

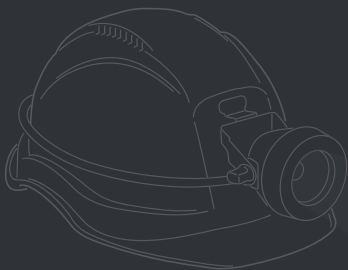
# Wallarrah 2 Coal Project

## Environmental Impact Statement

April 2013

### Appendix G

Subsidence Modelling Study





# **Wallarrah 2 Coal Project Subsidence Modelling Study**

**October 2012**





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# Wallarrah 2 Coal Project Subsidence Modelling Study

## October 2012

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## EXECUTIVE SUMMARY

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Mine subsidence and its potential impact on residential structures, water catchments, groundwater regimes and other natural and man made structures in the Wallarah 2 Coal Project (the Project) area has been recognised as an issue for consideration in the design of the mine plan for the Project. Similarly, any disruption to the water regime that would result in water ingress into the proposed mine workings has been identified as a major risk that must also be addressed through appropriate mine design.

The acquisition of data from the strata to be mined was commenced in the earliest stages of the exploration program as it was realised that the subsidence predictions and the mechanistic understanding of how and why subsidence occurs would be pivotal to both the mine design and environmental considerations for the Project. The aim of developing this understanding was to ensure that any potential impact on surface structures, groundwater features and flood patterns was both acceptable and manageable to the various stakeholders involved.

Throughout the early development of the Project, various subsidence predictions were prepared to provide a basis for conceptual mine design and environmental assessment. Upon review however, it was noted that the predictions based on initial numerical modelling were not consistent with the results of the empirically based predictions which had been developed for the Newcastle and Illawarra Coalfields. The review identified a number of limitations to the empirical methods that had initially been used and a “mechanistically based empirical approach” was subsequently developed. This new approach involved the use of numerical models to simulate the behaviour of particular geological sequences during mining, thereby enabling the development of subsidence profiles for the particular conditions for the Project. This in turn enabled the calibration of the subsidence prediction curves used in the empirical modelling and the provision of more realistic subsidence predictions across the area.

The development of this revised methodology involved a series of key stages:

- Validation, by back analysis, of the numerical model's capacity to satisfactorily reflect the effect of panel geometry and caving behaviour on subsidence development for a number of different geological environments;
- Characterisation of the input data for the subsidence model;
- Formulation of assumptions for the subsidence model;
- Numerical modelling of the ‘Hue Hue case’, the ‘Valley case’ and the ‘Forest case’;
- Development of the prediction curves for the Extraction Area;
- Calibration of the Incremental Profile Method of empirical subsidence prediction;
- Detailed site-specific subsidence predictions on various iterations of the mine design; and
- Incorporation of these predictions of both surface subsidence and rock mass behaviour into the flood studies and detailed hydrogeological investigations.

To achieve these outcomes, WACJV engaged the industry's leading experts and scientists to provide the solutions necessary to develop this aspect of the Project.



These studies concluded that the subsidence profiles that are likely to occur in the Extraction Area will be similar in shape to those of the Southern Coalfield, although will be greater in magnitude. This is due to:

- The greater depths of cover at the Project compared to other Newcastle Coalfield mines;
- An absence of massive strata at the Project compared to other Newcastle Coalfield mines;
- A thicker coal seam; and
- The occurrence of a relatively weak roof-pillar-floor system within the Extraction Area compared to the Southern Coalfield.

Accordingly, the detailed subsidence impact assessment completed has provided a more cautious and conservative basis for the development the Project mine plan, remaining consistent with the requirements of the Hue Hue and Wyong Mine Subsidence Districts (see Section 1) and to ensure the protection of surface and groundwater resources.

The conventional subsidence predictions presented in this study relate to the proposed mine layout as is described in the EIS. A fundamental part of the approvals and mining process will be to continue the iterative design. This will be achieved through the detailed monitoring of actual subsidence behaviour to further validate and refine predictions of the subsidence models and to serve as a basis for ongoing modification to the mine design as required.

This report serves as an overview of the subsidence modelling and prediction methodology that was developed specifically for the Project, with the assistance of numerical modelling from Strata Control Technology (SCT) and empirical modelling from Mine Subsidence Engineering Consultants (MSEC), along with a summary of the associated outcomes. These outcomes included:

- A validated numerical modelling technique to assess the rock mass response to longwall extraction;
- A fracture analysis upon which a site specific groundwater model could be developed;
- A set of subsidence curves upon which a site specific subsidence prediction could be developed; and
- A subsidence prediction model upon which a site specific flood model could be developed.

Detailed subsidence predictions at each of the natural features and items of infrastructure using this cautious mine design approach are presented in the Subsidence Impact Assessment Report that has been prepared by Mine Subsidence Engineering Consultants Pty Ltd (MSEC, 2012). Detailed assessments of the potential impacts of the mine subsidence effects are also contained in that report, and are further assessed within associated expert technical reports, such as Mackie Environmental Research Pty Ltd (MER, 2012) and G Herman and Associates (GHA, 2012).

## 1. BACKGROUND

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The Wyong Areas Coal Joint Venture (WACJV) was founded in 1995 at the invitation of the NSW Government following a successful tender by Coal Operations Australia Pty Ltd for the Wyong Coal Development Areas. In 2005, Kores Australia Pty Ltd, an original member of the WACJV, became the manager of the WACJV by increasing its equity in the venture to 82.25%. The WACJV then proposed the development of the coal resource under a new project known to as the Wallarah 2 Coal Project (the Project).

The Project involves the proposed longwall extraction of coal within the coalesced Wallarah and Great Northern Seams of the Newcastle Coal Measures. Over half of the mineable resource lies beneath the Wyong State Forest and surrounding ranges, whilst the remainder lies beneath the Dooralong Valley, the Hue Hue area, and to a much lesser extent, the Yarramalong Valley.

In recognition of likely future mining, the Hue Hue Mine Subsidence District was proclaimed in December 1985. This district overlies the initial area of the mine plan, and requires that mining induced ground movement effects on dwellings be limited to maximum ground strains of 3 mm/m, and maximum ground tilts of 4 mm/m.

The Wyong Mine Subsidence District was proclaimed in 1997 in recognition of the significant resource underlying the Wyong State Forest, the Dooralong Valley and the Yarramalong Valley. Initially, no specific ground movement limits applied, with single storey buildings less than 30 m in length on bearers and joists automatically approved, and longer structures or structures on slabs approved on their merits provided that they were designed to withstand tilt and strain predictions provided by the then Department of Mineral Resources. In 2000 the WACJV indicated their intention to limit tilts to 4 mm/m. The Mine Subsidence Board adopted this as an interim guideline, and a number of houses were built to that specification. Future houses in this district will be required to meet tilt and strain criteria supplied by the Mine Subsidence Board, on the basis of advice from WACJV, and to be consistent with the extraction of longwall blocks up to 255 m wide and working heights of up to 4.5 m.

The Project team recognised the importance of the Wyong River and the Dooralong and Yarramalong floodplains, in the region's water supply system and was determined from the outset to formulate a mine plan that avoided and did not cause impacts on these the important resources.

An iterative and cautious approach to mine design of the Project was therefore adopted to ensure that the effects, consequences and impacts of mine subsidence on overlying natural features, surface structures and groundwater systems are appropriately considered.

### 1.1 Preliminary Mine Planning and Empirical Subsidence Predictions for the Project

Subsidence, tilt and strain predictions were initially prepared by Waddington Kay & Associates (now Mine Subsidence Engineering Consultants, or MSEC) in January 1999, based upon the mine layout that was proposed at that time. The method used to prepare these subsidence predictions was the Incremental Profile Method (IPM), which was initially developed by Arthur Waddington and Don Kay during the course of a study for BHP Collieries Division, the Water Board and AGL in late 1995.

The IPM is an empirical method that is based on extensive measurement of mine subsidence that has taken place over mined areas for more than fifty years, and has been continually refined to suit a wide variety of mine layouts with differing geological conditions in NSW and Queensland coalfields.

While final subsidence profiles over a series of longwalls appears irregular in shape it was found that the incremental subsidence profiles were very regular reflecting the changes in local geology, the panel width, the pillar width, the depth of cover, the seam thickness extracted and the extent of previous extraction besides each incremental panel. The regularity of these incremental subsidence profiles became the basis of the IPM method it was found that it was better to predict the incremental subsidence due to each panel separately and then add up the effects at a point from each incremental panel rather than to try to predict the subsidence as a total in one calculation.

The IPM has the capacity to provide detailed site specific “empirical” predictions of subsidence, tilt and strain at any point over a series of mined panels with differing panel and pillar widths, depths of cover and extracted seam thicknesses. The IPM method has been exhaustively reviewed during a number of inquiries and reviews and is regarded as the best method available for the empirical prediction of subsidence parameters for a site, as long as the local geology at that site is similar to all those sites where the previous subsidence monitoring occurred.

The Project however is unique in a number of ways, in that:

- It involves the longwall extraction of coal at depths of cover of up 700 metres, which is well beyond those previously mined in the Newcastle Coalfield, and is higher than the depths of mining in the Southern Coalfield where the depths of cover extends up to 550 metres;
- Southern Coalfield mines usually mine at an extraction thickness of approximately 3.0 m whereas the Project includes plans to operate at extraction thicknesses of between 3.0 and 4.5 m;
- The Southern Coalfield seams are usually bounded above and below by reasonably strong strata whereas the near-seam strata in the Extraction Area are relatively weak in comparison; and
- In the traditional mining areas of the Newcastle Coalfield, the overburden often contains thick strong conglomerate units which tend to reduce surface subsidence. The overburden in the Extraction Area consists of finer grained sandstones and shales with minor conglomerates, suggesting that would behave more like Southern Coalfield overburden.

Therefore, since no empirical subsidence data were available that directly reflected the Project scenario, some of the initial IPM predictions for the Project were based on the Southern Coalfields subsidence prediction curves. Other analyses were also undertaken for comparison purposes based on the Newcastle Coalfields subsidence prediction curves.

To ensure that the use of these empirical data would be fully representative of the geological response to mining in the Wyong area, further studies were initiated to undertake a detailed review of the predictions.

## 1.2 Initial numerical modelling

In February 2003, Strata Control Technology Pty Ltd (SCT) was engaged to undertake numerical modelling for the Project mine layout. Subsidence predictions were prepared that considered the specific geology and depths of cover at the Project. SCT then compared the numerical modelling subsidence predictions against the preliminary empirical subsidence predictions that were based on data from the Southern Coalfield.

This numerical modelling suggested that surface subsidence above the proposed layouts in the valley area would exceed that based on the initial empirical predictions.

## 1.3 Review of the initial predictions

A review of the information gained from all the studies to date was then undertaken by the WACJV design team to re-assess the respective capabilities of the empirical and numerical models to combine these two methods to result in an improved predictive capability.

The fundamental conclusions from that review were:

- Surface subsidence is heavily dependent on the geological and geotechnical characteristics of the Extraction Area, as well as the depth and geometry of the workings;
- It is the complex interaction of chain pillar and rock mass behaviour that dictates the surface response;
- It is the strength of the roof-pillar-floor system, rather than simply pillar width, that is the controlling factor in pillar stability;
- The IPM remains the most advanced empirical method for predicting the likely subsidence across a proposed layout provided it is based on, or calibrated to, comparative data from that geological environment;
- The IPM utilises the surveyed response of the surface to mining based only upon changes in seam thickness, panel and pillar widths and depths of cover. It does not however include consideration of the caving mechanisms and rock mass behaviour that can also contribute to that subsidence;
- The numerical model has the capability to predict the chain pillar and rock mass behaviour;
- Numerical modelling is site specific and, in itself, cannot generate subsidence predictions across the entire mine area. However it can provide a basis for the development and calibration of empirical curves that can then be used in the IPM model for broader scale predictions; and
- The development and use of an empirical model, based on numerical modelling results, would provide the most robust predictive approach for the Project

As a result of this review, a mechanistically modified empirical model was developed that reflected the site-specific rock mass behaviour in satisfactorily predicting the surface subsidence associated with the extraction of Southern Coalfield geometries within a Newcastle Coalfield geological environment.

## 2. NUMERICAL MODELLING OF SUBSIDENCE

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### 2.1 Introduction

The computer modelling of strata caving, overburden fracturing and rockmass behaviour has evolved significantly over the last ten years and has been increasingly applied to coal mine design and subsidence predictions. The models are based upon estimates of the geotechnical characteristics of the overburden based on geotechnical properties derived from a combination of bore core testing, geophysical strength relationships and prior experience. Not all properties can be derived from borehole analyses, and estimates need to be made on the basis of either previous studies or sensitivity analyses of the impact of potential variation in certain properties.

The numerical model employed in this study, FLAC (Fast Lagrangian Analysis of Continua), is a two-dimensional explicit finite difference program developed specifically for solving mining and geotechnical engineering problems. It incorporates a coupled rock failure and fluid flow system to simulate the behaviour of the strata as well as the fluid pressure/flow effects as it models the behaviour of a representative cross section through the central zone of the series of longwall panels. The rock failure and permeability routines have been developed by SCT Operations and offer a more realistic representation of the rock fracture mechanics than is available in the standard codes.

The model simulates rock fracture and stores the orientation of the fractures. Shear fracture, tension fracture of the rock, bedding plane shear and tension fracture of bedding are also determined in the simulation, and the stability of pre-existing jointing, faults or cleat is also addressed where appropriate. Rock failure is based on Mohr-Coulomb criteria relevant to the confining conditions within the ground, whilst the in situ strength of the rock material is reduced to 0.58 of the laboratory UCS, which is consistent with the general Hoek & Brown relationships, as well as being consistent with scale effects as reported from other methods. Ground displacements, rock fracture and stress redistributions can be assessed within various rock units and geometries about the extraction panel.

The grid element size used in the model was approximately one square metre.

### 2.2 Validation of Longwall Caving Models with Measured Subsidence Data

The first step in the study was to develop confidence in the model by assessing its capability to reproduce the results of both generalised and known cases of subsidence. These verification studies sought to confirm that the model was satisfactorily simulating the deformation mechanics of the strata, and also determine the sensitivity of various parameters in the modelling process.

The validation studies conducted during this study were underpinned by previous studies conducted on various scales from roadways and coal pillars to multiple longwall panels (Gale and Tarrant 1997, Kelly et al 1998, Gale 2005, Doyle and Gale 2004, Gale 2001).

For the purposes of the Project case, studies were conducted in a general sense to compare modelled overburden behaviour of a “*typical overburden section*” with the regional empirical database, as well as on a number of specific sites.

### 2.2.1 Regional Subsidence Characteristics Relative to Panel Geometry

Validation on a regional sense has been reported (Gale 2006) whereby the subsidence and overburden fracture distributions were analysed relative to panel geometry and depth. The strata that were modelled were that of a typical Hunter Valley geological section, with the resultant subsidence being compared to the regional database of the Hunter and Western Coalfield.

The modelled data relates to a depth range of 150 to 312 m, and demonstrates a very good correlation with the regional database. The comparison of predicted subsidence relative to the database is presented in Figure 2.1. The overburden deformation, which is associated with the modelled data, is presented in Figure 2.2 to demonstrate the failure mechanics developed within the overburden for the various ratios of panel width to cover depth.

The results of this study provide confidence that the modelled overburden behaviour and resulting subsidence estimates, are consistent with the regional empirical database.

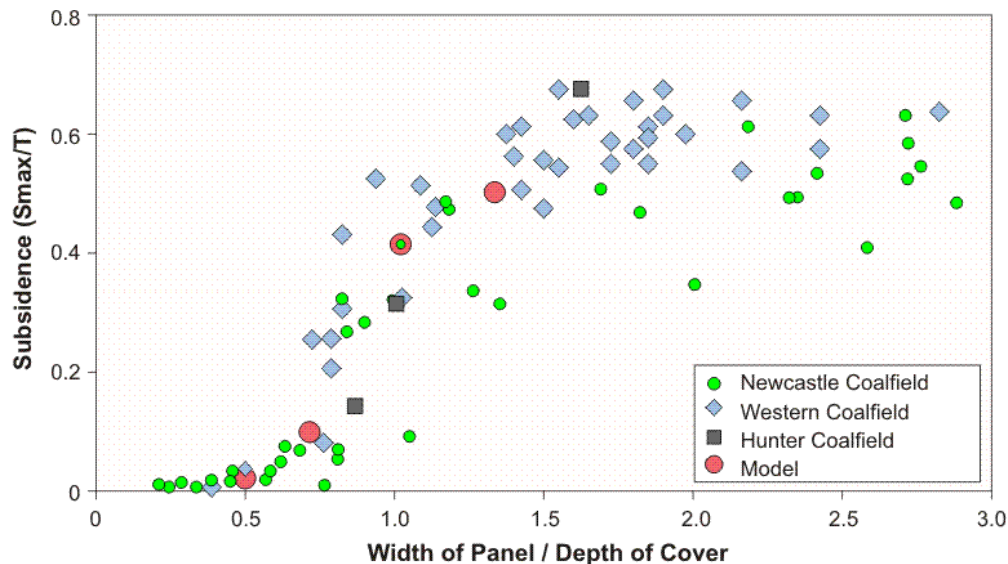
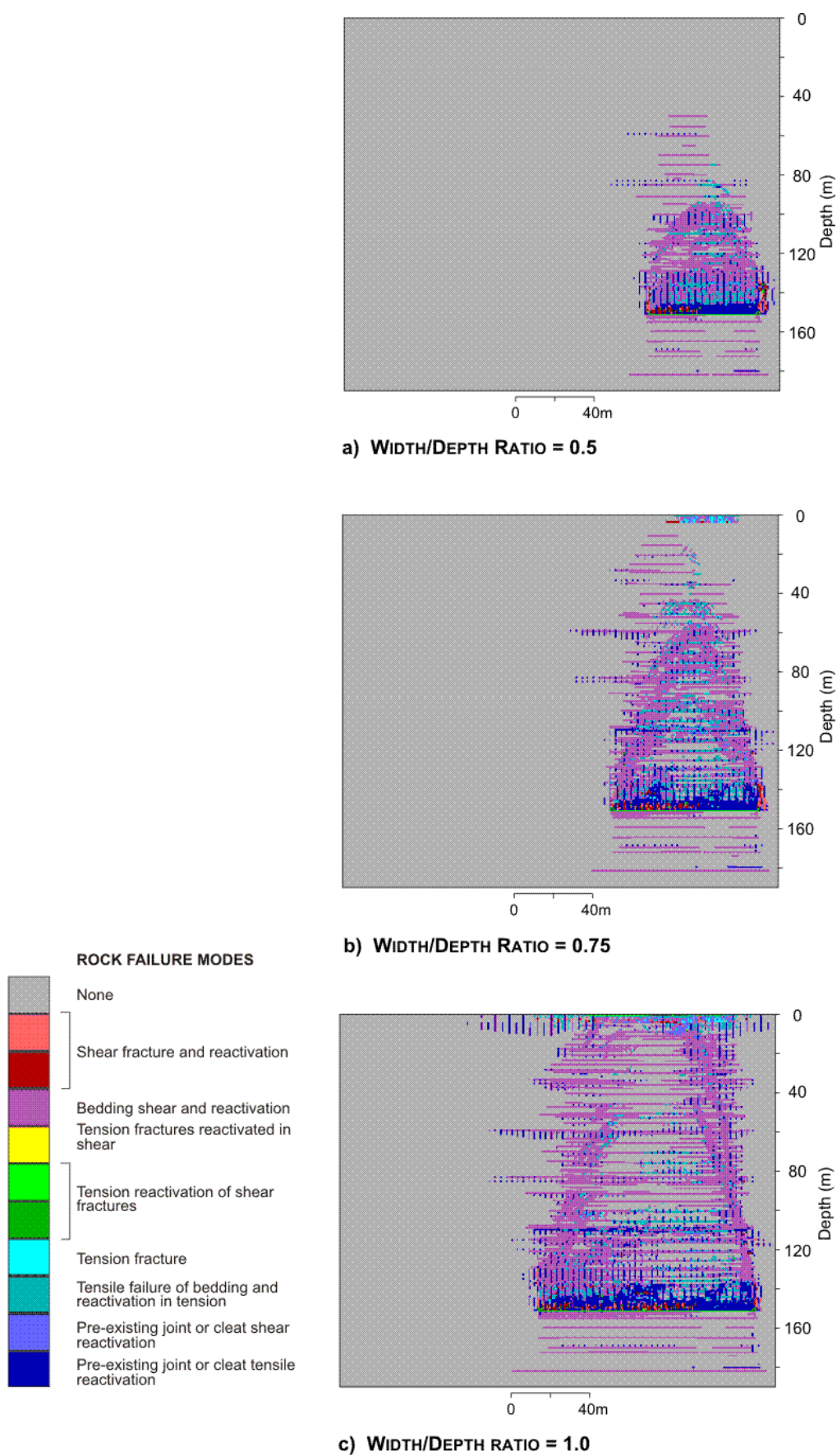


Figure 2.1 Regional Subsidence Data for Newcastle, Hunter and Western Coalfields





**Figure 2.2 Effect of Panel Width on Subsidence**

### 2.2.2 Validation for Vertical Subsidence

This phase of the study involved modelling to evaluate the capability to predict actually recorded results from pre-existing studies at various other mine sites throughout the Newcastle, Cessnock and Southern Coalfields.

#### ***Multiple longwall panels at 370 m depth - Greta Seam***

Validation of caving mechanics was done using published data from Ellalong Colliery Longwall 1-3 (Holla and Armstrong, 1986). A model of two longwall panels was undertaken to compare the resultant subsidence and the caving characteristics as monitored by a surface-to-seam extensometer.

The geology and geometry of the panel is presented in Figure 2.3. The subsidence monitoring data for the site was reported as point data and sub-surface ground displacement. The modelled rock fracture distribution, which resulted after two panels were extracted, is presented in Figure 2.4. The main caving zone extends approximately 40 m above the seam, beyond which, the strata exhibit mining related fractures particularly related to bedding planes.

The surface extensometer data from the model and that monitored by Holla and Armstrong is presented in Figure 2.5. The results are very consistent in terms of both magnitude and location. This indicates that the model is closely simulating the caving characteristics of the strata, and is able to simulate the overburden bridging characteristics in a realistic manner.

The overall subsidence results are presented in Figure 2.6, and display a close correlation to that provided by Holla for the two panels.

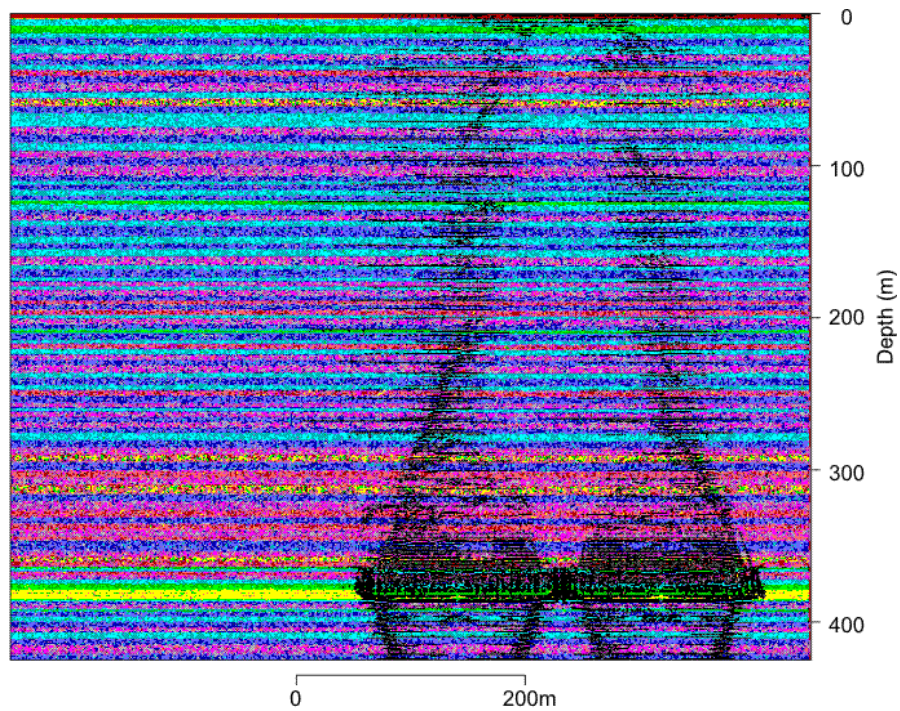
#### ***Partial extraction geometry at 470 m depth - Bulli Seam***

This validation study was done to assess the behaviour of a partial extraction geometry at depths similar to that proposed for the Project. The data available was from 501 to 502 Panels at South Bulli Mine. The panel geometry is presented in Figure 2.7 and the fracture geometry is presented in Figure 2.8. The subsidence predicted from the model was approximately 240 mm compared to the actual monitored result of 220 mm.

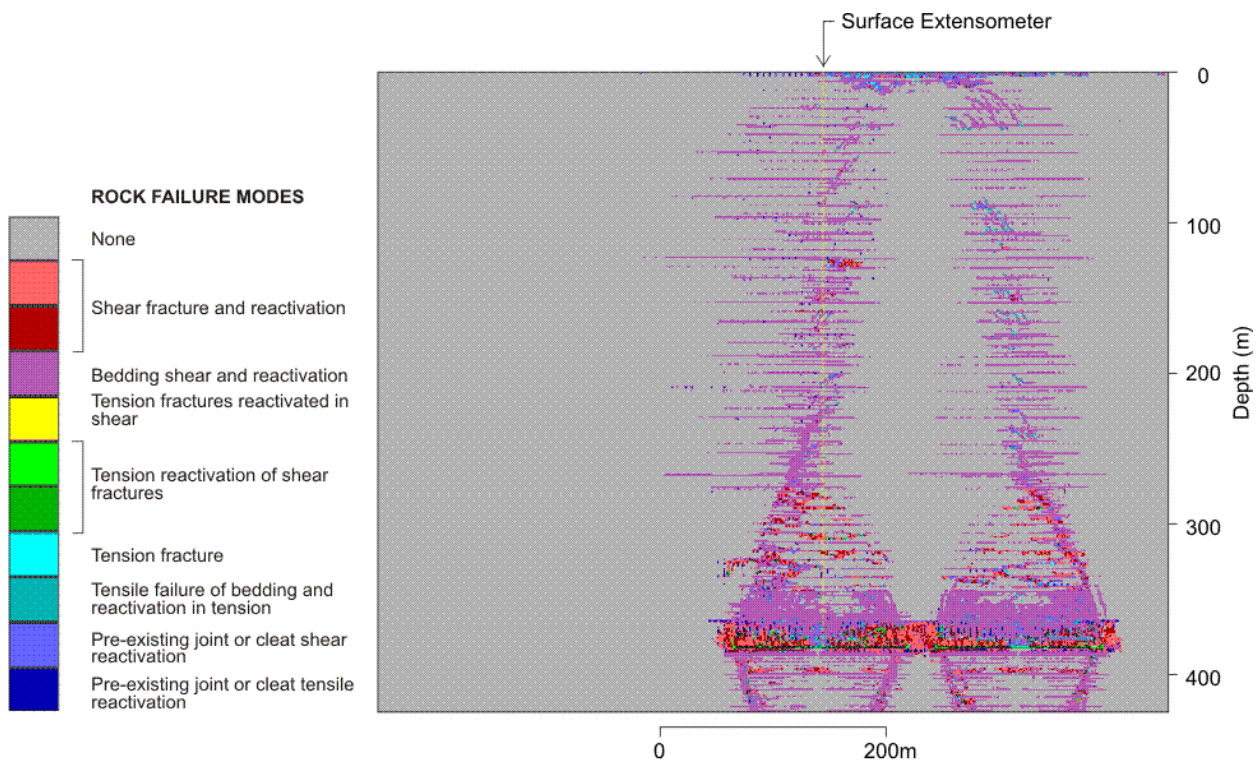
#### ***Multiple longwall panels at 500-520 m depth -Bulli Seam***

Models have been run on the Bulli Seam with various panel geometries. The modelled results and that of monitored and empirically predicted methods are presented in Figure 2.9. The results indicate that the subsidence profile from the models is very similar in shape and magnitude to the actual and empirical results. This indicates that the model is accurately simulating the overburden response together with the goaf and chain pillar loading characteristics in a suitable manner.





**Figure 2.3 Geological Section of the Ellalong Model**



**Figure 2.4 Modelled Rock Fracture Development after Ellalong Longwalls 1 and 2**

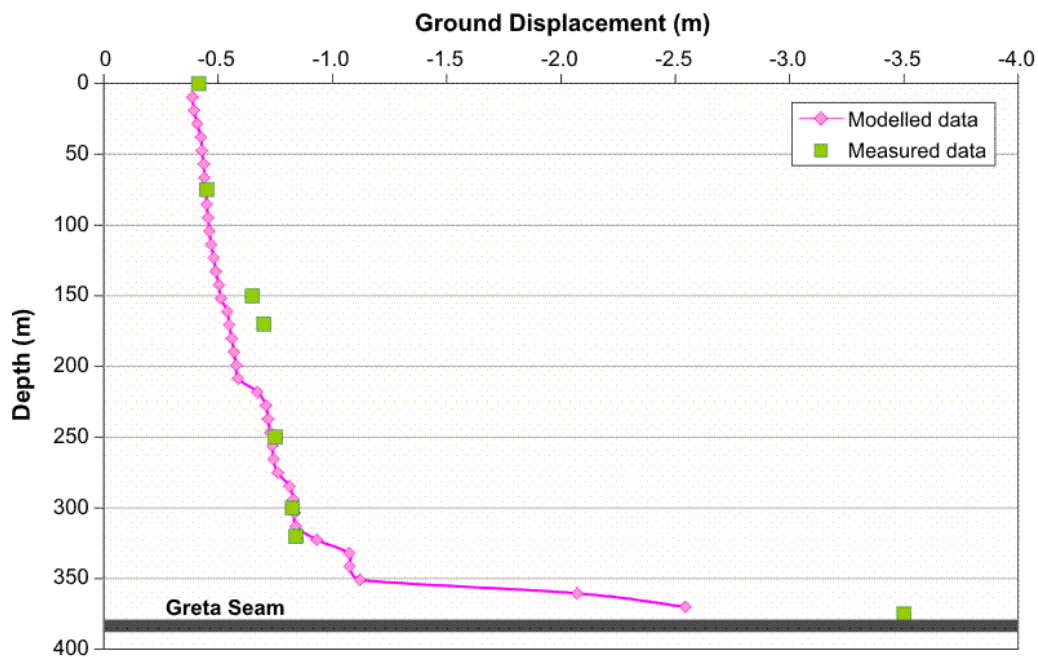


Figure 2.5 Modelled vs Measured Extensometer Data above Ellalong Longwall 2

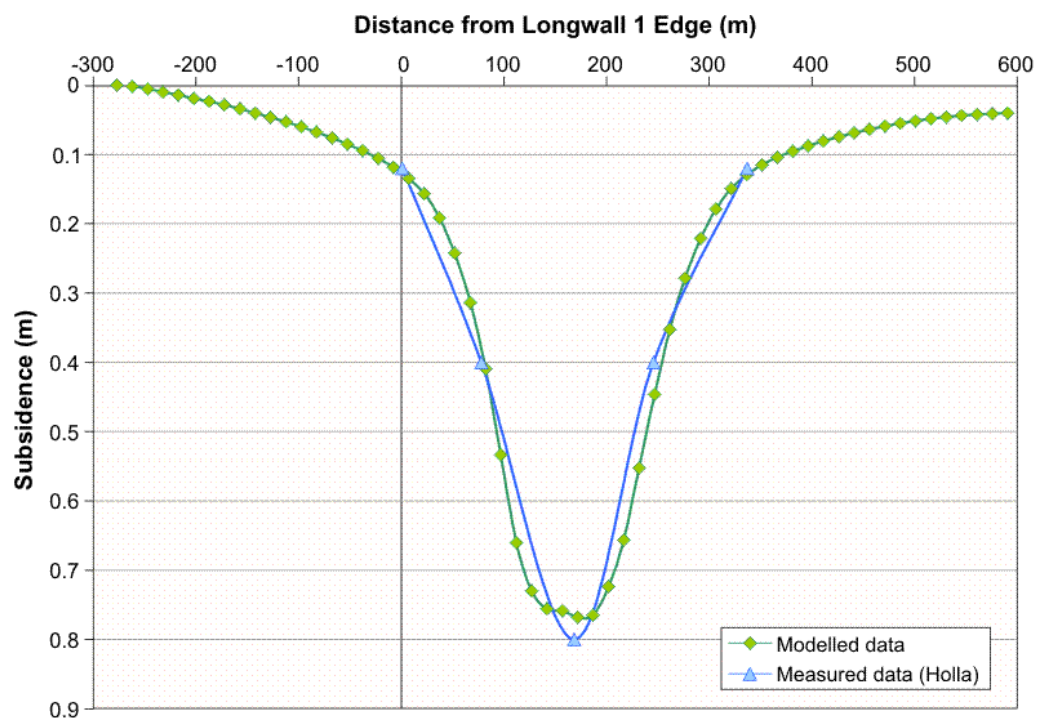
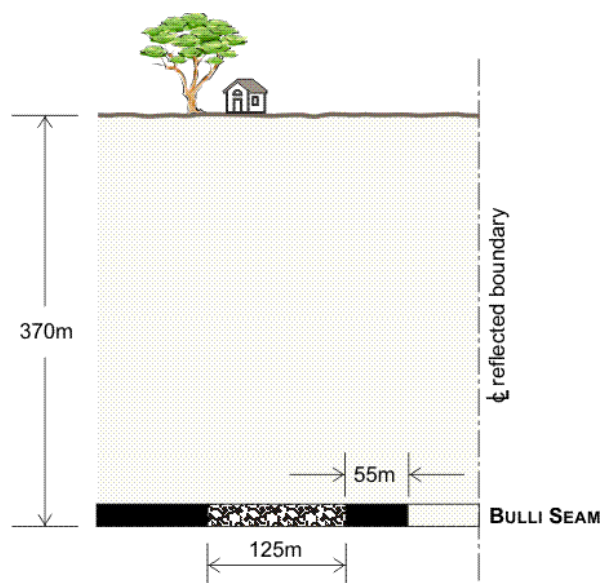
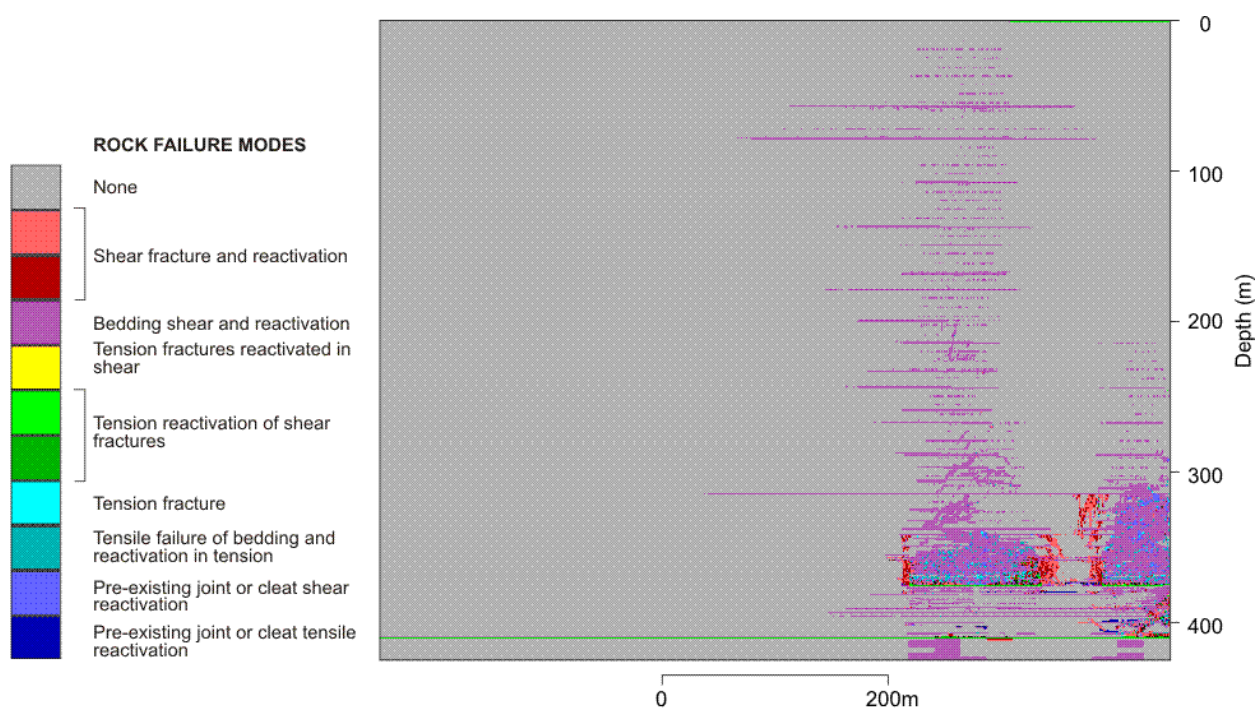


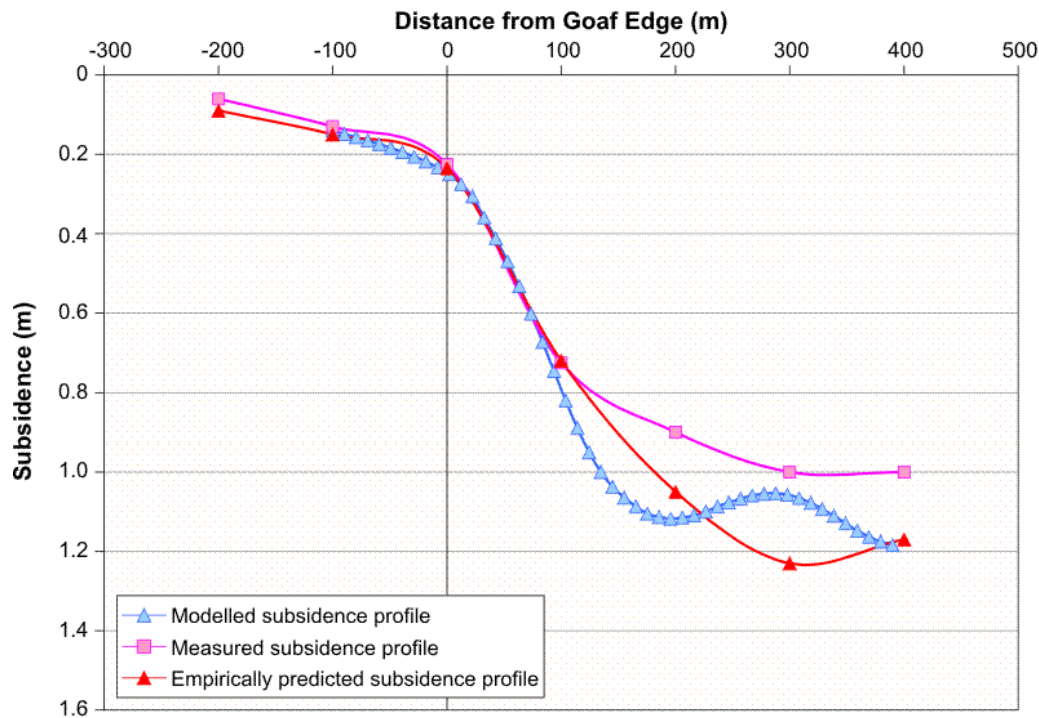
Figure 2.6 Modelled vs Measured Subsidence Data after Ellalong Longwalls 1 and 2



**Figure 2.7 South Bulli Model Geometry**



**Figure 2.8 Modelled Rock Fracture Development after South Bulli Longwalls 1 and 2**



**Figure 2.9 Comparisons of Modelled, Measured and Empirical Data for the Bulli Seam**

### 2.2.3 Conclusions

The results from these specific validation studies, and other previous studies, indicated that there was sufficient confidence in the capability of the model to satisfactorily simulate:

- Rock fracture distribution about the longwall panel;
- Overburden bridging and caving characteristics;
- Goaf loading characteristics;
- Chain pillar behaviour characteristics;
- Stress redistributions about the mining panels; and
- Overburden subsidence characteristics.

On these bases, it was adopted for the Project as the most realistic method by which to assess the ability of various mine layout options in controlling the associated surface subsidence to acceptable and manageable levels.

## 2.3 Considerations in the Numerical Modelling Process

Models of the strata section were developed for three areas of the Project, namely - the “Hue Hue” area, the “Valley” area and the “Forest” area. These models were chosen to represent firstly the shallower, urbanised area where tilts and ground strains are of primary consideration, secondly the deeper rural, flood plain area where vertical subsidence and groundwater impacts are the key issues, and the more rugged, forested area where upsidence and closure may be more apparent.



The results were to be used to provide:

- An estimate of the subsidence which would occur within this geological environment, of longwall panels of various widths, pillar sizes and extraction heights;
- Information to allow a better evaluation of empirical relationships as applied to this geological environment;
- An estimate of the hydrogeological permeability of the overburden following coal extraction; and
- an assessment of the impacts.

### 2.3.1 Geological Data

The geological and geotechnical characteristics of the strata were obtained from a total of 352 exploration holes drilled across the Extraction Area, with detailed rock strength data obtained from three fully cored geotechnical boreholes, that were incorporated into the exploration drilling program. The boreholes were B500W250, B750W350 and B650W150.

The data from these boreholes were used to develop the representative overburden section for the “Hue Hue”, “Valley”, and “Forest” cases. The occurrence of Quaternary sediments and erosion of the near surface geology was adjusted to correct for local geological and depth variations between the three sites.

The coal seam mined is a combined section of the Wallarah and Great Northern Seams (WGN section).

The overlying strata of the WGN section are interbedded siltstones, sandstones and mudstone of the Dooralong Shales in the immediate roof, progressing up to the more dominant sandstone – conglomerate sequence of the Munmorah Conglomerate. Above this sequence is a weak section of interbedded sandstone and claystones within the Tuggerah Formation. The Patonga Claystone in turn overlies the Tuggerah Formation. These units are characterised by abundant interbedded green and red claystone units of low bedding plane and material strength. The hills in the “Forest” area are composed of mainly sandstones of the Terrigal Formation which overly the Patonga Formation.

The geological floor section over the Extraction Area is variable from thick conglomerate in the east, through a transitional zone of the Warnervale Conglomerate unit and then onto the Awaba Tuff unit in the western area.

### 2.3.2 Rock Strength Data

The strength of the overall strata ranges from approximately 10M Pa to 120M Pa. The green and red claystone units typically are in the 10–30 MPa range whereas the shales, siltstones, sandstone and conglomerate units are in the 30 to 80 MPa range. Well-cemented strata within the Warnervale Conglomerate were found to have strengths up to the 120 MPa range, however they are typified by relatively thin units within a banded material of variable strength. Localised clay rich bands exist within the Warnervale conglomerate unit within 2 m of the WGN section floor.

The Warnervale Conglomerate is typically a strong, well-cemented sandstone unit, which grades via a tuffite unit of more clay rich matrix into the Awaba Tuff below. It does contain thin weak clay rich bands, which are best observed in the geophysical data.

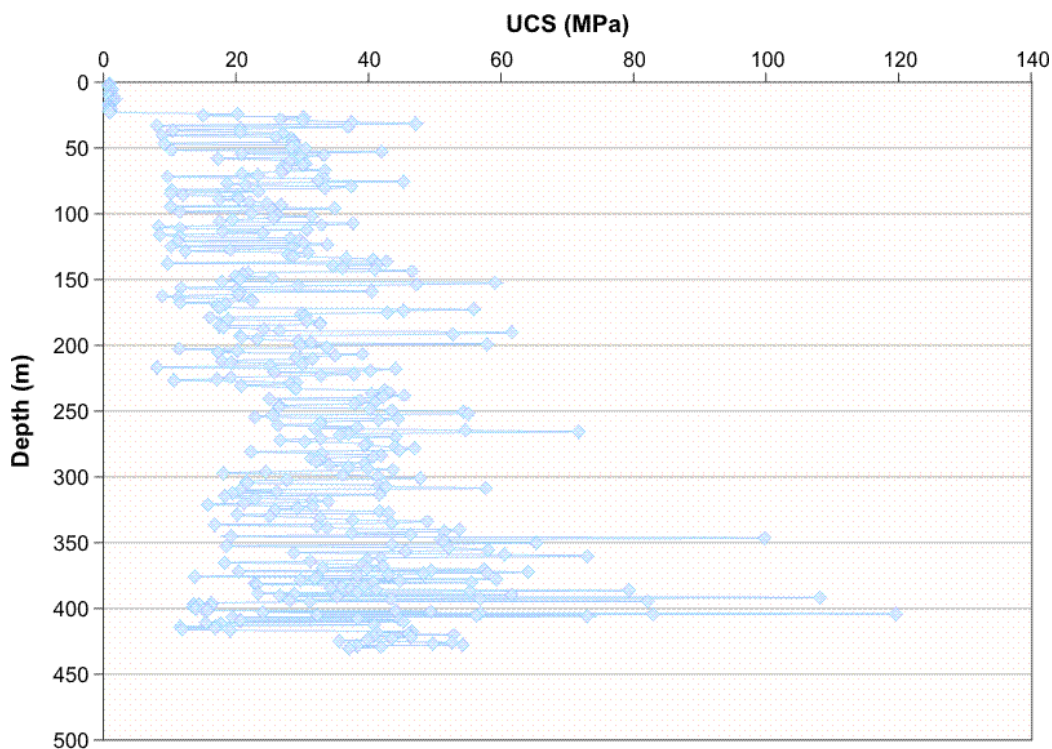
The floor strata vary from a strong but variably banded section of sandstone and siltstone units within the Warnervale Conglomerate to the claystone section within the Awaba Tuff. The Awaba Tuff is of variable strength ranging from approximately 30–70MPa, however local banding of high clay content occurs within this section.

The Dooralong Shale roof strata are well bedded, and many parting planes were identified within the overlying sandstone sections of the Munmorah Conglomerate.

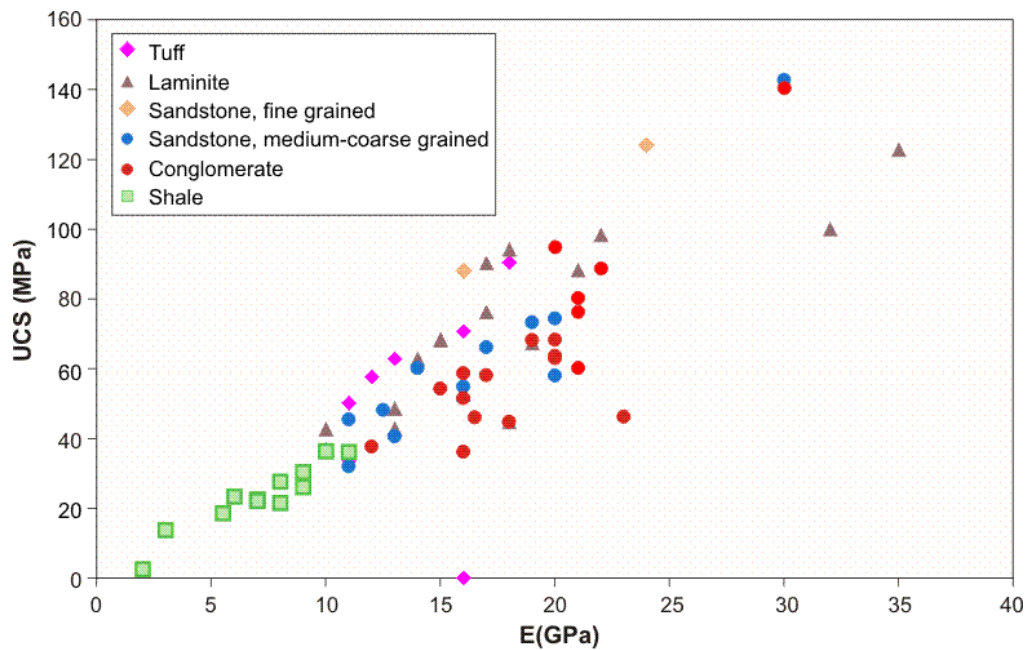
Bedding plane strength of a large core sample of the immediate roof section within the Dooralong Shale indicated cohesion of 8 MPa and a friction angle of approximately 39 degrees. A sample in the Karignan Formation indicated a cohesion of 4 MPa and a friction angle of 33 degrees. These data were obtained from sub-cored sections of bulk coal sample drill holes.

The strength of the core samples obtained during the exploration program were correlated against sonic velocity to obtain a method of using geophysical logging data to obtain a more detailed characterisation of the rock units within the overburden.

The overburden section as derived from the sonic velocity logs is presented in Figure 2.10 in terms of the Unconfined Compressive Strength (UCS) of the strata. The section is based on a 1 m interval.



**Figure 2.10 Typical Distribution in UCS of Overburden in Extraction Area**



**Figure 2.11 Typical Strength Characteristics of Rock Types in Extraction Area**

The relationship of rock strength to stiffness (Young's Modulus) is presented in Figure 2.11. In this figure the general ranges for the various strata types are identified. In general, the relationship indicates that the stiffer the rock, the stronger it is and the data fit a defined grouping within this relationship irrespective of rock type. The results indicate that there is local variability in terms of UCS and Modulus of the rock units. This relationship has been used to characterise the overburden stiffness characteristics relative to the UCS data derived from the geophysical methods.

It is well known that the nature and strength of strata is variable away from the sample location and as such the rock units are best estimated as having a strength range rather than a single universal property. This is reflected in the strength and stiffness data of the site as presented in Figure 2.11. In this figure it can be seen that the strength may vary by up to 50% from the mean for any given value of stiffness. In order to better estimate the field environment, the strength of the strata in each layer was varied randomly as a normal distribution from the "test" value within that range.

### 2.3.3 Claystone Floor Properties

The claystone associated with the Awaba Tuff section was modelled as bedded, tuffaceous sandstone with weak clay rich bedding planes, as noted in the large diameter coring program. It was assumed that the intact (drained) bedding friction angle was 8 degrees and when the material failed, the bedding friction angle reduced to 5 degrees and bedding cohesion to 10 kPa.

It was noted in the models that the formation of goaf loading adjacent to the pillars helped confine the claystone units in the floor to a greater extent than would be anticipated in pillar extraction operations.

The use of a low friction angle and adoption of yield pillar design was done to incorporate some of the potential strength reductions factors which relate to this material, however it does not account for all potential long-term moisture impacts as the material behaviour under such conditions is not well known.

The general concept applied to this study was that where the swelling minerals within the claystones are confined at levels greater than the swelling pressure, the material typically remains stable. Minimum confining stresses noted in the models was typically greater than 3 MPa under the pillars.

Experience of mining on these units is seen as the best assessment of long-term impacts. Studies of long term (up to 35 years) pillar behaviour on tuffaceous material in the Lake Macquarie area has been reported by Mills and Gale 1993, Edwards and Mills 1997, Li et al 2005. .

A design approach was adopted whereby pillars were designed to yield when isolated in the goaf so as to minimise the risk of long term pillar failure. With this approach pillars are designed to fail and then become confined by goaf material so that any subsequent strength losses would result from variation in the residual pillar strength due to long-term claystone behaviour rather than large-scale intact pillar strength losses. The resultant change in subsidence would be largely controlled by the goaf and would be expected to be significantly less than impacts from long-term failure of intact pillars.

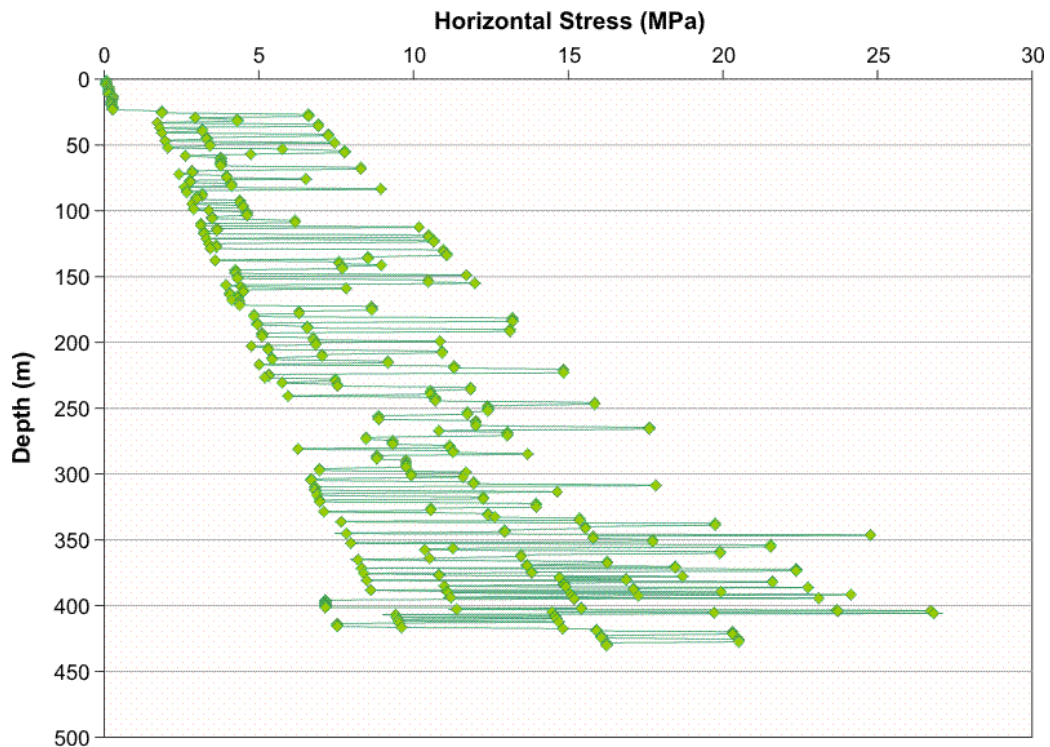
The ultimate success of this design is further enhanced by the high cover depths which will generate overburden pressures that would make it difficult to design a non-yielding system. This assumption is based on Southern Coalfield experience where pillars with similar width-height ratios and depth to those proposed for the Project have been seen to yield. In the unlikely event that evidence of non-yielding was to emerge, additional modelling and impact assessment would be carried out and appropriate remediation measures put in place.

#### **2.3.4 Stress Field Data**

Stress field information was obtained from interpretation of the acoustic scanner results within boreholes. The major stress direction over the area studied indicates that the major horizontal stress is in the NNE-SSW direction. The acoustic scanner information indicates that the stress magnitude would be similar to the South Coast mining area and is in the range of 10-12 MPa relative to a rock with a Young's Modulus of 10 GPa.

The horizontal stress field data used in the model is presented in Figure 2.12 as a profile from surface to seam. The variation in values is due to the stiffness variation of the various rock units. In general, the magnitude increases with depth. The vertical stress increases at a rate of approximately 2.5 MPa/100 m.





**Figure 2.12 Modelled Horizontal Stress vs Depth in Project Area**

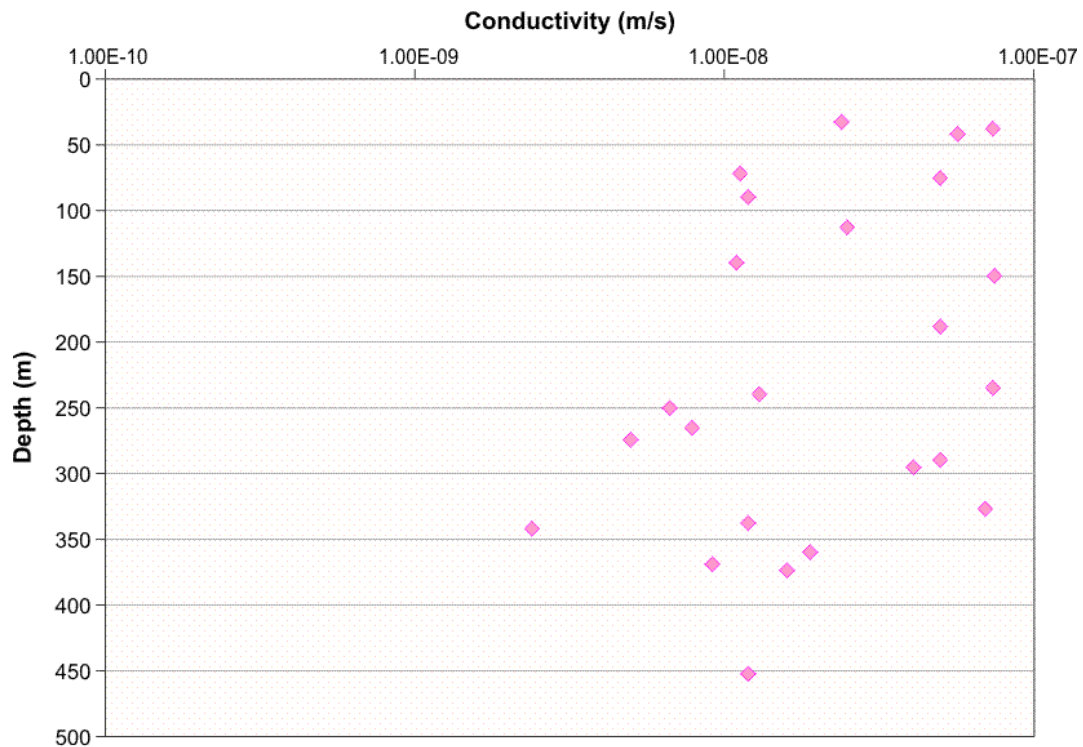
Jointing and pre-existing bedding plane fracture was simulated in the strata section on the basis of a random distribution with an average spacing.

### 2.3.5 Strata Permeability

The pre-mining permeability of the overburden was based on fracture related flow within the strata. Results of packer testing of the overburden together with regional information provided base permeability characteristics of the overburden. In general, the permeability is related to confining stress normal to the direction of flow. Therefore, horizontal permeability reduces with depth and permeability in the rock units is related to the lateral stresses.

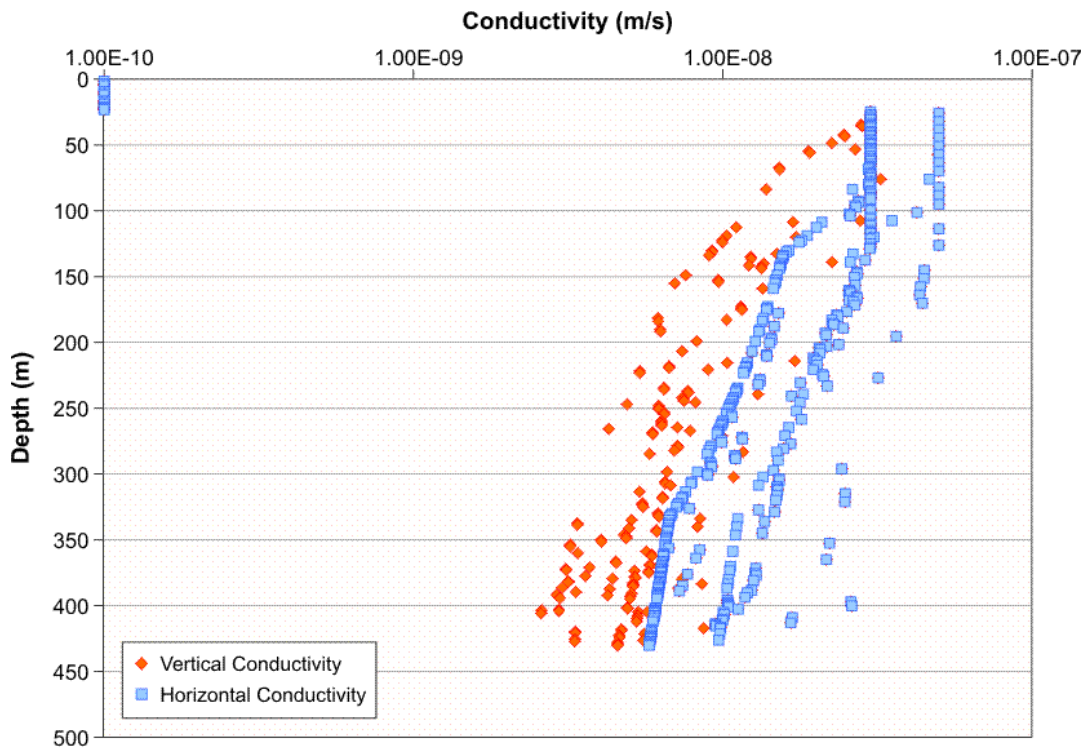
Mining induced changes to the stress field modify the overburden permeability, though these permeability changes reduce with height above the mining horizon.

The general overburden data available from packer testing during the exploration program at this site is presented in Figure 2.13. The permeability used within these models is presented in Figure 2.14.



**Figure 2.13 Permeability from Packer Testing**

The impact of mining on the permeability has been assessed by methods reported by Gale 2005, whereby the mining induced fracture permeability combined with the *in situ* strata permeability can be used to predict the permeability changes that may occur in the overburden above the mining horizon. In this way a section of the vertical permeability from surface to the seam level can be estimated. This provides an estimation of the height of the caving related damage and the impact of subsidence related fractures. In general, the mining related fractures are assessed in terms of flow through the fracture width using the cubic flow rule. The average permeability for a 1 m slice of the overburden is calculated taking the mining fracture damage and the *in situ* permeability into account over the mining goaf area. This is done progressively down from surface to the seam in 1 m intervals. This estimation assumes that there are numerous lateral bedding planes that can connect the vertical fracture systems that develop above the goaf. A key objective of the numerical modelling of the rock mass behaviour in Extraction Area is to confirm the presence and effect of these bedding planes so as to validate this assumption.



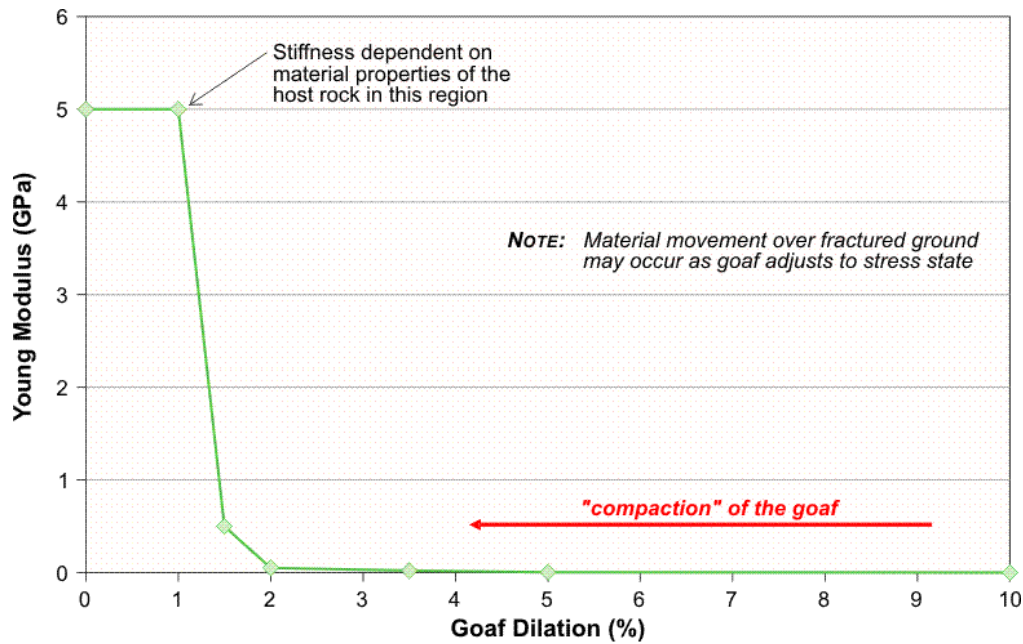
**Figure 2.14 Modelled Permeability**

### 2.3.6 Goaf Properties

Caved material forms the goaf in the models. The goaf develops strength on the basis of:

- An increasing stiffness with vertical strain; and
- Confinement within the goaf material that has developed as a result of the overburden converging onto the goaf.

The goaf loading characteristics are based on field extensometer data, together with measured vertical abutment load balance and subsidence validation from previous studies. The general goaf loading characteristics are presented in Figure 2.15.



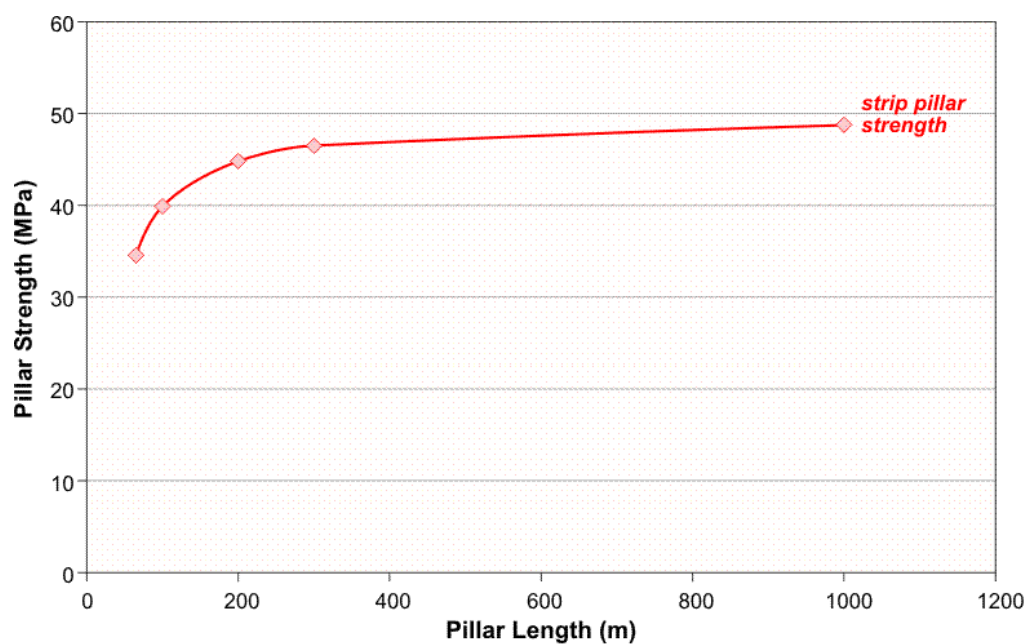
**Figure 2.15 Goaf Stiffness used in the Model**

### 2.3.7 Chain Pillar Strength

Since the model is a two dimensional slice across the panels, it simulates pillars as a continuous slice, and allowance needs to be made to simulate the impact of cut-throughs on the effective pillar strength. To represent the impact of cut-throughs on strength, the equivalent width of a continuous pillar, which represents the same strength as those planned with 100 m cut-throughs, was assessed.

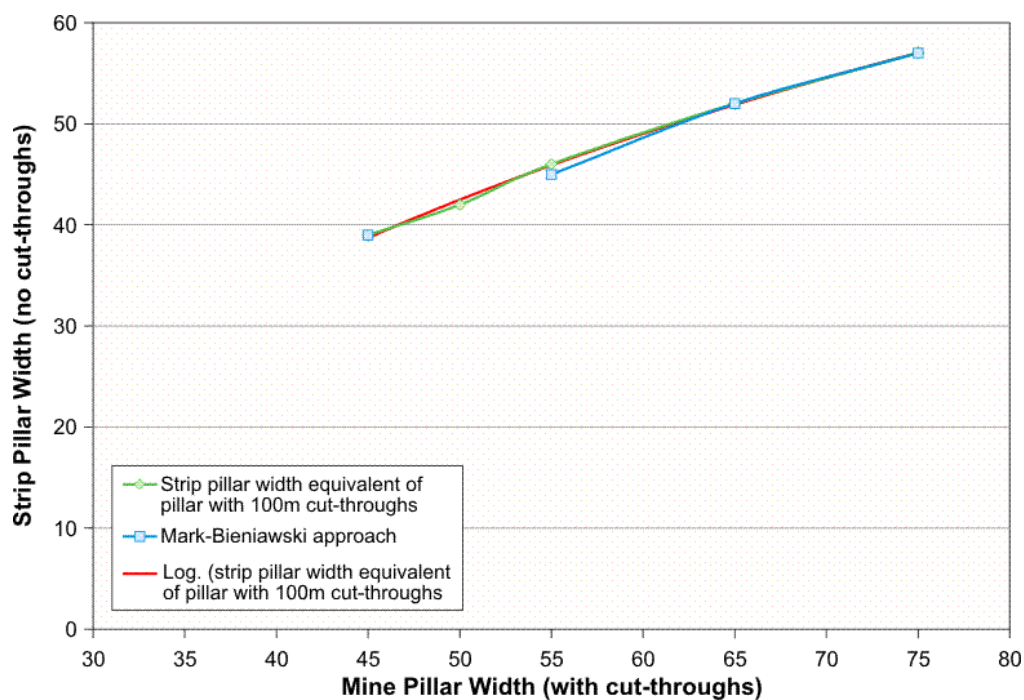
Two approaches have been used to evaluate this issue.

The first approach is the strength estimate of a pillar using the Mark-Bieniawski formula. This is an estimate of the intact strength for a coal pillar with certain width, height and length dimensions. The pillars proposed for the Project have widths ranging from 50-75 m and are typically 90 m in length. The pillar height for this analysis was 5 m, which is the approximate seam thickness. The impact of pillar length (cut-through spacing) is presented in Figure 2.16 and indicates that for the geometries envisaged for the Project the pillar strength is approximately 40 MPa whereas a strip pillar with no cut-throughs would be approximately 49 MPa. This is approximately 18% less and therefore the pillar geometry used in a 2 dimensional model needs to be adjusted to reflect the impact of cut-throughs.



**Figure 2.16 Impact of Cut-through Spacing on Pillar Strength (Mark and Bieniawski)**

The adjusted pillar width relative to the mine width using this relationship is presented in Figure 2.17.



**Figure 2.17 Equivalent Pillar Width used in the Model**

The second approach is similar to that of Mark–Bieniawski but is related to the post failure strength of the pillar. The average strip pillar yield strength was assumed to be 24 MPa in this analysis.

This is the approximate value of the yield strength of the pillars as modelled (see section 2.4.1). The reason it is less than the Mark-Bieniawski method is that:

- The actual geometry of the pillar varies due to caving adjacent to the pillar; and
- There is fracture of the strata above and below the pillar which changes the confining pressure and stress transfer about the pillar.

Overall, this changes the boundary assumptions of the Mark-Bieniawski approach.

The analysis assumes that the pillar has yielded and the stress distribution is “tent shaped”.

The impact of cut-throughs is to change the shape of the long “tent” distribution to a pyramidal tent of a square pillar. The height of the tent is dependent on pillar strength. The equivalent strip pillar width relative to the mine pillar width using this relationship is presented in Figure 2.17. It provides the same relative result as the Mark–Bieniawski relationship, despite the difference in pillar strength.

These relationships have been used to give some guidance as to the equivalent pillar width to use in the model for the various pillar geometries planned for the mine. The relationship assumes a tent shaped stress distribution. This distribution is not certain, and for this study a strip pillar of approximately 54 m in width has been used to represent a 65 m by 100 m chain pillar. This is a reduction of approximately 18%. Consequently, it was recommended that a 55 m wide chain pillar be used in the empirical modelling.

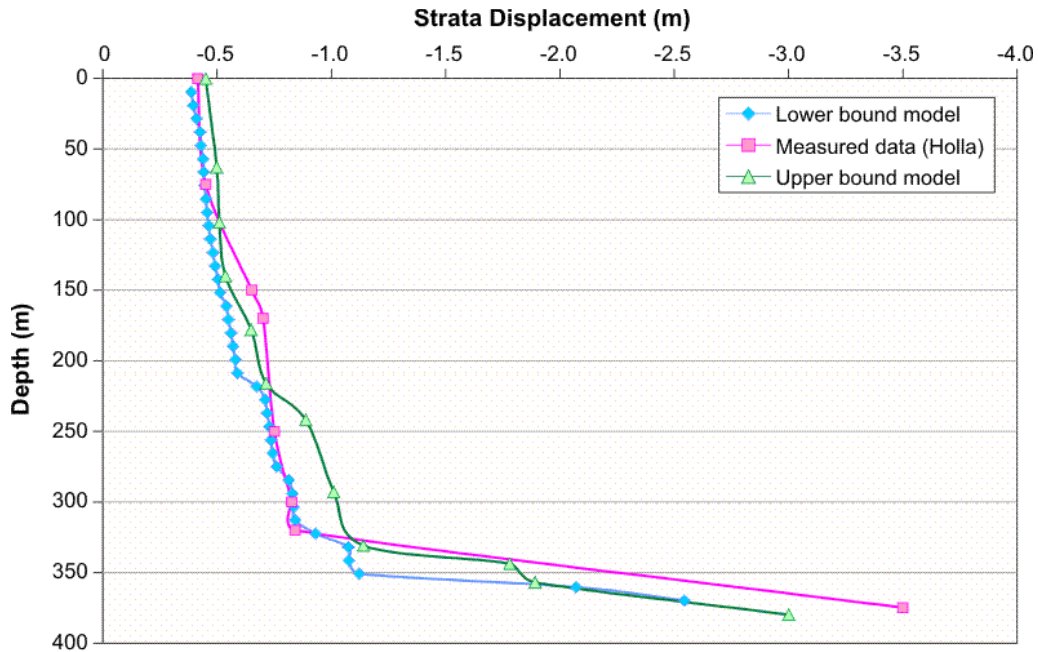
### 2.3.8 Caving Modes

During the modelling process, two caving modes were evaluated. The caving modes were termed “upper bound” and “lower bound” and relate to the rate at which the stress is reduced in the elements about the caving front. The upper bound case relates to a rapid stress loss associated with rapidly detaching blocks and the lower bound case relates to a more interlocking system of fractures and as such a lower rate of stress loss. This range was used to assess the potential impact of varied caving characteristics.

The main impact of these two cases is on the effective geometry and strength of the chain pillars. During the program, the effect of the two cases was evaluated for various sites for which there was validation data.

The upper bound case was used to evaluate the South Bulli partial extraction geometry and in this geometry the caving mode has not modified the overall result. Both the upper bound and lower bound methods were used to evaluate the Ellalong data set, and the result was that it had no significant impact on the overall subsidence or the nature of strata caving above the panel as indicated by the extensometer simulation. A comparison of the extensometer results relative to that measured by Holla and Armstrong is presented in Figure 2.18.

Variation in the goaf edge geometry did occur, however for seams in the 2-3.5 m range this did not have a major overall impact. However, in situations where extraction of 4.5-5 m was undertaken in preliminary models of the geology for the Project, the pillar strength and caving geometry was considered to represent an unlikely worst case situation rather than a typical caving characteristic. On this basis, the lower bound case was chosen to give a more accurate computational representation of the rock failure process, and therefore adopted as the standard mode in other simulations.



**Figure 2.18 Comparison of Caving Modes and Measured Data**

### 2.3.9 Limitations

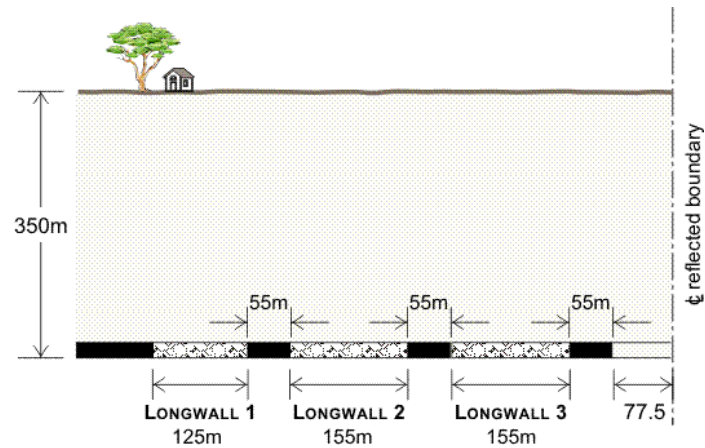
It should be noted that all numerical models are based on an extrapolated geological section, and rock properties derived from laboratory testing and geophysical logging, to provide an estimate of the ground conditions, around which the various subsidence predictions have been made. Validation studies by back analysis have provided a level of confidence that this state of the art prediction method is capable of providing a realistic overview of the anticipated ground behaviour for those conditions. The ground conditions modelled are likely to represent a conservative assessment in order to ensure a worst-case scenario. Whilst the conservative approach is appropriate for the current mine planning study, the monitoring and analysis of the actual subsidence measured during mining will enable further verification of the model and enhance its future predictive capabilities.

## 2.4 The “Hue Hue” Case

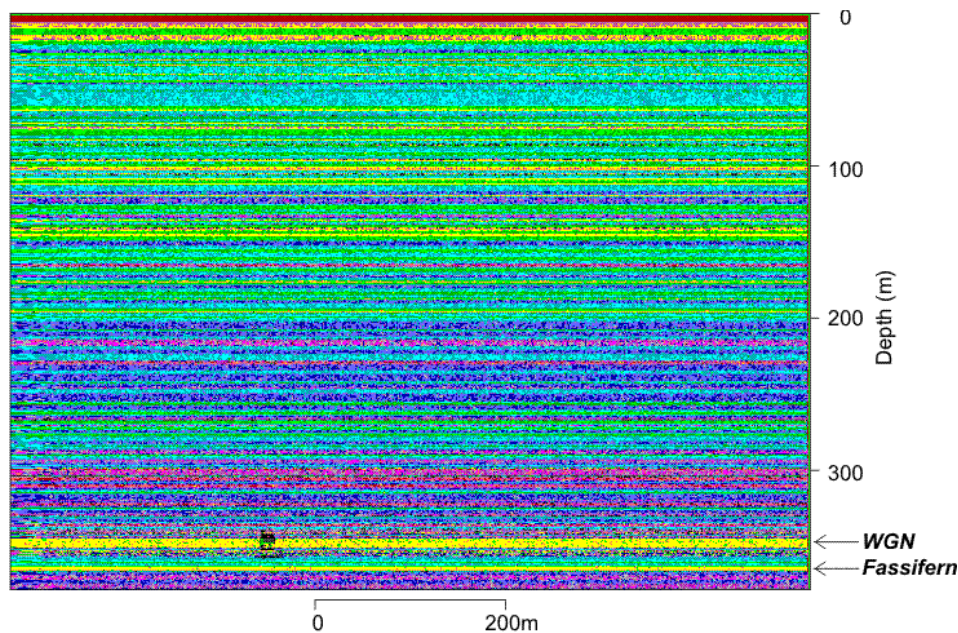
The “Hue Hue” case is a section where the depth is approximately 350 m with no significant occurrence of Quaternary unconsolidated sediments.

The model created for the Hue Hue Area is presented in Figure 2.19 and Figure 2.20, in terms of the UCS of the rock units. The geological layering is evident together with the variability function for each layer.





**Figure 2.19 Hue Hue Model Geometry**



**Figure 2.20 Geological Section of the Hue Hue Model**

The panel geometry assessed was Longwall 1 at 125 m width and Longwalls 2 and 3 at 155 m width. Chain pillar size planned was 65 m by 100 m long. Extraction height was 4 m from the top of the seam. The equivalent model pillar width was approximately 55 m, used to allow for the strength reduction factor associated with the affect of cut-throughs.



### 2.4.1 Caving Development and Subsidence Characteristics

The fracture distribution, which resulted from Longwall 1 and subsequent panels, is presented in Figure 2.21. It shows that a single panel would create caving related fractures up to around 100-120 m above the seam. The associated subsidence, of less than 100 mm, is shown in Figure 2.22.

The extraction of Longwall 2 was essentially similar to that of Longwall 1 although fracture of strata above and below the chain pillar occurred. The effective geometry of the chain pillar now included the caved zone from both longwall panels rather than just the geometry of the coal itself, with resultant subsidence of approximately 0.5 m. The overall extraction geometry at this stage was approximately 335 m at a depth of 350 m. This is approaching the transition from a sub-critical to critical geometry whereby the width of the extracted area is equal to the cover depth. In this geometry, the overburden response is controlled by the capability of the overburden to span across the panels, together with the support provided by the chain pillar. As more panels are extracted, the spanning capability reduces and a greater reliance is placed on chain pillar support and goaf loading.

Extraction of Longwall 3 within the model caused a further increase in subsidence as shown in Figure 2.22. This was due to the yielding of the pillars together with the loss in the spanning capacity of the overburden due to the larger (supercritical) extraction geometry. This pillar yield is caused in part by fracture in the strata above the pillars.

The fracture geometry presented in Figure 2.21 indicates that whilst the panels show individual caving zones, the overburden has sheared along bedding planes and is subsiding in relation to the overall extraction and pillar geometry. The resultant subsidence is therefore controlled by the pillar strength and the goaf load developed as the overlying strata lowers on to the goaf material. The model also confirms the occurrence of numerous lateral bedding planes that can connect the vertical fracture systems that develop above the goaf. This serves to confirm the underlying assumptions upon which the permeability modelling is based.

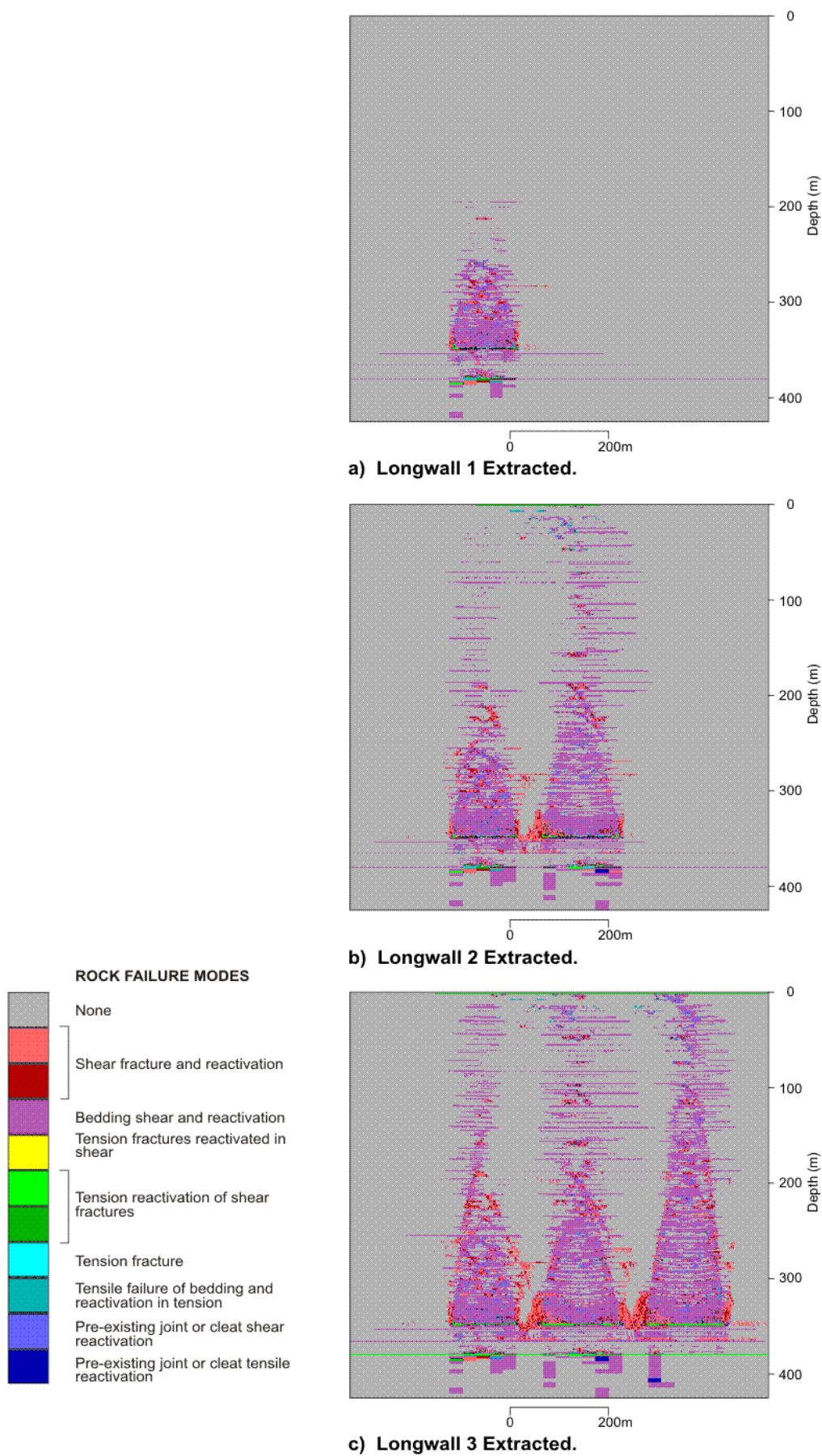
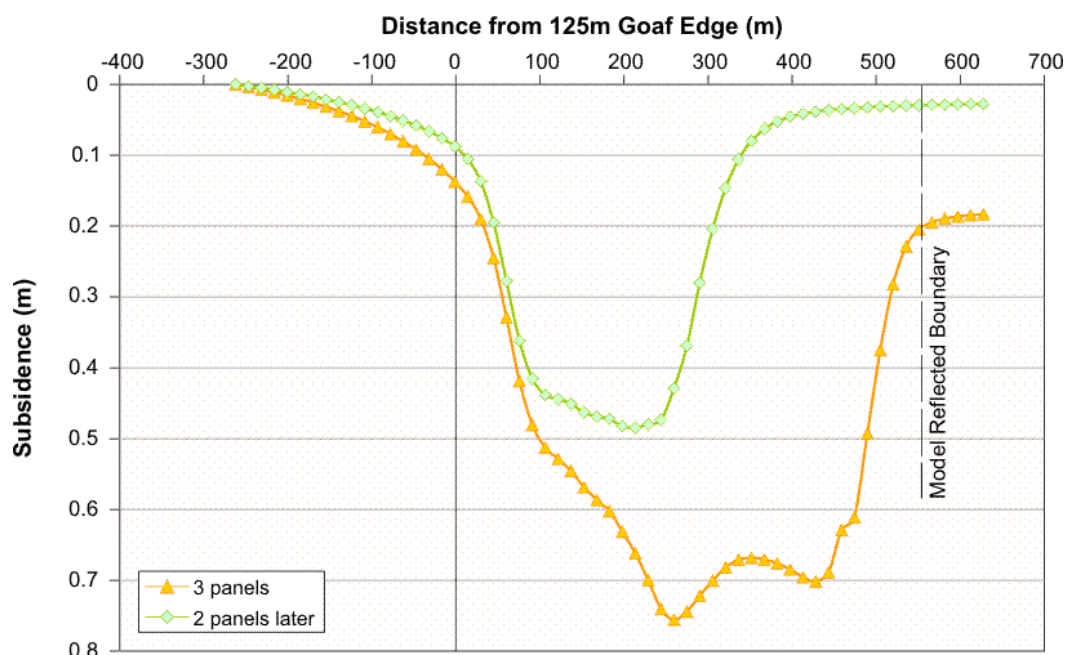
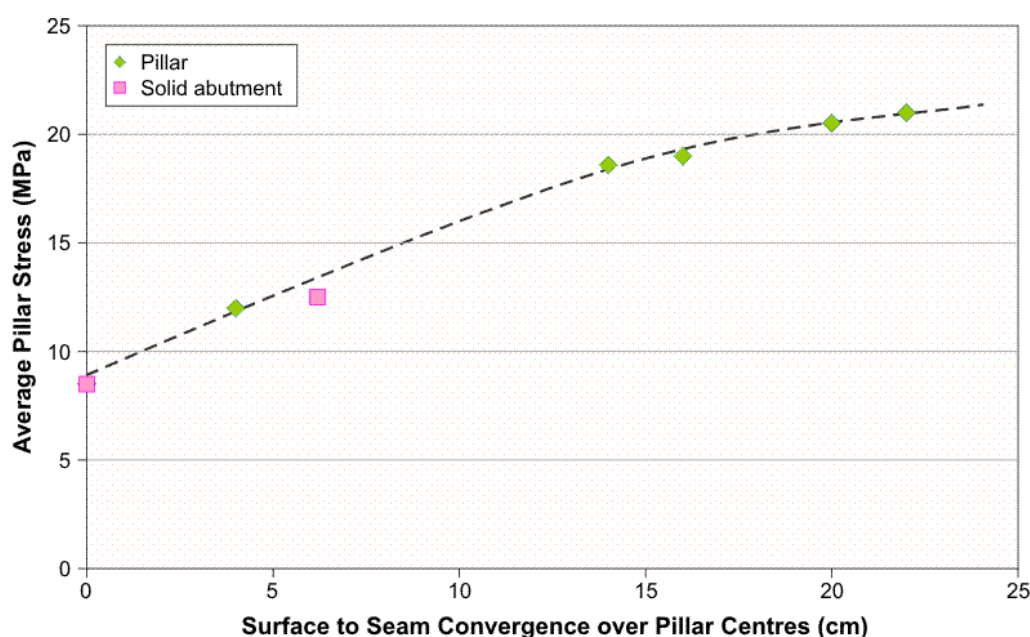


Figure 2.21 Modelled Rock Fracture Development for the Hue Hue 4.0 m Case.



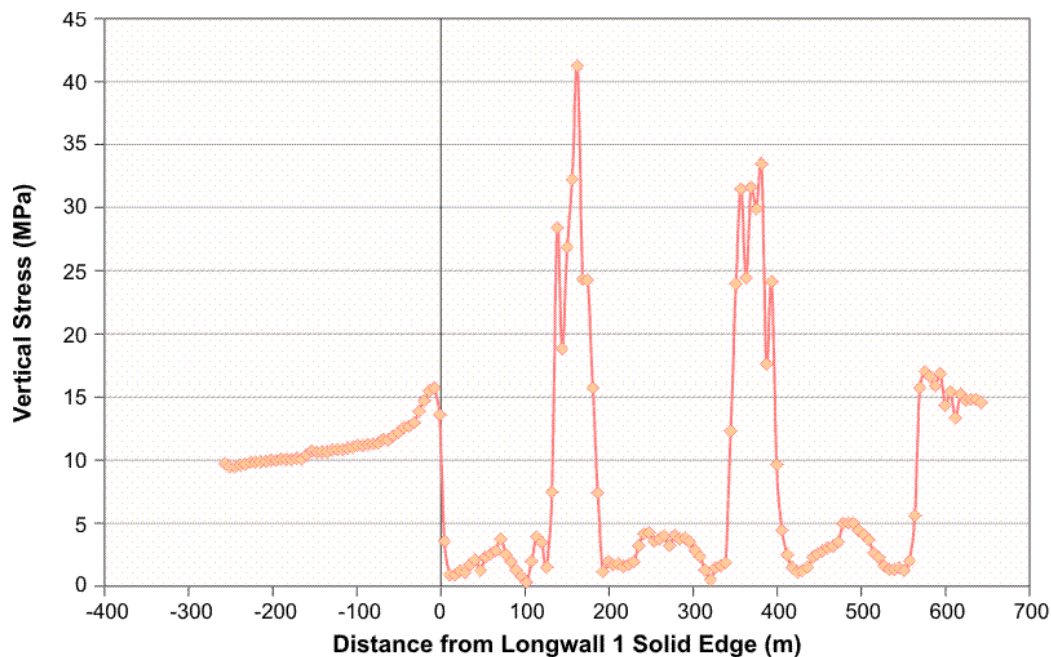
**Figure 2.22 Modelled Subsidence Profile for the Hue Hue 4.0 m Case**

The chain pillar strength characteristics noted in the model indicate that the yield strength of the pillars is approximately 20-24 MPa in this geometry. It was noted that as subsequent panels are mined, additional goaf consolidation occurs which provides confinement to the pillar zone and allows an increase in strength as the additional subsidence occurs. The pillar strength characteristics during Longwall 2 and then for the subsequent panels are presented in Figure 2.23. This indicates that once the pillars have yielded, they will maintain or increase their load bearing capacity as additional panels are mined. This increase is due to the confinement developed as overburden subsidence occurs and the goaf and pillar system come into equilibrium for this pillar load at this depth.



**Figure 2.23 Pillar Strength Characteristics for the Hue Hue 4.0 m Case**

The average goaf vertical stress attained after Longwall 3 was approximately 2-3 MPa. The vertical stress distribution across the total system is presented in Figure 2.24, which shows the loading within the abutments, pillars and goaf.



**Figure 2.24 Vertical Stress across the Model for the Hue Hue 4.0 m Case**

In order to assess the potential pillar geometry and extraction height required to significantly reduce subsidence, a model was run with a 3 m extraction height and a 65 m wide strip pillar. The same geometry with a 4.5 m extraction was also run to compare the difference. The aim of this was to obtain parametric data that would assist in defining the controls, which may be best, utilised.

The relative fracture distributions about the panels are shown in Figure 2.25 and indicate that:

- Chain pillars had yielded in the 4.5 m case and not the 3 m case;
- Caving geometry and the caving heights are similar; and
- Overburden deformation mode is similar.

The results in terms of subsidence are presented in Figure 2.26 and indicate that the 3 m extraction case has much lower subsidence and ground tilts. The 4.5 m case shows similar subsidence characteristics to that for the 55 m pillar case discussed above.

The pillar loading characteristics for the two cases are presented in Figure 2.27 which shows that the 3 m extraction height case is essentially behaving elastically with some late stage indication of potential yield whereas the 4.5 m case is yielding and the additional subsidence is loading the goaf. The yield strength of the 4.5 m pillar is approximately 18-20 MPa, and the load developed in the 3 m case was in the range of 22-24 MPa. It is apparent that the required strength of pillars is in the 22-24 MPa range for this geometry and depth.

This indicates that extraction height and pillar integrity are key parameters in subsidence control, and that the long-term stability of chain pillars in this geological environment is unlikely.

Consequently, to provide greater long-term predictability the layouts have been designed to incorporate chain pillars that will yield as mining progresses.

These data has been used to provide an initial guide as to the effect of extraction height on subsidence for use in planning, however, since the overburden response is a combination of pillar geometry, panel width and extraction height, this relationship will need to be reviewed where specific controls are required for particular sites such as urban developments and major infrastructure.

#### **2.4.2 Overburden Vertical Permeability**

The vertical permeability profile above the 125 and 155 m panels modelled is presented in Figure 2.28. It indicates that the major caving related changes occur up to approximately 175 m above the panels. In this area the strata is assumed to be free draining. Above this, the permeability is variable due to localised areas of fractured ground. The flow in this region is considered to be tortuous and limited by the thickness of strata which is not significantly modified by the subsidence movements.

Some enhanced permeability is anticipated in the near surface strata as a result of subsidence related cracking at rockhead. While local areas of horizontal flow and flow redirection may occur within the near surface, these are not directly connected to the mining zone.



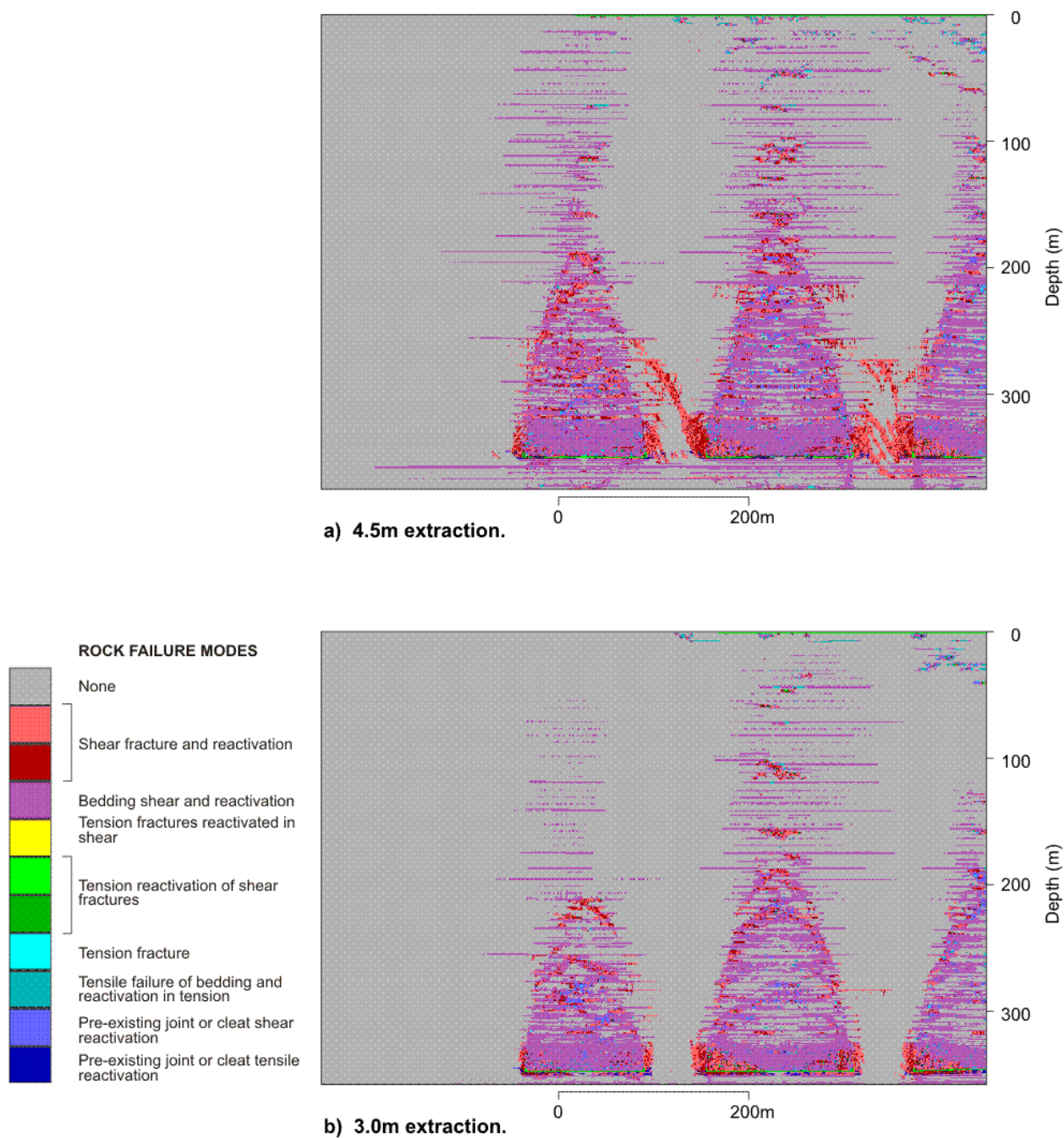


Figure 2.25 Modelled Rock Fracture Development for the Hue Hue 3.0 m and 4.5 m Cases



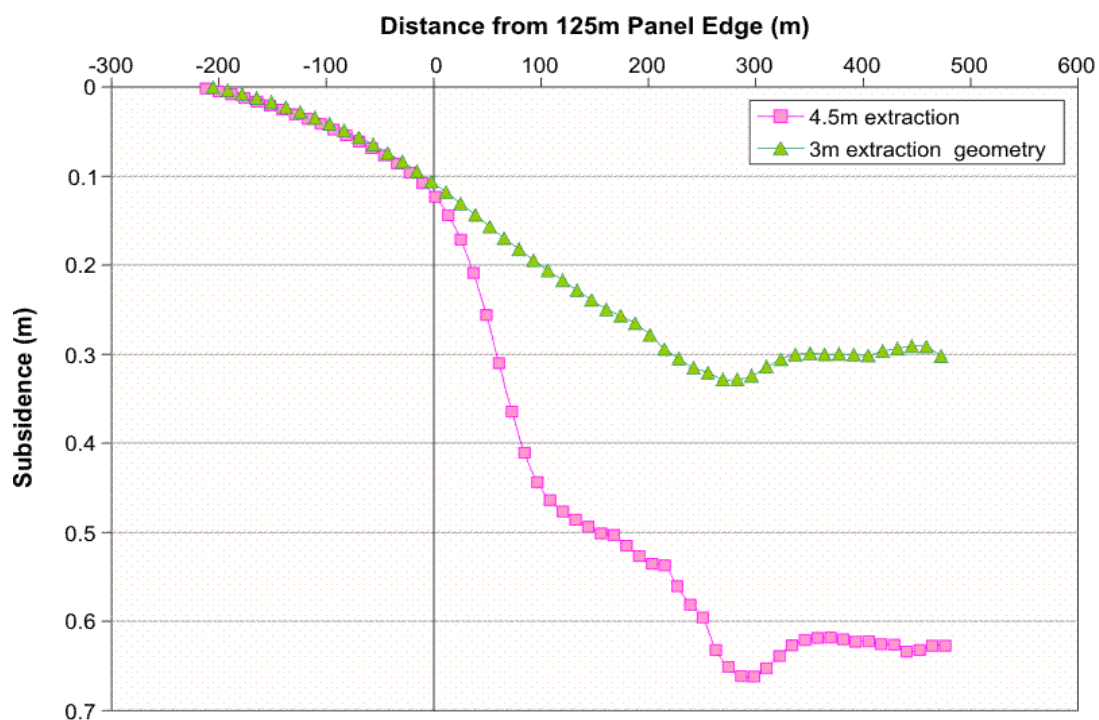


Figure 2.26 Modelled Subsidence Profiles for the Hue Hue 3.0 m and 4.5 m Cases

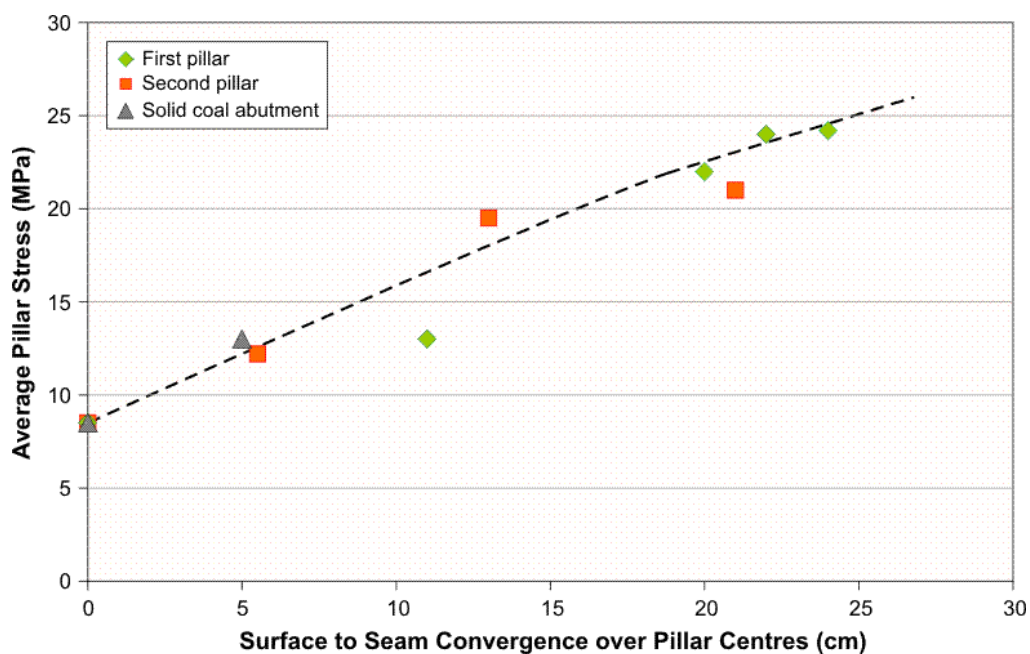
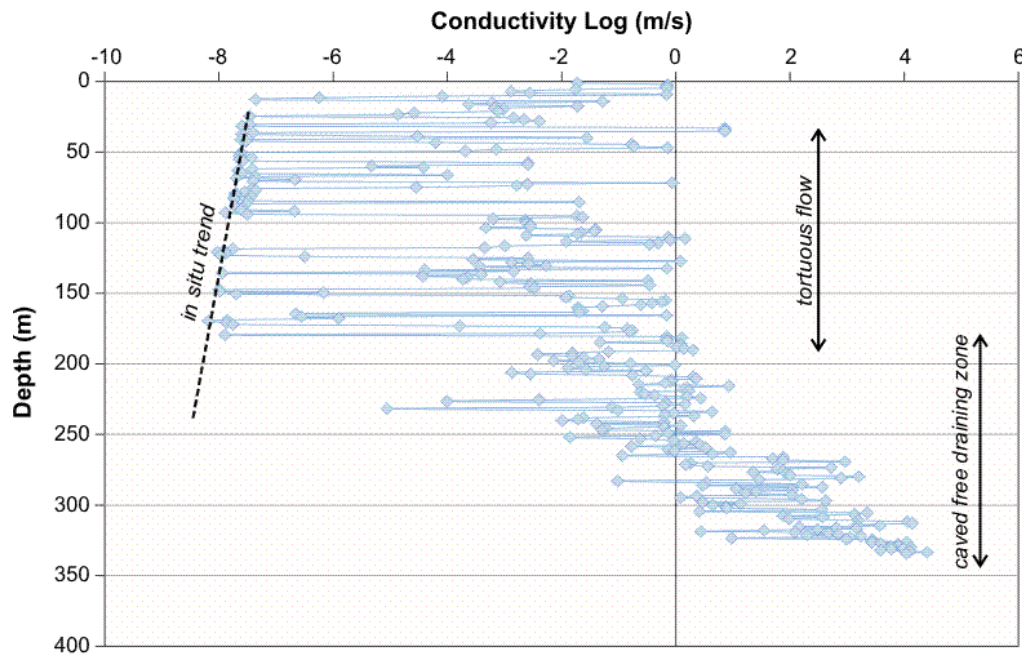


Figure 2.27 Pillar Strength Characteristics for the Hue Hue 3.0 m case



**Figure 2.28 Overburden Vertical Permeability Profile for the Hue Hue 4.0 m Case**

## 2.5 The “Valley” Case

The “Valley” case is a section where the depth is approximately 400 m and a cover of approximately 23 m of Quaternary unconsolidated sediments has been deposited by stream flow action.

The model geology for the “Valley” case is presented in Figure 2.30 in terms the UCS of the rock units.

The aim of this model was to assess the overburden response and subsidence behaviour for the 175 m wide panels.

Panels in this area are planned to have extraction widths of 175 m and pillars widths of 65 m. An extraction height of 4.5 m was used in the model as this is the approximate proposed extraction height in these areas of the mine.

The geometry modelled was three longwall panels progressively mined at 175 m widths with a 55 m chain pillar. The initial two panels were at a critical/super critical width and the additional Longwall 3 panel created a supercritical geometry.

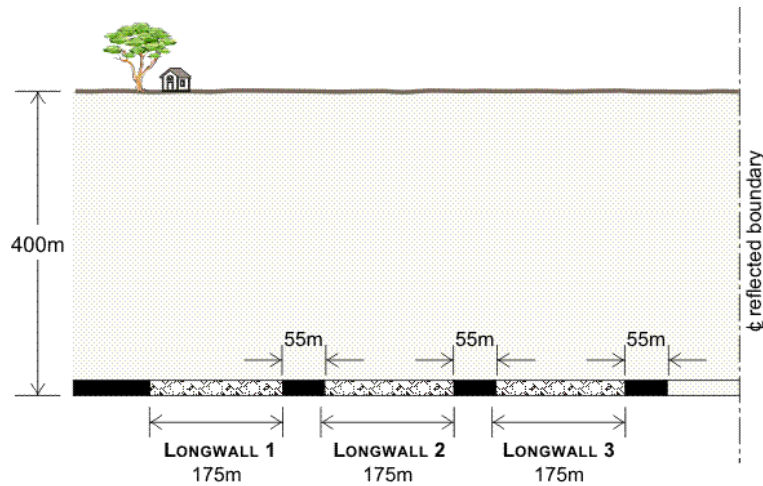


Figure 2.29 Valley Model Geometry

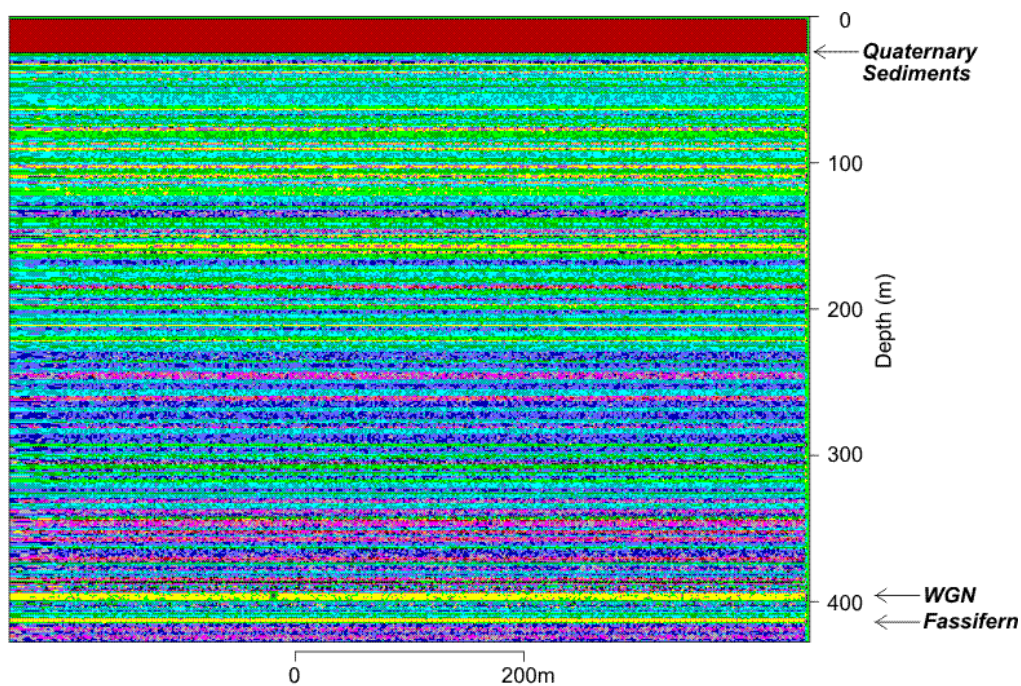


Figure 2.30 Geological Section of the Valley Model

### 2.5.1 Caving Development and Subsidence Characteristics

The fracture distribution for the progressive stages of extraction is presented in Figure 2.31, whilst the associated development of subsidence is presented in Figure 2.34. The model indicates that the caving related fracturing extends to approximately 200 m above the seam, beyond which the disturbance to the strata is limited to bedding plane shear and localised fracturing. The model also indicates that the chain pillars eventually yield and that fracturing of the strata above the pillars is evident as part of the yielding process.

At a depth of approximately 400 m, the pillar yield occurred at an average pillar stress of approximately 27-28 MPa. However, additional strength was obtained when adjacent panels were extracted causing additional subsidence and confinement within the goaf/pillar system. Pillar load up to 33 MPa was noted in the model as additional subsidence occurred and caused additional goaf “consolidation”.

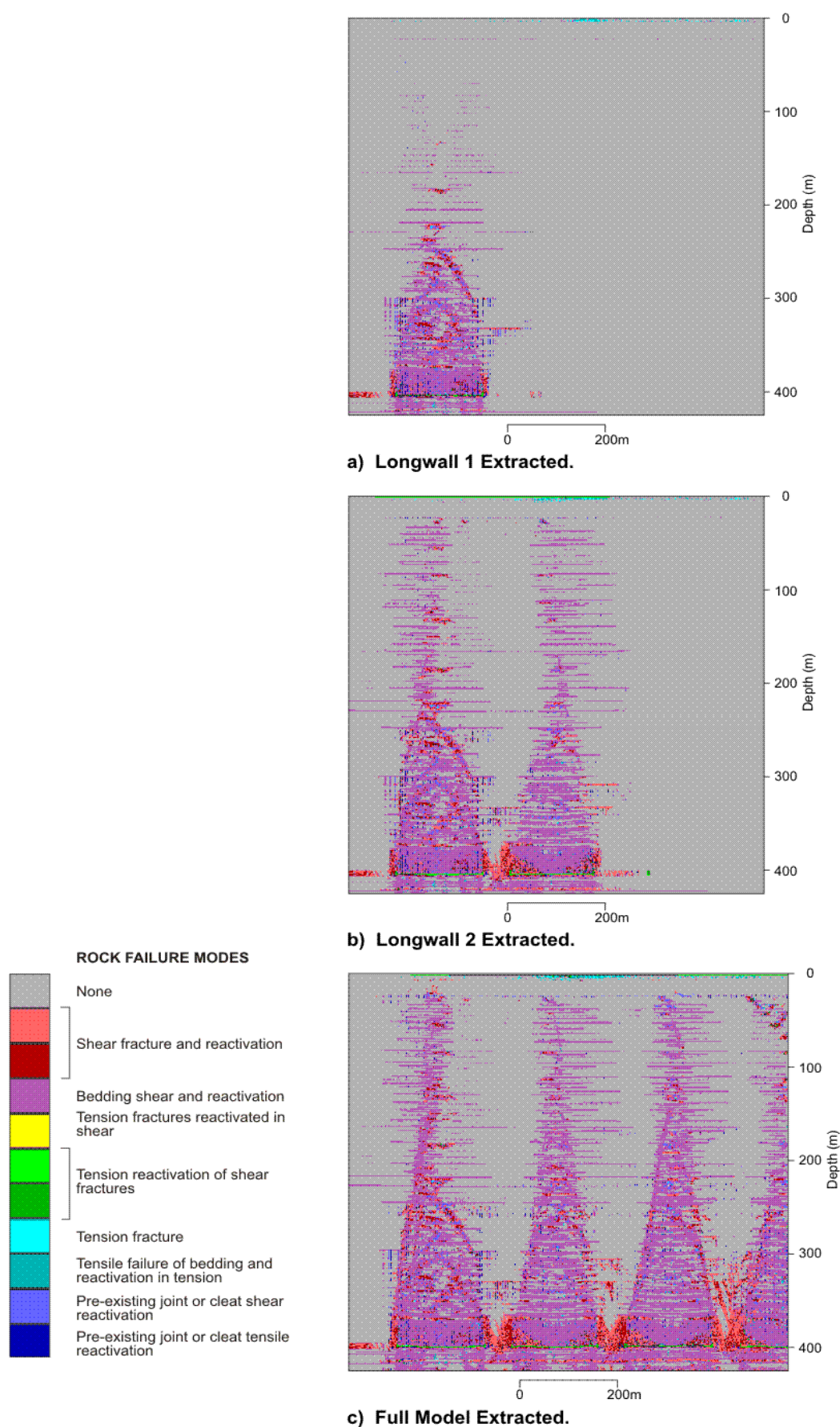
The concept of pillar load and yield for these pillars is one where the strength is intimately associated with confinement developed from the goaf consolidation. Therefore, if confinement is readily achieved, the pillars will progressively develop strength in association with goaf loading and extraction of subsequent panels. The pillar strength characteristics are presented in Figure 2.32.

The vertical stress profile across the panel geometry (at 5 m into the floor) is presented in Figure 2.33. This shows the side abutment, goaf load and pillar load distribution in the model. The average goaf load is approximately 5 MPa, which is higher than the “Hue Hue” case.

The model indicates that minimal subsidence would occur for a single panel, but once two panels were extracted, and achieved critical width, then subsidence close to the maximum value would occur at that time. The increase from the third and multiple panels is not great as the critical geometry was created after two panels and did not require additional panels to create a super critical geometry. This finding is consistent with that noted from field observations associated with the Ellalong case discussed previously. The model also confirms the occurrence of numerous lateral bedding planes that can connect the vertical fracture systems that develop above the goaf. This serves to confirm the underlying assumptions upon which the permeability modelling is based.

As in the case with the Hue Hue model, the overall subsidence geometry for the Valley case appears to be generally consistent with the shape noted for Bulli Seam extraction in the Southern Coalfield though with varying magnitude. This is consistent with the expected influence of the Newcastle Coalfield geology.





**Figure 2.31 Modelled Rock Fracture Development for the Valley Case**

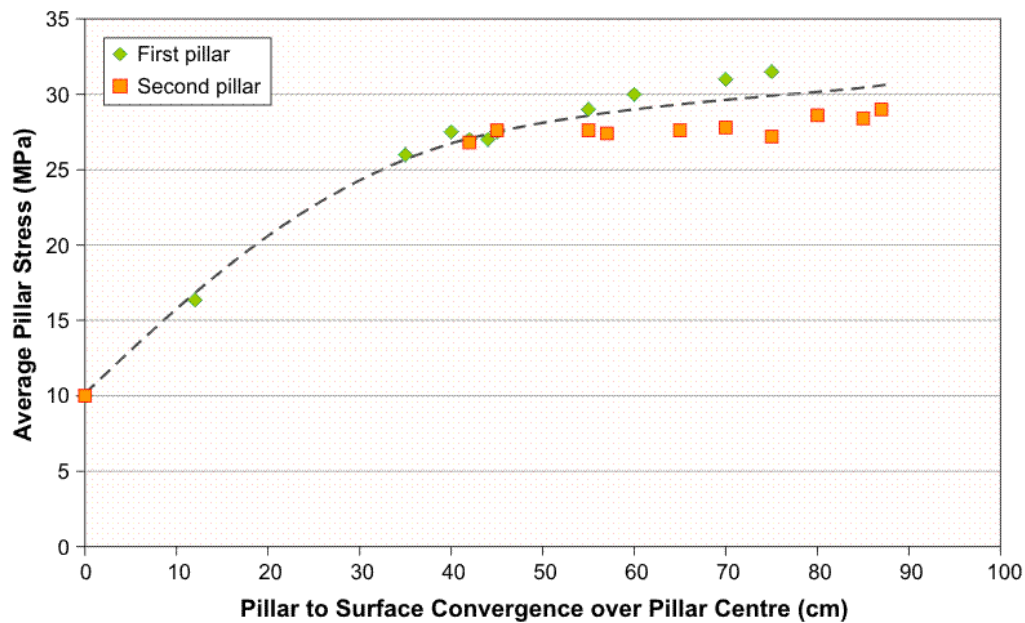


Figure 2.32 Pillar Strength Characteristics for the Valley Case

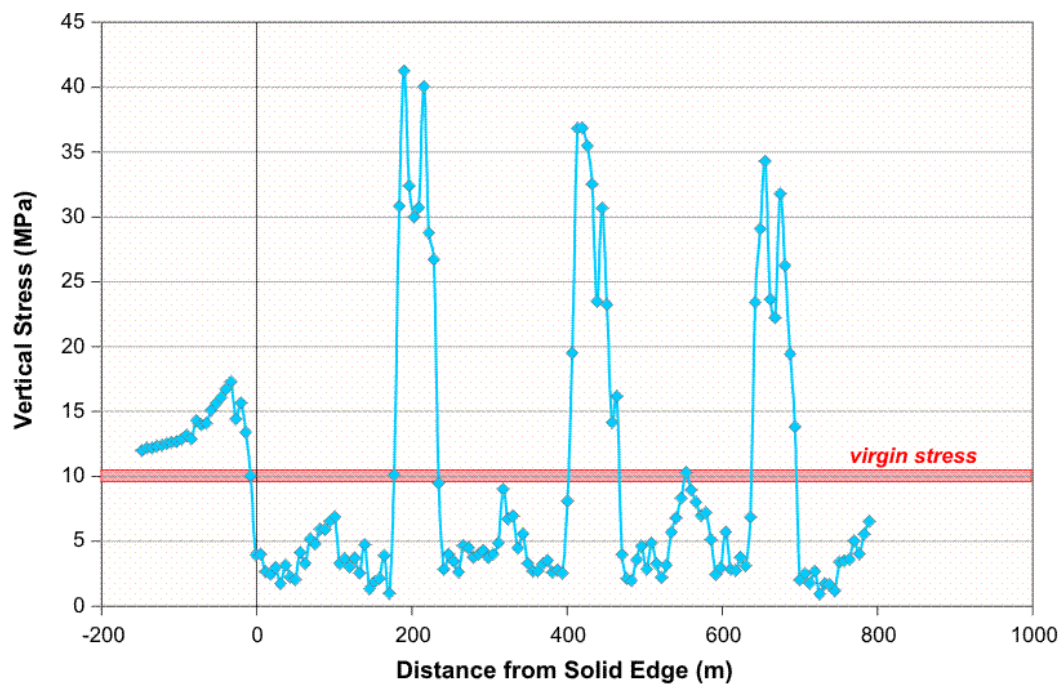
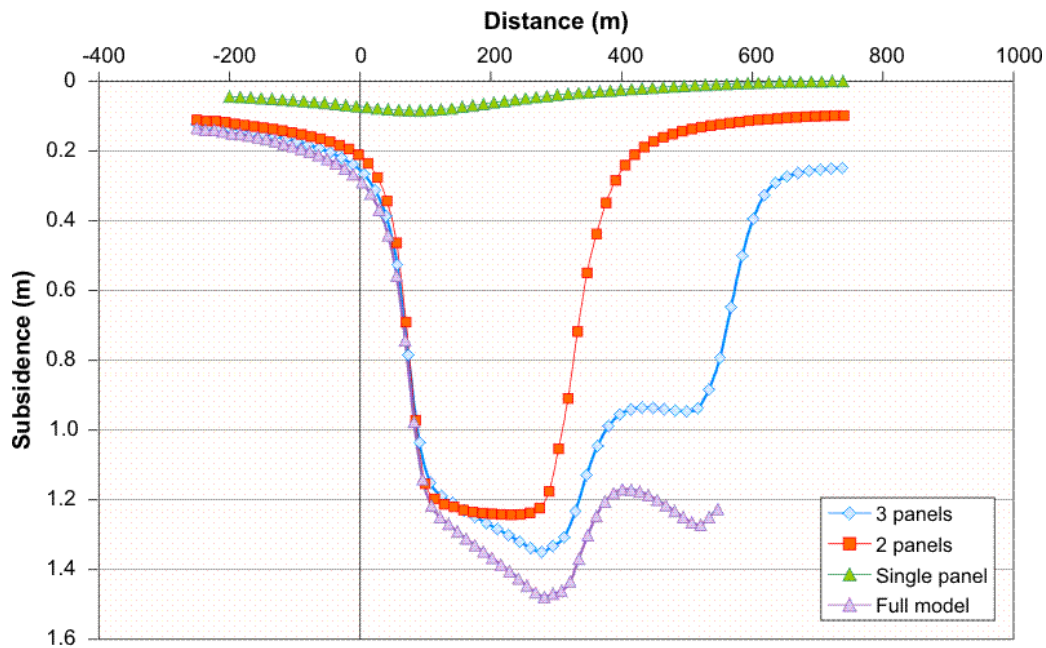


Figure 2.33 Vertical Stress across the Model for the Valley Case

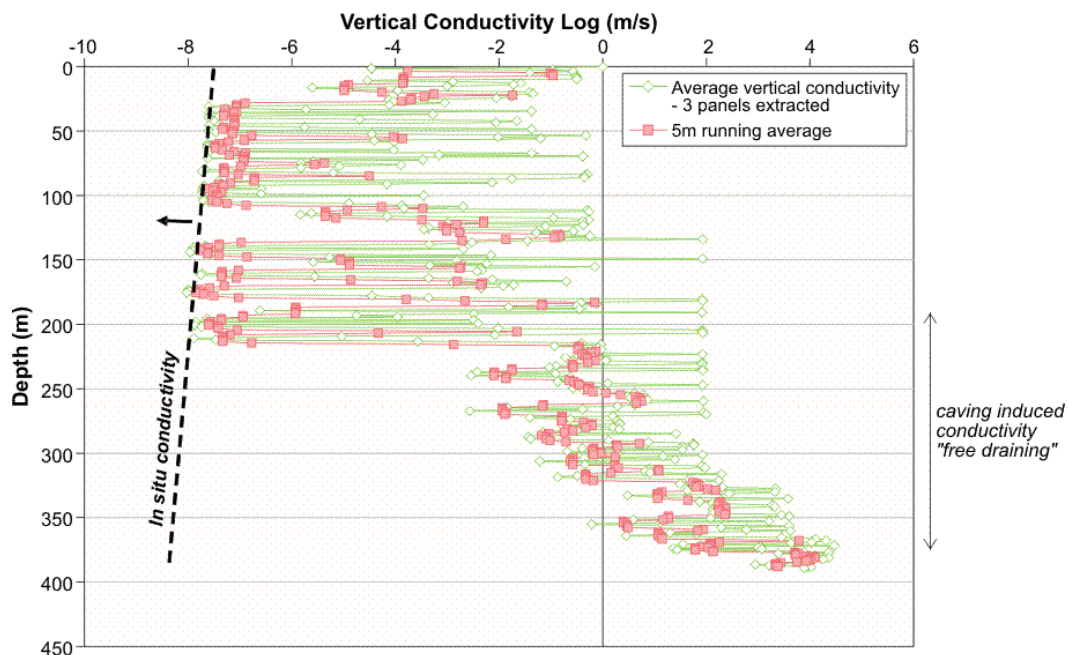




**Figure 2.34 Modelled Subsidence Profiles for the Valley Case**

### 2.5.2 Overburden Vertical Permeability

The vertical permeability profile above the 175 m panels modelled is presented in Figure 2.34. It indicates that the major caving related changes occur up to approximately 190 m above the panels. In this area the strata is assumed to be free draining. Above this the permeability is variable due to localised areas of fractured ground. Water flow in this region is considered to be tortuous and limited by the extent of strata that is not significantly modified by the subsidence movements.



**Figure 2.35 Overburden Vertical Permeability Profile for the Valley Case**

Some enhanced permeability is anticipated in the near surface strata as a result of subsidence related cracking at rockhead. While local areas of horizontal flow and flow redirection may occur within the near surface, however this is not directly connected to the mining zone.

## 2.6 The “Forest” Case

The “Forest” case is a section where the depth is approximately 500 m with no significant deposits of unconsolidated Quaternary sediments due to the hilly nature of the area.

The model geology for the “Forest” case is presented in Figure 2.37 in terms the UCS of the rock units.

The aim of this model was to assess the overburden response and subsidence behaviour associated with the extraction of 255 m wide longwall panels separated by 50 m wide pillars in hilly terrain.

Four longwall panels were progressively mined with the extraction of the third panel achieving a supercritical geometry.

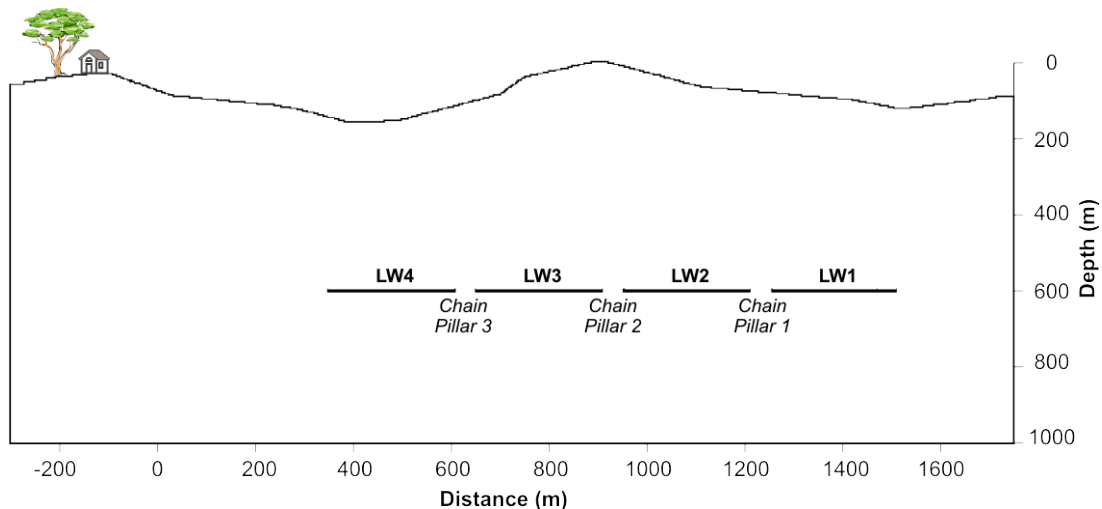


Figure 2.36 Forest Model Geometry

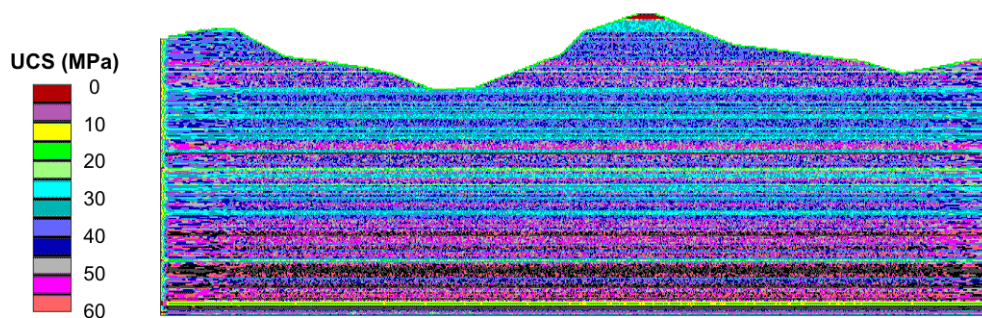


Figure 2.37 Geological Section of the Forest Model

### 2.6.1 Caving Development and Subsidence Characteristics

The fracture distribution for the progressive stages of extraction is presented in Figure 2.38, with a more detailed figure after Longwall 4 presented in Figure 2.39, and the associated development of subsidence presented in Figure 2.42.

The fracture distribution relates to the case of assuming that jointing is open within the hills above the water table. The longwall panels cause bedding plane shear to occur throughout the overburden and cause additional opening of jointing on the hills. Shear under valleys is increased.

The caving zone extends approximately 30-40m into the roof and above this the dominant fracture mode is bedding plane shear. Above this zone the strata tends to deflect down on the caving zone and breaks as “sheets or blocks” which relate to major units within the formations separated by bedding planes. Bending related fractures form in these units as they subside and deflect.

It was noted that sub vertical fractures form during deflection of the overburden and also due to stress concentration during the caving process. However the fractures formed do not form a continuous fracture network between the surface and the caved zone, rather they form a very discontinuous network within the general overburden. Similarly the fractures formed under the valleys only extended tens of metres below and did not indicate any potential to connect to the mine below.

The fracture systems created during Longwall 1 tend to form an arch approximately 1.25 times panel width which is typical of single panels. These fractures are primarily horizontal bedding plane shear planes. Above the “arch” the bedding plane zone extends to the surface.

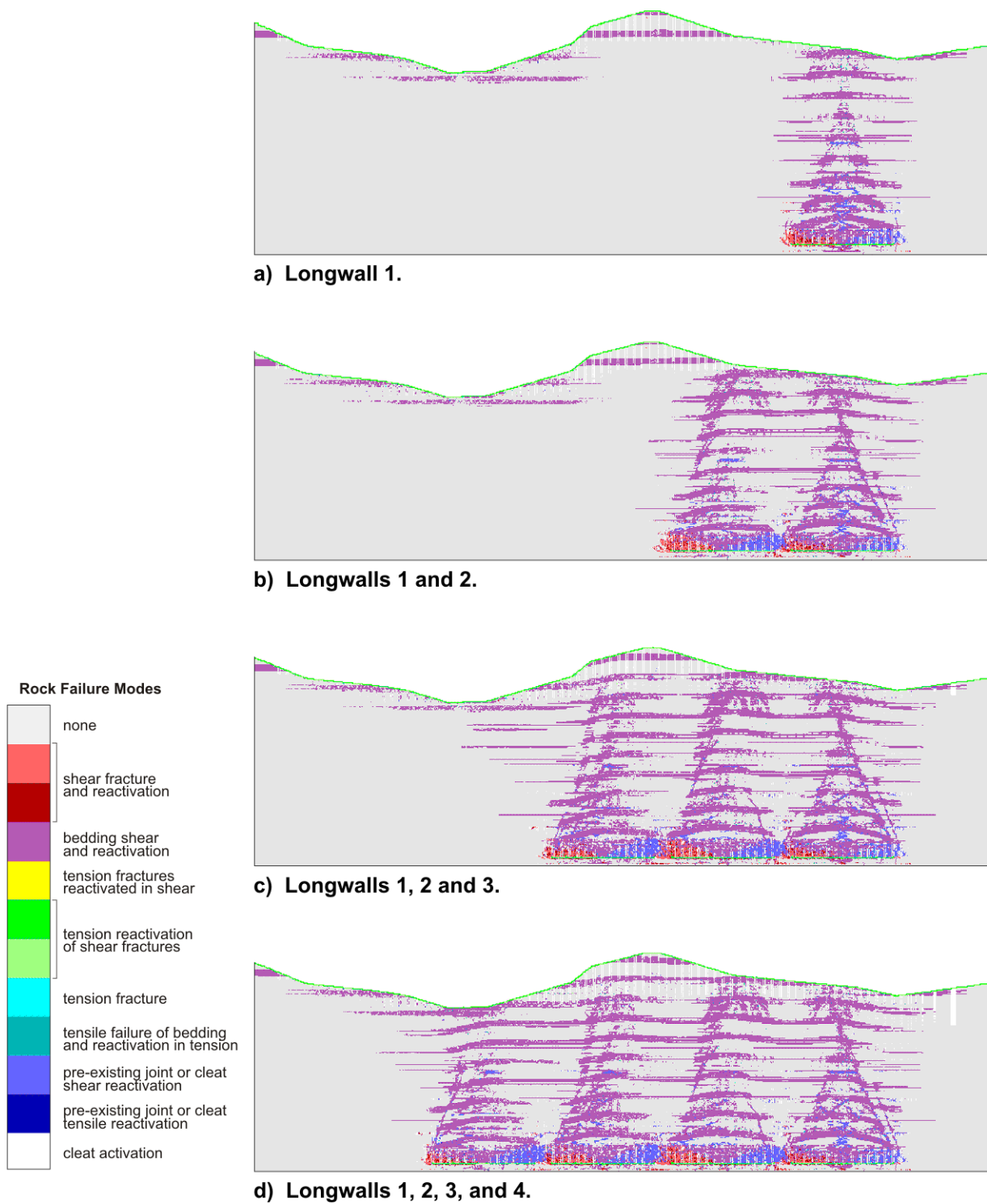
Longwall 2 interacts with Longwall 1 to act essentially as a wider panel and displays the horizontal bedding shear zones on the solid sides of the panels. The chain pillar has yielded between the panels which allows the two panels to interact in this manner. There is only a minor zone of shear on the right hand side of Longwall 2 which is related to formation of the arch zone. This arch zone is not well developed as the two panels have interacted as a wider panel and as such Longwall 2 does not act as single panel as did Longwall 1.

Longwall 3 interacts with the previous panels and only forms the bedding plane shear zone on the solid side of the panel. It interacts with Longwalls 2 and 1. There is very little vertical or sub vertical fracturing created in the overburden section.

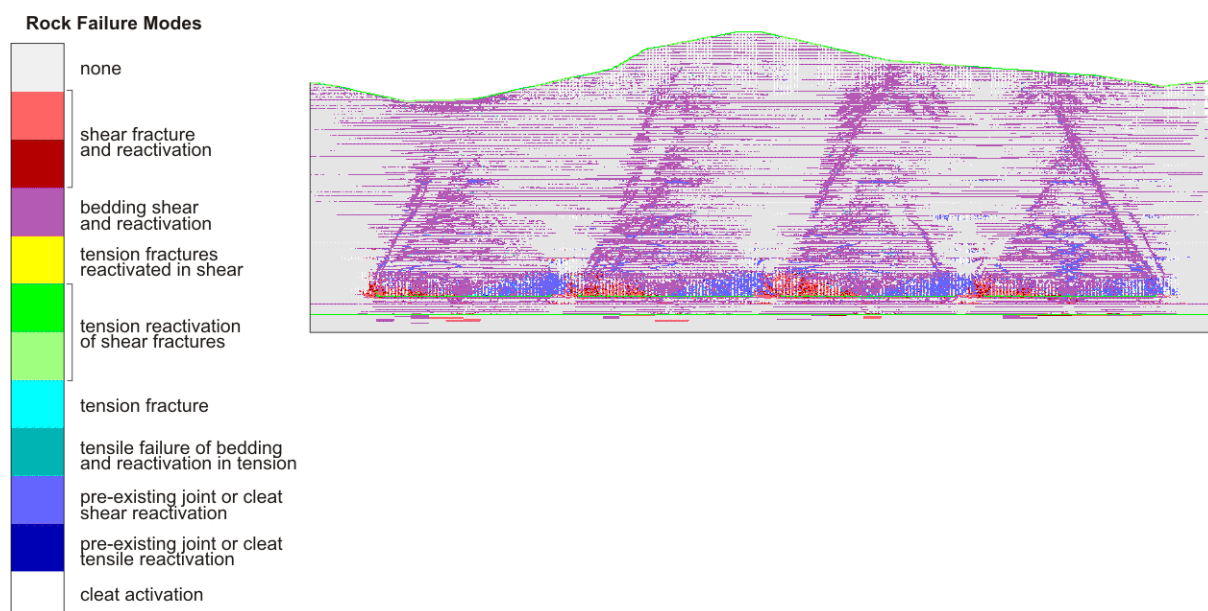
Longwall 4 interacts with the previous panels and has a zone of bedding plane shear on the solid side as did Longwalls 2 and 3. The height of the zone is lower which reflects the stable ongoing geometry of the panels and potentially the topographic effects adjacent to the hill and valley.

These results show that the longwall panels become super critical after approximately 3 panels and then tend to act as a group of panels after this geometry is established. Therefore the fracture zones formed about Longwalls 3 and 4 are most representative of the fracture systems anticipated in the western (Forest) area.

The effect of extraction at the surface and near surface is to activate pre-existing jointing on the hills and bedding planes which daylight into the valleys. Once the bedding planes have sheared, the ground tends to move toward the valley as part of a stress relief phenomenon. This was seen to cause valley closure above Longwall 4, however the closure was initiated during extraction of the earlier longwall panels.



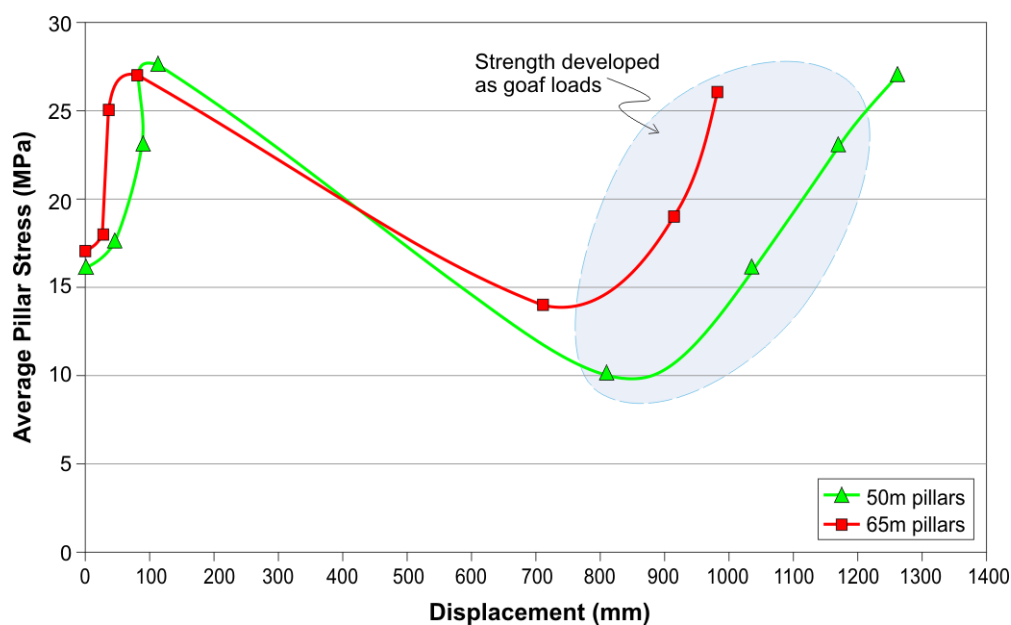
**Figure 2.38 Modelled Rock Fracture Development for the Forest Case**



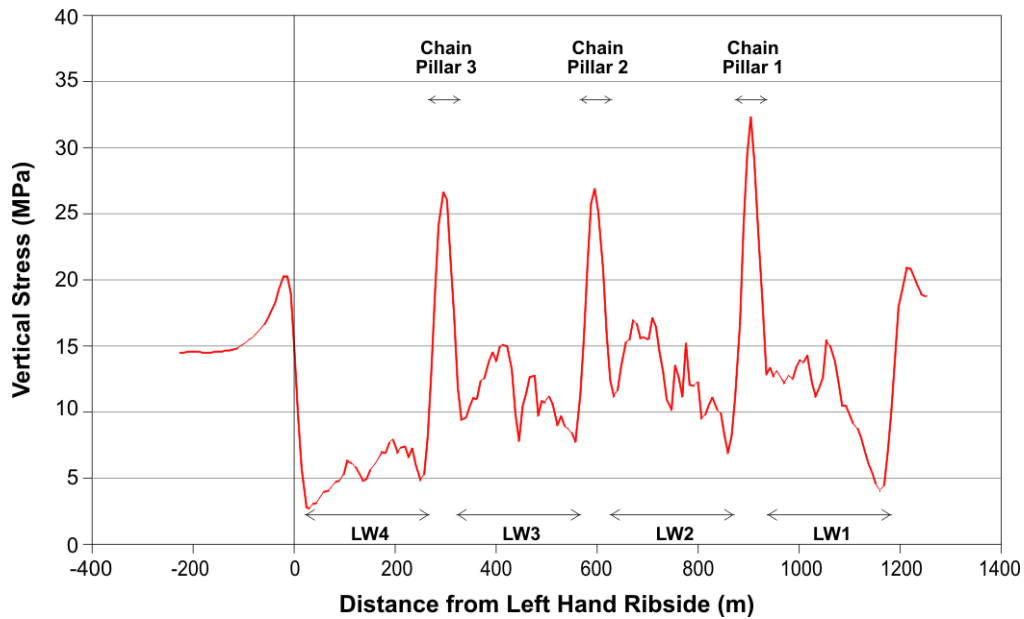
**Figure 2.39 Modelled Rock Fracture Development after Longwall 4 is extracted**

As in the previous models, the strata above the pillars tends to fracture due to a reduction in confinement resulting from lateral stress relief into the goaf, and the increased vertical abutment stress. The strength of the pillars was approximately 24-28MPa as seen from the load displacement characteristics of the pillar are presented in Figure 2.40, and once again the pillars were noted to fail and then reload due to confinement developed during goaf loading, with the total stress-strain behaviour being controlled by fracturing occurring above the pillar.

The vertical stress profile across the panel geometry (at 5 m into the floor) is presented in Figure 2.41. This shows the side abutment, goaf load and pillar load distribution in the model.



**Figure 2.40 Pillar Strength Characteristics for the Forest case**



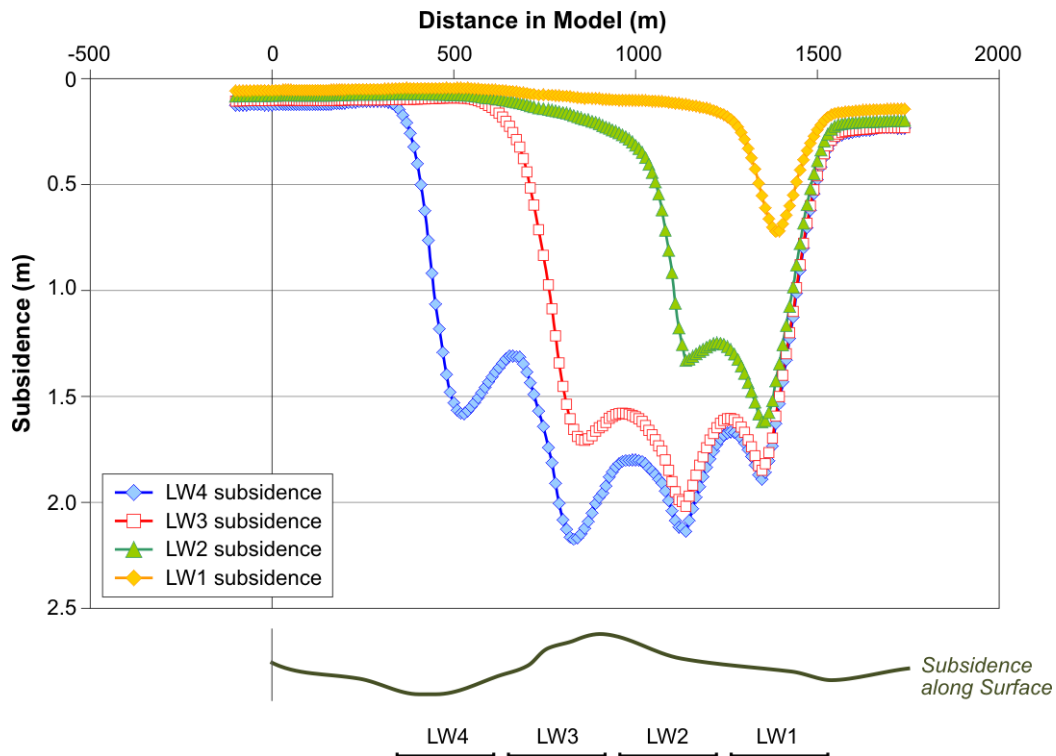
**Figure 2.41 Vertical Stress across the Model for the Forest Case**

The incremental subsidence associated with the extraction of each longwall panel is presented in Figure 2.42.

The model results once again indicate that subsidence increased as the panels became supercritical and then acted as a group thereafter, to produce subsidence in the range of 1.6-2.25m. The incremental subsidence associated with the extraction of these block was greater than that associated with the Hue Hue and Valley area designs, because of the wider longwall panels proposed for the Forest area.

It is noticeable that the maximum subsidence occurs under the hill, which has the greatest overburden. Under flat terrain the greater the overburden the lesser the subsidence however under dissected topography this relationship can be reversed. This is related to the fact that the hill is isolated by the valleys and potentially acts as a partial additional loading on the subsided overburden rather than contributing to the spanning capability of the overburden. The existence of open joints above the water table would assist in reducing the spanning capability of the hills.





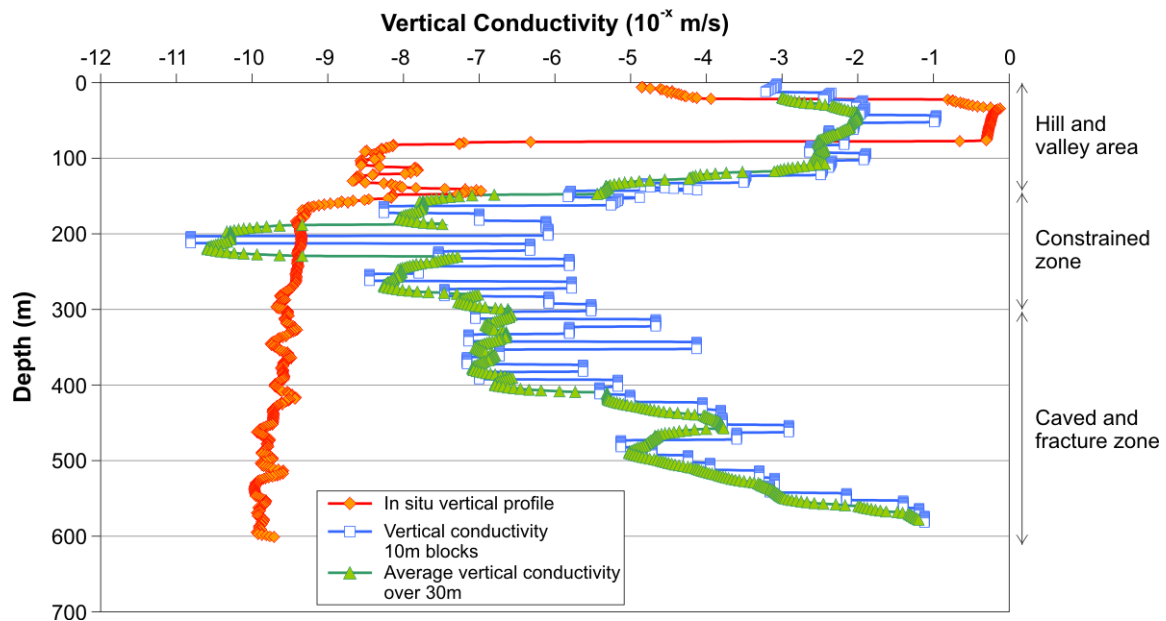
**Figure 2.42 Modelled Subsidence Profiles for the Forest Case**

### 2.6.2 Overburden Vertical Permeability

The impact on the average vertical conductivity across Longwalls 3 to 4 in the Forest Area model is presented in Figure 2.43.

Model results from above Longwalls 3 and 4 are considered to be the most representative for the Forest Case since they represent a situation where the overall mine panel geometry has become supercritical in width.

The conductivity is averaged across the model for each 1 m thick row of elements. This is done progressively down the model and then averaged over a running 10 m section. The in situ conductivity within the model is presented for comparison.



**Figure 2.43 Overburden Vertical Permeability Profile for the Forest Case**

The result shows the high conductivity about the caved zone and the hills. The central zone forms a constrained zone, of approximately 150 m, with conductivity greater than or slightly below the in situ magnitude. As in the Hue Hue and Valley cases this central constrained zone will limit connection from the surface to the seam.

The average vertical conductivity over a 30 m section is also presented to provide a general overview of the effective conductivity across the Longwalls 3 and 4.

### 3. EMPIRICAL MODELLING OF SUBSIDENCE

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#### 3.1 Introduction

An empirical method of subsidence prediction was used to determine the conventional subsidence, tilt and strain contours, associated with the proposed longwall layouts, across the entire Extraction Area. This method normally uses observed monitoring data from previously extracted longwalls as a basis for the subsidence predictions. For the Project however, the empirical curves have been calibrated using the output from the SCT computer modelling that was detailed in Chapter 2. This calibration was required because there is limited empirical subsidence monitoring data for environments with proposed thick extraction thicknesses and a weak claystone floor. As discussed within this Chapter, the SCT computer modelling has resulted in subsidence predictions with a greater proportion of the extracted seam thickness and steeper subsidence profiles.

#### 3.2 The Incremental Profile Method

This method of empirical prediction is based upon predicting the incremental subsidence profile for each longwall in a series of longwalls and then adding the respective incremental profiles to show the cumulative subsidence profile at any stage in the development of a series of longwalls. The magnitudes and shapes of each incremental profile are based upon each longwall panel's void width (i.e. rib to rib), the tail gate chain pillar width (rib to rib), extracted seam thickness, longwall panel number in the series, depth of cover, panel width-to-depth ratio, factors to adjust for proximity to the ends of each panel, multi-seam effects and local geological factors, which account for the variations in seam thickness and the presence of the weak claystone floor.

The IPM provides accurate predictions in cases where the mine conditions and geology are similar to those in the areas where the mine subsidence surveying data was collected and it has provided reasonable predictions for greenfield sites where the geology is different from previously surveyed areas, provided the modifying influence of that geology is clarified. The predictions can be further tailored to local conditions where observed monitoring data is available close to the proposed mining area.

The method has a tendency to over-predict the conventional subsidence parameters (i.e. is considered conservative) where the proposed mining geometry and geology are within the range of the empirical database as the predictive method is based on various upper bound prediction curves that encompass the previously observed monitored data. This strategy of over predicting is purposefully undertaken so as to ensure that management strategies are more likely to exceed requirements than prove insufficient. Since the geological conditions, and the proposed extraction heights, within the Extraction Area are both outside the IPM empirical database, the IPM model subsidence predictions that have been made for the Project have been calibrated to suit these local geological conditions using the results from SCT's numerical modelling described in Chapter 2.

#### 3.3 Calibration of the Standard IPM Model

The total seam height of the combined Wallarah and the Great Northern Seams within the mining area varies between 4.5 m and 7.0 m, of which it is proposed to extract between 3.5 and 4.5 m. The seam is underlain by the Awaba Tuff which provides a much weaker seam floor than typically observed in the Southern Coalfield, and numerical modelling has confirmed that the proposed chain pillars will be weaker than similar sized pillars from the Southern Coalfield.

The modelling included the influence of the thicker coal seam and the softer seam floor, whilst the impact of cut-through spacing on pillar strength was also recognised and considered. The SCT modelling included analysis of cases with seam thicknesses of 3, 4, 4.3 and 4.5 m thicknesses and found a linear relationship for predicted subsidence within this extracted seam thickness range.

It was concluded, therefore, that the predicted subsidence profiles should show a greater proportion of subsidence than is typically observed in the Southern Coalfield, particularly over the chain pillars.

The IPM model was therefore calibrated for both the magnitude of subsidence and the shapes of the incremental subsidence profiles using the results from the numerical model at specific cross-sections within the Extraction Area. The calibrated model was then used to predict the conventional subsidence, tilt and strain contours all across the mining area for the proposed longwalls, based on the variations in the proposed extracted thickness, depths of cover and mining geometry.

The depth of cover varies considerably across the Extraction Area, between a minimum of 350 m in the Hue Hue area and a maximum of 650 m beneath the hills in the south-western section of the Extraction Area. In addition to this, the proposed longwall widths vary, between a minimum of 125 m and a maximum of 255 m. The numerical modelling indicated that chain pillar performance varied significantly in response to changes in cover depth and/or panel width.

After extensive validation, confidence was developed in the model's ability to indicate the magnitude and shape of the predicted subsidence profiles for thick seams and with soft seam floors and these results represent the best available data for calibrating subsidence predictions for the Project at this stage.

After the SCT model was validated, three cases were modelled by SCT, namely the "Hue Hue" case, where the depths of cover were shallower and the longwalls were narrower, and the "Valley" case, where the depths of cover were deeper and the longwalls were wider, and the "Forest" case where the longwall blocks were deeper and wider again.

### 3.4 The Hue Hue Case

The predicted conventional subsidence, tilt and strain profiles, obtained using the IPM Model and the numerical model, were compared for a series of three longwalls within the Hue Hue Mine Subsidence District. The dimensions of the proposed longwalls are summarised in Table 3.1.

**Table 3.1 Dimensions of Longwalls for the Hue Hue Case**

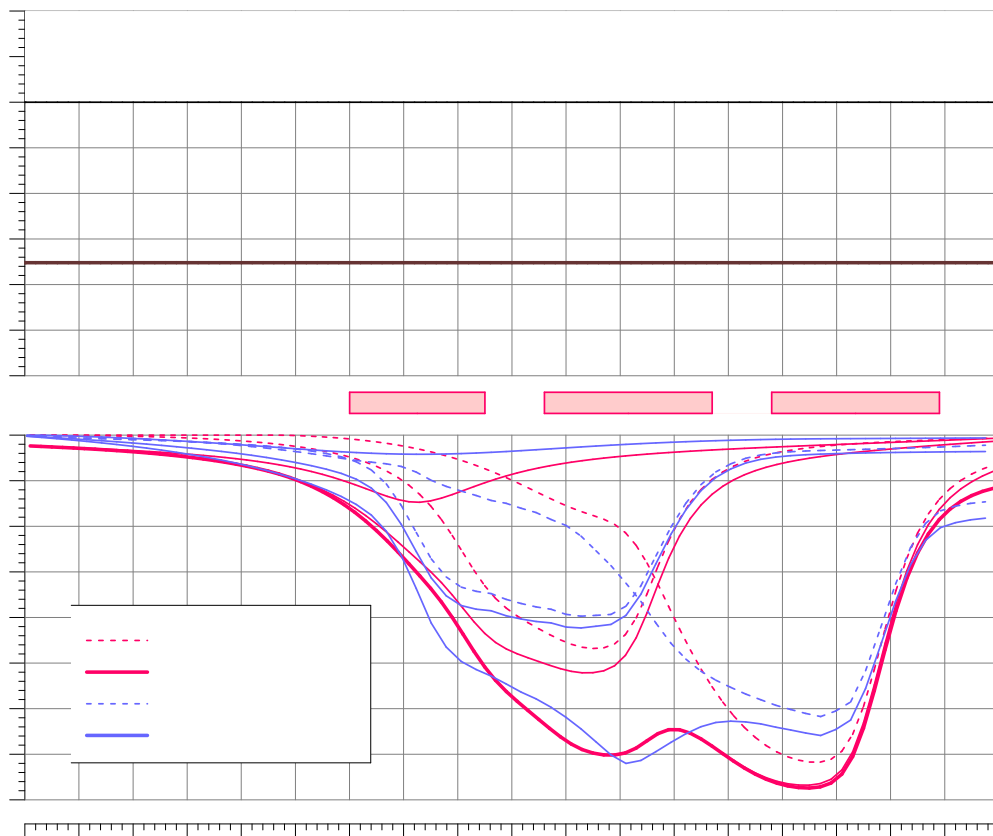
Longwall	Void Width	Actual Chain Pillar Width (m)	Modelled Chain Pillar Width (m)
LW1N	125	-	-
LW2N	155	65	55
LW3N	155	65	55

Although the longwalls are actually separated by 65 m wide chain pillars, an equivalent 55 m wide chain pillar was adopted in the subsidence predictions, to account for the affect of the cut-throughs on chain pillar strength and performance (see Section 2.3.7). The average depth of cover along the prediction line was 350 m and the extracted seam thickness was 4.0 m. A flat surface and seam was adopted for the comparison between the SCT numerical modelling and the standard IPM predictions.

It was found that the IPM empirical model predicted greater subsidence than the numerical model for the first and second longwalls. The predicted shapes of these profiles obtained using these two methods were however similar. The IPM model, however, predicted less incremental subsidence than the SCT numerical model for the third longwall. The predicted shape of this third profile, however, obtained using the two methods were also similar.

These findings were consistent with the expected behaviour of the chain pillars from the SCT numerical model. The chain pillar between the first and second longwalls was under-stressed after the extraction of the second longwall. That is, as these panels were relatively narrow, the overlying strata were able to bridge from one solid coal abutment to the other solid coal abutment without placing undue load on the intervening chain pillar. Hence, it was concluded that the maximum predicted subsidence was governed by the longwall geometry, rather than the geological response to the extraction. The extraction of the third longwall however resulted in the bridging capability of the overlying strata becoming exceeded thereby placing excessive load on the intervening chain pillars causing them to yield. This indicated that the geological response to the extraction had now become the dominant factor controlling the associated surface subsidence.

It was found that by increasing the magnitude of the predicted incremental subsidence of the third longwall by a factor of 1.5 (i.e.: an increase of 50 %), the predicted subsidence profiles obtained using the IPM model were similar to those obtained using the numerical model. A comparison between the predicted incremental and total subsidence profiles for the Hue Hue case, obtained using the calibrated IPM model and the numerical model, is provided in Figure 3.1.



**Figure 3.1 Comparison of Predicted Profiles for the Hue Hue Case**

It can be seen from the above figure, that the predicted incremental and total subsidence profiles obtained using the calibrated IPM model are similar to those obtained using the numerical model. In addition to this, the calibrated IPM model generally provides slightly conservative predictions when compared to the SCT model, particularly over the advancing goaf edge or over the currently mined longwall's main gate.

For the Hue Hue area, therefore, all the subsidence predictions made using the IPM model used a geological factor of 1.5 for the third and subsequent longwalls in the series.

It was thought that the incremental subsidence profile for the second longwall did not need to be factored up because some bridging was occurring above the first and second longwalls, i.e. across a distance of 345m (125 m + 65 m + 155 m) and hence the single chain pillar at this time was not yet fully loaded.

### 3.5 The Valley Case

The predicted conventional subsidence, tilt and strain profiles, obtained using the IPM model and the numerical model, were compared for a series of three longwalls west of the Hue Hue Mine Subsidence District, where the depth of cover and the proposed longwall widths were greater. This model was called the Valley Case. The dimensions of the proposed longwalls are summarised in Table 3.2.

**Table 3.2 Dimensions of Longwalls for the Valley Case**

Longwall	Void Width	Actual Chain Pillar Width (m)	Modelled Chain Pillar Width (m)
1st	175	-	-
2nd	175	65	55
LW12N	175	65	55

It should be remembered that there are no 175 m first or second panels in the valley area west of the Hue Hue area, and that this modelling was undertaken to develop an understanding of the likely subsidence magnitude and profile shapes over the third panel in this series.

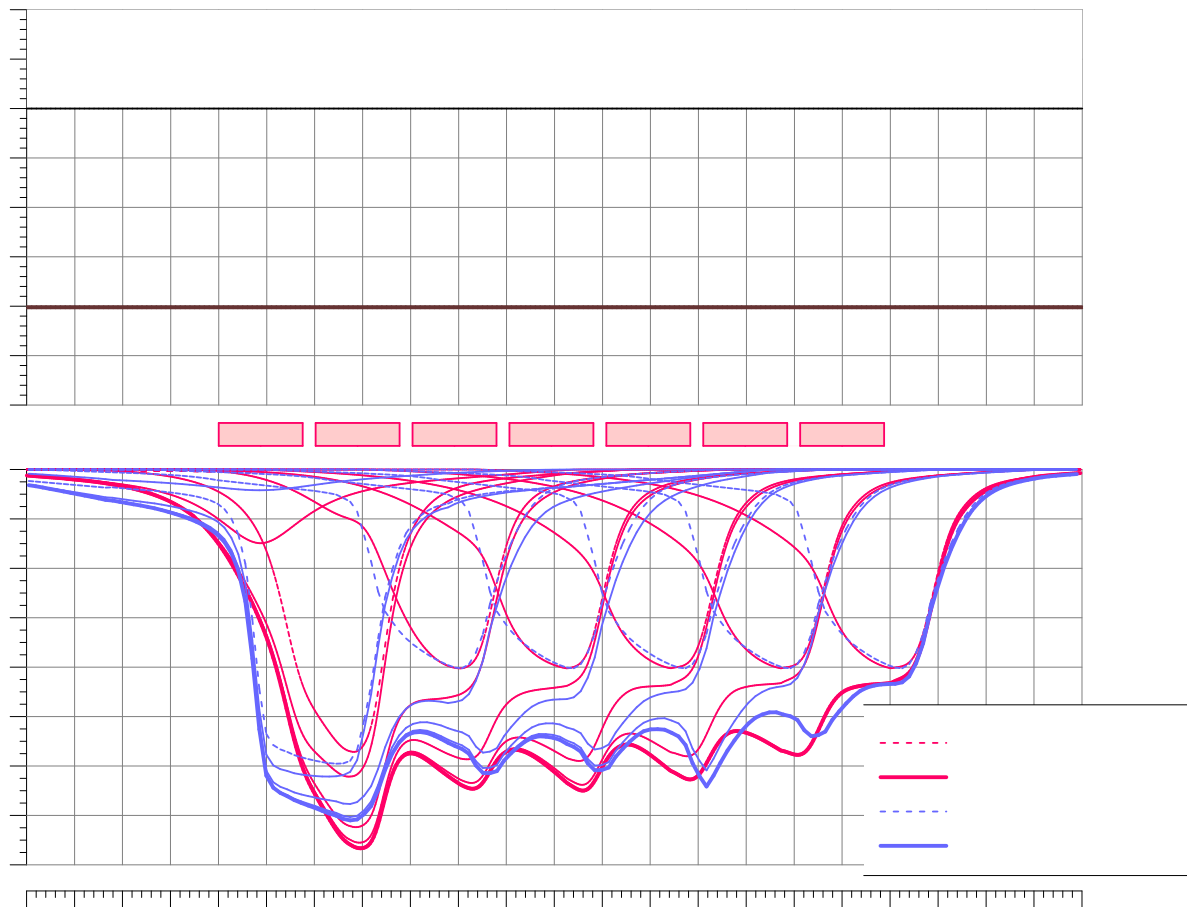
Although the longwalls were actually separated by 65 m wide chain pillars, an equivalent 55 m wide chain pillar was adopted in the subsidence predictions, to account for the affect of the cut-throughs on the chain pillar strength and performance. The average depth of cover along the prediction line was 400 m and the extracted seam thickness was 4.3m. A flat surface and seam was adopted for the comparison between the SCT numerical modelling and the standard IPM predictions.

In this case, the standard IPM model predicted greater subsidence than the SCT numerical model for the first longwall only, and less incremental subsidence for the second and third longwalls. These findings were again consistent with the expected behaviour of the chain pillars from the numerical model. In the Valley case, it became apparent that the wider panel widths resulted in the chain pillar between the first and second longwalls yielding after the extraction of the second longwall and, therefore, the maximum predicted subsidence is governed by the bridging capability of the geology becoming exceeded after the extraction of only two longwalls.

It was found that by increasing the magnitude of the predicted incremental subsidence of the second and third longwalls by factors of 2.0 and 1.5, respectively, the predicted subsidence profiles obtained using the IPM model were similar to those obtained using the numerical model.



The predicted shapes of the second and third profiles obtained using the two methods were similar and a comparison between the predicted incremental and total subsidence profiles for the Valley case, obtained using the calibrated IPM model and the SCT numerical model, is provided in Figure 3.2.



**Figure 3.2 Comparison of Predicted Profiles for the Valley Case**

It can be seen from the above figure, that the predicted incremental and total subsidence profiles obtained using the calibrated IPM Model are similar to those obtained using the SCT numerical model, particularly over the third panel. In addition to this, the calibrated IPM model generally provides slightly conservative predictions for tilt and strain over this third panel when compared to the SCT numerical model.

For this Valley case, therefore, a geological factor of 1.5 has been adopted for the subsidence prediction made using the IPM model for all the third and following longwalls within a series.

### 3.6 The Forest Case

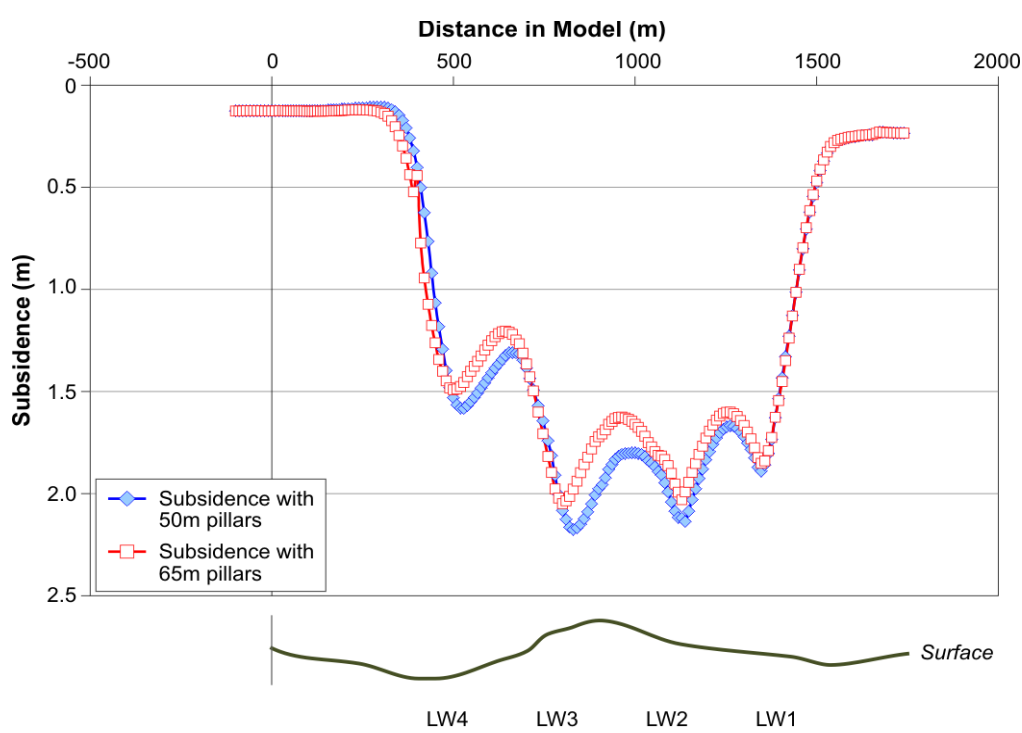
The predicted conventional subsidence, tilt and strain profiles, obtained using the IPM model and the numerical model, were compared for a series of three longwalls west of the Hue Hue Mine Subsidence District, where the depth of cover and the proposed longwall widths were greater. This model was called the Valley case. The dimensions of the proposed longwalls are summarised in Table 3.3.

**Table 3.3 Dimensions of Longwalls for the Forest Case**

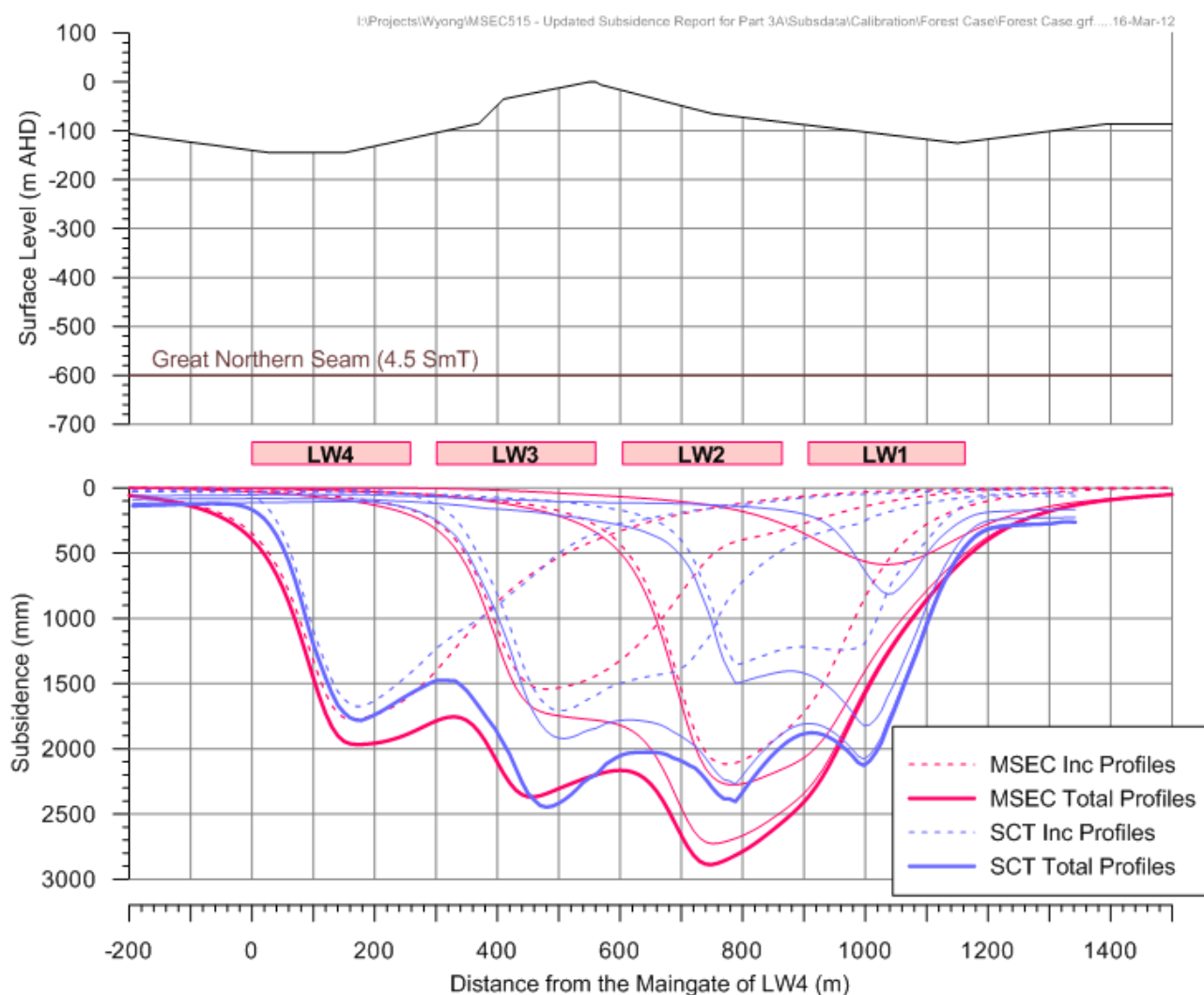
Longwall	Void Width	Actual Chain Pillar Width (m)	Modelled Chain Pillar Width (m)
1st	255	-	-
2nd	255	55	55
LW21N	255	55	55

As in the previous case, there are no 255 m first or second panels in the Forest area west of the Valley area, and that this modelling was undertaken to develop an understanding of the likely subsidence magnitude and profile shapes over the third and fourth panels in this series.

On the basis of the model results from the previous cases an actual 55 m wide chain pillar was adopted for the subsidence modelling of the Forest case, though an assessment of the comparative behaviour of a 65m chain pillar indicated that it only retained a marginally greater strength core once it was isolated in the goaf – this is shown in Figure 3.3.

**Figure 3.3 Comparison of Predicted Profiles for 50m and 65m Chain Pillars**

The average depth of cover along the prediction line was approximately 500 m and the extracted seam thickness was 4.5m. A variable topographic surface was adopted to assess the behaviour of the hilly terrain though a flat surface was used to represent the seam when the SCT numerical modelling and the standard IPM predictions.



**Figure 3.4 Comparison of Predicted Profiles for the Forest Case**

In this case, the standard IPM model predicted slightly greater subsidence than the SCT numerical model for all longwalls except the first. This is consistent with the general findings in the Hue Hue and Valley cases and continues to form the basis of the conservative approach adopted in the subsidence management of the Project.

Again, it was found that by increasing the magnitude of the predicted incremental subsidence of the second and third longwalls by factors of 2.0 and 1.5, respectively, the predicted subsidence profiles obtained using the IPM model were similar to those obtained using the numerical model. The predicted shapes of the second and third profiles obtained using the two methods were similar and a comparison between the predicted incremental and total subsidence profiles for the Forest case, obtained using the calibrated IPM model and the SCT numerical model, is provided in Figure 3.4.

It can be seen from the above figure, that the predicted incremental and total subsidence profiles obtained using the calibrated IPM Model are similar to those obtained using the SCT numerical model, particularly over the third and fourth panels. In addition to this, the calibrated IPM model generally provides slightly conservative predictions for tilt and strain over this third panel when compared to the SCT numerical model.

For this Valley case, therefore, a geological factor of 1.5 has been adopted for the subsidence prediction made using the IPM model for all the third and following longwalls within a series. The results of the Forest model indicate that an equally reliable subsidence prediction could have been achieved for the forest area by applying the numerical modelling results for the Valley case.

### 3.7 Summary of the Calibrated Incremental Profile Method

It was concluded from the Hue Hue, Valley and Forest cases that the calibrated IPM model provides realistic, if not conservative subsidence predictions when compared to those obtained from SCT's numerical modelling, while the compounding use of the 'worst case' suggest that both sets of predictions will be significantly conservative when compared to eventual monitoring results. The calibrated model uses the standard Southern Coalfield subsidence profiles, with geological factors applied to the magnitudes of the incremental profiles as summarised in Table 3.4.

**Table 3.4 Summary of Geological Factors adopted for the Incremental Profile Method**

Longwall Series Number	Hue Hue Case	Valley Case	Forest Case
1 <sup>st</sup> longwall in a series	1.0	Not Applicable	Not Applicable
2 <sup>nd</sup> longwall in a series	1.0	Not Applicable	Not Applicable
3 <sup>rd</sup> and subsequent longwalls in a series	1.5	1.5	1.5

The original IPM Model was developed using MS Excel spreadsheets and the prediction process has been upgraded using the C++ programming language. The method uses the same database of empirical monitoring data and, therefore, provides the same conventional subsidence predictions as the previous model. The new C++ model, however, automates the prediction process and has dramatically increased the speed of analysis. The IPM Model is capable of predicting the conventional subsidence parameters at any point within the mining area using the local surface and seam information. Each model is capable of predicting the conventional subsidence parameters at over 25 million points, and multiple models can be used in conjunction to make predictions at an even greater number of points. Predictions for the proposed longwalls were made at points on a regular grid orientated north-south and east-west across the Extraction Area. A grid spacing of 20 m in each direction was adopted, which provided sufficient resolution for the generation of subsidence, tilt and strain contours across the Extraction Area.

Once the base model has been established, the method allows for fast re-prediction of the conventional subsidence parameters for variations in the longwall layout and proposed seam extraction heights. This rapid re-modelling capability enabled a variety of planning options to be readily considered in the formulation of a final design that would for the environmental issues at hand. The ability to quickly re-predict modified longwall layouts and seam extraction heights has enabled the refinement of the final mining layout to take into account environmental issues.

## 4. SUBSIDENCE MODELLING IN MINE DESIGN

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The SCT numerical modelling component of this study confirmed that surface subsidence results from a complex interaction between longwall geometry, rock mass characteristic, extraction height and chain pillar behaviour, and enabled the standard IPM empirical prediction curves to be calibrated or supplemented to reflect the likely response to mining in the Extraction Area.

The calibrated IPM Model was then used to predict conventional subsidence profiles for varying longwall geometries and varying seam extraction heights.

### 4.1 Preliminary layout assessments

Four preliminary assessment options were considered to provide a basis for designing a final mine layout. These were:

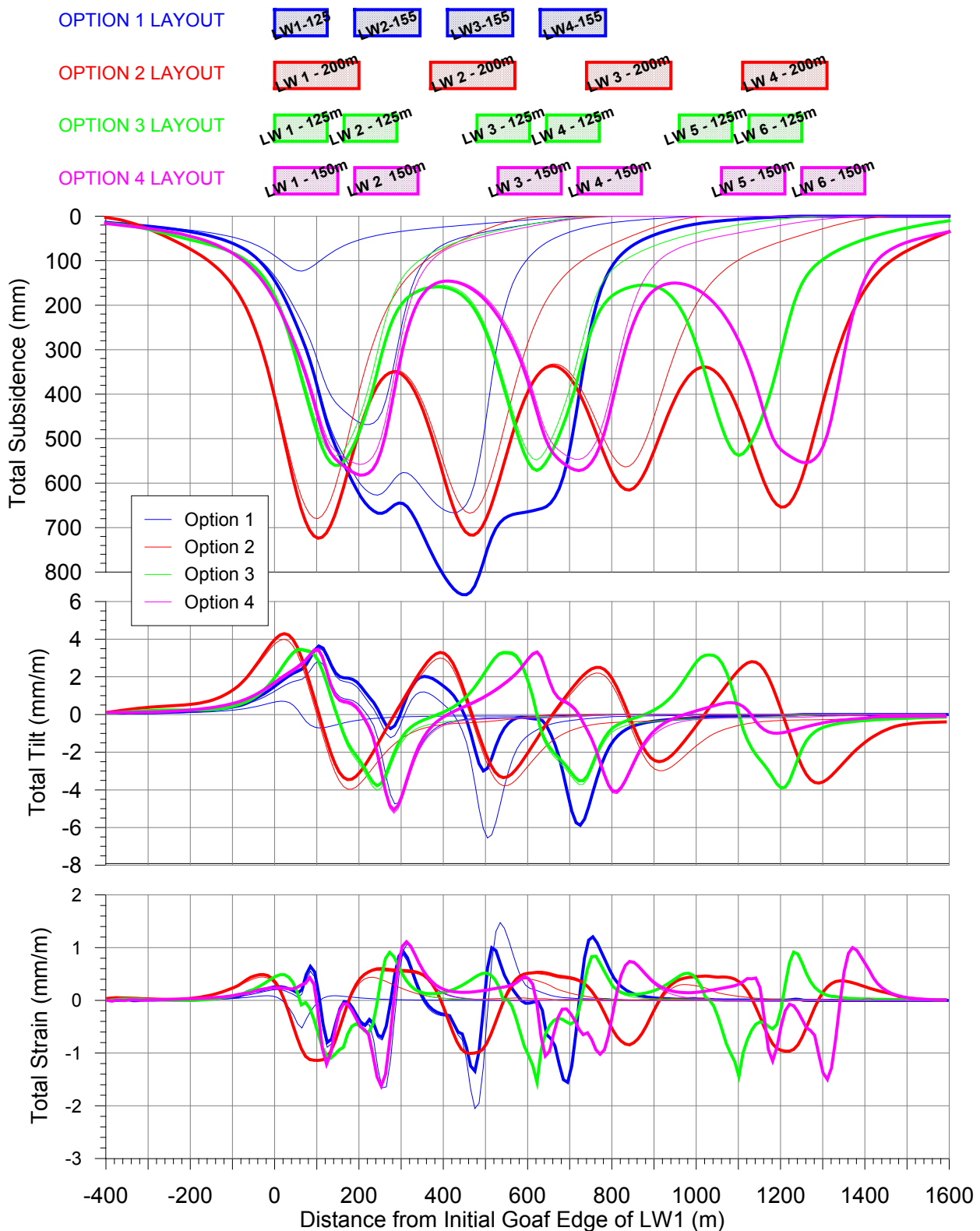
**Option 1** – comprised four longwalls, the first having a 125 m void width, and the remainder having 155 m void widths. The proposed chain pillars were 65 m wide. The depth of cover varied between 350 and 450 m, and the proposed extracted seam thickness was 4.0 m.

**Option 2** – comprised four longwalls having 200 m void widths. The area between each longwall comprised of a 30 m chain pillar, a 5 m heading, 100 m of solid coal, a 5 m heading, and a 30 m chain pillar, which provided a total distance of 170 m between the longwalls. The depth of cover varied between 350 and 450 m, and the proposed extracted seam thickness was 4.5 m.

**Option 3** – comprised six longwalls having 125 m void widths. The longwalls were grouped into three pairs. A 40 m chain pillar was used between the longwalls within each pair. The area between the longwall pairs comprised of a 40 m chain pillar, a 5 m heading, 100 m of solid coal, a 5 m heading, and a 40 m chain pillar, which provided a total distance of 190 m between the longwall pairs. The depth of cover varied between 350 and 450 m, and the proposed extracted seam thickness was 4.5 m.

**Option 4** – comprised six longwalls having 150 m void widths. The longwalls were grouped into three pairs. A 40 m chain pillar was used between the longwalls within each pair. The area between the longwall pairs comprised of a 40 m chain pillar, a 5 m heading, 100 m of solid coal, a 5 m heading, and a 40 m chain pillar, which provided a total distance of 190 m between the longwall pairs. The depth of cover varied between 350 and 450 m, and the proposed extracted seam thickness was 3.5 m.

The predicted conventional subsidence, tilt and strain profiles for each option are overlaid in Figure 4.1.



**Figure 4.1 Comparison of Predicted Conventional Subsidence Profiles for Options 1 to 4**

It can be seen from the above figure, that the maximum predicted total tilts and total strains are similar for the four options. Option 1, however, gives a slightly higher transient tilt and strains above Longwall 3, and gives a slightly higher final tilt above Longwall 4.



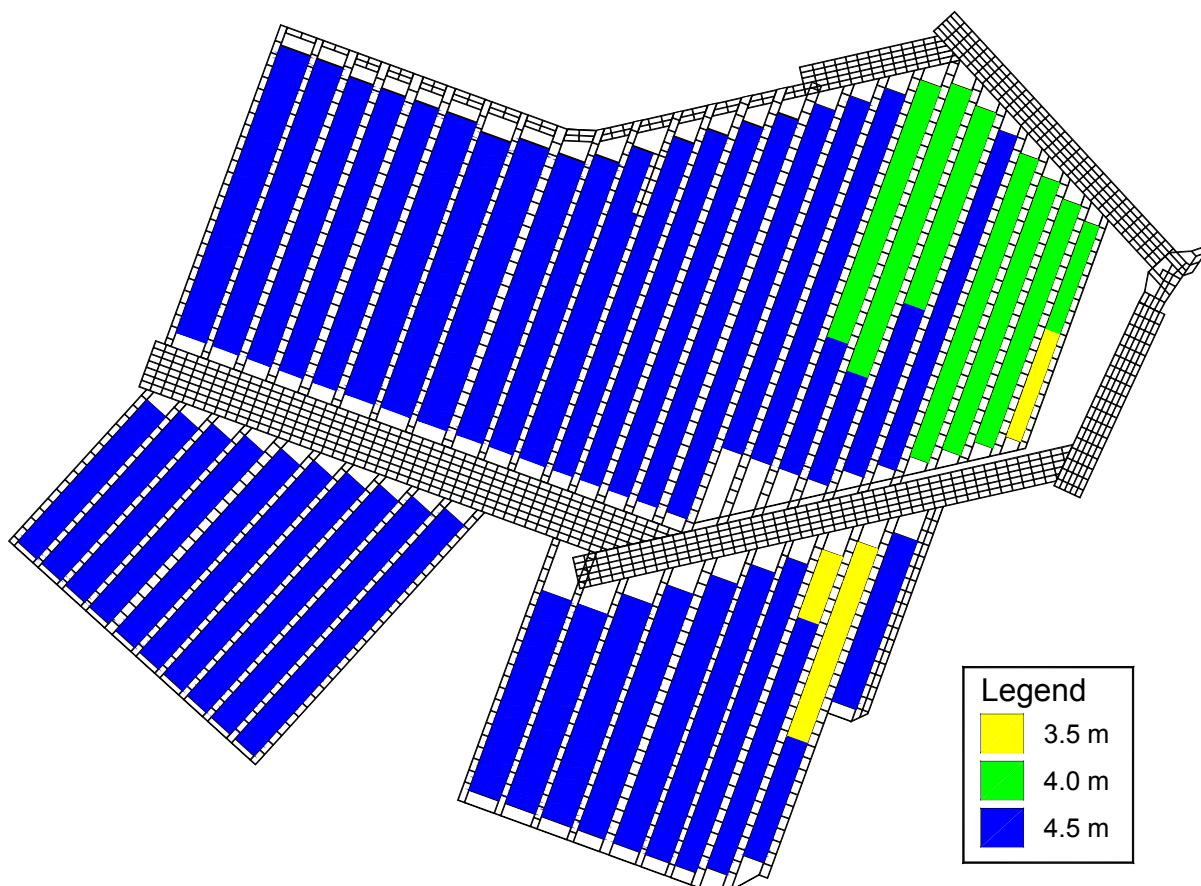
## 4.2 Iterative design process

The preliminary layout assessments provided a clear insight into the speed and the detail with which the IPM could evaluate various combinations of panel geometry and extraction height to enable planners to quickly review the impacts of a complex matrix of design options.

Consequently, a number of iterative changes to the mine design were made to enable the subsidence parameters relevant to particular structures and features to be controlled.

On the basis of these assessments a layout was developed which was then run with three different extraction heights – 3.5 m, 4.0 m and 4.5 m. The results of these runs were then used to further optimise the layout by varying the extraction height in certain areas to offer additional control of surface affects in line with particular environmental sensitivities.

The current layout, showing the proposed extraction heights, is shown in Figure 4.2. This design was developed in recognition of the Hue Hue and Wyong Mine Subsidence Districts, as well as to adhere to the public commitment that the proposed mine would mitigate impacts on the water supply catchments.



**Figure 4.2 Current layout showing areas of various extraction heights**

## 5. RESULTS AND CONCLUSIONS

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### 5.1 The Impact of Rock Strength on the Subsidence Process

Modelling indicates that subsidence and overburden fracture distributions result from the combined interaction of extraction geometry, strata section, goaf stiffness and pillar strength characteristics. The empirical database reflects various combinations of these factors. As outlined in Chapter 1, in situations where the mine geometries or other factors are outside the range contained within the regional empirical database, the resultant overburden behaviour and subsidence may vary from that predicted from that database.

The overall pillar strength and convergence characteristics for the WGN section have been presented for all cases studied. The models indicate that the pillars will load and then exhibit yield and or a slight strength increase with overburden convergence.

The key impact of this is that if the geometry of the mine layout is such that pillars are loaded past the yield point, then convergence will occur until an equilibrium point is reached, whereby the overburden load is shared between the pillars and the goaf. That is, when the pillars yield, the deficit in load balance must be carried by the goaf. This is why the goaf carries more load in the Valley and Forest cases relative to the Hue Hue case.

The relative stiffness of the goaf is greater for thin extraction than thick extraction. In the latter case, more compaction (convergence) is required to develop the same load. Therefore in thicker seam extraction, and where pillars yield, subsidence will be greater by the amount required to compress the goaf in the higher void space. It would be expected that for the same pillar size and mine geometry, and for situations where pillars yield, the subsidence for a thin seam extraction will be less than that of a thick seam extraction.

This appears to be the case at this site whereby the predictions from the empirical data need to be increased to compare with the modelled results.

The models indicate that the overburden subsidence profile shape is similar to the South Coast characteristics, but the subsidence is greater than that which the empirical database would suggest on a pillar width to depth relationship.

This is in part due to the fact that the empirical database for mining at this depth relates primarily to Bulli Seam operations with a seam thickness range of 2-3 m, compared with the 3.5-4.5 m working sections proposed in the Extraction Area.

Another factor in this is the pillar strength achieved in this environment and seam section relative to that of other mines within the database.

These results are consistent with the overall mechanics of the subsidence process. The adjustments to the empirical approach as applied at this site are discussed in more detail in Section 3.

## 5.2 The Impact of Geology and Geometry on the Subsidence Process

One of the key aspects of this study has been to evaluate the impact of overburden and panel geometry on the subsidence process. The effect of panel width to depth can be seen in the regional data whereby the bridging of the strata occurs for panel widths up to approximately 0.7-1.0 times the seam depth. For these widths only partial subsidence occurs since the subsidence is a combination of the ability of the overburden to span that width, as well as deflect and rest onto the goaf. Within this geometry range, the nature of the overburden can influence the subsidence. For example, thick massive conglomerate units are known to reduce the subsidence and overburden fracture characteristics at Wyee Mine and Moonee Colliery for width to depth ratios approaching 1. Alternatively overburden that is composed of weak bedded units may fully subside at ratios of less than 1.

However, once spans become supercritical, (width to depth of 1-1.5) the full subsidence capacity is developed onto the goaf, as the spanning capability of the overburden is lost, irrespective of its geological composition.

The variation in subsidence within the regional data set reflects this effect, however it should be recognised that this data set is based on single panel information.

A review of the geological section at this site shows that there are no significant conglomerate units above the WGN and as such the overburden appears to behave in a more “average” manner that that of Wyee and other mines influenced by thick conglomerate units.

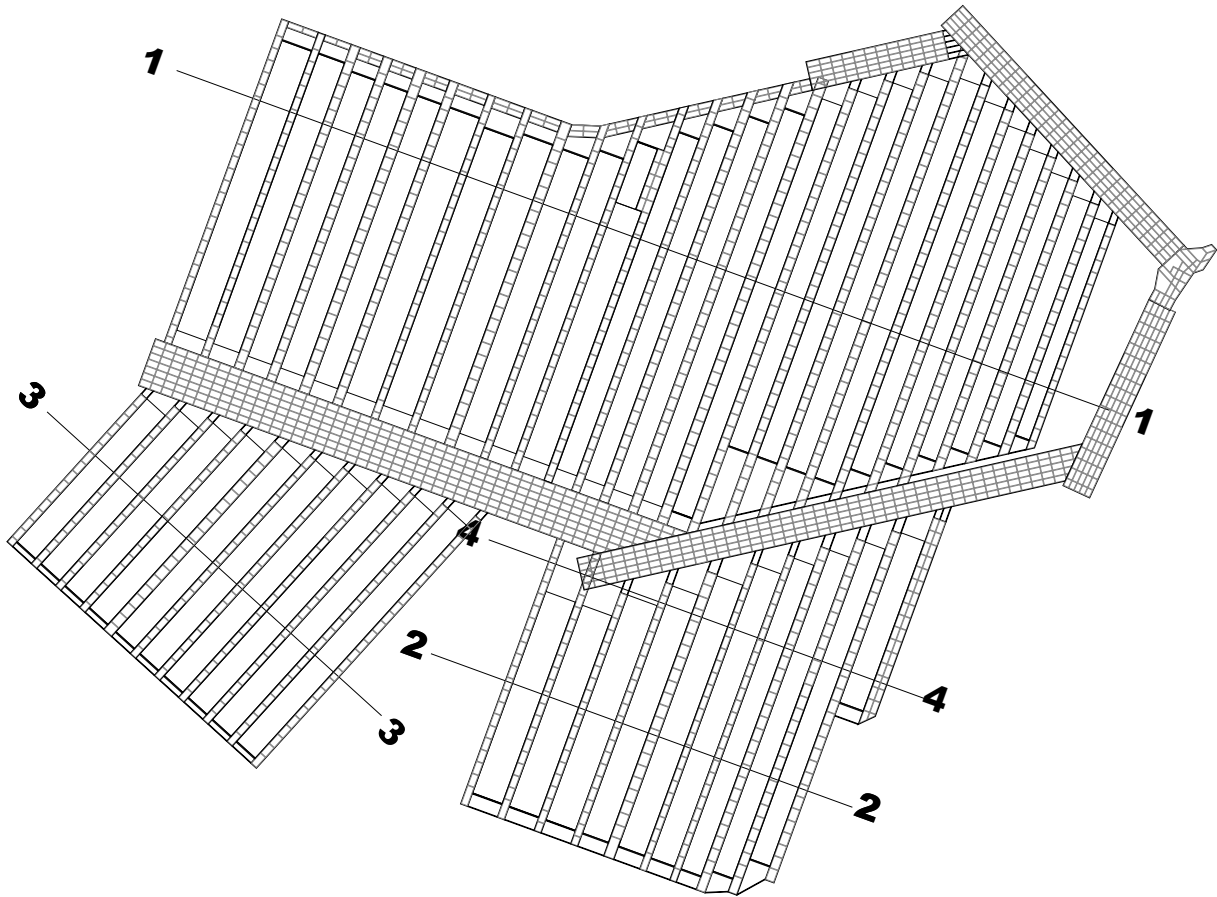
The proposed panels for the Project have spans that are typically less than 0.7, however due to the impact of pillar yield, the geometry effect occurs for multiple panels. Once the total combined panel width exceeds a width to depth ration of approximately 1, the overburden subsidence is controlled primarily by the behaviour of the intervening pillars and amount of load that it transferred onto the goaf.

The result of this is that overburden subsidence will occur in response to large scale overburden geometries and not individual panels. Subsidence will continue to occur over goaf and pillars until a supercritical geometry is established at that site. This means that mining that occurs two panels away may influence subsidence at a site mined earlier in the extraction sequence.

Once the supercritical geometry is established the subsidence equilibrium is created by pillar strength/stiffness together with goaf strength/stiffness.

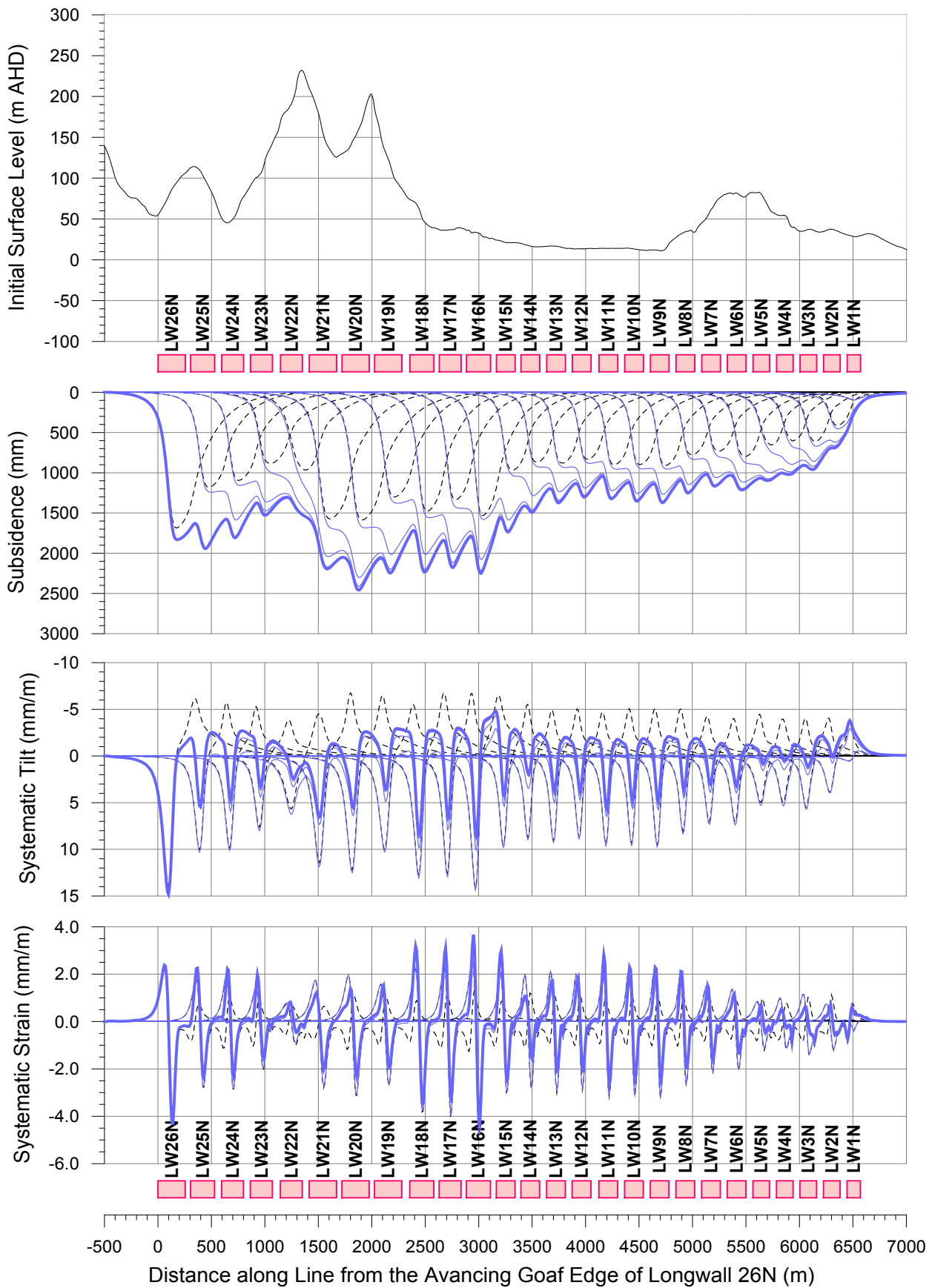
## 5.3 Predicted Conventional Subsidence Profiles

The predicted conventional subsidence parameters were determined along four prediction lines, labelled Lines 1, 2, 3 and 4, all of which were orientated transversely to the proposed longwalls. The locations of the prediction lines are shown in Figure 5.1.

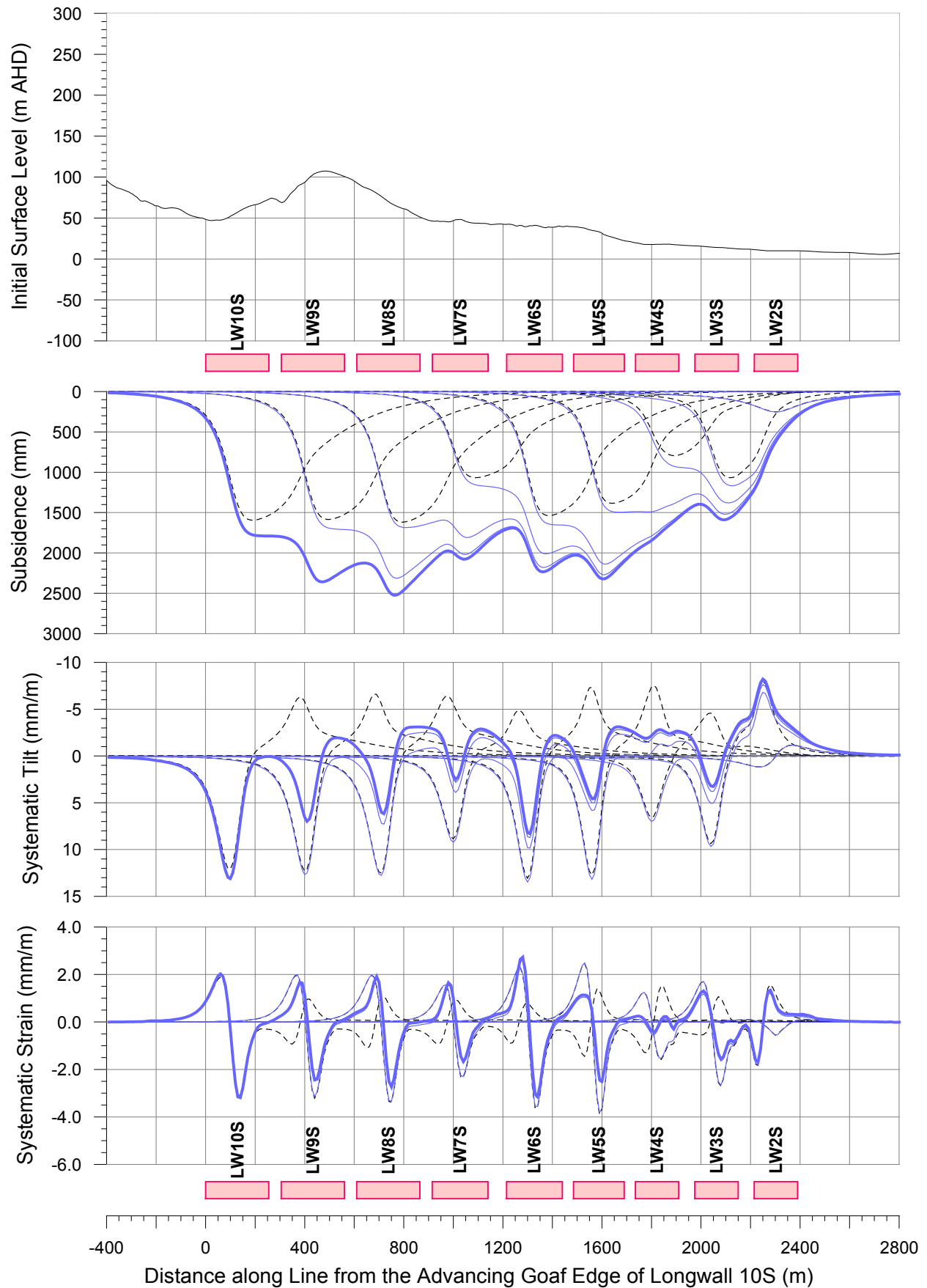


**Figure 5.1 Location of Prediction Lines 1 to 4**

The predicted profiles of conventional subsidence, tilt and strain along Prediction Lines 1, 2, 3 and 4 are shown in Figure 5.2, Figure 5.3, Figure 5.4, and Figure 5.5 respectively.

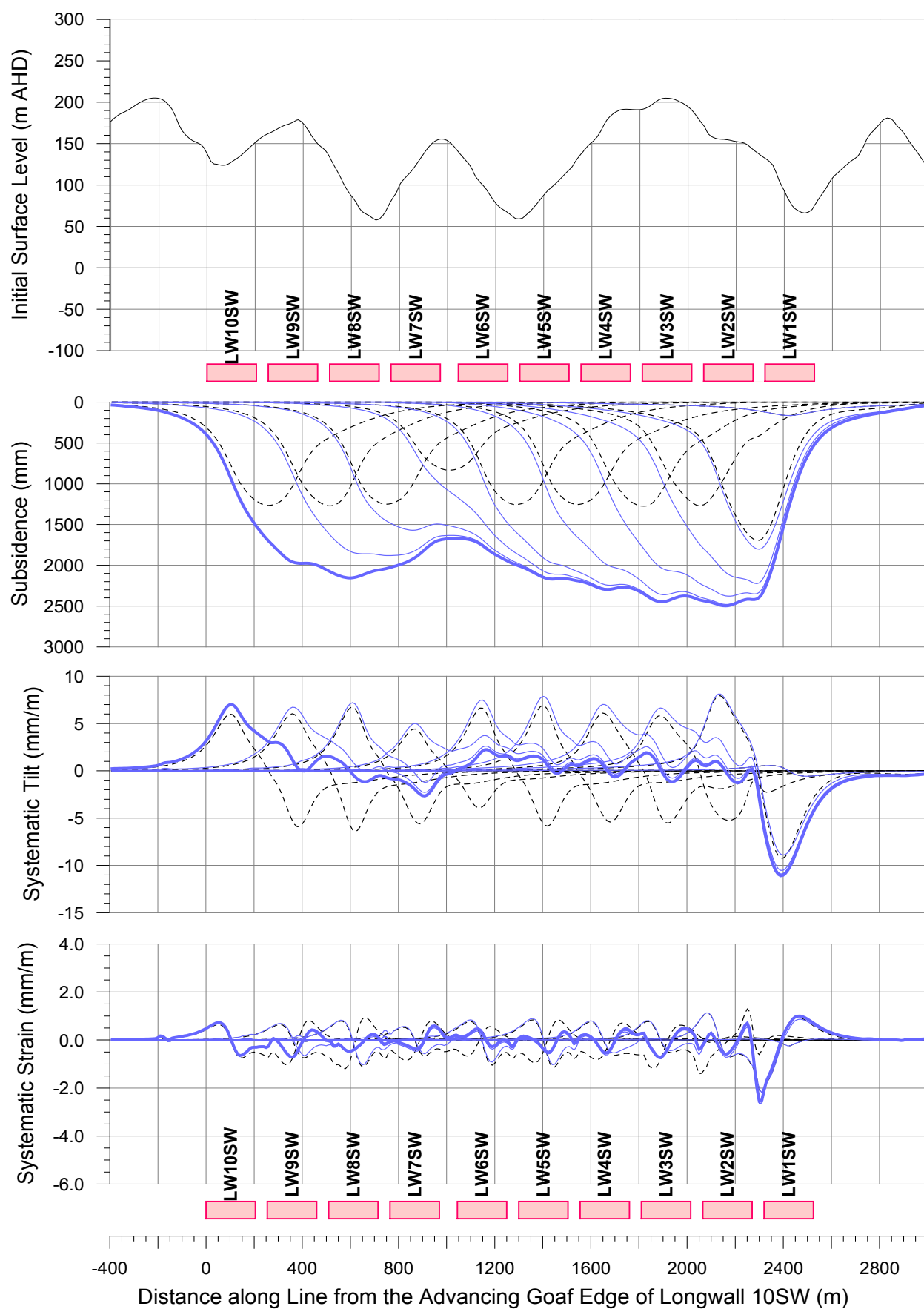


**Figure 5.2 Predicted Subsidence, Conventional Tilt and Conventional Strain Profiles  
Prediction Line 1**

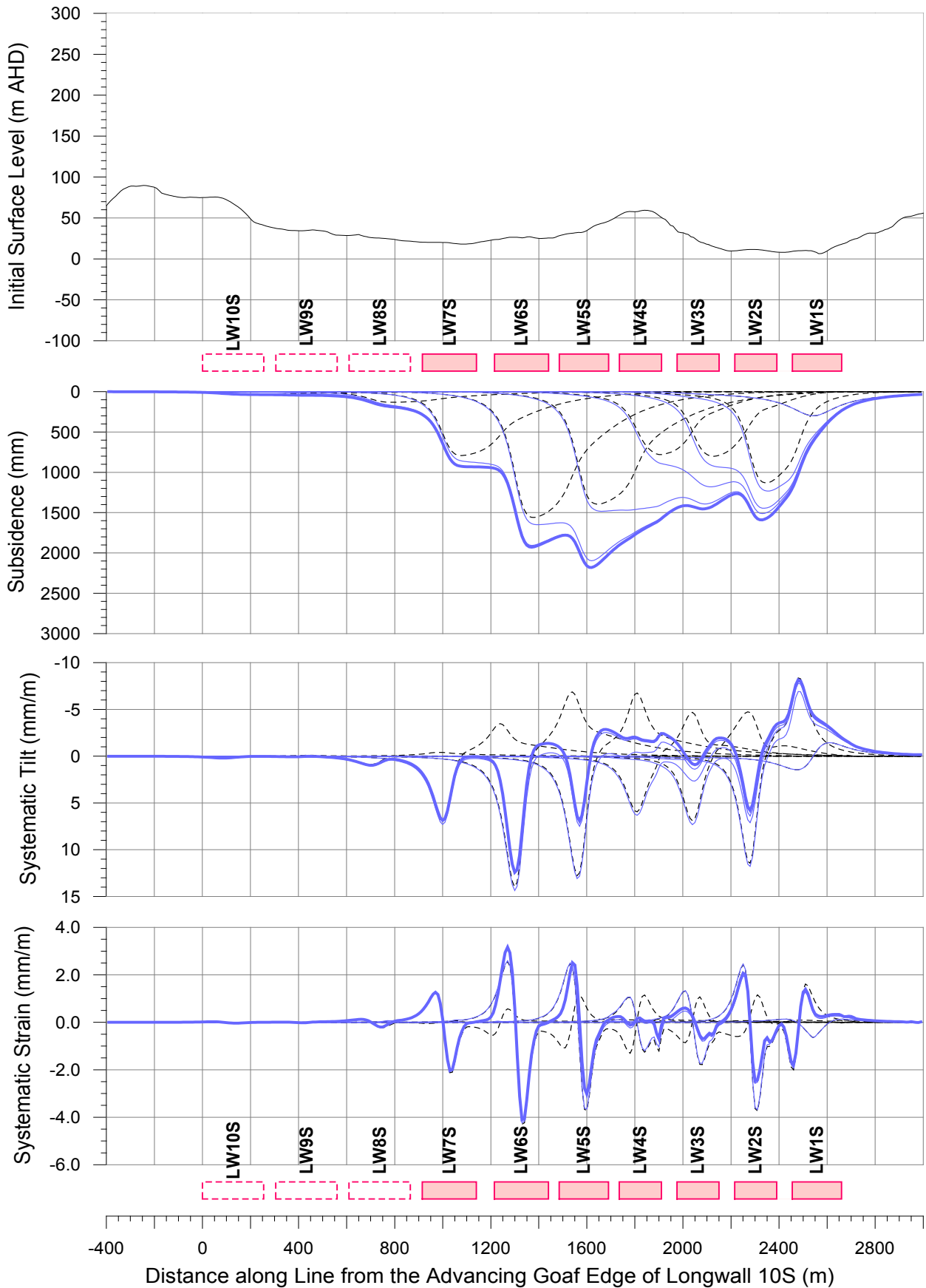


**Figure 5.3 Predicted Subsidence, Conventional Tilt and Conventional Strain Profiles Prediction Line 2**





**Figure 5.4 Predicted Subsidence, Conventional Tilt and Conventional Strain Profiles  
Prediction Line 3**



**Figure 5.5 Predicted Subsidence, Conventional Tilt and Conventional Strain Profiles Prediction Line 4**

The variations in the maximum predicted subsidence parameters along the prediction lines are the result of the variations in the proposed longwall widths, chain pillar widths, topography, depths of cover, and proposed seam extraction heights.

#### **5.4 Predicted Conventional Subsidence Parameters**

The predicted total conventional subsidence, tilt, tensile strain and compressive strain contours, at the completion of the proposed longwalls, are shown in Figure 5.6, Figure 5.7, Figure 5.8 and Figure 5.9 respectively.

The extraction of each successive longwall reduces the maximum predicted tilt and strains above the maingate of the previously extracted longwall. The maximum predicted total tilts and strains as subsequent panels are extracted therefore, are less than the maximum predicted transient tilts and strains at the completion of individual longwall blocks.

It should be noted that within the Hue Hue Mine Subsidence District, the maximum predicted total strains and tilts at the completion of mining, are consistent with criteria prescribed for that district.

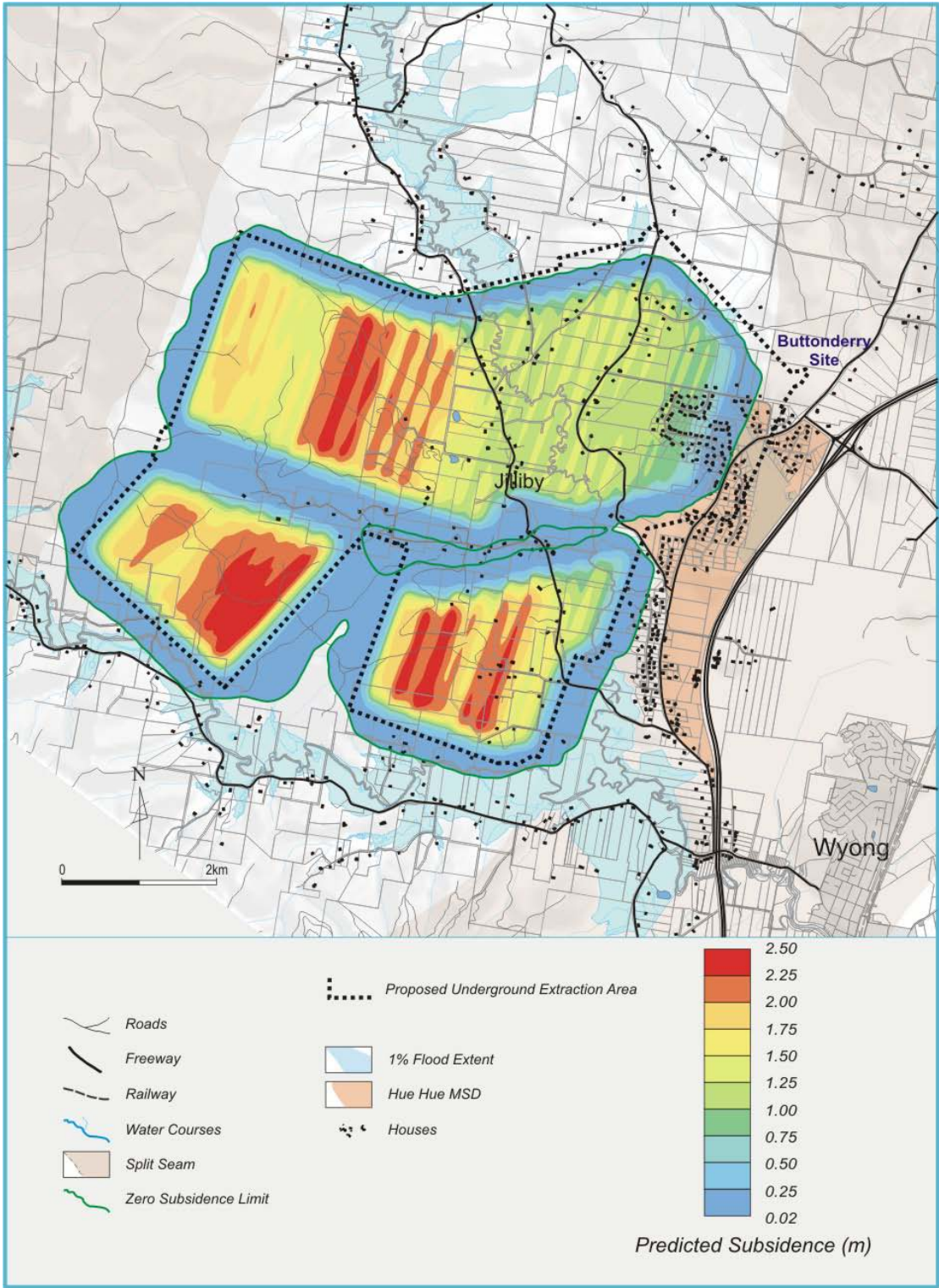
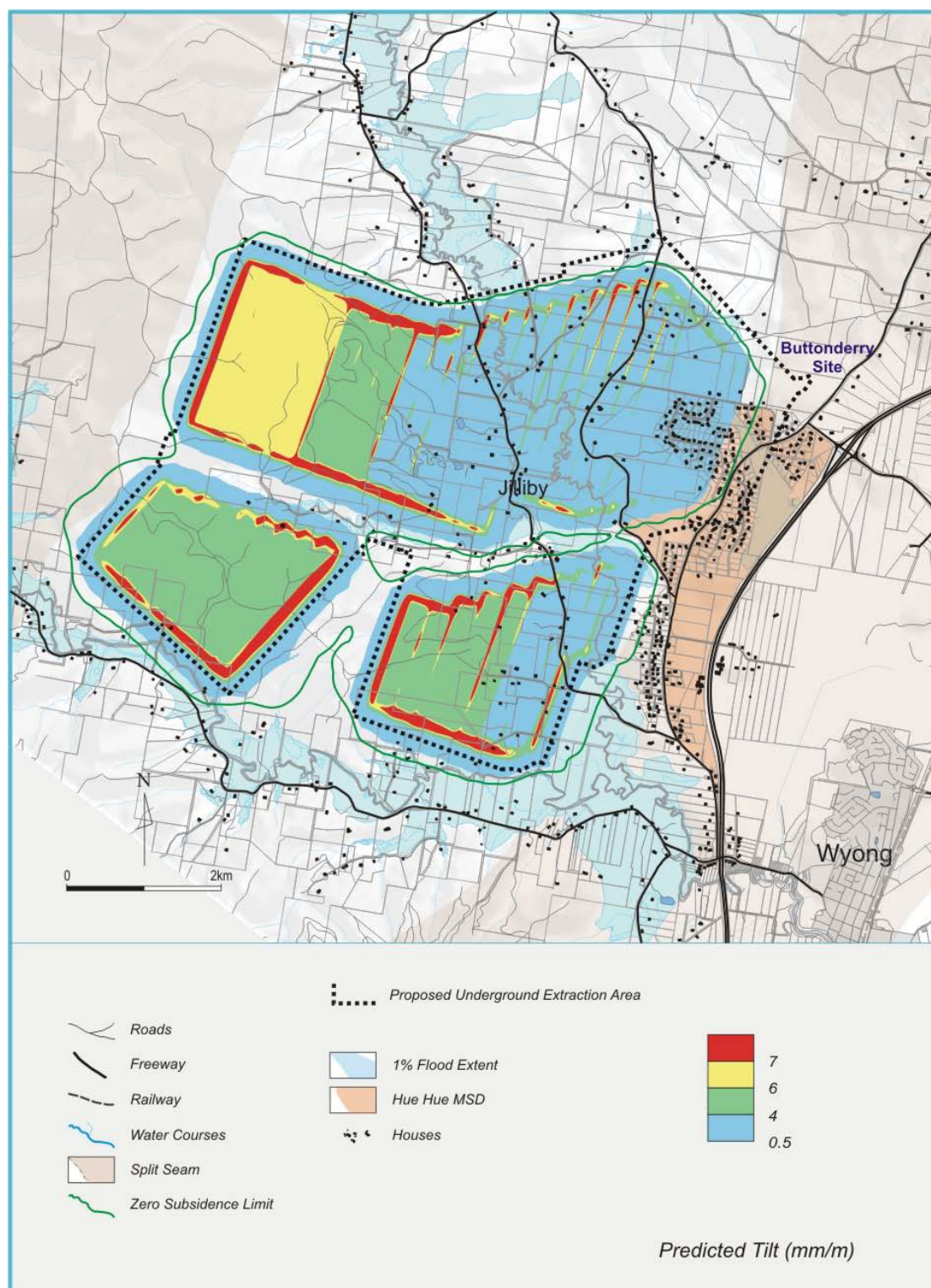


Figure 5.6 Predicted Total Subsidence Contours





**Figure 5.7 Predicted Total Tilt Contours**

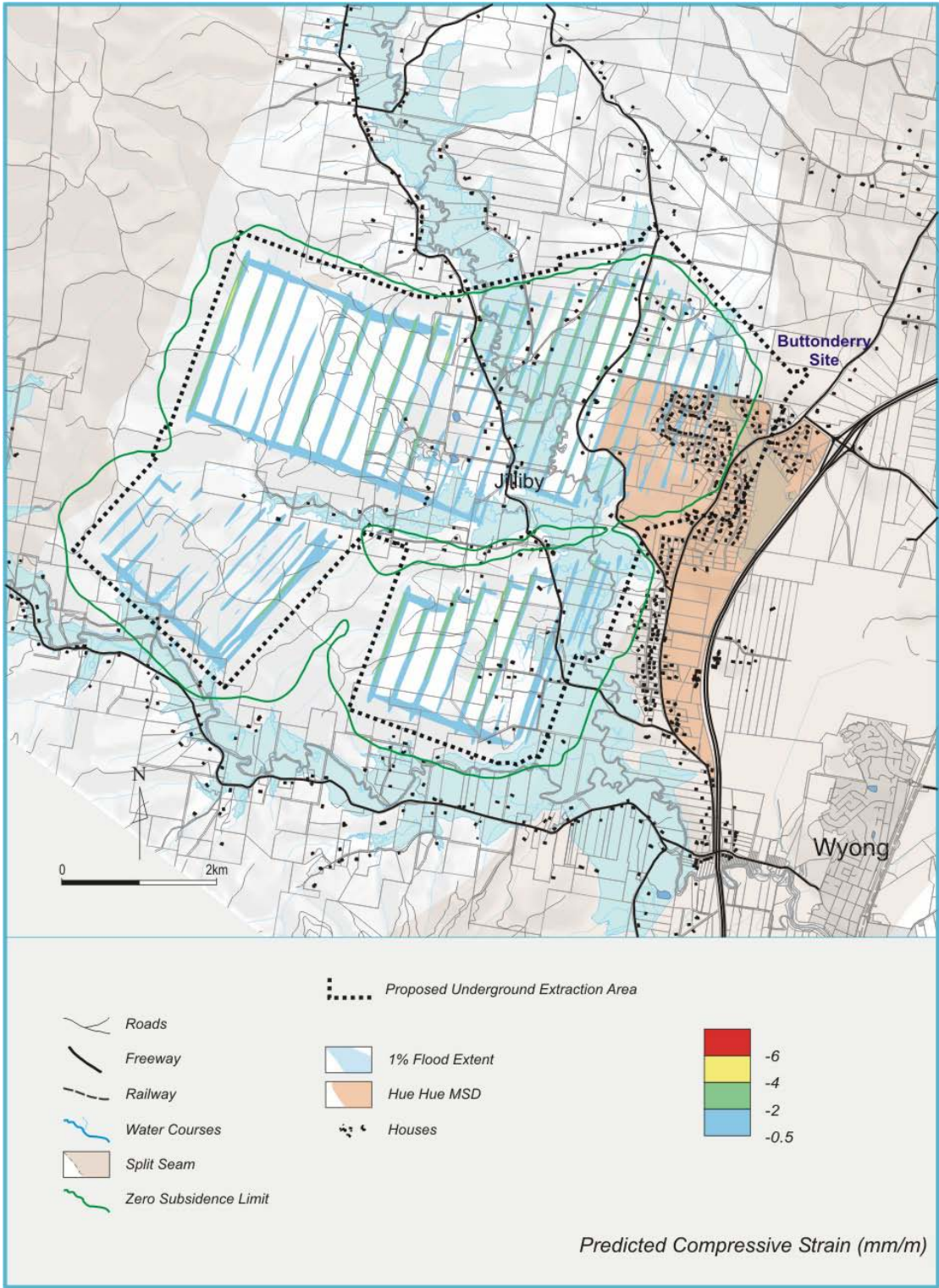
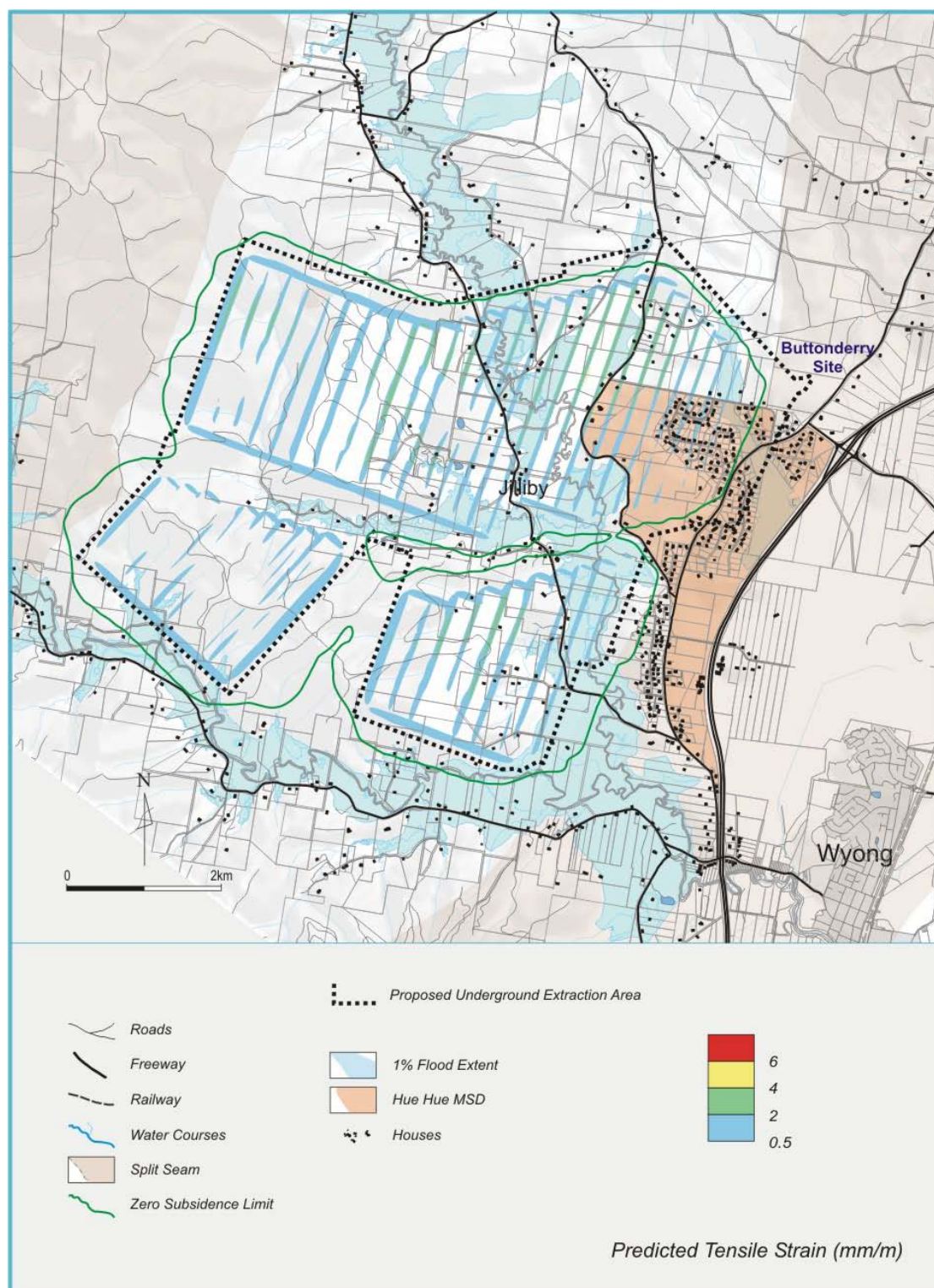


Figure 5.8 Predicted Total Compressive Strain Contours





**Figure 5.9 Predicted Total Tensile Strain Contours**

## 6. IMPACT OF SUBSIDENCE EFFECTS

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The WACJV recognises that the proposed mine layout must address key concerns and issues associated with longwall mining and subsidence. Final approval from DRE to commence longwall extraction in the Extraction Area will be conditional upon the development and submission of a detailed Subsidence Management Plan (SMP) or Extraction Plan (EP) by WACJV. These plans will involve a detailed assessment of the potential impacts of mine subsidence in the proposed mine area together with details of how they will be mitigated and managed to meet the expectations of the various stakeholders. In preparing these plans emphasis will be placed on the significance of the impact rather than the specific magnitude of the effect alone. Once finalised, approval for these plans is then sought from relevant government agencies by way of the Subsidence Management Plan Interagency Committee.

This study has sought to provide:

- Realistic predictions of the character and magnitude of mining induced movement; and
- Input data to adjunct impact assessments of various specific effects.

This has been achieved through the development of a mechanistically based modelling process that provides predictions for a 'worst case' scenario. Empirical data gathered during the mining process will be used to back analyse these predictions, revise them where necessary, and underpin further optimisation of the mine layout if required.

### 6.1 Vertical subsidence

The main impact of vertical subsidence is upon the flood implications within the existing flood prone areas of Dooralong and Yarramalong Valleys. This results from a combination of increasing and decreasing flood retention capacity, flood depth and duration.

While Wyong Shire Council currently requires that all dwellings in Mine Subsidence Districts be located such that their floor levels are at least 600 mm above the 100 year flood level, WACJV recognises that subsidence has the potential to modify this free-board as well as increase the inundation potential of non-habitable structures, roads and other elements of infrastructure. Consequently a number of mine layouts were modelled to determine the sensitivity of flood impacts to vertical subsidence. The output of this modelling has provided direct input into flood modelling to assess the impact on the 100 yr extent line, relative flood levels and various inundation issues in the Dooralong Valley and Hue Hue Creek areas. The detailed results of these studies are contained within the GHA flood study report, and will act as a key element in the preparation of the SMP. That SMP will contain specific management strategies for structures that are deemed to be at risk.

### 6.2 Ground movement

The main impact of ground movement is the effect of strains and tilts on relatively rigid structures such as houses. The Hue Hue Mine Subsidence District is the only portion of the proposed mine area where specific limits apply for mining induced ground movements. These limits are 3 mm/m of strain and 4 mm/m of tilt. The iterative design process described in this report has been used to ensure that the current mine layout will comply with these legislative requirements.

All of the houses that have been built in the Hue Hue Mine Subsidence District since it was proclaimed in 1985 have been designed to criteria that will safeguard against structural damage if they experience ground movements of these magnitudes.

In the event that any impacts do occur, the Mine Subsidence Board will rectify them. In addition, any houses that were constructed prior to the proclamation of the Mine Subsidence District are similarly covered.

The WACJV has compiled an exhaustive database containing the accurate location and construction details of buildings in the entire Extraction Area to serve as a key element in the preparation of the SMP. That plan will contain specific management strategies for structures that are deemed to be at risk.

Similarly, public infrastructure such as transmission lines, pipelines, roads and cables, which cross the Extraction Area, have been identified for detailed consideration in the SMP. Initial discussions with representatives of the owners of such assets have been undertaken to gain a full appreciation of the possibilities and limitations that may exist in managing potential effects. No insurmountable issues have been identified at this stage.

### **6.3 Upsidence and Closure**

When creeks and river valleys are affected by mine subsidence, the observed subsidence in the base of the creek or river is generally less than the level that would normally be expected in flat terrain. This reduced subsidence is due to the floor of the valley moving upwards and this phenomenon is referred to as valley bulging or upsidence. At the same time the sides of the valley are observed to move towards the centre of the valley. The reduced distance across the valley is referred to as valley closure.

The local reduction in subsidence (or upsidence) is generally accompanied by localised changes in tilt and curvature, cracking and void creation to a depth of up to 10 m below the rockhead in the base of the valley. The reduction in width across the valley, or closure, is generally accompanied by high compressive strains in the centre of the valley. In the case of escarpments and wide river gorges the movements may be limited to the cliffs that are closest to the extracted area.

Valley bulging is a natural phenomenon resulting from the formation and ongoing development of the valley. The impact of mining may be to accelerate this process. The process of valley formation is a relatively slow one and is further complicated by the weathering of the strata in the sides of the valley, which results in rock falls and a gradual widening of the valley.

The effects of upsidence and closure are much more apparent in dramatic geomorphological features such as steep sided gorges with rock bar floors than in broad alluvium filled valleys such as in the Extraction Area.

Research undertaken by MSEC has included reviews of previous experience of longwall mining in the Cataract, Georges, Nepean and Bargo Rivers to assist in evaluating the likely impact of these effects in the Extraction Area.

The water flows in the Cataract, Georges and Bargo Rivers are dependent on bed gradients, rock bars and pools and the riverbeds are perched above the local groundwater levels. A downstream weir however, predominantly controls the water level in the Nepean River, and the riverbed is permanently flooded along its entire length. Consequently the alluvials in that riverbed are fully flooded or saturated.

Exploration drilling for the Project indicates the presence of alluvial deposits of up to 30 m deep in the Wyong River, Little Jilliby Creek and Jilliby Creek valleys. This suggests that experiences of longwall mining in the Nepean River area are more applicable to the Extraction Area than case histories relating to features such as Cataract Gorge.

It is expected that the bedrock beneath these saturated riverbeds may fracture, buckle, or uplift due to the valley closure and upsidence movements creating a zone of increased permeability in the upper few metres of rockhead. However, since this will occur beneath the saturated alluvial deposits the fracture zone will fill as it develops with little or no affect to the ground water level. Similarly, since this permeability zone will develop quite gradually, and its volume will be small compared to the volume of the overlying saturated alluvium, the impact on overall stream flow will be insignificant.

It is also worthwhile noting that whilst longwall mining has occurred directly beneath the Cataract, Georges, Nepean and Bargo Rivers, no longwall extraction is proposed directly beneath the Wyong River or lower sections of Jilliby Creek.

## **6.4 Rock mass disturbance**

The main impacts that may emerge from rock mass disturbance are the disruption of aquifers and/or surface water regimes. These may occur where mining induced fracture systems that develop above the longwall goaf intersect an aquifer or propagate through to the surface. Surface fracturing such as this however is mainly confined to areas of relatively shallow depths of cover.

The numerical modelling that has been undertaken as part of this study, indicates that the caving related fracturing extends to approximately 200 m above the seam, beyond which the disturbance to the strata is limited to bedding plane shear and localised fracturing. Whilst some enhanced permeability is anticipated in the near surface strata as a result of subsidence related cracking at rockhead (see Section 6.3) there is no evidence of connectivity with the deeper, mining induced fracture systems. This is not unexpected since the two fracture systems will be vertically separated by 200-300 m of strata. To further evaluate this possibility however, further studies using acoustic scanner results from key boreholes were undertaken to determine the possible existence of natural fracture networks that may contribute to future connectivity. These investigations failed to identify any such zones that could facilitate large-scale shear movements which may connect to the mine.

Although no significant aquifers have been identified in the proposed mine area, the numerical modelling results prepared by SCT have been forwarded to Mackie Environmental Research Pty Ltd to assess the affect of mining induced fracturing on the groundwater regime. That modelling, analysed in conjunction with acoustic scanner results also sought to confirm that mining induced fracturing is unlikely to result in excessive water ingress to the proposed mine workings. The detailed results of these studies are contained within the Mackie Environmental Research groundwater study report.

## **6.5 Far field horizontal movements**

Far field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain. Impacts attributed to this form of movement results from the differential displacement, and are therefore confined to large rigid structures and steep natural features such as cliffs or gorges. These movements generally do not result in impacts on surface infrastructure, or small rigid structures such as buildings.

These horizontal surface movements are associated with the phenomenon of bedding plane slip and although they are very small in magnitude, they have been recorded over 1 km beyond the mining zone. They may occur if bedding planes with sufficiently low frictional properties, such as claystones, experience sufficient horizontal stress relief to enable them to experience shear failure. Since these planes are typically on the verge of their stability equilibrium only minor changes in the stress field are therefore required to initiate some degree of movement.



Experience from mining operations within the South Coast suggests that whilst mining in the Extraction Area will probably result in some activation of such planes, the impact on low lying areas is not likely to be noted particularly where there is a covering of Quaternary sediments and no significant relief to create differential movement across rigid man made structures or natural features. The greatest likelihood of potential impacts would be confined to the high relief areas in the western part of the Extraction Area.

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