REPORT TO:

AUSTAR COAL MINE

Subsidence Estimates
Austar Coal Mine - Longwalls A1-A2

ACM3011

Strata Control Technology

Mining Research and Consulting Group
SCT Operations Pty Ltd PO Box 824 Wollongong NSW 2520 Australia
sctnsw@sctaust.com

Report To	Mr Matthew Fellowes Technical Services Manager Austar Coal Mine Locked Bag 806 CESSNOCK NSW 2325
Subject	Subsidence Estimates For Austar Coal Mine Longwalls A1-A2
Report No	ACM3011
Prepared By	Ken Mills
Date	5 April 2006

Ken Mills
Senior Geotechnical Engineer

Winton J. Gale
Managing Director

SUMMARY

Austar Coal Mine commissioned SCT Operations Pty Ltd to prepare subsidence estimates and an assessment of likely impacts from the proposed mining of Longwalls A1 and A2. Previous assessments have been undertaken during the Environmental Impact Assessment (Holt 1995) and subsequently for conventional longwall mining geometries. This report presents the subsidence levels expected for the proposed top coal caving method, an assessment of the likely impacts of this subsidence and measures that might be implemented to manage these impacts.

Longwalls A1 and A2 are located in an area of undeveloped bushland adjacent to, and part of, Abedare State Forest. The proposed mining section ranges from 5.0m high up to 6.5m high, the actual mining height being dictated by a combination of coal quality and the practicalities of the top coal caving method. The impacts of mining this area on current land use and surface improvements are considered likely to be generally imperceptible, manageable and of no practical consequence.

While it is recognised that the levels of surface subsidence have the potential, should the rock strata above the pillars become overloaded, to be higher than the 1.1-1.6m range indicated in the EIS, the impacts of any higher subsidence are not expected to be significantly greater or any less manageable than the subsidence impacts discussed in the EIS.

At the completion of Longwall A1, surface subsidence above the panel is expected to have a magnitude of less than 100mm and be imperceptible for all practical purposes.

As Longwall A2 is mined, a broad subsidence trough centred on the combined geometry of Longwalls A1 and A2 is expected to develop behind the longwall face. There is no previous subsidence experience in NSW of mining using the top coal caving method or of mining 6m high sections at 500m deep, so the subsidence estimates are recognised to be outside the current experience base. Consistent with a conservative approach to estimating surface subsidence so that the potential impacts can be properly assessed and managed, a range of approaches has been used to estimate the maximum subsidence above Longwall A2.

Empirical estimates of vertical subsidence based on past experience at lower mining heights would indicate maximum subsidence in the range 1.1-1.6m.

Computational modelling suggests that the chain pillar and overburden strata immediately above the chain pillar may become overloaded when they become isolated in the goaf between two extracted longwall panels. The characteristics of this yielding process are not well defined, so it is possible that subsidence may occur sufficient to cause the 6-6.5m high goaf to be reconsolidated. Computational modelling indicates that subsidence of about 3m would be expected in this case.

Austar Coal Mine has requested an indication of the subsidence that would represent an absolute maximum value above which there would be no possibility of greater subsidence occurring. There are limited methods available to make this estimate. In keeping with taking a conservative approach, any contribution of the chain pillars to overall stability is ignored and it is assumed that the overall panel width is effectively supercritical in width. While it is recognised that, in reality, neither of these assumptions is valid, the maximum subsidence can be estimated as 65% of seam thickness on the basis that this value represents the maximum subsidence that has previously been observed in NSW over a single longwall goaf. This approach would give an upper limit on possible subsidence in the range 3.9-4.2m. It should be recognised that this estimate is likely to be conservative with actual subsidence being less.

It should be recognised that ground strains, tilts and curvature arising from subsidence are typically more significant in terms of subsidence impacts than vertical subsidence itself. However, the other parameters are found to be proportional to vertical subsidence divided by overburden depth, so maximum subsidence is a useful indicator of the significance of the other parameters.

Subsidence is expected to develop, for the most part, slowly and incrementally as mining proceeds. It is likely that some vibrations and rock breaking sounds will be perceptible on the surface as rock fracturing occurs. However, there is no potential for craters or subsidence holes to develop suddenly. It is possible, but unlikely, that step changes in surface subsidence may occur adjacent to geological structures, but no significant geological structures have so far been identified in the area of Longwalls A1 and A2.

Vertical subsidence is expected to become less than 20mm, which is regarded as the limit of practical significance for subsidence, at a distance from the edge of the longwall panels of less than 30° angle of draw (or 0.6 times overburden depth). This distance is about 300m for an overburden depth of 500m and represents for practical purposes, the edge of the area affected by mining subsidence.

At the outside edge of the longwall panels, referred to as the goaf edge, vertical subsidence is likely to be less than 200-300mm once a full subsidence trough has developed over the extracted longwall panels. Outside of the immediate mining area, surface subsidence is likely to be decrease gradually from 200-300mm at the goaf edge to 20mm at a distance of 300m. Subsidence of this level is likely to be imperceptible for all practical purposes in a bushland environment.

Given that top coal caving is a new technology for Australia that is capable of mining thicker coal sections than conventional longwall systems, there is an element of uncertainty about the influence that this thicker mining section would have on the magnitude of subsidence. It is therefore recommended that surface and sub-surface subsidence monitoring is used to confirm the magnitude of subsidence impacts from top coal caving in

Longwalls A1 and A2. A program of subsidence monitoring and sub-surface monitoring is described and would be recommended to better understand the effects on surface subsidence of mining a 6.5m high seam section.

TABLE OF CONTENTS

PAGE NO

1. INTRODUCTION

Austar Coal Mine commissioned SCT Operations Pty Ltd to prepare subsidence estimates and an assessment of likely impacts from the proposed mining of Longwalls A1 and A2. Previous assessments have been undertaken during the Environmental Impact Assessment (Holt 1995) and subsequently for conventional longwall mining geometries. This report presents the subsidence levels expected for the proposed top coal caving method, an assessment of the likely impacts of this subsidence and measures that might be implemented to manage these impacts.

Previous SCT Reports MIN2876 "Subsidence Assessment for Austar Mine Section 138 Application" dated February 2005 and STHL2479 "Subsidence Assessment for Section 138 Application" dated 13 March 2003, provide subsidence assessments for the various panel geometries proposed at those times. The surface features described in this report are based on the work undertaken in preparation of these earlier reports.

The significant changes to the 2003 assessment relate to the greater seam thickness able to be mined using the top coal caving method and the narrower panel widths proposed for Longwall A1. The changes to the 2005 assessment relate to the omission of a panel in the middle of SL4 and an upgraded estimate of maximum subsidence after Longwall A2 is complete based on computational modelling.

The report is structured to provide:

- A description of the site, the mining geometry and the surface features likely to be impacted by mining subsidence.
- A discussion of the mechanics of surface subsidence and a summary of the methods available to estimate subsidence.
- A review of previous subsidence monitoring experience at Ellalong Colliery and Southland Mine.
- A review of results of computational modelling and the implications of this modelling for surface subsidence estimates.
- Estimates of maximum subsidence and associated parameters based on three approachs – empirical, numerical modelling and an absolute maximum for impact assessment purposes.
- An assessment of the impacts that the predicted subsidence would have on each of the features identified.
- Recommendations for subsidence monitoring to confirm the mechanics of the subsidence processes associated with high seam extraction mining methods.

2. SITE DESCRIPTION

Figure 1 shows a 1:25,000 topographic series plan of the area with the location of the proposed longwall mining superimposed. Longwalls A1 and A2 are located below an area of undeveloped bushland that is part of Abedare State Forest and adjacent land owned by Austar Coal Mine.

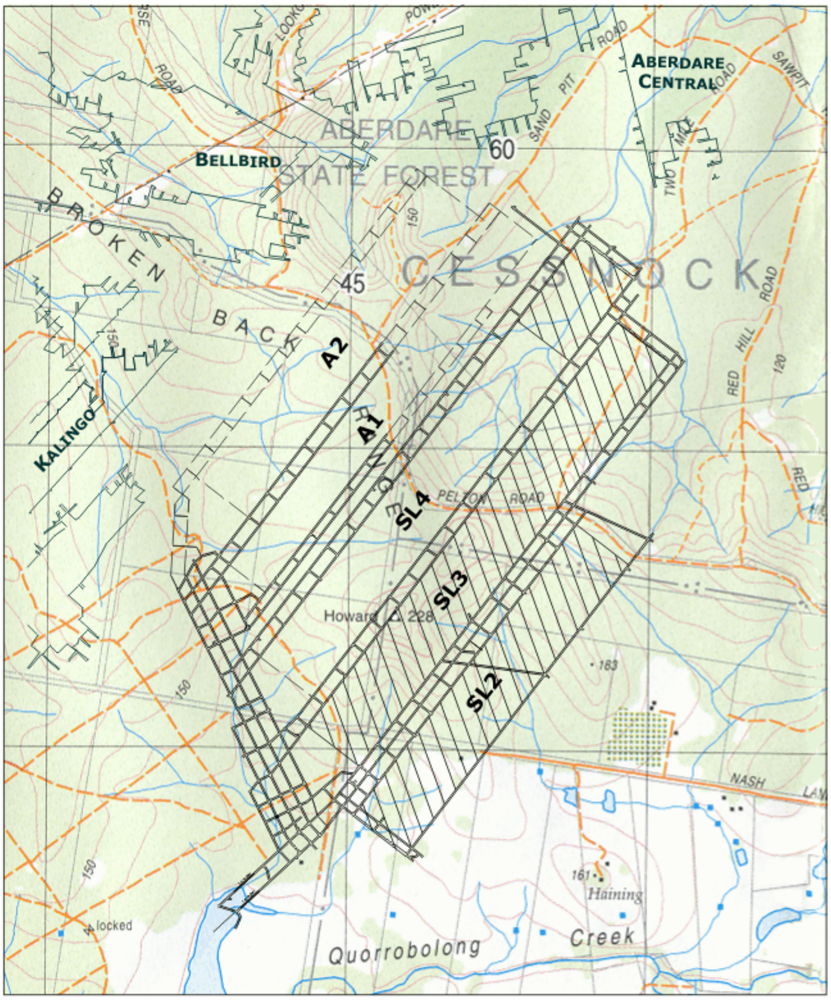

Figure 1 Site plan showing mine layout superimposed on 1:25,000 topographic series map.

Figure 2 shows a plan of the mine layout, proposed extraction thickness and overburden depth.

Austar Mine mines the Greta Seam which dips toward the south east at an average grade of approximately 1 in 9. The overburden depth generally increases to the south east as a result of seam dip with superimposed topographic variation providing local variations of up to 40m. The overburden depth ranges from 385m at the start of Longwall A1 to 470m deep midway along Longwall A2.

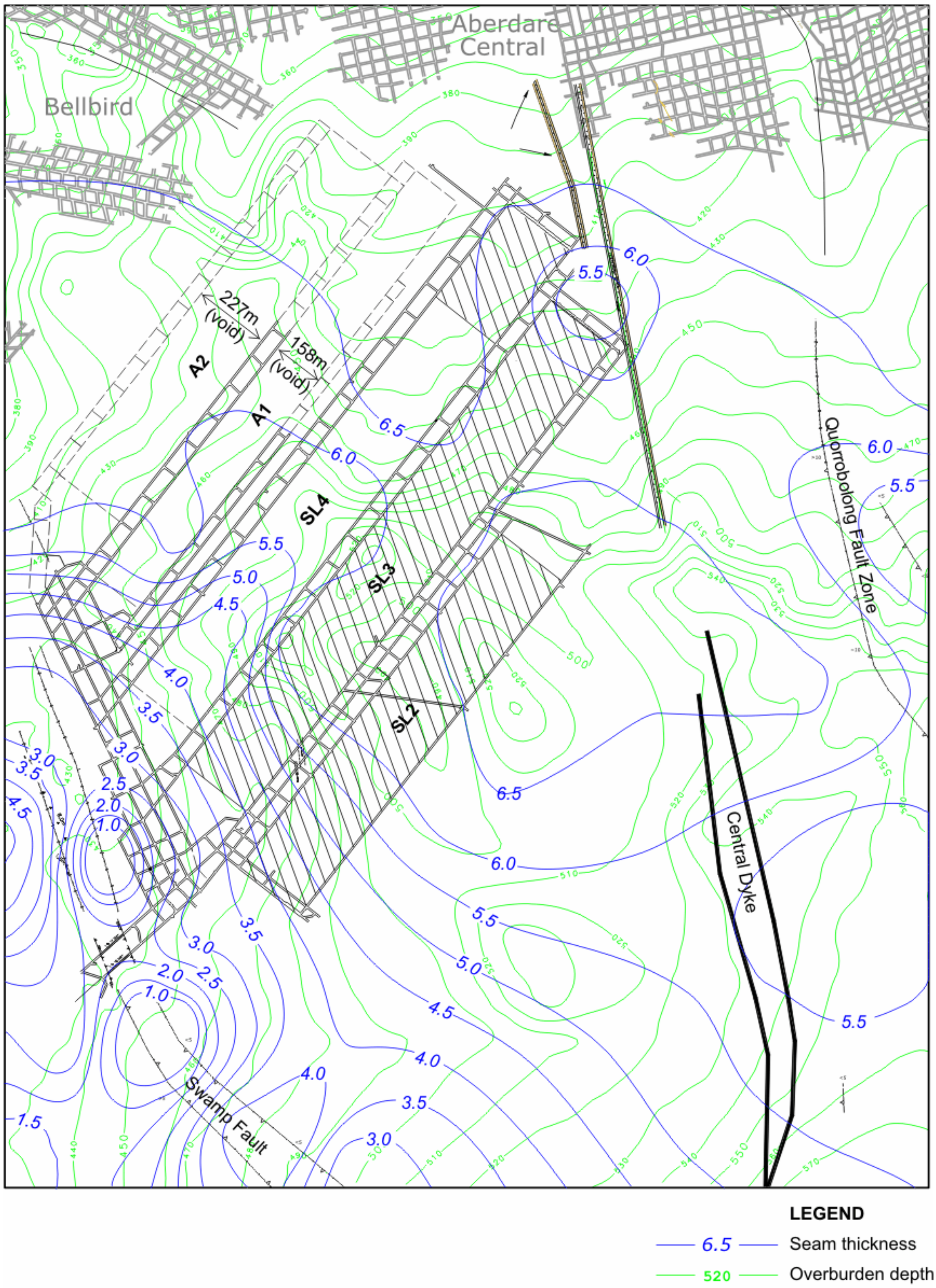

Figure 2 Site plan showing overburden depth and seam thickness isopachs.

The Greta Seam ranges from 5.0m to 6.5m thick but the actual mining section is based on coal quality considerations and the practicalities of top coal caving. For instance, in practice, it is necessary to grade down from the full mining in the middle part of the longwall face to the roadway height near each end of the longwall face to protect some critical items of longwall face equipment.

Historically, the longwall mining section at Ellalong and Southland has been about 3.5m high, but it is proposed to use the top coal caving method to allow mining up to the full seam height of about 6.5m. The maximum extraction height has been used for subsidence estimation purposes.

Table 1 provides a summary of the longwall panel geometries. The cut-throughs are nominally located at 100m centres. All the panels are individually of subcritical width and less than bridging width of 0.6 times depth.

Table 1: Summary of Longwall Panel Geometries

Longwall Panel	**A1**	**A2**
Final Void Width (m)	158	227
Maingate Chain Pillar (m cns)	45	35
Tailgate Chain Pillar (m cns)	30	45
Minimum Overburden Depth (m)	395	385
Maximum Overburden Depth (m)	470	450
Minimum W/D Ratio	0.34	0.50
Maximum W/D Ratio	0.40	0.59

The proposed longwall panels are surrounded to the north, west and southwest by the old workings of Kalingo, Bellbird and Aberdare Central Collieries and to the east by two previous longwall panels, Longwalls SL2, SL3 and a short section of SL4. However, the main part of the SL4 block is still intact and provides a significant subsidence barrier to the previous longwall area.

The total effective width of Longwalls A1 and A2 is 425m, giving an overall width to depth ratio of about 1.0 which is approaching critical width in subsidence engineering terms. Critical width is equivalent to a width to depth ratio of 1.2. This means in effect that the solid coal on either side of Longwalls A1 and A2 are so far separated that subsidence in the centre of the panel is predominantly controlled by the behaviour of the central chain pillar and strata immediately above it.

2.1 Surface Features

The surface is essentially undeveloped bushland that drops away on either side of Broken Back Range. Figure 3 shows an example of the type of vegetation. The northern part of the area is located within Aberdare State Forest and the southern part is owned by the colliery.

Figure 3 Typical vegetation in subject area.

The only developments identified within the mining area are various access tracks and a survey trig station located on the top of Mt Howard (on the chain pillar between Longwalls SL3 and SL4).

The access tracks include a section of Pelton Road, Sand Pit Road, and several minor link roads. All of these tracks are only really suitable for four-wheel drive vehicles. Figure 4 shows an example of one of the access tracks located on the northern side of Broken Back Ridge.

The watercourses in the area are all unnamed ephemeral first and second order channels. Figures 5 and 6 show examples of these features. On the northern side of Broken Back Ridge the watercourses flow into Black Creek. On the southern side of Broken Back Ridge, they flow into Congewai Creek (via Quorrabolong Creek off the eastern flanks of Mt Howard).

There are no cliff lines, escarpments, dams, flood prone land, areas of significant geological interest, ground water sources, wetlands or any other significant natural features within the subject area.

There are no man made features of significance apart from the four-wheel drive access tracks, and the trig station. We understand that an independent archaeological survey has been undertaken and is reported elsewhere. We understand that there are no features of significance.

Figure 4 Example of four wheel drive access track in subject area.

Figure 5 Example of ephemeral stream channel.

Figure 6 Example of ephemeral water course.

There are no buildings of any kind, no public utilities, roads (except those mentioned above), bridges, pipelines, telecommunications, rail, or other infrastructure in the area. We understand that there are no known wells or bores in the area and that there are no new developments proposed in the area.

3 SUBSIDENCE COMPONENTS

Previous subsidence monitoring results from Ellalong and Southland Mines are for a 3.5m high mining section. Austar Coal Mine proposes to mine at up to 6.5m which is beyond the range of experience not only at this mine, but elsewhere in NSW. In order to meaningfully use previous monitoring experience, it is helpful to consider how this increase in mining section might influence subsidence behaviour.

Subsidence associated with longwall mining can be divided into two main components, sag subsidence and strata compression subsidence. The sag subsidence component refers to the sagging, draping or trough subsidence that occurs above each individual panel. Strata compression subsidence refers to the subsidence that occurs from compression of the chain pillars, overburden and floor strata when mining causes overburden weight to be redistributed from over the goaf onto the chain pillars. In panels that are relatively deep compared to their width, such as at Austar Mine, maximum subsidence is controlled predominantly by strata compression.

Sag subsidence is directly proportional to the thickness of the mining section (height of coal extracted), but strata compression subsidence is less sensitive to mining height as long as the chain pillars and adjacent strata do not become so overloaded that they effectively collapse.

3.1 Sag Subsidence

Sag subsidence is found to be a function of the ratio of panel (or void) width to overburden depth and is directly proportional to the height of the seam section mined, particularly for panel width to depth ratios above about 0.6.

Figure 7 shows the sag subsidence measured at numerous sites for a range of panel width to depth ratios. The seam thickness on which this dataset is based typically ranges from 2.0m to about 3.5m. This data shows that sag subsidence behaviour can be divided into three zones based on the ratio of void width to overburden depth (W/D).

At W/D ratios less than about 0.6, the overburden strata is able to substantially bridge across individual panels, resulting in low levels of surface subsidence across individual panels irrespective of the thickness of the coal seam mined.

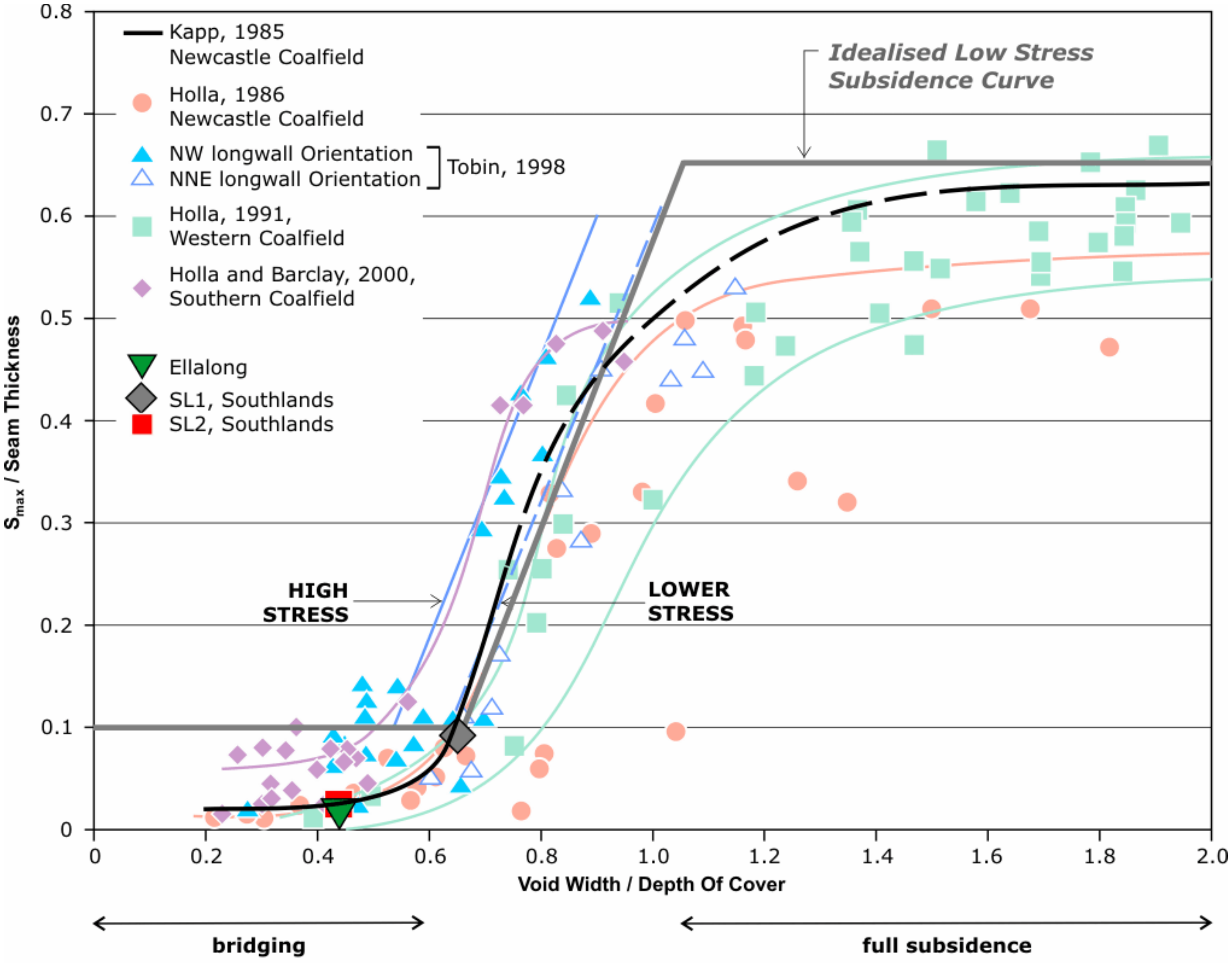

Figure 7 Summary of sag measurements in NSW.

At W/D ratios between 0.6 and 1.0, sag subsidence increases linearly with increasing W/D ratio. Between 1.0 and 1.4, sag subsidence increases more slowly but still increases. In this interval, maximum subsidence is proportional to the seam section mined but factors such as horizontal stress in the overburden strata and overburden geology also have an influence on the maximum subsidence for any particular mining geometry.

At W/D ratios above about 1.2-1.6, maximum subsidence is reached within each panel, or total width of all panels, where width relates to the combined width of several panels. At these W/D ratios, final subsidence is entirely dependent on the height of the seam section mined, the bulking and reconsolidation characteristics of the goaf and overburden strata, and, in multiple panels, the behaviour of the chain pillars and adjacent strata. Experience in NSW indicates maximum subsidence reaches a maximum of about 65% of seam thickness.

Data available from Southland Mine and Ellalong Colliery is consistent with the general experience of sag subsidence measured elsewhere, for panels where the overburden strata substantially bridges across individual panels. Results of sag subsidence in the Newcastle Coalfield (Kapp 1985) show a close correlation with sag subsidence values measured at Ellalong and Southland mines.

The implication of the sag subsidence data for W/D ratios expected at Austar Coal Mine is that while the panel width remains less than 0.6 times depth (almost the entire area for the proposed geometries), the sag subsidence over individual panels will remain a small component of the overall subsidence because the overburden substantially bridges across each individual panel.

3.2 Strata Compression Subsidence

Strata compression subsidence occurs because mining redistributes overburden load from over the mined out area (goaf) onto the chain pillars and the strata above and below the chain pillars. The subsidence profile observed previously at Ellalong Colliery and over Longwalls SL2 and SL3 are examples of subsidence profiles that are due almost entirely to strata compression subsidence. The individual longwall panels are barely visible in the subsidence profile because the sag component is small and the overburden strata bridges across each panel. Nevertheless the total subsidence is still significant because of the general lowering of the surface that occurs when the chain pillars and associated strata are compressed by redistributed overburden load. In these geometries, a subsidence trough develops across multiple panels with the maximum subsidence controlled by strata compression.

3.3 Effect of Seam Thickness Mined

Surface subsidence observed over longwall panels that are wider than the overburden depth suggest that final subsidence is directly proportional to seam thickness mined. However, the relationship between final subsidence and seam thickness mined is much less definitive when the overburden strata is able to substantially bridge across individual panels.

It is considered, based on the mechanics of strata compression subsidence, that surface subsidence at Austar Coal Mine is likely to be essentially independent of the thickness of the seam section mined because the longwall panels are relatively narrow compared to overburden depth, provided the chain pillar systems remain stable.

The insensitivity of strata compression subsidence to seam thickness mined needs to be confirmed by monitoring because the seam sections proposed to be mined are much higher than previous experience in NSW for this depth of mining. Fortunately there is opportunity to monitor the subsidence over Longwalls A1 and A2 because this area is not particularly sensitive to mining subsidence impacts. The results of this monitoring are expected to confirm the effect of mining height on the total subsidence for this type of mining geometry.

3.4 Empirical Methods for Estimating Subsidence Over Multiple Panels

Holla (1988) presented an empirical method for estimating subsidence over multiple longwall panels based on experience in the Southern Coalfield, but regarded as applicable in the Newcastle Coalfield as well. This method has been widely used for estimating maximum subsidence over multiple panels and was used by Holt (1995) to estimate maximum subsidence for the EIS. The method implies that maximum subsidence is directly proportional to the thickness of seam section mined.

Holla and Barclay (2000) present a revision of this 1988 method based on concepts of pillar loading. Again the method implies that maximum subsidence is directly proportional to the thickness of seam section mined which is somewhat surprising given the mechanics that are used to underpin the method.

Both these methods are used to back calculate the subsidence that was measured over previous longwall panels and as a basis for prediction.

4. PREVIOUS SUBSIDENCE MONITORING RESULTS

In this section, available subsidence data from Longwalls 2 and 6 at Ellalong Colliery, and from SL1, SL2 and SL3 at Southland Mine provide a basis for estimating surface subsidence likely above the proposed longwall panels. The measured subsidence is compared with the subsidence that would be calculated using three different approaches to give an indication of the variability that can be expected.

4.1 Longwall 2 at Ellalong Colliery

Holla and Armstrong (1986) present the results of monitoring sub-surface caving behaviour over Longwall 2 at Ellalong Colliery. While the sub-surface monitoring is interesting in its own right as showing that the overburden strata at Ellalong has a spanning capacity similar to, but slightly better than, that observed elsewhere in NSW, the results of subsidence monitoring reported are of primary interest to the current study.

At the completion of Longwalls 1 and 2 maximum subsidence of 950mm was measured over the central chain pillar. Subsidence midway across Longwall 2, at the collar of the extensometer, was 415mm. Longwalls 1 and 2 were 155m wide (across the final void), at a depth of approximately 370m. The mining section was nominally 3.5m high.

Although there is no specific subsidence profile presented, there has been almost no sag subsidence given that the subsidence measured half way across the panel is less than half the maximum subsidence measured in the centre of both panels. The 950mm of subsidence observed over the chain pillar gives a measure of the strata compression subsidence for this geometry.

Back calculation of the subsidence using three different approaches is summarised in Table 2.

Table 2: Comparison of Subsidence Calculated for Longwalls 1 and 2 at Ellalong Colliery

Approach	**Maximum Subsidence (mm)**
Strata Compression	800
Holla (1988)	1400
Holla & Barclay (2000)	1400
Measured	950

4.2 Longwall 6 at Ellalong Colliery

Subsidence monitoring data is available for the main set of longwall panels at Ellalong Colliery in the vicinity of Longwall 6. Figure 8 shows a section of the subsidence profile measured on a cross line comprising three branches that follow the alignment of three roads that converge at an intersection. The results shown in Figure 8 are measured on the sections of the line that starts above Longwall 5 and continues over Longwall 7. The subsidence hump is located above the chain pillar between Longwalls 6 and 7 at the location where two parallel dykes cross the chain pillar.

Longwalls 4-7 were 190m wide measured rib to rib with Longwalls 8 and 9a increasing to 212m void. The chain pillars are 30m wide (rib to rib) in Longwalls 2 to Longwall 7, and 35m in Longwalls 7 to 9. The seam section mined was 3.5m and the overburden depth about 420m.

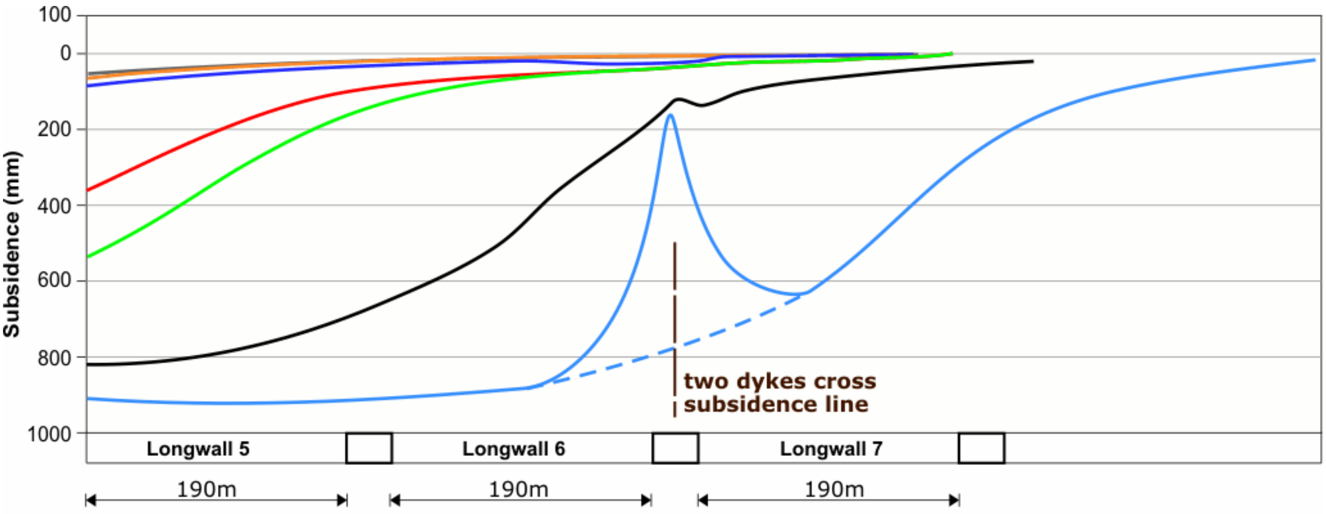

Figure 8 Subsidence monitoring results over Longwalls 5-7, at Ellalong Colliery.

It is clear from this subsidence profile that, except where the two dykes have locally influenced the profile, the surface subsidence is responding to the super-panel effect of multiple adjacent longwall panels rather than to individual panels. The sag subsidence associated with individual panels is not evident in the subsidence profile for the 190m wide panels at approximately 420m deep. Compression of the chain pillars, and the adjacent roof and floor strata, control the level of surface subsidence at about 0.9m.

Back calculation of the subsidence above Longwall 6 using three different approaches is summarised in Table 3.

Table 3: Comparison of Subsidence Calculated for Longwall 6 at Ellalong Colliery

Approach	**Maximum Subsidence (mm)**
Strata Compression	1050
Holla (1988)	1400
Holla & Barclay (2000)	1600
Measured	900

Above Longwall 6, the surface strains are generally less than 1mm/m except in the vicinity of the dyke where they are locally as high as 4mm/m on a 20m bay length. Maximum systematic tilts measured were 3mm/m. Strains predicted using the guidelines developed for the Southern Coalfield Holla (1985) would indicate maxima of 2mm/m strain and 6mm/m tilt for the 0.9m of subsidence measured.

The surface expression of the dyke structures in the subsidence profile directly above their location at seam level illustrates the vertical persistence of dyke structures and their potential to influence overburden caving behaviour and surface subsidence when the dyke structure is located directly over longwall panels.

4.3 Subsidence Monitoring Longwall SL1

Longwall SL1 was mined adjacent to the main headings in Ellalong Colliery. Figure 9 shows subsidence monitoring results from Longwall SL1 at the completion of mining and then again about 5 years later when additional subsidence has occurred.

Longwall SL1 was mined 227m wide at a depth of approximately 350m. Maximum subsidence measured in the centre of the panel was 320mm immediately after mining.

Over the 5 years or so since Longwall SL1 was completed, some 50-100mm of additional subsidence has been observed, mainly on the eastern side of the panel and over the main heading pillars. This additional subsidence is interpreted to be a result of ongoing floor heave and pillar movement in the main headings. This additional subsidence is not expected for the proposed mining geometries at Austar Coal Mine.

Since the panel is a single panel the maximum subsidence is a consequence of sag subsidence only. Kapp (1985) provides a summary of maximum subsidence measured in the Newcastle Coalfield at low values of W/D ratio (shown in Figure 7). Based on this data, maximum sag subsidence of up to 350mm would be expected. This agrees very closely with the 320mm of sag subsidence measured.

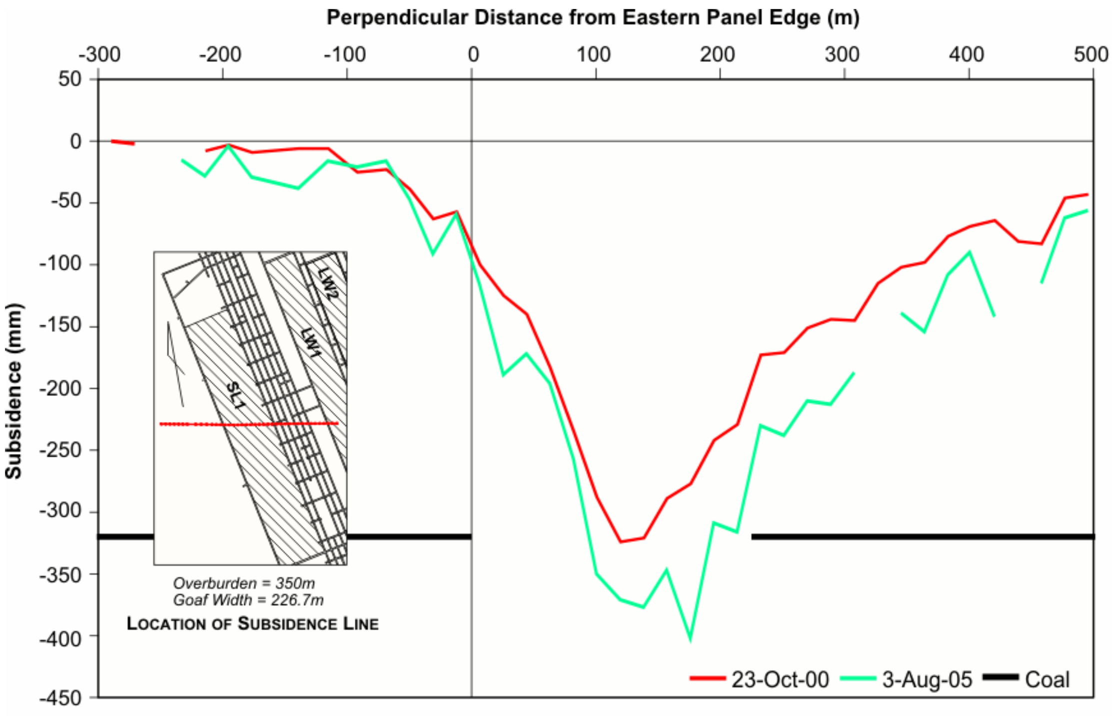

Figure 9 Subsidence monitoring results over Longwall SL1 at Southlands Mine.

4.4 SUBSIDENCE MONITORING SL2 AND SL3

Longwalls SL2 and SL3 were mined by Southland Mine as part of the series of longwall panels. Figure 10 shows a plot of subsidence profiles measured at the completion of Longwalls SL2 and SL3. An adjustment of -70mm distributed proportionally to distance from the eastern end of the line has been made to the initial survey on the basis of correcting the form of the subsidence data to be consistent with general experience.

Both longwall panels are 225m wide (rib to rib) and the overburden depth is approximately 510m in the vicinity of the subsidence line. The pillars separating the two panels are split by a third heading. The subsidence measured over Longwall SL2 at the completion of the panel reaches a maximum value of 87mm.

The sag subsidence estimated using the empirical relationship published by Kapp (1985) is 70mm which compares well with the measured value of 87mm.

When Longwall SL3 was mined, the maximum subsidence reached 450mm in the centre of the panel. This maximum is centred over the chain pillar and its magnitude is controlled by compression of the chain pillars rather than by overburden sag. The three heading pillar geometry makes it difficult to get a meaningful back calculation of strata compression subsidence using any of the available techniques.

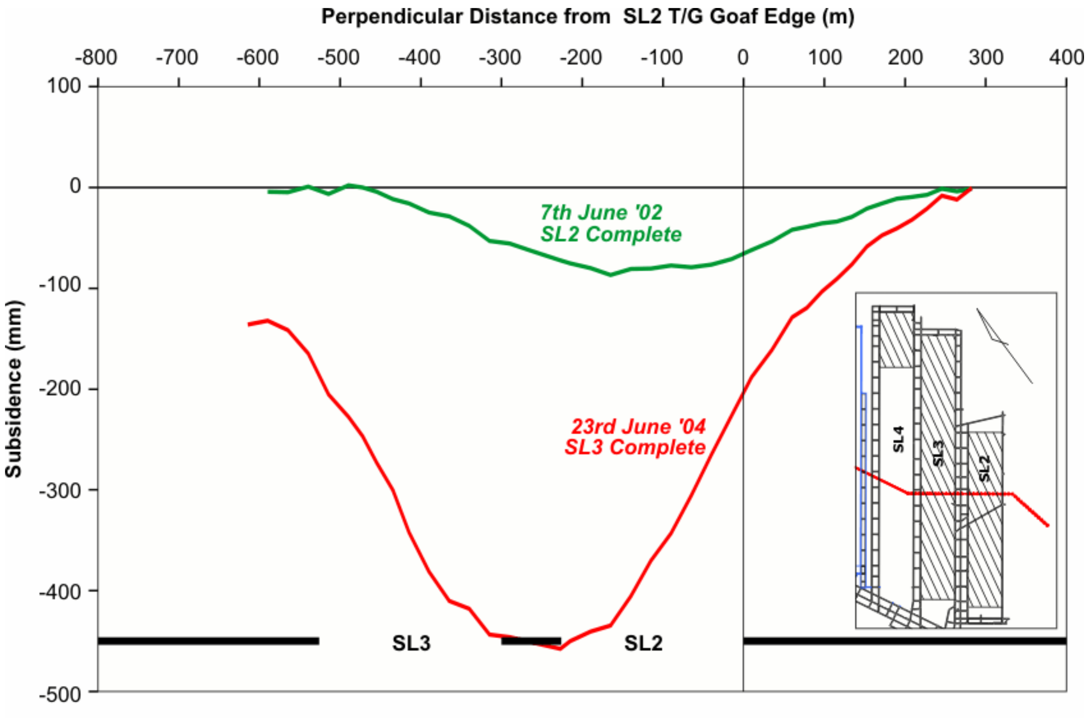

Figure 10 Subsidence monitoring results over Longwalls SL2 and SL3 at Southlands Mine.

5. REVIEW OF COMPUTATIONAL MODELLING

The overburden and subsidence characteristics of Longwalls A1 and A2 have been modelled to assess the impact of full seam extraction associated with top coal caving. The geological section of the overburden strata about the Greta and Pelton Seam has been derived from borehole SBD 1052 and the rest of the geological section was derived from the shaft borehole SBD 1012.

The strata properties have been estimated from geophysical relationships, core testing and core observation. This geological section and properties have been used to model longwall caving and longwall support issues for SL3 and SL4 panels. The results obtained provided a close correlation to the observed behaviour and background experience of the mining personnel. However, it should be noted that the model is based on an extrapolated geological section, rock properties and input parameters which represent an estimate of the ground and its properties. The results should be viewed as providing an overview of the potential ground behaviour and guidance as to the options available to optimise operations under the conditions modelled.

The Greta Seam has been modelled as 6m thick with an interburden of 15m to the Pelton Seam. The strata within the interburden to the Pelton Seam are interbedded sandstone with strength in the 10-30MPa range. Some local channel sandstones exist in this section. Above the Pelton Seam is the Cessnock sandstone which is 20-30 m thick, bedded and of moderate to high strength. This unit is overlain by a siltstone sequence of at least 70m thickness. This unit is bioturbated to a variable extent, however for this model it is assumed that the bedding is disturbed and not pervasive within the strata section. The strength of the siltstone is variable from approximately 40 to 70MPa. The in situ strength of coal is modelled as 6.5MPa which is a typical in situ coal strength.

For the purpose of this study the depth selected was 420m to the Greta Seam. This provides a reasonable estimation of the A1-A2 pillar loading and the overburden behaviour for A2 Panel.

The individual panels are sub critical in width/depth ratio. However as a combined layout the mine geometry approaches critical width. Under these circumstances the overburden response will be dependent on the chain pillar behaviour and goaf loading characteristics.

The model indicates that overburden subsidence at the completion of Longwall A1 is less than approximately 170mm.

A2 Panel was modelled as approximately 250m wide. It has subsequently been noted that this is wider than the planned panel width, however the results have indicated some issues regarding the overall subsidence characteristics for a 6m seam extraction.

Caving within this panel extends above the Cessnock sandstone and into the bioturbated siltstone and sandstone section. The model indicates that at this depth, the chain pillar yields and allows the Longwall A1-A2 geometry to combine and act as a single panel approaching critical width.

The model indicates that there is potential for the chain pillar to yield and allow fracturing of the strata overlying the chain pillar up to and above the Pelton Seam. This strata is relatively weak, however the high pillar loading combined with a horizontal stress reduction into the adjacent goaf zones overloads the coal and strata above the pillar. This strata fracture softens the overall stiffness of the overburden and allows overburden convergence in the fractured zone above the pillar. This convergence of the overburden then causes the goaf to load.

The surface subsidence is a function of the pillar strength (coal and fractured strata section above) and goaf loading. The model indicates that subsidence will be in excess of 2m and may extend to 3m. The subsidence characteristics may be modified by the existence of the topographic relief over SL4 and parts of A1 Panel, however the overall trends are considered to be similar to expectation. The barrier pillar between A1 Panel and SL4 Maingate maintains stability during the extraction of A2.

It should be noted that this geometry is not exactly equivalent to that proposed for Longwalls A1 and A2, however the modelling does flag some issues to be addressed in the planning process.

The issues raised are:

i. The model indicates that the chain pillar yields and therefore the overburden will be supported by a combination of pillar strength and goaf load. This phenomenon is also evident in the 3m extraction models.

ii. The model indicates that in the 6m high extraction void, there will be greater subsidence required to load the goaf than would be the case for a 3m high extraction panel.

iii. If the mechanics depicted in the model are correct, then subsidence over Longwalls A1 and A2 would be significantly greater for the 6m extraction than for a typical 3m type extraction thickness. Subsidence in the range of 2-3m is indicated by the model.

6. SUBSIDENCE ESTIMATES

In this section, maximum surface subsidence values are estimated on the basis of three different, empirical subsidence prediction methodologies. These different methodologies are compared and discussed. Profiles of surface subsidence at the completion of each longwall panel, a plan of the final subsidence contours and estimates of maximum horizontal strain and tilt are presented.

6.1 Comparison of Methodologies

Back calculation of the subsidence from measured subsidence has provided a means of testing the applicability of various methods for estimating subsidence.

The empirical data presented by Kapp (1985) shows a close correlation with the sag subsidence observed over previous longwall panels at Ellalong and Southland Mines.

The method for estimating strata compression subsidence described in Mills (1998) based on calculating sag and strata compression subsidence separately appears to have provided estimates of subsidence that are within about 0.2m of the measured subsidence at the two sites for which subsidence data is available.

Holla (1988) presents an empirical method for estimating subsidence over multiple panels taking into account panel width. This approach has been widely used as a method for estimating subsidence over multiple panels at other sites. Somewhat surprisingly, back calculation using this approach does not closely correlate with the measured subsidence at Ellalong, with the method apparently overestimating subsidence by up to 50% in the two cases where data is available.

Holla and Barclay (2000) present a semi-empirical technique for estimating subsidence about longwall panels. The application of this method to the Ellalong mining geometries does not show a close correlation with the subsidence measured being overestimated by up to 90%.

6.2 Estimated Maximum Subsidence Values

The maximum subsidence estimates are based on the three different empirical approaches discussed above. The maximum strain and tilt are based on an empirical dataset from the Southern Coalfield where overburden depth is similar to that at Austar Coal Mine (Holla 1985b).

Table 4 summarises the maximum subsidence that would be expected at the completion of each panel using the various approaches.

Table 4: Subsidence Estimates

At Completion of Longwall Panel	A1	A2
Sag Subsidence (mm)	100	330
Strata Compression (mm)	0	1100
Maximum Subsidence (mm)	100	1100
Maximum Subsidence (Holla 1988)	100	2100
Maximum Subsidence (Holla 2000)	100	2900

Back calculation indicates that the sag subsidence for each of the panels can be determined with some confidence based on previous experience. Sag subsidence only really becomes significant over Longwall A2 where it is estimated to reach 330mm and even then this level of sag subsidence is expected to be small compared to the strata compression subsidence.

The various approaches yield a range of magnitudes for total subsidence that are not particularly convincing. However, if the overestimation by each of the methods of the measured subsidence over Ellalong Colliery is taken into account, the range narrows considerably to a range from 1.1m to about 1.6m. This range is the same as that predicted by Holt (1995) in the EIS.

Furthermore, the combination of strata compression and sag subsidence appears to give the closest estimate of measured subsidence over Longwall 6 and is expected to give the closest estimate for the subject area as well, provided the behaviour of the chain pillars does not change and they remain substantial load bearing elements in the system.

Table 5 shows estimates of maximum strain and maximum tilt based on the expectation of 1.6m of maximum subsidence, the possibility of 3m (as indicated by numerical modelling), and 4.2m in the unlikely event that the chain pillars fail to contribute to the support of the overburden strata. These estimates are based on experience in the Southern Coalfield (Holla 1985b) where overburden depths are similar to those at Austar Coal Mine.

It should be noted, that surface topography has been found to significantly influence horizontal movements in steep terrain. In steep terrain, there can be a large component of downslope movement that tends to cause increased tensile strains on topographic highs and compressive strains at topographic lows. These strains would be additional to the systematic strains indicated in Table 5.

Table 5: Estimated Subsidence, Strain and Tilt Values

Subsidence Predictions	**Empirical**		**Numerical**		**Absolute Maximum**	
At completion of longwall panel	A1	A1+A2	A1	A1+A2	A1	A1+A2
Max. Subsidence (m)	0.1	1.1 – 1.6	0.2	2 – 3*	0.2	3.9 - 4.2
Max. Tensile strain (mm/m)	0.1	2	0.1	4	0.1	5
Max. Comp. strain (mm/m)	0.2	4	0.2	7	0.2	10
Max. Tilt (mm/m)	0.8	11	0.8	21	0.8	30

**If the chain pillars and overlying strata become overloaded. Numerical modelling indicates that overloading is possible, but this mechanism is yet to be confirmed by monitoring.*

6.3 Subsidence Profiles

Figure 11 shows the form of the subsidence profiles anticipated at the completion of each panel.

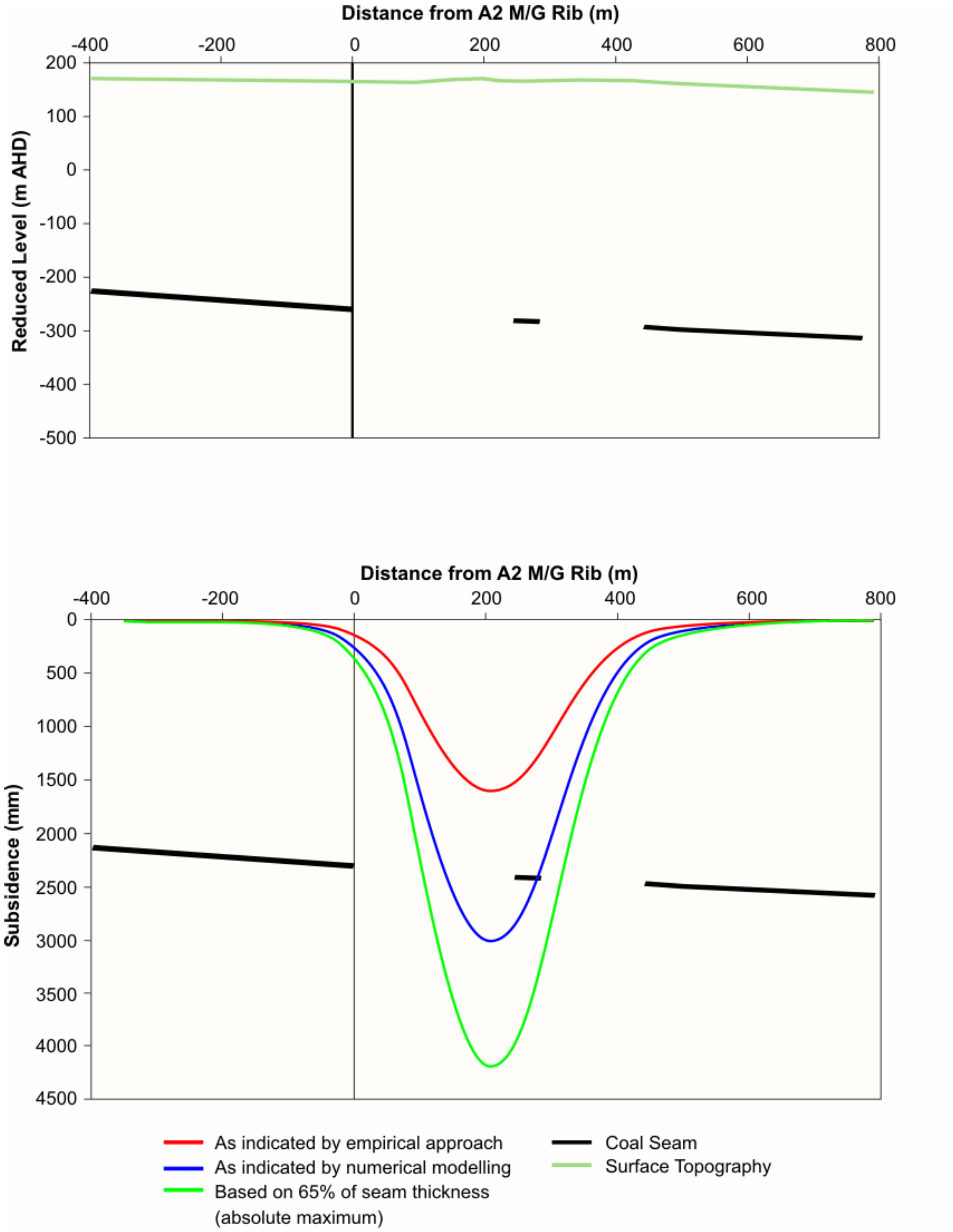

Figure 11 Estimated subsidence profiles in as each longwall panel is mined.

At the completion of Longwall A1, subsidence is likely to be imperceptible for all practical purposes. At the completion of Longwall A2, a broad subsidence trough centred on the combined geometry of Longwalls A1 and A2 is expected to develop. The maximum subsidence in this trough is expected to be in the range 1.1-1.6m, but may be as high as 3m depending on the stability of the chain pillars. The surface in the area of Longwalls A1 and A2 is not particularly sensitive to subsidence magnitude, and there is not expected to be any perceptible difference in terms of subsidence impacts for this range of maximum subsidence values.

This site provides a good opportunity to measure the effects of a higher seam section on subsidence magnitude.

Subsidence is expected to develop, for the most part, slowly and incrementally as mining proceeds. It is likely that some bumping and rock breaking sounds will be perceptible on the surface as rock fracturing occurs. However, there is no potential for craters or subsidence holes to develop suddenly. It is possible, but unlikely, that step changes in surface subsidence may occur adjacent to geological structures, but no significant geological structures have so far been identified.

Since there do not appear to be any convincing measurements of vertical subsidence outside of the immediate mining area available from Ellalong Colliery or Southlands Mine, the extent of subsidence expected is based on monitoring experience at other sites, particularly in the Southern Coalfield. Vertical subsidence is expected to become less than 20mm, which is regarded as the limit for subsidence of practical significance, at a distance from the edge of the longwall panels of less than 30° angle of draw (or 0.6 times overburden depth). This distance is about 300m for an overburden depth of 500m and is regarded as the maximum distance from the mining area that vertical subsidence is likely to be perceptible.

At the outside edge of the longwall panels, referred to as the goaf edge, vertical subsidence is likely to be less than 200-300mm once a full subsidence trough has developed over the extracted longwall panels. Outside of the immediate mining area, surface subsidence is likely to be less than 200-300mm and to be so gentle as to be imperceptible for most practical purposes.

7. ASSESSMENT OF IMPACTS

The potential subsidence impacts are assessed for the three scenarios of maximum subsidence equal to 1.6m, 3m and 4.2m recognising that 1.6m represents the value of subsidence expected on the basis of past experience, 3m represents a likely upper limit in the event that the chain pillars become overloaded as indicated by numerical modelling and 4.2m represents the absolute maximum credible subsidence based on subsidence equal to 65% of seam thickness mined. It is noted that these scenarios are essentially similar to the 100%, 200% and 300% scenarios outlined in the guidelines for subsidence assessment used in the past for Section 138 approvals.

Table 6 summarises the maximum subsidence values that would be anticipated at the completion of each longwall panel for the three scenarios considered.

Table 6: Maximum Estimated Subsidence, Strain and Tilt Values

	Empirical		**Numerical***		**65% of Seam**	
At Completion of Longwall Panel	A1	A2	A1	A2	A1	A2
Maximum Subsidence (m)	0.1	1.6	0.1	3.0	0.1	4.2
Max Tensile Strain (mm/m)	0.1	2	0.1	4	0.1	5
Max Comp. Strain (mm/m)	0.2	4	0.2	7	0.2	10
Max Tilt (mm/m)	0.8	11	0.8	21	0.8	30

**If the chain pillars and overlying strata become overloaded. Numerical modelling indicates that overloading is possible, but this mechanism is yet to be confirmed by monitoring.*

The impact of the anticipated subsidence movements in the subject area is expected to be imperceptible for most practical purposes for all three scenarios. It is usually difficult to see the effects of subsidence movements in this type of terrain.

Figure 12 shows a contour plan of the final subsidence that would be expected. The distance from the goaf edge of the point of maximum subsidence is essentially constant irrespective of the magnitude of the maximum subsidence, so the contour lines have the same shape for each scenario. The only difference between scenarios is the magnitude of the subsidence value for each contour line.

The trig station on Mt Howard is likely to be affected by mining subsidence when Longwall A2 is mined by movements in the range of a few centimetres, most likely in a horizontal direction to the north-west. The movements will be larger for larger values of subsidence, but in all three scenarios, resurvey of the Mt Howard trig station is likely to be required. It is understood that the Department of Lands and Survey have been notified of this potential.

There may be some tensile cracking apparent on extensive bare surfaces such as access tracks. Such cracking is likely to be concentrated near the top of steep slopes but is not expected to substantially alter the character of the tracks recognising that they are bush tracks and suitable only for four-wheel drive vehicles and other recreational vehicles. The difference in the impact for each of the three scenarios is likely to be one of magnitude of crack width rather than any substantial difference in the nature of the impact. Warning signs notifying that the area is subject to mining subsidence movements would be considered prudent in the unlikely event of a large crack forming.

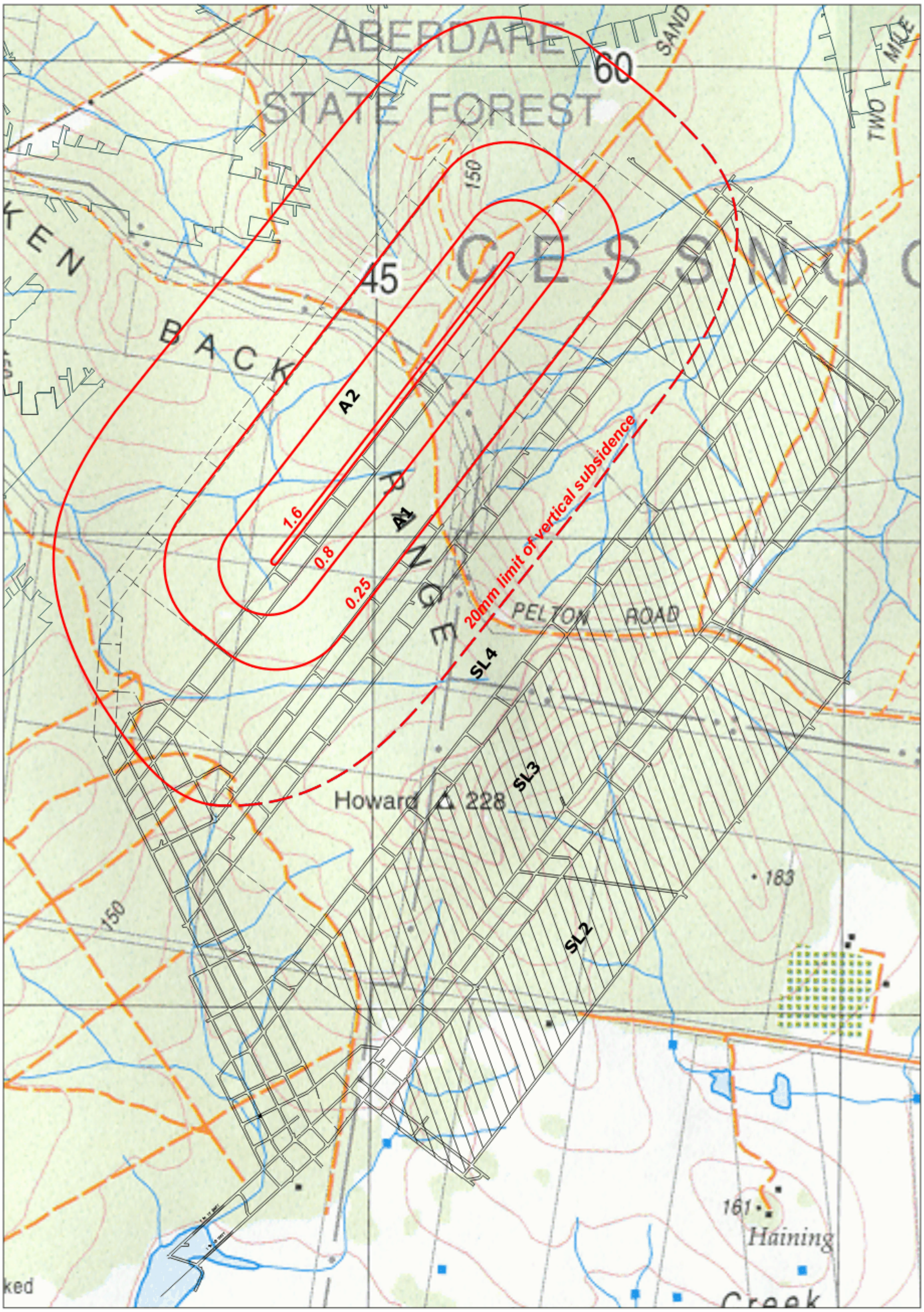

Figure 12(a) Contour plan of estimated final subsidence - based on empirical approach.

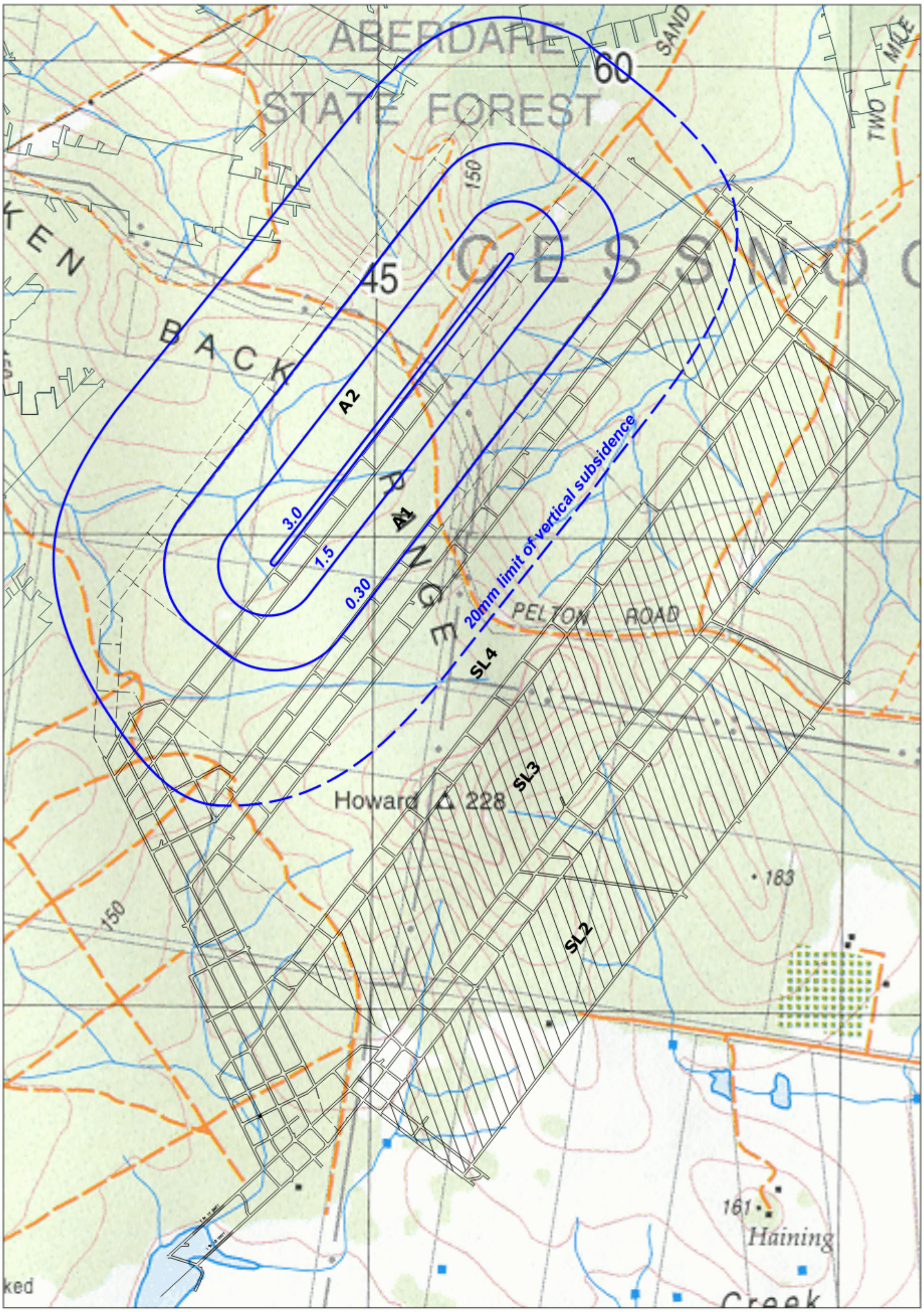

Figure 12(b) Contour plan of estimated final subsidence - based on numerical modelling.

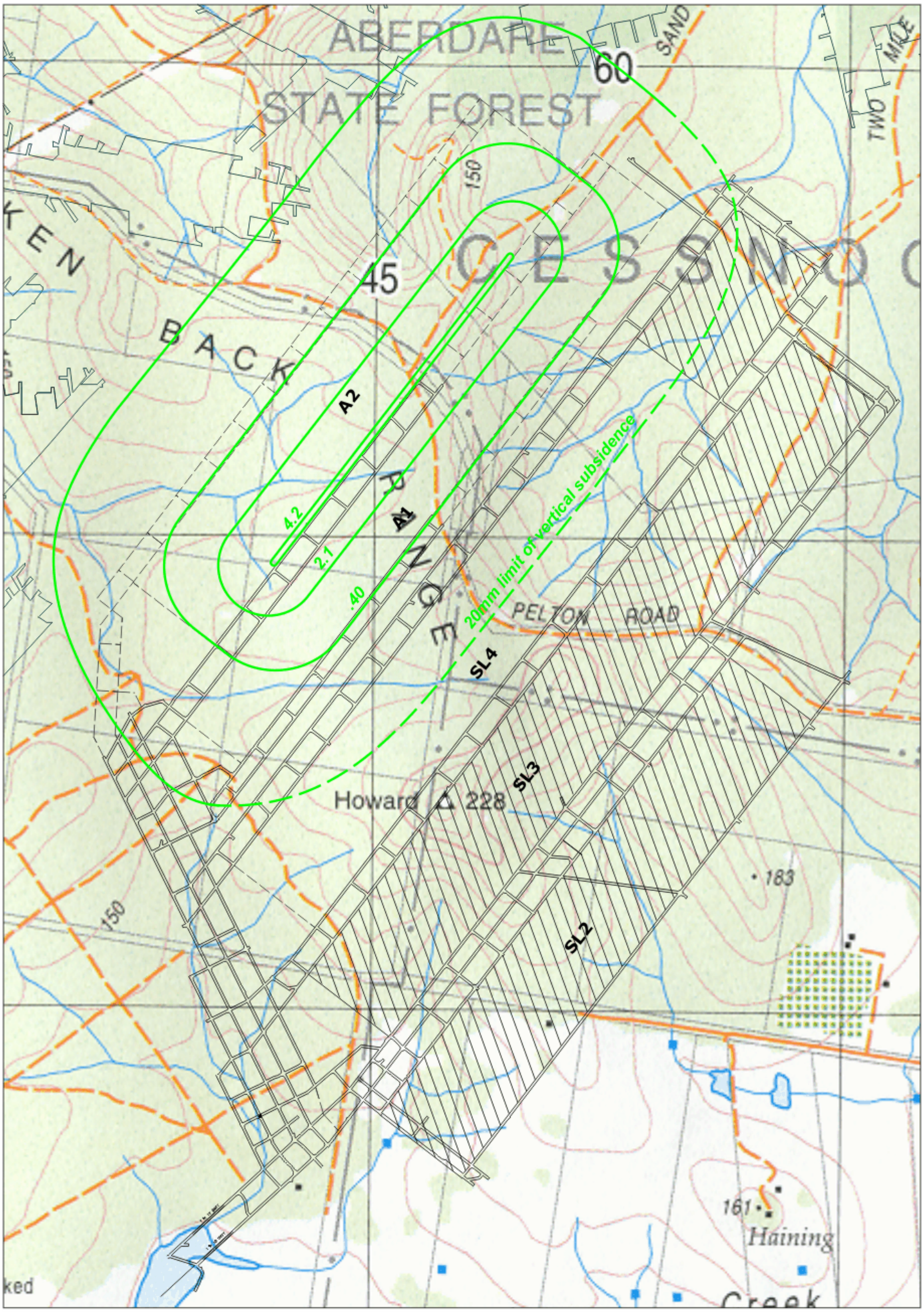

Figure 12(c) Contour plan of estimated final subsidence - based on 65% of seam thickness (absolute maximum).

The Management Information Handbook for the Undermining of Cliffs, Gorges and River Systems (2002) provides a summary of the experience of crack widths measured above longwall panels at various overburden depths. At 500m depth, the maximum crack width indicated would be 30mm for a likely maximum subsidence of about 1-1.5m, although most cracks are likely to be much less than this maximum. On this basis, maximum crack widths of 60mm may be expected for 3m maximum subsidence and 90mm for 4.2m of maximum subsidence. It should be noted that there have been some examples of wider cracks, but these have occurred in much steeper terrain than the terrain in the subject area.

We understand that the impacts of vertical subsidence on run-off and potential ponding in the ephemeral watercourses in the area and the effects of subsidence on near-surface groundwater are being assessed by others.

In the event that the subsidence is greater than the anticipated 1.6m, it is not expected that there would be any significant change in the impacts experienced. Greater vertical subsidence may cause larger strains and tilts, but it is likely that even at the absolute maximum possible subsidence of 4.2m, subsidence impacts would remain essentially imperceptible for most practical purposes.

8. RECOMMENDED SUBSIDENCE MONITORING STRATEGY

We would recommend the following general subsidence monitoring strategy is followed. We would recommend that:

1) Two subsidence monitoring lines are established at convenient locations across the central part of each of the two longwalls with peg spacings nominally at 1/20th depth (20-25m). These lines are surveyed in three dimensions with survey control provided from two remote locations at either ends of the line. An initial survey is conducted prior to commencement of mining (even on existing lines). Subsequent re-surveys are conducted at the completion of each longwall panel. The subsidence lines do not need to be absolutely straight, at right angles to the panels or in the centre of the panels, but wherever possible, it would be helpful to have them as close as practical to straight, perpendicular and central.

2) A longitudinal subsidence line with pegs at 20m centres is located centrally over the combined area of Longwalls A1 and A2 (about 210m from the maingate of Longwall A2 offset sufficiently from Sand Pit Road to avoid the pegs being damaged by road maintenance activities). Optimally the line would start 150m north east of the start of Longwall A1 and extend to the middle of the block. This line would be intended to measure the development of the combined subsidence from Longwalls A1 and A2 and would be measured in three dimensions.

3) A short cross-line located 400m from the starting rib of Longwall A2 and extending 80m either side of the longitudinal line just to confirm that the longitudinal line is located on the line of maximum subsidence.

4) A surface extensometer located at a convenient point 300-400m from the start of, and on the centreline of, Longwall A1. Multiple anchors would be used to confirm the height of caving above a 6.5m mining section. It would also be helpful to have a second extensometer located in a similar position over Longwall A2, but it should be recognised that this second extensometer would measure a combination of movements associated with individual panel sag and general strata compression making it difficult to differentiate the two components.

5) A surface extensometer located at a convenient point 300-400m from the start of Longwall A2 over the chain pillar between Longwalls A1 and A2 to confirm the compressibility characteristics of the chain pillar.

9. CONCLUSIONS

At the completion of Longwall A1, subsidence is expected to be imperceptible for all practical purposes, with a maximum magnitude of less than 100mm irrespective of mining height or which model is applied.

At the completion of Longwall A2, a broad subsidence trough centred on the combined geometry of Longwalls A1 and A2 is expected to have developed. The maximum subsidence in this trough is expected to be in the range 1.1-1.6m based on empirical approaches and past experience at the mine. Numerical modelling suggests that the chain pillars and overlying strata may become overloaded allowing maximum subsidence of up to 3m to develop.

Austar Coal Mine has requested an estimate of the absolute maximum subsidence possible. Maximum subsidence of 4.2m (65% of seam thickness mined) has been estimated as the absolute maximum subsidence that would be possible by assuming that the chain pillars do not contribute at all to the support of the overburden strata.

For the 1.6m scenario, maximum systematic strains of up to 4mm/m and tilts of 11mm/m are expected. Maximum crack widths are expected to be less than 30mm. There have been some examples of wider cracks at 500m overburden depth, but these have occurred in much steeper terrain than the terrain in the subject area.

For the 3m scenario, maximum systematic strains of 7mm/m and tilts of 21mm/m are expected. Maximum crack widths may be up to 60mm, although it is possible that larger cracks may form at topographic high points.

For the 4.2m scenario, maximum systematic strains of 10mm/m and tilts of 30mm/m would be expected with maximum crack widths up to 90mm, although again with the possibility of larger cracks at topographic high points.

The impact of the anticipated subsidence movements in the subject area is expected to be largely imperceptible for most practical purposes given current land use and surface infrastructure. It is usually difficult to see the effects of subsidence movements in bushland terrain. Some cracking along topographic high points may be perceptible. Warning signs notifying that the area is subject to mining subsidence movements would be considered prudent in the unlikely event of a large crack forming.

The trig station on Mt Howard is likely to be affected by mining subsidence when Longwall A2 is mined. It is understood that the Department of Lands and Survey have been notified of this potential.

There may be some tensile cracking apparent on extensive bare surfaces such as access tracks. Such cracking is likely to be concentrated near the top of steep slopes but is not expected to substantially alter the character of the tracks recognising that they are bush tracks and suitable only for four-wheel drive vehicles and other recreational vehicles.

In the event that the subsidence is greater than anticipated, it is not expected that there would be any significant change in the nature of the impacts experienced although the degree may be more.

A program of subsidence monitoring and sub-surface monitoring is recommended to better understand the effects on surface subsidence of mining a 6.5m high seam section.

In our view, the impacts on the surface of the proposed coal mining subsidence are not likely to be substantially different to those described in the EIS.

10. REFERENCES

Holla, L. 1988, "Effects of underground mining on domestic structures – prediction versus performance". Proceedings of the 5th Australia-New Zealand Conference on Geomechanics, Institution of Engineers Australia, Canberra, August 1988, pp 351-355.

Holla, L. 1985, "The minimisation of surface subsidence by design of mine workings". Proceedings of Australasian Institute of Mining and Metallurgy, Vol 290, No.6, September 1985.

Holla, L. & Barclay, E. 2000, "Mine subsidence in the Southern Coalfield, NSW, Australia", Published by NSW Department of Mineral Resources, ISBN 0 7313 9225 6.

Kapp, W.A. 1985 "Mine subsidence in the Newcastle district, NSW". Transactions of the Institution of Engineers, Australia, Civil Engineering. Vol CE27, No 4, October, pp331-340.

Mills, K.W. 1998, "Subsidence mechanisms about longwall panels". Proceedings of the International Conference on Geomechanics/Ground Control in Mining and Underground Construction, 14-17 July Wollongong, Australia ed Aziz N.I. and Indraratna B. pp. 745-756.

Waddington, A.A. 2002 "Management Information Handbook – The Undermining of Cliffs, Gorges and River Systems" Version 1 Sept 2002.