metropolitan and Wollemi/North Wambo Mines) with a broad range of mining geometries and geological conditions included. The database also includes three cases in which connective cracking reached the surface (South Bulga, Homestead and Invincible

[4] Typically 15-20 m in the Gunnedah Coalfield.

Collieries). Statistics for the database are presented in Table 1, and best-fit back-calculated effective beam thicknesses for different coalfields are listed in Table 2.

Table 1. Statistics for the Ditton Model Database for Australian Coalfields.

STATISTIC	Panel Width [W (m)]	Cover Depth [H (m)]	Mining Height [T (m)]
Mean	191	254	3.0
Standard Deviation	65	138	0.8
Minimum	110	75	1.9
Median	179	213	2.8
Maximum	355	500	6.0

Note that the maximum mining height in the database is 6.0 m.

Table 2. Minimum Effective Thickness of a Spanning Stratum.

COALFIELD	SOUTHERN	WESTERN	NEWCASTLE	HUNTER	GUNNEDAH
Normal Condition [t'(m)]	20 - 40	20 - 30	15 - 20	15 - 20	15 - 20
Adverse Condition [t'(m)]	15	10	10	10	10

The variation of the A-Zone height for each factor is illustrated in Figure 3 to Figure 6. In each figure, the other three parameters are held constant at their database median values.

Ditton (2014, pers. comm.) has a procedure for estimating the increased fractured zone height for multi-seam mining, in which 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[5].

Tammetta Model Formula

[5] One unpublished case study in the Hunter Coalfield showed an increase in the effective mining height of about 70%. This had the effect of increasing the A-height by 27%.

The Tammetta conceptual model is illustrated in Figure 2.

The Tammetta model includes the key fracture height driving parameters of panel width (W), cover depth (h), and mining height (t) to estimate the height of "complete groundwater drainage", which corresponds with the height of the zero-pressure region, an unsaturated "collapsed zone". The model relies on the same parameters as the Ditton Geometry Model. There is no geology factor corresponding to the effective thickness of Ditton's Geology Model.

The formula for collapsed zone height (H) for single-seam mining is:

<u>Geometry Model</u>: $H = 1438 \ln[(4.315 \times 10^{-5})\ h^{0.2}\ t^{1.4}\ W + 0.9818] + 26$ (metres)

Using Ditton's notation to avoid confusion, the formula for collapsed zone height (A) for single-seam mining is equivalent to:

<u>Geometry Model</u>: $A = 1438 \ln[(4.315 \times 10^{-5})\ H^{0.2}\ T^{1.4}\ W + 0.9818] + 26$ (metres)

The 95th percentile (maximum) A-height is estimated by adding 37 m.

The model has been validated to Australian and international case-studies, using hydraulic head and ground movement (extensometer) data. An important assumption is that "*H* is taken as being equal to the top of the zone of large downward movement". This level is said to correspond with zero groundwater pressure, according to the examined head database. Statistics for the database are presented in Table 3.

Table 3. Statistics for the Tammetta Model Database for Australian and International Coalfields.

STATISTIC	Panel Width [W (m)]	Cover Depth [H (m)]	Mining Height [T (m)]
Minimum	110	64	1.2
Mean	179	243	2.5
Maximum	260	470	4.1

Note that the maximum mining height in the database is 4.1 m.

No formula is offered for multi-seam mining.

Sensitivity Formulas

The sensitivity of the A-zone height to each of the driving parameters is obtained by differentiation.

The sensitivity formulas for the Ditton Geometry Model are:

$$\frac{\partial A}{\partial H} = 0.600\ H^{-0.729}\ W'^{0.357}\ T^{0.372}$$

$$\frac{\partial A}{\partial T} = 0.824\ T^{-0.628}\ W'^{0.357}\ H^{0.271}$$

$$\frac{\partial A}{\partial W'} = 0.791\ W'^{-0.643}\ H^{0.271}\ T^{0.372}$$

The sensitivity formulas for the Ditton Geology Model are:

$$\frac{\partial A}{\partial H} = 0.813 * H^{-0.465}\ W'^{0.4}\ T^{0.464}\ t'^{-0.4}$$

$$\frac{\partial A}{\partial T} = 0.705\ T^{-0.536}\ W'^{0.4}\ H^{0.535}\ t'^{-0.4}$$

$$\frac{\partial A}{\partial W'} = 0.608\ W'^{-0.6}\ H^{0.535}\ T^{0.464}\ t'^{-0.4}$$

$$\frac{\partial A}{\partial t'} = 0.608\ \ t'^{-1.4}\ W'^{0.4}\ H^{0.535}\ T^{0.464}$$

The Tammetta model sensitivity formulas are:

$$\frac{\partial A}{\partial H} = \frac{0.2\ C1\ E1\ H^{-0.8}}{0.9818 + E1\ H^{0.2}}$$

$$\frac{\partial A}{\partial T} = \frac{1.4\ C1\ E2\ T^{0.4}}{0.9818 + E2\ T^{1.4}}$$

$$\frac{\partial A}{\partial W} = \frac{C1\ E3}{0.9818 + E3\ W}$$

where: $C1 = 1438$

$C2 = 4.315 \times 10^{-5}$

$E1 = C2\ W\ T^{1.4}$

$E2 = C2\ W\ H^{0.2}$

$E3 = C2\ H^{0.2}\ T^{1.4}$

The sensitivities to each causative factor are illustrated in Figure 7 to Figure 9, with comparison between Ditton and Tammetta models.

Figure 7 considers the increase in fractured zone height for an increase of 25 m in either the (effective) panel width or the cover depth. The findings for (effective) panel width are:

- The Ditton Geometry Model has an A-Zone increase of 3-10 m (12-40% of 25 m increment);
- The Tammetta (Geometry) Model has an A-Zone increase of 15-19 m (60-76% of 25 m increment); and
- The Ditton Geology Model has an A-Zone increase of 5-14 m (20-56% of 25 m increment).

The findings for cover depth are:

- The Ditton Geometry Model has an A-Zone increase of 1.5-8 m (6-32% of 25 m increment);
- The Tammetta (Geometry) Model has an A-Zone increase of 1.5-10 m (6-40% of 25 m increment); and
- The Ditton Geology Model has an A-Zone increase of 5-15 m (20-60% of 25 m increment).

Figure 8 considers the increase in fractured zone height for an increase of 0.5 m in mining height. The findings for mining height are:

- The Ditton Geometry Model has an A-Zone increase of 3.8-8.6 m (10-17 times the 0.5 m increment);
- The Tammetta (Geometry) Model has an A-Zone increase of 26-37 m (52-74 times the 0.5 m increment), and it trends in the opposite direction; and
- The Ditton Geology Model has an A-Zone increase of 6.5-14 m (13-27 times the 0.5 m increment).

As the Ditton model has a basis in geotechnical theory, while the Tammetta model is an empirical best-fit procedure, it is expected that the Ditton model would give the more correct sensitivity trend for mining height. The departure of the Tammetta model, in terms of trend and magnitude of its sensitivity to mining height, might be due to database limitations. It has previously been noted that the respective Ditton and Tammetta databases had maximum values of 6.0 m and 4.1 m for mining height. This means that the Tammetta model is uncontrolled for the higher mining heights.

Figure 9 shows the decrease in fractured zone height for an increase of 0.5 m in the effective thickness of a spanning beam. The finding for beam thickness is:

- The Ditton Geology Model has an A-Zone decrease of 0.3-7 m (0.6-14 times the 0.5 m increment).
- There is no equivalent parameter in the Tammetta model, but it is noted in Tammetta (2012) that "Host geology appears to play a minor role".

Database Probability Statistics

Representative statistics for characteristic ratios derived for the Ditton database are listed in Table 4 and Table 5. When applied to the Ditton database for Australian coalfields, the Tammetta formula leads to similar statistics in Table 6.

A common first-order estimate of fractured zone height is afforded by the ratio A/W, which is 0.45 for the Ditton concept at the median (Table 4) and 0.78 for the Tammetta concept at the median (Table 6). The Ditton B-Zone ratio is 0.60 at the median (Table 5).

Another common first-order estimate of fractured zone height is afforded by the ratio A/T, which is 21-37 for the Ditton concept (Table 4) and 33-61 for the Tammetta concept (Table 6). The Tammetta estimates would appear excessive and are likely to include areas of disconnected fractures given that the B-zone range, which does include disconnected fractures, is 27T to 71T.

Table 4. Exceedance Probabilities for Ditton Continuous Fracture Zone (A-Zone) Height for Australian Coalfields.

EXCEEDANCE PROBABILITY	Height of Fracture Zone / Panel Width [A/W]	Height of Fracture Zone / Cover Depth [A/H]	Height of Fracture Zone / Mining Height [A/T]
20%	0.38	0.23	21
50%	0.45	0.43	32
80%	0.73	0.69	37

For the parameters W, H and T in turn, the median B-height exceeds the median A-height by 33%, 100% and 34% (Table 5).

Table 5. Exceedance Probabilities for Ditton Discontinuous Fracture Zone (B-Zone) Height for Australian Coalfields.

EXCEEDANCE PROBABILITY	Height of Fracture Zone / Panel Width [B/W]	Height of Fracture Zone / Cover Depth [B/H]	Height of Fracture Zone / Mining Height [B/T]
20%	0.47	0.60	27
50%	0.60	0.86	43
80%	1.07	0.95	71

Table 6. Exceedance Probabilities for Tammetta Desaturated Zone Height for Australian Coalfields. [Derived using Tammetta formula applied to the database of Ditton]

EXCEEDANCE PROBABILITY	Height of Desaturated Zone / Panel Width [H/W]	Height of Desaturated Zone / Cover Depth [H/d]	Height of Desaturated Zone / Mining Height [H/t]
20%	0.61	0.32	33
50%	0.78	0.80	48
80%	1.02	1.13	61

There is a substantial difference between the Ditton A-height and the Tammetta desaturation-height. Table 7 shows comparative statistics for the Ditton and Tammetta conceptual models. For the parameters W, H and T in turn, the median desaturation-height exceeds the median A-height by 73%, 86% and 50%.

Table 7. Exceedance Probabilities for Ditton Continuous Fracture Zone (A-Zone) Height and for the Tammetta Desaturated Zone Height for Australian Coalfields.

STATISTIC	Height of Fracture Zone / Panel Width [A/W]		Height of Fracture Zone / Cover Depth [A/H]		Height of Fracture Zone / Mining Height [A/T]	
	Ditton	Tammetta	Ditton	Tammetta	Ditton	Tammetta
20%	**0.38**	0.61	**0.23**	0.32	**21**	33
50%	**0.45**	0.78	**0.43**	0.80	**32**	48
80%	**0.73**	1.02	**0.69**	1.13	**37**	61

Model Probability Distributions

Calculations of A-Zone and B-Zone heights, and associated ratios, for the entries in the Ditton database have been sorted and ranked to give cumulative probability distributions in Figure 10 to Figure 14. The Ditton Geology Model and Geometry Model track each other closely.

Comparative cumulative probability distributions (Ditton and Tammetta models) are shown in Figures 12, 13 and 14 where it appears that the Tammetta formulation agrees better with the B-zone definition. For the parameters W, H and T in turn, the median desaturation-height exceeds the median B-height by -0.4%, 5% and -8%.This suggests that the Tammetta formulation includes zones of disconnected fractures.

Conclusion

Opinions have been offered in this report on two literature reviews endorsed by the IESC:

A. Commonwealth of Australia 2014, *Temperate Highland Peat Swamps on Sandstone: evaluation of mitigation and remediation techniques, Knowledge report*, prepared by the Water Research Laboratory, University of New South Wales, for the Department of the Environment, Commonwealth of Australia; and

B. Commonwealth of Australia 2014, *Temperate Highland Peat Swamps on Sandstone: longwall mining engineering design—subsidence prediction, buffer distances and mine design options, Knowledge report*, prepared by Coffey Geotechnics for the Department of the Environment, Commonwealth of Australia.

The opinions are restricted to statements on surficial and deep fracturing as a result of underground mining:

1. The treatment of fractured zone algorithms in the literature reviews is inadeqate as the work of Ditton, documented in Ditton and Merrick (2014), is ignored;

2. The Ditton model for fractured zone height is considered superior to the Tammetta algorithm due to a basis in geotechnical theory, a correct trend for sensitivity to mining height, calibration to Australian conditions, and inclusion of a host geology term;

3. The association of the Collapsed Zone in the Tammetta model with complete desaturation is disputed, given the retention of significant volumes of water in the matrix of the rock material in this zone, and statistical correlation of the height of this zone with the B-Zone altitude in the Ditton model, which marks the top of a zone that has disconnected fractures;

4. The treatment of fracture permeabilities in the literature review (in Report A) is inadeqate as the substantial body of work on discrete fracture networks is ignored;

5. The estimates for fracture permeability are simplistic and grossly overstated, due to lack of consideration of fracture connectivity influenced by closure or truncation;

6. The conclusion that "a few small cracks through the swamp substrate can lead to substantial vertical drainage" is invalid, due to over-reliance on the cubic law for relating water flow to aperture size, and lack of consideration of the relative sizing of water-holding cracks and the water stored within intact swamp sediments."

Historical context

Since 2002, Centennial has conducted extensive research on the effects to groundwater systems and ecosystem resilience of longwall mining under the Newnes Plateau. An extensive groundwater monitoring network (comprising 36 swamp piezometers, 36 open hole aquifer piezometers and 26 multi-level vibrating wire piezometers) has been installed and monitored in current and future mining areas. The geology of the overlying strata has been modelled using data from 501 boreholes on the Newnes Plateau. Hydrogeological characterisation of THPSS on the Newnes Plateau has been conducted for the swamps in the Angus Place and Springvale Mine Extension Project areas.

The COSFLOW groundwater model used by CSIRO, and referenced as Appendix K: CSIRO Numerical Modelling Report to the SVMEP EIS and the APMEP EIS, is arguably the most representative model currently in use (Merrick (2014), Kay (2014)). NSW Office of Water reviewed the EIS' and stated in part: "In general, the impact assessment on aquifers has been carried out to a high standard, including preparation of a large and complex groundwater model by CSIRO. The most sensitive receptors in the area are the protected Temperate Highland Peat Swamps on Sandstone, for which longwall mining has been declared a key threatening process under the Threatened Species Conservation Act 1995. A great deal of attention has been paid in the EIS to demonstrate that the proposed extensions will not significantly harm overlying swamps and no specific shortcomings have been found in this assessment."

The COSFLOW model is able to predict groundwater behaviour as measured by changes in piezometric head in response to mine subsidence, which appear to occur as changes to phreatic surfaces within aquifers, instead of as a "height of complete dewatering". The COSFLOW model uses a "ramp function" to simulate the reduction in changes to permeability higher in the overburden. This ramp function is based on measured A, B and C zone data which is correlated to measured changes in permeability (from actual packer test results). As such this model is more representative of what actually occurs than other groundwater models.

In addition to using a groundwater model for the Angus Place and Springvale MEP's, an empirical model has also been used to characterise changes to groundwater systems caused by longwall mining throughout the overburden lithology. The height of continuous fracturing (HoCF) has been assessed for all longwalls in the proposed MEP areas using the DgS and Hydrosimulations Geology Pi-Term model. A presentation on the new methodology was co-authored by Steve Ditton and Noel

Merrick and presented at the Australian Earth Sciences Convention (AESC) in July 2014. The new methodology recognises the key fracture height driving parameters of panel width (W), cover depth (H), mining thickness (T), and local geology factors (t'), which represents the effective thickness of strata at height of A-Zone to estimate the A-Zone and B-Zone horizons above a given longwall panel. This model is superior to the existing models as it does recognise geology from a geotechnical perspective. The Pi-Term empirical model is based on an extensive database of 34 Case Studies from all NSW and Qld Coalfields.

It has also been calibrated against local data from a number of multi-level extensometers, multi-level vibrating wire piezometers and groundwater level monitoring bores. Microseismic data from overburden monitoring at Longwall 413 also appears to support the modelled height of the A-Zone. The effective delineation of A, B and C Subsidence Zones is critical to understanding effects to groundwater in the overburden.

The process by which the Pi-Term empirical model was calibrated to the geological and hydrogeological conditions and then used to model subsidence zones in future mining areas at Angus Place and Springvale was through:

- Measuring subsidence zones using extensometers
- Measuring groundwater effects within different subsidence zones using vibrating wire piezometers AND water level monitoring piezometers (changes in storage though minor bed separation may change pressures without measurable changes in water level)
- Modelling of subsidence zones using the Pi-Term Model (calibrated to site measured data)
- Use of historical piezometric response within the measured subsidence zones to approximate future groundwater response in the overburden (modelled subsidence zones) throughout the mine extension areas.

It is certainly the case that significant claystone aquitards are present in the overburden lithology and that these have a significant effect on groundwater behaviour in response to longwall mining. The Mt York Claystone (analogous to the Bald Hill Claystone in the Southern Coalfield) is a major claystone unit (average 22m thick and laterally continuous across the historical and proposed mining areas) which lies approximately 200m above the Lithgow Seam. Measurement with multi-level vibrating wire piezometers in 26 different boreholes over up to a 12 year period indicates that desaturation of the AQ3 aquifer which underlies the Mt York Claystone is very significant, compared to a relatively minor response in the AQ4 aquifer which overlies the Mt York Claystone (this is also modelled in the COSFLOW groundwater model).

In addition, there are a number of claystone units (up to 4m in thickness) located in the Burralow Formation, which lies immediately below the surface. These units appear to have a significant influence on retarding downward movement of groundwater flows and causing lateral movement of groundwater into the adjacent valleys, where it represents a significant source of water to the THPSS (GDE's) which lie in those valleys. These do not appear to be significantly affected by longwall mining, as measured in five water level monitoring bores installed in 2005 and subsequently undermined by longwall panels, without measurable response to water levels. This measured lack of change to groundwater levels has been measured at a number of other bores also.

In a Peer Review of Mine Subsidence Induced Height of Fracturing Issues for Angus Place and Springvale Collieries, Kay (2014) wrote: "MSEC has reviewed the above referenced CSIRO and DgS Reports and found that they provide detailed information on the existing environment, the groundwater systems, the overburden and the presence of layers of low permeability for this

Western Coalfields area. The selection and use of both numerical and empirical models which have been calibrated to site data over many years and used for the Angus Place and Springvale Mine Extension Projects, are believed to represent the current "industry best practice".

MSEC has reviewed these reports and, in our opinion, we consider the assessments of the HoCF for the proposed longwalls at Angus Place and Springvale Collieries that are included in these reports are reasonable for this particular geological region.

It is noted that these reports have provided geologically adjusted and calibrated predictions and assessments of the likely HoCF over the proposed longwalls at Angus Place and Springvale Collieries, which, in our opinion, appear to be appropriate for this geological region and, hence, should provide a satisfactory estimate for the impact assessments on the groundwater systems from the proposed mining for this particular geological region. The selection and use of both numerical and empirical models (calibrated to site data over many years) which has been used in the Angus Place and Springvale Mine Extension Projects, represents current industry best practice and provides a satisfactory estimate of the effects to groundwater systems of the proposed mining."

Based on the research undertaken and described above, a site specific hydrogeological model has been developed that is considered by a number of experts in the field as best practice. The level of detail, as well as the calibration with a significant geological and hydrological data set, is unprecedented for longwall mining operations in the Western Coalfield and is superior to the modelling summations made in the IESC Report.

7.6 Observed impacts on peat swamps from longwall mining

7.6.6 Simulation of groundwater hydrographs

The data and analysis conducted in CoA (2014) contains numerous errors of fact and contradictory arguments. These are summarised below:

Table 7.4 –Errors of Fact

The stated mining height of 3.7m is incorrect (116% of actual).

Timing of undermining of WE1 piezometer (Aug 2006) is not correct. WE1 piezometer was outside of the angle of draw of LW411 and lay directly over Angus Place LW960, which undermined the piezometer in 2010.

Licenced Discharge Point 6 is approximately 500m downstream of NS1 and NS2 and thus can't have influenced data.

Data from 2006 to 2009 clearly show periodic waterlogging of swamp (outside of periods influenced by mine water discharges).

At WE2 piezometer, 2 different seam heights have been used (3.2m and 3.7m). Angus Place and Springvale both minethe same seam section, which is approximately 3.2m in height. NB the height of the collapsed zone calculated by Tametta equation varies by 44m (13%) as a result of this change.

The reduced number of spikes in the hydrograph at WE2 piezometer after LW960 occurred because mine water discharges ceased in 2010.

The “Clear impact” at WE2 piezometer in Aug 2006 was due to cessation of MWD

Analysis of Table 7.4

Analysis of Table 7.4 on page 129, references WE1 as having the greatest angle of influence at 45 degrees (“From the database, the angle of influence for impacts (defined as the angle whose tangent is the lateral distance to an impact at the surface, divided by the overburden thickness) is a maximum of approximately 45° (WE1 and LW411 Springvale”). In Table 7.4, in the context of WE1 piezometer and Longwall 411, the analysis states “Impact masked by drought effect”. These analyses are contradictory and do not support the stated position.

The text on page 128 states “The impact at piezometer WW1 (and WW2 close by) is interpreted from comparing the deficit cumulative residual (R) to measured WW1 water level, as shown in Figure 7.17. Undermining by LW940 in late 2008 appears to have had negligible impact.”). The analysis continues on page 129 “The responses at …. at WW1 and WW2 (West Wolgan Swamp), suggest that the most severe impact occurs at the edge of the panel, to a minimum distance of half the panel width (0.5w) past the edge of the panel (i.e. a distance of 1 panel width from the centre of the panel).” Does this mean that undermining causes negligible impact and that only subsequent panel extraction causes impact (i.e. negative angle of influence)? The author goes on the say “Impacts were not interpreted to occur at two locations where the angle was approximately 50° (WW1 and LW930) and 45° (WW2 and LW930). The database is too small to draw definite conclusions about the generic extent of off-panel impact; however, the results agree closely with field observation discussed in Ouyang and Elsworth (1993) where a probable angle of influence of 42° was interpreted from a large database of dewatering information for water supply wells.”. This logic fails to acknowledge the earlier statement “ Undermining by LW940 in late 2008 appears to have had negligible impact” in this argument.

Comparison to Tametta’s height of complete dewatering model (incorrectly calculated using 3.7m seam height, then stating “Clear impacts on a swamp groundwater system occurred for ground surfaces as high as 86 m above the top of the collapsed zone (see the model of Tammetta 2012).”.

Data from WW3 and WW4 piezometers was dismissed as “No pre-impact water-level data available”. As per figure below there was at least 6 months pre-mining data for these piezometers.

It is notable that data from only two swamps (4 piezometers) was discussed in the analysis (East Wolgan and West Wolgan) was discussed in the analysis, with data from the other 36 swamp piezometers not used in analysis.

KC1 piezometer is in Table 7.4, but not discussed as impacts were "over panel" with zero degree angle of influence.

Data from NS1 and NS2 piezometers at Narrow Swamp was dismissed as "Impact masked by last discharges at LDP06. Following water levels show impact". LDP06 is downstream of NS1 and NS2 piezometers by approximately 500m and does not influence water levels at NS1 and NS2.

There is no mention of data from Sunnyside West Swamp, Sunnyside Swamp, Junction Swamp, where monitoring showed no measurable influence in response to mining.

Review of the IESC Cumulative Residual of Water Deficit 'R' Method

Below is a critique of the Water Deficit 'R' Method used for the analysis of hydrographs in the EISC report. The analysis of hydrograph data at West Wolgan Swamp is disputed as concluded by the analysis below.

Background

The correlation between rainfall and groundwater level has been frequently observed. Bredenkamp et. al. (1995) proposed that the relationship between these two series is explained based on groundwater mass balance. The work by Bredenkamp et. al. was based on case studies in South Africa. Butterworth et. al. (1999) presents a review of this method. Butterworth et. al. note that, with some limitations, water levels in a specific aquifer will fluctuate according to Cumulative Rainfall

Departure (CRD) from the mean, given a proportionality of *a/S*, where *a* is fraction of rainfall that recharges the groundwater system and *S* is storativity.

Application of the method is presented in Butterworth et. al. (1999) and Baalousha (2005) and further discussion of the CRD method is presented in Xu and van Tonder (2001).

A critique of the CRD method is presented by Weber and Stewart (2004). Weber and Stewart note that there are several limitations to the method that require consideration, however, it has valid hydrologic meaning in the short term. Weber and Stewart's criticisms include: the choice of beginning and end points of the data can affect the results, a lack of consideration that above average rainfall can reset the hydrological system without mathematically eliminating the accumulated deficit, and lack of support for the necessary inference that rainfall events and observed groundwater level response that are widely separate in time are related.

The methodology presented by the IESC (Commonwealth of Australia (CoA), 2014) is called Cumulative Residual of Water Deficit, R. The methodology is unorthodox and, as will be presented below, results in an incorrect identification of impact at West Wolgan Swamp in the period 2009/10 and post 2011. This letter presents a critique of the proposed IESC methodology.

Additional discussion of observed simultaneous groundwater level response behaviour in West Wolgan Swamp and Sunnyside West Heath Swamp, spatially separate to LW950, is presented elsewhere in the Response to Submissions.

Model Approaches

The CRD method, when fully deployed, correlates groundwater level response to rainfall recharge to the groundwater system via a simplified water balance. Rainfall recharge in the CRD method is effective recharge, namely inclusive of the effect of surface water rainfall-runoff processes, evapotranspiration etc. The CRD method does not explicitly incorporate evaporation, rather it is incorporated into the concept of effective recharge.

In general, the CRD method is usually only partially deployed. The typical approach is as per Bredenkamp et. al. (1995), namely calculation of the departure of observed rainfall over a defined interval from the mean. The departure is then added cumulatively. Equation (1) presents the general form, after Xu and van Tonder (2001):

$$ {}_{av}^{1}CRD_i = \sum_{n=1}^{i} R_n - \kappa \sum_{n=1}^{i} R_{av} \quad (i = 0, 1, 2, 3, \ldots N) $$

Equation (1)

where R_i is rainfall in the i^{th} period, usually months; R_{av} is average rainfall; and $K = 1$ when there is no pumping and/or natural net outflow from the groundwater system. As noted by Weber and Stewart (2004), caution should be exercised with respect to calculation of the mean. In general, the mean is calculated outside of the period of interest and normally based on long-term climatic statistics of the relevant BOM station.

The methodology presented by the IESC (CoA, 2014) uses a different approach to Bredenkamp et. al. (1995), namely inclusive of Pan A evaporation to derive a water deficit. CoA (2014) states "*Fortnightly rainfall … and fortnightly average pan evaporation from the Australian Bureau of Meteorology gridded dataset were used to construct a running cumulative residual (R) of the difference between fortnightly rainfall and evaporation (the water deficit). R is calculated by first finding the time series of fortnightly rainfall minus fortnightly pan evaporation, referred to as the fortnightly water deficit. The average of the time series of the fortnightly water deficit is then found. A second time series is then created, comprising the fortnightly deficit minus the average, creating a time series of deficit residuals. These deficit residuals are then cumulatively added to create R. This simple yet powerful formulation tracks the groundwater levels reasonably well.*".

Critique

To investigate the impact of the inclusion of evaporation to the CRD method, Figure 7.17 of CoA (2014) is presented as Figure 1 below, which includes groundwater level in West Wolgan Swamp, WW1, together with the reconstructed 'R' model. It is noted that the IESC model was based on the SILO (http://www.longpaddock.qld.gov.au/silo/) gridded datasets (both rainfall and evaporation) whereas the reconstructed 'R' model was based on observed rainfall on the Newnes Plateau (BOM Station No. 63062) and Lithgow (BOM Station No. 63132). Evaporation in the reconstructed 'R' model was obtained from the BOM Station at Bathurst (Station No. 63005).

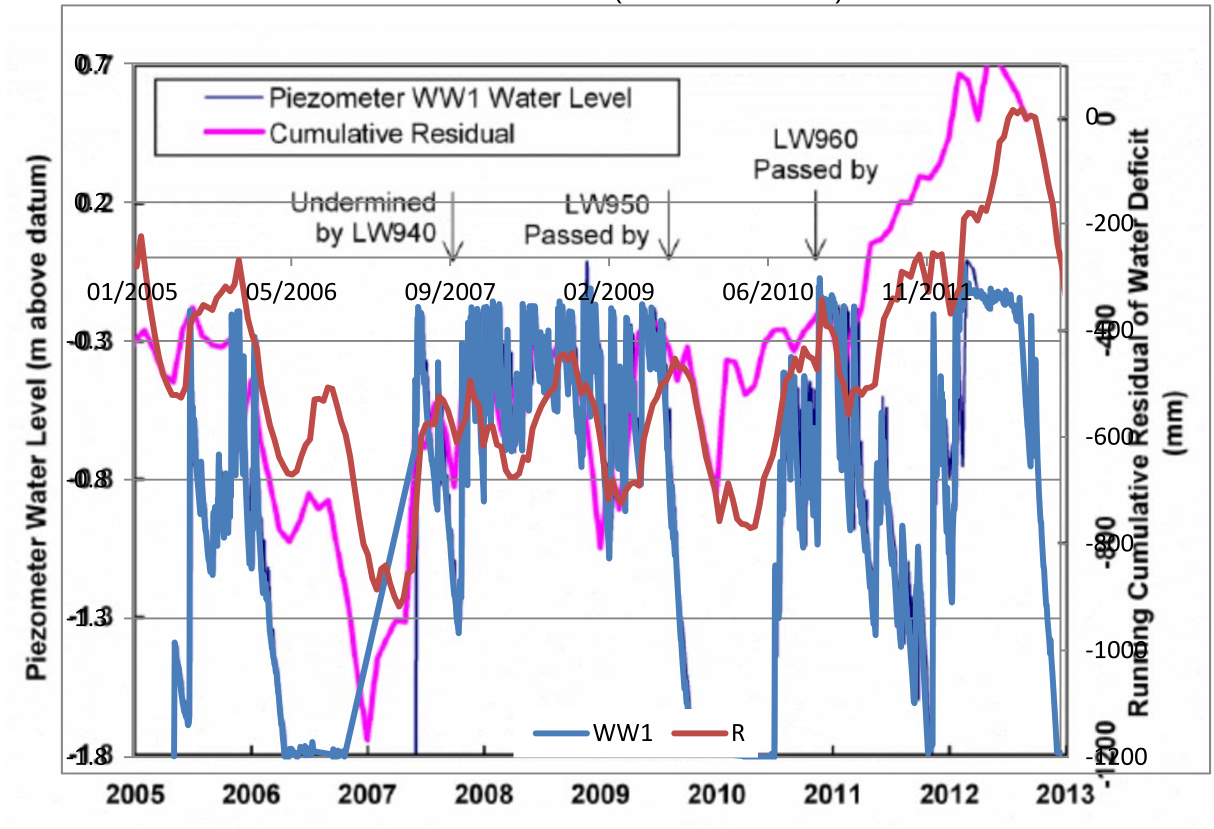


Figure 7.17 Modelled hydrograph for piezometer WW1, West Wolgan Swamp, Angus Place Mine, 2005 to 2013.

Figure 1: Reconstructed 'R' model and Groundwater Level Observation in Monitoring Piezometer, WW1 in the West Wolgan Swamp (adapted from CoA, 2014).

From Figure 1, it is apparent that the reconstructed 'R' model is based on slightly different rainfall and evaporation data, however, the magnitude of fluctuation and increasing and decreasing trends are reasonably replicated, in particular during the periods of interest between 2009/10 and post 2011.

A conclusion from the IESC study is that in the period of interest in 2009/10 and post 2011 that the trend in 'R' diverges from observed groundwater level response and thereby implies impact to West Wolgan Swamp. As will be presented below, this conclusion is disputed because 'R' depends on evaporation and as groundwater level in the swamp drops, the assumption that full Pan A evaporation can occur, despite a groundwater level of more than 1m below ground surface, becomes invalid.

To test the impact of evaporation on the IESC method, the 'R' model was reconfigured as follows:

fortnightly evaporation was excluded

fortnightly residual was redefined as difference between fortnightly rainfall and average of fortnightly rainfall

cumulative residual was calculated as per normal.

Figure 2 presents the reconfigured IESC model. It is highlighted that the rainfall dataset used in the reconfigured model was the same as adopted in the reconstructed 'R' model presented in Figure 1.

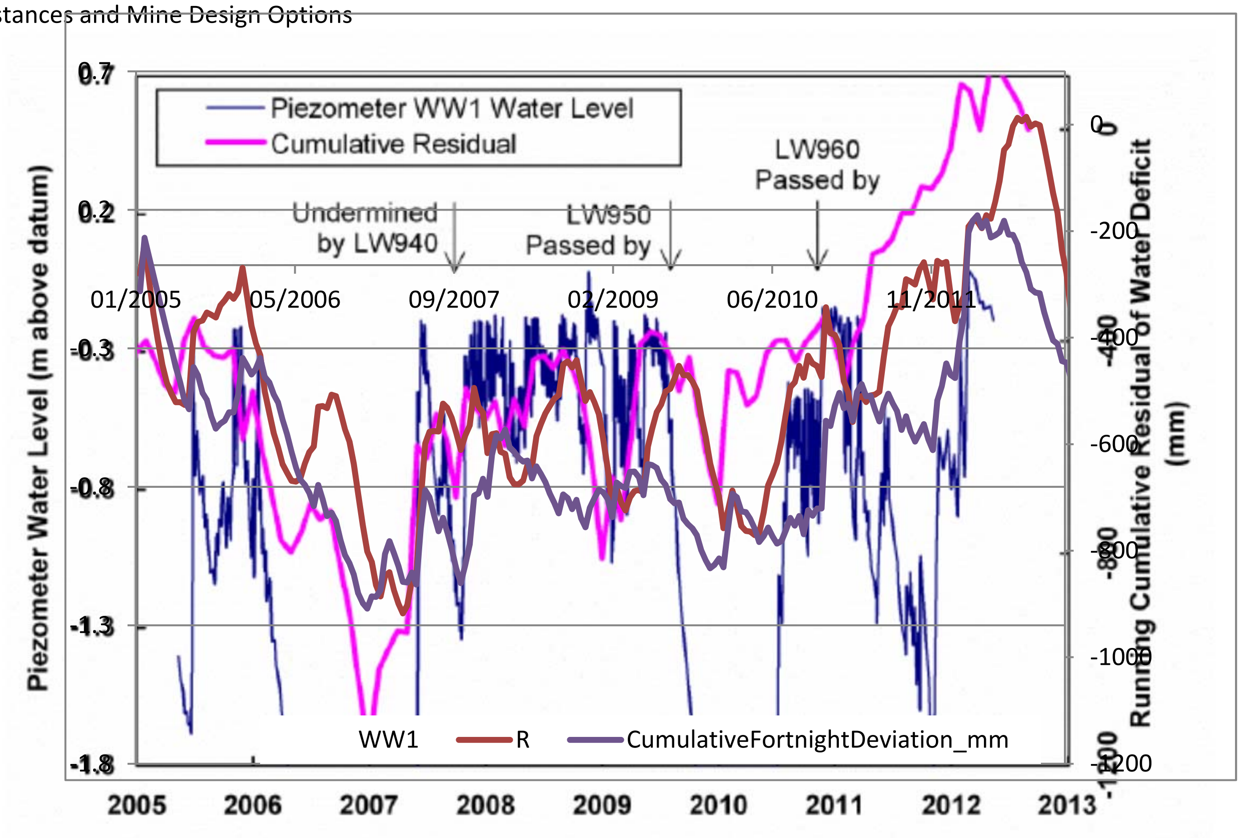


Figure 7.17 Modelled hydrograph for piezometer WW1, West Wolgan Swamp, Angus Place Mine, 2005 to 2013.

Figure 2: Reconfigured IESC model without evaporation (adapted from CoA, 2014).

From Figure 2, in the period of interest in 2009/10 and post 2011, the reconfigured IESC model illustrates either a stationary or declining trend rather than an increasing trend. The analysis indicates that during dry periods, evaporation dominates the 'R' model, however, the assumption that full Pan A evaporation can occur from the naturally declining water table is not valid.

Weber and Stewart (2004) do comment, however, that the link between observed change in groundwater level and average can be problematic when the CRD method is applied over the long term. It is considered that the presented period of 10 years is at the upper limit of validity and it is likely that there have been 'hydrologic' resets.

The influence of the assumption of a single and internal mean instead of an externally derived, month to month varying, mean was investigated and the results are presented in Figure 3. This model comprised:

fortnightly rainfall as per the reconstructed 'R' model

fortnightly departure from mean obtained from long-term climatic statistics, varying dependent on month cumulative departure calculated as per normal.

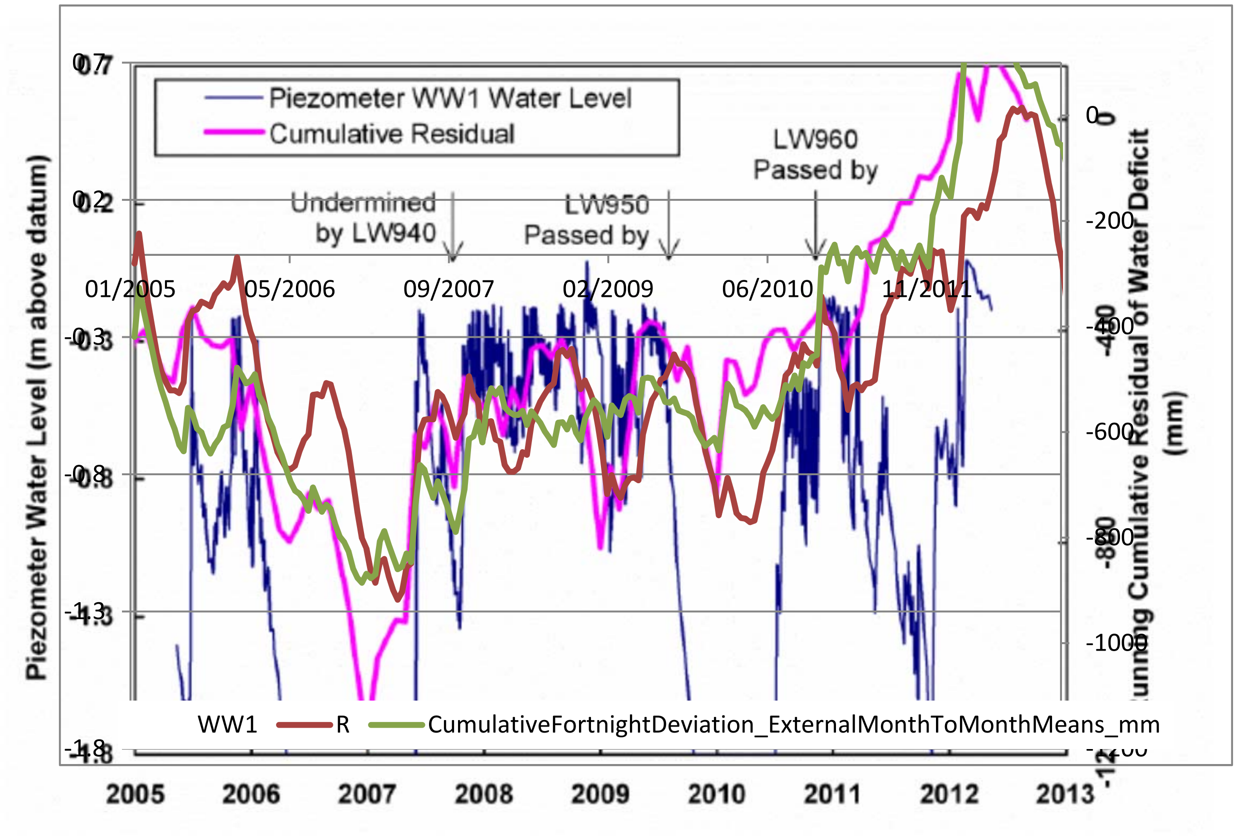


Figure 7.17 Modelled hydrograph for piezometer WW1, West Wolgan Swamp, Angus Place Mine, 2005 to 2013.

Figure 3: Reconfigured IESC model without evaporation but including external month to month 'mean' (adapted from CoA, 2014).

From Figure 3, in the period of interest in 2009/10 and post 2011, month to month 'mean' improves the correlation between observed decline in groundwater level and 'static' cumulative rainfall departure. The results imply that seasonal variation in mean rainfall is a useful consideration in the CRD method.

Conclusion

A technical summary of the origin of the CRD method is presented, which does not include evaporation or the concept of water deficit. The CRD methodology is typically only partially deployed, however, is based on a simplified groundwater mass balance. Issues such as effect of surface rainfall-runoff processes and evapotranspiration are incorporated via the concept of effective recharge in the full method.

It is presented that the assumption in the IESC 'R' model that full Pan A evaporation occurs during naturally declining groundwater levels, to a maximum of 1.8m below ground surface, is not valid. It is demonstrated that reconfiguration of the IESC model to correct this assumption, as well as incorporation of an externally derived month to month varying mean, leads to an improved correlation between groundwater response and climatic conditions.

It is concluded that there was no impact to West Wolgan Swamp, as is asserted in the EISs of the Angus Place and Springvale Mine Extension Projects, and the identified divergence between the IESC 'R' model and observed groundwater level can be explained by assumptions made in the 'R' model.

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Commonwealth of Australia, 2014a. *Temperate Highland Peat Swamps on Sandstone: longwall mining engineering design – subsidence prediction, buffer distances and mine design options*. Reference No. N/A, dated August 2014.

Weber, K. and M. Stewart, 2004. *A Critical Analysis of the Cumulative Rainfall Departure Concept*. Groundwater, 42(6): 935-938.

Xu, Y. and G.J. van Tonder, 2001. *Estimation of recharge using a revised CRD method*. Water SA, 27(3): 341-343.

The following analysis was conducted on the hydrographs from Sunnyside West Swamp Heath and West Wolgan Swamp and also does not reach the same conclusions as those reached in CoA (2014).

Sunnyside West Swamp Heath and West Wolgan Swamp

The Sunnyside West Swamp Heath is located upstream of the Sunnyside Swamp over Springvale Colliery, and West Wolgan Swamp is located over Angus Place Colliery. While these swamps have been classified as different botanical types, both are located at higher elevations, where the groundwater table beneath the low flanking ridges is situated well below the base of the swamps. As a result, these swamps are not fed by the main aquifer in this area, but rely to a large extent on rainfall to contribute to the groundwater. The swamps have probably formed in these areas due to the presence of a perched water table on a high-level aquitard.

Sunnyside West Swamp Heath is located over the pillar between LW412 and 413 at 10 cut-through at Springvale Colliery (Figure 9). West Wolgan Swamp is located over LW 940 and LW 950 at 17 cut-through at Angus Place Colliery (Figure 10). Both swamps are periodically waterlogged swamps in which the groundwater level varies significantly with rainfall.

Groundwater monitoring commenced at West Wolgan Swamp in two piezometers (WW1 and WW2) in May 2005, while monitoring in one piezometer (SW1) at the Sunnyside West Swamp Heath commenced in July 2007. Monitoring data are shown in Figure 11. West Wolgan Swamp was undermined by LW 940 in November 2007, while LW 950 passed the site in July 2009. At the Sunnyside West Swamp Heath, LW 912 passed beneath the swamp in January 2009 and LW 413 passed the site in July 2010. Groundwater monitoring results are presented in Figure 11, and discussed in detail in the following section.

These two swamps are discussed together as they display almost identical hydrogeological behaviour (even though they are separated by about 4 km), and the data from the piezometers in one swamp can be compared with data from the piezometers in the alternate swamp, to check for mining-related impacts. There is no flow monitoring at either of these swamps as they are both periodically waterlogged and flow from the downstream ends of these swamps occurs very rarely.

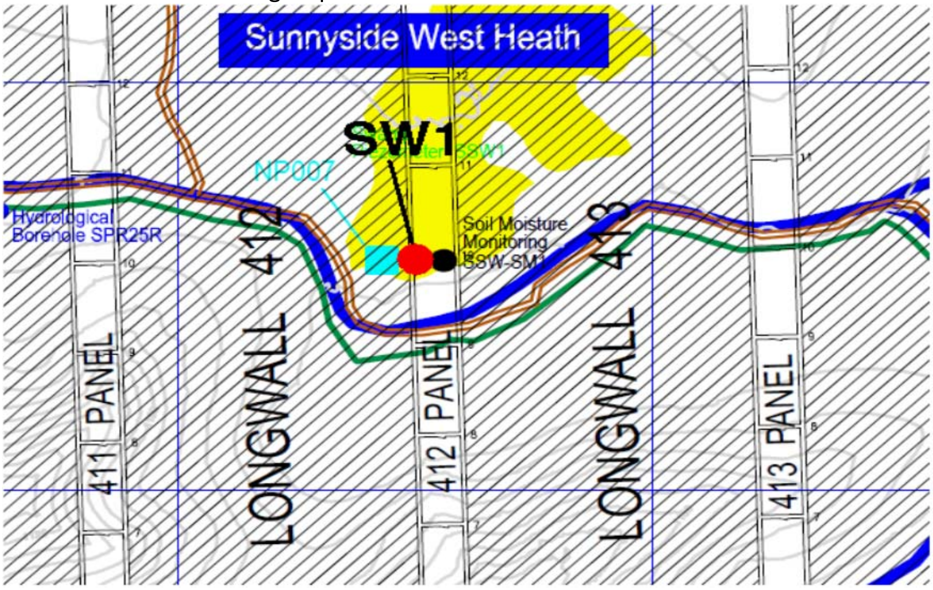


Figure 9 - Sunnyside West Swamp Heath - location of piezometer

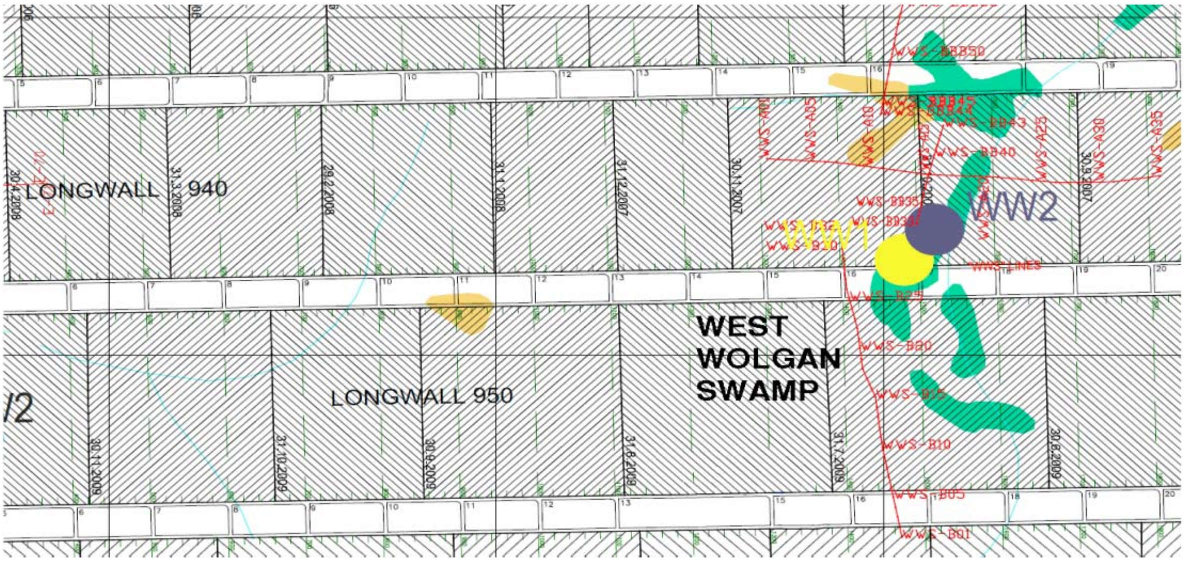


Figure 10 - West Wolgan Swamp - location of piezometers

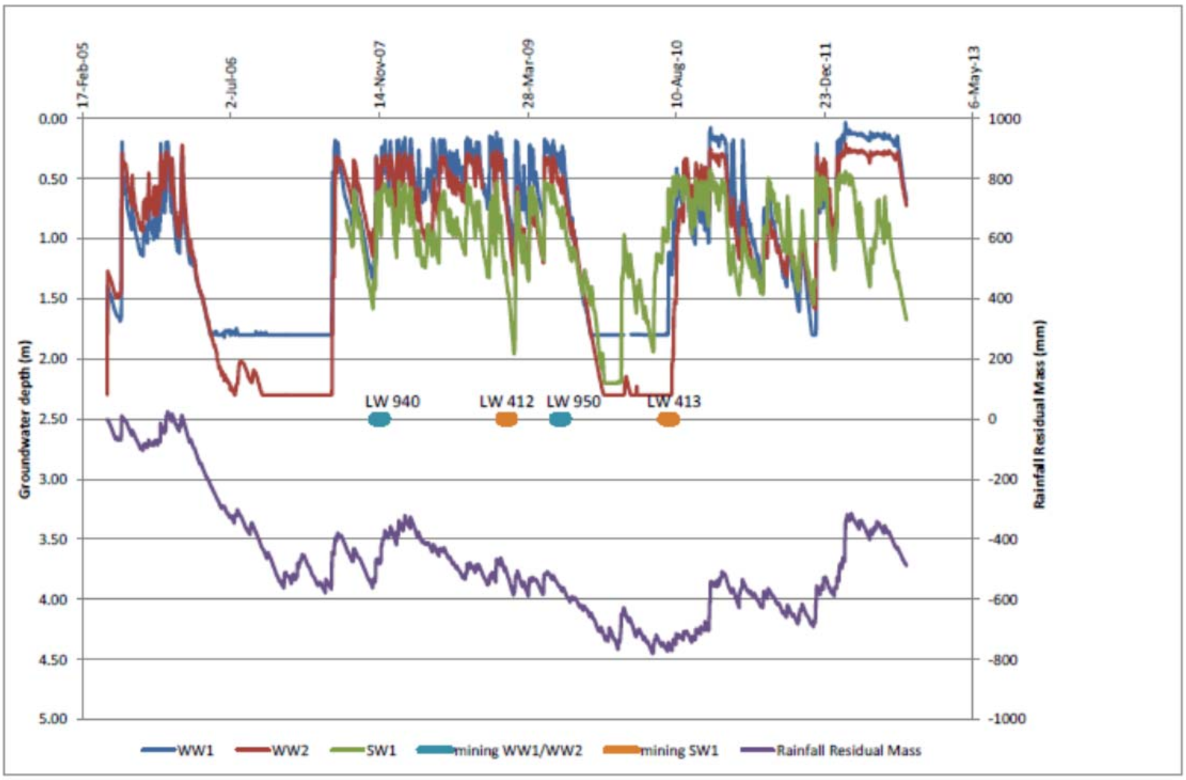


Figure 11 – West Wolgan Swamp and Sunnyside West Swamp Heath – groundwater levels

Monitoring results and analysis

The monitoring results for WW1 and WW2 (Figure 11) in the West Wolgan Swamp show groundwater level movements which are typical of a periodically waterlogged swamp, where the groundwater level rises rapidly, then declines more gradually following rainfall events. The low groundwater level in both WW1 and WW2 in 2006/2007 (pre-mining) was due to the severe drought conditions at the time. This drought period is also evident on the rainfall residual mass plot shown in Figure 11. Above average rainfall in the latter half of 2007 raised the groundwater to pre-drought levels prior to the swamp being undermined by LW 940 in November 2007.
Following the undermining, the monitoring shows no change in the groundwater level behaviour in WW1 and WW2 to that observed prior to mining, with the same pattern of rapid rise followed by gradual decline after rainfall events. It is also clearly evident from Figure 11 that the post-mining groundwater level behavior in WW1 and WW2 is identical to the pre-mining behavior in SW1 in the Sunnyside West Swamp Heath, which at that time had not been undermined. This provides further evidence for a lack of mining-related impacts at the West Wolgan Swamp.
An identical pattern of groundwater movements is also evident after the undermining of SW1 in January 2009. These patterns are very similar to the patterns in WW1 and WW2 at the same time, and there is no discernible difference in the pre- and post-mining patterns or in the SW1 data and the WW1/WW2 data.

WW1 and WW1 showed a decline in groundwater level following the passage of LW 950 past the site in July 2009, but this was not due to mining. The low groundwater levels between September 2009 and early 2010 were due to abnormally low rainfall over this period, as there was a similar decline in the level in SW1. This again is evident in the decline of the rainfall residual mass during this period. Additionally, during this time, the data logger in WW1 malfunctioned and had to be replaced. These below average rainfall conditions reversed in late 2010 about the time that LW 413 passed SW1, and the groundwater level patterns returned to normal in both swamps. Again, there was no material difference between the groundwater level behaviour in the swamp after the passage of this longwall panel.

Conclusions

The recent pattern of groundwater level movements in piezometer SW1 in the Sunnyside West Swamp Heath is consistent with the response measured prior to undermining by LW 412 in March 2009 (and almost identical to the movements in WW1 and WW2). The data indicate conclusively that there has been no impact from the mining in LW 412 or LW 413 on the hydrogeological conditions recorded within the swamp at SW1. No mining-related impacts are evident from the hydrogeological data, even though this swamp experienced near-maximum subsidence for the panel, which would have been of the order of 1.2 metres.
Similar analyses have also confirmed that mining at Angus Place has had no impact on the West Wolgan Swamp, where the post-mining groundwater level patterns have been compared to patterns in the Sunnyside West Swamp Heath and found to be near-identical. The groundwater level movements in both swamps are closely related to the rainfall residual mass, which reinforces the fact that both swamps are periodically waterlogged swamps.

Hydrology of East Wolgan and Narrow Swamps (Baseline and Post-Mining)

Detailed analysis was conducted in the context of establishing the baseline hydrology of East Wolgan and Narrow Swamps was conducted Springvale Coal Pty Ltd (2013) EPBC Approval 2011/5949 Application to Allow Longwall Mining Under Temperate Highland Peat Swamps on Sandstone on the Newnes Plateau – Supplementary Data Volume 1. This analysis is summarised in Corbett et al (2014) and an extract presented below:

Groundwater levels at East Wolgan Swamp began to decline rapidly in February 2006 when Centennial commissioned the Water Transfer Scheme (WTS), which transferred water pumped from the mine via a pipeline off the Newnes Plateau for use by industrial water users (Wallerawang Power Station).

Hydrographs of East Wolgan Swamp piezometers WE1 and WE2, presented with the timing of mine water discharge and longwall mining as well as the cumulative rainfall deviation trend show strong correlations between groundwater levels and mine water discharges prior to mining. Following the cessation of mine water discharges, the hydrograph trends can be seen to be strongly influenced by rainfall.

There are periods (in excess of two years) during which pre-mining data for WE1 piezometer was not influenced by mine water discharge (March 2006 to March 2008), which may be used to characterise the pre-mining hydrology of East Wolgan Swamp. It is important to note that, at both piezometer locations, the data shows that the standing water level was at or below the WE1 piezometer instrument (indicated by discontinuities in the hydrograph trend) for most of the periods not influenced by mine water discharge. The standing water levels rise in response to rainfall events which are in excess of the long-term average trends and fall in response to less than average rainfall trends. The responses are typically immediate and of short duration, indicated by the "spikes" in the hydrograph trends. When the data recorded during mine water discharged is removed, the same trend can be seen in the pre-mining baseline data at WE1 piezometer (March 2006 to March 2008). Based on this baseline data it is concluded that East Wolgan Swamp was a periodically waterlogged swamp before commencement of mining activities.

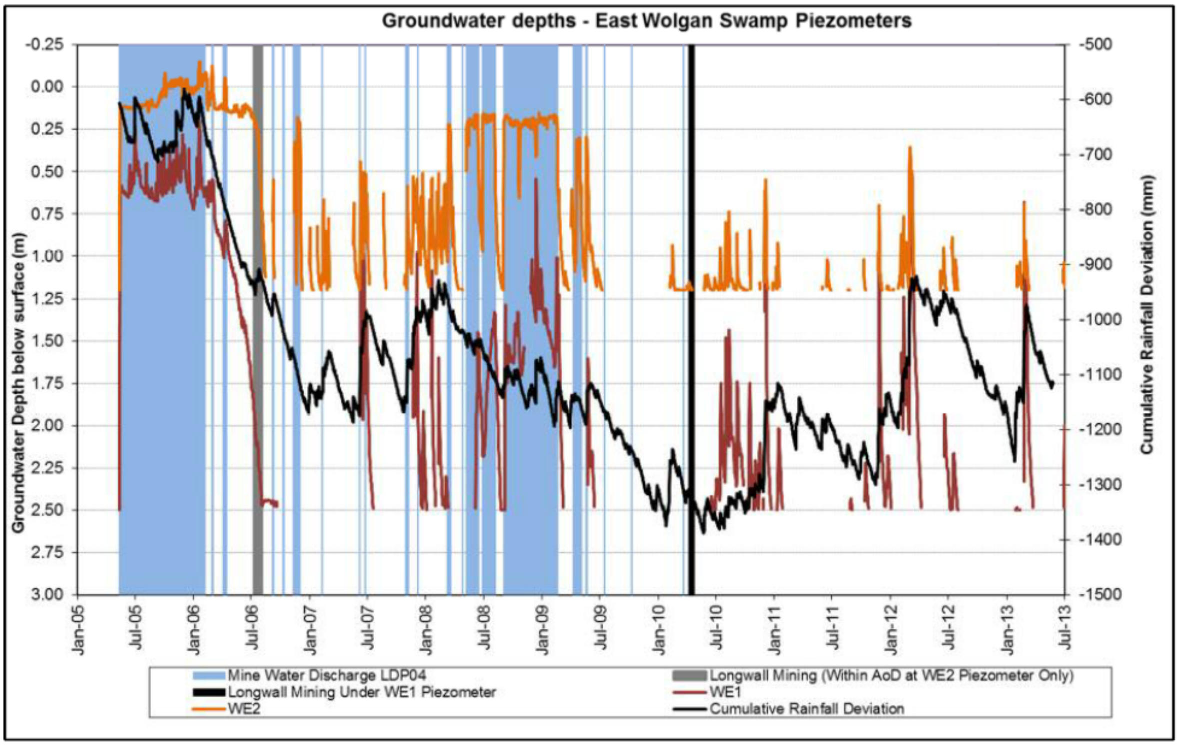


Figure 8 Hydrographs of East Wolgan Swamp Piezometers WE1 and WE2 showing the timing of mine water discharge and longwall mining and the cumulative rainfall deviation trend

Narrow Swamp baseline hydrology

Figure 18 is a hydrograph of Narrow Swamp piezometers NS1, NS2, NS3 and NS4 showing the timing of mine water discharge and longwall mining as well as the cumulative rainfall deviation trend. The timing of mining was similar to that of the cessation of mine water discharges at LDP05 in February 2009, but the dominant influencing factor can be seen to be mine water discharges. Following the cessation of mine water discharges, the hydrograph trends can be seen to be strongly influenced by rainfall. The standing water levels rise in response to rainfall events that are in excess of the long term average trends and fall in response to less than average rainfall trends. The responses are typically immediate and of short duration, indicated by the 'spikes' in the hydrograph trends. When the data recorded during mine water discharged is removed, the same trend can be seen in the pre-mining baseline data. There is approximately 12 months pre-mining data (between March 2007 and March 2008) that is not affected by mine water discharge, which clearly shows that the swamp was periodically waterlogged prior to mining. It remains periodically waterlogged following mining.

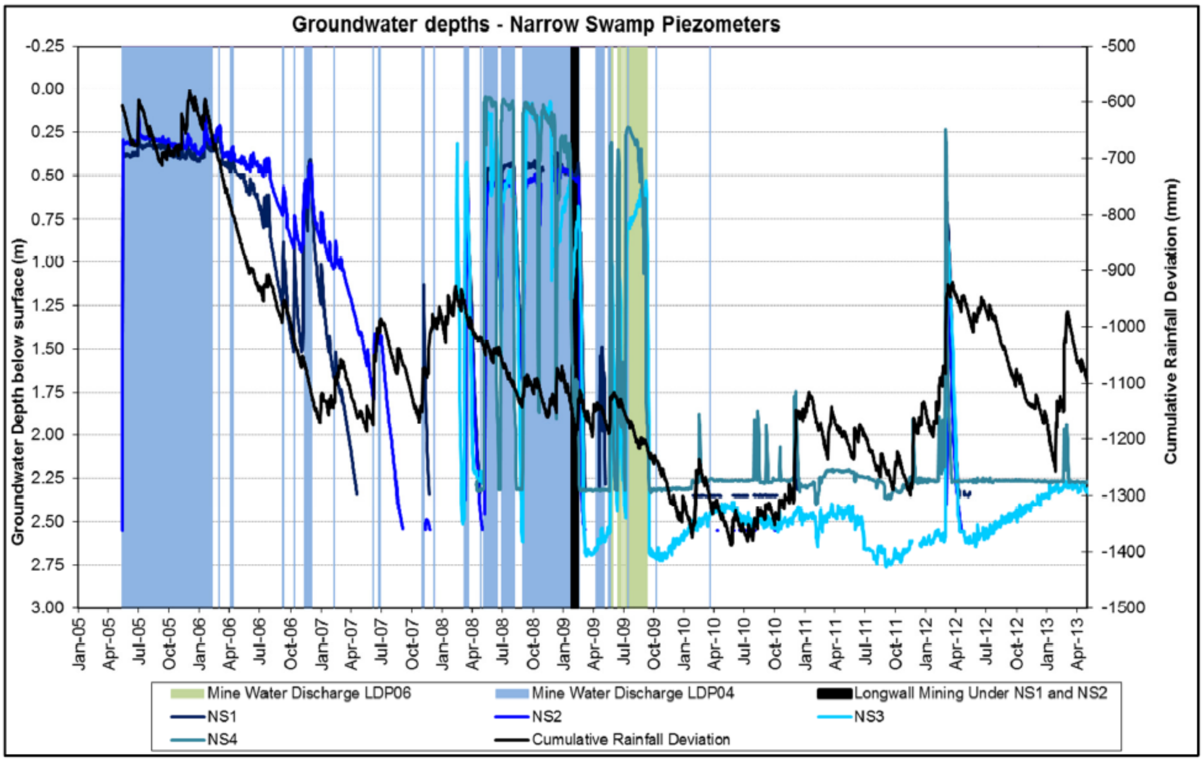


Figure 18 Hydrographs of the four piezometers in Narrow Swamp, together with timing of mine water discharges and cumulative rainfall deviation

7.6.6.1 Baal Bone Colliery

There are six piezometers installed in the vicinity of the Coxs River Swamp at Baal Bone Colliery. Of these, there are two installed into the swamp itself, BBP5 and BBP6. Piezometer BBP1 is identified in Figure 7.18 of CoA (2014) as being topographically up-gradient of piezometer BBP2 and both BBP1 and BBp2 reside within a mapped structural stress zone. Piezometer BBP3 lies approximately 1km southwest of LW29, again within a mapped structural stress zone. Piezometer BBP4 is located on the western side of the Coxs River Swamp.

As identified in CoA (2014), from Figure 7.19, a drop in groundwater level is observed in BBP1, BBP2 and BBP6 from July 2009. For BBP6, the monitoring piezometer is dry between October 2009 to July 2010. At BBP2, the groundwater level declines from ~952mAHD to a low of 945mAHD before recovering to 952mAHD in October 2010. The monitored water level at BBP1 shows a sharp decline until August 2009 and then abruptly stabilises and essentially remains static through to the end of the monitoring record. The water level response in BBP1 is unusual for two reasons, firstly the abrupt change in trend from declining to flat at about August/September 2009 that does not appear to correspond with a large recharge event, and secondly, the subdued magnitude of variation in response since that time. It is suspected that piezometer BBP1 has been damaged by ground deformation or the logger has malfunctioned. An alternative explanation is there has been a change in hydraulic properties induced by subsidence at that location, as proposed by CoA (2014).

In terms of the longer term impact of mining at Baal Bone Colliery on the Coxs River Swamp, groundwater level response in BBP2, located topographically down-gradient of BBP1, has recovered to pre-mining levels from the potential mining induced change in storage by July 2010, as has BBP, which is located in the swamp itself. At the end of the monitoring record, aside from BBP1, the absolute groundwater level of all monitoring piezometers equals or exceeds pre-mining levels and the magnitude of variation in level post-mining is indiscernible from pre-mining. If mining of LW29 lead to permanent decline in inflows to Coxs River Swamp then this would be reflected in observed water level response of BBP2 and BBP6, given they are topographically and hydrogeologically down-gradient. The temporary decline in observed water level in BBP2 is explained by a local change in storage, potentially limited to the structural stress zone, with no long term consequence.

8 Subsidence impacts on peat swamps and valleys

The case studies and analysis presented in Section 8 are from the Southern Coalfield of NSW and do not necessarily represent the scale of impacts in other Australian Coalfields for reasons related to geology, topography and in-situ stress regimes. Below are presented relevant data related to subsidence impacts to groundwater systems at Angus Place and Springvale mines in the Western Coalfield of NSW.

8.4 Impacts on peat swamps

The following case studies are provided as examples of monitoring results and interpretation in terms of longwall mining effects to swamps on the Newnes Plateau. They are provided in terms of the general headings in the IESC report.

General lowering of groundwater table

The following excerpt is copied from Corbett et al (2014), and describes monitoring results of groundwater levels between valleys in undermined areas of the Newnes Plateau.

"Water level data from ridges between valleys containing Newnes Plateau Shrub Swamps

Five water level monitoring boreholes were drilled in 2005 from the topographic ridges that lie between the valleys containing the following shrub swamps: West Wolgan Swamp, Narrow Swamp, East Wolgan Swamp, Sunnyside Swamp, Sunnyside East Swamp, Carne West Swamp and Gang Gang Swamp. Figure 14 is a plan showing the location of each of these bores (along the transect marked in red). Figure 15 shows the hydrographs of each of these boreholes since monitoring commenced in December 2005. The vertical lines on the hydrographs show the timing of mining beneath the borehole locations (in colours corresponding to the hydrographs). The black dashed line indicates the measured cumulative rainfall deviation. Figure 16 shows a cross section though the strata between the Lithgow Seam and the surface (along the transect indicated on Figure 14), including the location of mined longwall panels and the height of connected fracturing above them. The piezometer locations are also shown with the minimum and maximum standing water levels monitored at each location over the life of the monitoring installation. Monitoring of standing water levels at bores installed from the ridges between the shrub swamps indicates that there is no apparent change in response to mine subsidence and that observed minor fluctuations correspond with the cumulative rainfall deviation trend. This trend is the same for the ridges on either side of East Wolgan Swamp. The data indicates that the Burralow Formation (perched aquifer system) has not been significantly affected by mining over the period since 2005. The effect of the Mount York Claystone is evident in Figure 16, where mine design limits the height of connective fracturing to well below this stratigraphic unit. The objective of the mine design is to eliminate the potential for direct connectivity between the mine workings and the aquifer system above the Mt York Claystone."

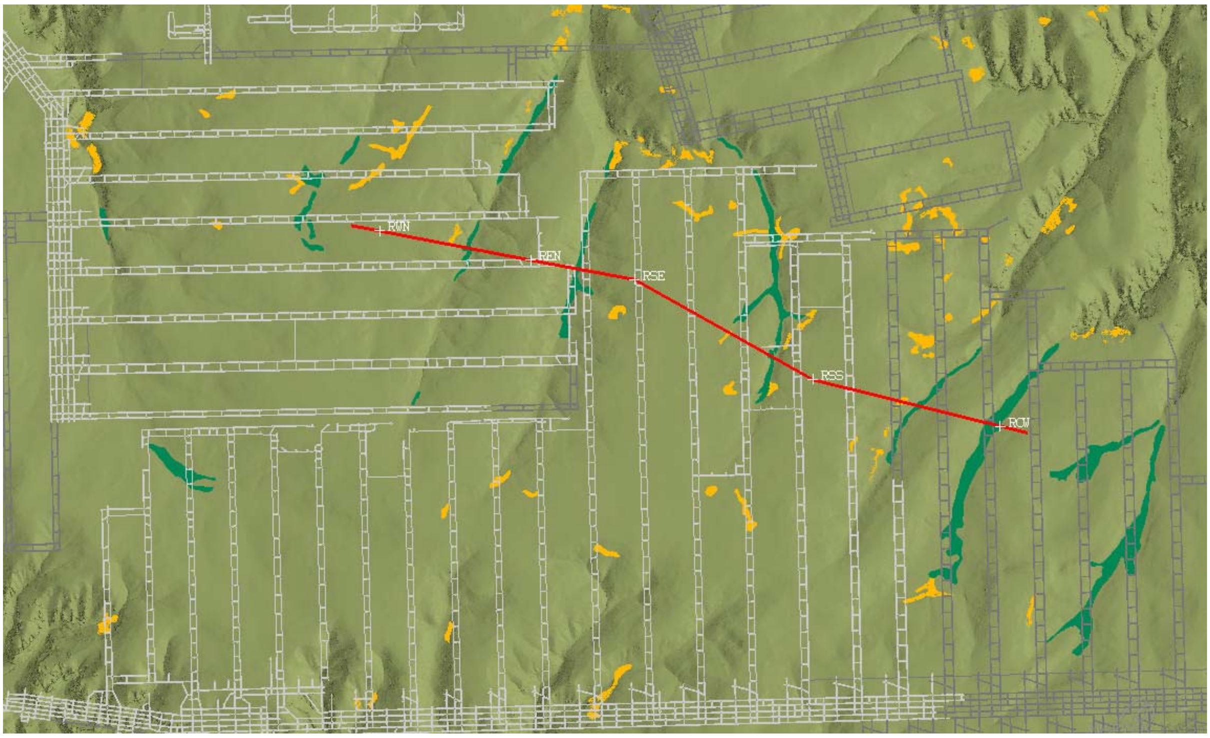


Figure 14 Plan view of transect through ridge water level monitoring bores

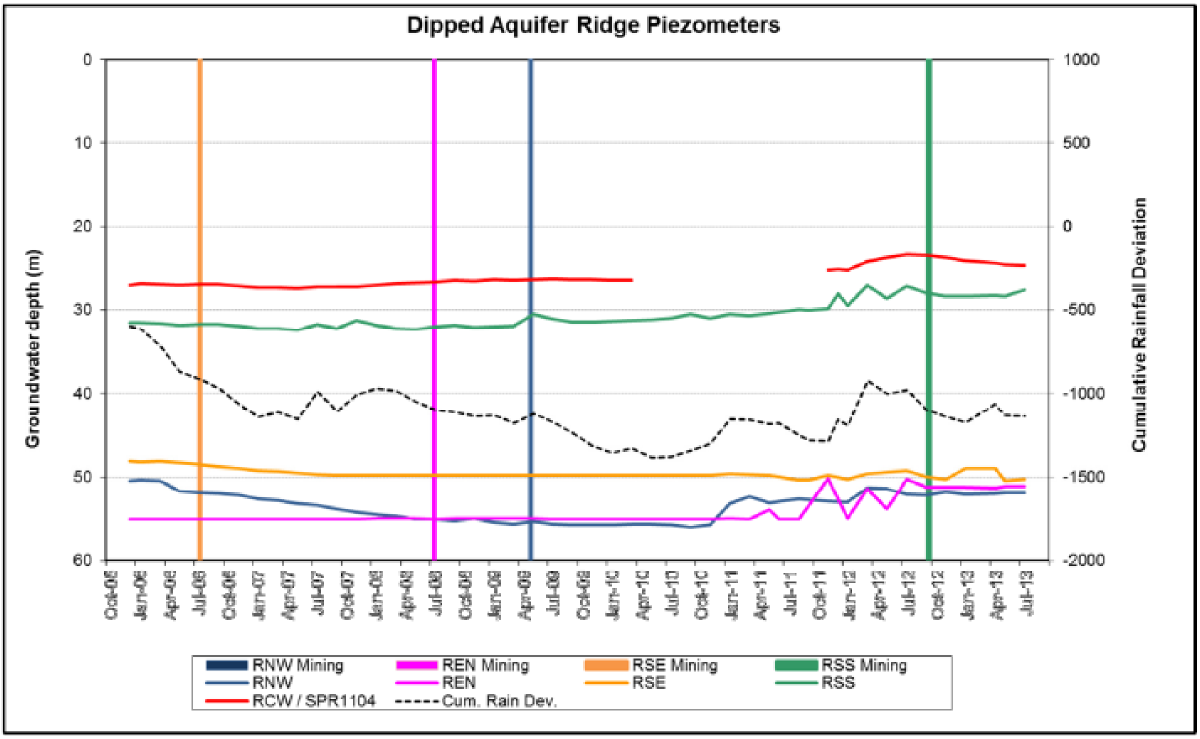


Figure 15 Hydrographs of ridge water level monitoring bores related to timing of mining

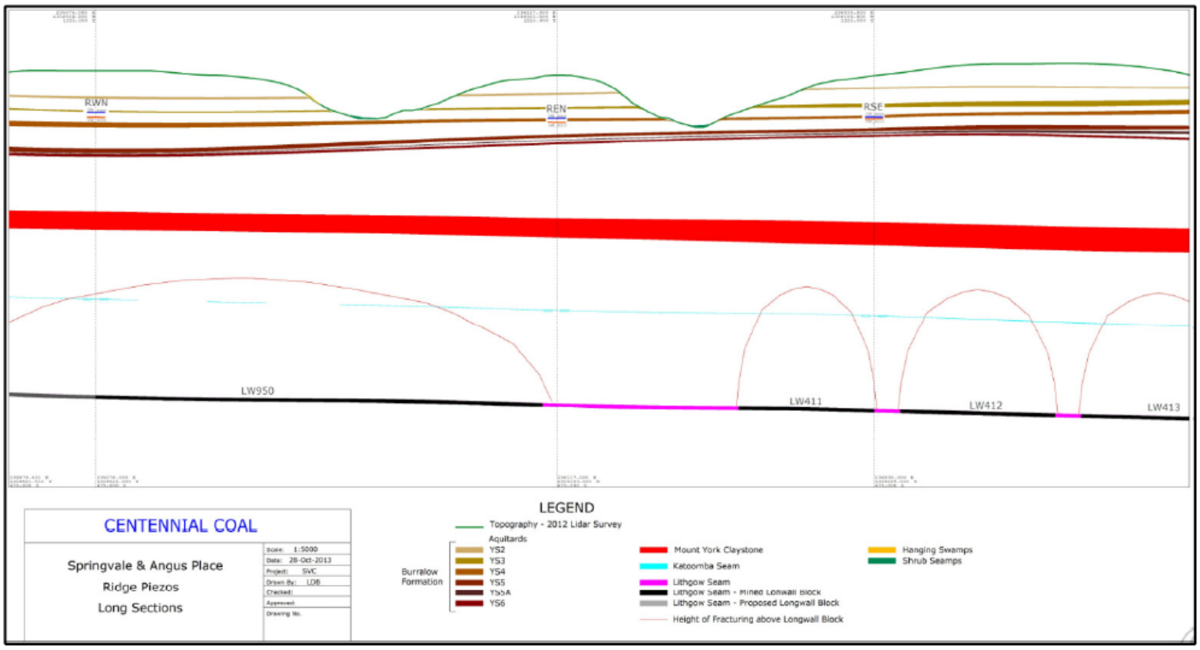


Figure 16 Cross-section through Narrow Swamp (left) and East Wolgan Swamp (right) showing topography, geology, mining areas and related height of connected fracturing

Fracturing of hydraulic control and local groundwater drawdown and Fracturing of underlying sandstone strata

The following excerpt is copied from Corbett et al (2014), and describes monitoring results of groundwater levels in West Wolgan Swamp and Sunnyside West Swamp on the Newnes Plateau.

"5. Longwall mining under Newnes Plateau Shrub Swamps

Monitoring of West Wolgan Swamp and Sunnyside West Swamp, which have been directly undermined by longwalls at Springvale and Angus Place, has not detected changes to swamp hydrology in response to mining related activities.

5.1 West Wolgan Swamp

West Wolgan Swamp was undermined by Angus Place Longwalls 930 and 940 in 2006 and 2007. The hydrographs on Figure 6 show four West Wolgan Swamp piezometers. Other data related to this case study are tabulated in Table 1. Figure 6 shows hydrographs of the four swamp piezometers installed at West Wolgan Swamp together with the time of longwall mining beneath the piezometers (indicated by the vertical black lines) and the Cumulative Rainfall Deviation (CRD) which is indicated by the black trendline. Note that there is a very strong correlation between the trendline of standing water level beneath the swamp and the CRD trendline for the four West Wolgan Swamp piezometers over the eight years of monitoring at this location. These data indicate that the swamp is periodically waterlogged (standing water levels respond to rainfall). The data also indicate that there has been no significant impact to swamp hydrology in response to longwall mining.

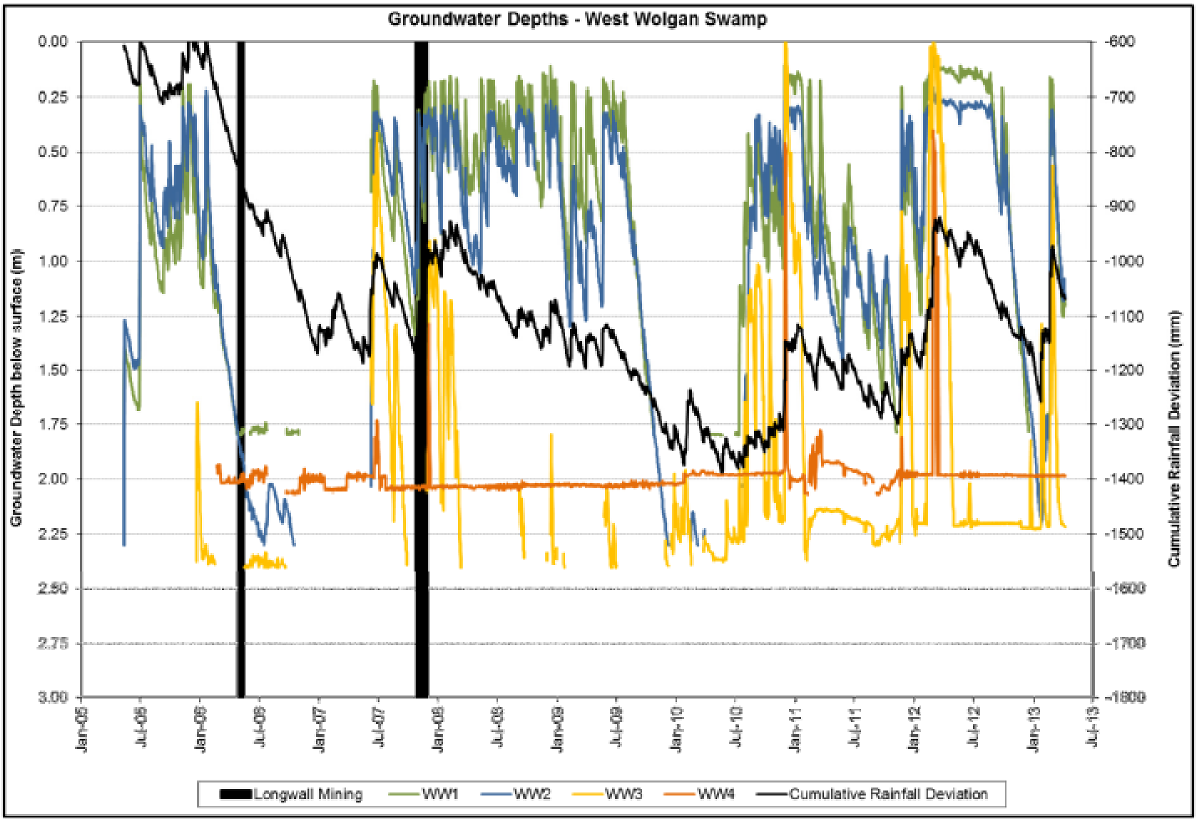


Figure 6 Hydrographs of West Wolgan Swamp piezometers

5.2 Sunnyside West Swamp

Sunnyside West Swamp was undermined by Springvale Longwalls 412 and 413 in 2009 and 2010. The hydrographs on Figure 7 show one Sunnyside West Swamp piezometer. Other data related to this case study is tabulated in Table 1. Figure 7 shows hydrographs of the swamp piezometer installed at Sunnyside West Swamp, together with the time of longwall mining adjacent to the piezometer. Mining within the angle of draw is indicated by the vertical grey lines and the Cumulative Rainfall Deviation (CRD) is indicated by the black trendline. Note that there is a very strong correlation between the trendline of standing water level beneath the swamp and the CRD trendline for the SW1 swamp piezometer over the six years of monitoring at this location. This data indicates that the swamp is periodically waterlogged (standing water levels respond to rainfall). The data also indicates that there have been no significant impacts to swamp hydrology in response to longwall mining.

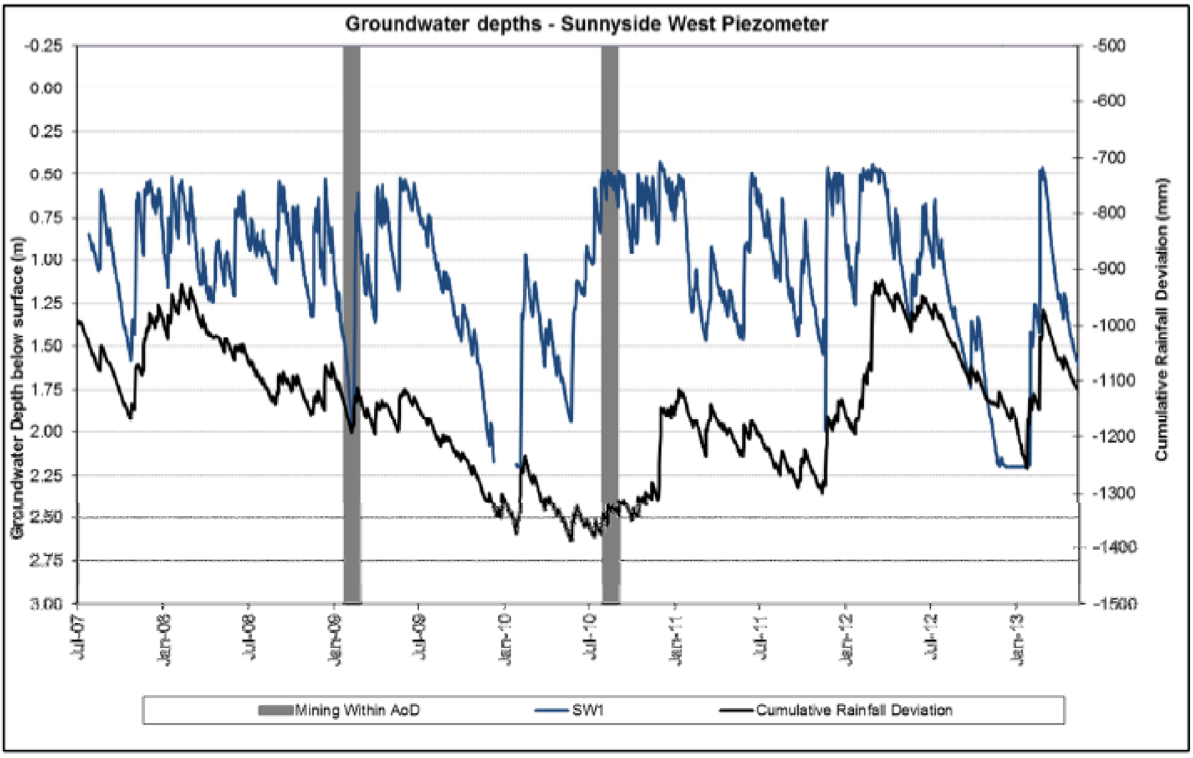


Figure 7 Hydrographs of Sunnyside West Swamp piezometer"

East Wolgan Swamp, Newnes Plateau (Western Coalfield)

Goldney et al (2010) concluded the following with regard to East Wolgan Swamp: 'Site 10 (East Wolgan Samples a and b): There has been a significant and catastrophic impact on this swamp, where ecological and geomorphic thresholds have been exceeded.
Shrub components had disappeared, a significant thickness of peat had been washed away and a heavy deposit of patchy sand of unknown origin was deposited over what remains of the swamp bed. We attributed this swamp's destruction principally to mine water discharge. However, we are unable to determine the role of longwall mining as a contributing factor since mine water discharge impacts have very likely masked the longwall mining impacts. We have determined that these impacts were very likely significant."

The findings of the Goldney et al (2010) report are supported by further research by University of Queensland. An extract from ACARP Project - C20046 Report (Monitoring surface condition of upland swamps subject to mining subsidence with very high-resolution imagery) is included below:

"Imagery collected by the small-UAS clearly show spatially discrete impacts on the vegetation within a shrub swamp associated with mine discharge flow channel (Fig. 21a,d), including slumping and scouring of peat and underlying sand (Fig. 21b) and trampling as a result of subsidence monitoring (Fig 21e). Mine water discharge rates were as high as 240l.sec-1 which, combined with a continuous slope of 1.53 degrees along the length of the shrub swamp (25m decline over 960m), resulted in a channel up to 28m wide. Vegetation outside the flow path of the mine associated water is still intact present (Fig. 22). As imagery was collected in mid-June (late autumn) condition is difficult to assess from imagery.

To allow classification of shrub swamp impacts a 15cm GSD orthophoto product was segmented using multi-resolution segmentation algorithm (eCognition Developer v8.7 scale 30, shape 20, compactness 30) resulting in recognizable features in the image. The segments were converted to polygon features and exported to ArcGIS (v10.1, ESRI, CA, U.S.A.). Manual interpretation was then applied to each segment to assign a class of shrub vegetation, bare ground/dead vegetation or other. Dead vegetation was characterized by high reflectance while bare peat in eroded areas was dark in colour. Shrub vegetation was defined by a combination of colour, surface elevation and texture. The imagery detected both live vegetation and areas of bare ground allowing the spatial extent of disturbance to be classified in two categories (Fig. 22). Waypoints (Fig. 22; e.g., 14 and 15) could be separated in two categories even if they had similar estimates of bare ground (10-25 percent), high estimates of leaf litter (55-80%), and differed only in low percentage cover estimates of vegetation. For example, waypoint 14 had cover from a common shrub swamp species Leptospermum obovatum (7%), while waypoint 15 had small low growing species, including Baumea rubiginosa (6%) and Centella asiatica (5%). In contrast to ground surveys, the classification process utilized surrounding information to quantify natural breaks in shrub swamp habitat and disturbed areas over a broad geographic area. The utility of small UAS can bridge the gap between data collected from the ground (local) and information captured using remote sensing tools (regional), to provide broad landform assessments covering key conservation concerns in protected and threatened ecosystems (Kerr and Ostrovsky, 2003; Turner et al., 2003).

The primary cause for vegetation loss appears to be the flow path of mine discharge water through the studied shrub swamp community. This conclusion is supported by the presence of shrub swamp species surrounding impacted areas caused by discharge events which ended in March 2010. The extensive areas of dead vegetation and bare ground remaining more than three years later demonstrates a sustained and extensive degradation of this community. UAS imagery combined with field survey demonstrates the capacity for assessment of impacts at an actionable scale by applying ground derived knowledge to spatial extents.
Manual delimitation of extent and context of spatially discrete impacts to vegetation is not necessarily quantitative but provides coverage of entire shrub swamp communities at a known date without impact to the community.

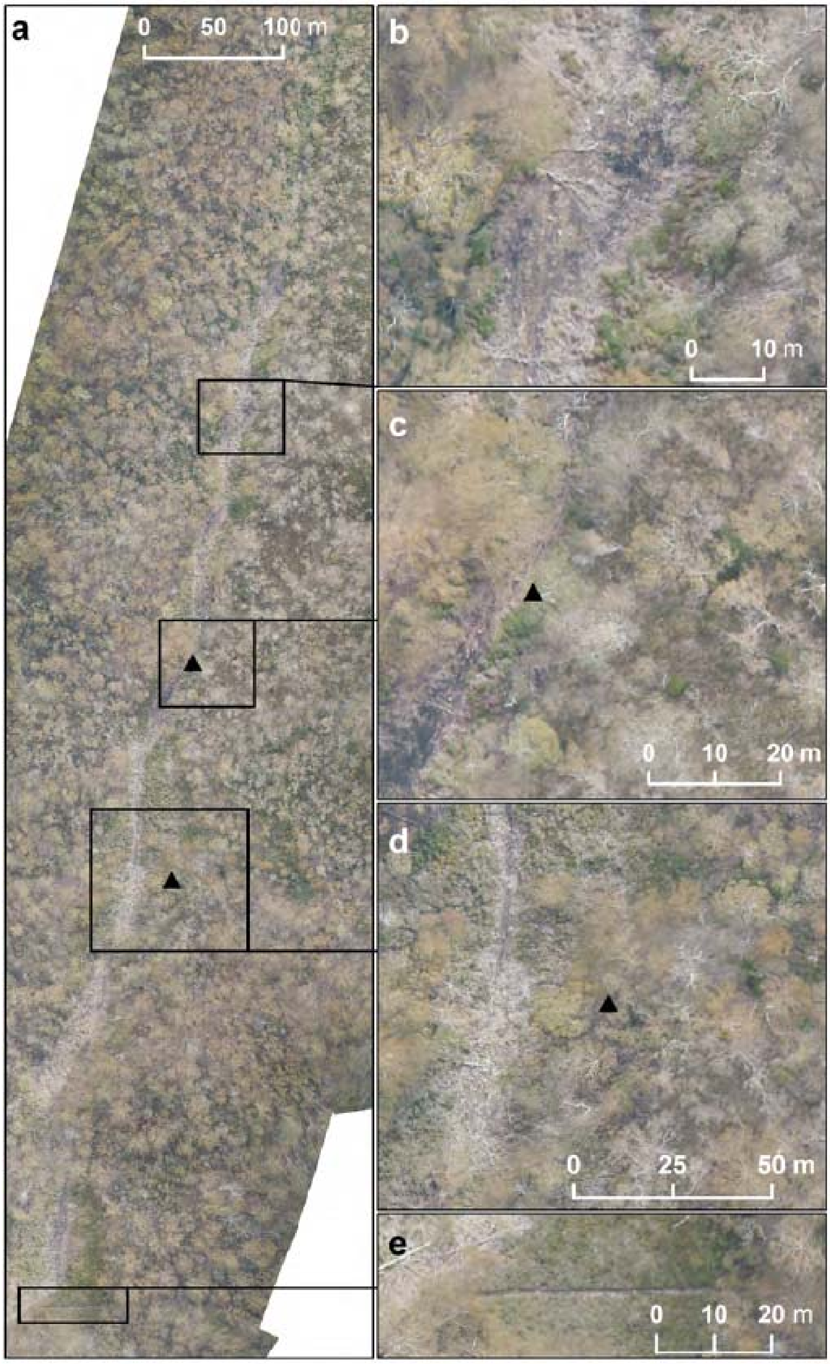


Figure 21: (a) UAS orthophoto mosaic of a shrub swamp collected in June 2013 showing outline of community as described in VISmap 2231 by New South Wales Office of Environment and Heritage. (b). Detail of slump towards downstream end of swamp caused by preferential flow of mine discharge water to below ground strata. (c) Detail image of location of monitoring plot EW01. (d) Detail image of location of EW02 monitoring plot. (e) Upstream end of shrub swamp community showing trampling impact of subsidence monitoring line.

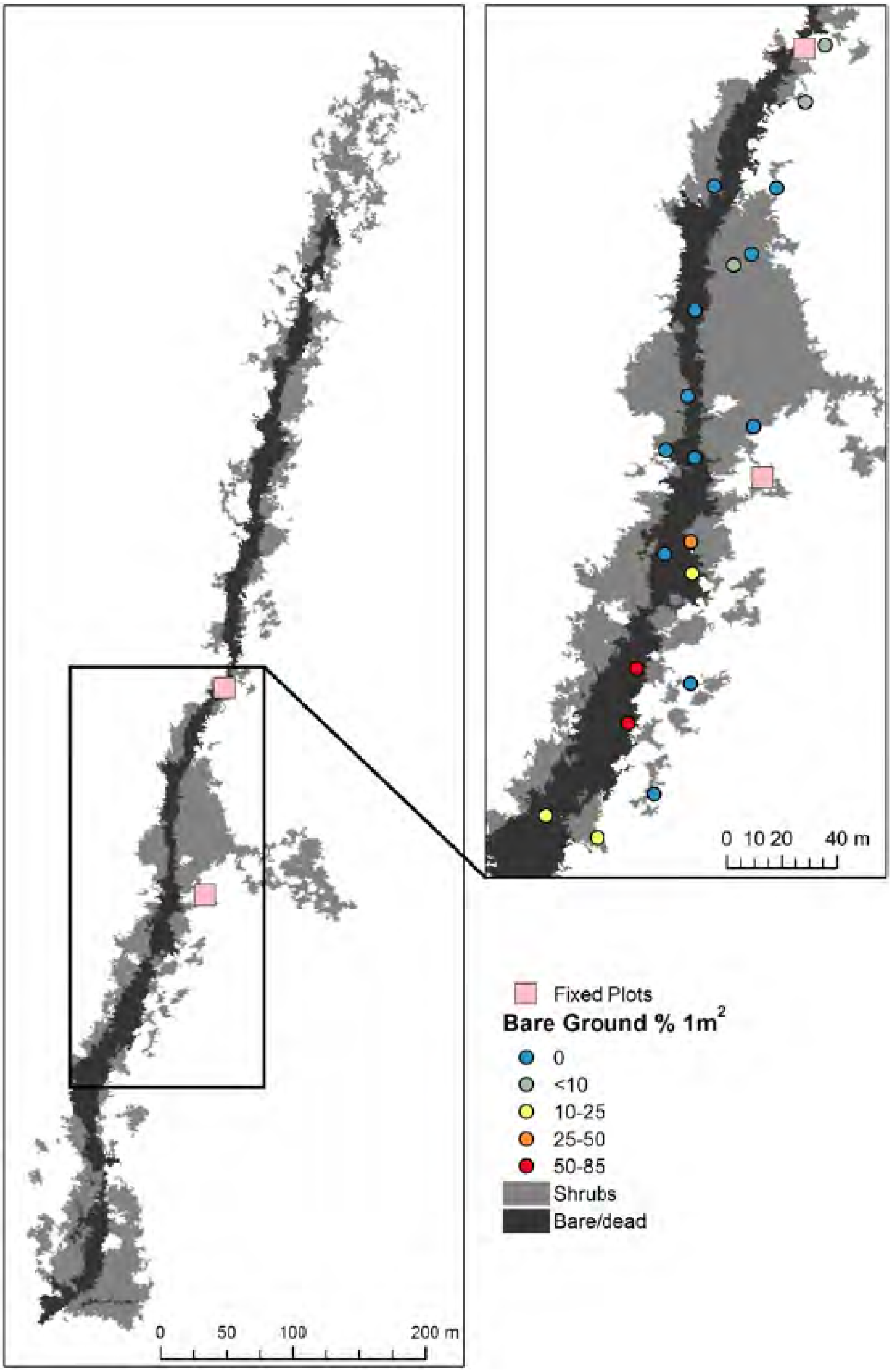


Figure 22: (main) Thematic map of a shrub swamp describing shrub vegetation and dead or bare ground. (inset) Area of mini-plot vegetation assessment ranked by proportion of bare ground identified in 1m2 plot."

The key co-incident factors related to cavity formation at East Wolgan Swamp (into which water discharge flowed and erosion / peat slumping occurred) are listed below:

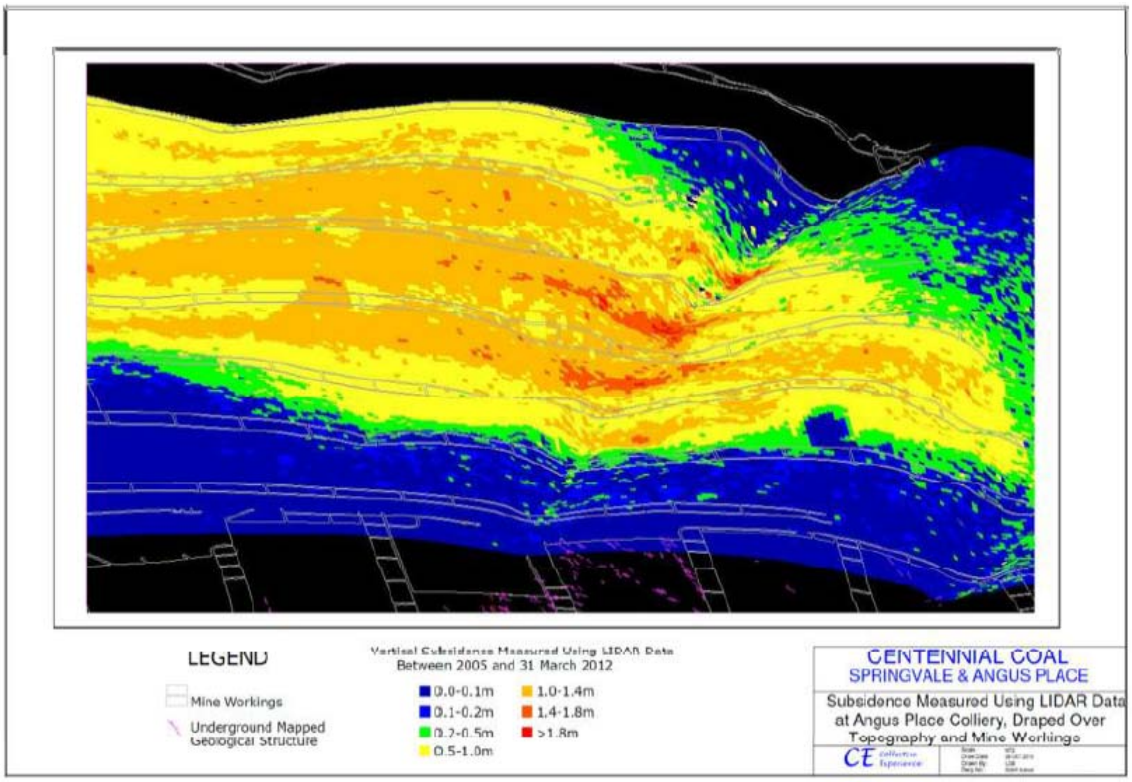
• licensed mine water discharge at rates of up to 12Ml/day;
• intersection of major geological fault structures;
• orientation of the longwall panel subparallel to the major structures;
• steepness and depth of East Wolgan Swamp valley at northern end;
• prevailing in-situ stress direction and magnitude (Springvale longwalls sub-perpendicular to principal horizontal stress direction);
• critical width longwall panel design;
• location of the geological structure close to the permanent barrier pillar (at cavity location); and
• interaction of Angus Place and Springvale mine workings and subsidence effects due to close proximity (at cavity location).

There is no data to validate the assertion of pre-mining flows. Evidence of return of natural flows to East Wolgan Swamp in the period since 2010 is discussed in EPBC Approval 2011/5949 Application to Allow Longwall Mining Under Temperate Highland Peat Swamps on Sandstone on the Newnes Plateau – Supplementary Data Volume 1 (2013).

Narrow Swamp, Newnes Plateau (Western Coalfield)

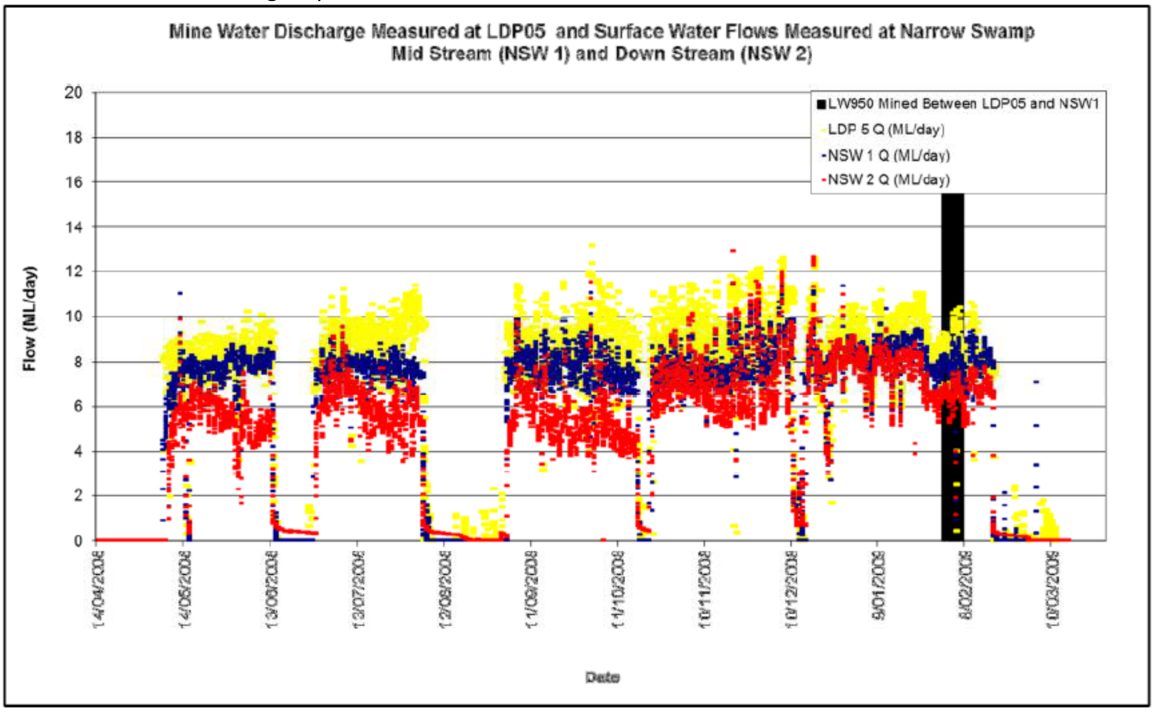
Narrow Swamp was undermined by Longwall 920 in March 2004, Longwall 940 in May 2007 and Longwall 950 in February 2009.

Subsidence monitoring from Angus Place A and F subsidence monitoring lines across the surface valleys associated with the Wolgan River Lineament (which contain Narrow Swamp and East Wolgan Swamp) has identified greater subsidence levels (up to 1.75m) compared to previous predictions. Further analysis of subsidence associated with major geological structures was conducted using LiDAR data (from pre-mining survey in 2005 compared with post-mining data from 2012). LiDAR subsidence data draped over topography from the Digital Terrain Model and mine workings shows subsidence levels in excess of previously predicted values (>1.4 m) can be clearly seen to be concentrated around the valley that contains Narrow Swamp (and identifies the western flank of the Wolgan River Lineament major geological structure zone). These elevated levels of subsidence did not cause changes to swamp hydrology at Narrow Swamp.



A graph of mine water discharge at Angus Place Colliery's Licensed Discharge Point 5 (upstream of Narrow Swamp) compared to two downstream flow monitoring stations at Narrow Swamp shows that there is a similarity of the trend of mine water discharge volumes compared to upstream and downstream flow monitoring (similar losses through the monitoring period from pre-mining to post-mining period). The monitoring data shows that the three longwall panels which have passed under Narrow Swamp during the period of licensed mine water discharge (i.e. Angus Place LW920 in 2004, LW940 in 2007 and LW950 in February 2009) have caused no significant loss of flow in the watercourse.

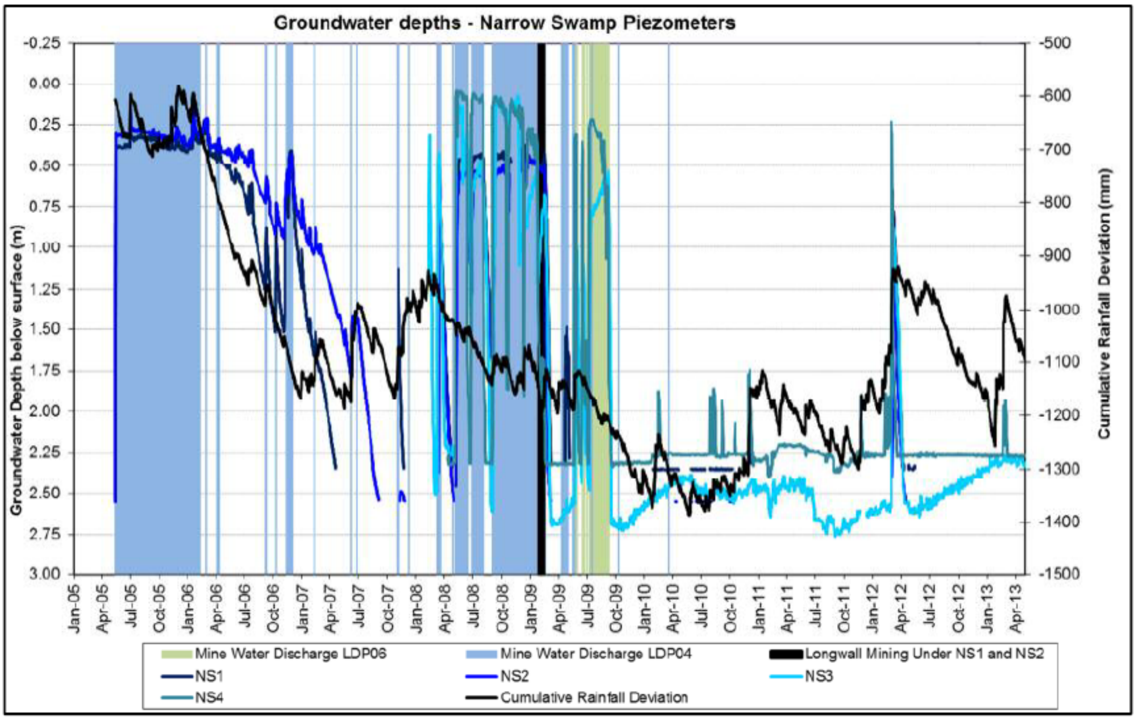
Flow monitoring carried out in this swamp prior to the extraction of LW950 has shown that approximately 91% of the discharge from Angus Place Colliery LDP005 reached a weir (NSW1) in the centre of the Narrow Swamp. After undermining by LW950 in February 2009, the monitoring indicated no change in the percentage of the discharge that reached NSW1. In addition, the percentage of discharge from NSW1, which reached a weir at the northern end of the Narrow Swamp (NSW2), was also 91%. Two longwall panels have undermined the Narrow Swamp in the section of the watercourse between NSW1 and NSW2, and so the flow monitoring indicates that the mining to date has not resulted in any significant cracking in the base of the swamp.



A hydrograph of Narrow Swamp piezometers NS1, NS2, NS3 and NS4 presented with the timing of mine water discharge and longwall mining as well as the cumulative rainfall deviation trend shows that the timing of mining was similar to that of the cessation of mine water discharges at LDP05 in February 2009, but the dominant influencing factor can be seen to be mine water discharges.

Following the cessation of mine water discharges, the hydrograph trends can be seen to be strongly influenced by rainfall. The standing water levels rise in response to rainfall events that are in excess of the long term average trends and fall in response to less than average rainfall trends. The responses are typically immediate and of short duration, indicated by the ‘spikes’ in the hydrograph trends.

When the data recorded during mine water discharged is removed, the same trend can be seen in the pre-mining baseline data. There is approximately 12 months pre-mining data (between March 2007 nd March 2008) that is not affected by mine water discharge, which clearly shows that the swamp was periodically waterlogged prior to mining. It remains periodically waterlogged following mining.



Goldney et al (2010) reported the following in terms of Narrow Swamp: 'Site 5 (Narrow Swamp South): A significantly impacted THPS which we attributed to a combination of mine discharge and sediment movement. Lack of baseline data pre-LWM made it difficult to assess this site. As argued above we have ruled out drought as a likely explanation. Any other minor impacts due to LWM would be completely masked by the greater impacts.

'Site 9 (Narrow Swamp North): There has been a significant and catastrophic impact on this swamp, where ecological and geomorphic thresholds have been exceeded. Based on snagged clumps of vegetation we were able to ascertain that at times the depth of water has reached up to 1 m across a 75 m wide bed. That represents a very considerable flow and one potentially very destructive. Shrub components had disappeared (no mean feat), a significant thickness of peat had been washed away and a heavy deposit of patchy sand of unknown origin was deposited over what remains of the swamp bed. We attributed this swamp's destruction to mine water discharge, since this appears to be the only viable explanation.'.

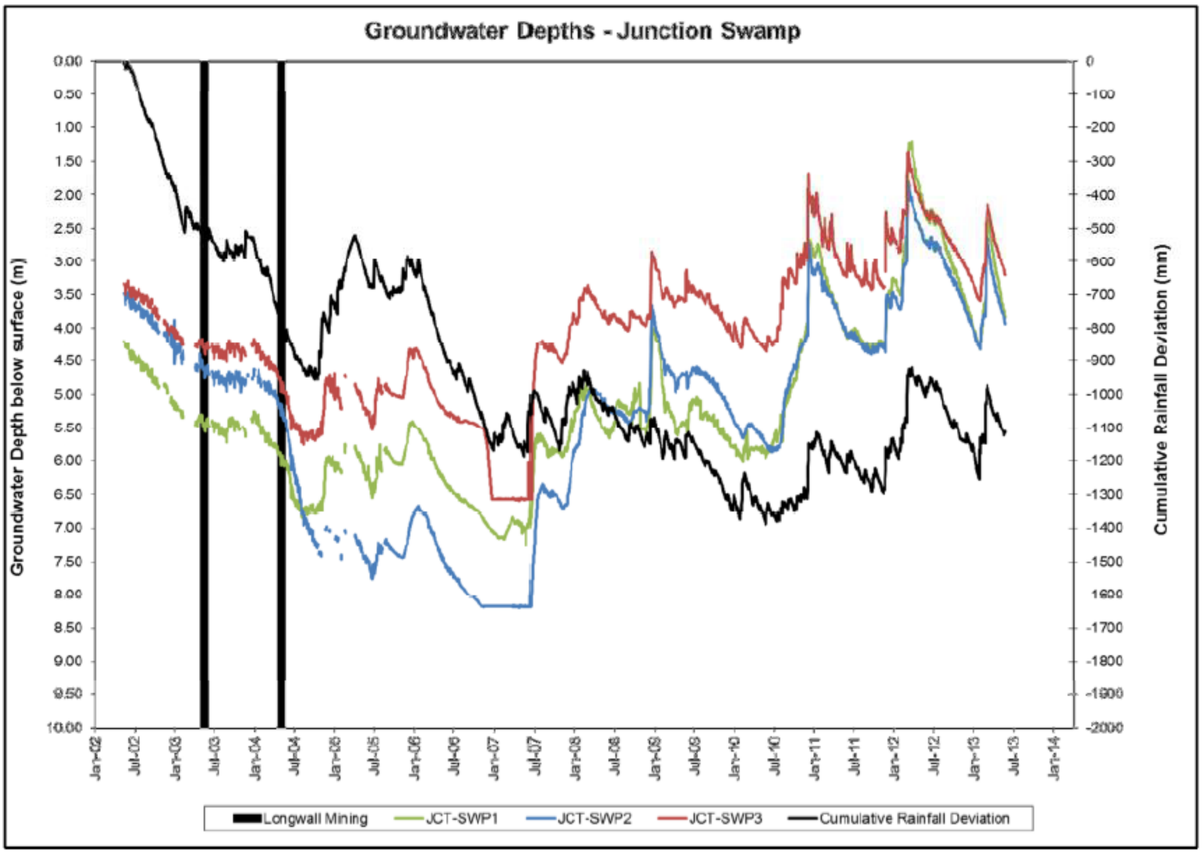
OEH approved the undertaking restoration actions at East Wolgan Swamp and Narrow Swamp, and issued a certificate under Section 95 of the TSC Act on 25 November 2013. Approved remediation works have been carried out since January 2014 in East Wolgan Swamp and will also be conducted in 2014 in Narrow Swamp.

Junction Swamp, Newnes Plateau (Western Coalfield)

Surface water flow from the swamp was unaffected by LW 408, but ceased after the passage of this panel due to the ongoing rainfall residual mass deficit and the reduced downstream groundwater gradient. The flow from the swamp did not recommence until December 2010, even though the downstream groundwater gradient was above the threshold gradient for a period of two months. This suggests that there has been some tilting of the unconfined aquifer that has possibly changed the subsurface flow direction.

There is a very strong correlation between the trendlines of standing water levels beneath the swamp and the cumulative rainfall deviation trendline for all swamp piezometers over the eleven years of monitoring at this location.

This data indicates that the swamp is periodically waterlogged (standing water levels respond to rainfall). The data also indicates that there has been no significant vertical drainage of groundwater from the aquifer supporting the swamp (i.e. no significant impacts to swamp hydrology) in response to longwall mining as the standing water levels now are similar to pre-mining levels (Corbett et al 2014).



Kangaroo Creek Swamp

Kangaroo Creek Dam monitoring conducted in the period 2009 -2012 shows that the dam has contained water on 22 out of 24 monitoring occasions (conducted monthly or bi-monthly). This dam lies downstream of Kangaroo Creek (upper) Swamp, which was undermined by Springvale Longwall 401 in 1996.

In the Save Our Swamps - Newnes Plateau Shrub Swamp Aerial Assessment Project Report (2010), Kangaroo Creek Swamp (upper) was assessed to be in "Good" condition (no visible impact) in all categories (channelisation, desiccation, erosion, swamp crossing, access track, blackberry) except pine wildings, where a minor impact assessment was made. This swamp was undermined by Springvale Mine Longwall 401 in 1996. In the absence of data, this information suggests either:

1. No significant impact from longwall mining

2. Recovery of the swamp system over time

Either way, no long term impacts from longwall mining were detected.

The photo above is the mapped Kangaroo Creek (mid) Swamp in July 2013. Flora monitoring at Kangaroo Creek Shrub Swamp indicated no trend of decreasing condition and that species abundance is not declining.

Kangaroo Creek (Mid) Swamp

Figure 1 shows Kangaroo Creek Piezometer Monitoring Data (KC1 and KC2) and Cumulative Rainfall Deviation over the period between 2006 and 2014. It shows hydrographs of the swamp piezometers installed at Kangaroo Creek Swamp, together with the cumulative rainfall deviation, which is indicated by the black trendline. Note that there is a very strong correlation between the trendline of standing water level beneath the swamp and the cumulative rainfall deviation trendline for the KC2 piezometer over the eight years of monitoring at this location. This data indicated that the swamp is periodically waterlogged at this location (standing water levels respond to rainfall). The data also indicates that there have been no significant impacts to swamp hydrology in response to longwall mining at KC2. Groundwater levels at KC1 appear to have been affected by the longwall mining of Angus Place LW940, which was below the lower reaches of the swamp, as there was a sudden reduction in groundwater levels in June 2008, unrelated to rainfall.

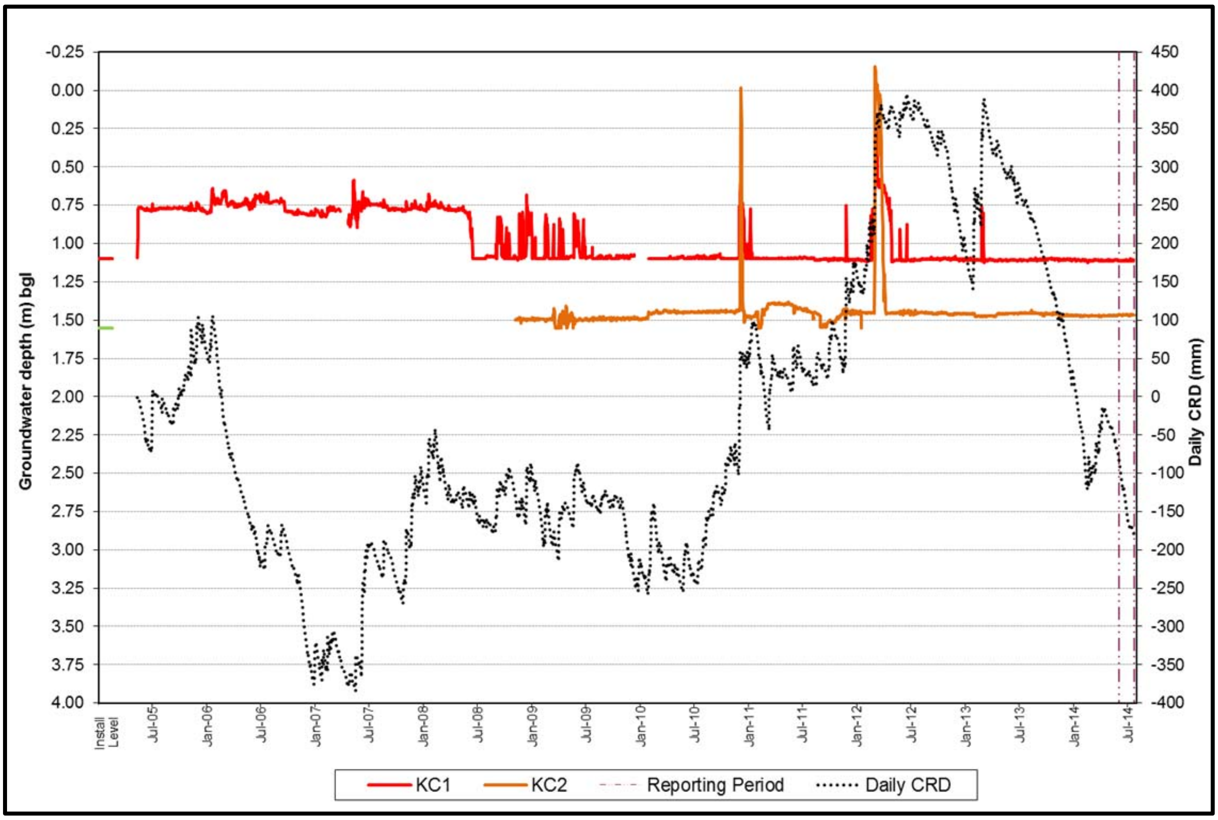


Figure 1 – Kangaroo Creek Piezometer Monitoring Data and Cumulative Rainfall Deviation

Kangaroo Creek Shrub Swamp is fed by a perennial spring. This spring, which in turn is fed by the aquifer-aquitard systems within the Burralow Formation, was unaffected by mining and the creek remained permanently wet below the spring. This, together with the presence of healthy hanging swamps along the valley walls surrounding Kangaroo Creek Shrub Swamp, indicates that the water supply from the spring and valley wall seepage has not been interrupted by longwall mining and that groundwater inputs to the swamp hydrological system remain intact.

Plate 5 **(2013) Spring (left) and hanging swamp (right) at Kangaroo Creek Shrub Swamp**

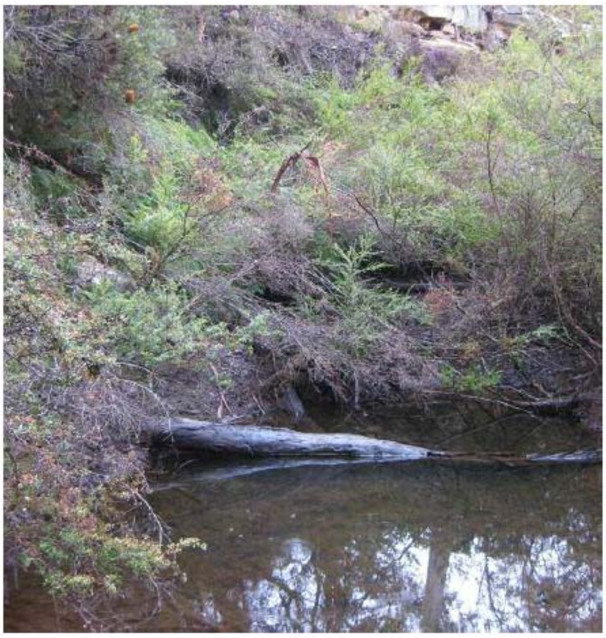


Plate 6 **(2013) Waterhole upstream of Kangaroo Creek Shrub Swamp (left) and Kangaroo Creek Shrub Swamp (right)**

Plates 5 and 6 illustrate that the Burralow Formation aquifer/ aquitard system has not been affected by longwall mining, as evidenced by the Spring, Waterhole and Hanging Swamps surrounding Kangaroo Creek Shrub Swamp. Flora monitoring at Kangaroo Creek Shrub Swamp indicated no trend of decreasing condition and that species abundance is not declining. The available evidence indicates that underground mining has not resulted in any negative effects on Kangaroo Creek Shrub Swamp. Investigation of mining related impacts at Kangaroo Creek Swamp showed that high levels of differential subsidence movements were measured, including strains (up to 6 mm/m tensile and 26mm/m compressive) and tilts (up to 13mm/m). The reasons for the high levels of differential movement are as follows.

• Mine Design: Longwall Void Width (w) to Depth of Cover (H) ratio of 0.94 to 1.04 (Critical Width). NB These are the highest w/H ratios of any of the longwalls at Angus Place and Springvale.

• Major Geological Structure Zone: Kangaroo Creek is located within the Kangaroo Creek Lineament, which has been identified as a 'Type 1' Geological Structure Zone.

• Topography: Valley slope angles >18 degrees.

• Location of Kangaroo Creek Swamp being near the western end of Angus Place Colliery's LW940 and LW950 (adjacent to permanent barrier pillar).

Investigations have concluded that for the Kangaroo Creek Swamp, the presence of major fault zones and incised valleys in combination with mine design factors caused localised hydrological impacts.

The CRD trend also helps to understand changes in presence and flows of surface water. Since March 2013, there has been rainfall deficit in excess of 550mm (a significant proportion of the annual average Newnes Plateau rainfall of 1092mm). The rainfall deficit in the past 18 months is greater than any period since the end of 2005 (including the drought of 2006-2007). This helps to explain the lack of surface water present in recent monitoring periods e.g. February, June and August 2014 (and photos taken in May 2014 for the purpose of community submissions to the Angus Place and Springvale Mine Extension Project EISs). The photo used in the EIS was taken on 16 July 2013 and can be seen to be consistent with monitoring photos in prior and subsequent periods. In the five years of photographic monitoring since the measured reduction in groundwater levels at KC1 piezometer, there have only been three monitoring events out of 41 monthly or bi-monthly monitoring events where water has not been present in the waterhole (February 2014, June 2014 and August 2014). On these occasions groundwater seeps from upstream can still be seen to be present.

8.4.3.1 Fracturing of underlying sandstone base

Centennial is in agreement with the following statement copied from pp164 of the IESC report, as it is consistent with monitoring data from the Newnes Plateau.

"In general, when the overburden depth to the mining horizon is greater than about 400 m, maximum systematic tilts are expected to be less than 5 mm/m and systematic strains are expected to be less than 1 to 2 mm/m. At these levels, surface cracking and changes in gradient are likely to be imperceptible and impacts associated with mine subsidence are expected to be slight."

9 Subsidence models and prediction methods

The subsidence prediction methods identified in Section 9 are accepted by Centennial, however, it is observed that the majority of the research work has been conducted in the Southern Coalfield and that differences in geology, topography and stress regimes result in different behaviour in other coalfields. Details are discussed in Section 5 (above).

9.1 Introduction

The use of the Tametta (2012) model for groundwater effect of longwall mining is discussed in Section 7 (above).

9.5 Prediction of mining impacts on peat swamps

Centennial has used industry best practice methods to predict subsidence and groundwater effects of longwall mining under the Newnes Plateau, detailed in Section 7 and 8 (above). Investigations into historical impacts of mining related activities to THPSS on the Newnes Plateau have identified causative factors. Future planned mining activities mitigate identified causative factors.

10 Monitoring

Centennial agrees with methods nominated for monitoring of subsidence and groundwater and has used all of the techniques nominated with the exception of the following:

- Interferometric Synthetic Aperture Radar (InSAR) – due to issues related to resolution of vertical and horizontal movement vectors. This may become a viable method in the future.
- Borehole inclinometers – lateral strata movement has been measured using conventional survey technicques.

- Time domain reflectometry – as this is related monitoring infrastructure and not environmental effects.

11 Management strategies

11.4 Setback or buffer distances

Springvale's EPBC2011/5949 approval required buffer zones to be defined. Initially these were approved based on 26.5 degree angle of draw. Subsequently, based on the information gained from extensive studies conducted by Centennial Coal, the buffer zones were were modified for the purposes of EPBC2011/5949 approval for Springvale Mine, when permission to mine within approved buffer zones and directly mine beneath THPSS on the Newnes Plateau was granted by DotE on 21 October 2013.

11.4.1.1 General guidelines

The magnitudes of 0.5 mm/m tensile and 2 mm/m compressive are guides to the potential for fracturing in bedrock due to conventional subsidence movements. The basis for these values is that fracturing is rarely seen in the Southern Coalfield as a result of conventional subsidence movements, i.e. away from valley bases, where the maximum ground strains are typically in this order. These strain values should not be used as an indicator of the potential for environmental consequence (i.e. impact) on surface features, as fractures at these magnitudes tend to be minor and isolated. This is supported by the PAC review (2010) for the Bulli Seam Operations which stated that *"As already noted, it is based on MSEC's advice that fracturing of sandstone has generally been observed in the Southern Coalfield once systematic compressive strain has exceeded 2 mm/m. This concurs with the Panel's experience. However, based on the Panel's own inquiries, field inspections and experience, total diversion of surface flow into a subsidence-induced subsurface fracture system requires higher total compressive strains that are very dependent on geological factors such as strata composition, thickness and bedding laminations. Limited measurements suggest a threshold total compressive strain[156] value for total diversion of flow in sandstone environments of the order of 7 mm/m, however the database is too small to be reliable at this point in time."*

11.4.1.2 Additional considerations for valley infill swamps and hanging swamps

An extensive groundwater monitoring network has been established on the Newnes Plateau, with monitoring commencing in 2002.

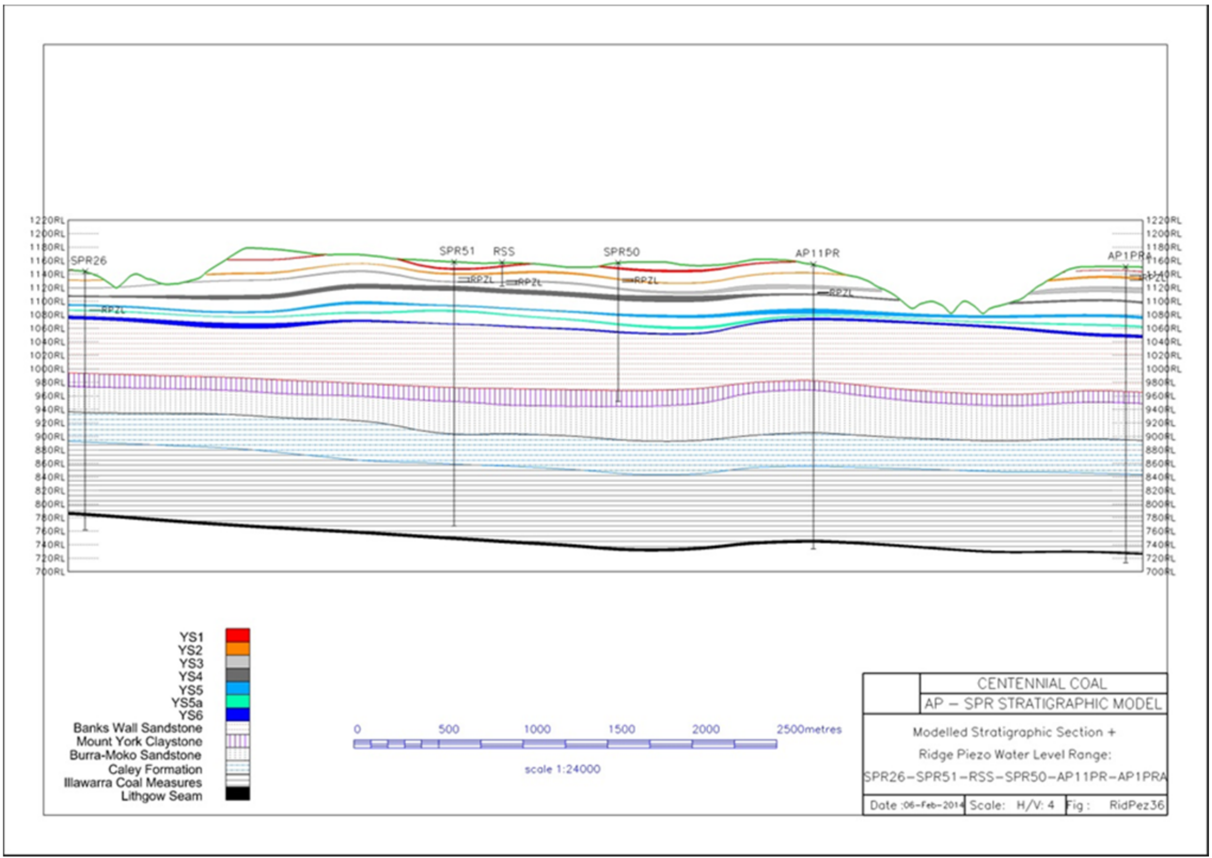
Groundwater monitoring has been used in mining areas at Springvale and Angus Place mines since 2005 (e.g.Junction Swamp, Kangaroo Creek Swamp, West Wolgan Swamp, Narrow Swamp, East Wolgan Swamp, Sunnyside Swamp, Sunnyside East Swamp, Carne West Swamp and Gang Gang Swamp). Each of these swamps has multiple piezometers installed within the swamp and aquifer piezometers installed in the ridges between the swamps.

All other Newnes Plateau Shrub Swamps (NPSS) in the Angus Place and Springvale Mine Extension Project areas have at least one piezometer installed in them, with a minimum of two years baseline data.

Due to potential impacts to THPSS associated with using truck mounted drill rigs required to drill into the rock underlying the swamps (to allow for installation of multi-level piezometers), it was decided to use a combination of piezometers as follows:

- Swamp Piezometers, which monitor water level every three hours using a datalogger and are installed in hand augered holes within the peat / soil profile of the swamp (bottom of monitoring bore at or near bedrock)
- Aquifer Piezometers, which monitor water levels every three hours using a datalogger and are installed in boreholes drilled from the top of the ridges adjacent to Newnes Plateau Shrub Swamps (NPSS) using truck mounted drill rigs. They monitor standing water levels in the Burralow Formation aquifers (AQ5 and AQ6), which supply water through the valley floor / wall seepage mechanism.
- Multi-Level Vibrating Wire Piezometers, which monitor water pressure at different levels within the strata every two hours using a datalogger and are installed in boreholes drilled from the top of the ridges adjacent to Newnes Plateau Shrub Swamps (NPSS) using truck mounted drill rigs. They monitor groundwater pressure in aquifers between the surface and the Lithgow Seam (AQ1 to AQ6),

The close proximity of instruments in the piezometer network has been used in conjunction with a three dimensional topographic and stratigraphic model to enable an understanding of groundwater levels and their interaction with swamps. The figure below shows a cross section of topography, stratigraphy, groundwater levels along a transect between a number of monitoring bores. EIS Section 2.6.2.6 Figures 2.24 to 2.26 shows a similar transect between ridge piezometer bores installed in 2005.



Despite the statement CoA (2014) “Hanging swamps are expected to be more vulnerable to subsidence impacts than headwater and valley infill swamps, due to their location in steep topography where natural stresses are highest”, there are no documented cases of impacts to Newnes Plateau Hanging Swamps in the history of mining at Angus Place and Springvale since 1979.

11.4.1.3 Monitoring

The peer reviewed THPSS Monitoring and Management Plan (THPSS MMP) which has been approved by the Federal Department of the Environment (DotE) is aligned with **Before-After/Control-Impact (BACI)** design. It incorporates monitoring of subsidence, groundwater levels and quality, surface water flows and quality, flora and fauna. It is based on studies of individual swamp geology, hydrogeology and hydrology in the EPBC2011/5949 Controlled Action Area. A similar baseline characterisation and monitoring approach has been adopted for the following swamps in the Angus Place and Springvale Mine Extension Project areas: Trail 6 Swamp, Twin Gully Swamp, Tri-Star Swamp, Crocodile Swamp, Carne West Swamp, Gang Gang Southwest Swamp, Gang Gang East Swamp, Carne Central Swamp, Barrier Swamp, Nine Mile Swamp, Pine Swamp, Upper Pine Swamp, Paddy’s Creek Swamp, Paddy’s Creek East Swamp, Marrangaroo Swamp.

11.4.1.4 Trigger action response plans

The THPSS Monitoring and Management Plan (THPSS MMP) is based on a **Before-After/Control-Impact (BACI)** design and incorporates TARPs with triggers for subsidence, groundwater levels and quality, surface water flows and quality and flora.

11.5 Remediation

As indicated in section 2.6.2.6 of the EIS, OEH approved the undertaking restoration actions at East Wolgan Swamp, and issued a certificate under Section 95 of the TSC Act on 25 November 2013. Approved remediation works have been carried out since January 2014 and are ongoing.

12 Future work

Centennial has conducted extensive investigations in order to determine the hydrogeological characteristics of THPSS’. The purpose of these investigations was to ascertain the coincident characteristics which lead to THPSS formation and to understand the sensitivity of those characteristics to mine subsidence behaviour.

Centennial Coal has Conducted extensive investigations to determine the factors which caused historical impacts at East Wolgan Swamp, Kangaroo Creek Swamp, Narrow Swamp and Junction Swamp.

The results of investigations have allowed Centennial Coal to understand the multiple co-incident factors that have led to historical mining-related impacts and implement management practices to ensure mining impacts will be avoided in the future or can be managed appropriately.

Mine water management and mine design were the key controllable factors by Centennial management and Springvale’s mine design was changed in 2011 following the investigations in order to mitigate potential impacts to THPSS on the Newnes Plateau.

Since the investigations were conducted, Centennial Coal has been proactive in avoiding or minimising potential subsidence impacts to the geodiversity and biodiversity of the mining area using a comprehensive multi-disciplinary risk-based approach to mine planning and mine design in conjunction with a rigorous monitoring program.

The monitoring techniques employed are wide-ranging and complementary and the combined results provide insights into roles that factors such as geology, hydrogeology, topography play in THPSS formation and the effects of mine subsidence on THPSS.

The extensive monitoring and investigation process employed by Centennial Coal, which utilised multiple lines of evidence to support the management decisions, created the foundations for an adaptive management outcome. Mine design changes (in the form of reduced longwall void width and increased chain pillar width) were implemented in 2011 and are planned in all MEP areas where NPSS are present.

The following shows how Centennial has responded to the points raised in Section 12 of the IESC report.

- Determine how peat swamps fail due to being undermined, based on field measurements of ground deformations, groundwater levels, and changes in flora and fauna in the undermined swamp and using a control swamp. Detailed case studies have been conducted on West Wolgan Swamp, Sunnyside West Swamp, Sunnyside Swamp, East Wolgan Swamp, Kangaroo Creek Swamp, Narrow Swamp and Junction Swamp on the Newnes Plateau, in terms of geology, hydrogeology, hydrology, ground deformations, groundwater levels, and changes in flora and fauna. Control swamps used for comparison were Trail 6 Swamp, Twin Gully Swamp, Tri-Star Swamp, Crocodile Swamp, Carne West Swamp, Gang Gang Southwest Swamp, Gang Gang East Swamp, Carne Central Swamp, Barrier Swamp, Nine Mile Swamp, Pine Swamp, Upper Pine Swamp, Paddy's Creek Swamp, Paddy's Creek East Swamp, Marrangaroo Swamp.
- Study damaged swamps. Detailed studies have been conducted at East Wolgan Swamp, Kangaroo Creek Swamp, Narrow Swamp and Junction Swamp on the Newnes Plateau.
- Perform trial remediation projects on damaged swamps and monitor the swamp to assess if improvement of the swamp occurs over time. Remediation work is currently underway at East Wolgan Swamp.
- Improve predictive capability to assess impacts on peat swamps based on a revised understanding of deformation and peat swamp function. Predictive modelling of mine subsidence effects to groundwater systems associated with the THPSS on the Newnes Plateau has been conducted by CSIRO and DgS as described in Sections 7 and 8 above
- Monitor, simultaneously, groundwater levels in a peat swamp and the sealing layer beneath a swamp before, during and after mining. Monitoring ground movement (strain) must also be conducted simultaneously with the water-level monitoring, so that any relationship between hydraulic head behaviour and ground deformation can be investigated.
- Monitor the long-term hydraulic head behaviour in the peat following mining (this can be conducted at some of the swamps analysed in this report). Monitoring has been conducted of hydraulic head behaviour at THPSS on the Newnes Plateau for up to 10 years post-mining.

- Monitor long-term changes in groundwater levels and chemistry to develop a database for the coalfields for comparison with predictive models. Monitoring has been conducted of groundwater levels and chemistry THPSS on the Newnes Plateau for up to 8 years post-mining.
- Modify the preliminary guidelines for setback criteria, based on the information gained from the above activities. Setback criteria, based on the information gained from the above activities, were modified for the purposes of EPBC2011/5949 approval for Springvale Mine, when permission to mine within approved buffer zones and directly mine beneath THPSS on the Newnes Plateau was granted by DotE on 21 October 2013.

Appendix A-1

It is noted that all case studies presented in Appendix A-1 are from the Southern Coalfield.

Appendix A-2

It is noted that all case studies presented in Appendix A-2 are from the Southern Coalfield.

Appendix B

The work done by CSIRO in "Hydrological response to longwall mining—ACARP project C14033" built upon and superseded the models identified in the literature survey referenced in Table 1.

Appendix C

It is noted that the example of application of general guidelines using the ACARP1 method IN Appendix C is an example from the Southern Coalfield and that differences in geology, topography and stress regimes result in different behaviour in other coalfields. Case studies of undermining THPSS in the Western Coalfield experiences on the Newnes Plateau are discussed in Section 7and 8 (above).

Appendix D

The extract presented in Appendix D is generalised and does not reflect measured response of groundwater systems to subsidence in the Western Coalfield experiences on the Newnes Plateau are discussed in Section 7and 8 (above).

References

A number of relevant publicly available references were not used in the preparation of these reports. These include:

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Corbett, P., White, E., Kirsch, B., (2014) Case Studies of Groundwater Response to Mine Subsidence in the Western Coalfields of NSW

Brownstein, G., Johns, C., Blick, R., Fletcher, A., Erskine, P., (2014) Flora monitoring methods for Newnes Plateau Shrub Swamps and Hanging Swamps

PAC (2010). *Bulli Seam Operations - PAC Report*. NSW Planning and Assessment Commission, July 2010.