Strata Control Technology

REPORT TO:

ASHTON UNDERGROUND MINE

Assessment of Longwall Panel Widths and Potential Hydraulic Connection to Bowmans Creek - Ashton Mine

ASH2963A

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REPORT TO	Brian Wesley Mine Manager Ashton Underground Mine PO Box 699 SINGLETON NSW 2330
SUBJECT	Assessment of Longwall Panel Widths and Potential Hydraulic Connection to Bowmans Creek - Ashton Mine
REPORT NO	ASH2963A
PREPARED BY	Winton Gale
DATE	29 October 2008

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EXECUTIVE SUMMARY

Ashton Mine is assessing mining options for longwall panels located in the vicinity and under the alluvials associated with Bowmans Creek.

One of the major considerations on the mining layout is the potential of direct hydraulic connection from the underground mine to the surface and saturated alluvium of Bowmans Creek.

An initial review of the potential interconnection was conducted as part of the mining approval process. This information used was primarily based on experience from Cumnock Colliery under Davis Creek and experience from mining about Lake Macquarie. On a more regional and international basis, the experience base was often conflicting as site conditions play a major role in the outcome. An initial estimate of 150m was presented in the approval as suitable to control direct connective cracking to the surface from a 210m longwall panel.

The understanding of cracking and water flow through the subsided overburden has been an evolving science since the approval was granted and a greater understanding of the issues has developed. A number of ACARP studies have been undertaken on this subject over the last 5 years and have provided more information and insights into this process.

During the last 18 months, a study of the inflow potential for mining under the Bowmans Creek area has been conducted. This study has involved a review of empirical data of inflow experience around the world, computer modelling of caving and water flow potential for the Ashton site and field site investigations of conductivity and connectivity of the fracture systems in the overburden of Longwall 1. This report is a compilation of the geotechnical aspects of that study and relates primarily to mining of the Pikes Gully seam.

The empirical review and computer modelling conducted for the Ashton site are complementary. The potential for hydraulic connection from the mine to surface aquifers is related to the magnitude of subsidence, overburden, panel geometry and geological nature of the overburden. It is also noted that clay rich soft units can act as aquicludes and significantly restrict water migration.

The height of cracking above the extraction panel typically extends 1-1.5 times the panel width, however these cracks may not be interconnected and allow any significant fluid migration. It was found that the extent of cracking and interconnection potential above the extraction panels increases with increasing subsidence.

It was found that the hydraulic conductivity of the overburden below aquifers could be maintained at values similar to the in situ values by controlling the amount of subsidence and cracking in the overburden. This control was accomplished by reducing panel width to a value of 0.7 or less times overburden.

As panel width increased, the amount of subsidence and cracking increased to the point at which cracking extended to the surface. In this situation, the conductivity of the overburden was enhanced above the in situ values. The potential for inflow is related to the extent and interconnection of the fractures created by subsidence. For small subsidence movements the inflow would be imperceptible but as subsidence increased, greater interconnection of fractures occurred and as such inflow increased from a seepage to a perceptible inflow. The nature of inflow for increasing subsidence and interconnection is therefore a continuum ranging from negligible impact to one causing significant operational problems.

The impact of inflow into the fractured overburden on an aquifer will be related to the inflow rate and recharge characteristics of the site.

The outcome for extraction of the Pikes Gully Seam is that subsidence magnitude and characteristics are likely to be similar to the regional average trend. Subsidence for a 2.4m extraction is anticipated to be in the range of 1-1.6m for current width panels at 100-150m depth. Review of geology indicated that there were no significant aquicludes which would restrict flow through a cracked and subsided overburden.

The results indicate that for a maximum subsidence magnitude in the range of 1-1.6m there is likely to be significantly enhanced conductivity from seam to surface. Inflow is then likely to result, however the magnitude will be dependent on the nature and extent of the alluvial sediments.

It was concluded that the impact on the Bowmans Creek alluvium system can be controlled by limiting the panel width to dimensions that do not induce significant water loss. A review of regional subsidence information together with an initial assessment of ULD seam extraction beneath the Pikes Gully seams supported selection of panel widths up to 0.6 times depth in order to maintain a barrier of overburden below the aquifer which had conductivity characteristics similar to the in situ state. Further modelling of the extraction of multiple longwall panels in the Pikes Gully Seam supported the 0.6 layout and resulted in increasing the chain pillar dimensions between sub critical panels from 30m centres to 35m centres. This provided a factor of safety for the pillars of at least 2.5 (based on empirical formulae) in order to maintain a stable overburden geometry.

The actual impact of such a mine geometry on the alluvium will need to be defined by regional hydrological modelling which takes into account the alluvium recharge and conductivity. Such an analysis is being undertaken by Peter Dundon and Associates.

It was also concluded that considering the evolving nature of this field, ongoing monitoring of the hydrological impacts of mining at Ashton is required to confirm the results of this study. It is also recommended that an ongoing review of subsidence data for panels having a width to depth ratio less than 0.7 be undertaken to ensure that the design assumptions as outlined in Section 7 are met.

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1. INTRODUCTION

Ashton Mine proposes to undertake multi seam mining of 4 seams within its mining lease. The depth of seams ranges from approximately 24m to greater than 200m. One of the major considerations on the mining layout is the potential of mining induced direct hydraulic connection from the underground mine to the surface and saturated alluvium of Bowmans Creek. The mine layout in the Pikes Gully Seam, together with the location of the creek is presented in Figure 1.

It is understood that the requirement for protection results from two issues:

i. water ingress into the mine;

ii. potential contamination of the water flowing to the Hunter River from Bowmans Creek after mine decommissioning and flooding of the mine.

An initial review of the potential interconnection was conducted as part of the mine approval process. This information used was primarily based on experience from Cumnock Colliery under Davis Creek and experience from mining about Lake Macquarie. On a more regional and international basis, the experience base was often conflicting as site conditions play a major role in the outcome. An initial estimate of 150m was presented as suitable to control direct connective cracking to the surface from a 210m longwall panel.

The understanding of cracking and water flow through the subsided overburden has been an evolving science since the development consent was granted and a greater understanding of the issues has developed. A number of ACARP studies have been undertaken on this subject over the last 5 years and have provided more information and insights into this process.

During the last 18 months, a study of the inflow potential for mining under the Bowmans Creek area has been conducted.

The primary purpose of this aspect of the work is to assess the potential for connectivity under Bowmans Creek for longwall panels, ranging in width from 75m to 208m, within the Pikes Gully Seam. The Pikes Gully Seam is modelled as 2.4m thick for this study. The overburden thickness investigated has been primarily 150m, however the effect of overburden in the range of 100-150m also has been assessed.

The approach undertaken was:

i. apply state of the art computer modelling of overburden caving and associated mining induced conductivity to estimate the extent and severity of connectivity to Bowmans Creek;

Figure 1 Pre-study mine layout, borehole location plan and surface topography.

ii. review the current experience base of water inflow incidences into mines within Australia and overseas with regard to the characteristics of the Ashton Mine site;

iii. undertake a computer model of caving and the hydraulic properties of the overburden above Longwall 1 and conduct field measurements to provide a validation check on the modelling process.

This report is a compilation of the geotechnical aspects of that study.

The techniques applied are considered to be state of the art. The work conducted within this study draws on recent and current industry research of:

i. Aquifer Inflow Potential from Longwall Panels (current ACARP Project C13011);

ii. Multi Seam Layout Guidelines and Feasibility of Partial Chain Pillar Removal (ACARP Project C11032, 2004);

iii. The Influence of Subsidence Cracking on Longwall Extraction beneath Water Courses, Aquifers Open Cut Voids and Spoil Piles (ACARP Project C5016, 2000).

Aspects of this work and other relevant studies have been reported (Gale 2004, Gale 2004).

2. COMPUTER MODELLING OF CAVING AND RESULTANT OVERBURDEN CONDUCTIVITY DUE TO MINING

Computer modelling is considered to be the best method to assess site specific geological characteristics of a site relative to variable mine geometries. However modelling requires a good characterisation of the geotechnical properties of the strata. The geotechnical characterisation of the strata is based on geophysical data from recent boreholes, and extrapolated characteristics using experience from other sites. This allows an approximation of the material strength and stiffness, however other characteristics such as bedding plane strength and overburden conductivity need to be extrapolated from experience elsewhere. This characterisation therefore should be seen as an estimate based on available geotechnical information.

The computer model of the strata section to the Liddell Seam has been created on the basis of geophysical data from borehole logs from WML 97 and estimated properties associated with such data. This borehole is in close proximity to the area impacted by Bowmans Creek and is presented in Figure 1. The Pikes Gully Seam is approximately 150m depth in the model.

A review of the geological data of other boreholes revealed that the strata section is relatively consistent across the area. Therefore the data used from WML 97 is considered to be representative of the site. The near surface material under the alluvial deposits is assumed to be partially weathered. Alluvial and weathered material has been conservatively modelled to approximately 20m below surface.

The definition of geotechnical parameters for deeper seams has been incorporated into the model. The principal focus for this study has been the Pikes Gully Seam, however the Upper Liddell Seam, located approximately 30m below the Pikes Gully Seam, has had some initial assessment in subsequent models to assist in optimising the design of the Pikes Gully layout. The Pikes Gully Seam is modelled as approximately 2.4m thick and the Upper Liddell Seam has also been modelled at 2.4m thick.

The model geometry is presented in Figure 2 and the strata are characterised on the basis of unconfined compressive strength (UCS). Coal is modelled with an in situ unconfined compressive strength of 6.5MPa. The overburden is assumed to be jointed and contain pre-existing bedding plane breaks. Jointing is assumed to have an average spacing of 3m and a similar spacing is assumed for pre-existing bedding plane fractures. The fractures exist in the model with a random distribution.

The UCS profile of the overburden is presented in Figure 3. The stress field is based on regional estimates and is characterised by a tectonic component and a vertical component. Vertical stress is based on overburden density and increases at 2.5MPa/100m. Horizontal stress is dependent on the stiffness of the strata. The horizontal stress within the model is presented in Figure 4. The overburden hydraulic conductivity is based on regional data (Gale 2004) and the vertical conductivity profile presented in Figure 5.

The model used is based on FLAC 4 code with SCT control routines used to control the material properties and rock failure properties of the ground. The section modelled is two dimensional and simulates the pre and post failure properties of the strata. The model has coupled mechanical and fluid interaction, such that the water pressure and flow is modelled together with mechanical ground movements. The water pressure within the model is assumed to be initially hydrostatic.

The approach has been used for strata behaviour on scales ranging from mine roadways to longwall panels within extensive sections of overburden exceeding 1km (Gale et al, 2004, Gale 2004).

The model simulates shear fracture, bedding plane shear, tensile fracture, tension bedding plane parting and remobilisation of pre-existing joints or cleat.

The material properties required are typically extensive and for the purposes of this report only the key normally recognised parameters are presented.

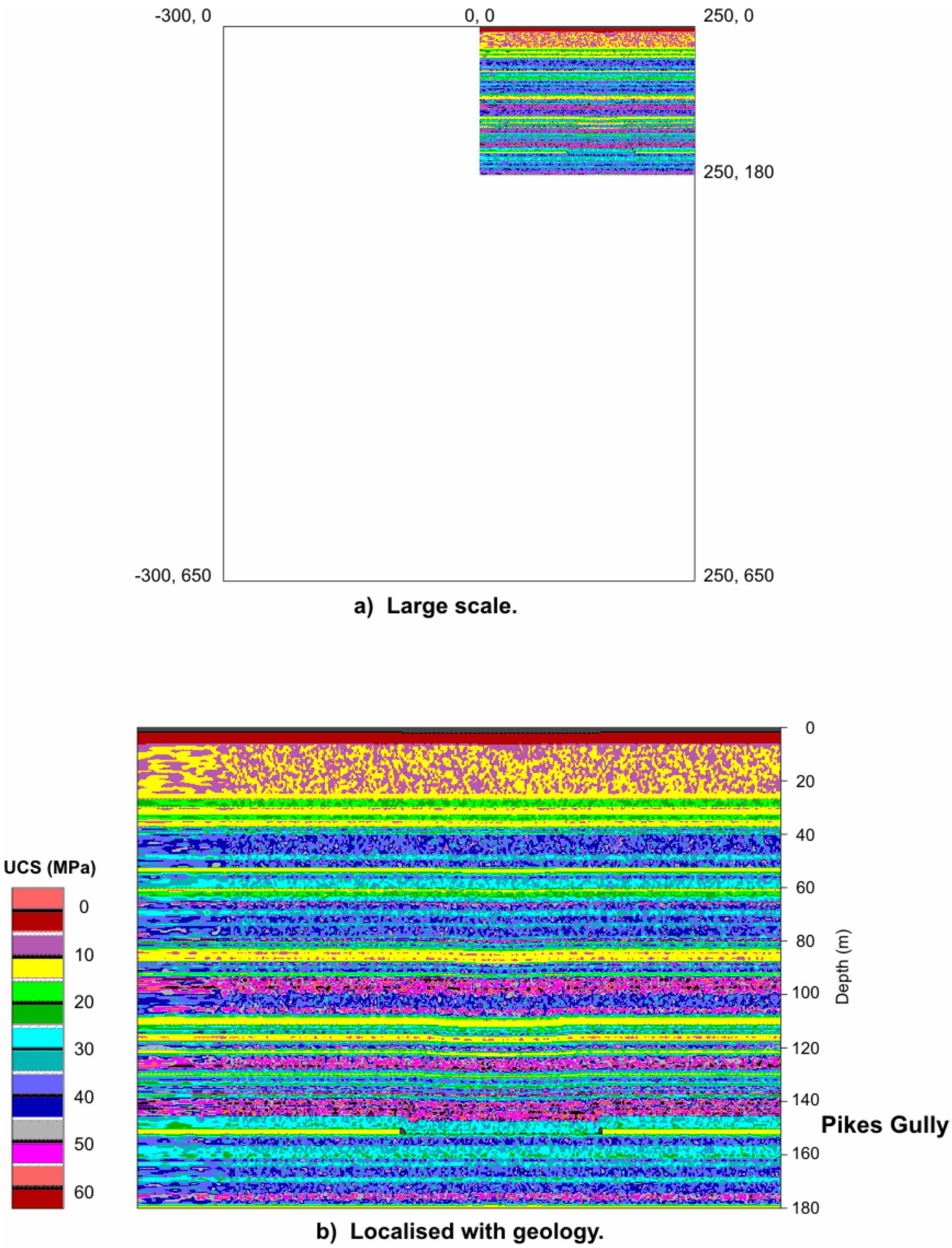


Figure 2 Model geometry.

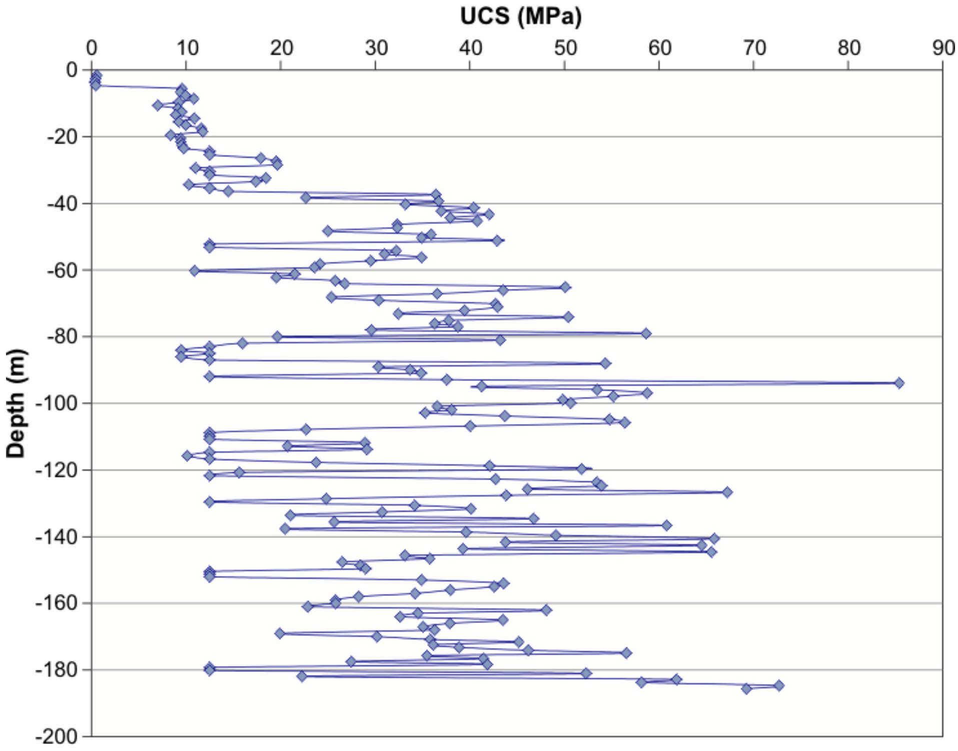


Figure 3 UCS profile of overburden.

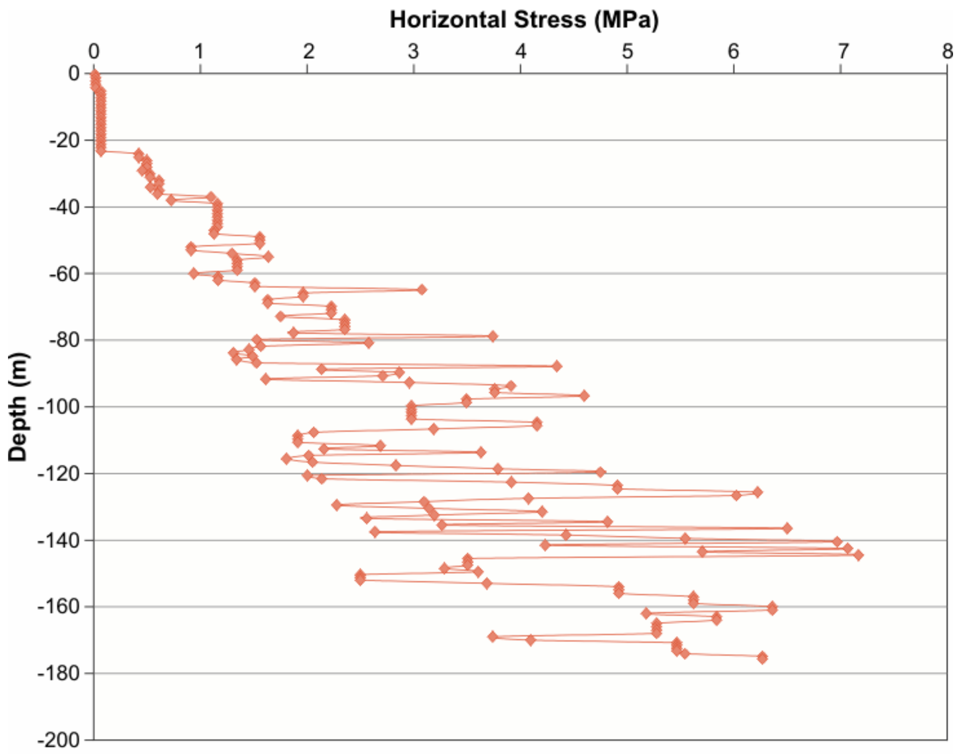


Figure 4 Horizontal stress in model.

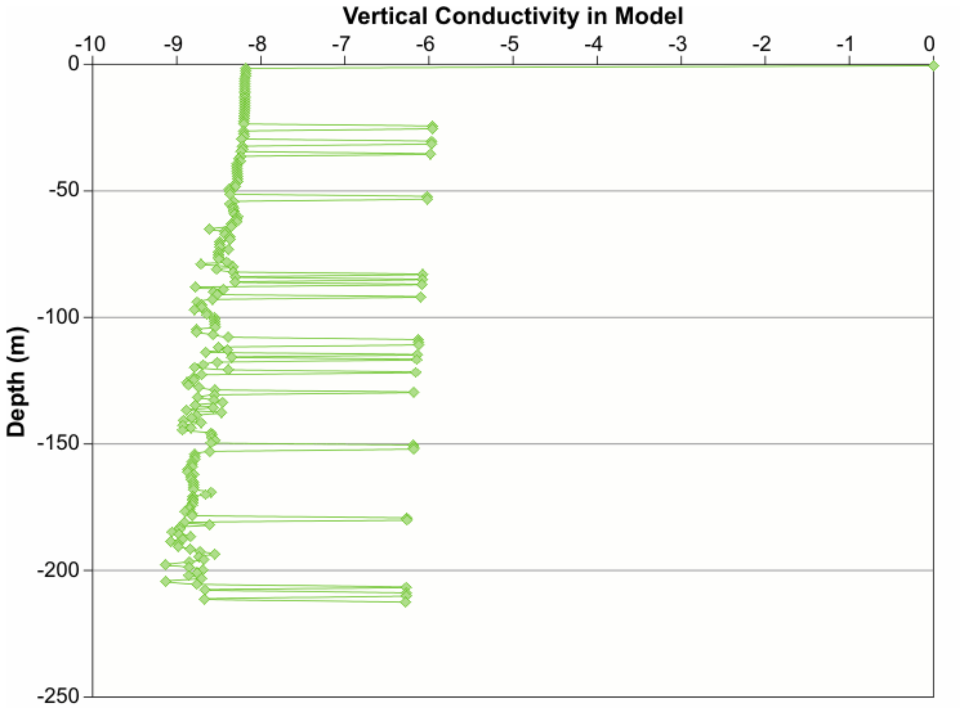


Figure 5 Overburden hydraulic conductivity used in the model.

3. MODEL RESULTS

3.1 Subsidence Characteristics of the Overburden for Single Panels

The subsidence characteristics of the overburden have been assessed on the basis of various panel widths at 150m depth. The results relate to single panels and are presented in Figure 6 together with the regional subsidence information of the published Newcastle and Western Coalfield. This data is presented in terms of percent maximum subsidence relative to seam extraction thickness plotted against width/depth of the panel. The modelled results are consistent with the regional data but appear to plot on the lower bound of the range. Overall, the results indicate that the overburden is likely to behave in a similar manner to the regional data set.

The data from Longwall 1 and Longwall 2 start line subsidence behaviour is also plotted for comparison. This data is somewhat different to the regional data in that the Ashton data was obtained from the longitudinal subsidence lines, not cross section lines as in the regional data. The Ashton data was obtained at the start line of the panels and the width was assumed to be related to the distance retreated. This is not a direct correlation with the cross line approach as the impact of time is not taken into account. The data is seen as potentially being biased to over representing the spanning characteristics of the ground relative to the cross section lines. This is certainly apparent for Longwall 1 and to a lesser extent Longwall 2. The Longwall 2 data is more like the regional data set.

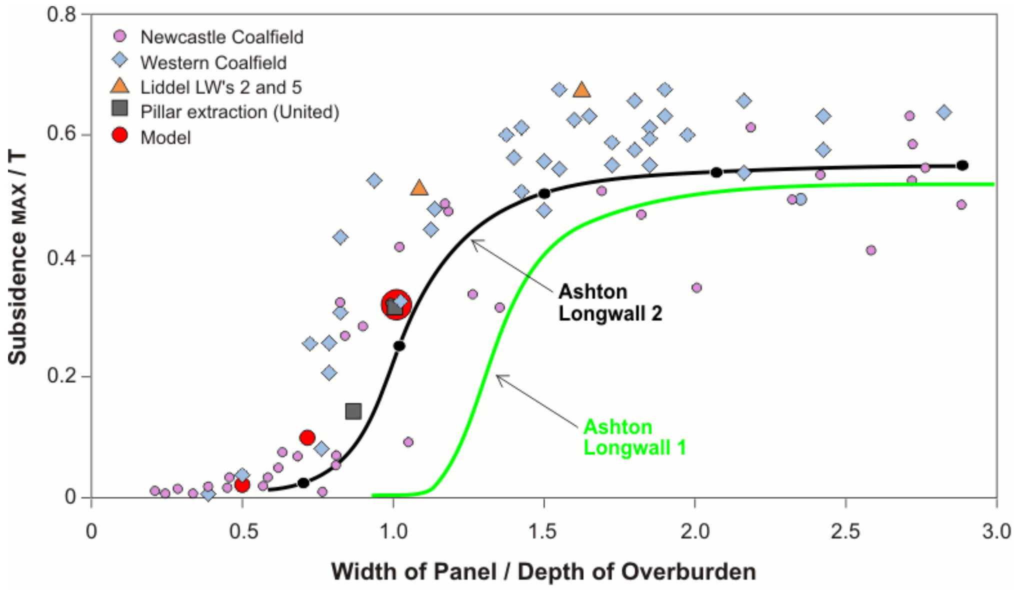


Figure 6 Regional subsidence data for Hunter and Western Coalfields. NOTE: Local data and modelled data included.

Examples of nearby subsidence measurements are also presented to assess local experience relative to the regional data. It appears that the Ashton characteristics are likely to be consistent with the regional data set.

The modelled overburden response is therefore considered to:

i. be consistent with regional experience;

ii. have simulated the overburden deformation characteristics in a suitable manner;

iii. simulate the goaf loading and compaction characteristics.

3.2 Overburden Cracking Relative to Panel Width at 150m Depth Single Panels

The mode and extent of cracking within the overburden for panels of 75m, 100m, 150m and 208m width at 150m depth are presented in Figure 7. This plot shows the overburden section together with the fracture distribution relating to each panel width. The results indicate that cracking extends to the surface for panels of 150m and 208m wide. The 75m panel shows no connection and the 100m panel shows no connection but does display additional cracking between the main cracking zone and the surface.

General experience and the results in Figure 7 indicate that the height of cracking is the range of 1-1.2 times the panel width. Experience at other sites indicates that this range may extend depending on the geological characteristics.

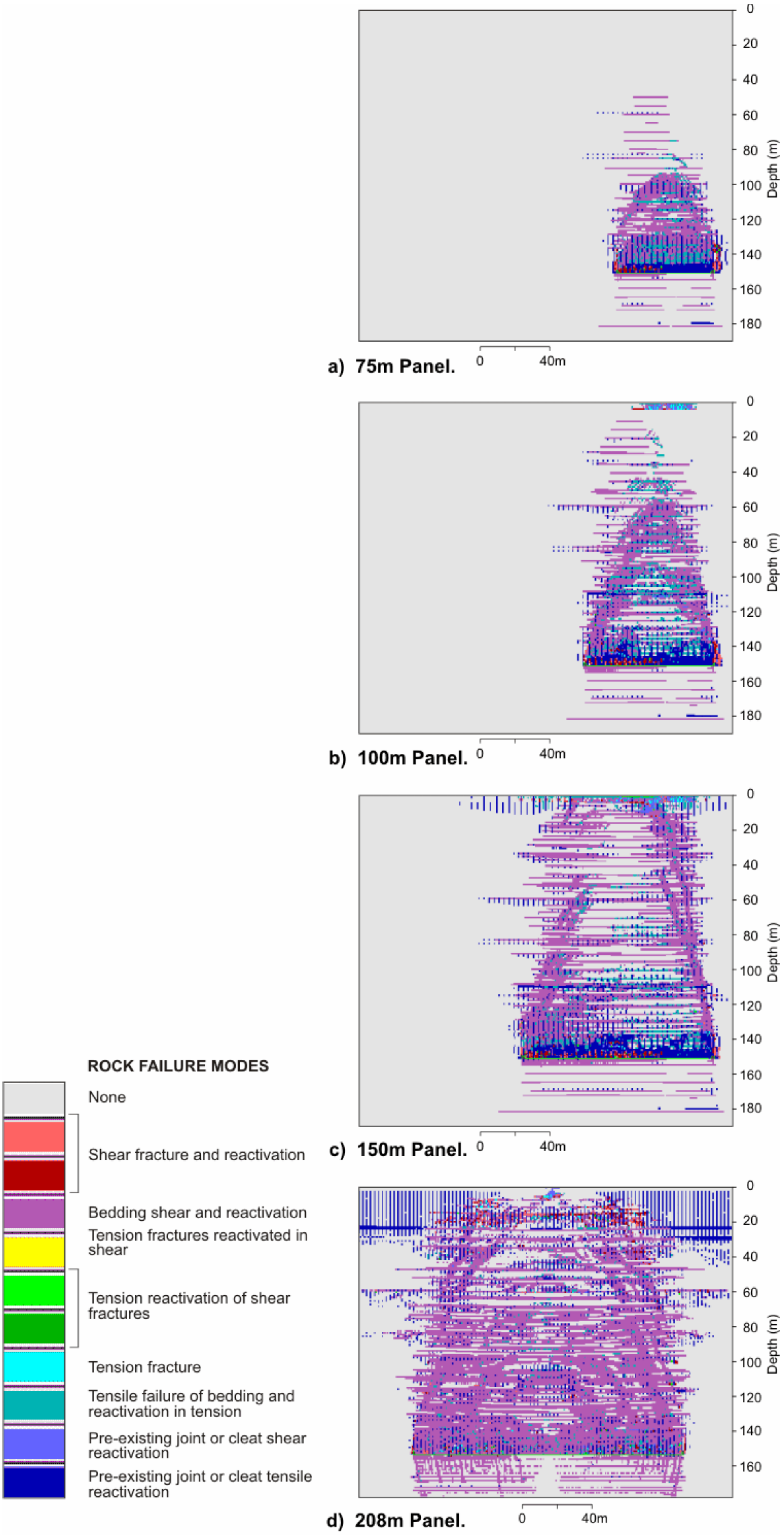


Figure 7 Height and mode of rock fracture for various panel widths.

The height of cracking is a rock mechanics term and does not necessarily indicate that all of the fractures are connected in a manner that allows water migration. The fractures are typically a combination of sub-vertical joints, mining induced fractures and horizontal bedding planes. The issue for water flow is the degree of connection or networking of the fracture systems.

3.3 Overburden Conductivity Profiles Relative to Panel Width at 150m Depth Single Panels

The in situ overburden profile modelled is presented in Figure 5. The conductivity of the strata is enhanced by the creation of fractures. Quantification of the fracture on conductivity is estimated within the model on the basis of the equivalent material conductivity calculated from aperture flow within a fracture. The conductivity (k m/s) estimated from the flow quantity through a $1m^2$ area with unit pressure gradient. This then simplifies to solve k as approximately equal to:

$$k = t^3 \text{ x } 10^{\ 6} \text{ m/s}$$

where t is the hydraulic aperture (m).

The dilation of the strata which occurs after fracture of the rock is considered to be related to fracture dilation. It has been assumed that there is 1 fracture per element in the model and that the aperture is equal to the average dilation less 0.5mm. This value is used in an attempt to account for surface roughness of the fractures.

This should be seen as an estimate, and the data is best analysed on the basis of relative impacts. The fracture and joint dilation within the model is then analysed on the basis of the aperture formula to obtain an estimate of the vertical conductivity that the fracture would represent.

The vertical and horizontal conductivity of the fracture systems is analysed in this way within the model. The vertical and maximum conductivity (either vertical or horizontal) is presented in Figure 8 for panels of 100m, 150m and 208m. The main conductivity component relevant to inflow is the vertical conductivity rather than the maximum. The maximum has been included for completeness to assess the results that packer testing would provide in terms of goaf conductivity. It is apparent that general packer testing is likely to be biased to horizontal conductivity rather than the vertical conductivity. For that reason the ongoing analyses relate to vertical conductivity rather than the maximum.

This data provides an overview of the potential conductivity of the overburden but does not assess the flow pathways and its continuity. In order to obtain a better understanding of the flow pathways a plot of the flow velocity vectors is used. Flow is typically the flow which results from the pore pressure within the model as overburden caving occurs.

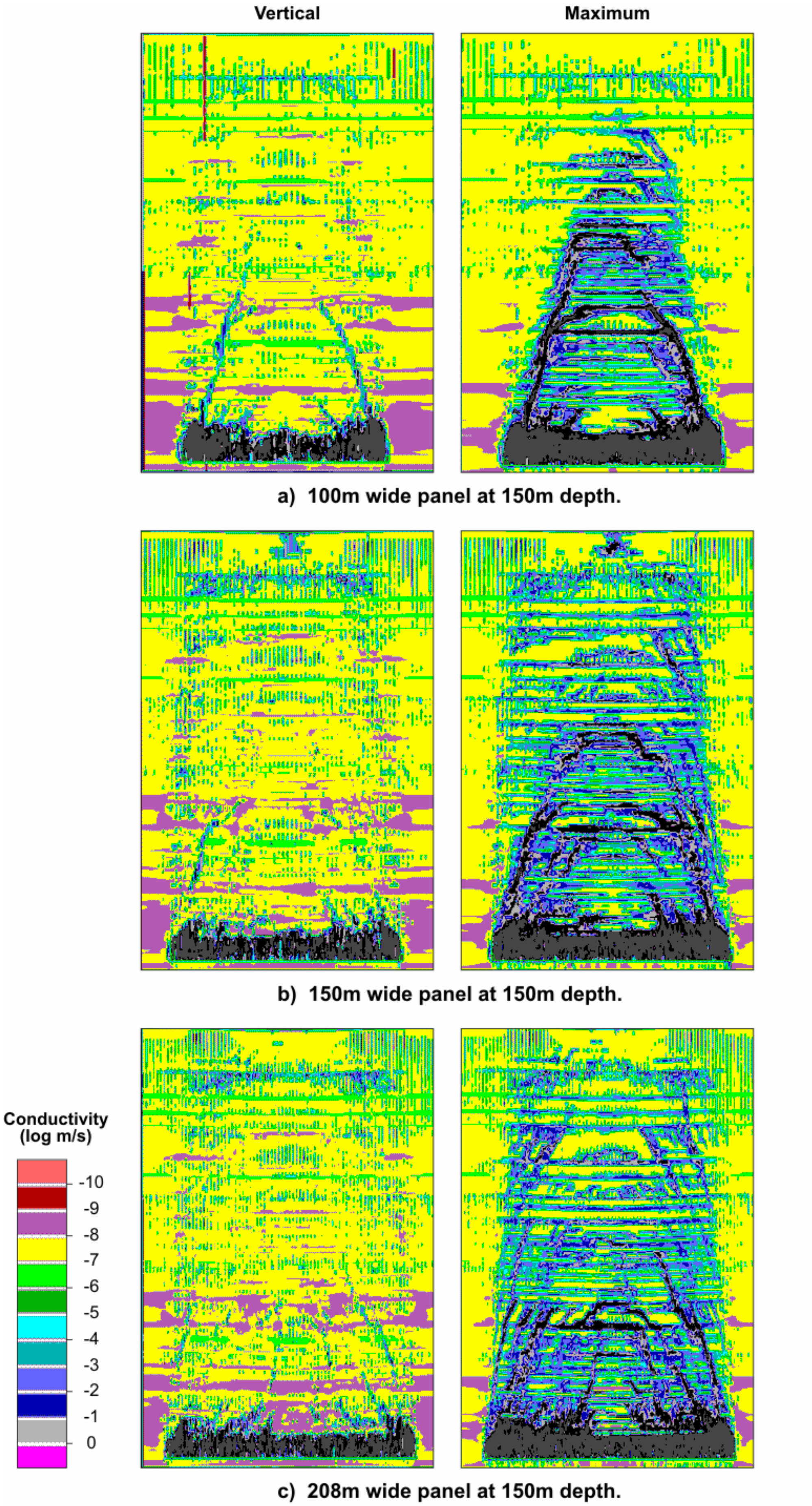


Figure 8 Model sections of vertical and maximum (horizontal or vertical) conductivity in the models.

Examples of flow for various panel widths are presented in Figure 9. These models are approximately 100m and 150m wide.

The flow within the overburden for the various models shows that the flow system is a combination of flow through highly fractured zones and tortuous flow in essentially un-impacted (constrained) strata.

Two methods of quantifying the conductivity of the overburden have been applied. These are:

i. average the sum of the vertical conductivity of the fractures across the model layers. This may over estimate the effective conductivity if the flow system is highly tortuous and horizontal connections between vertical fractures are limited;

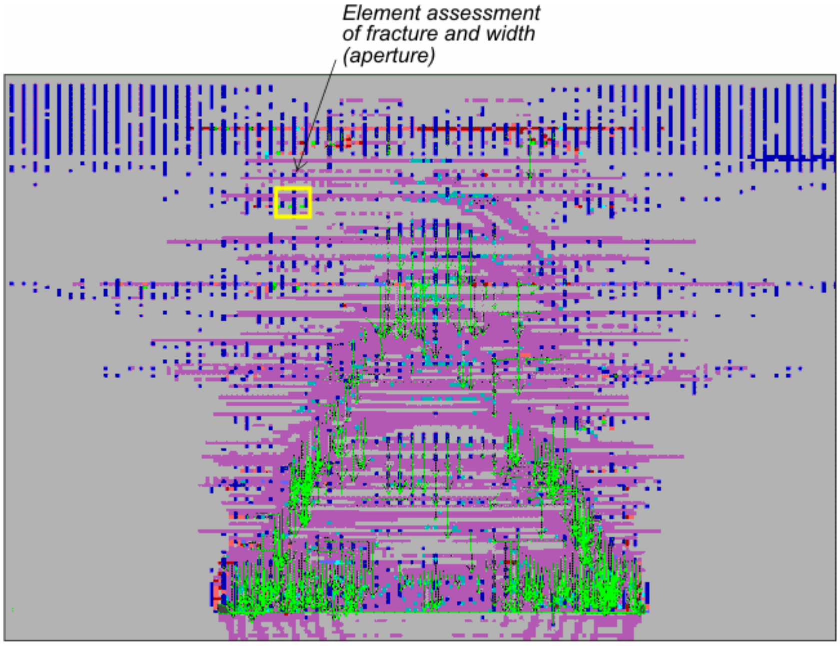
ii. average the sum of flow velocity across each strata unit above the panel. This provides an average value which may overestimate the conductivity if the system has not reached equilibrium. The pore pressure in the overburden strata above the panels is typically depressurised by the overburden relaxation and caving. In this case the long term equilibrium may not be established.

These approaches are most accurate in highly fractured zones where connectivity between fractures and bedding is high. It should be recognised that these approaches may overestimate the conductivity in certain cases and as such they are presented for review of the potential impacts which would need to be verified by further monitoring.

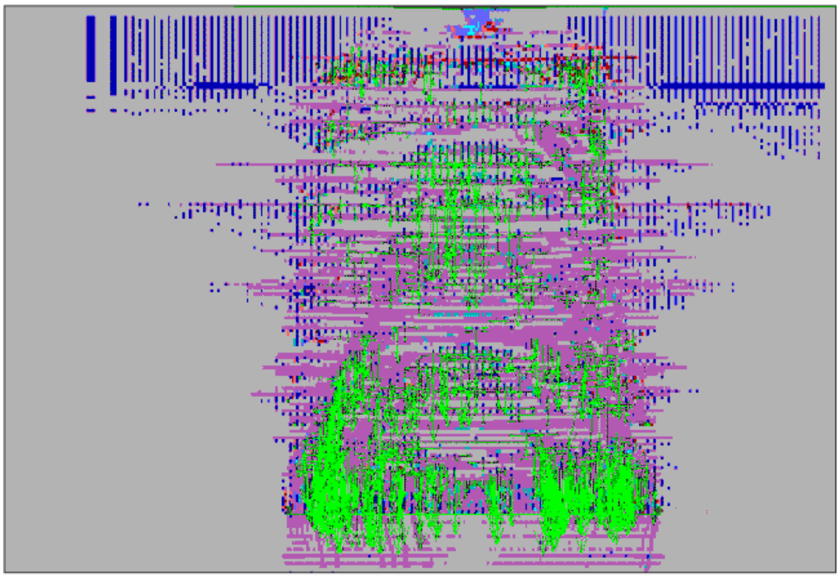
The results obtained are presented in Figure 10 in terms of the average vertical conductivity for each individual layer across the panel throughout the overburden. It was noted that the conductivity in each layer varies and for the purpose of comparison of the results, the range has been plotted.

The 100m wide panel showed fracturing up to approximately 100-120m above the Pikes Gully Seam. The main form of cracking is bedding plane shear and remobilisation of joint planes (Figure 7). The conductivity profile for this geometry (together with the flow vectors in Figure 9) indicates that connected cracking occurs up to approximately 75m below surface, and above that, the fracture system is very tortuous and behaves as an essentially un-impacted overburden.

The 150m wide panel shows enhanced conductivity from the Pikes Gully Seam to the surface. The conductivity of the overburden of these models was typically in the range of 10^{-4} m/s to 10^{-6} m/s. These models indicated that the flow system was indirect and tortuous along a combination of mining induced fractures, bedding planes and pre-existing joints. This was presented in Figure 9 for the panel widths.



a) 100m wide at 150m depth.



b) 150m wide at 150m depth.

Figure 9 Fracture and flow velocity through fractured strata in 100 and 150m wide panels.

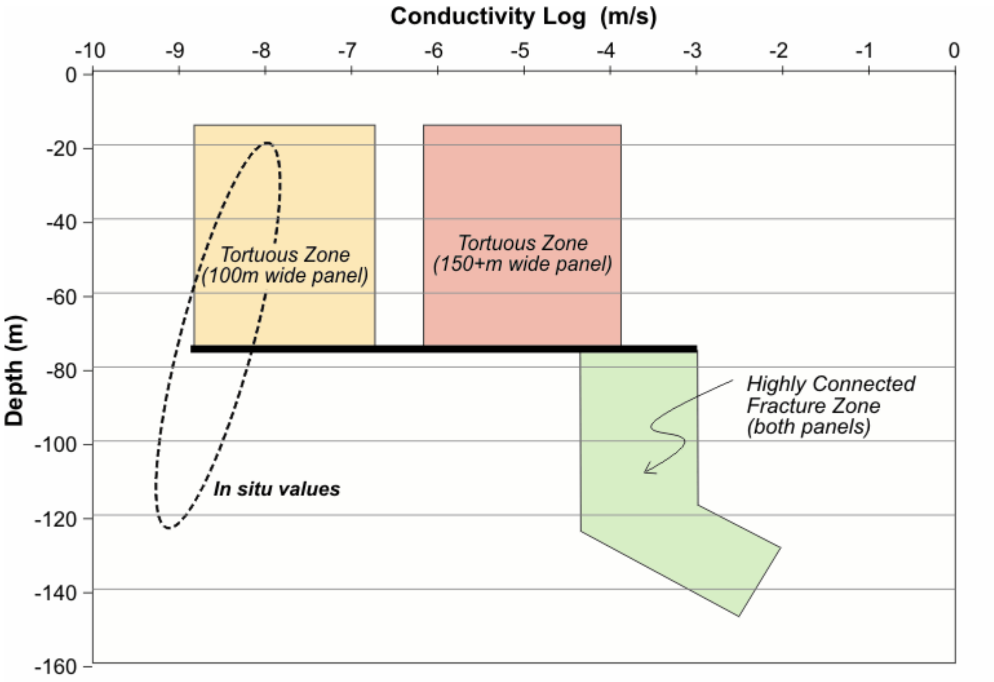


Figure 10 Vertical conductivity of individual layers above panels.

It was noted within the model that it was possible for one bedding unit which was not fractured to locally form a barrier to vertical flow. It is uncertain whether such situations are sustainable with variation in strata and structure in the area. For the purposes of this study, such units are not considered reliable barriers. A reliable barrier is one which contains a continuous section of low conductivity (such as the 100m wide panel example).

Models of 208m wide panels were also run which indicate similar or marginally lower conductivity characteristics as the 150m wide panels. The wider panels appear to have a conductivity profile of approximately 10^{-6} m/s. This is likely to be due to the lower bending strains developed for the upper strata to sit on the goaf material.

This phenomenon is also likely to occur for thinner seam extraction, whereby lower bending strains would be generated in the upper strata. The extent of cracking and the networking of those cracks in the overburden would be related to the magnitude of subsidence. Therefore, for a constant panel geometry, the cracking and conductivity increase as the magnitude of subsidence increases.

These results indicate that panels of width less than approximately 100m provide a control on inflow through the natural ground system, whereas panels of 150m width or more, indicate indirect inflow through the fractured overburden.

The 100m wide panel was found to form a low conductivity barrier to the surface. The conductivity of the barrier is similar to that of the unmined overburden.

The results of this work indicate that panels up to approximately 100m provide a panel geometry for which there is a reliable zone of "substantially un-impacted strata" above the mining induced cracking zone to act as a significant control on the flow regime above the extraction panel. The conductivity of the "substantially un-impacted strata" controls the rate of fluid migration.

Panels of greater width are likely to cause increased conductivity through to surface, however the flow system is likely to occur through a network of fractures and bedding rather than single continuous fracture planes.

3.4 Impact of Depth Variation on Caving for Single Panels

It has been seen in the modelling, at 150m depth, that panel width is a significant control on the subsidence and height of cracking in the overburden. It was found that panels with w/d 0.7 or less maintained a zone of substantially un-impacted strata above the mining induced cracking zone. In order to assess the application of a design control (based on w/d of 0.7) over the site, the caving characteristics of the overburden at 100m and 120m was modelled. The thickness of alluvium modelled ranged from approximately 2-8m.

The results are presented in Figure 11 which indicate that for panels having w/d of 0.7, a significant zone of "substantially un-impacted strata" exists below the alluvial deposits of Bowmans Creek for this depth range. It was also found that the subsidence magnitude was similar to the regional data set.

Longwall panels of 208m width at 120m depth displayed cracking to the surface. Subsidence was approximately 1m in the model which is at the lower bound of regional expectation. The overburden for this amount of subsidence did not display direct connection but the average conductivity of the near surface overburden was in the range of 10^{-5}m/s to 10^{-7}m/s. This would be consistent with tortuous flow (seepage flow).

It is apparent that control of caving height, subsidence and potential surface inflows can be achieved by selection of panel width relative to overburden depth. A panel width/depth ratio of 0.7 or less is anticipated to minimise subsidence and potential inflow under Bowmans Creek.

4. IMPACT OF MULTIPLE PANELS AND GOAF RECOMPACTION EFFECTS

4.1 Multiple Seam Extraction Effects

The discussion above relates to single panels, however in order to assess the impact of multiple panels and goaf compaction effects which may relate to chain pillar compression and potential multiple seam extraction, a range of extraction geometries has been modelled.

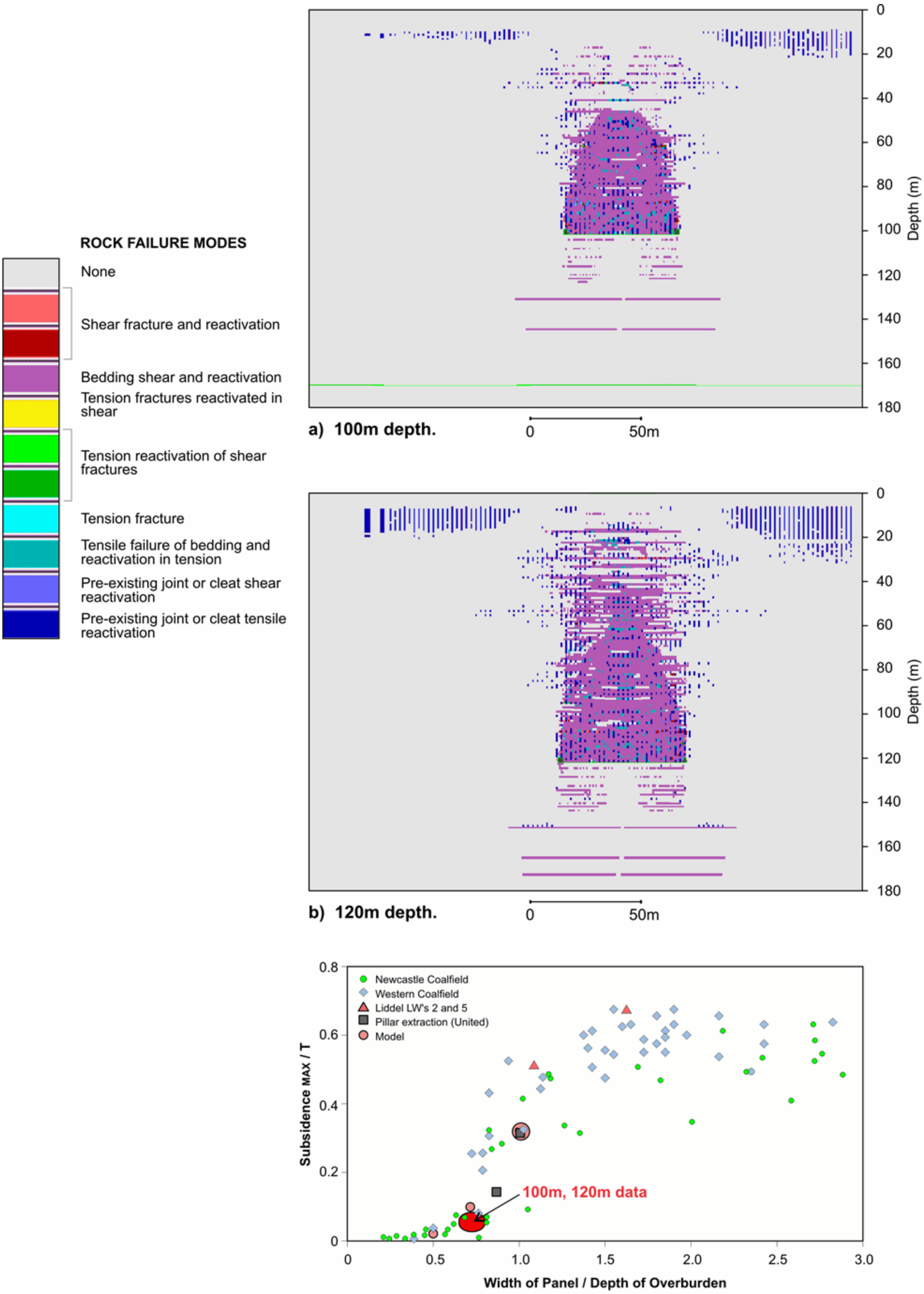


Figure 11 Overburden fracture and subsidence characteristics at 100m and 120m depth at a width to depth extraction ratio of 0.7.

A further model was developed to assess the impact of extraction of the Upper Liddell Seam immediately below the Pikes Gully Seam. This was modelled as a superimposed single panel. This model assessed the effect of remobilisation of the Pikes Gully goaf as a result of the extraction of the Upper Liddell Seam.

In order to assess the issues in a broader context and at shallower depth, the behaviour of the overburden at 120m with panel width to depth ratios of 0.6 and 0.7 were evaluated. The extraction thickness in the Upper Liddell Seam was 2.4m and the roof was located 26.3m below the Pikes Gully Seam floor. The thickness of alluvial sediments is approximately 8m.

The geometry evaluated is presented in Figure 12 together with the geotechnical section. It should be noted that this is purely assessing the undermining impacts on overburden stability. The impact of chain pillar behaviour and larger scale interactions has not been assessed at this stage.

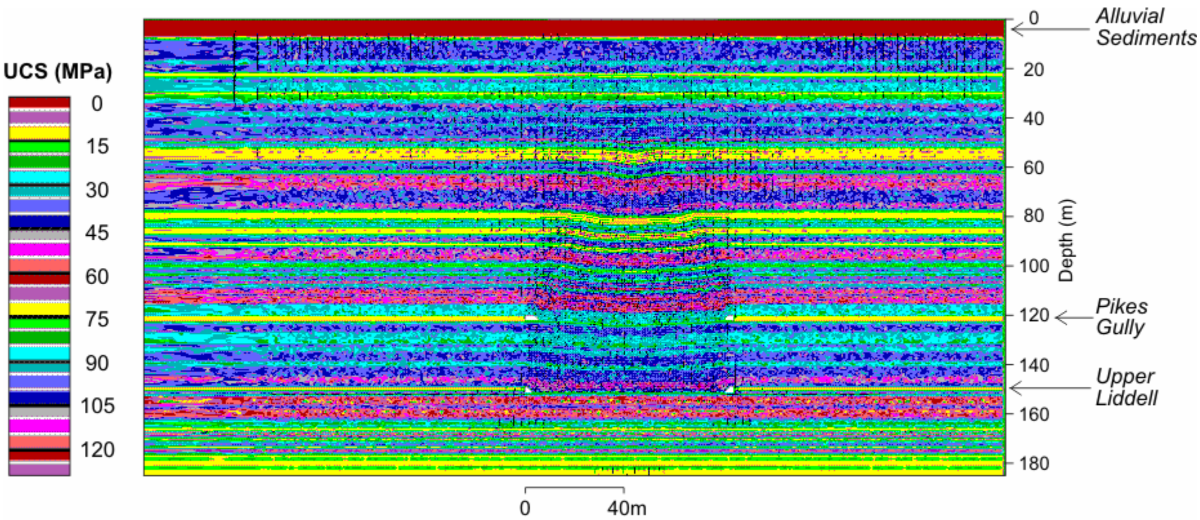


Figure 12 Multi seam geometry assessed.

NOTE: *Width of panels varied to suit w/d ratio of 0.6 and 0.7 at Pikes Gully level.*

The overburden fracture geometry at the time of mining the Pikes Gully Seam is presented in Figure 13 for the two panel geometries. The height of major caving zones is presented in Figure 14. An extensometer plot of vertical displacement through the overburden is presented in Figure 15. This plot indicates where significant strata dilation is occurring.

These syntheses of the results indicate thickness of substantially un-impacted overburden for the two cases is approximately 35m for w/d of 0.7 and 65m for the 0.6 w/d panel. Subsidence for the 0.7 and 0.6 geometry is approximately 85mm and 35mm respectively. The subsidence is very small and the nature of the strata within these un-impacted zones is such that the vertical conductivity would be expected to be similar to the in situ state.

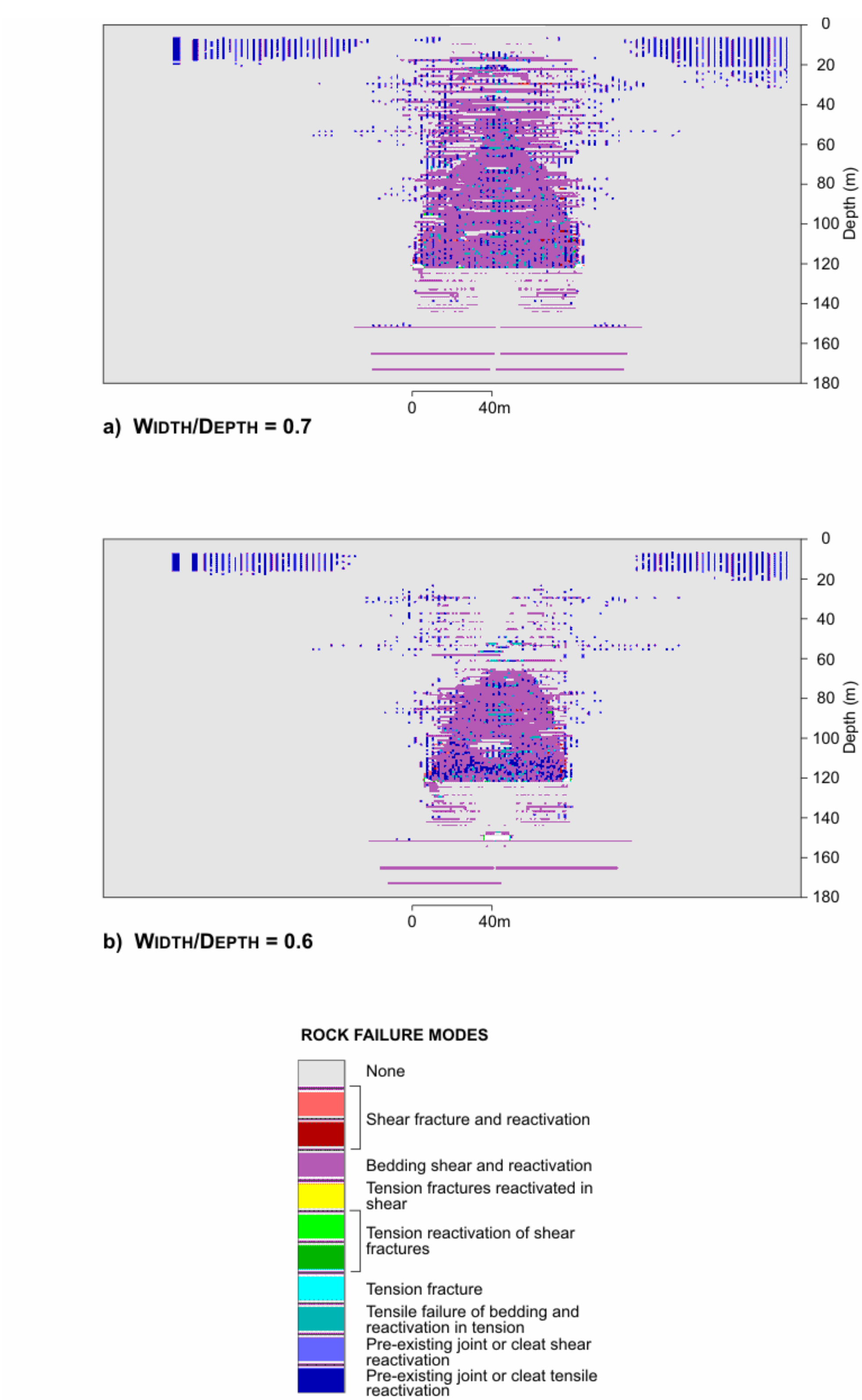
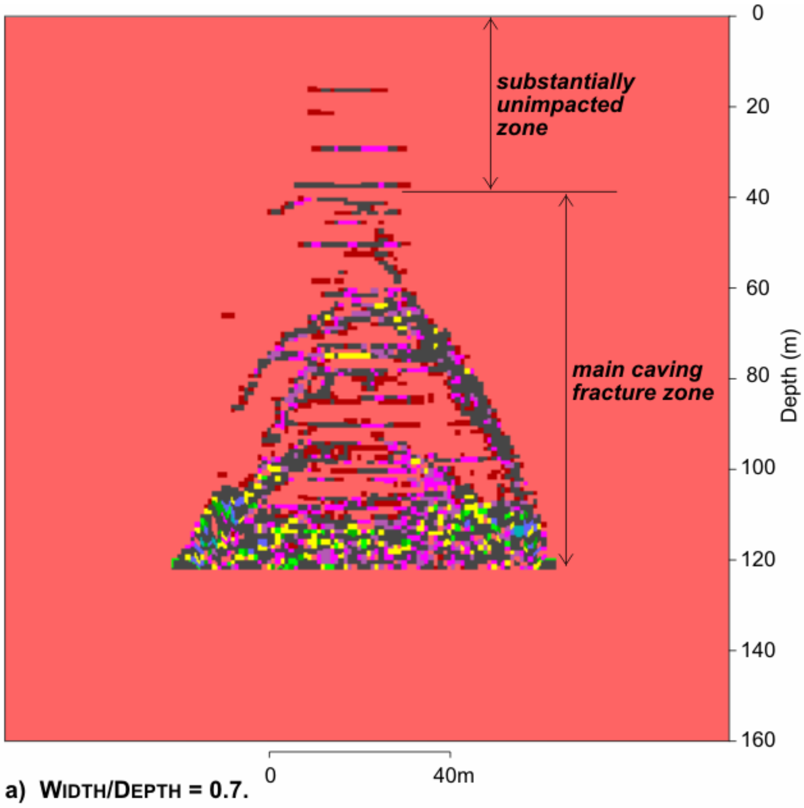
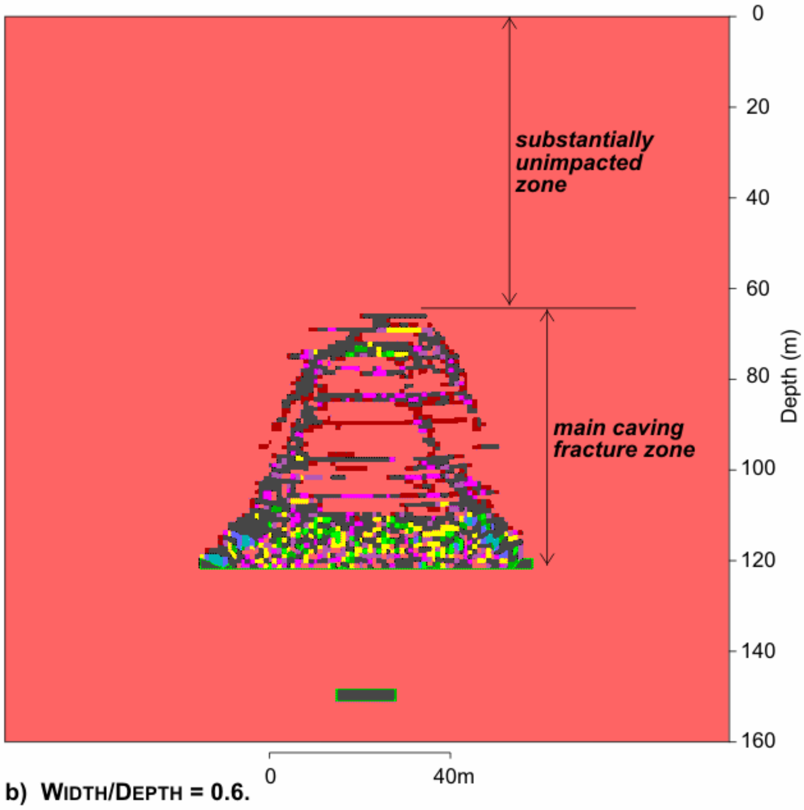


Figure 13 Fracture geometry during Pikes Gully extraction for w/d of 0.6 and 0.7.



a) **WIDTH/DEPTH = 0.7.**



b) **WIDTH/DEPTH = 0.6.**

Figure 14 Height of major caving zones during Pikes Gully extraction for w/d of 0.6 and 0.7.

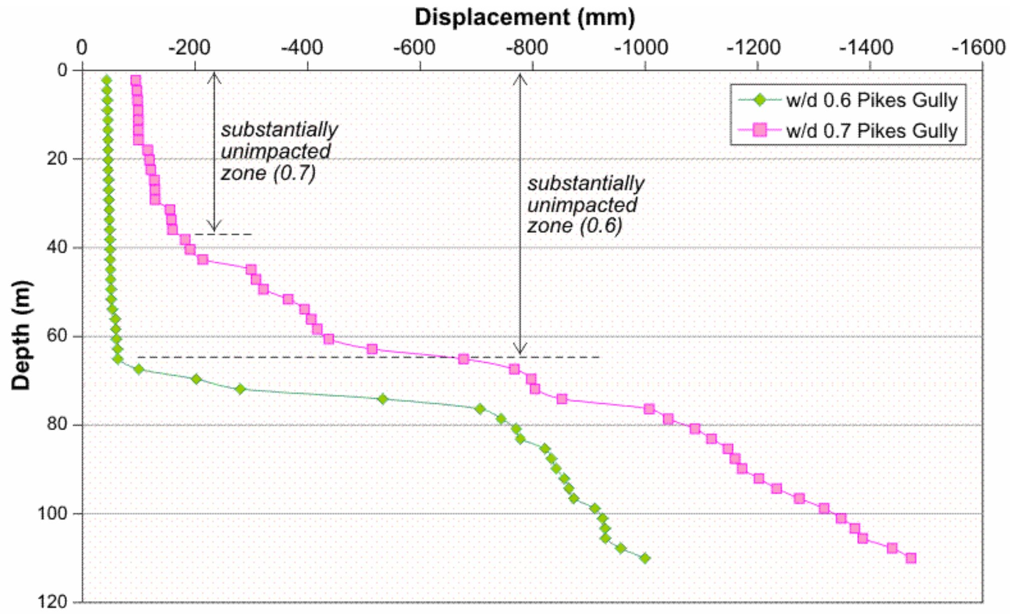


Figure 15 Vertical displacement above Pikes Gully extraction panel centreline for w/d of 0.6 and 0.7.

The effect of mining the Upper Liddell Seam directly under these panels is presented in Figure 16 which shows the fracture geometry and major caving zones for the panels. The results indicate that there is remobilisation of the overburden for both the panels which causes the height of fracture to extend and reduce the barrier zone to the alluvial sediments.

An indication of the impact can be seen in the caving characteristics of the overburden as defined in an extensometer plot of displacement down through the overburden above the centre of the panel. This is presented in Figure 17 for the Pikes Gully and Upper Liddell Seam extraction.

This strata dilation and caving related movements extend up higher in the overburden with the panel geometry of 0.6, however an intact overburden zone of approximately 40m is maintained. The strata dilation and displacement in this zone is depicted in the extensometer plot presented in Figure 17 (a).

The fracture, caving zones and extensometer data for the 0.7 panel is presented in Figure 17 (b) and indicates that strata movement extends up to approximately 13-25m from the surface.

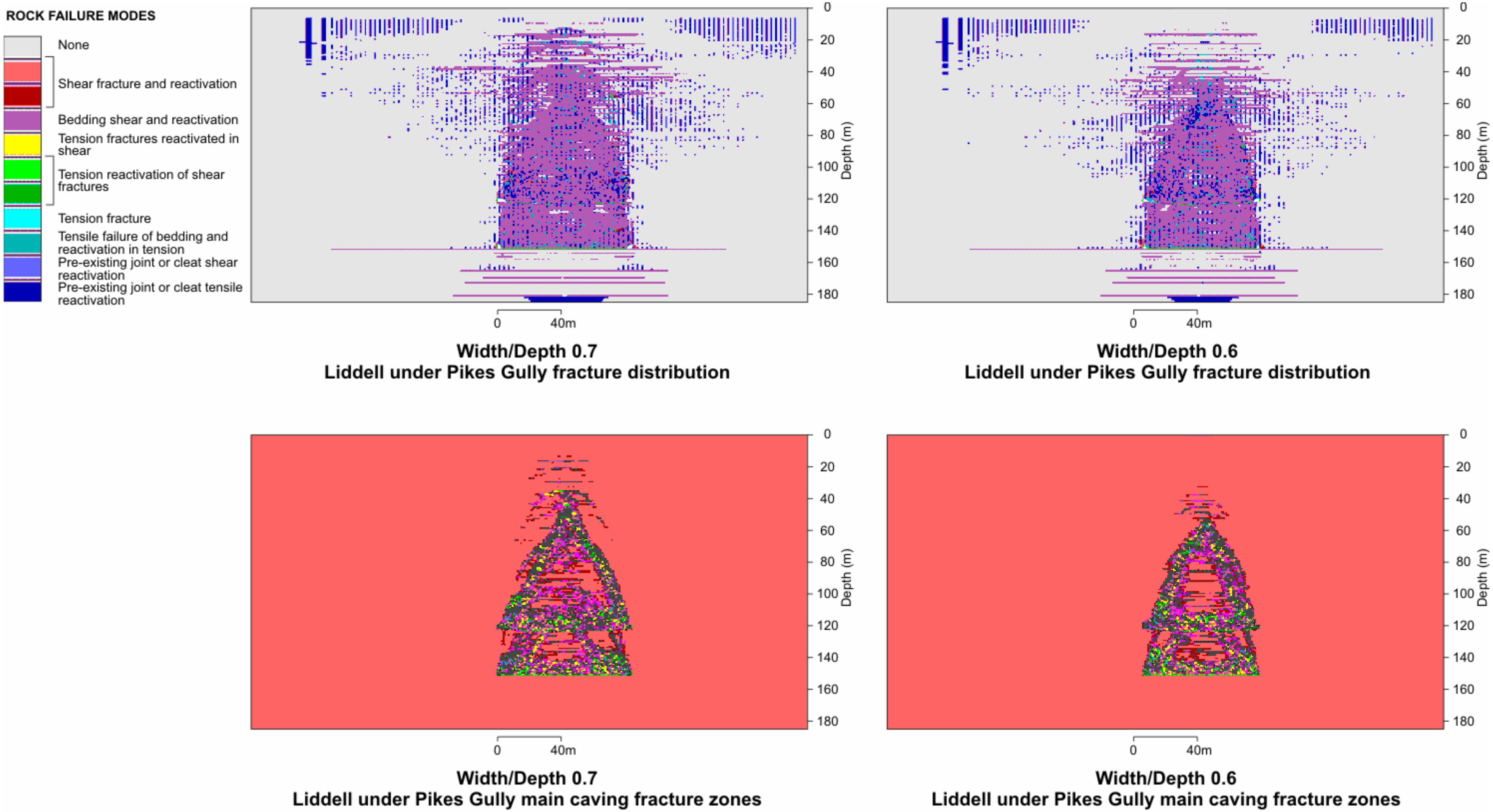
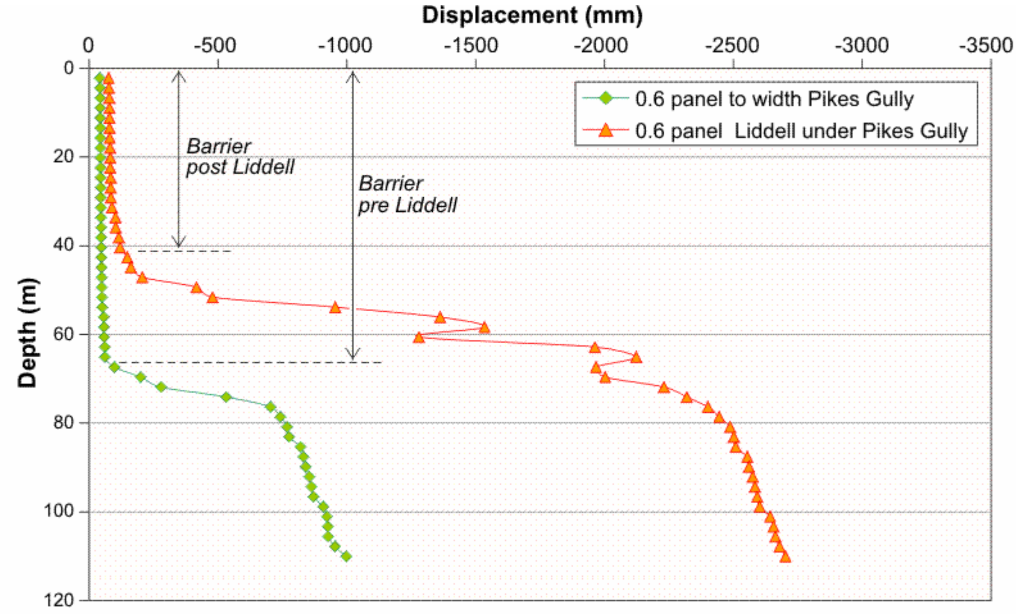
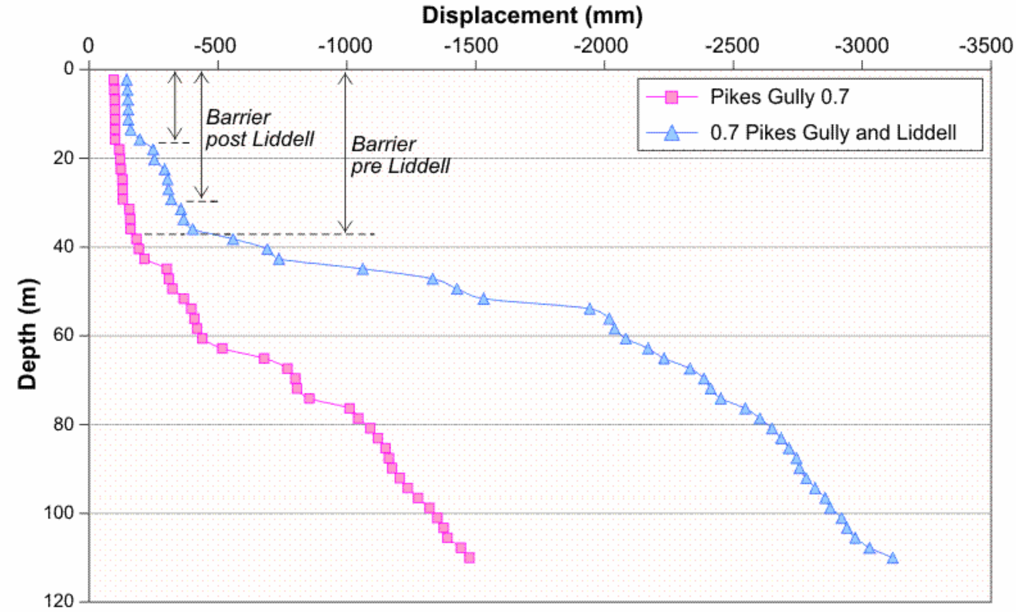


Figure 16 Impact of undermining Upper Liddell Seam on fracture distribution and major caving zones Pikes Gully Seam.



a) Extensometer plot down centre of 0.6 panel for Pikes Gully and Liddell extraction.



b) Extensometer plot for width to depth ratio of 0.7.

Figure 17 Vertical displacement above Pikes Gully panels after extraction of Upper Liddell Seam.

4.2 Multiple Panel Effects

In this section, the impact of chain pillar yield on overburden fracture and caving was assessed. Yield of chain pillars is a common occurrence in mines where the factor of safety for the pillars is designed to maintain tailgate stability rather than maintain the chain pillar strength when isolated in the goaf. The impact of this form of design has been evaluated by choosing chain pillar dimensions which display yield in the model.

The panel geometry modelled related to a cross section across mini walls 6 to 9 whereby a panel width to depth ratio of 0.6 was used for mine planning. The approximate location of the model section is presented in Figure 18a.

The location and mode of fracture about the panels and pillars is presented in Figure 18b. The amount of subsidence over the mini walls was in the range of 160-220mm prior to Longwall 9. The subsidence increased toward 1.2 m over Longwall 9 and caused a small increase in subsidence over the rest of the panels, resulting primarily from chain pillar compression.

The subsidence effects of multiple panel extraction are presented in Figure 19.

The results indicated that the chain pillars based on 30m centres would yield due to fracture of the strata above the pillars. The strength of the coal pillar itself is not the issue but fracture of strata in the initial 20m above the Pikes Gully Seam. The chain pillars have yielded but are carrying close to the tributary load. In a situation where the chain pillars were to yield substantially then the overburden deformation is likely to increase and spanning characteristics would be reduced.

In order to mitigate against such effects the mine plan was adjusted so that chain pillars increased from 30 to 35m centre to centre between sub critical panels in the mini wall layout such that the factor of safety is at least 2.5 for each chain pillar.

4.3 Overburden Caving

The caving of the overburden for the initial panel shows similar characteristics to that previously modelled for a single panel.

When the subsequent panels are mined, the height of caving related fracture and potential connection increases to the level that was found when the Liddell Seam was mined under a single Pikes Gully panel. The main caving zones developed are presented in Figure 20. This indicates that the chain pillar yield which occurs for additional panels in the Pikes Gully has the same effect in modifying the goaf and overburden as was the case with undermining.

The overall impact is that for a layout having a width to depth ratio 0.6 there is approximately 40m of barrier to the surface. This is the same as for the multi seam case previously modelled.

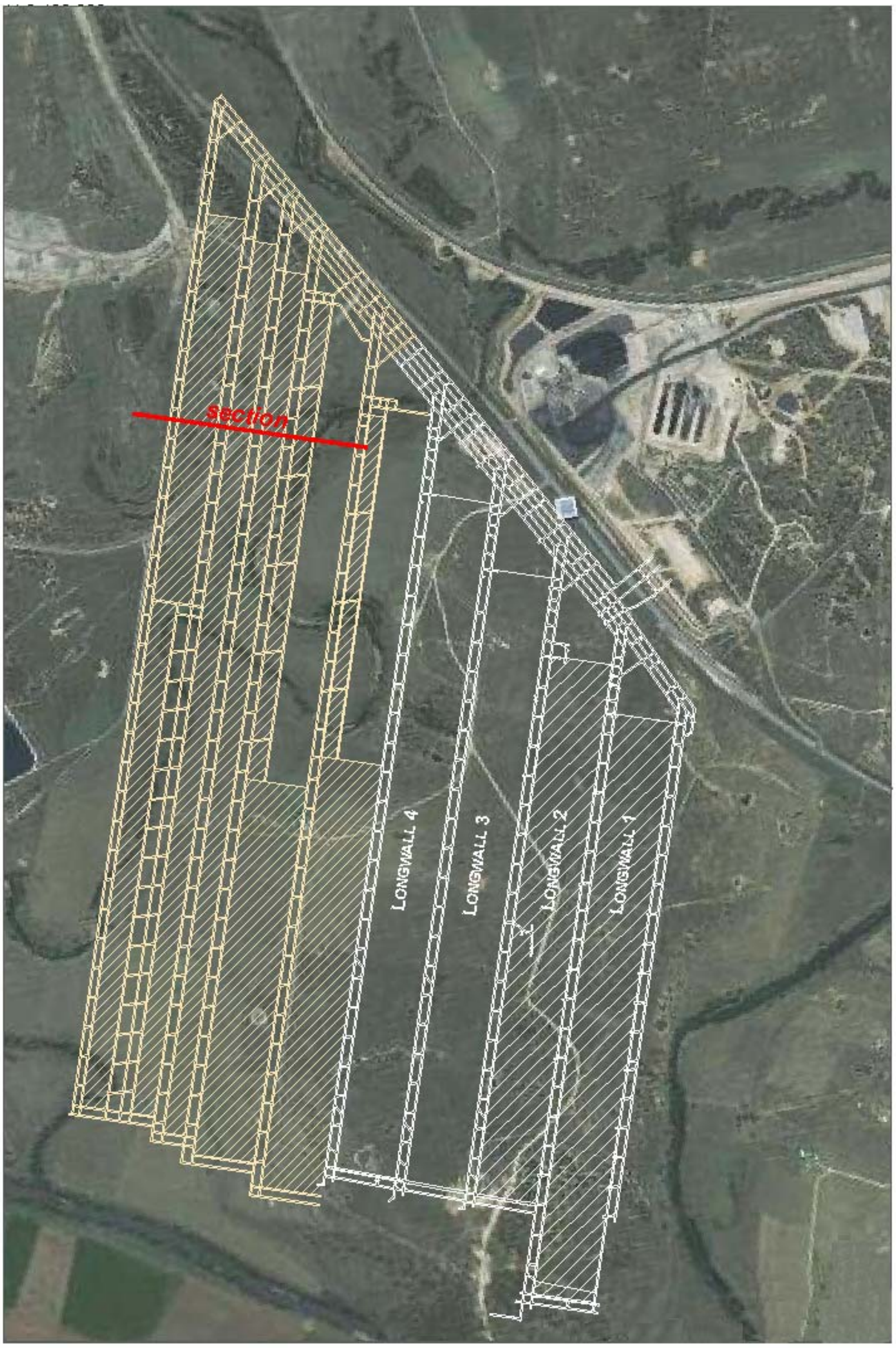


Figure 18(a) Approximate location for modelled cross-section of miniwalls 6-9 based on a width to depth of 0.6 with subcritical chain pillars designed to a Factor of Safety of 2.5.

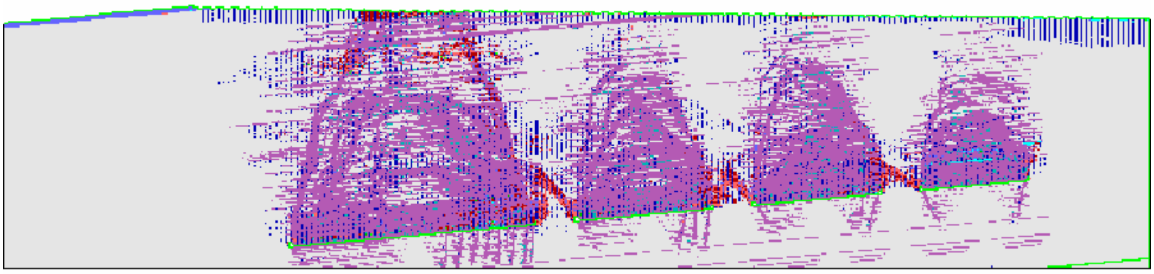


Figure 18(b) Fracture mode and distribution for miniwalls 6-9. Miniwall 6 is on right hand side.

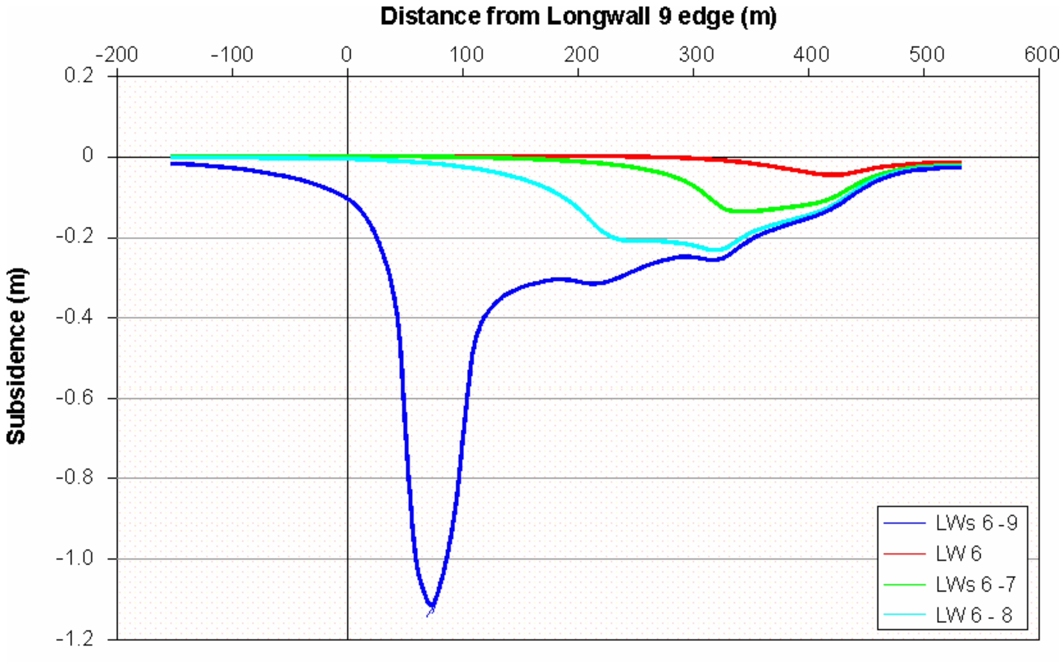


Figure 19 Subsidence profile over miniwalls 6-9.

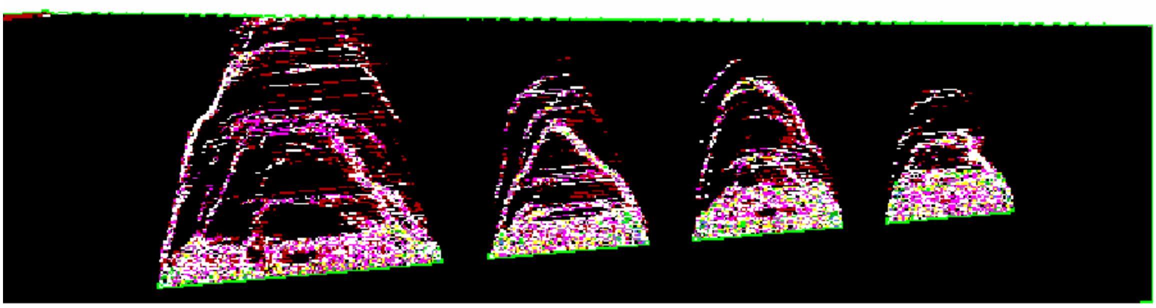


Figure 20 Main caving zones formed for miniwalls 6-9.

The extensometer plots down through the centre of each panel are presented in Figure 21. The comparison with the previous undermined case is shown also.

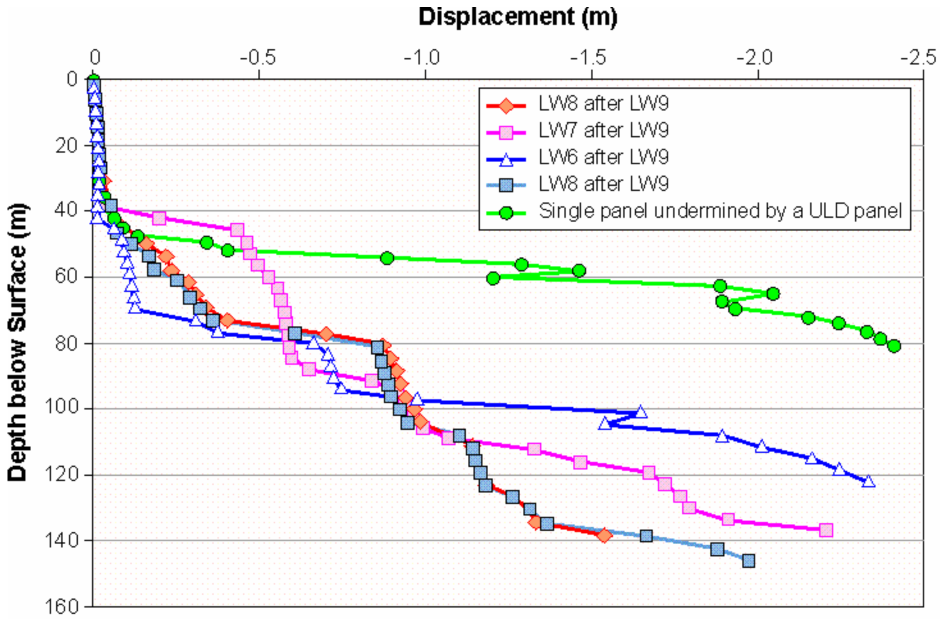


Figure 21 Overburden displacement above centre of miniwalls 6-9.

5. DISCUSSION AND CONCLUSIONS FROM THE MODELLING STUDY

The subsidence obtained from the models provided results consistent with the empirical expectation for the area and that from monitoring of Longwall 2.

The results of the modelling at 150m depth indicated that tortuous connection to the surface would occur for normal width longwall panels (210m) in the Pikes Gully Seam. Single panels having a width to depth ratio less than 0.7 maintained a substantially un-impacted overburden zone under the surface and alluvial sediments associated with Bowmans Creek.

In the shallower parts of the area results for single panels having widths to depth ratios of 0.6 and 0.7 indicated that at 0.6 a clear barrier of essentially undisturbed overburden existed for approximately 65m below the surface. This barrier zone had reduced to approximately 35m for a panel geometry of 0.7.

Undermining in the Upper Liddell Seam in the 0.7 panel geometry caused the strata dilation to extend very close to the surface and it would be conceivable that the flow barrier to the alluvial sediments could be compromised in this situation.

Undermining of the 0.6 panel geometry caused dilation and caving movements to extend higher but a substantially intact zone of 40m to the surface remained. A similar effect was noted for multiple panels whereby a substantially intact zone of 40m was maintained for panels having a width to depth of 0.6.

An initial review of the conductivity of the overburden barrier related to the 0.6 geometry indicated that average conductivity was approximately similar to the in situ state and that water pressure within the barrier zone was close to hydrostatic. This indicates that the flow through the barrier was controlled by a relatively un-impacted strata section. The hydrological implications of this will need to be reviewed in larger scale model.

These results indicate that there is some variability in the goaf compaction process and in the overburden spanning capability. This variability is likely to be reflected in the regional database in terms of the relative scatter in results for a particular width to depth geometry. The scatter will also relate to variation in geological section.

The computer simulation of the 0.7 geometry indicated that approximately 35m of overburden remained under the surface to act as a flow barrier during mining of the Pikes Gully Seam. However, the results from undermining the Pikes Gully Seam indicate that the overburden is sensitive to changes in the goaf formation and as such variation in overburden characteristics may modify the effective barrier thickness. It is conceivable that changes in goaf formation and reduction in flow barrier thickness may occur if weaker strata, more extensive subsurface weathering and structural weakness exist.

The adoption of the w/d depth ratio of 0.6 for Pikes Gully Seam provides a robust design that takes into consideration both the effect of multiple adjacent panels as well as preliminary multi seam impacts. This layout will mitigate against the risk of interconnection during mining of the Pikes Gully Seam and is therefore recommended for panels under sensitive areas of the Bowmans Creek alluvial sediments.

6. EXPERIENCE OF WATER INFLOW INTO MINES

Experiences of water inflow into mines has been reviewed to provide another basis for assessment of panel geometries appropriate for water inflow control. The data collated is associated with a concurrent ACARP Project (C13011), however more specific assessment has been made of that data with reference to this site. The data used is a mix of published data and confidential information. As such only part of the data set will be referenced to location.

It should be noted that the understanding and data available for analysis in this technical field has been evolving over the last 5-10 years. The application of computer modelling and field measurements have greatly increased the general knowledge in this field, however it is still realised that this area is an evolving science, which requires ongoing monitoring and review of experience.

The data presented in this report is categorised in terms of confirmed inflow and no flow. The sites having flow may be based on actual inflow experience. Sub-sets of the data have been collated for sites at which remedial repair has been conducted to provide a water resistant seal against future inflow. It should be noted that the amount of flow has not been categorised in the data. It is noted in the literature that the term inflow commonly refers to an obvious and significant ingress of water into a mine, rather than a slow (potentially tortuous) flow which may not be readily perceptible, but is greater than the pre-mining situation. The data contained in this data set primarily relates to significant inflow rather than slow seepage flow.

The results of the study are summarised in Figure 22, for which the data is presented relative to depth and panel width. The results show that for situations of normal overburden, without significant aquacludes, panels with a width to depth ratio greater than 1 commonly show confirmed connection. Panels with a width to depth ratio of less than 0.4 (in this data set) show no connection. The sites categorised as having aquacludes are those which have significant clay layers (i.e. 4m+) between the aquifer and the normal rock section or have low permeability aqueous deposited silt layers above the normal rock section.

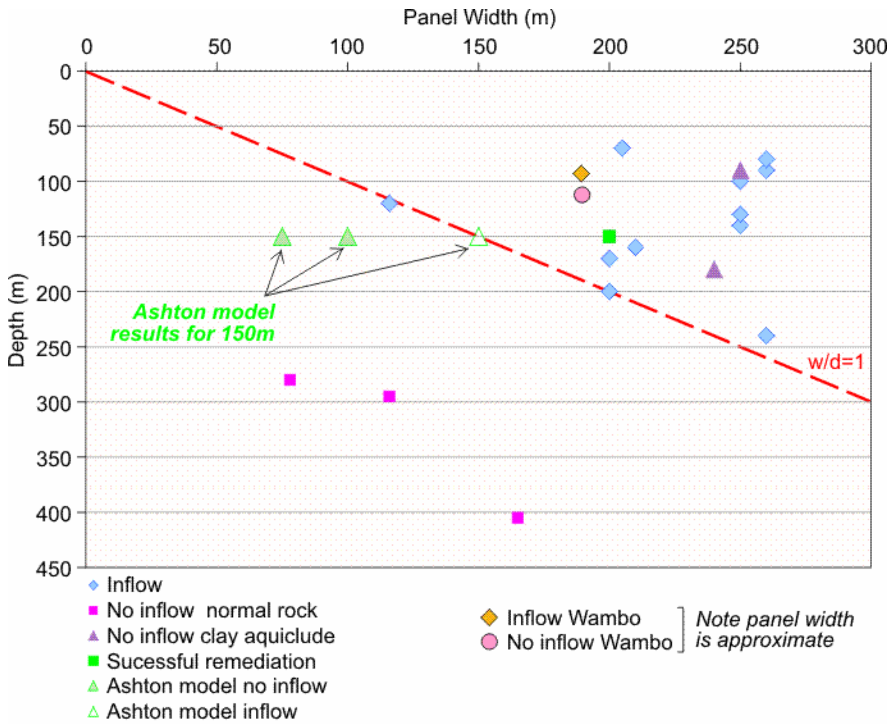


Figure 22 Water inflow experience with longwall panels.
NOTE: Modelled data included.

Examples of sites for which the existence of significant clay layers have controlled the inflow of water for geometries having width to depth ratios greater than 1 include Crinum and Gordonstone (Kestrel) Mines. These sites have significant sections of clay rich layers which are sufficiently compliant and have sufficiently low permeability to maintain an effective seal between the water source and the fracture zone. These are relatively unique in the overall database.

Similarly, sites at Oaky Creek for which inflow was noted were subsequently repaired by ripping and compacting the surface to perform as a low permeability membrane (generally $1e^{-8}$ m/s or less) above the fractured rock section.

The sites at Crinum, Gordonstone and Oaky Creek (repaired surface) are consistent with the concept of having a low permeability section which is able to control the flow between the water source and the mining induced fracture zone.

There are instances of ash dams for which limited flow occurs or which remain intact above extraction panels. The permeability of sub-aqueous deposits within ash dams are typically low (1e-9m/s or less) whereas the permeability of the overburden below the dam may be several orders of magnitude higher. Mannering Creek ash dam is one instance which was undermined by Wyee State Mine (Longwall 4) without major issue. It is not conclusive (to the author) as to whether it was breached and subsequently healed. This instance is viewed as an extension of the aquaclude scenario for which the compliance of the low permeability silt/clay lining is sufficient to survive the strains imposed by mining, or can subsequently "heal" the initial cracking. Mining under Lake Macquarie (Wyee longwall panels) has occurred without significant impact, however these occurrences are considered to be relatively unique. The nature of the conglomerate overburden in this area appears to significantly limit the amount of subsidence and probably does not fall within the "normal rock grouping" from a subsidence characteristic viewpoint. Therefore the Wyee data is considered to fall within the aquaclude category or in a special overburden category rather than be part of the "normal rock section" data set. It is considered that the base of the lake is composed fine silts which have very low permeability characteristics.

Mining has occurred under the Pacific Ocean at Burwood Mine, however the mine geometry had a width to depth ratio less than 0.3.

Recent research within a current ACARP Project (C13013) indicate that the amount of subsidence and nature of the overburden is also a factor influencing fracture geometry and resultant hydraulic conductivity.

An example of this is the experience at Wambo Mine where significant inflow occurred under a creek with an overburden of approximately 90m. Significant inflow was not noted at depths of approximately 110m and greater. The width to depth ratio is over 1.5 at the site of no reported inflow at 110m depth. These results suggest that major inflow is not only w/d related but also a function of the height of the highly connected zone.

Experience from the UK mines which operated under the sea, indicated that water inflow was not noticeable for strain values less than approximately 4mm/m on the water bearing aquifer, but as the strain increased water inflow also increased. For values greater than 10mm/m significant inflows were noted which impacted on the mining operation. The data suggested that the amount of subsidence and thickness of overburden were key factors.

This relationship is presented in Figure 23 relative to depth and the amount of subsidence. The depth is derived on the basis of general strain relationships used within the subsidence engineers handbook as applied to the UK data.

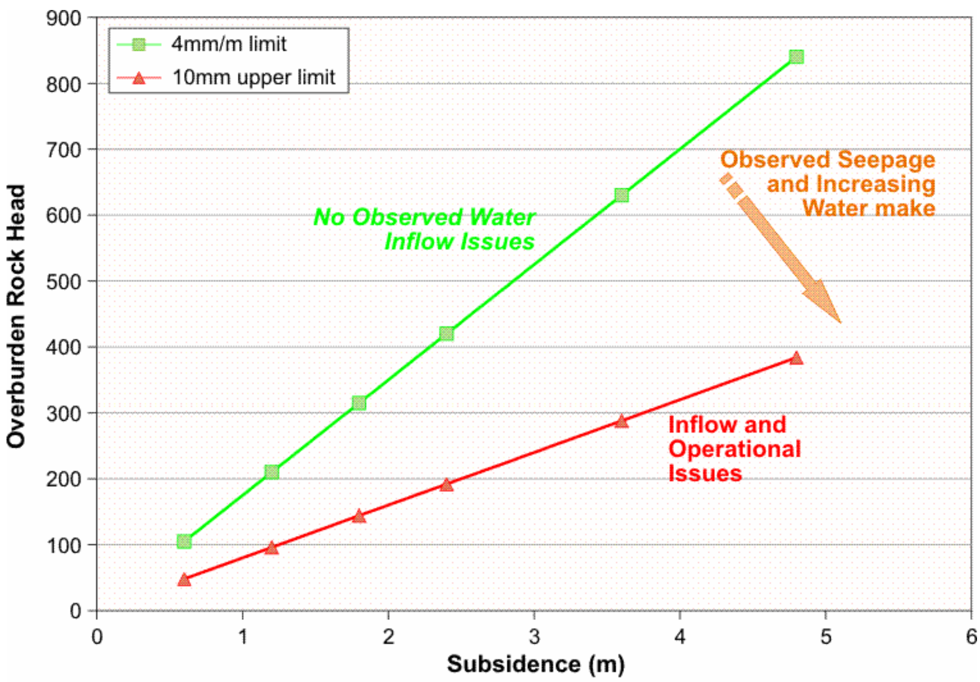


Figure 23 Experience summary from UK under sea operations.

If this analysis is applied to the Hunter Valley, then strain greater than 10mm/m would be experienced at a depth of approximately 100m for subsidence greater than 1.5m. This is consistent with the data reported for Wambo. It is anticipated from the UK experience that lower (seepage) flows would occur at the greater depths, but were not obvious.

Overall, it appears that for a "normal rock section" (without aquacludes), longwall panels with a width to depth ratio above 1 have a high probability of cracking extending to the surface and the enhancement of hydraulic conductivity of the overburden. The increase in conductivity and nature of hydraulic connection appears to be related to the magnitude of subsidence and nature of the overburden. In situations of low subsidence, the connection may be very tortuous, whereas with larger subsidence the connection may have low tortuosity or be essentially direct.

7. DISCUSSION OF RESULTS FOR INFLOW POTENTIAL FROM MINING OF THE PIKES GULLY SEAM

The information determined from the modelling and the review of inflow experience for longwall mines is consistent and complementary. It forms a good basis for understanding the key design issues relevant to water flow above longwall panels and is the basis for design recommendations provided in this report.

The term "inflow control" relates to the instance where the conductivity of the overburden controls the flow for a required outcome. Other workers have recognised the occurrence of overburden cracking but note that water migration may be controlled by the existence of a zone of fractured rock for which the fractures are not well connected and which does not allow significant water migration. This has been termed the "constrained zone" (Reid and Anderson 1997). For the purposes of this discussion, the constrained zone as depicted in the modelling would be equivalent to the tortuous zone in Figure 10. The degree of interconnection within the constrained zone is controlled to a large extent by the panel geometry and the amount of subsidence.

In this case if the panel is narrow (w/d < 0.6) then the constrained zone has similar characteristics as the in situ strata and would be termed substantially un-impacted natural strata. For wider panels, the constrained zone may exhibit conductivity above the in situ value, however the flow may still be via a tortuous network of fractures.

The modelling and the experience database indicates that in order to maintain a zone of substantially un-impacted strata above the panel, then the panels must be sub-critical.

In overview, a width to depth < 0.6 is one for which the overburden is still substantially bridging over the panel for depths in the range to be experienced under Bowmans Creek (100-150m). A review of the subsidence data (Figure 6) and the modelling indicates that the subsidence for panels having a width to depth ratio less than 0.7 is low.

The subsidence data used for this analysis is presented in Figure 6 highlighting the anticipated subsidence at Ashton and that noted in the region. The aim of this is to define the subsidence characteristics expected for Ashton but ensure that the design would be robust to cope with the upper bound found in the empirical data set for the region. The upper bound is presented in Figure 6 and highlights that the data scatter for panels having a width to depth range of 0.6 is very low. Panels with a width to depth ratio of 0.7 have a wider scatter. This is consistent with a review of subsidence in the Newcastle region undertaken by Kapp which indicated that subsidence for panels having width to depth ratios less than 0.6 had an essentially a stable spanning overburden.

Modelling indicates that subsidence for mini walls 6-8 having a width to depth ratio of 0.6 is anticipated to be in the range of 160-220mm. A significant component of the subsidence is related to chain pillar compression rather than sag subsidence between individual panels.

The modelling indicates that the integrity of the overburden would be maintained for panels of width to depth ratio of 0.6 and the empirical database indicates that the potential range of subsidence is narrow and close to the predicted behaviour. An alternate assessment can be made by plotting the anticipated subsidence and depth on the empirical water inflow criteria. This has been done in Figure 24 and indicates that the mini wall geometry would mitigate the risk of interconnection with the Bowmans Creek alluvial sediments.

In order to obtain another assessment of the risk of interconnection, the amount of subsidence that would be required to cause a connection can be determined from Figure 24, to be approximately 700mm. This represents a smax/seam thickness of approximately 0.25.

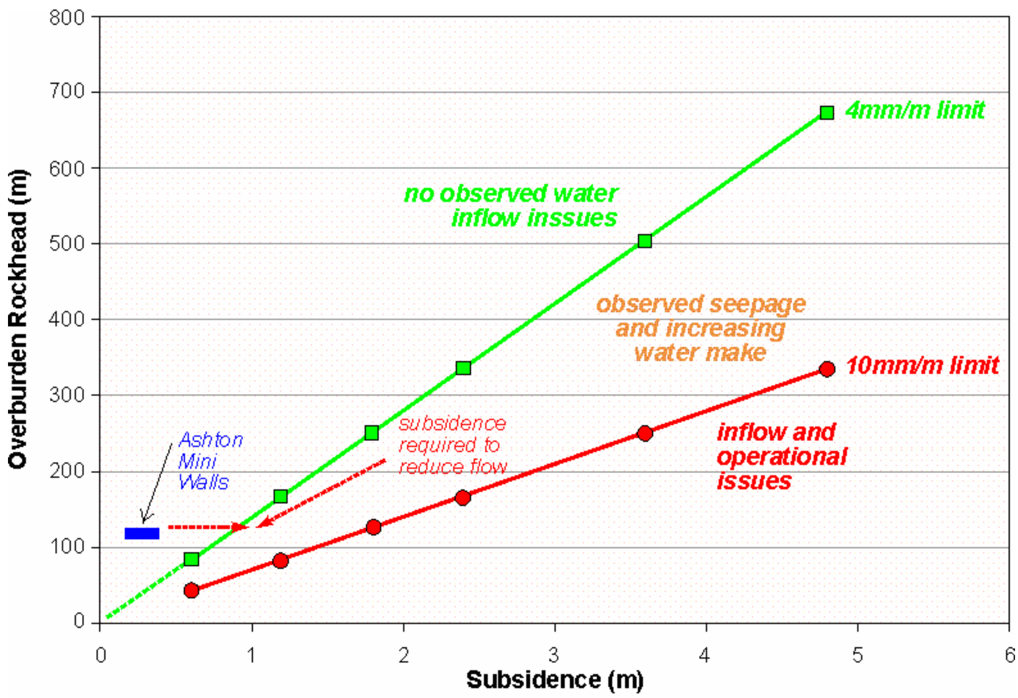


Figure 24 Subsidence and depth criteria for strain based interconnection - UK undersea experience.

This is plotted on the subsidence data in Figure 25 as the red line (onset of increased conductivity) and indicates that under the worst case of measured data, the subsidence required to induce an incipient flow (4mm/m) is at 3-4 times greater than the maximum measured data point based on the 0.6 w/d ratio.

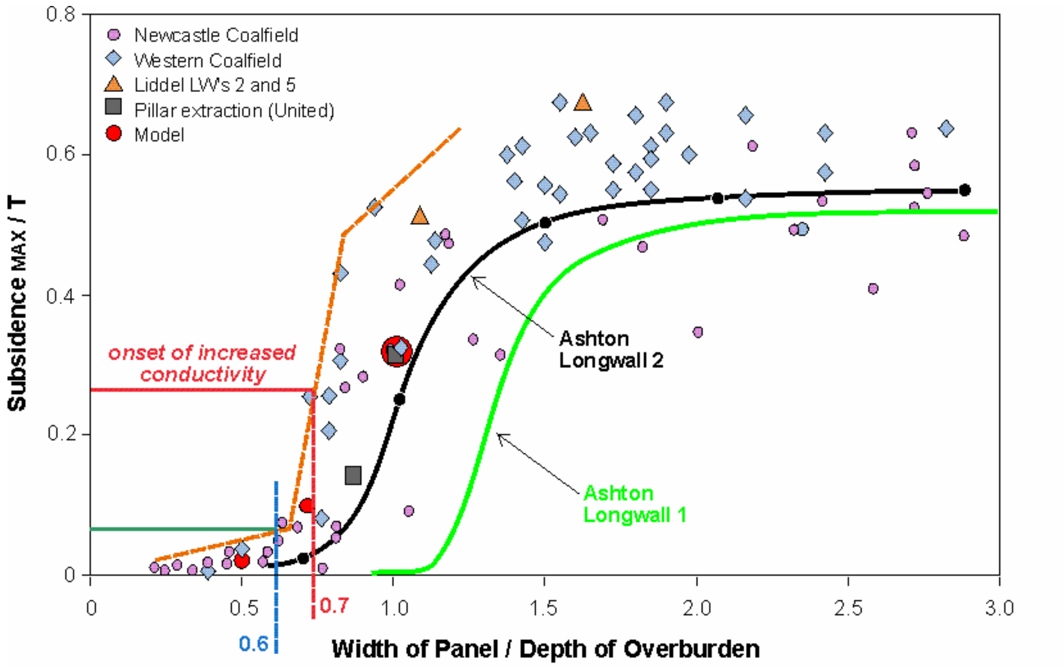


Figure 25 Regional subsidence data for Hunter and Western Coalfields. NOTE: Local data and modelled data included.

This analysis gives confidence that the width to depth ratio of 0.6 is a robust design for the site.

The same approach applied to a panel having a width to depth ratio of 0.7 indicates that under the expected conditions, the overburden integrity would be maintained, however under the worst case conditions the amount of subsidence to induce incipient flow would be initiated.

These results are very similar to the modelling outcomes and provide a level of validation for the methodology. However, it is based on published subsidence data available to the author as presented in Figure 6. It is recommended that an ongoing review of subsidence data for panels having a width to depth less than 0.7 be undertaken to ensure that the design assumptions are confirmed.

The width to depth criteria provide a good guideline for the ability to create a stable overburden geometry and the estimated conductivity of the strata above panels of various width to depth ratios. The actual flow system and volumes which result from the various mine geometries will need to be assessed on the basis of regional flow modelling.

It should be noted that the impact of faults and dyke has not been taken into account in the modelling. To some extent, the impact of general structural features is within the general experience and subsidence data sets. In general, for panel geometries having a width/depth ratio less than 0.6, the conductivity of structures would not be anticipated to be significantly enhanced in the constrained zone within the overburden.

However where significant structural features exist, their impact will need to be assessed on a case by case basis.

The effect of multi seam mining is also a variable on the system for which the experience database is not directly applicable. The impact of subsequent mining in lower seams will need to be evaluated further to assess the overall mine design requirements for extraction of the subsequent seam.

8. REVIEW OF LONGWALL 1 CAVING AND OVERBURDEN CONDUCTIVITY WITH REGARD TO VALIDATION OF THE MODELLING PROCESS

A review of the subsidence and conductivity of the fractured overburden above Longwall 1 has been undertaken. The review has involved both physical measurements and computational modelling of the caving process.

The modelling of Longwall 1 was done as part of a validation process to confirm the application of computer simulation to predict overburden fracture distributions and the related hydraulic conductivity of the fracture systems. The overall application of the modelling is to assess accuracy of the modelling process as applied above in the deeper cover under Bowmans Creek.

Physical measurements undertaken of Longwall 1 include:

i. subsidence profiles;

ii. Helium injection into the goaf from underground sites;

iii. Helium injection into the goaf at various depths via a vertical borehole (WMLC 195);

iv. water quality and flow balances underground at the maingate and tailgate side of Longwall 1;

v. piezometer monitoring of water pressure over the Ashton mining area.

The subsidence data is summarised in SCT Report ASH3342 and the field monitoring studies are summarised in SCT report ASH3305. Water flow and quality is reported elsewhere (P. Dundon).

Computer modelling of the caving, stress redistribution and rock fracture process was undertaken for a two dimensional cross section located close to maingate 21 Cut-through. The geological section used for the section was based on a general review of boreholes in the area, but largely related to WML 107. The geotechnical properties were estimated from geophysical data, regional rock testing information and from testing of core samples from the site.

9. LONGWALL 1 MODEL GEOMETRY

The model was created as an "E-W" cross section at approximately 21 Cut-through (maingate) which included surface topography and seam dip. The model extends from Glennies Creek on the East to approximately Longwall 3 on the Western boundary. The section is presented in Figure 26. The depth to seam ranges from approximately 50m to 90 across the model.

The model geotechnical section is presented in Figure 27. The strata units are presented in terms of UCS. In order to simulate natural variability in the sedimentary system, the UCS of each layer is allowed to vary within a normal distribution about its average strength.

The element size over the key sections of the model is approximately 1m. Water pressure has been included in the section based on standing water in boreholes, the level of Glennies Creek and piezometer data. Monitoring data indicates that the water pressure below the water table is typically hydrostatic.

A hydrostatic pressure has been used and the hydraulic conductivity of the overburden is based on regional information and is considered to reflect water flow via the natural joint and bedding plane system. The overburden conductivity is modified by confining pressure normal to the flow direction and as such the conductivity reduces with depth and also with higher stress zones in the section. Conversely, conductivity increases in the stress relieved areas of the mine. This method and examples of its application is discussed in more detail in Gale 2005, and Guy et al 2006.

The conductivity of the coal seams is based on site measurements. The conductivity of the Pikes Gully Seam ranges from approximately 1.6e-6 m/s to 2.5e-7 m/s over the depth range of the model. The seam thickness modelled was approximately 2.35m.

The general hydraulic conductivity of the overburden was presented in Figure 5.

Stress field data is based on regional information. Vertical stress is based on an average rock density of 2.5 g/cc and horizontal stress is based on a tectonic strain within the strata and a lithostatic component. The stress field in the near surface area is modified by the surface topography and areas where the strata daylight into the valleys and hills. The overall stress field and water pressure system was in equilibrium prior to simulation of mining within the model.

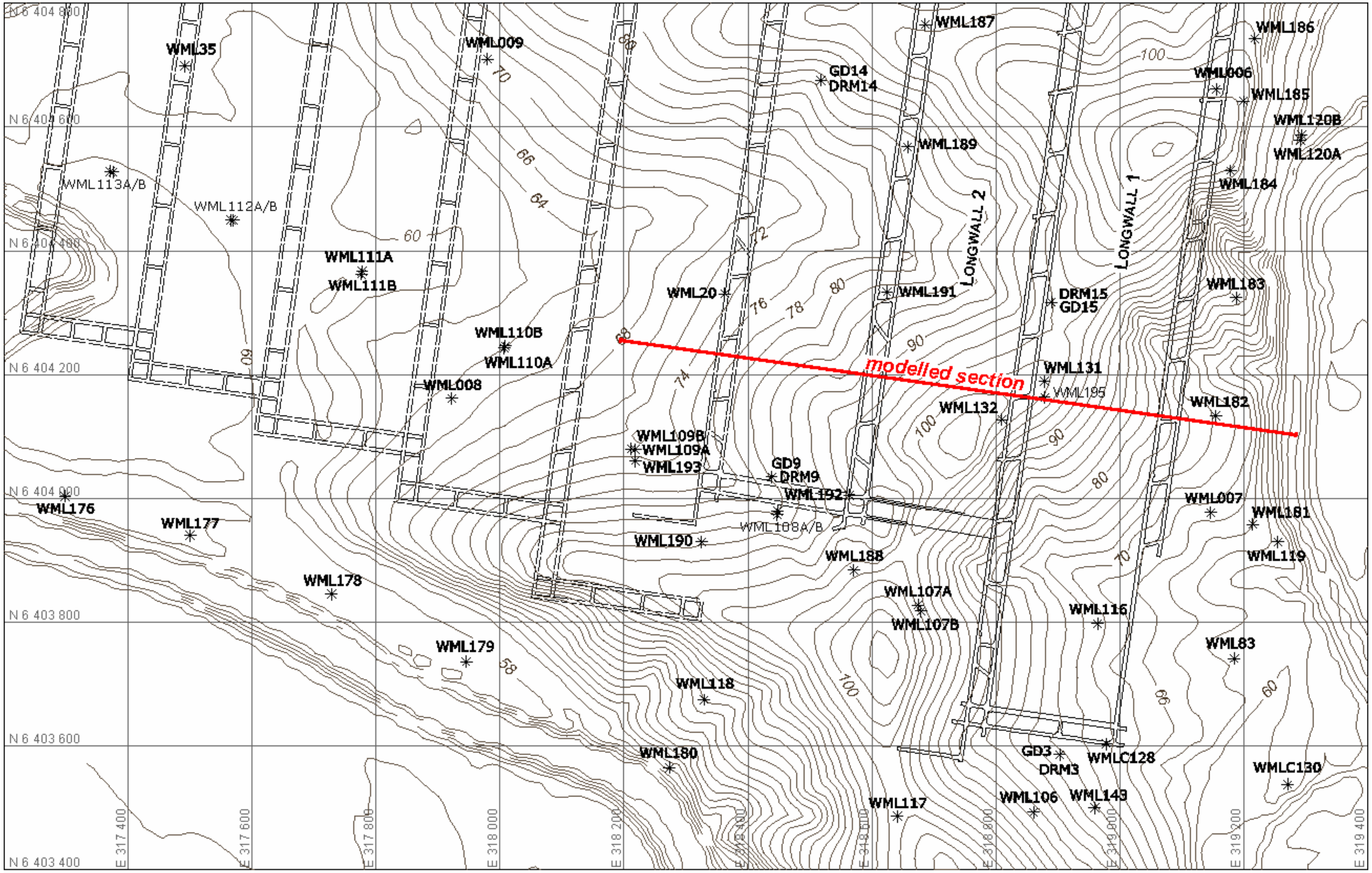


Figure 26 Pre-study panel layout with Longwall 1 section modelled.

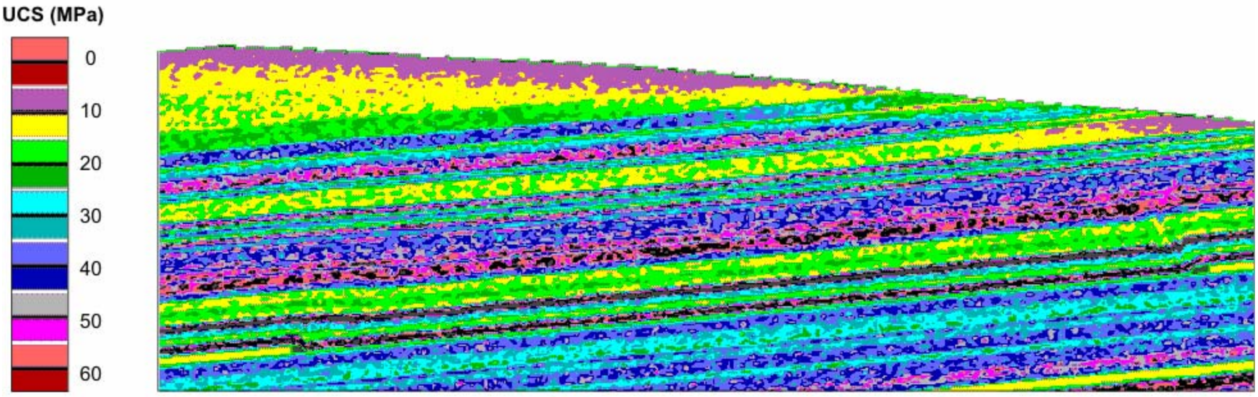


Figure 27 Geological/geotechnical layers in the Longwall 1 model.

10. IMPACT OF GATEROADS ON WATER PRESSURE

The impact of the tailgate and maingate roadways was to cause depressurisation of the Pikes Gully Seam. This caused depressurisation within the strata above the seam as well, which was evident in the piezo data of 107, 189. In general, depressurisation caused by roadways appears to be noted up to at least 150m from the roadways. Flow into the tailgate was noted to be recharged by alluvial deposits associated with Glennies Creek where the coal seam daylighted the creek system. The flow rate into the tailgate at this location was approximately 0.06 l/s per 100 metres of roadway and is very similar to that monitored for the inbye area.

The pore pressure distribution noted in the model after the gateroads of Longwall 1 were mined is presented in Figure 28 and is very close to the monitored data presented in Figure 29. A comparison of results from the model and borehole data is presented in Figure 30 at a distance of approximately 200m. The measured data relates to boreholes located approximately 100m and 300m from Longwall 1 maingate.

This indicates that the in situ conductivity distribution within the model is providing a good fit to measured information.

11. LONGWALL 1 CAVING SIMULATION

The fracture mode and distribution created by extraction of the Pikes Gully Seam is presented in Figure 31. In general, bedding plane shear is a major deformation mode in association with remobilisation of existing joint planes. Fracture of the strata occurs but this is typically associated with subsidence movements rather than due to abutment stresses.

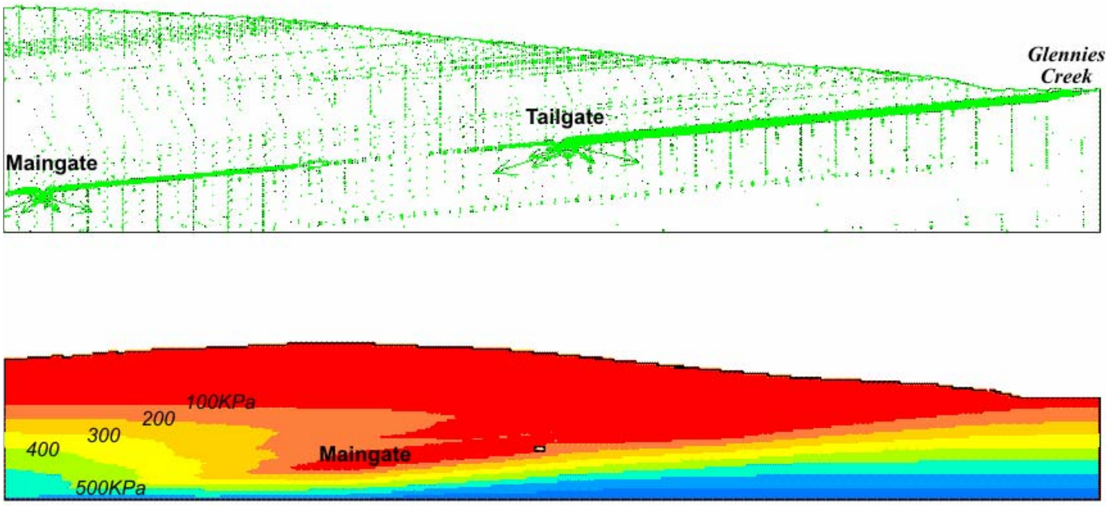


Figure 28 Modelled water pressure in the strata after development of Longwall 1.

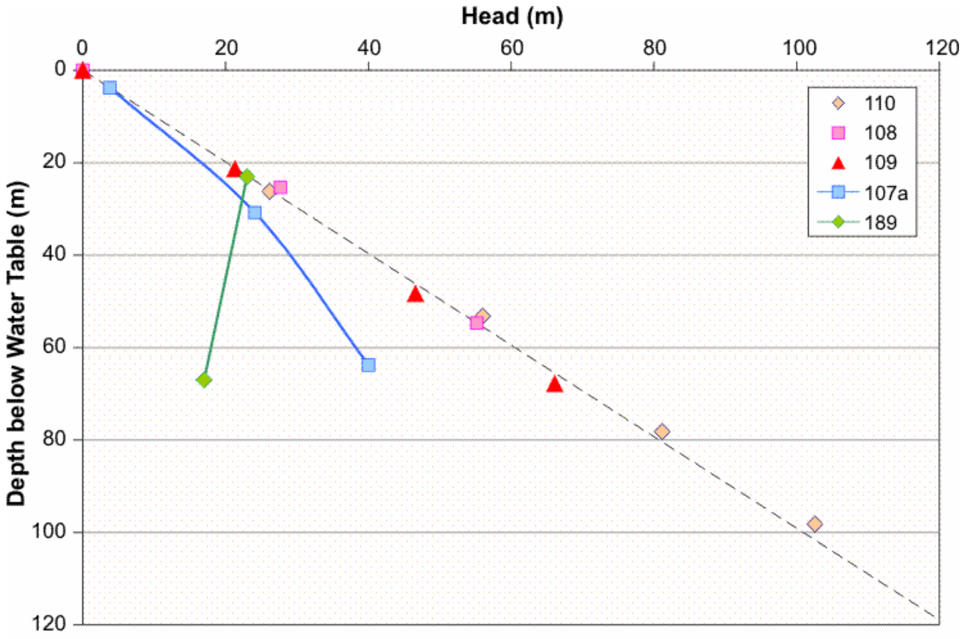


Figure 29 Measured water pressure in boreholes in the area.

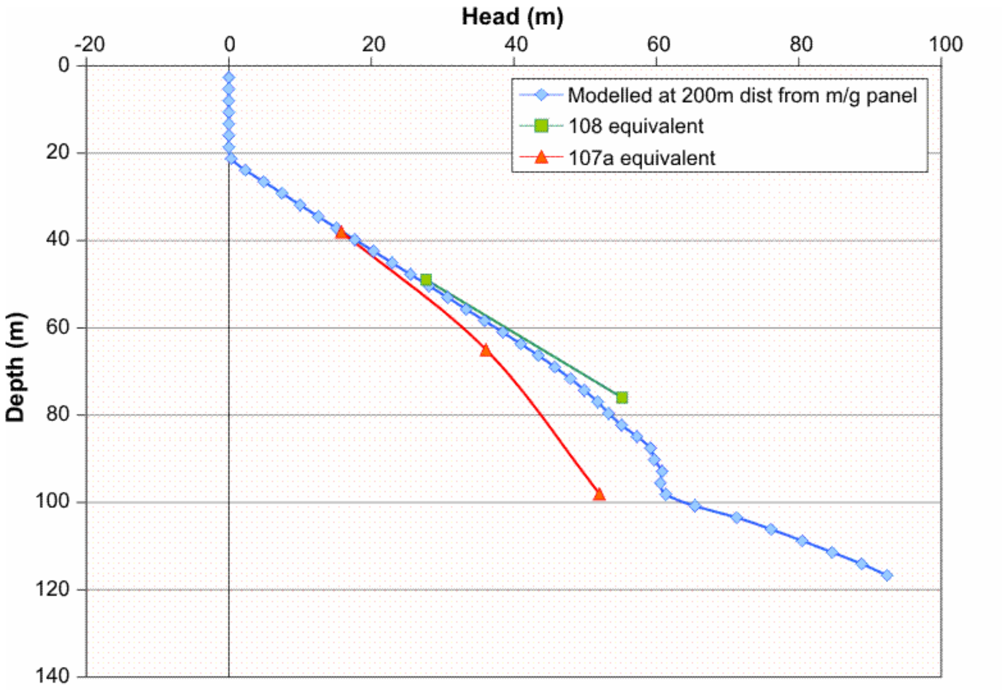


Figure 30 Comparison of modelled and measured data at approximately 200m from the panel.

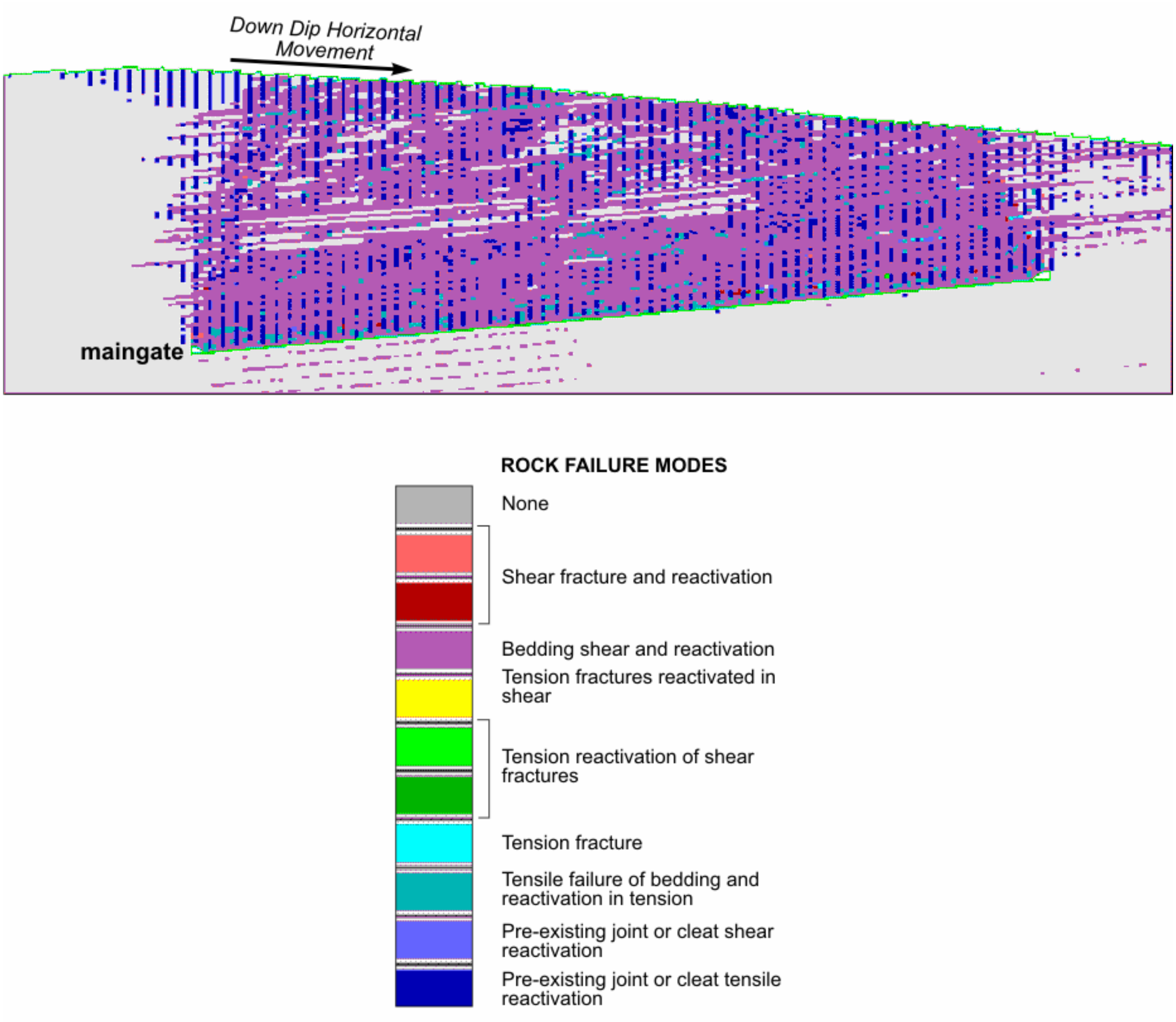


Figure 31 Fracture geometry modelled for Longwall 1.

The pore pressure distribution is presented in Figure 32 and indicates that the goaf and overburden above the panel are depressurised. However the water pressure re-establishes laterally and is not significantly modified past approximately 150m from the panel. This is consistent with the monitoring information.

The overburden movement noted in the model has a significant component of topographic down slope movement, whereby the movement tended to open up joints above the maingate and minimise any tensile fracture opening on the tailgate area.

The subsidence obtained from the model on the tailgate side is presented in Figure 33 together with that monitored in a similar location (Cross Line 1). The subsidence results are very close in terms of maximum subsidence and importantly the slope over the panel edge. The model shows a greater impact of local down slope movement relative to that monitored.

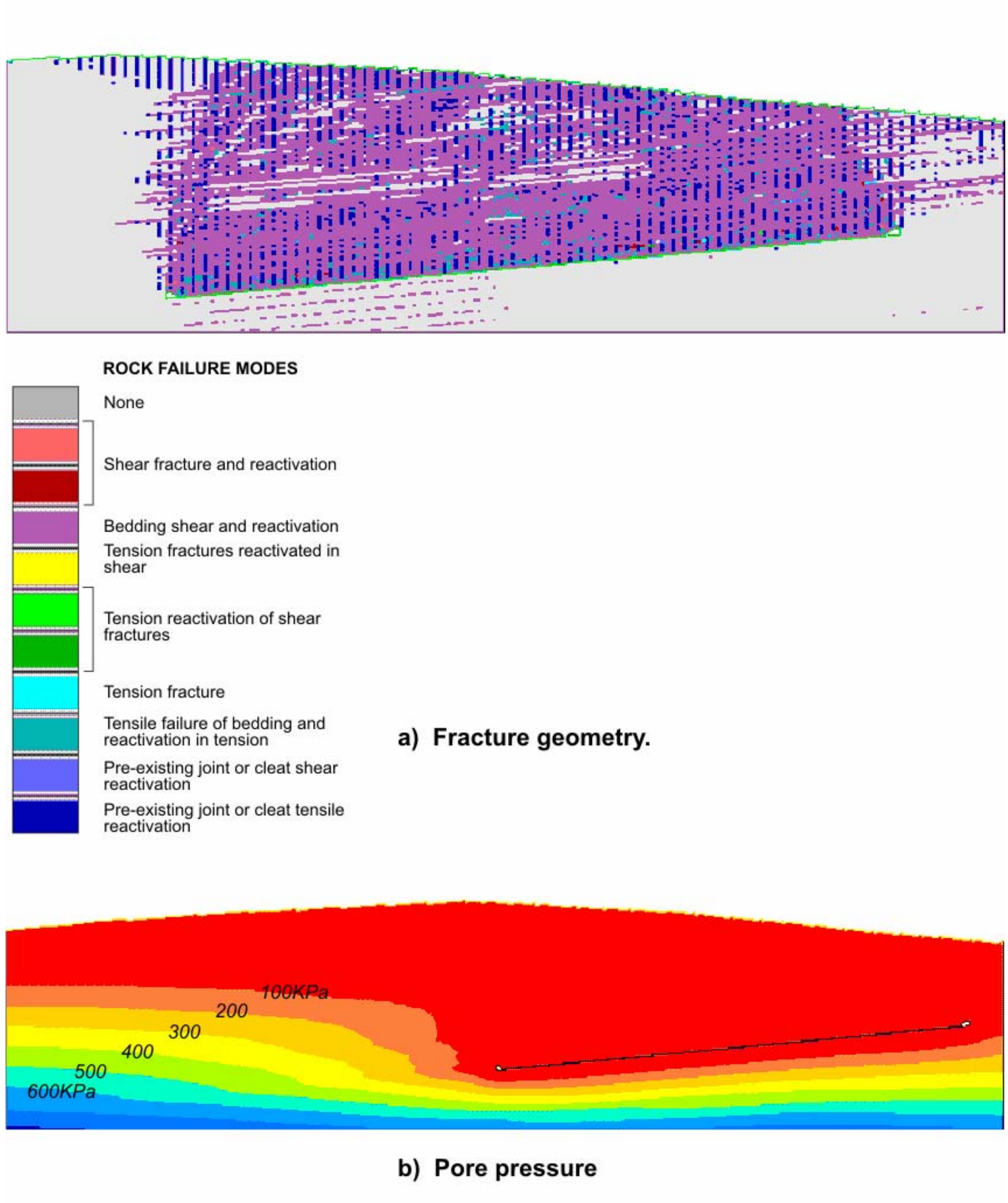


Figure 32 Pore pressure and fracture geometry within Longwall 1 model.

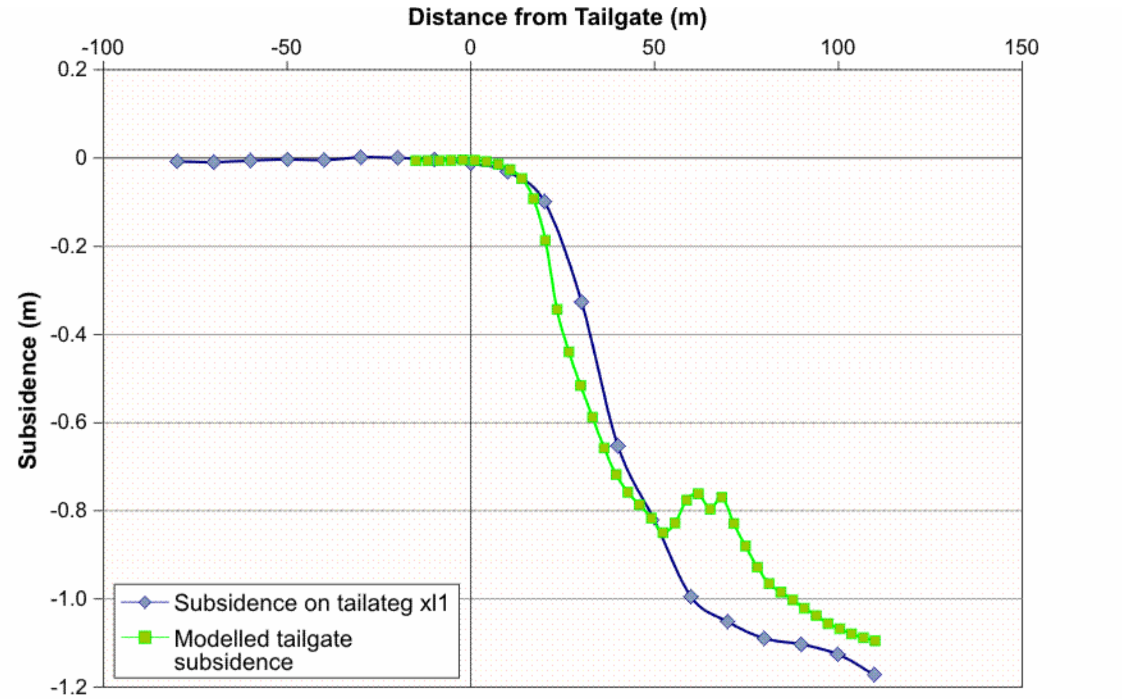


Figure 33 Modelled and measured cross line subsidence data.

Overall, it is anticipated that the subsidence profiles will vary along the panel due to topography and depth, however the model appears to have simulated the key aspects of subsidence at this cross section. The variability in subsidence characteristics is presented in Figure 34 where the subsidence of Cross Line 5 is presented. Line 5 is at a shallower location.

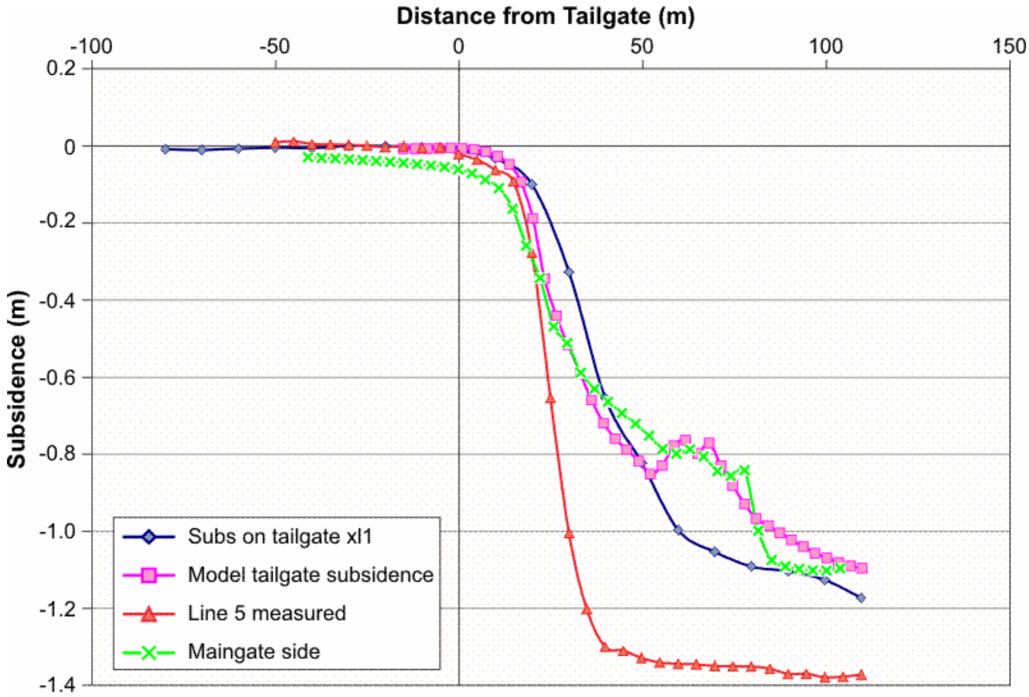


Figure 34 Example of variation in subsidence along panel.

12. STRATA HYDRAULIC CONDUCTIVITY ABOVE LONGWALL 1

The hydraulic conductivity of the strata has been estimated from the model fracture distribution and displacement results. The approach was presented in Gale 2005, and generally relates the conductivity to the fracture width (aperture) within the model. The conductivity is derived from the Darcy cubic flow equation, on the basis of unit head for an equivalent material of 1 sq m area. This approach is forwarded as an estimate and the results should be compared to field measurements and local experience.

The vertical and horizontal conductivity is estimated by this process. The vertical conductivity and the maximum (either vertical or horizontal) within the model are presented in Figure 35. The data is contoured from 10^{-10} m/s to 1 m/s. The conductivity of the goaf material is at the high end of the range and virgin material at the low end. It is evident that the vertical conductivity is locally variable depending on the fracture networks. It appears that one major zone has developed and that the rest of the overburden has a tortuous system of locally conductive fractures which require a network of bedding and other factures to transmit fluids.

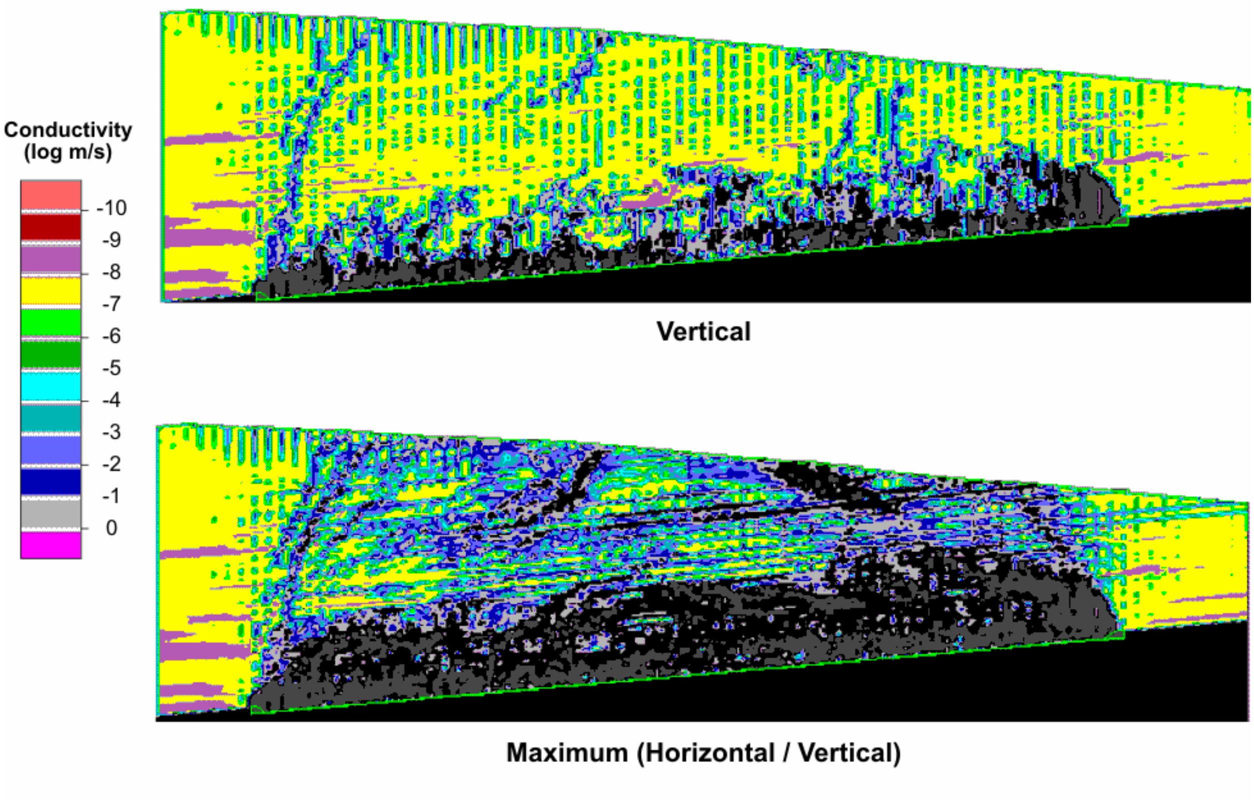


Figure 35 Vertical and maximum hydraulic conductivity in model.

In order to provide a better overview of the flow pathways, flow in the model with the caved conductivity distribution was assessed. Two methods were used to assess flow. The first was to put a constant pressure (1m of water) at the level of the previous water table and let the water flow occur; the second was to set the pore pressure to hydrostatic in the overburden above the goaf and let it drain out. The results for each method give similar results in terms of providing an overview of the flow regime.

The flow and water pressure for the constant water pressure at the previous water table is presented in Figure 36. This shows flow down the left hand side fracture system and interactive flow (tortuous) along fractures and bedding planes elsewhere.

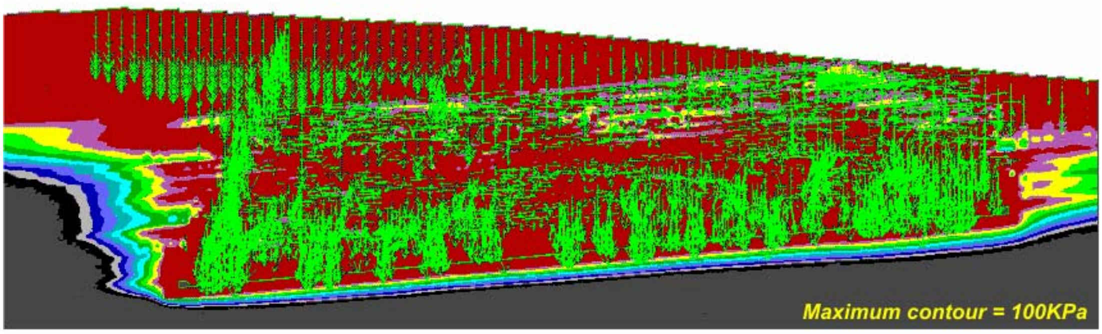


Figure 36 Flow vectors through overburden - Longwall 1.

Overall, the water table above the goaf is depressurised and flow occurs into the goaf.

Drilling of Borehole WMLC195 adjacent to 21 Cut-through over goaf indicated that the water table had dropped below pre-mining levels, and that the hole could not hold water. The hole extended to approximately 50m below surface in the upper section of the caved zone.

The overall vertical hydraulic conductivity above Longwall 1 has been plotted in Figure 37 as an average conductivity for every 1 metre slice down through the overburden. This has been done to provide an overview of the distribution but is an average and does not take the flow pathways into account. In situations of tortuous flow this averaging method tends to overestimate the flow potential as it assumes that every vertical fracture is connected to a horizontal flow pathway.

The figure shows two methods used. The first is the aperture width derived conductivity and the second shows the average conductivity obtained from the flow model. The difference is that the flow values give a better estimate of the actual flow potential rather than the possible flow potential. The flow model provides a better overview of the flow system and its interaction (Figure 36).

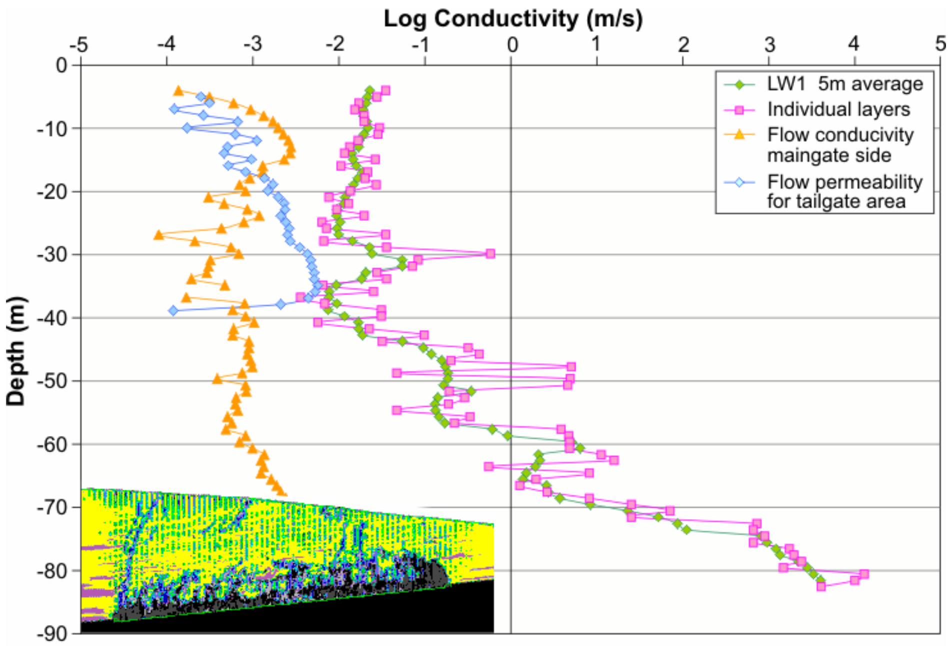


Figure 37 Average vertical conductivity along individual layers across the model for the two methods used.

However, both approaches in conjunction with the flow model can be used to provide a general overview of the conductivity and connectivity of the system.

The plot indicates that the average conductivity of the system is in the range of 10^{-2} to 10^{-4} m/s. Under this situation, the overburden would be expected to remain depressurised and local recharge of goaf voids could occur during rain events. It is also possible that locally high surface flows need not enter the mine as surface inflow may be restricted in the rate it can enter (e.g. 10^{-4} m/s). It is noted that no inflow was observed in association with heavy rainfall events.

In order to better understand the overburden conductivity, tracer gas (Helium) was injected into a borehole over the goaf at various depths. This was done to determine if there was a vertical connection at different depths down to the goaf.

Helium injection occurred into Borehole 195 (Figure 38) and displayed return to surface in the area without any significant delay. The conductivity estimated was in the order of 10^{-1} to 10^{-2} m/s for this zone. These results match the model very well and at least in this area, validate the process being used.

Figure 38 Conductivity section and location of helium injection tests.

It is interesting to note that when Helium was injected into the goaf from underground via tubes in the cut-throughs, no Helium return was found at the surface. This indicates that the Helium flow into the goaf did not connect to the zone noted during the borehole injection of Helium. It is considered that the underground injection was very local and that the gas may have been able to be trapped in less conductive areas of the caved roof zone. Review of Figures 35 and 36 shows that such a situation is possible, however such behaviour is considered unusual.

13. VALIDATION AND UNEXPLAINED RESULTS

The aim of the modelling was to assess the computer simulation capability as applied to Longwall 1. This provides validation for the method as applied to other areas of the mine, particularly Longwall 5-8.

The validation information is summarised below. It includes measured and observed information of water flow related to Longwall 1 and is an overview/check list of what the model has replicated and what is has not.

1. *Subsidence at the equivalent cross line location.*
   The model simulated the subsidence characteristics well.

2. *Hydraulic conductivity of the overburden.*
   The model matched the Helium injection results very well for WMBH 195 on the maingate side of the panel.

3. *Connection from underground to surface using underground Helium injection.*
   It was expected to have Helium return from the underground injection, however local trapping of flow is possible in the fracture configuration noted in the model. The underground injection aspect of the validation is inconclusive.

4. *Water levels in the goaf.*
The water level in the overburden was found to be below the termination of WMBH 195 and it is assumed that the goaf/overburden is essentially “dry”. This is consistent with the model results.

5. *Water pressure in the strata surrounding Longwall 1.*
Water pressure changes in the overburden and in the Pikes Gully Seam in the area of Longwall 2 and 3 were simulated by the model.

6. *Inflow characteristics through the Pikes Gully Seam for Longwall 1 tailgate.*
The inflow in the area of the tailgate at the location of the cross section was replicated by the model.

7. High water flows during a rain event on 8-10 June 2007 were observed to enter large subsidence cracks on the tailgate side but appeared to re-emerge. There was no evidence of water reporting to the underground as a result of this event. Local redirection of surface flow on the tailgate side and re-emergence is consistent with the model, however water make would be expected in the mine associated with the rain event. This aspect is puzzling particularly considering the water losses during drilling and the “dry” nature of the overburden.

Overall, the model has simulated the overburden deformation and key aspects of the overburden conductivity very well. It is considered that local surface characteristics will influence water inflow characteristics, particularly during rain events. Anomalous field data associated with nil inflow from rain events and the lack of demonstrated connection from underground helium injection support the conservative approach taken in this assessment.

It is concluded that the model can be used to provide an overview of the overburden response and impact on the hydraulic characteristics of the strata which results from mining. It is recognised that the geological regime and surface characteristics of a mine site can vary and as such the model should be used as a guide as to the strata deformation characteristics and water inflow potential. It represents an estimate based on the assumptions and input parameters used. It is recommended that the inflow evaluation process utilise a combination of the modelling results and general mining experience.

14. CONCLUSIONS AND RECOMMENDATIONS FOR MINING UNDER THE BOWMANS CREEK ALLUVIUM

The modelling has been used to assess the extent of fracture and potential for inter-connection of the mine to the surface for various panel widths at depths ranging from 100m-150m.

The results from the modelling are consistent with overburden behaviour from the empirical data available on subsidence measurements and experience of water inflow into mines. The modelling provides an overview of the caving and potential conductivity impacts however, considering the evolving nature of understanding in this field, it is recommended to monitor water pressure and flow characteristics above panels in the deeper areas of the mine to assess these results.

The results indicate that panel width can provide a control on subsidence, overburden fracture and induced conductivity. It was found that narrow panels are likely to maintain a reliable zone of "substantially un-impacted" strata above the induced cracking zone to provide a "natural" control on water flow.

Modelling of width to depth ratios up to 0.6 at this site indicated that an un-impacted zone was maintained.

Width to depth ratios of 1 and greater may allow some water migration through a network of fractures and bedding planes having enhanced conductivity. In the 150m depth cases, there was not any direct (single fracture) connection from the goaf to the surface.

In the 120m depth case with panel widths greater than 1, there was no direct single crack from the alluvials to the seam for a subsidence of approximately 1m, however the conductivity of the overburden was significantly enhanced and seepage flow would be expected. This result is consistent with the UK data and the Wambo data. It should be noted that if subsidence were greater than 1m, (lower bound of the regional data) then the interconnection risk would be expected to increase.

The actual flow system and volumes which result from the various mine geometries will need to be assessed on the basis of ground water modelling and the site characteristics.

Further assessment of Upper Liddell Seam layout options is required to optimise the mine design for extraction of this second seam.

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