20th September 2014

Level 1, 228 Victoria Avenue
Chatswood NSW 2067
PO Box 3047
Willoughby North NSW 2068
Tel +61 2 9413 3777
Fax +61 2 9413 3822
enquiries@minesubsidence.com
www.minesubsidence.com

msec
mine subsidence
ENGINEERING CONSULTANTS

Centennial Coal Australia Limited
Angus Place Colliery
Wolgan Rd
Lidsdale
NSW 2790

For the attention of Mr. Peter Corbett,
Technical Services Manager

Dear Peter,

Peer Review of Mine Subsidence Induced Height of Fracturing Issues for Angus Place and Springvale Collieries

Centennial Coal has requested Mine Subsidence Engineering Consultants Pty Ltd (MSEC) to undertake an initial review of and provide comments on the height of connected fracturing (HoCF) that are 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.

We are pleased to provide the following generalised overview or summary on this subsidence induced HoCF issue.

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)"

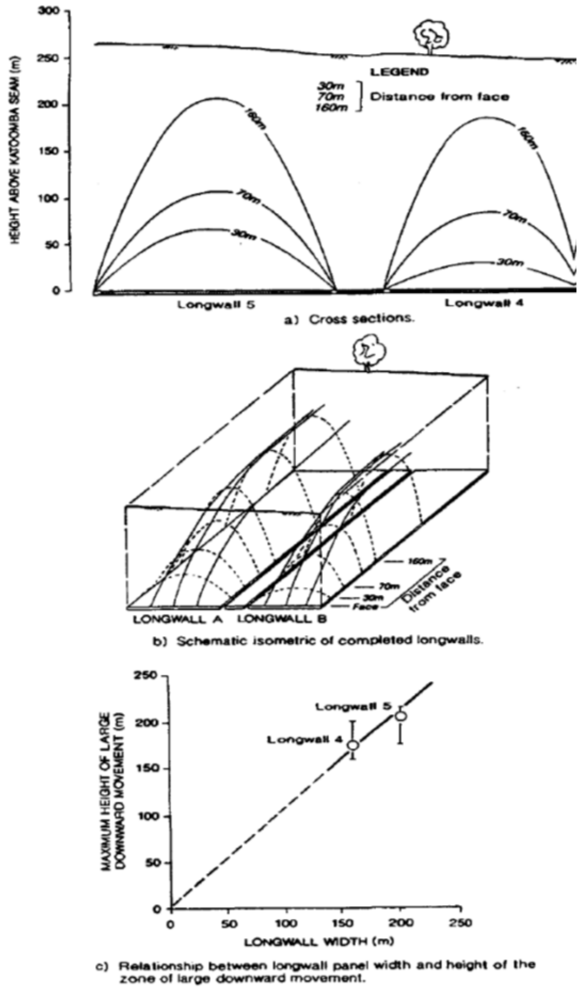


Fig. 7 - Zones of large downward displacement above two Longwall panels of different widths at Clarence Colliery
(Mills and O'Grady 1988)

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 0'Grady 1998, Holla and Armstrong 1986, Holla and Buizen 1991, Guo et al. 2005, Hatherley et al. 2003) and predicted to occur from computer models (Gale 2006). This indicates that cracking and deflection related to such caving and cracked beam subsidence could extend to the surface for panel widths greater than 0.75-1 times depth, 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.

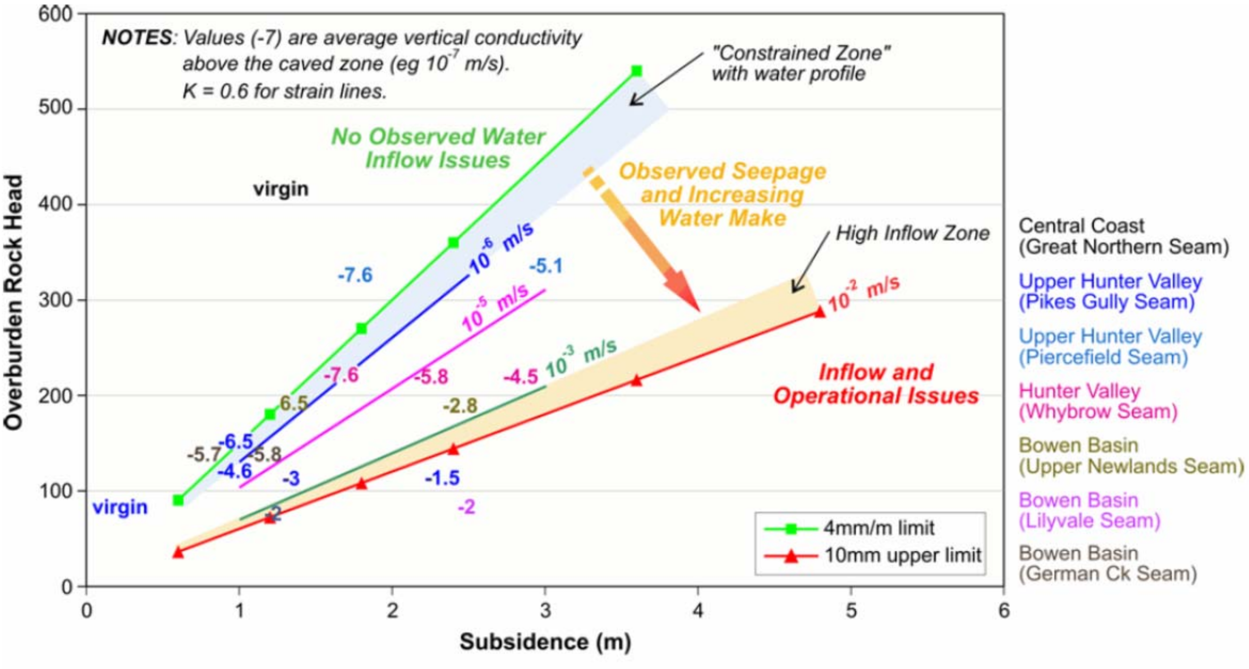


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

"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.

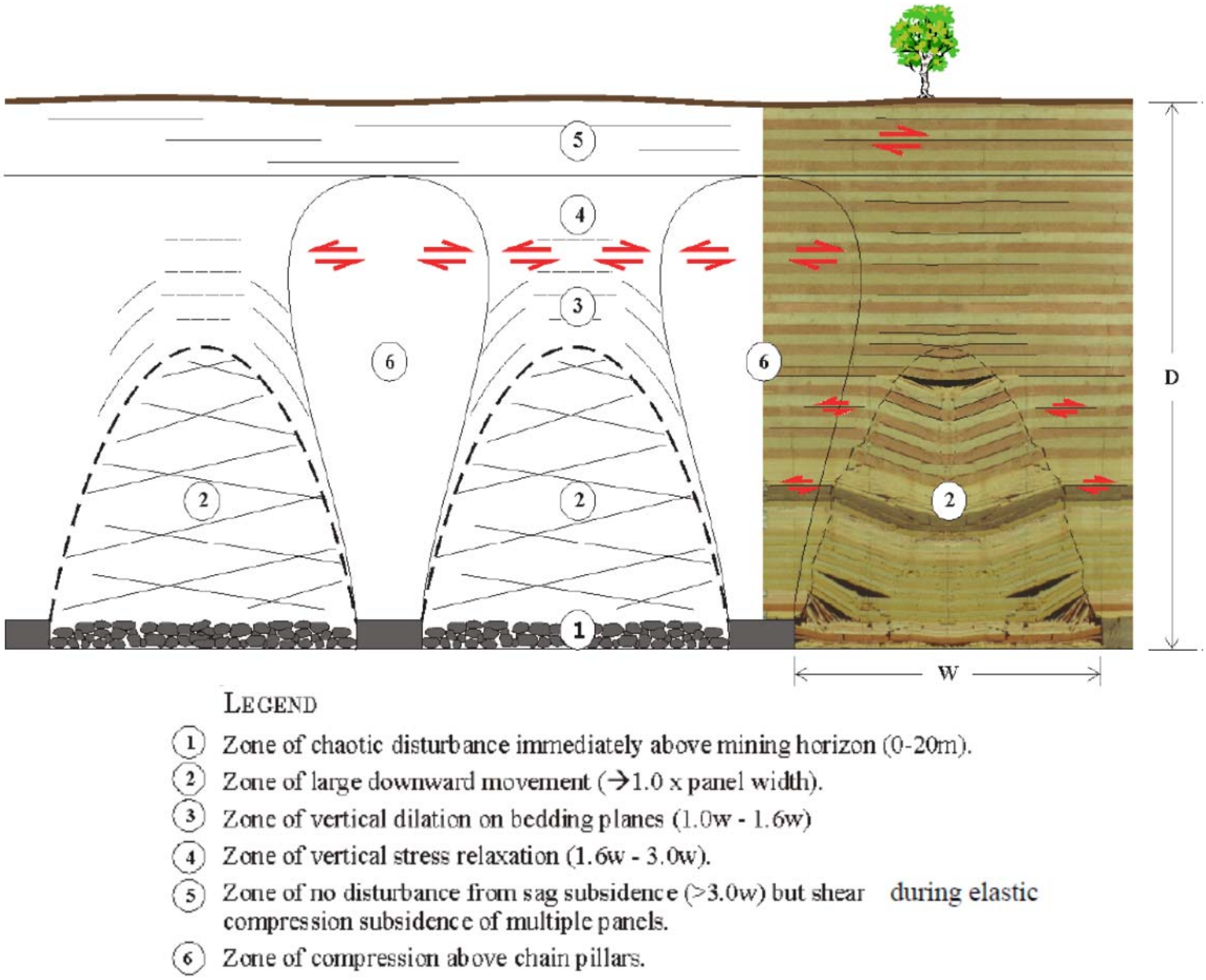
"The panel width has been found to influence the height that mining induced fractures can extend above the coal seam. However, for mine inflow to occur, the fractures must have formed a connected network to allow observable volumes of inflow. It is considered that the frequency, networking and aperture 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.”



“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.

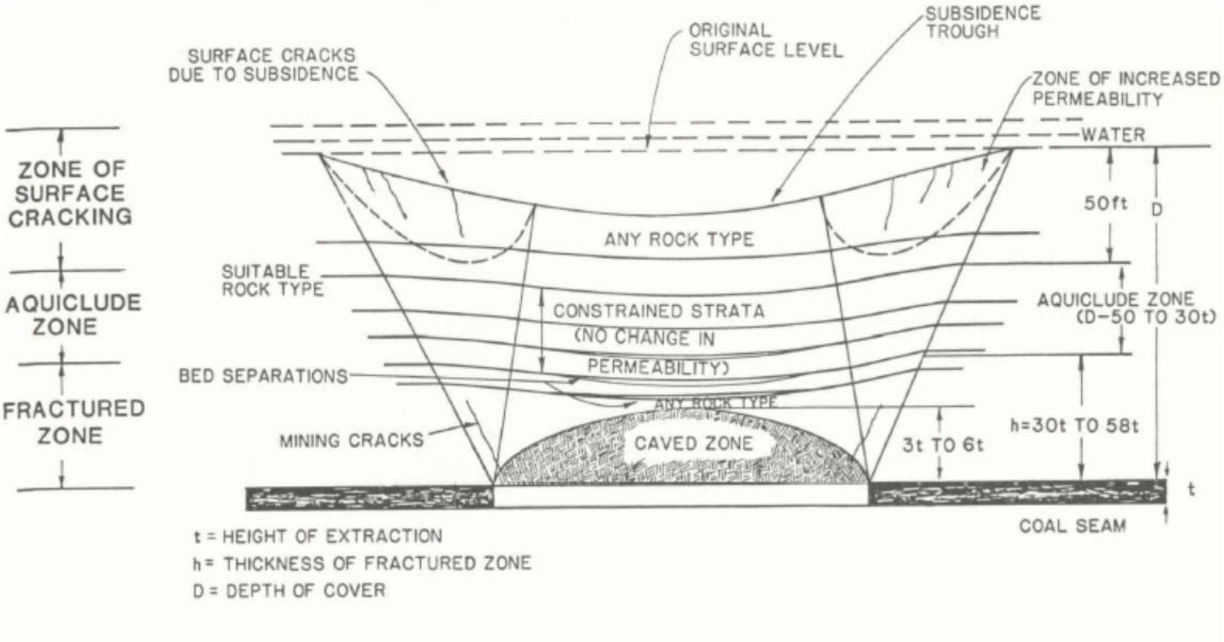
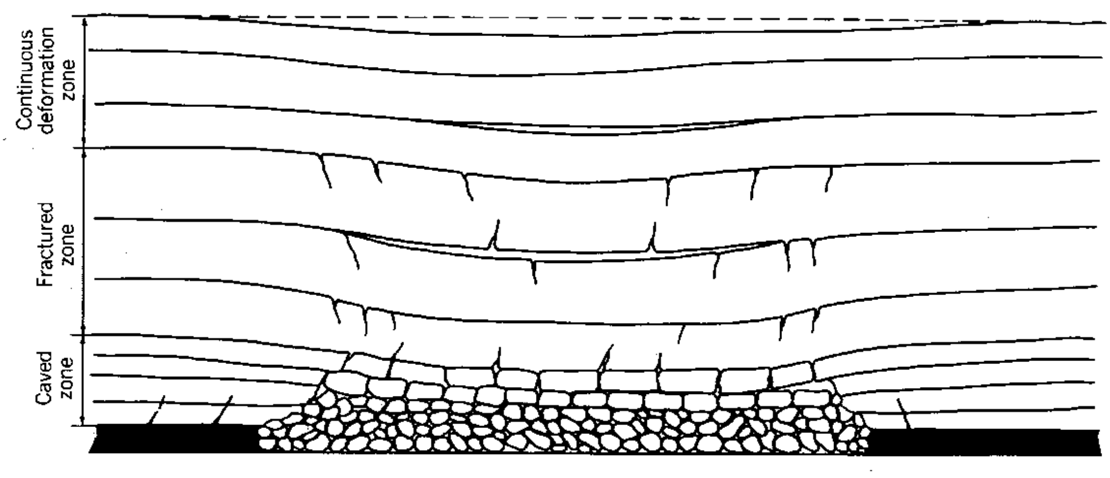


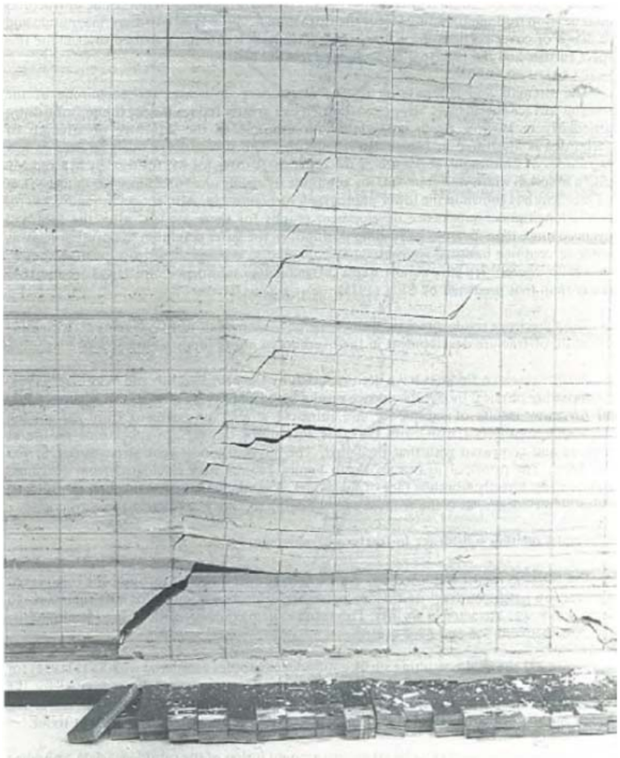
Fig. 4 - Generalized Depiction of Strata Behavior With Total Extraction Mining

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.

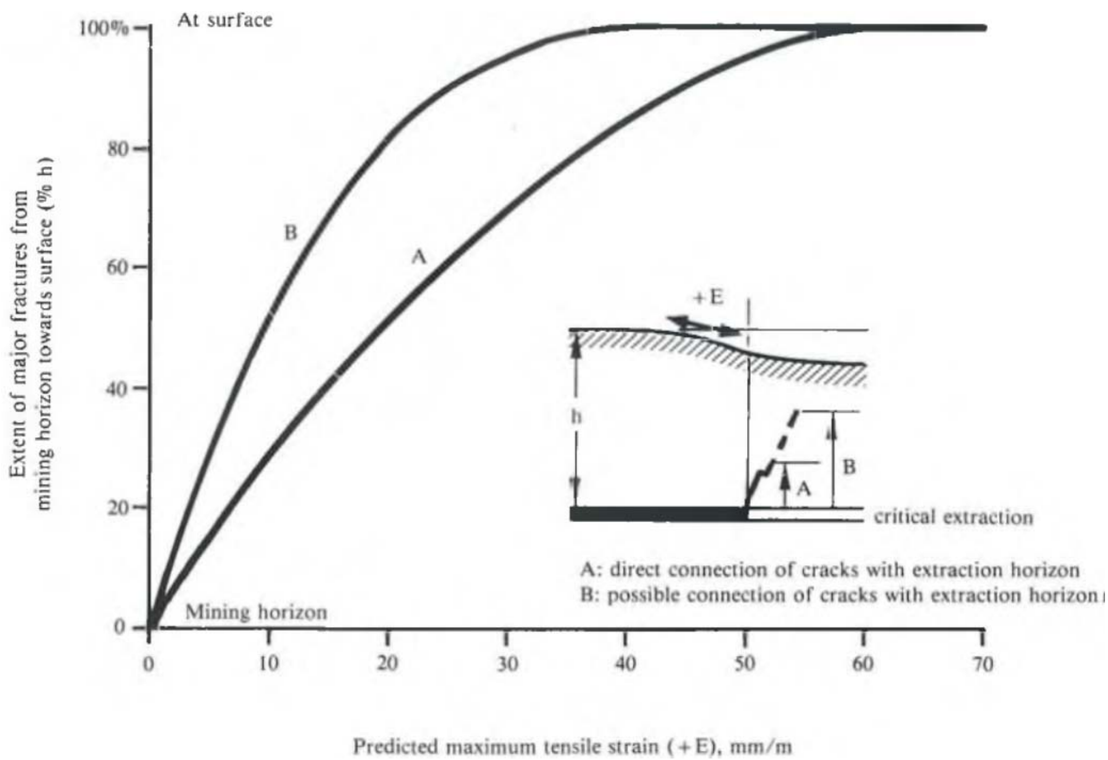


Whittaker and Reddish (1989) in their text book titled "***Subsidence - Occurrence, Prediction and Control***", used physical models built of sand/plaster/water mixes, as shown in the sketch below, that were suitably scaled in strength and size to simulate ground movement of the overburden to illustrate 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).

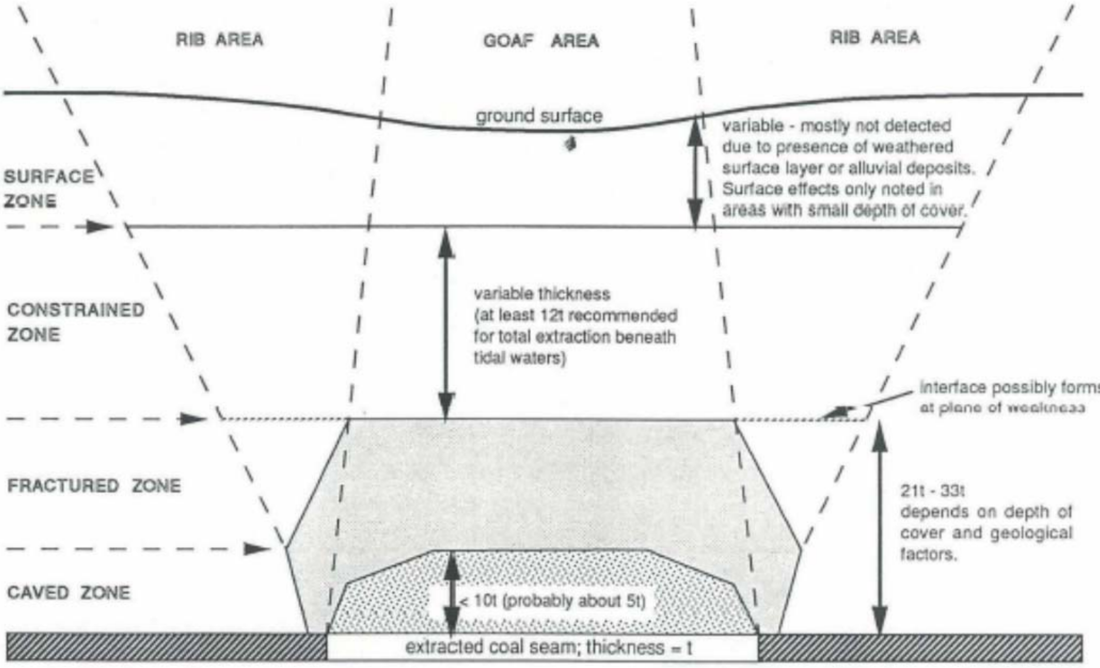


Zone A fracture development was interpreted as being indicative of where free flow from an overlying aquifer would readily occur, whilst the second could be indicative of where there might be a risk of water inflow seeping horizontally from an overlying aquifer but not necessarily flowing downwards to 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.

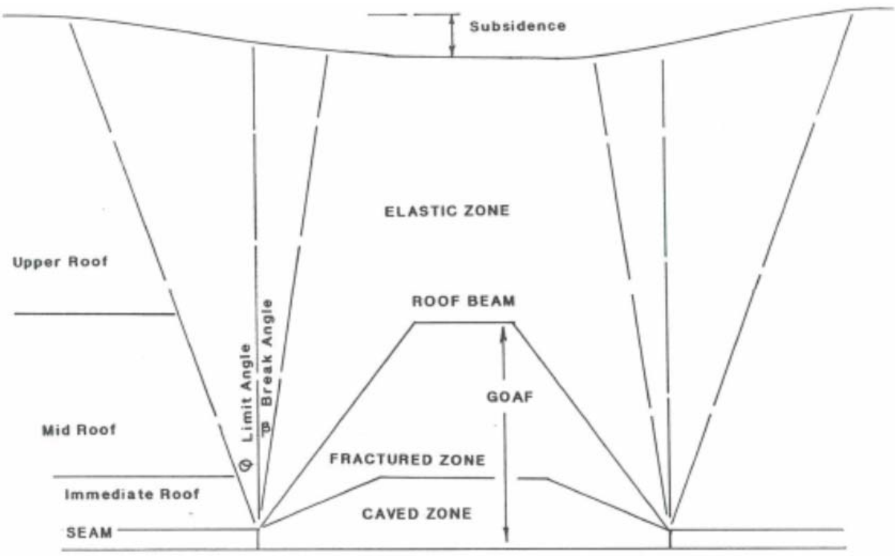
Whittaker and Reddish (1989) also recognised that local geology and depth of mining play important roles, especially in influencing the magnitude and extent of fracture development. They stated that bands of clay and aquicludes that can be located in the overburden can act as major factors in controlling 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.

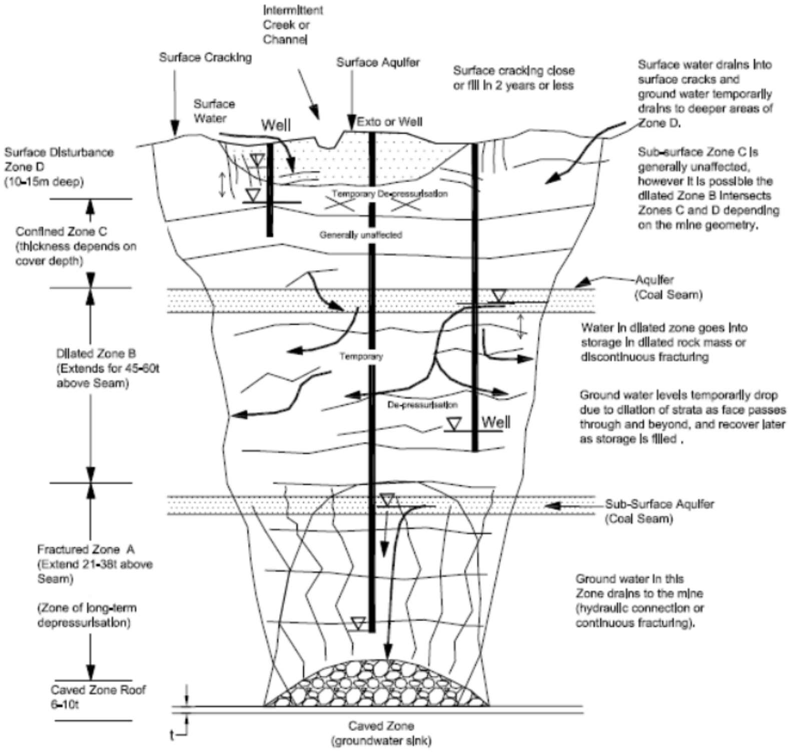


McNally et al (1996) in their paper titled “***Geological factors influencing longwall-induced subsidence***”, recognised only three zones, which they referred to as the caved zone, the fractured zone and the elastic zone.

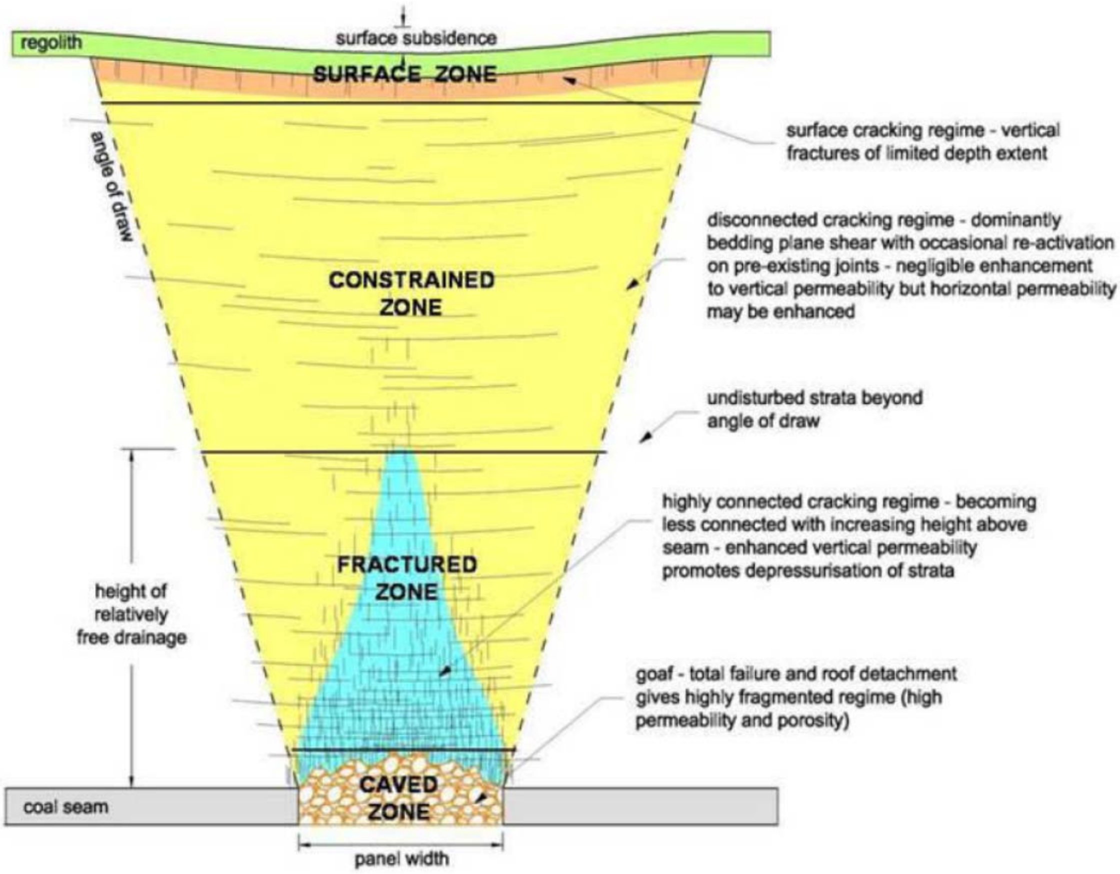


Ditton, Frith and Hill (2003) in their report titled “***Review of Industry Subsidence Data in Relation to the Influence of Overburden Lithology on Subsidence and an Initial Assessment of a Sub-Surface Fracturing Model for Groundwater Analysis***”, reviewed the above Whittaker and Reddish Model plus 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.

Hence MSEC believes that this is a complex issue and it is not possible for a simple geometrical and geotechnical equation to accurately estimate the heights of the connected collapsed and fractured zones. Perhaps these equations can estimate the HoF, but a more thorough analysis is required to determine the HoCF and this analysis should include other groundwater factors, including the presence of strata layers of low permeability within the overburden strata.

Therefore the HoCF zone above extracted longwalls are 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 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 January April 2013.

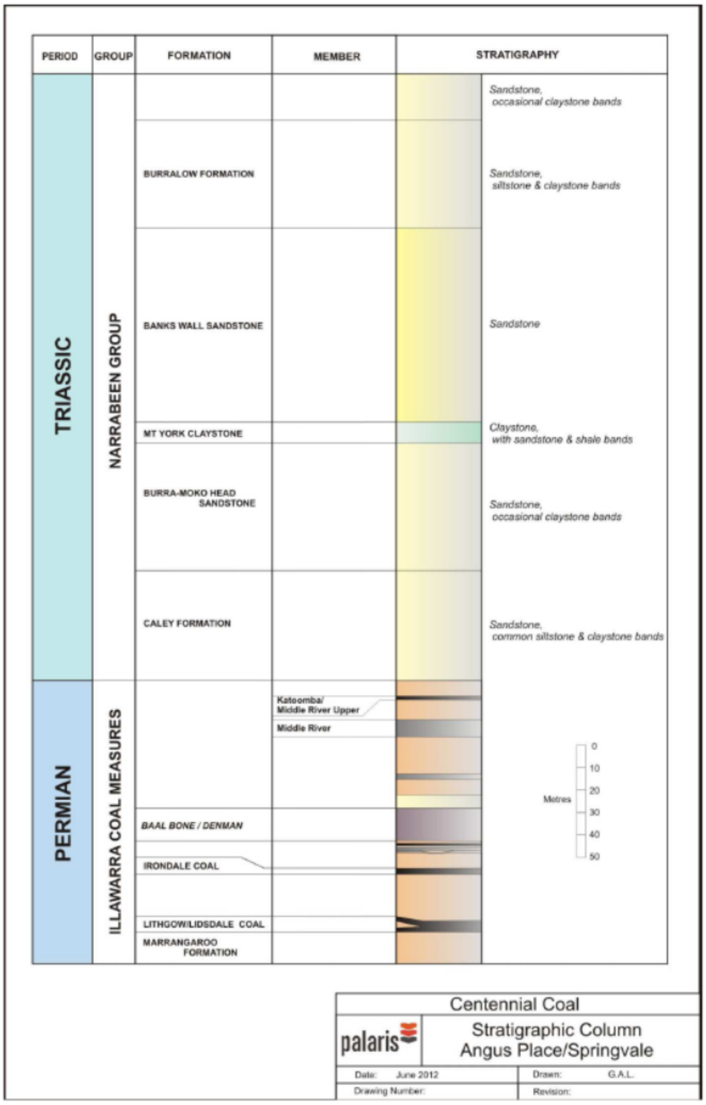


Figure 1.1 Generalised Stratigraphic Column

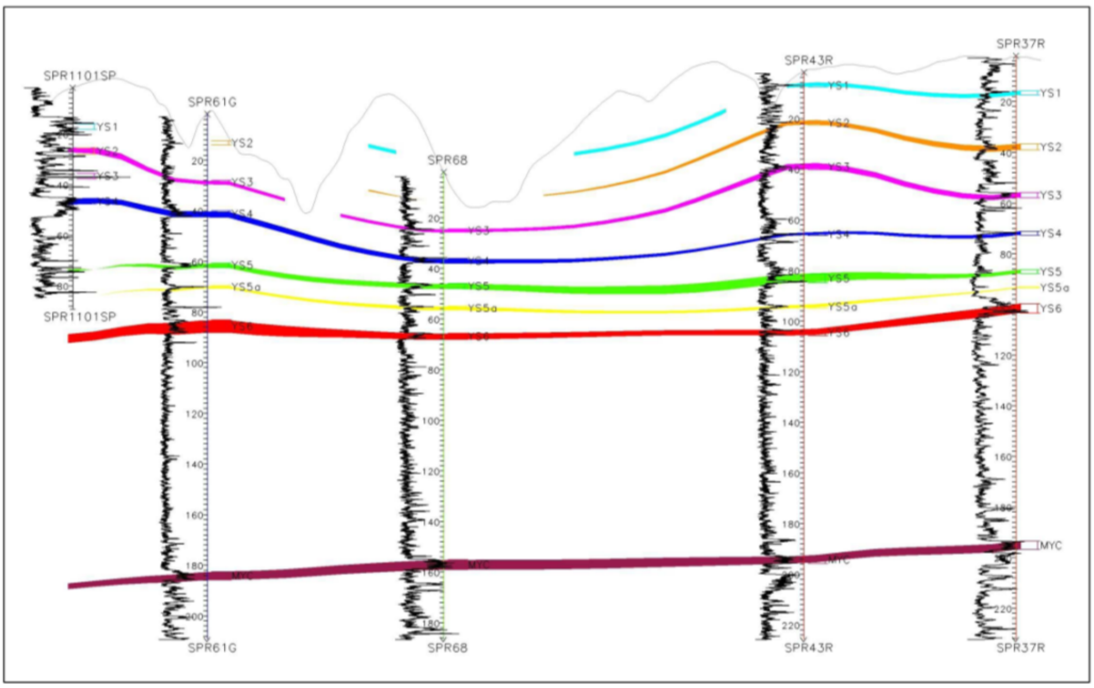


Figure 1.3 Correlated & Modelled Units in the Narrabeen Group

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.

Yours sincerely

Don Kay

Mine Subsidence Engineering Consultants