REPORT: INDEPENDENT REVIEW OF SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

ASHTON COAL OPERATIONS LIMITED:

Upper Liddell Seam - Longwalls 1 to 8

An Independent Review of Mine Subsidence Predictions and Impact Assessments

DOCUMENT REGISTER

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Report produced for:- Support an Extraction Plan for the proposed mining of Longwalls 1 to 8 in the Upper Liddell Seam for the Ashton Coal Project.

Discussions in this report have been based on reviews of the following reports;

- Strata Control Technology Report, "*Ashton Multi-Seam Subsidence Predictions 3D Extrapolations"*, ASH3852, Yvette Lewis, 24th October 2011.
- Strata Control Technology Report, "*Subsidence Assessment for Upper Liddell Seam, Longwalls* 1 to 8 *Extraction Plan"*, ASH3657, Draft for Consideration, Ken Mills, 4th December 2011.

Background reports available at *www.minesubsidence.com*:-

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

CONTENTS

Figure numbers are prefixed by the number of the chapter in which they are presented.

1.0 EXECUTIVE SUMMARY

Mine Subsidence Engineering Consultations Pty Ltd (MSEC) has been engaged by Ashton Coal Operations Pty Ltd (ACOL) to review the various mine subsidence ground movement predictions and the mine subsidence impact assessments that have been provided by SCT Operations Pty Ltd (SCT) for the Ashton Coal Project.

MSEC concluded that the mine subsidence ground movement predictions provided by the SCT reports provide a reasonable range of the likely ground movement that can be used to manage the likely subsidence impacts at the Ashton Coal Project and the subsidence impact assessments and consequences that are provided by SCT are considered to be appropriate and reasonable assessments of the likely impacts at the Ashton Coal Project.

The Ashton Coal Project is located near Camberwell approximately 14 kilometres north-west of Singleton in the Hunter Valley, New South Wales, and is adjacent to the several open-cut mines and several other underground mines. Planning approval for the Ashton Coal Project was received from the Minister for Planning on the 11th October 2002. The overall project includes an open cut coal mine, an underground coal mine, a coal handling and preparation plant and a rail siding.

The Ashton Coal Project operation is an unincorporated Joint-Venture between Yancoal Australia Ltd (90%) and Itochu Corporation of Japan (10%). Yancoal Australia Ltd acquired the interest in the Ashton Open-Cut and Underground Coal Mines effective from December 2009 through its purchase of Felix Resources Pty Ltd. Yancoal Australia Ltd is the operator of these mines and manages the Joint-Venture.

Ashton Coal Operations Pty Ltd (ACOL) is proposing to mine longwall panels in four seams, i.e. the Pikes Gully Seam (PG), Upper Liddell Seam (ULD), Upper Lower Liddell Seam (ULLD) and Lower Barrett (LB) Seam at this site.

These Permian aged coal reserves are part of the Hunter Coalfield of the Northern Sydney Basin. These coal seams are located within the Foybrook Formation of the Vane Sub-Group, which is part of the Whittingham Coal Measures and is the basal coal-bearing sequence of the Singleton Supergroup. These four target seams dip at approximately 5 degrees to the west over the mine area. The target coal seams are separated by interburden sediments which comprise sandstone, siltstone, conglomerate, mudstone and shale, as well as occasional minor coal seams.

The majority of the surface area affected by mine subsidence is owned by ACOL. There is approximately 60 metres of natural topographic variation over the mine area. The overburden depth range for the PG Seam over the mine area is approximately 40 metres to180 metres. For the ULD Seam the overburden depth ranges approximately 80 metres and 220 metres. The ULLD and LB Seams have overburden depths approximately ranging between 100 metres and 260 metres and between 150 metres and 290 metres, respectively.

The extracted heights for the PG Seam vary between a minimum height of 2.2 metres and a maximum height of 3 metres. Similarly, the proposed extraction heights for the ULD and the LB Seams also range between 2.2 metres and 3 metres. However, the proposed extraction heights for the ULLD Seam vary between a minimum extraction height of 2.2 metres and a maximum extraction height of 2.8 metres.

Longwall mining has occurred in seven of the eight proposed longwalls in the PG Seam. In accordance with the development consent, ACOL is now preparing an Extraction Plan (EP) to address the proposed extraction of Longwalls 1 to 8 in the ULD Seam.

ACOL propose to adopt an offset geometry whereby the longwall panels in the ULD Seam are setback to the west by 80 metres relative to the previously mined longwall panels in the PG Seam. This staggered layout arrangement is now common in supercritical width multi-seam longwall operations to to assist in subsidence outcomes and to optimise mining conditions in the second seam mined.

ACOL commissioned SCT Operations Pty Ltd (SCT) to undertake the mine subsidence ground movement predictions and an assessment of the likely mine subsidence impacts as a result of the proposed mining for submission with the EP. Discussions in this MSEC review report are based on the reviews of the following two SCT reports;

- "*Ashton Multi-Seam Subsidence Predictions 3D Extrapolations"*, SCT ASH3852, Yvette Lewis, 24th October 2011.
- "*Subsidence Assessment for Upper Liddell Seam, Longwalls* 1 to 8 *Extraction Plan"*, SCT ASH3657, Draft for Consideration, Ken Mills, 4th December 2011.

These SCT reports provide;

- predicted subsidence ground movements using both a numerical modelling approach and an empirical approach that is based on the latest available published data,
- descriptions of the significant natural and built surface features over and near the proposed longwalls,
- assessed potential subsidence impacts,
- identified where further subsidence monitoring may be required, and
- discussed the need for possible remedial work.

As longwall mining in the PG Seam is ongoing in the area of this assessment and, even though subsidence associated with mining in the PG Seam is not the focus of this assessment, the cumulative effects of mining both the PG and the ULD seams have been taken into account where it is relevant. The SCT predictions and assessments recognised the challenges of estimating subsidence ground movements in a multi-seam environment because of the limited history of multi-seam subsidence experience in NSW and Australia.

The maximum subsidence predicted using the SCT caving numerical model, (ASH3852), after the completion of extraction of the proposed PG and ULD Seams, ranges from 2.2 metres to 3 metres. Whilst the maximum subsidence predicted, after the completion of extraction of the proposed PG and ULD Seams, using a more conservative empirical approach, (ASH3657), is expected to be typically less than 4.0 metres but would range up to 4.5 metres where the nominal ULD Seam extraction thickness is greater and where destabilisation of the PG Seam pillars is expected to cause additional subsidence from the PG Seam.

The empirical subsidence estimates in the SCT Report ASH3657 are purposefully greater than the SCT numerical model results and were also greater than the previous maximum subsidence estimates that were provided in the EIS (Holt, 2001) for the proposed mining within the PG and ULD Seams, i.e. the EIS presented a maximum subsidence of 2.7 metres to 3.4 metres and greater than the 2009 SCT Report ASH3584 which provided a maximum subsidence of 3.7 metres. This increase in predicted subsidence is partly due to differences in mine layout geometry that have occurred and is partly due to an increase in the seam thickness that is proposed to be mined. But, the increase is primarily because a more conservative approach has been taken by SCT in this current assessment, (ASH3657), in order to provide conservative ground movements for assessing the potential subsidence impacts and determining subsidence management measures in the light of the conclusions presented in a paper published by Li et al (2010) on predicting multi-seam subsidence.

In order to provide an independent peer review of the subsidence predictions and impact assessments that were provided by SCT, MSEC has;

- reviewed the observed subsidence over longwalls at neighbouring underground coal mines and compared the observations with the MSEC predicted subsidence ground movements. These comparisons indicate that the standard MSEC Incremental Profile Method (IPM) provides reasonable subsidence predictions for the top seam at the Ashton Coal Project (the PG Seam).
- prepared independent predictions of subsidence for the proposed Ashton Coal Project Longwalls 1 to 8 in the PG Seam at Ashton Coal Project using the standard MSEC IPM model. These predictions compared well with the available observed data and the SCT subsidence predictions.
- prepared independent predictions of subsidence over the multi-seam longwalls at Ashton for the lower ULD Seam, using the Incremental Profile Method (IPM) which has been calibrated for multi-seam conditions based on all the available multi-seam longwall data.
- obtained and reviewed recent monitoring data from various multi-seam monitoring cases to assist future predictions of multi-seam subsidence.
- compared the subsidence predictions that were presented in the two SCT reports with the MSEC predictions, and
- reviewed the subsidence impacts and consequences presented in the SCT report (ASH3657).

It should be noted that it is difficult to predict these multi-seam ground movements accurately until more cases of multi-seam mining with longwalls under longwalls have been monitored in Australia. After the first few longwalls have been extracted at Ashton Coal Project in the ULD Seam, then, the multi-seam predictions for the later longwalls can be further calibrated and more accurate predictions can be provided for these later ULD longwalls.

On reviewing the available multi-seam longwall on longwall monitoring cases, MSEC agrees with the range of multi-seam mine subsidence predictions that have been provided by SCT for the extraction of the PG and ULD Seams at the Ashton Project. The actual monitored maximum subsidence value after the extraction of both the PG and ULD Seams at the Ashton Coal Project may be closer to the higher value of 4.5 metres than the lower value 3 metres, but, these higher empirical predictions, which are based on very conservative assumptions, are unlikely to be exceeded and these values are considered to provide the best basis to manage the future possible impacts. It is concluded that the mine subsidence ground movement predictions in these two SCT report provide a reasonable range to manage the likely subsidence impacts at the Ashton Coal Project and the SCT subsidence impact assessments and consequences are considered to be appropriate and reasonable assessments of the likely impacts at the Ashton Coal Project.

2.0 BACKGROUND AND INTRODUCTION

Fig. 2.1 shows the range of surface levels (m AHD) over the Ashton Coal Project and the proposed Ashton longwalls in the PG and ULD Seams based on detailed geological and mine layout files that were supplied by ACOL in 2008. This figure also shows the location of the Hunter River, Bowmans Creek, Glennies Creek, New England Highway and the Main Northern Railway in relation to these longwalls.

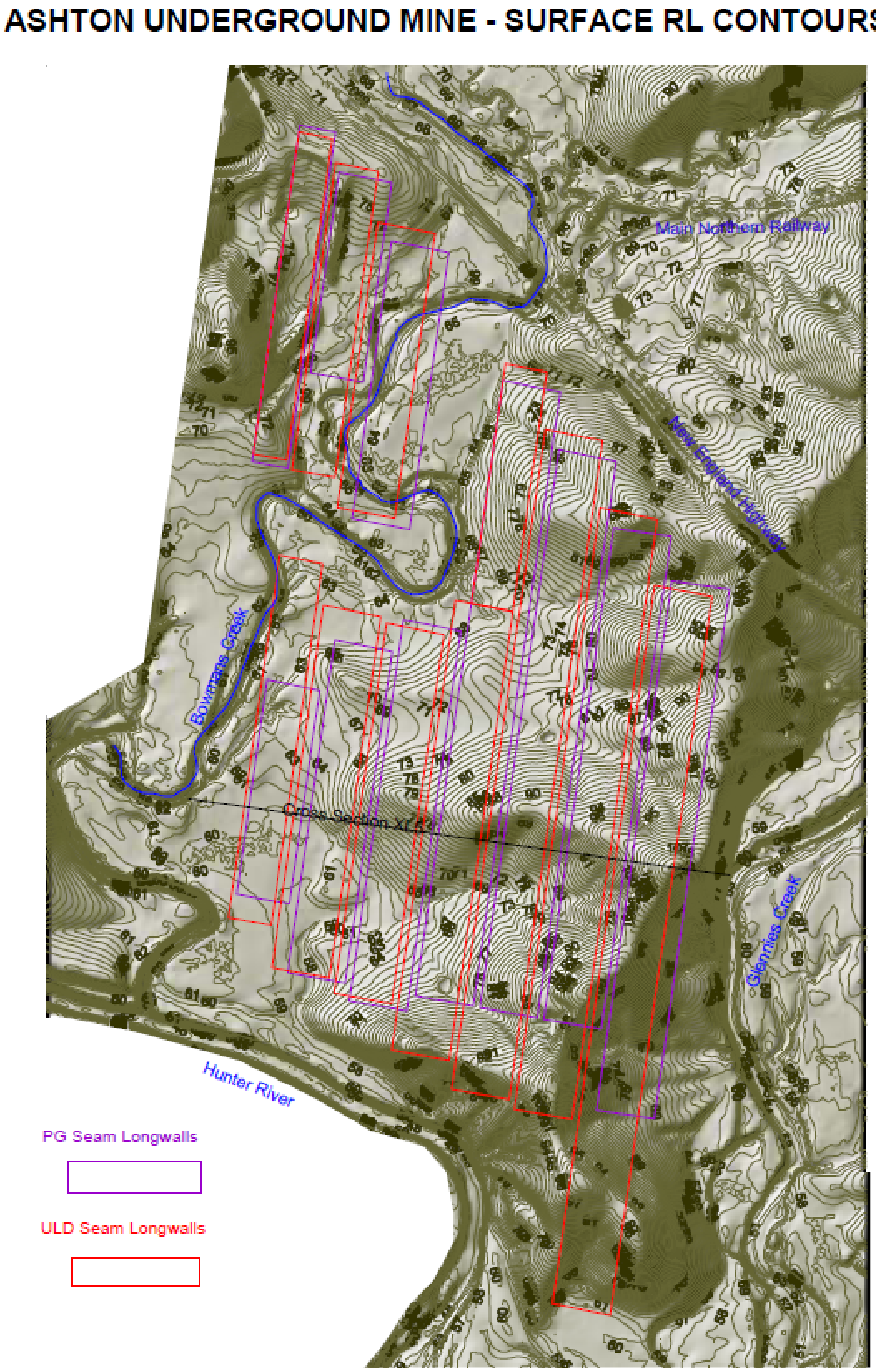

Fig. 2.1 Surface Level Contours over the Ashton Coal Project

Fig. 2.2 shows the range of depths of cover (metres) above the PG Seam and the proposed Ashton longwalls in the PG Seam based on detailed geological and mine layout files that were supplied by ACOL in 2008.

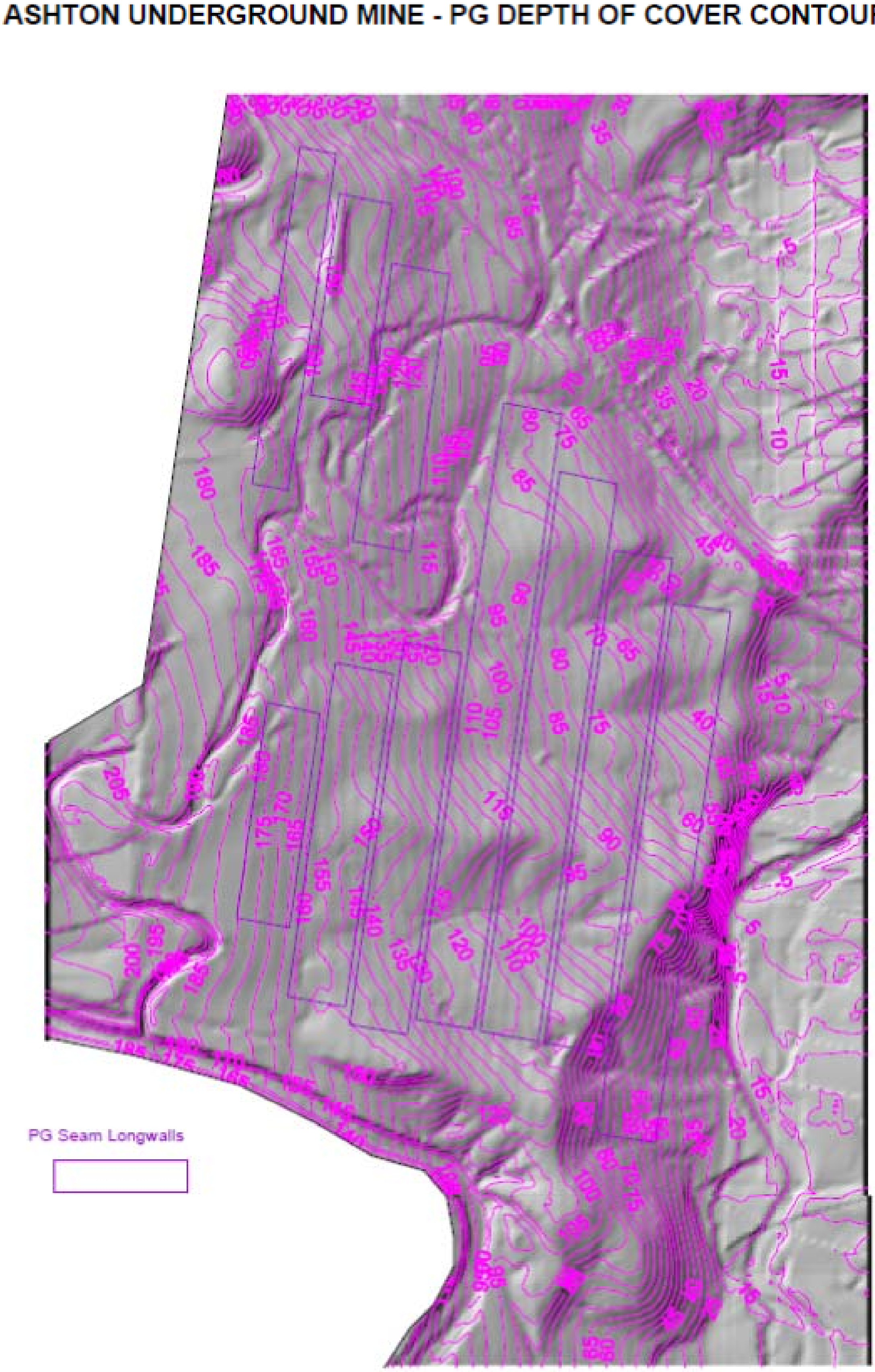

Fig. 2.2 PG Seam Depth of Cover Contours over the Ashton Coal Project

Fig. 2.3 shows the variation in seam thicknesses in the PG Seam and the proposed Ashton PG longwalls based on detailed geological and mine layout files that were supplied by ACOL in 2008. It can be noted that the seam thickness across LW1 at the cross section XL5 varies from 2.8 metres to 3 metres.

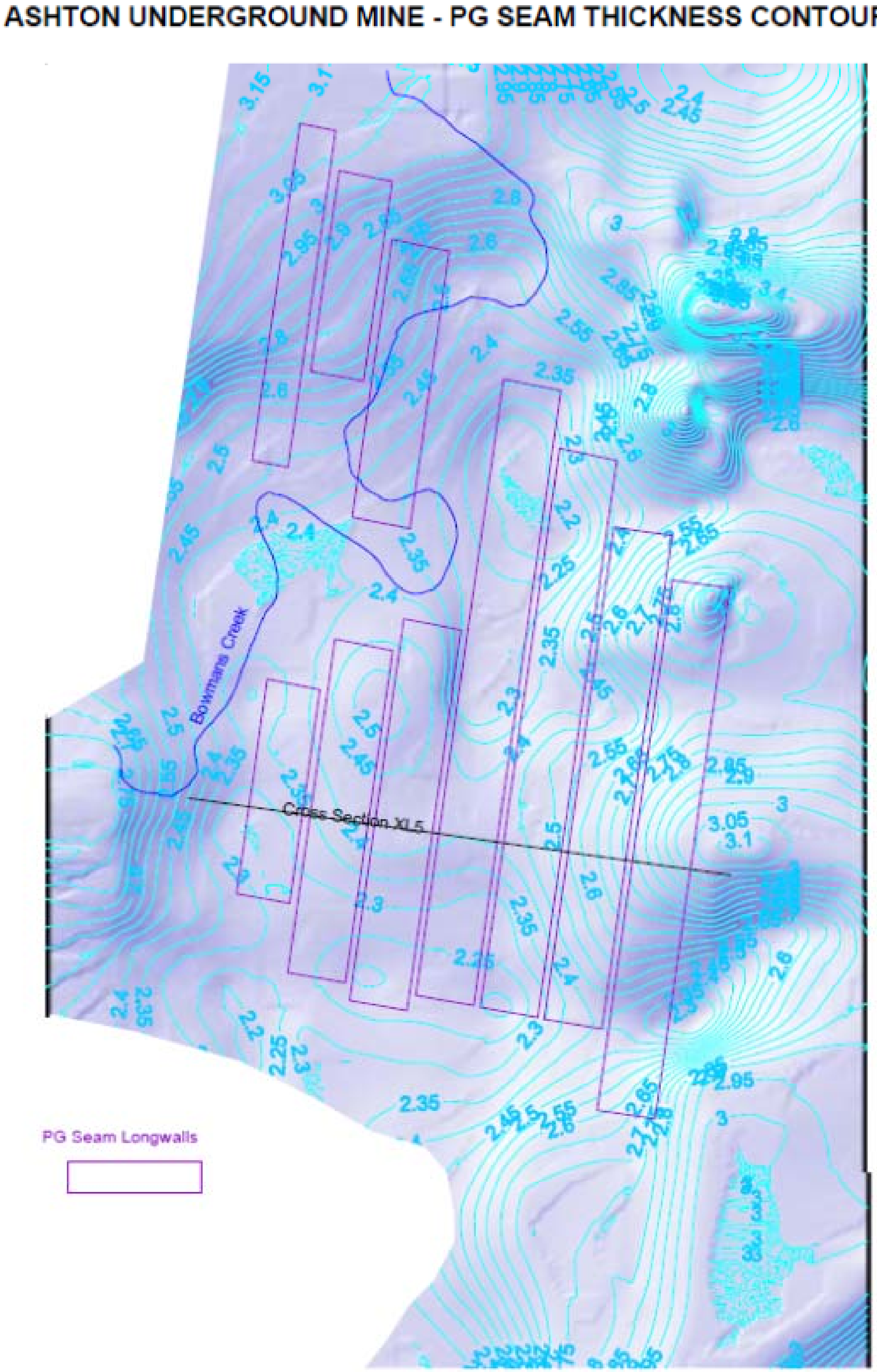

Fig. 2.3 PG Seam Thickness Contours over the Ashton Coal Project

Fig. 2.4 shows the variations in the interburden thickness between the PG and ULD Seams and the proposed Ashton PG and ULD longwalls based on detailed geological and mine layout files that were supplied by ACOL in 2008. It can be noted that the interburden thickness varies approximately from 20 metres to 50 metres.

Fig. 2.4 PG to ULD Seam Interburden Thickness Contours over the Ashton Coal Project

Fig. 2.5 shows the variations in ULD seam thicknesses over the Ashton Coal Project and the proposed Ashton longwalls in the ULD Seam based on detailed geological and mine layout files that were supplied by ACOL in 2008.

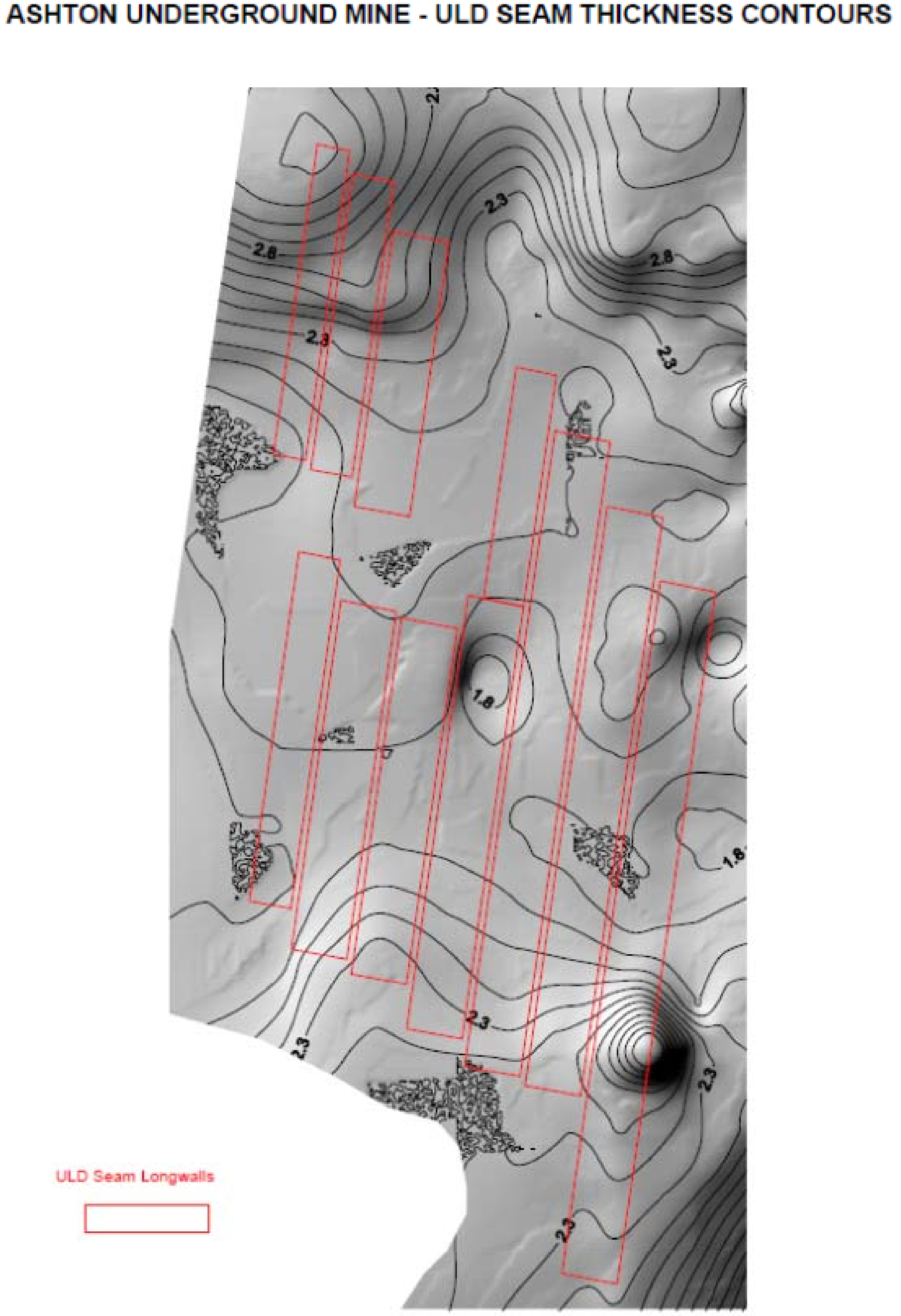

Fig. 2.5 ULD Seam Thickness Contours over the Ashton Coal Project

3.0 PREDICTIONS OF SINGLE-SEAM MINE SUBSIDENCE PROFILES AND CONTOURS OVER THE ASHTON COAL PROJECT PG SEAM LONGWALLS

The following plot, Fig. 3.1, shows the preliminary predicted subsidence contours using our MSEC standard Newcastle Coalfield IPM model after extraction of all the proposed PG Seam Longwalls (i.e. single-seam mining conditions). The maximum predicted subsidence using this model after extraction of all the Ashton PG Seam Longwalls was 1.9 metres where the available averaged seam thickness was advised to be 2.9 metres. No geological adjustments for strong channels have been made to the standard IPM prediction model at this initial stage.

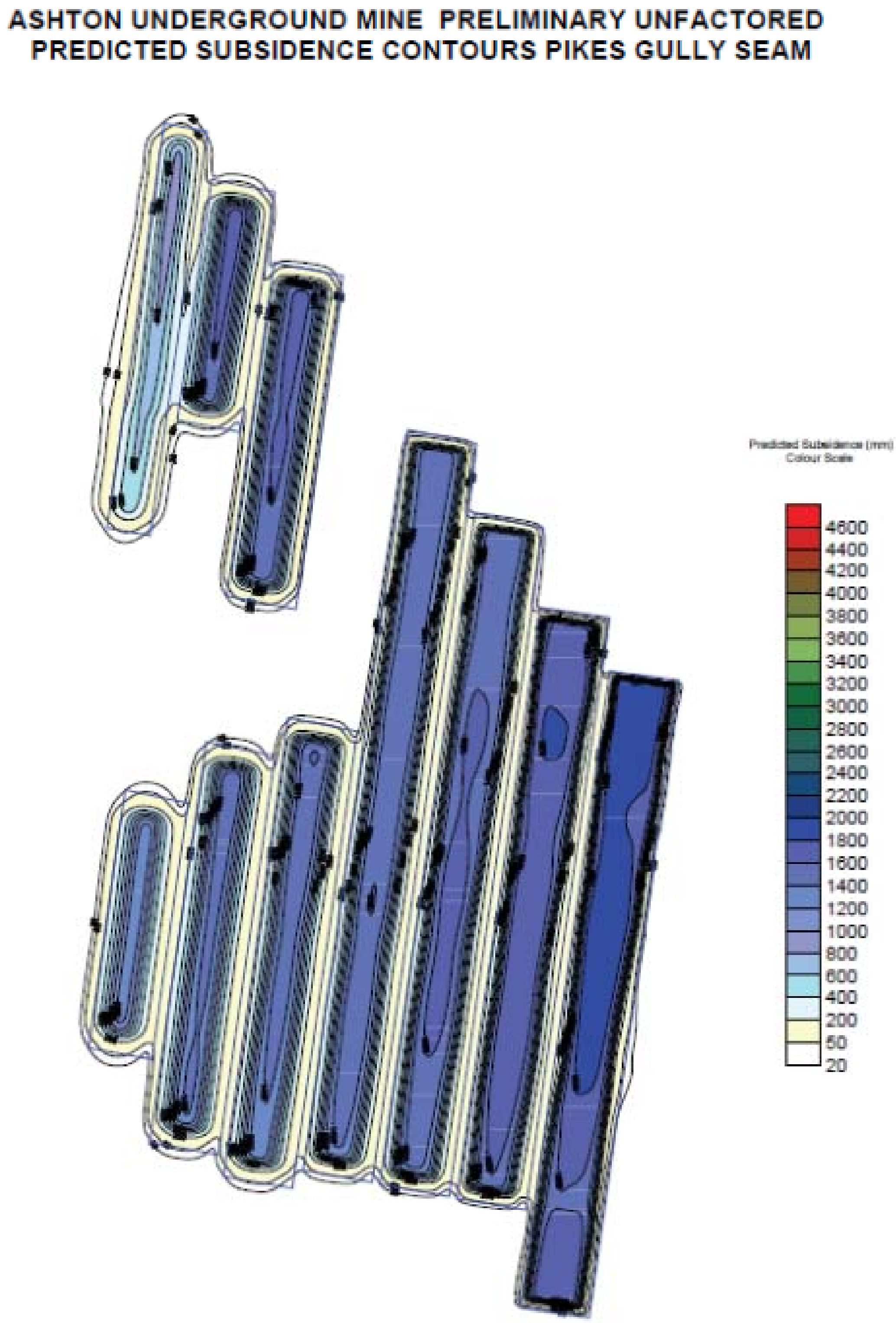

Fig. 3.1 MSEC Predicted Subsidence Contours after the Extraction of All PG Seam Longwalls

The following plot, Fig. 3.2, shows the predicted subsidence contours after the extraction of the PG Seam Longwalls as presented in the SCT numerical modelling Report ASH3852. The maximum predicted subsidence shown in this SCT Report (ASH3852) after the extraction of the PG Seam Longwalls was 1.6 metres.

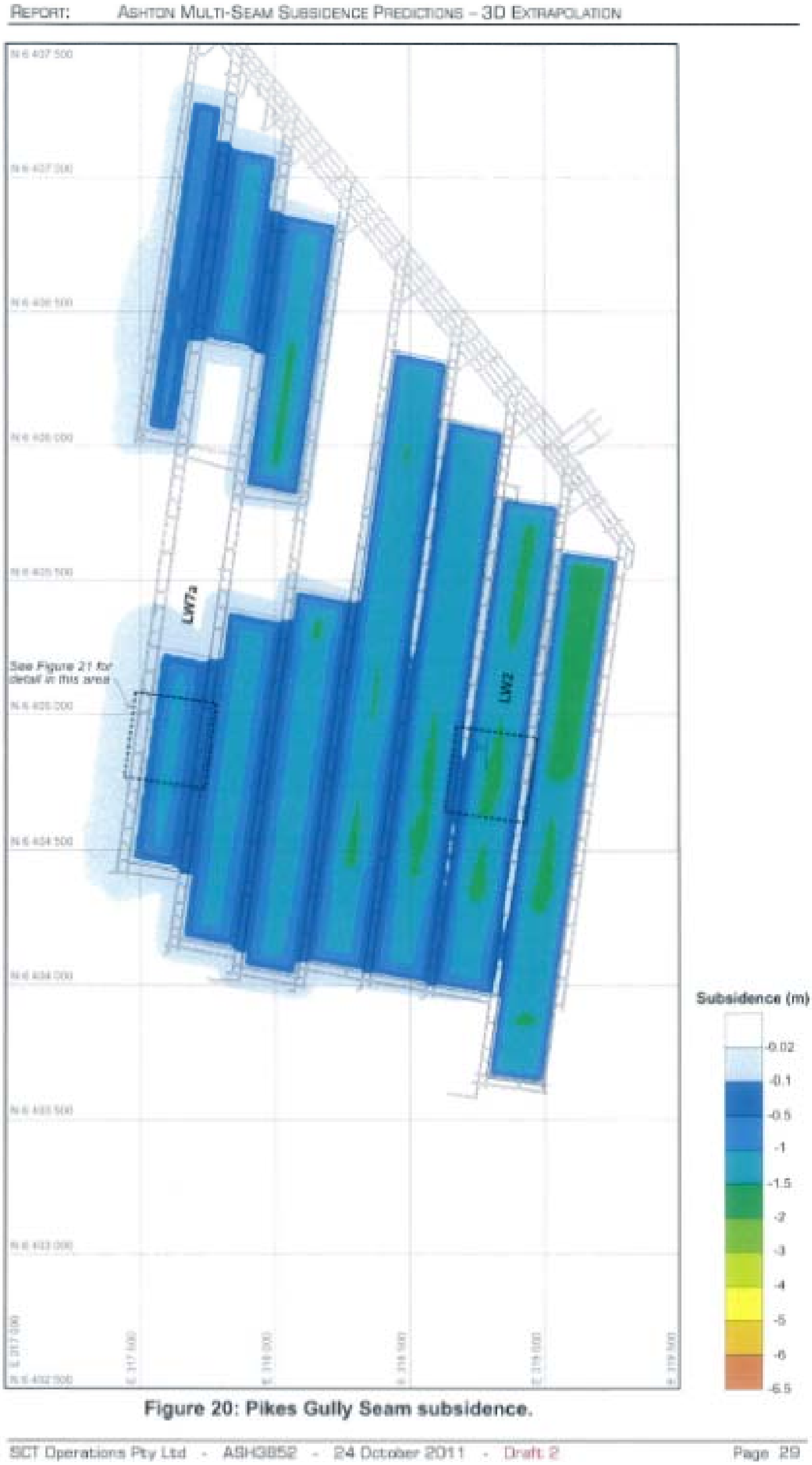

Fig. 3.2 SCT Predicted Subsidence Contours after the Extraction of the PG Seam (ASH3852)

The following plot, Fig. 3.3, shows the extent of longwall extraction to date in the PG Seam and the locations of the available subsidence monitoring lines at the Ashton Coal Project.

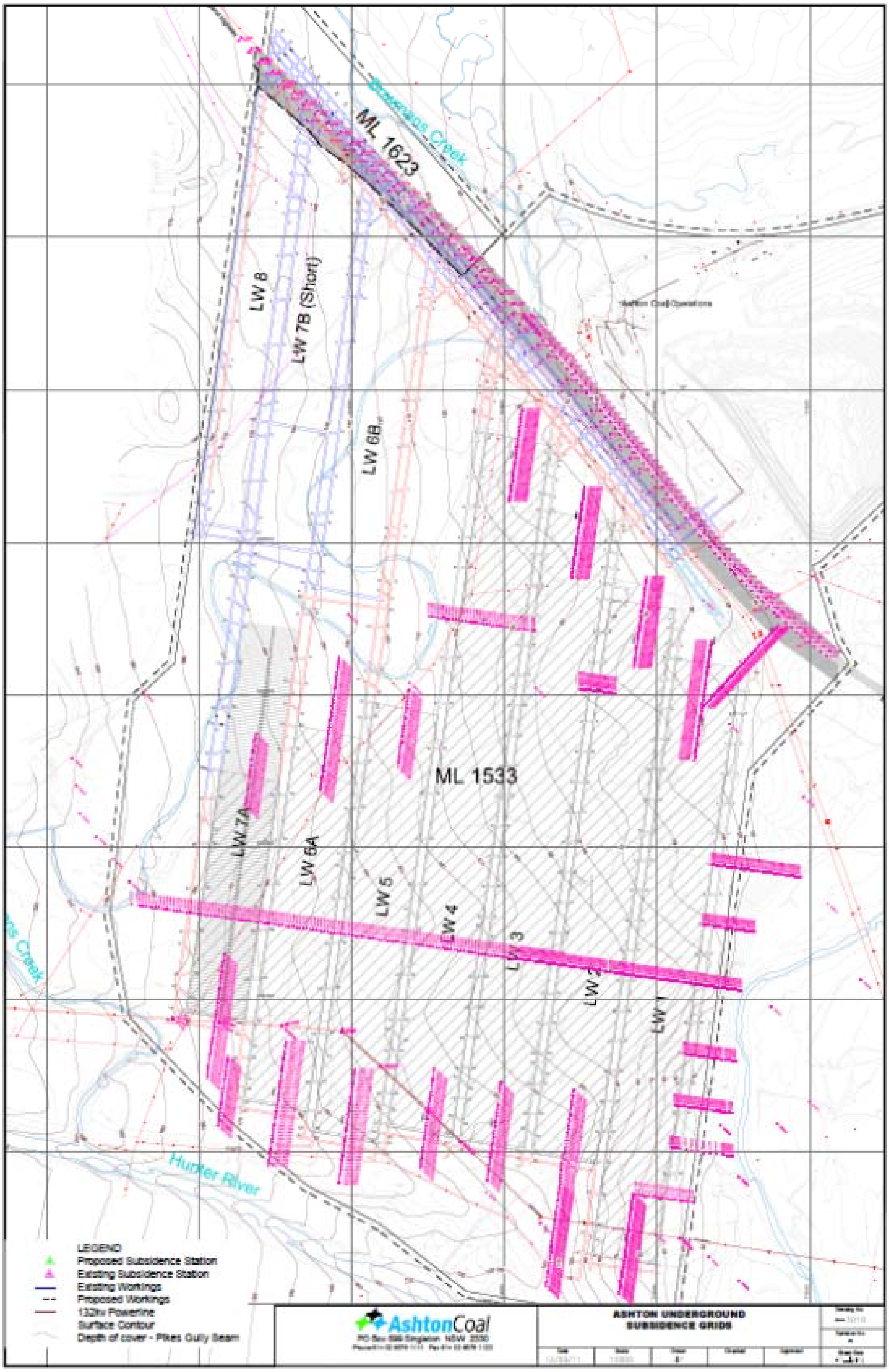

Fig. 3.3 Locations of Subsidence Monitoring Lines over the Ashton Coal Project

The following plot, Fig. 3.4, shows the observed subsidence ground movements after the extraction of the full available PG Seam, as provided by ACOL, along the main cross section, called the XL5 monitoring line which runs across Longwalls 1 to 7A, (the location of which is shown in Fig. 3.3). Fig. 3.4 also shows the predicted preliminary subsidence assuming the full extraction of the PG Seam Longwalls using the standard MSEC IPM model for single-seams in the Newcastle Coalfield with no specific geological adjustments.

Fig. 3.4 also shows the variations in surface levels, seam floor levels and available seam thicknesses along this XL5 monitoring line.

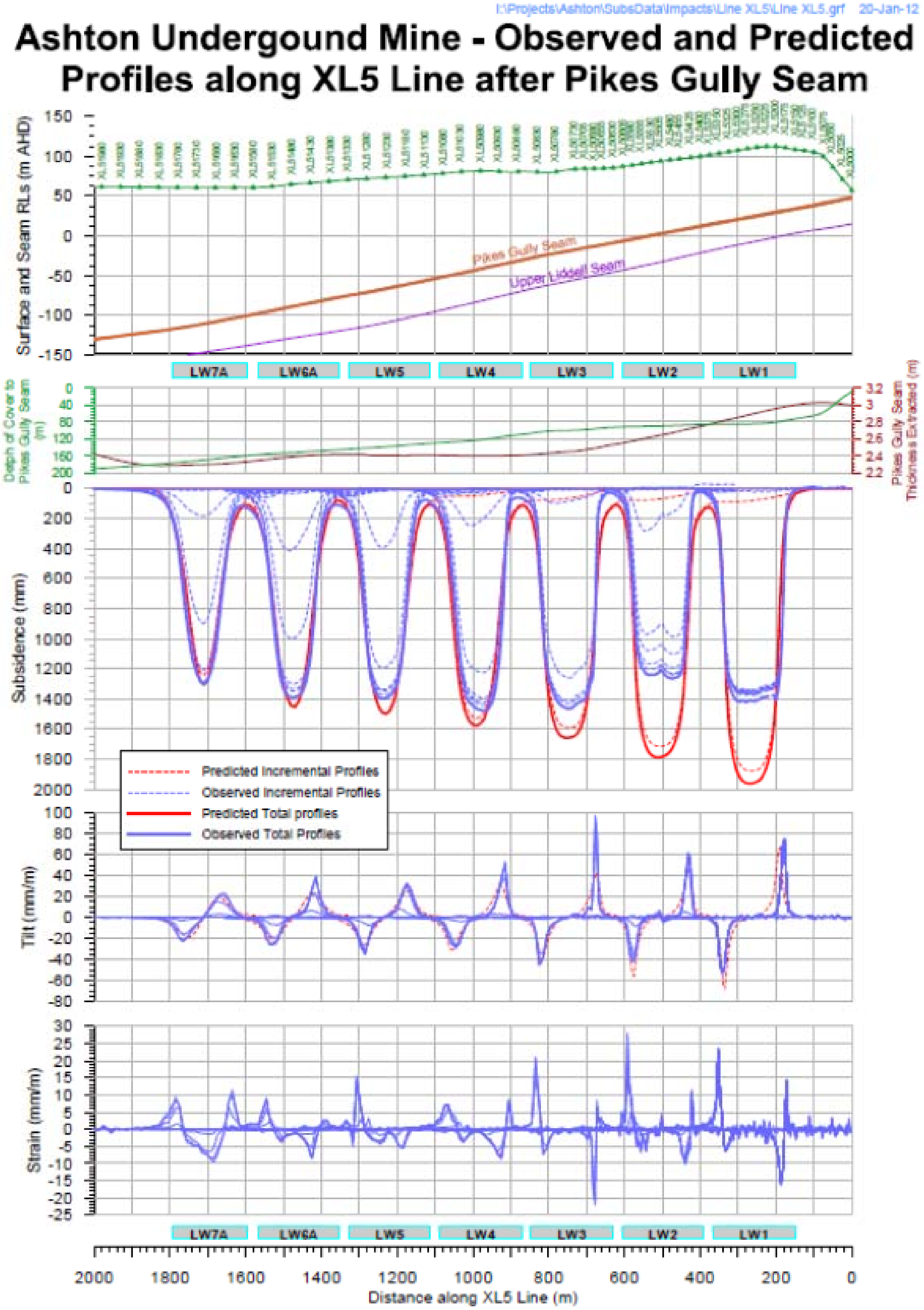

Fig. 3.4 MSEC Predicted Subsidence Profiles along Cross Section XL5 after the extraction of the PG Seam Longwalls 1 to 7A

As shown in Fig. 3.4, the preliminary MSEC IPM model results over Longwalls 4 to 7 reasonably matched the observed subsidence, however, the preliminary IPM model appears to over predict subsidence over the first three longwalls. Hence a review was undertaken to confirm the actual seam height that was extracted in these first three longwalls.

The averaged seam thickness across LW1 as used in the MSEC IPM model was 2.9 metres, which was based on PG Seam data provided by ACOL to MSEC in 2008, however, comments were provided by Ken Mills of SCT indicating that the mined seam heights over the first three longwall panels could have been less than the **available** seam thicknesses. So information was sought on the actual seam heights mined over Longwalls 1 to 3. Unfortunately though ACOL advised that details on the actual seam heights mined are readily available since Longwall 5, no readily available reports were available for the earlier Longwalls. Hence, past Ashton Coal Project subsidence prediction reports have been reviewed for data on the seam heights within the Longwalls 1 to 3 in the PG Seam.

The initial EIS report, prepared in October 2001 by Graham Holt titled "Ashton Coal Project - Assessment of the Impact of Subsidence from Longwall Mining" reports, advised the mining height for Longwall 1 in the PG Seam was 2.6 metres.

In the February 2008, SCT Report ASH3342a, titled "*Review of Longwall 1 Subsidence Monitoring and Comparison with Predictions*" Ken Mills provided the following advice regarding the mined PG Seam thickness and a comparison of the observed and predicted levels of subsidence over Longwall 1;

> "*The seam section mined ranges along the length of Longwall 1 from 2.6m at the start to 2.7m at the northern end of the panel. The seam dips to the southwest at a grade of up to about 1 in 10. The overburden depth ranges from 65m at the start of Longwall 1 to approximately 85m midway along the panel before decreasing to 35m at the northern end*."
>
> *"The magnitude of the final subsidence is less than would be expected. At the start of Longwall 1, the maximum subsidence is approximately 1.2m for a nominal seam height extracted of 2.6m, giving a ratio of S_{max} to seam thickness of 46%, a value that is much lower than the 55-65% typically observed at other sites. At the northern end of Longwall 1, the ratio increases to 53% of seam thickness."*
>
> *"Our review indicates that subsidence behaviour above Longwall 1 at Ashton is consistent with supercritical subsidence behaviour, Subsidence movements have been less than the maximum predicted except for the tensile strains at the start of Longwall 1, which were 49mm/m compared to the 42mm/m predicted, The predicted and measured subsidence values are summarised as follows:"*
>
> "

	Maximum Predicted	Maximum Measured	
North End of LW1		**CL2**	**XL8**
Subsidence (mm)	1800	1528	1500
Tilt (mm/m)	244	100	103
Horizontal Movement (mm)	500+	476	500
Tensile strain (mm/m)	73	40	15
Compressive strain (mm/m)	98	28	27
Remainder of LW1		**CL1**	**XL5**
Subsidence (mm)	1700	1318	1377
Tilt (mm/m)	141	60	75
Horizontal Movement (mm)	300-500	480	384
Tensile strain (mm/m)	42	49	24
Compressive strain (mm/m)	56	23	16

The data above supports the view that the extracted PG Seam thickness near the XL5 cross line was 2.65 metres.

The following discussions that were presented in the Ashton PG Longwall 3 End of Panel report on this issue of subsidence predictions over the first three longwalls (Mills SCT Report ASH3485 - Review of Subsidence Monitoring and Comparison with Predictions of Longwall 2 and Longwall 3 at the Completion of Longwall 3 2009). This End of Panel Report on the extraction of PG Longwall 3 was prepared by SCT for ACOL and it also advises that less than the available seam height was extracted in these first three longwalls.

> *"Maximum subsidence has been less than the maximum predicted in the EIS."*

"XL5 is the main cross-line over all the longwall panels. The line is located midway along the panels. The overburden depth ranges from 80-130m across Longwalls 1-3."

"Maximum subsidence measured in the centre of Longwall 1 is panel is 1436mm or 54% of a nominal 2.65m seam section mined, a 2% increase in the maximum subsidence measured at the completion of Longwall 1."

"Maximum subsidence measured in the centre of Longwall 2 was 1 253mm at the completion of Longwall 2 and 1 266mm at the completion of Longwall 3, or 53% of a nominal 2.4m mining section."

"Maximum subsidence over Longwall 3 was 1429mm or 57% of a nominal 2.5m mining section."

"The magnitude of subsidence movements observed appears to be generally less than predicted magnitudes and in the range 50-60% of seam thickness.

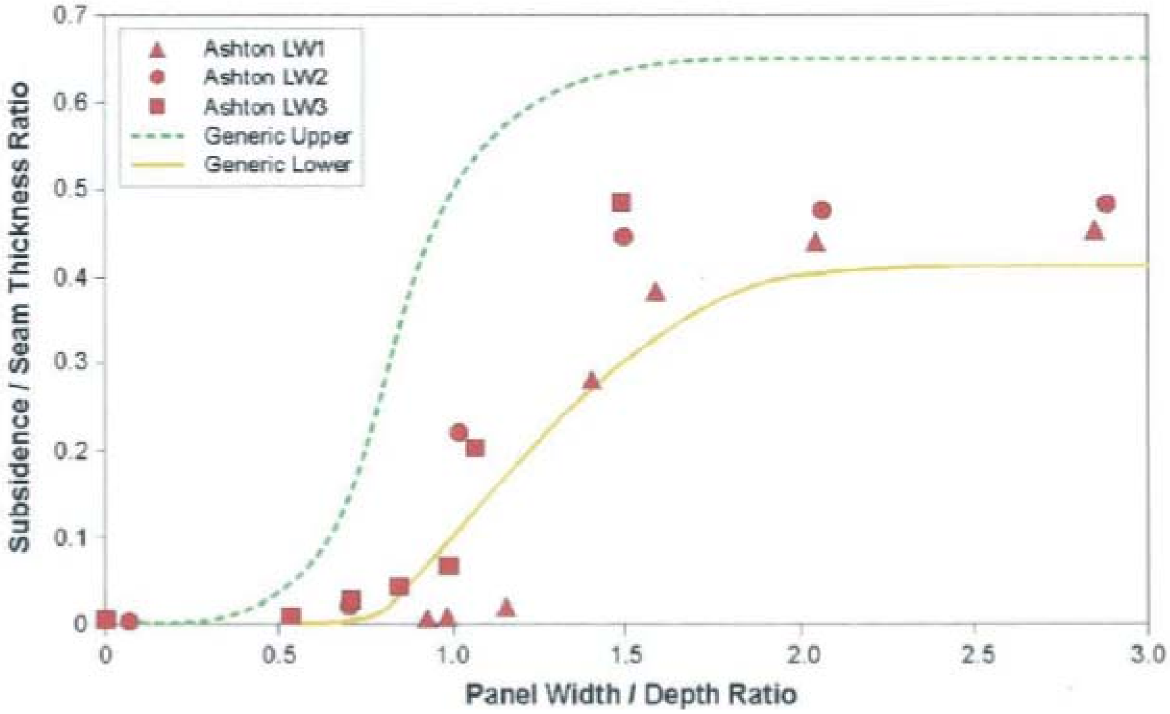

Fig. 3.5 Plot showing Maximum Observed Subsidence per Longwall along Cross Section XL5 for each of the PG Seam Longwalls 1 to 3 (From SCT ASH3485)

"There is some variability from panel to panel that may be a consequence of overburden caving and bulking characteristics from panel to panel and variations in the seam thickness mined."

In the SCT Report ASH3852 titled "Ashton Multi-Seam Subsidence Predictions 3D Extrapolation" Yvette Lewis advised;

"The seam extraction heights (PG) as outlined by Ashton personnel include a maximum extraction height of 3.0m and a minimum extraction height of 2.2m. Where the seam thickness is between this maximum and minimum, the seam thickness was adopted as the extraction height."

"The Pikes Gully seam thickness is generally within the maximum 3m and minimum 2.2m extraction heights, except for the far north and southern extents of the mine plan where the seam thickness is less than the minimum 2.2m extraction height. The Pikes Gully Seam extraction height contours for the seam are presented in Figure 3" (reproduced as Fig. 3.6 see below).

It is noted that this Fig. 3.6 in SCT Report ASH3852, which was based on a file provided by ACOL called "PGTHICK.XYZ", shows the PG Seam thicknesses near where the XL5 monitoring line crosses over Longwall 1 ranging from 2.3 metres to 2.8 metres, which is different the level of 2.65 metres indicated in SCT Report ASH3342a and less than the seam thickness of 2.9 metres as used MSEC Incremental Profile Method modelling.

It is therefore concluded that the PG Seam thicknesses that was extracted over Longwalls 1 near the XL5 cross line was less than those used in the preliminary IPM subsidence modelling. If the smaller mined seam thickness of 2.65 metres had been modelled, then the predicted levels of subsidence using the standard IPM modelling, due to the extraction of the PG Seam, would have been (1.9 * 2.65/2.9 = 1.7m), which is similar to the predicted subsidence values in the SCT Report ASH3342a and slightly more than the predicted levels of subsidence of 1.6 metres as presented in the SCT Report ASH3852. As discussed all of these predicted levels of subsidence are greater than the level of subsidence of 1377 mm that was observed after the extraction of Longwall 1.

Based on these MSEC subsidence reviews, including the preliminary IPM subsidence model and the observed ground monitoring data, it is therefore concluded that the single-seam mine subsidence contours that were predicted by the SCT Report ASH3852 are reasonable, (Fig. 3.2).

REPORT: ASHTON MULTI-SEAM SUBSIDENCE PREDICTIONS – 3D EXTRAPOLATION

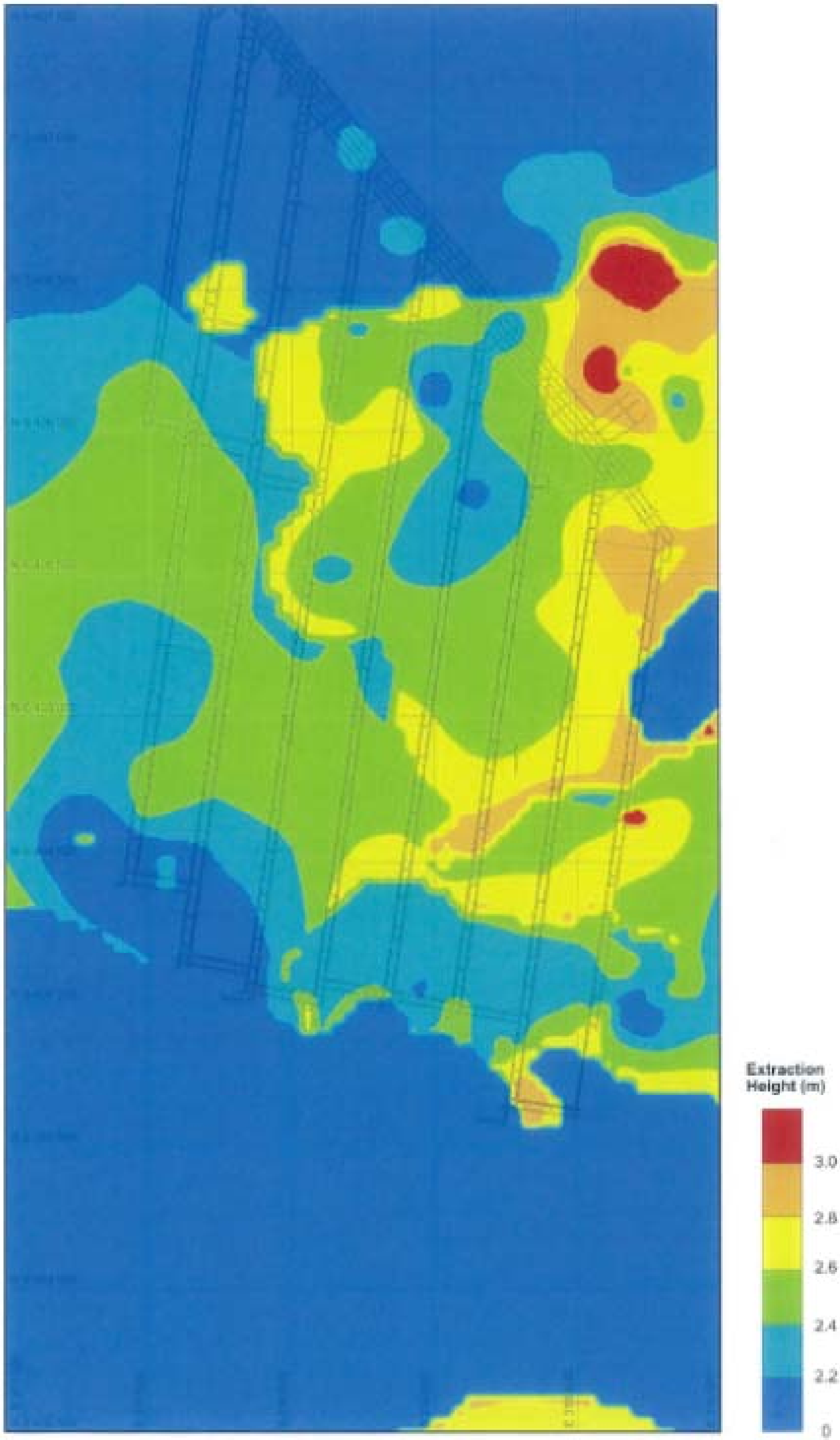

Figure 3: Pikes Gully Seam extraction height.

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Fig. 3.6 PG Seam Extraction Height Contours

4.0 PREDICTIONS OF MULTI-SEAM MINE SUBSIDENCE CONTOURS OVER THE ASHTON COAL PROJECT ULD SEAM LONGWALLS

The following plot, Fig. 4.1, shows the preliminary predicted incremental subsidence contours, modelled using the MSEC IPM model for multi-seam extraction, due to the extraction of the proposed Ashton ULD Longwalls (i.e. additional subsidence due to the ULD Seam only). The MSEC IPM multi-seam model is an empirical method based predominantly on the standard MSEC IPM model for the Newcastle Coalfield, with the magnitudes and shapes of the predicted subsidence profiles calibrated using the available multi-seam empirical data. No geological adjustments were undertaken for strong channels at this stage.

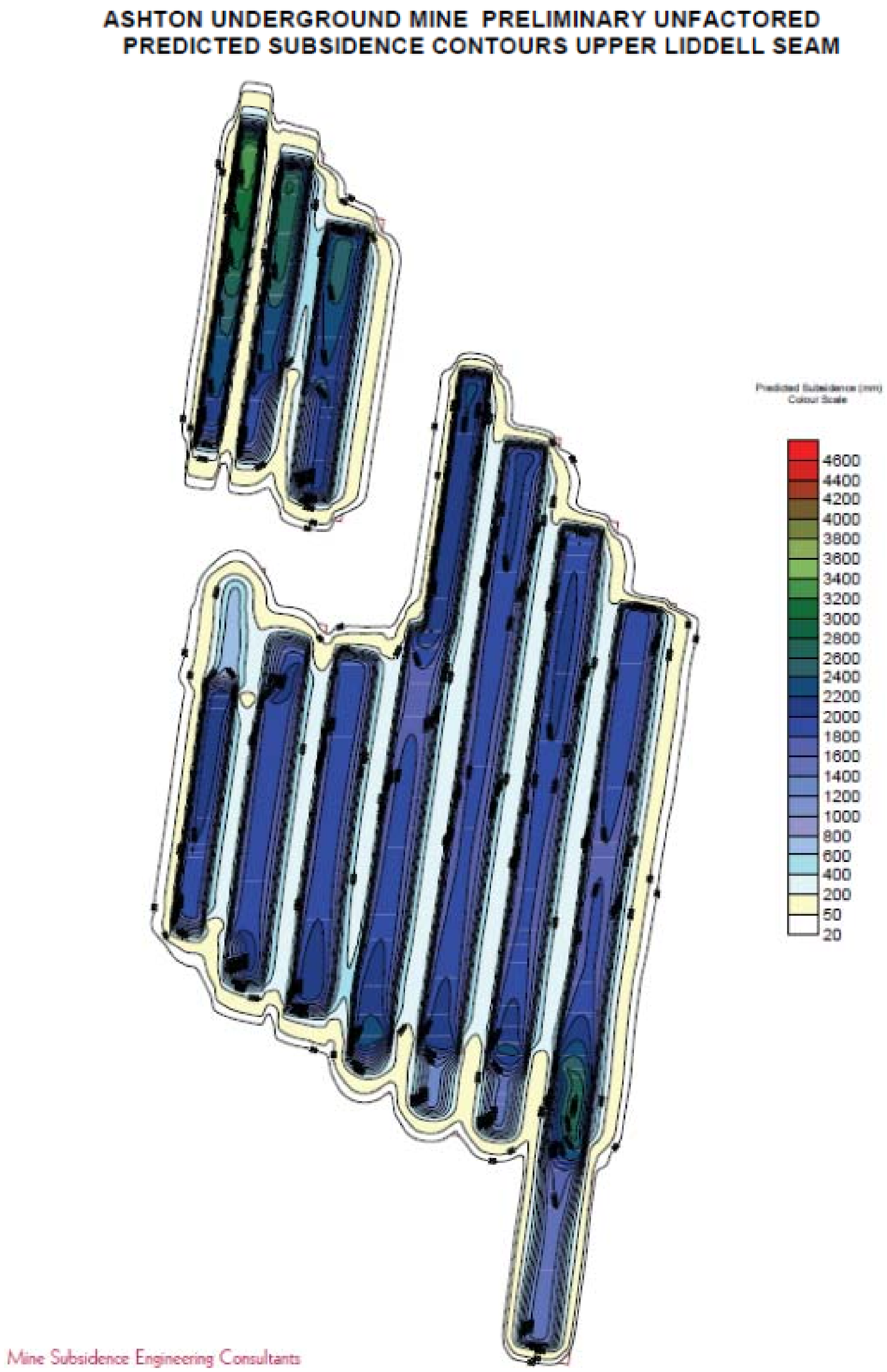

Fig. 4.1 MSEC Predicted Incremental Subsidence Contours due to the Extraction of All Longwalls in the ULD Seam Only

The following plot, Fig. 4.2, shows the predicted incremental subsidence contours due to the extraction of the proposed Ashton ULD Longwalls as prepared by Yvette Lewis in the SCT Report ASH3852. The three dimensional (3D) subsidence contours were extrapolated from the two dimensional (2D) subsidence modelling results in numerical caving models conducted by SCT Operations (FLAC 2D).

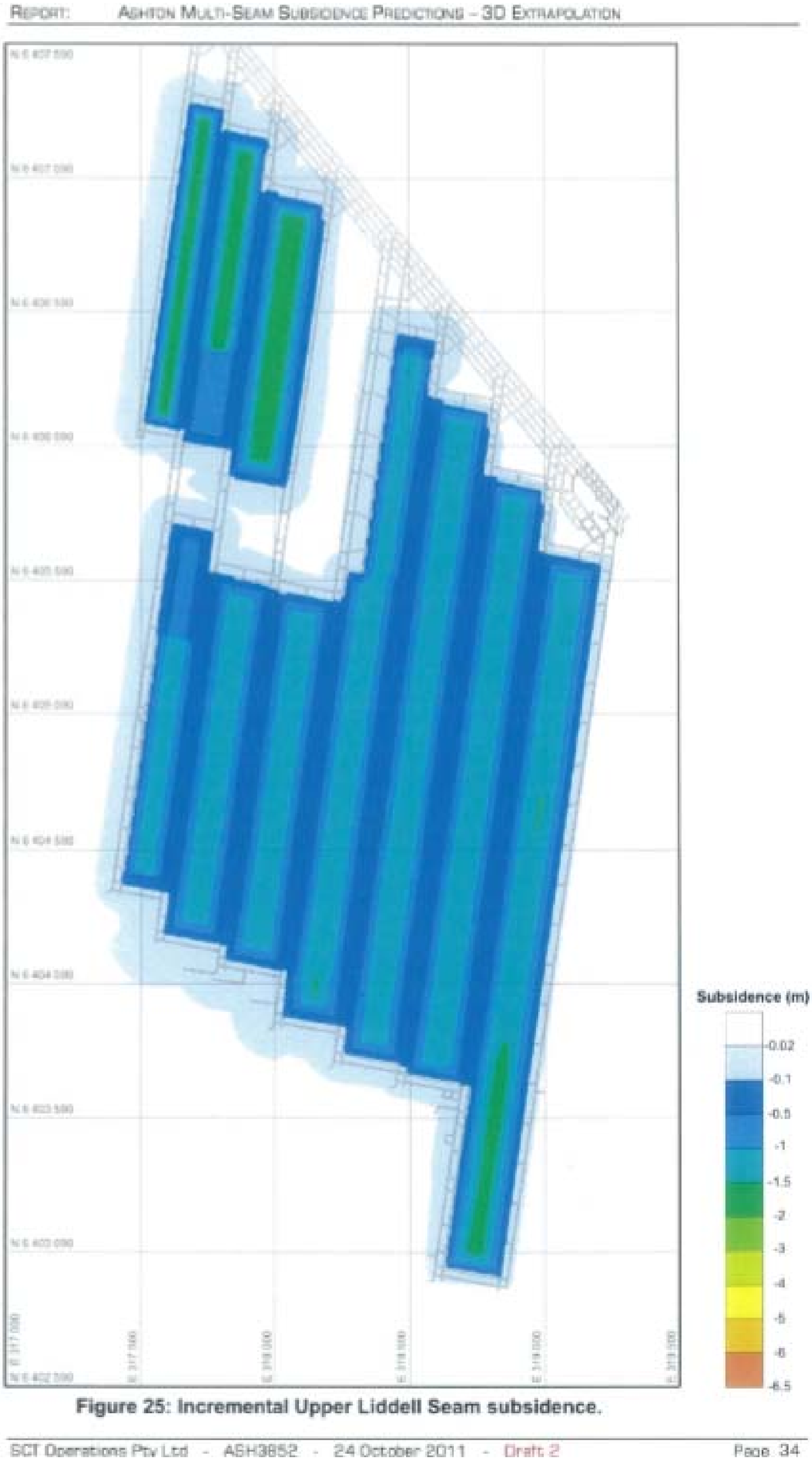

Fig. 4.2 SCT Predicted Incremental Subsidence Contours due to the Extraction of All Proposed Longwalls in the ULD Seam Only (ASH3852)

The following plot, Fig. 4.3, shows the predicted incremental subsidence contours due to the extraction of the proposed Ashton ULD Longwalls as published in the SCT report ASH3657 that was prepared by Ken Mills. The subsidence predictions were based on empirical experience and proposed multi-seam model reported by Li et al (2010).

REPORT: SUBSIDENCE ASSESSMENT FOR LONGWALLS SUBSIDENCE ASSESSMENT FOR UPPER LIDDELL SEAM, LONGWALLS 1-8 EXTRACTION PLAN

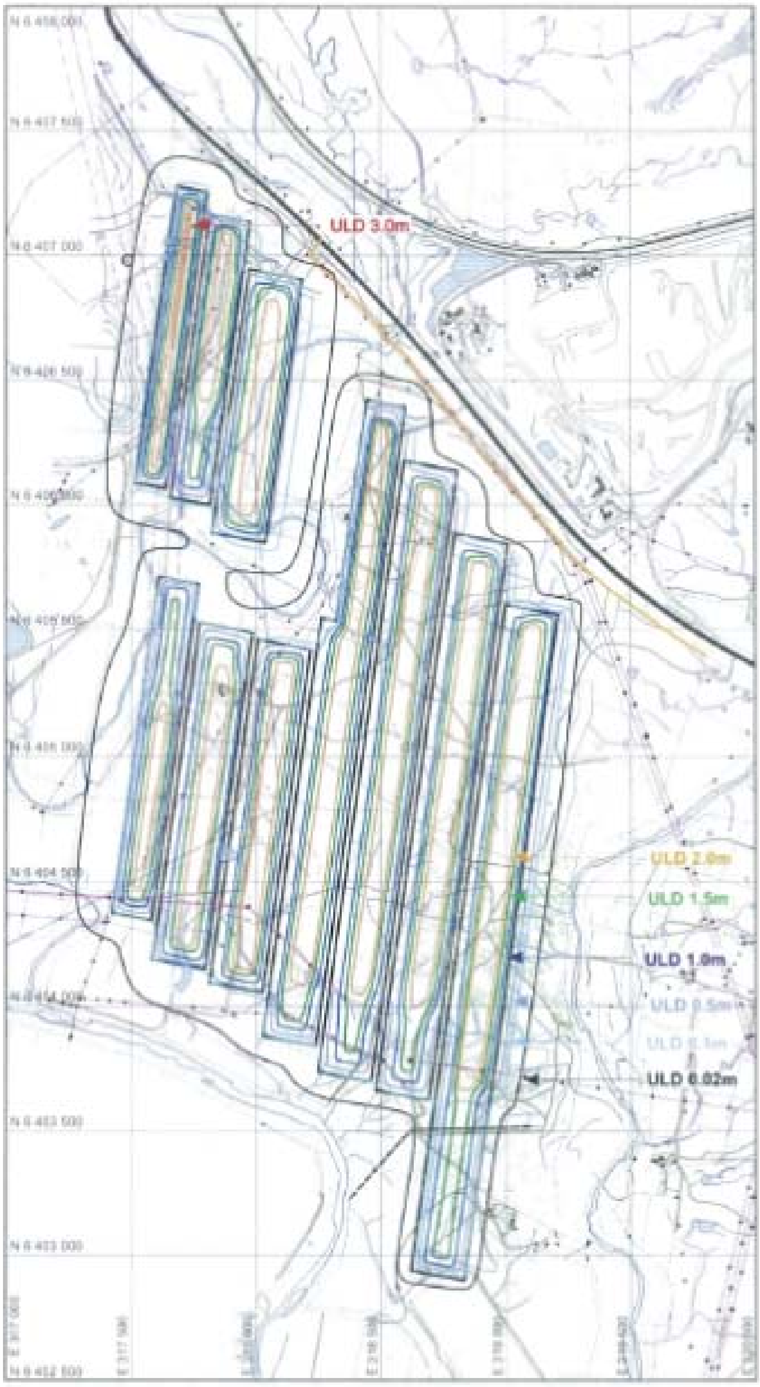

Figure 7: Incremental subsidence associated with mining ULD Seam only.

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Fig. 4.3 SCT Predicted Incremental Subsidence Contours due to the Extraction of the ULD Seam (ASH3657)

The following plot, Fig. 4.4, shows the predicted cumulative or total subsidence contours from the MSEC IPM subsidence model, after the extraction of all the proposed Ashton ULD Longwalls, i.e. the cumulative subsidence after the extraction of both the PG and the ULD Longwalls.

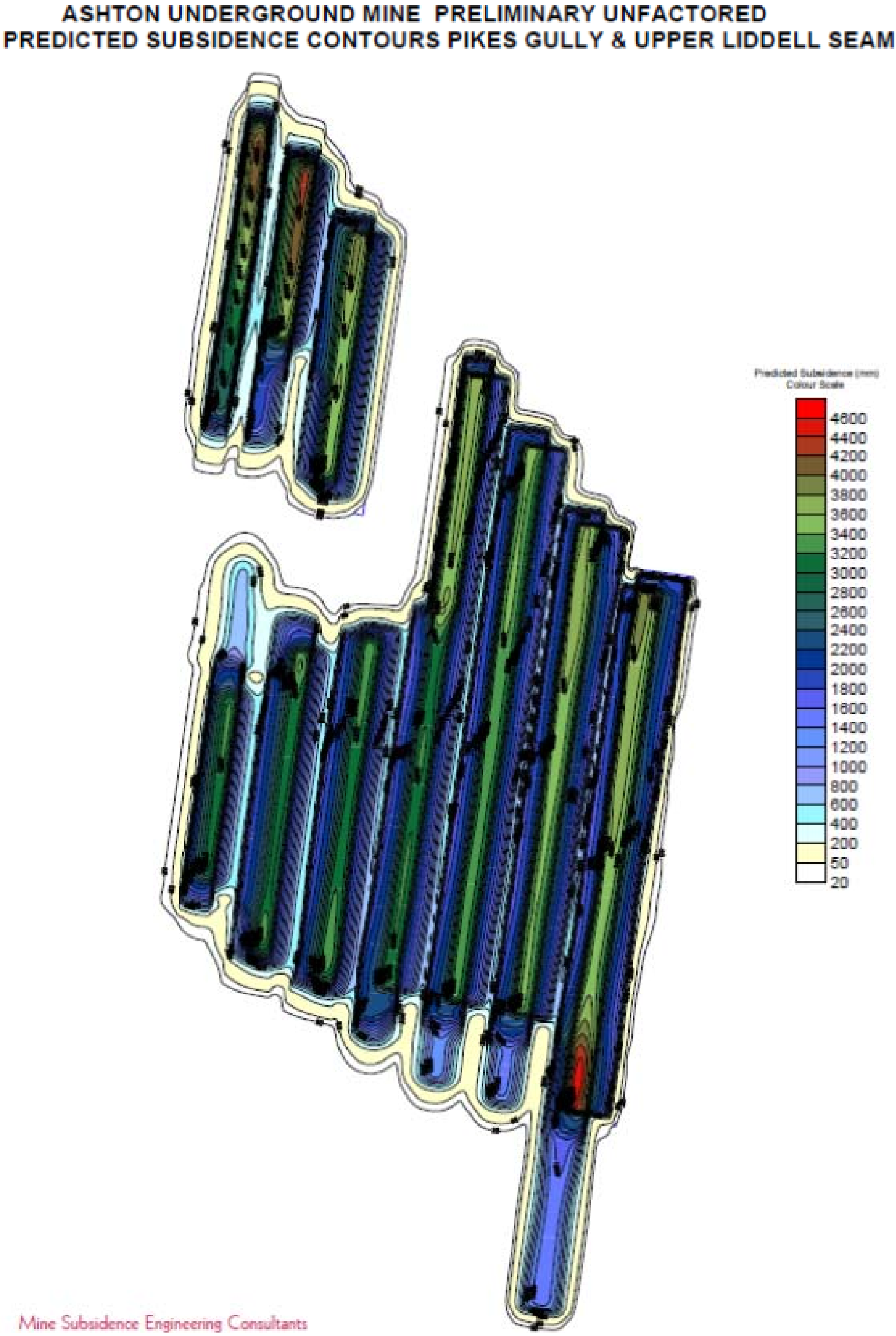

Fig. 4.4 MSEC predicted Cumulative or Total Subsidence Contours after the Extraction of Both the PG plus the ULD Seam Longwalls

The following plot, Fig. 4.5, shows the predicted cumulative or total subsidence contours that were prepared by Yvette Lewis in the SCT report ASH3852, using the numerical model, due to the extraction of both the PG and the proposed ULD Longwalls.

REPORT: ASHTON MULTI-SEAM SUBSIDENCE PREDICTIONS – 3D EXTRAPOLATION

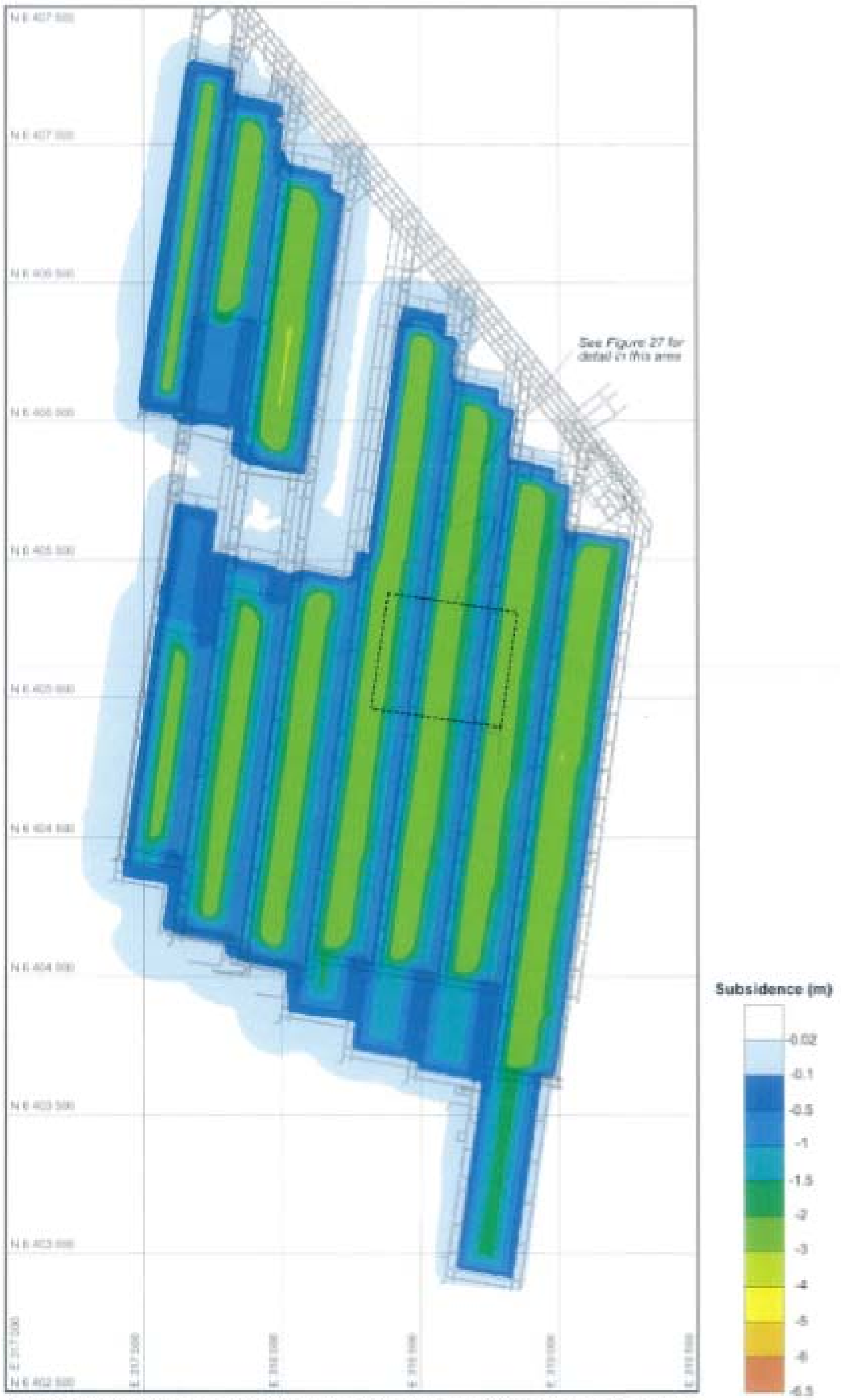

Figure 26: Cumulative Pikes Gully and Upper Liddell Seam subsidence.

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Fig. 4.5 SCT predicted Cumulative or Total Subsidence Contours after the Extraction of Both the PG plus the ULD Seam Longwalls (ASH3852)

The following plot, Fig. 4.7, shows an alternative SCT prediction for the cumulative or total subsidence contours due to the extraction of both the PG and the proposed ULD Longwalls that were prepared by Yvette Lewis in the SCT report ASH3852, using the numerical model, but adjusting the magnitude so as to match levels suggested by Li et al (2010).

REPORT: ASHTON MULTI-SEAM SUBSIDENCE PREDICTIONS – 3D EXTRAPOLATION

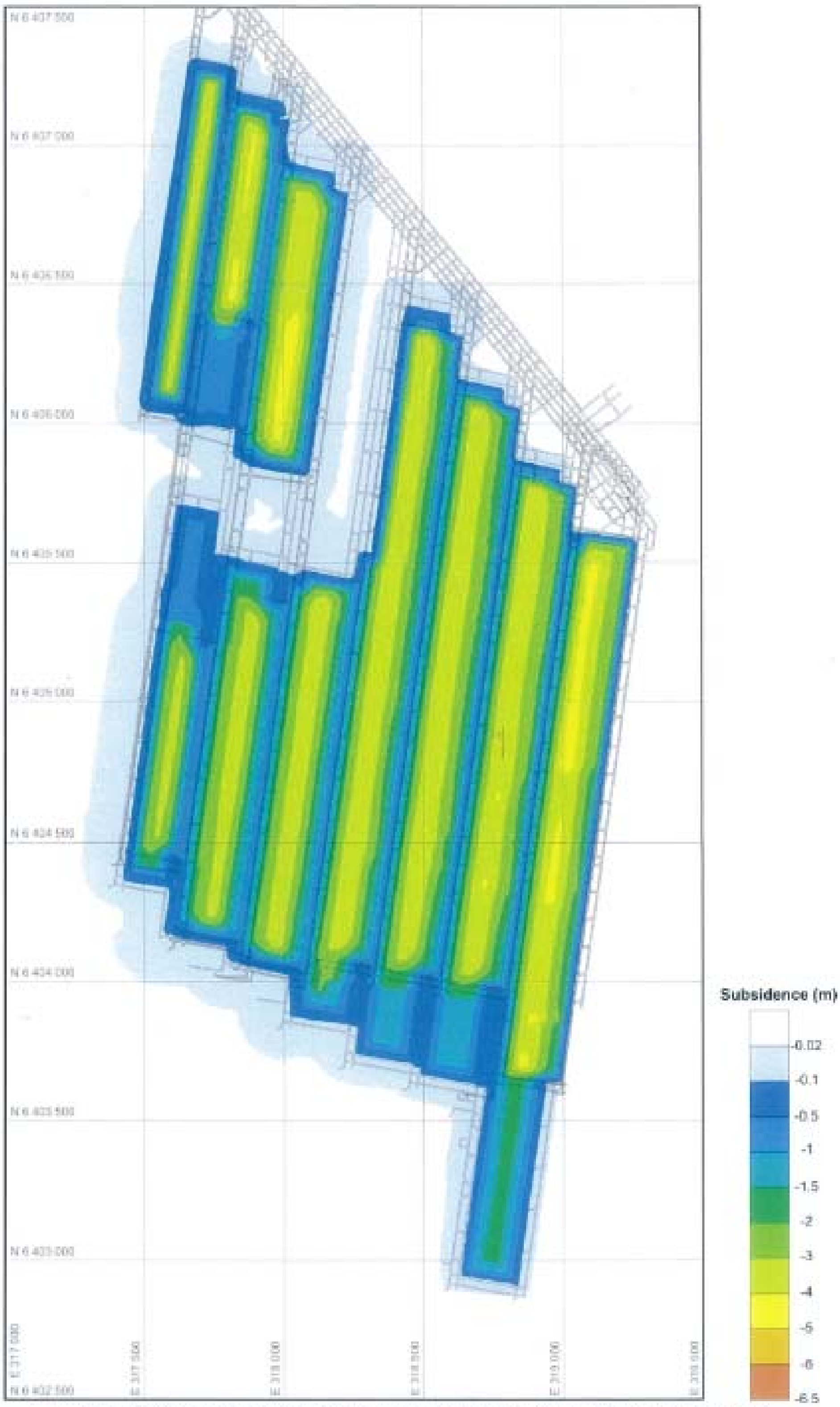

Figure 38: 85% Cumulative Pikes Gully and Upper Liddell Seam subsidence.

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Fig. 4.6 SCT predicted 85% Cumulative or Total Subsidence Contours after the Extraction of Both the PG plus the ULD Seam Longwalls (ASH3852) based on Li et al (2010)

The following plot, Fig. 4.7, shows the predicted cumulative or total subsidence contours after the extraction of the proposed Ashton ULD Longwalls, as published in the SCT report ASH3657, that was prepared by Ken Mills that were based on empirical experience reported by Li et al (2010), i.e. these are the combined predicted subsidence contours after the extraction of both the PG and the ULD Longwalls.

REPORT: SUBSIDENCE ASSESSMENT FOR LONGWALLS SUBSIDENCE ASSESSMENT FOR UPPER LIDDELL SEAM, LONGWALLS 1-8 EXTRACTION PLAN

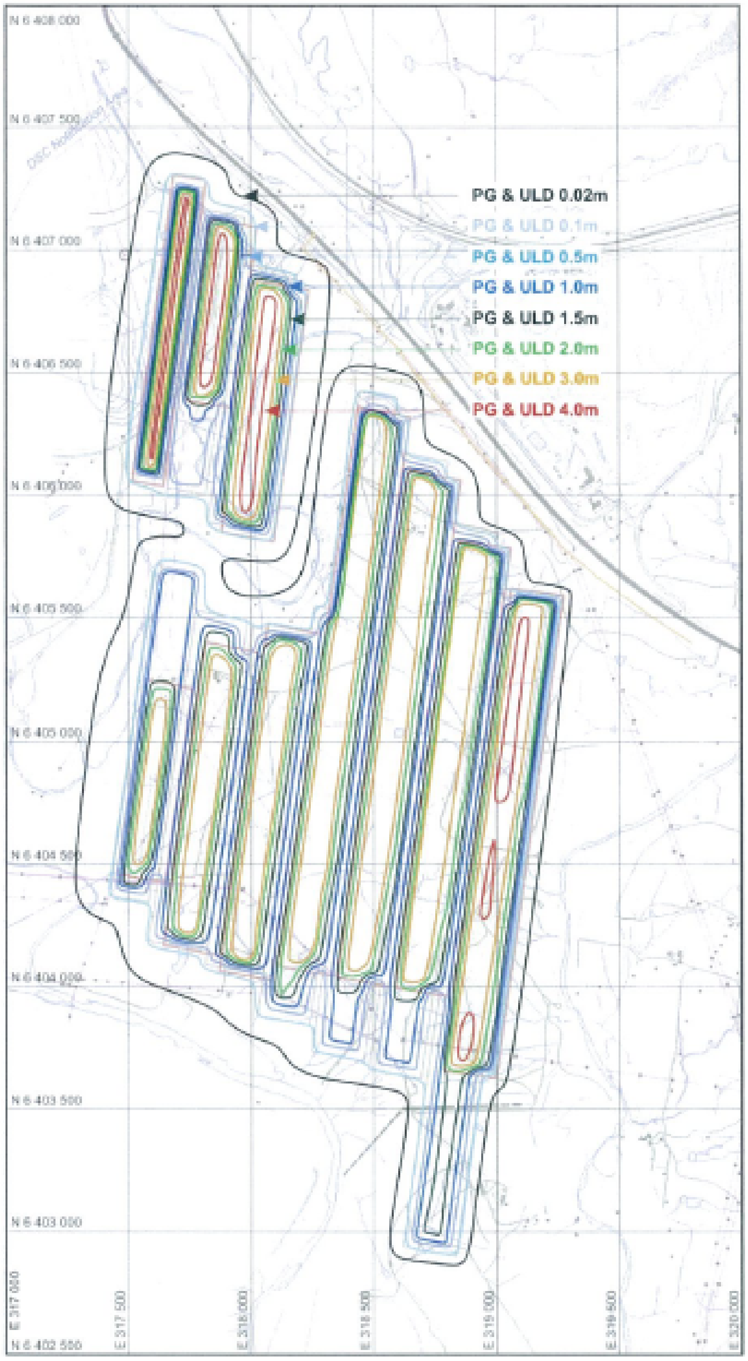

Figure 8: Cumulative subsidence associated with mining PG and ULD Seams.

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Fig. 4.7 SCT predicted Cumulative or Total Subsidence Contours after the Extraction of Both the PG plus the ULD Seam Longwalls (ASH3657)

4.1. General comments on the range of Multi-Seam Subsidence Predictions for the Ashton Coal Project

The maximum total subsidence after the extraction of both the PG and ULD Seams has been predicted at various levels ranging from;

- 3.0 metres (Fig. 4.5) for the 3D extrapolation of the FLAC 2D numerical modelling, as presented in the SCT Report ASH3852, to
- 3.7 metres as reported in the SCT Report ASH3584 (2009), to
- 4.3 metres for the 85% cumulative modified version of SCT Report ASH3852 (Fig. 4.6), to
- 4.5 metres for the MSEC modified empirical IPM model (Fig. 4.4), and to
- 4.5 metres as predicted in the SCT Report ASH3657 (Fig. 4.7).

There is generally a greater range in provided multi-seam subsidence predictions than are provided for single-seam subsidence predictions. This is partly because there is far less monitoring data over multi-seam mining conditions compared to single seam conditions; partly because the accuracy of any multi-seam subsidence prediction should be viewed as being far less than the accuracy of single seam subsidence predictions; and partly because of the additional complexities and variables that are involved in these multi-seam predictions.

MSEC suspects that the actual monitored maximum subsidence value after the extraction of both the PG and ULD Seams will be closer to the higher value (4.5 metres) than the lower value (3 metres) as the limited multi-seam monitoring data that is available indicates to us that this lower value will be exceeded but we feel the empirical predictions are based on very conservative assumptions. However, it should be noted that it is extremely difficult to predict these multi-seam ground movements accurately until more cases of multi-seams mining with longwalls under longwalls have been monitored in Australia.

It is important to recognise that after the first few longwalls have been extracted in the ULD Seam, then, the multi-seam predictions for the later longwalls can be further calibrated and more accurate predictions can be provided for these later ULD longwalls.

4.2. Background on the available Multi-Seam Subsidence Predictions

For this review project, it should be noted that MSEC has only undertaken preliminary subsidence predictions for the single-seam panels or the multi-seam panels with no site specific geological adjustments or calibrations being applied for possible strong channels or for changes in local geology compared to the standard Newcastle or Hunter IPM subsidence prediction model.

The MSEC IPM model for predicting single-seam subsidence is based on an extensive database of monitoring results over a wide variety of cases in the NSW Coalfields. Extensive experience has shown that reasonably reliable subsidence ground movements can be provided by the IPM empirical model for single-seam mining layouts, where the magnitudes of subsidence predictions and shapes of the subsidence profiles are based on site specific values of seam thickness, depth of cover, width of the mined panel, width of the immediate chain pillars, the geology and stability of these chain pillars, the presence of immediately adjacent mined panels, the extent of subsidence over these previous panels, the seam dip, and variations in the surface geology and the surface topography.

The MSEC IPM model for predicting multi-seam subsidence for longwalls under longwalls is also empirical, but it is supported by far less monitoring data than for single-seam cases. The additional multi-seam monitoring data that is available for longwalls under pillar extraction areas helps in developing a better understanding the mechanisms that are involved in multi-seam subsidence cases.

Essentially the magnitudes of the MSEC multi-seam subsidence predictions and the shapes of the multi-seam subsidence profiles are supported by the same empirical site specific values as our single seam predictions, but, for multi-seam predictions, the important additional factors that influence the magnitudes and shapes of the MSEC multi-seam subsidence predictions and profile shapes are the;

- extent and magnitude of the subsidence experienced after the previously mined panels, plus, the
- stability of the pillars in the previously mined seam, plus, the
- ratio between the extracted seam thickness of the currently mined panels compared to the panels in the previously mined seams, plus, the
- variations caused by the interburden cover thickness between the current panels and the previously mined seams.

Monitoring data from multi-seam longwall mining cases in New South Wales and overseas show that the maximum subsidence in multi seam cases, as proportions of the extracted seam heights, are greater than those for equivalent single-seam mining cases. In some cases the magnitude of the observed multi-seam subsidence for the newly extracted longwall has been greater than the extracted seam thickness of the new panel being mined and this result has occurred when relatively low values of subsidence were measured as a result of mining the previous seam with marginally stable previously mined chain pillars.

The proportion of observed multi-seam subsidence to seam thickness extracted is also seen to increase when the previously mined seam was much thicker than the newly mined longwall panel. In these cases, as the new seam is mined, not only is the observed subsidence generated from the extraction of the new panels, but, additional high levels of subsidence can be experienced above the previously mined seam when the previously mined chain pillars collapse.

The observed multi-seam monitoring data from the limited number of multi-seam cases therefore clearly shows that the shapes of the multi-seam subsidence profiles are affected by the locations of and stabilities of the goafs and chain pillars in the previously extracted seam as the new longwalls are extracted beneath or above these existing workings. The MSEC subsidence prediction model therefore predicts different magnitudes and subsidence profiles in multi-seam cases depending on whether the previously mined longwall panels were stacked cases (i.e. chain pillar above chain pillar) or staggered cases (i.e. chain pillar above goaf) which affect or influence the stability of previously mined chain pillars. The shapes of these profiles were based on the available observed single seam and multi-seam subsidence profiles plus extensive numerical modelling work on multi-seam layouts that was undertaken by Winton Gale of SCT in reports such as SCT BEL2136A, dated 20 December 2001 and SCT ACA2169, dated 18 October 2004.

However the MSEC multi-seam subsidence prediction model was further modified after a paper was presented by Li et al in 2007 that was titled "*A Case Study on Multi-seam Subsidence with Specific Reference to Longwall Mining under Existing Longwall Goaf*". As described in this paper, the authors, promoted the following concepts and equation, (as copied from this published paper), for determining the maximum additional subsidence resulting from the extraction of second seam longwalls in multi-seam mining conditions:-

$$a_1 = S_1/T_1 \qquad (1)$$

$$a_2 = S_2/T_2 \qquad (2)$$

$$a_m = S_m/(T_1+T_2) \qquad (3)$$

where,

- S_1 is the maximum (vertical) subsidence due to the first extraction in virgin conditions, whereas a_1 and T_1 are the corresponding subsidence factor and extraction thickness;

- S_2 is the maximum (vertical) subsidence due to subsequent mining at a different seam level, whereas a_2 and T_2 are the corresponding subsidence factor and extraction thickness, and

- S_m is the total maximum (vertical) subsidence as a result of mining of both seams and a_m is the subsidence factor for the combined subsidence.

The maximum subsidence is estimated from the following formulae.

$$S_2 = a_2T_2 \qquad (5)$$

where,

$$a_2 = (a_m - a_1)(T_1/T_2) + a_m \qquad (6)$$

a_1 = Maximum subsidence resulting from the extraction of the first seam (single-seam conditions) as a proportion of the extracted seam thickness and ($a_1 = S_1/T_1$)

a_2 = Maximum subsidence resulting from the extraction of the second seam (multi-seam conditions) as a proportion of the extracted seam thickness of the second seam and ($a_2 = S_2/T_2$)

a_m = Maximum total subsidence resulting from the extraction of both the first seam (single-seam conditions) plus the extraction of the second seam (multi-seam conditions) as a proportion of total extracted seam thickness of both seams and ($a_m = S_m/(T_1+T_2)$)

T_1 = Extracted seam thickness in first seam

T_2 = Extracted seam thickness in second seam

As suggested by Equation (6), the values of subsidence factors a_1 and a_m must be known prior to the prediction.

For most sites in NSW, the value for subsidence factor a_1 related to longwall mining in virgin conditions should be known or can be estimated with a relatively high level of confidence.

It is recommended to use 80% as the value for a_m according to the discussions in Section 4.1.1. The observed lower variability of this parameter is noted.

Li et al (2010) republished many of the equations, concepts and data from their 2007 paper, with additional supporting data from Cumnock Colliery and North Wambo Colliery, where the interburden thicknesses were greater than those cases that were available for the 2007 paper.

Li et al (2007) suggested further ongoing research as reproduced below.

It follows that there is a need to understand the physical processes that cause such modifications. As a result, the following fundamental aspects are suggested for further research:

- The timing, magnitude, distribution and nature of goaf formations/interactions;
- The stability of remnant structures within the overlying workings, such as chain pillars, ribs, etc., during each phase of multi-seam mining;
- Changes in stress distributions during each phase of multi-seam mining, especially in areas above chain pillars or ribs in the overlying workings;
- Changes in mechanical properties of the overburden strata as a result of each phase of multi-seam mining, and
- The proportion between the unmodified (original) and modified strata within the overburden, especially the thickness and mechanical properties of the interburden.

4.3. Review of the available of Multi-Seam Subsidence Monitoring Data to determine site specific 'S_1', 'S_2', 'S_m', 'S_T', 'a_1', 'a_2', 'a_m' and 'a_T' values

Fortunately, recent monitoring has provided observed ground movements at many locations and at many surveyed pegs over mined multi-seam panels. Previously only a few pegs were surveyed over longwall panels, but, the more recent monitoring case studies provides observed data at many pegs over the mined multi-seam longwall panels. Based on this new data, the observed subsidence, as a proportion of the extracted seam thickness has been determined over the first extracted single-seam panels, over the second extracted multi-seam panels and then over the combined panels using the combined or total subsidence on the total extracted seam thicknesses.

From these many site specific observed subsidence and subsidence on seam proportions values, the **maximum** subsidence and **maximum** subsidence-on-seam proportions were determined over the first extracted single-seam panels, i.e. the 'a_1' value as defined by Li et al, over the second extracted multi-seam panels, i.e. 'a_2' value as defined by Li et al, and over the combined panels, i.e. 'a_m' value as defined by Li et al.

The interesting development on reviewing the spatial distribution of all these site specific values is that the maximum subsidence 'S_m' and the 'a_m' value rarely occur at the same location that the maximum subsidence 'S_2' and the 'a_2' values occur. It was also noticed that the maximum subsidence 'S_1' and the 'a_1' values can occur at different locations to where both the 'S_2' and the 'a_2' value were measured and to where the 'S_m' and the 'a_m' values were measured.

The relevance of this observation is that it raises a query as to whether it is valid, in the above Equation 6 from Li et al (2010), to combine the values of 'a_1', 'a_2' and 'a_m' if these maximum values do not occur at the same location.

After reviewing this site specific information, it is suggested that the above Li et al (2007) and (2010) formulas should be modified so that, instead of being defined above as the '**maximum'** values of subsidence and '**maximum**' subsidence-on-seam values for each seam, these values could be replaced with the being observed subsidence and subsidence-on-seam proportions at a specific point over the panels, i.e. only applying at the one point or at the same location, i.e. the new definitions are;

S_1 = subsidence resulting from the extraction of the first seam (single-seam conditions) **at a point**

S_2 = subsidence resulting from the extraction of the second seam (multi-seam conditions) **at that point**,

S_T = total subsidence resulting from the extraction of both the first seam (single-seam conditions) plus the extraction of the second seam (multi-seam conditions) **at that point**. [n.b. *This differs from 'S_m' which is the maximum total subsidence after the extraction of both seams, irrespective of location*,]

a_1 = subsidence resulting from the extraction of the first seam (single-seam conditions) as a proportion of the extracted seam thickness and ($a_1 = S_1/T_1$) **at that point**,

a_2 = subsidence resulting from the extraction of the second seam (multi-seam conditions) as a proportion of the extracted seam thickness of the second seam and ($a_2 = S_2/T_2$) **at that point**,

a_T = total subsidence resulting from the extraction of both the first seam (single-seam conditions) plus the extraction of the second seam (multi-seam conditions) as a proportion of total extracted seam thickness of both seams and ($a_T = S_T/(T_1+T_2)$) **at that point**. [n.b. *This differs from 'a_m' which is based on the maximum total subsidence after the extraction of both seams, irrespective of their locations*,]

T_1 = Extracted seam thickness in first seam **at that point**,

T_2 = Extracted seam thickness in second seam **at that point**,

In this way, many values of 'S_1', 'S_2', 'S_T', 'a_1', 'a_2' and 'a_T' are determined over a mined panels and then one value for the **maximum** subsidence 'S_1', 'S_2', and 'S_T', and the **maximum** subsidence -on-seam proportions 'a_1', 'a_2' and 'a_T' can be determined over each panel for each seam and for the total seams case in the same manner as detailed in Li et al (2010).

All the comments and observations made by Li et al (2010) still apply, however, slightly different values will result when taking values at the same point rather than the maximum values from anywhere over a panel. (see examples detailed in the discussions below.) Similar limiting values will result and these can then be the subject of future research papers as more monitoring data on multi-seam cases become available.

The above suggested revised definitions of the factors 'S_1', 'S_2', 'S_T', 'a_1', 'a_2', and 'a_T' are now used in the remainder of this report.

4.4. General Observations on Recent Multi Seam Subsidence Monitoring Cases

Li et al (2007) and (2010) suggested that further research is needed into the distributions of multi-seam subsidence interactions and there is a need to better understanding the processes that cause the additional subsidence in multi-seam mining.

Studies have now been undertaken to obtain and review further multi-seam monitoring data to check on the spatial distribution of observed multi-seam subsidence over the mined panels. Where extensive monitoring has been undertaken at many pegs over the mined panels, after the extraction of each of the seams, it has been noticed that the maximum subsidence 'S_T' and the maximum 'a_T' proportion mainly occurs near the centre of both mined panels.

However, the location where the maximum subsidence 'S_2' and maximum 'a_2' proportion occurs is often not in the centre of both panels, but, is often located near the edges of the first single seam mined panel where low values of subsidence and subsidence-on-seam proportions 'a_1' were observed.

This confirms that the maximum observed subsidence 'a_2', as a proportion of the extracted second seam, includes a proportion of additional settlement or reworking over the previously mined seam and much of this additional proportion occurs where small narrow pillars collapsed, or where overlying strata was cantilevered out from the pillars and bridged across small voids. It is also interesting to note that these areas near the edges of panels are also the location where most of the long term settlement or residual time dependant subsidence is usually observed over single-seam panels as it is understood that these areas have not been compacted as much as the central areas of the panel.

Two case studies with extremely close interburden thicknesses between mined seams were;

- Newstan Colliery Longwall 8 which was extracted in the Fassifern Seam under Longwall 6 in the Great Northern Seam, as was reported by Holla and Thompson (1992), and at the
- South Bulli Colliery where longwalls in the Balgownie Seam were extracted under old Bulli Seam workings case as has been reported by Kapp (1982) and Seedsman (2012).

In both these cases the interburden thicknesses were less than 20 metres and the observed 'a_2' subsidence proportion after extracting the lower multi-seam longwall panel was greater than the extracted thickness of the second seam panels (T_2).

As shown in Fig. 4.8, Newstan Longwall 6, in the Great Northern Seam, was 155 metres wide at shallow depths of cover that varied between 40 metres and 60 metres and the extracted seam thickness that was provided in a published paper by Holla (1992) was 3.4 metres. Longwall 8 in the Fassifern Seam was 210 metres wide and the extracted seam thickness that was provided in a published paper by Holla (1992) was 3.2 metres. The interburden thickness between these seams was only 15 metres.

The observed maximum subsidence after the extraction of Longwall 6 in the Great Northern Seam was 2.03 metres, 'S_1', at peg 15, which represented approximately 60% of the extracted seam thickness 'a_1'. The observed maximum additional subsidence after the extraction of Longwall 8 in the Fassifern Seam was 3.215 metres, 'S_2', which is just greater than the extracted seam thickness of 3.2 metres. This additional subsidence 'S_2' due to the extraction of Longwall 8 in the Fassifern Seam was observed near peg 24 approximately 80 metres away from peg 15 where the maximum subsidence 'S_1' after the extraction of Longwall 6 in the Great Northern Seam was observed.

The observed maximum total subsidence anywhere after the extraction of Longwall 6 & 8 was 5.01 metres, 'S_T', near peg 15.

Hence in this case 'a_1' = 60 %, 'a_2' = 100 % and 'a_T' = 76 % and it should be noted, that the maximum 'a_T' proportion was located near the centre of both longwall panels whilst the maximum 'a_2' proportion was over the edge of Longwall 6, as shown in Fig. 4.9.

An alternative extracted seam thickness of 3.74 metres has been provided for Newstan Longwall 6, in the Great Northern Seam and this value is currently being checked by geologists at Newstan Colliery.

An alternative extracted seam thickness of 3.61 metres has been provided for Newstan Longwall 8, in the Fassifern Seam and this value is currently being checked by geologists at Newstan Colliery.

If these alternative seam thicknesses are correct then for this case 'a_1' could be 54 %, 'a_2' = 89 % and 'a_T' = 68 %.

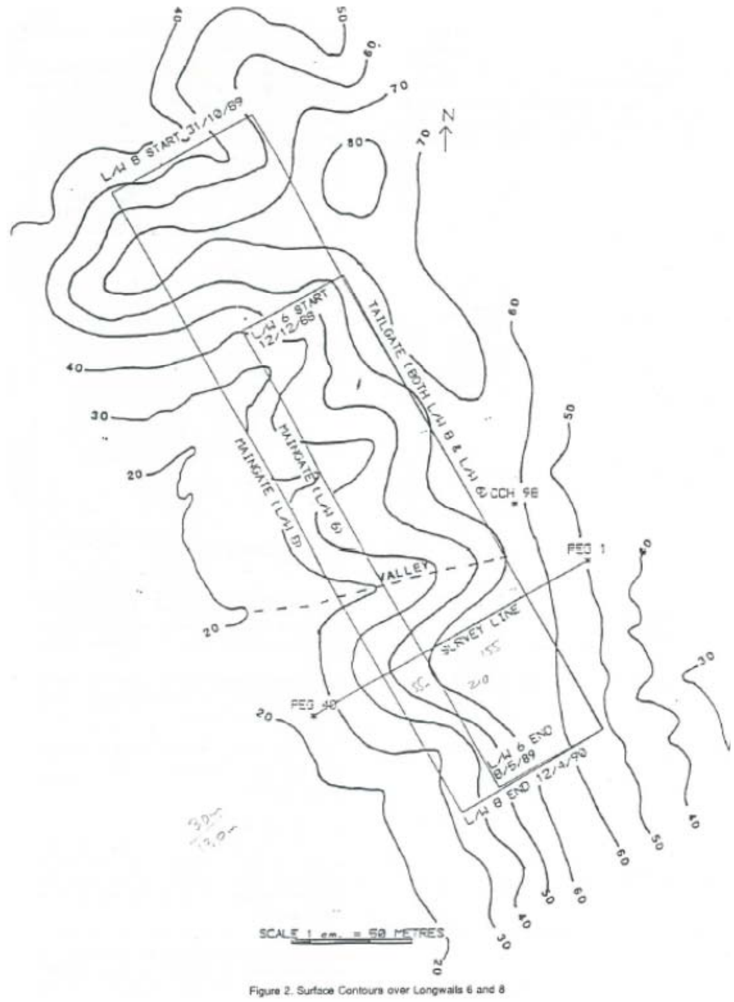

Fig. 4.8 Mine Layout for Newstan Colliery Longwalls 6 and 8

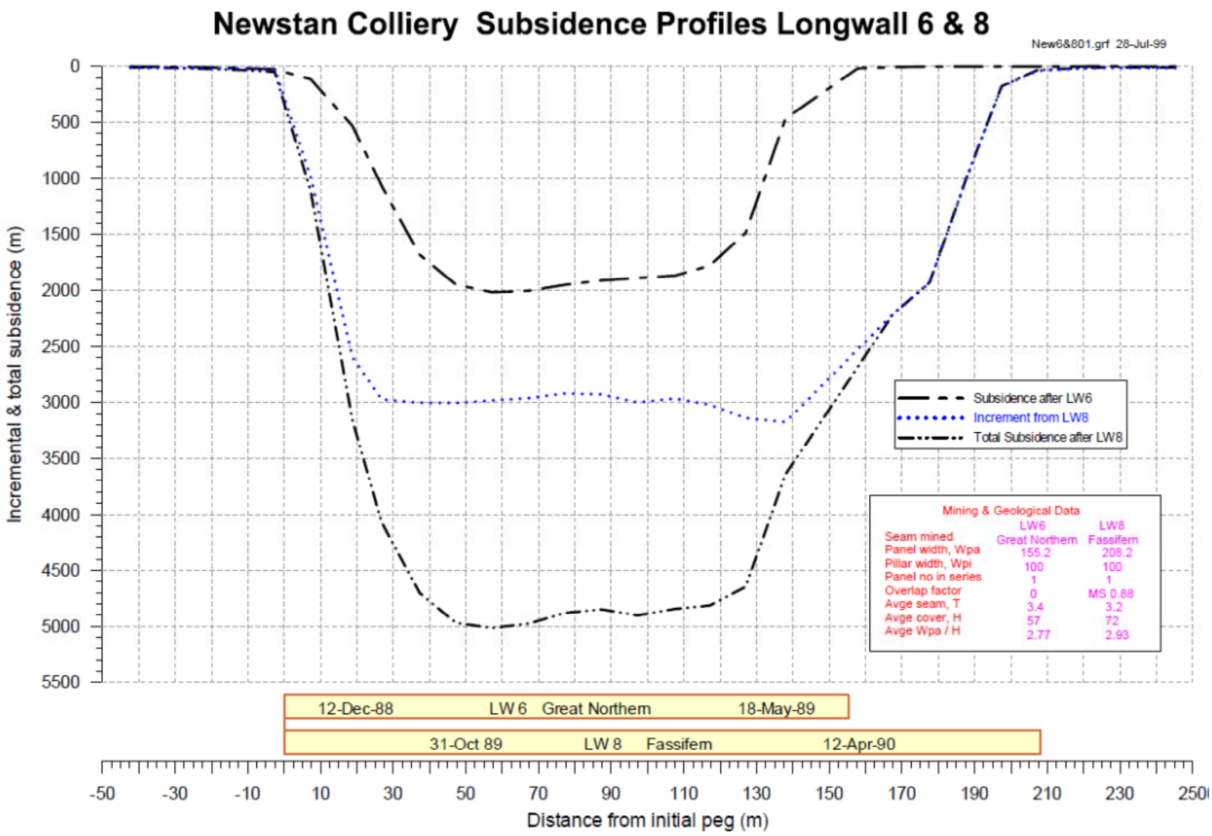

Fig. 4.9 Observed Incremental and Total Subsidence Profiles across Newstan Colliery Longwalls 6 and 8

The Bulli Seam at South Bulli Colliery was mined at least 70 to 80 years ago with large areas of fully extracted second workings and large areas where narrow small pillars or stooks remain. The underlying Balgownie longwalls were extracted in the 1970s and 1980s. There are no mine subsidence monitoring records available for the extraction of the Bulli Seam workings, but details of subsidence monitoring over the Balgownie Seam workings are available. The Balgownie Seam in this area was about 1.35 metres thick and the mined heights may have been slightly greater. Panel widths ranged from 144 metres to 186 metres and the pillar widths were initially 25 metres increasing to 40 metres. The depth of cover to this lower Balgownie Seam was about 280 metres to 290 metres and the interburden thickness between the Bulli and Balgownie Seams was between 8 metres and 16 metres. The general or averaged subsidence after the extraction of the Balgownie Seam was 1.1 metres, although a maximum subsidence of 1.4 metres was measured where it is understood that there were narrow small pillars or stooks in the overlying Bulli Seam. Hence in this case 'a_2' = 103%, but no details are available on extraction in the Bulli seam, i.e. no information on the extracted Bulli seam thicknesses, the 'a_1', the 'a_T' proportion or the locations of where the values of 'S_1', 'S_2', 'S_T', 'a_1', 'a_2', or 'a_T' were monitored.

These two cases are relatively extreme cases where the observed subsidence after the extraction of a multi-seam longwall panel was greater than the extracted thickness of the second seam. The main reasons for this appear to be the very low interburden thicknesses, of less than 20metres, and the presence of many narrow small pillars or stooks in the overlying seam. It is also possible that voids were created when the upper workings were extracted which were re-activated during the extraction of the lower seam panels. Generally, for supercritical panel widths, the observed additional subsidence on seam proportions, 'a_2', after extracting a lower multi-seam longwall panel can be between 60% and 100% of the thickness of the extracted multi-seam longwall panel depending on, amongst other factors, the amount of reactivation that occurs in the overlying seam. In some multi-seam cases the lower longwall panels can be sub-critical in width and they can be positioned so as to not cause instability of any of the overlying pillars and, in these cases, the observed additional subsidence on seam proportions, 'a_2', can be very small.

More recently detailed and extensive monitoring has been undertaken over various multi-seam longwall panels at the Liddell Colliery, North Wambo Colliery, Cumnock Colliery and at the Blakefield South Mine where the interburden thicknesses were greater than at the above Newstan and South Bulli Colliery multi-seam monitoring cases.

As shown in Fig. 4.10, Liddell Colliery Longwall 1 was fully extracted, in 1987, with a width of 180 metres within the Upper Liddell Seam. Longwall 3 was extracted in 1988/89, with a width of 181 metres within the Middle Liddell Seam. The depth of cover at the intersection of the centrelines of Longwalls 1 and 3 to the base of the Upper Liddell Seam was 167 metres and the depth of cover to the base of the Middle Liddell Seam was 200 metres. The interburden thickness between Longwall 1 and Longwall 3 was 43 metres.

The extracted Upper Liddell Seam thickness contours, as supplied by the Colliery after the extraction of Longwalls 1 and 2, are shown in Fig. 4.11 and Fig. 4.12 and the extracted Middle Liddell Seam thickness contours, as supplied by the Colliery after the extraction of Longwall 3, are shown in Fig. 4.11 and Fig. 4.13.

The panel width-to-depth of cover ratio for Longwall 1 was 180/167 = 1.08 and the panel width to total depth of cover ratio for Longwall 3 was 180/201 = 0.9.

The observed subsidence contours after the extraction of Longwall 1 in the Upper Liddell Seam that are shown in Fig. 4.14 were prepared by Liddell Colliery in 1989.

The observed additional subsidence contours due the extraction of Longwall 3 in the Middle Liddell Seam that are shown in Fig. 4.15 were prepared by Liddell Colliery in 1989.

The observed total subsidence contours after the extraction of Longwall 1 in the Upper Liddell Seam and Longwall 3 in the Middle Liddell Seam that are shown in Fig. 4.16 were prepared by Liddell Colliery in 1989.

It can be noted that the maximum observed additional subsidence 'S_2' and 'a_2' due to the extraction of the Longwall 3 in the Middle Liddell Seam did not occur at the same location where the maximum observed additional subsidence 'S_1' and 'a_1' was observed or where the maximum observed additional subsidence 'S_2' and 'a_2' was observed.

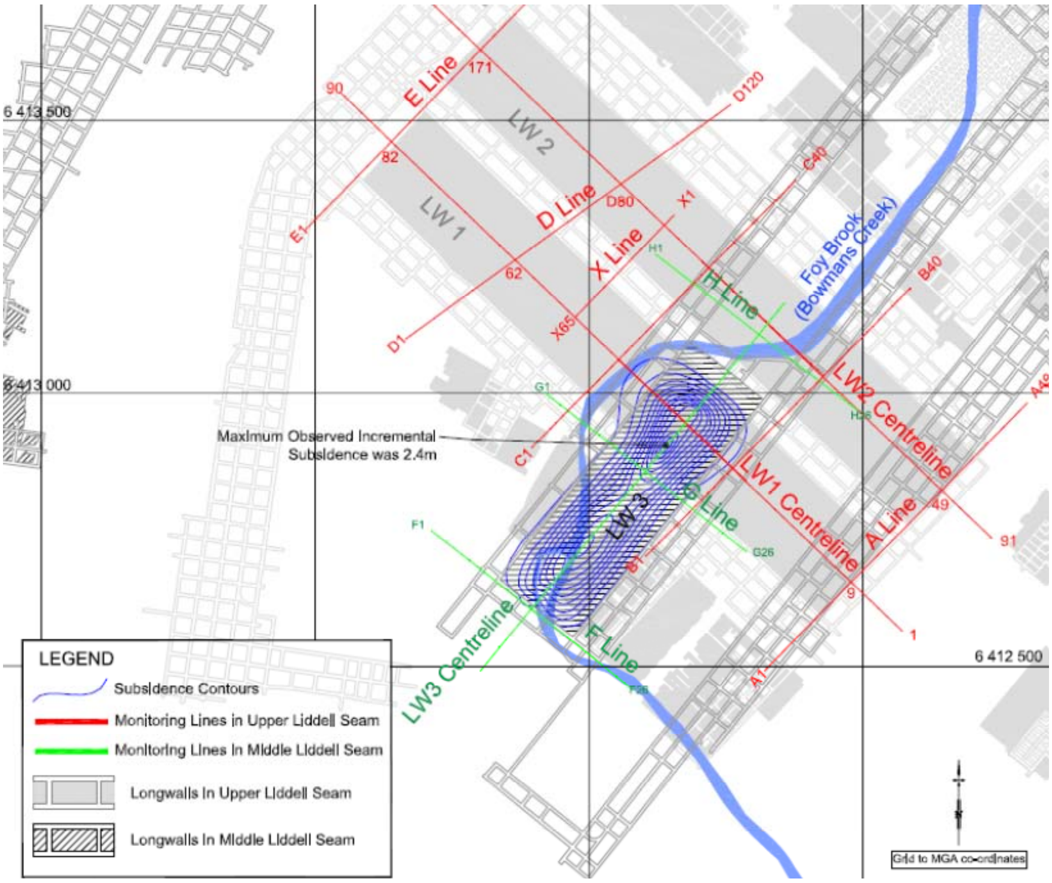

Fig. 4.10 Mine Layout for Liddell Colliery Longwalls 1, 2 and 3, Locations of Subsidence Monitoring Lines and Incremental Subsidence Contours due to the Extraction of Longwall 3

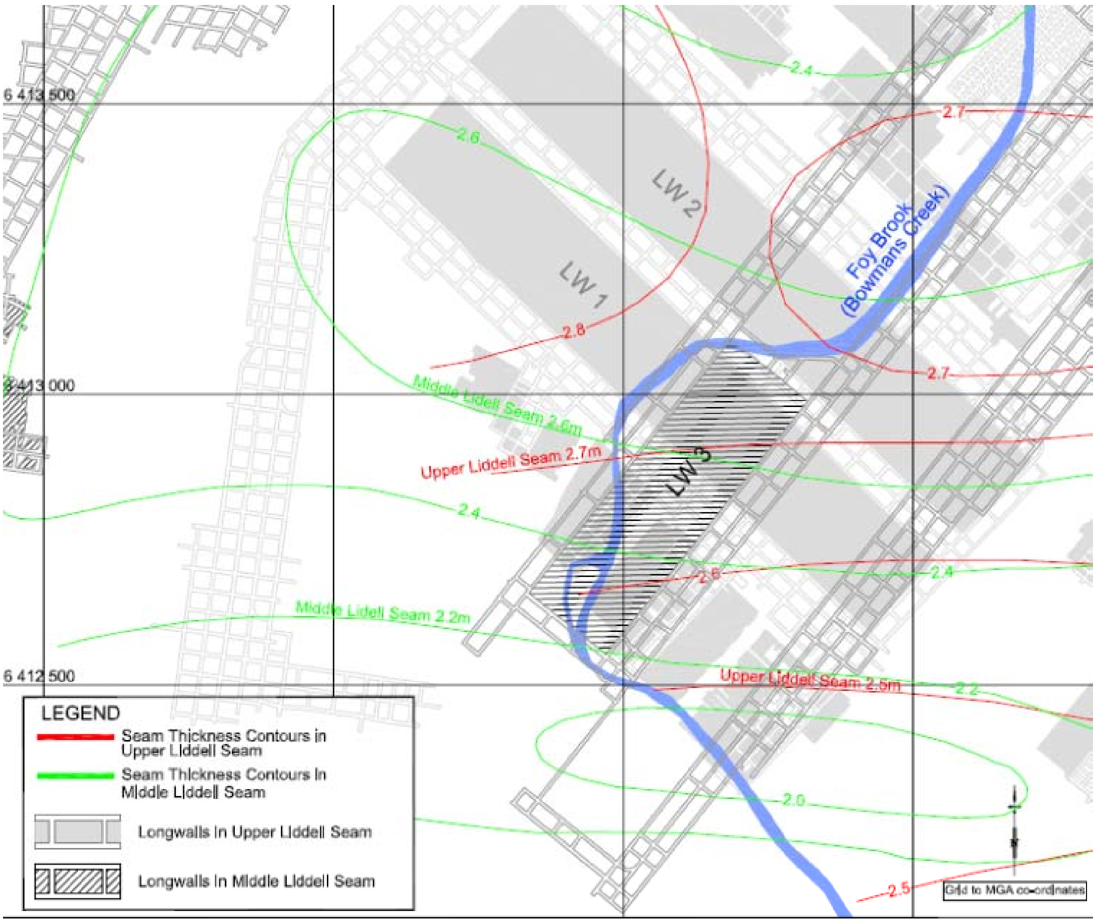

Fig. 4.11 Mine Layout for Liddell Colliery Longwalls 1, 2 and 3 and Variations in the Upper Liddell and Middle Liddell Seam Thicknesses

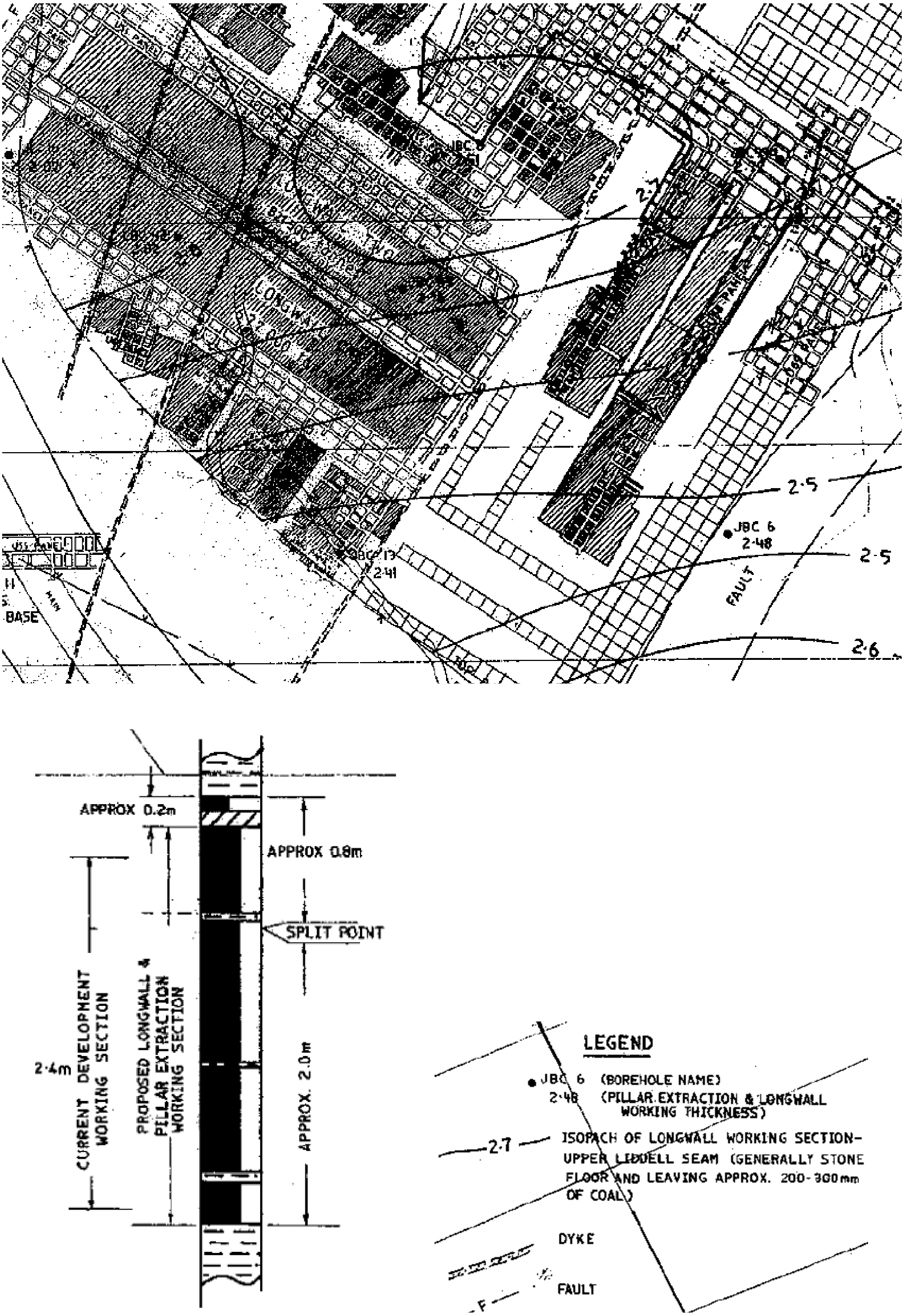

Fig. 4.12 Upper Liddell Seam Working Section Information provided by Liddell Colliery over Liddell Colliery Longwalls 1 & 2 in

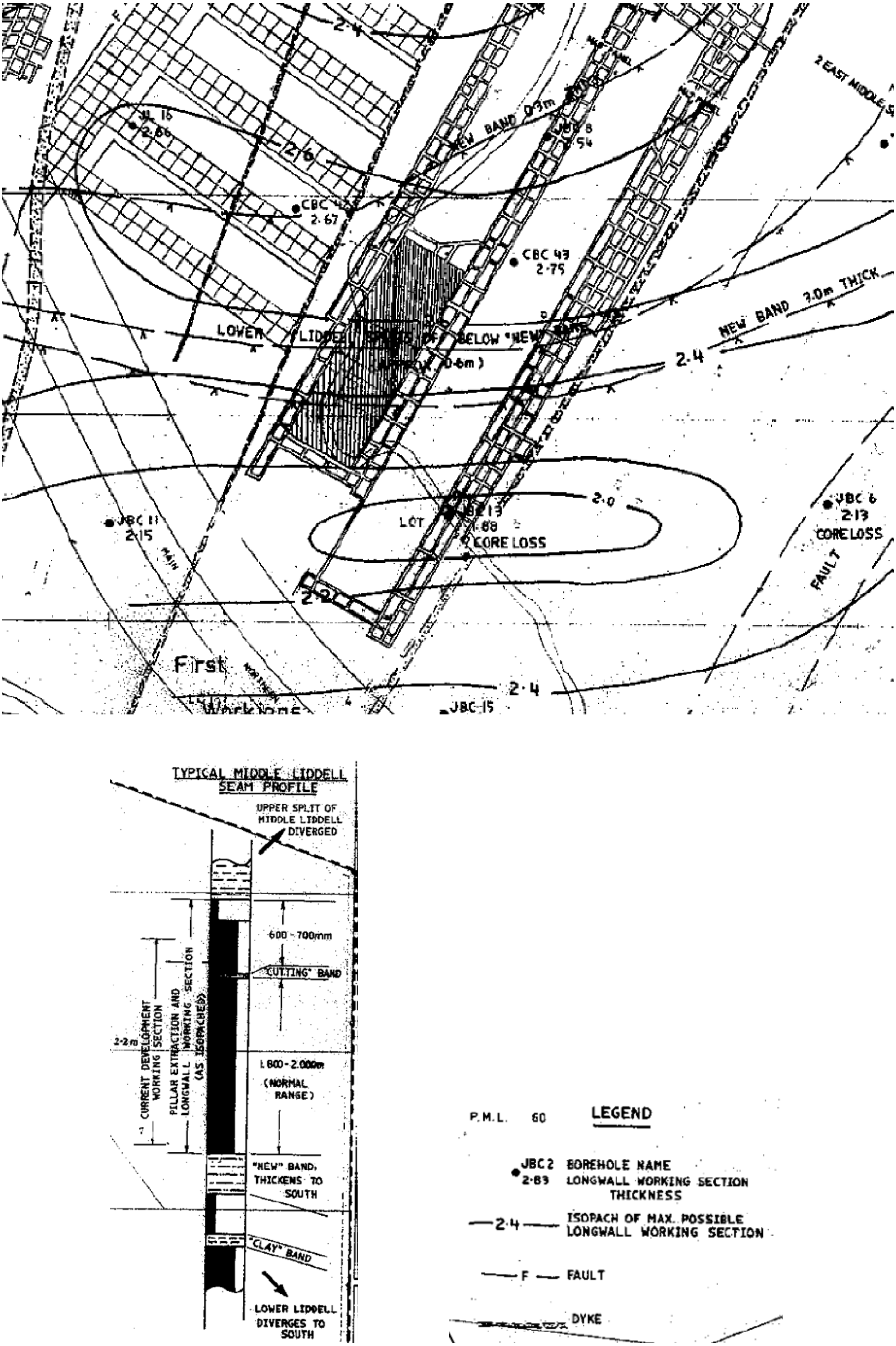

Fig. 4.13 Middle Liddell Seam Working Section Information provided by Liddell Colliery over Liddell Colliery Longwalls 3

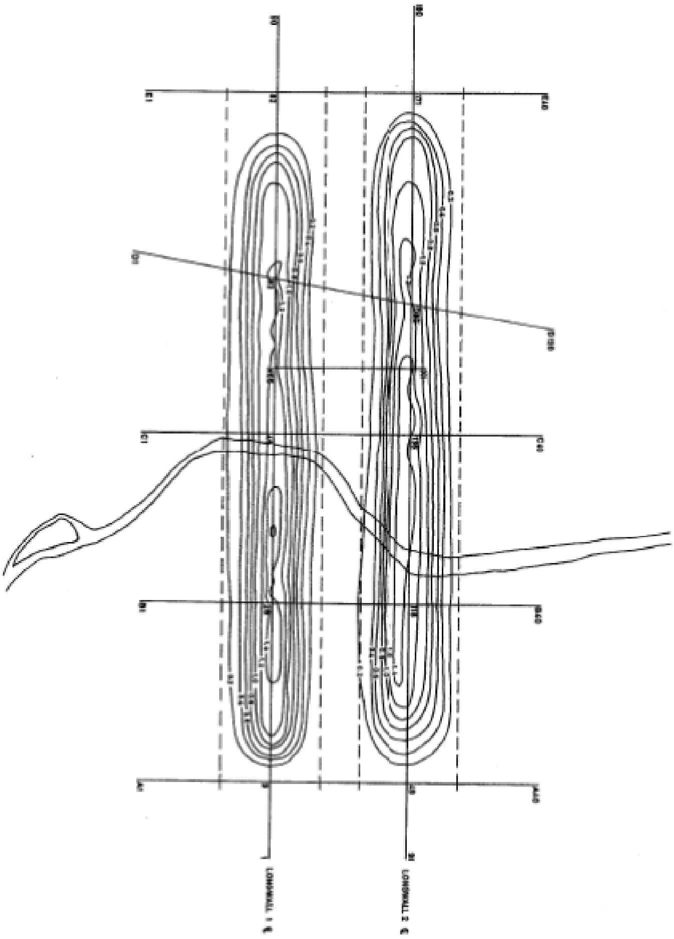

Fig. 4.14 Observed Incremental Subsidence Contours
after the extraction of Liddell Colliery Longwall 1 in the Upper Liddell Seam

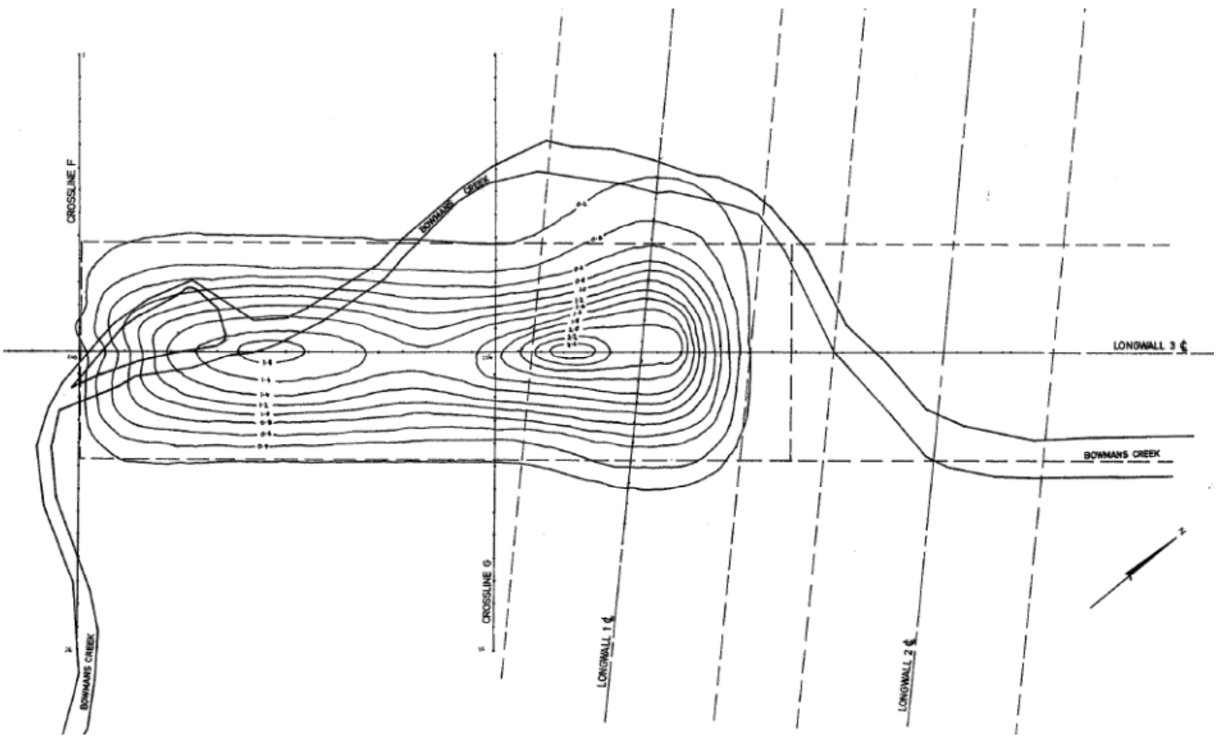

Fig. 4.15 Observed Incremental Subsidence Contours
after the extraction of Liddell Colliery Longwall 3 in the Upper Liddell Seam

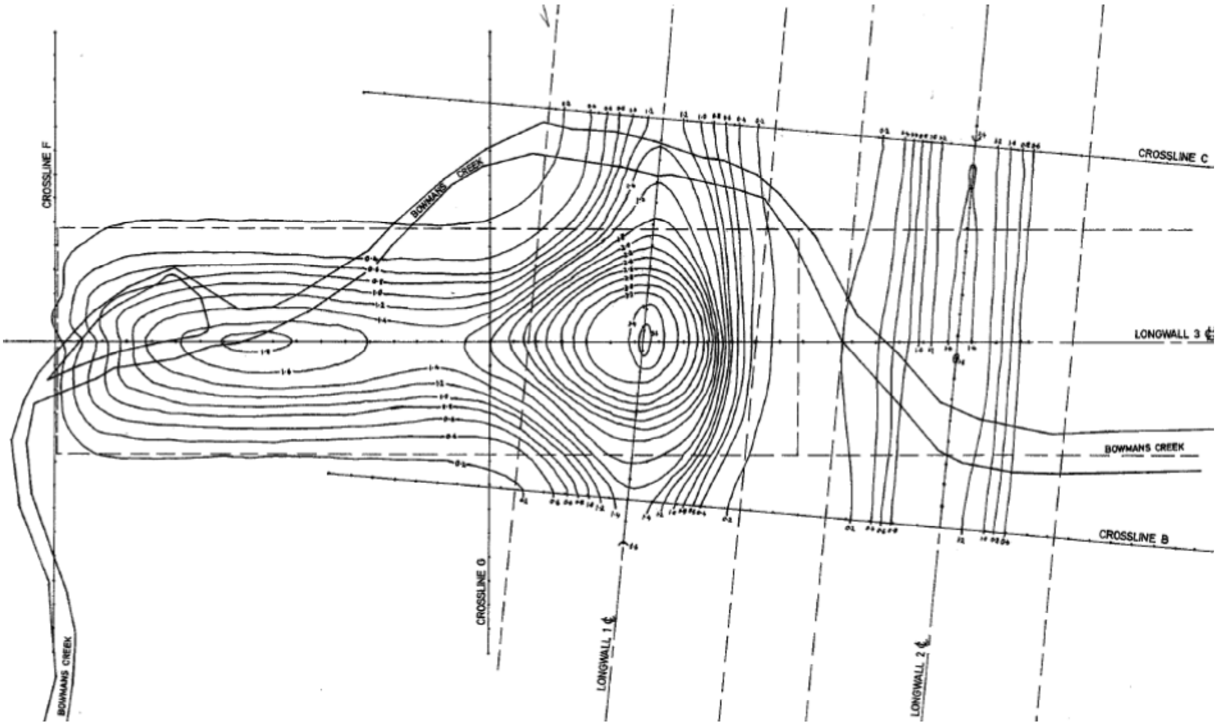

Fig. 4.16 Observed Incremental Subsidence Contours after the extraction of both Liddell Colliery Longwall 1 in the Upper Liddell Seam and Longwall 3 in the Middle Liddell Seam

TABLE 1

Summary information from case studies on longwall mining under existing longwall goaf.

Location	Upper/lower seam	Panel	Mining sequence	T (m)	W (m)	H (m)	W/H	IB (m)	S (m)	a_1 (%)	a_2 (%)	a_m (%)	Overburden conditions
Sigma Colliery, South Africa, Schumann (1987)	No 3	LW4	First	2.75	211	133	1.59	13.0	1.10	40			Dominant sandstone strata and a strong dolerite sill with UCS from 130 MPa to 230 MPa (Schumann, 1987).
	No 2B	LW4A	Second	3.04	187	148	1.26		2.92		96		
												69	
Newstan Colliery, NSW, Holla and Thompson (1992)	Great Northern	LW6	First	3.40	155	60	2.58	15.0	2.03	60			Highly complicated conditions, due to massive Teralba Conglomerate and weak claystone strata in Awaba Tuff.
	Fassifern	LW8	Second	3.20	210	75	2.80		3.03		95		
												77	
Liddell Colliery, NSW	Upper Liddell	LW1	First	2.40	180	160	1.13	40.0	1.55	65			Relatively consistent fine to medium grained sediments typical of the area, with no significant complexities.
	Middle Liddell	LW3	Second	2.00	180	200	0.90		2.10		105		
												83	
North Wambo Mine, NSW	Wybrow	LW13	First	3.30	210	260	0.81	85.0	-	-			Relatively consistent fine to medium grained sediments typical of the area, with no significant complexities.
	Wambo	LW1	Second	2.80	260	345	0.75		2.75		98		
North Wambo Mine, NSW	Wybrow	LW10b	First	3.30	210	95	2.21	65.0	-	-			Relatively consistent fine to medium grained sediments typical of the area, with no significant complexities.
	Wybrow	LW1	Second	2.60	260	160	1.63		2.54		98		
NCB (1975), UK	-	-	-	-	-	-	-	-	-	80			Mainly weak, argillaceous strata in the overburden (Kapp, 1979; Ren, 2007; Sheorey *et al*, 2000).
	-	-	-	-	-	-	-		-		90		
												85	

T = extraction thickness
W = panel width
H = average cover depth
W/H = panel width to cover depth ratio
IB = average interburden thickness
S = maximum subsidence
a_1 = subsidence factor related to the first extraction, refer to Equation 1
a_2 = subsidence factor related to the subsequent extraction, refer to Equation 2
a_m = subsidence factor for the combined subsidence, refer to Equation 3

Fig. 4.17 Table 1 from Li et al summarising Available Multi-Seam Subsidence Monitoring Data

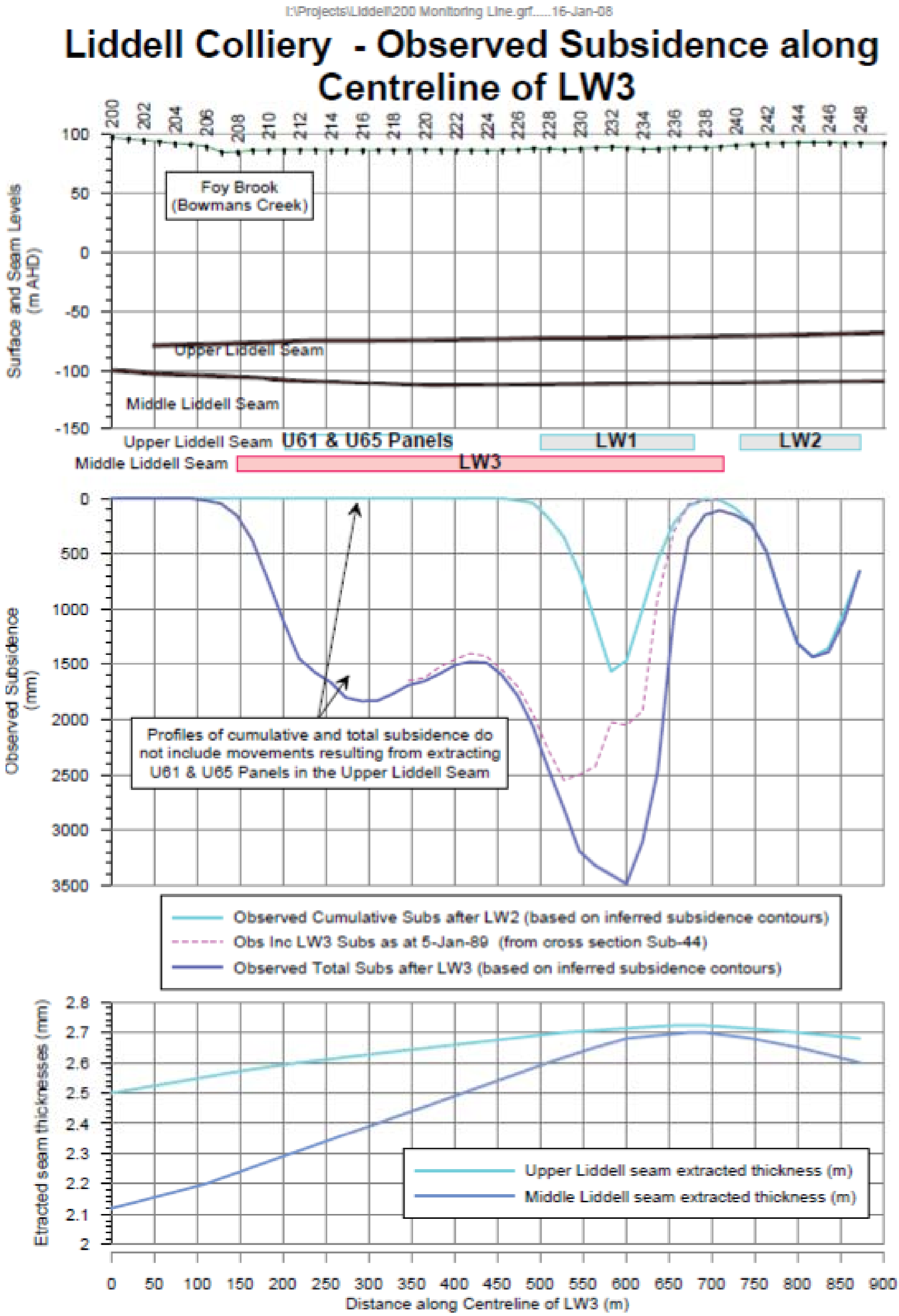

Fig. 4.18 Observed Incremental and Total Subsidence Profiles across Longwall 1 and Longwall 2 and along Longwall 3 at Liddell Colliery

First a review was undertaken along the Liddell Colliery Longwall 1 Centreline. The maximum observed subsidence 'S_1' along the Longwall 1 Centreline, after the extraction of Longwall 1, was 1.62 metres, which occurred close to the intersection of centrelines of Longwalls 1 and 3, at Peg 36, and this value represents 'a_1' = 60 % of the extracted seam thickness at this point, which was the maximum 'a_1' value observed over this panel. The observed additional subsidence due to the extraction of Longwall 3 at Peg 36, 'S_2', of 2.09 metres represents an 'a_2' value at this point of 79 %. The observed subsidence 'S_T' at Peg 36, after the extraction of both seams, was 3.62 metres representing an 'a_T' value at this point of 67%, which was the maximum 'a_T' value observed anywhere.

A review was then undertaken along the Longwall 3 Centreline, and, as shown in Fig. 4.18, the maximum observed subsidence, 'S_1', along the Longwall 3 Centreline, after the extraction of Longwall 1 was 1.57 metres, which occurred near the intersection of centrelines of Longwalls 1 and 3, at Peg 232, and this value represented 'a_1' = 58 % of the extracted seam thickness at this point. The observed additional subsidence due to the extraction of Longwall 3 at Peg 232, 'S_2', of 1.95 metres represents an 'a_2' value at this point of 73 %. The observed subsidence 'S_T' at Peg 232, after the extraction of both seams, was 3.51 metres representing an 'a_T' value at this point of 65%.

The observed additional subsidence, 'S_2', along the Longwall 3 Centreline due to the extraction Longwall 3, of 2.53 metres, which occurred at Peg 230, represents an 'a_2' value at this point of 96 %, which was the maximum 'a_2' value observed anywhere. It can be noted in Fig. 4.10 and Fig. 4.15 that this location is approximately 50 metres away from the centre of Longwall 1 and is approximately 33 metres from the edge of Longwall 1. The observed subsidence, 'S_1', at this point, Peg 230, after the extraction of Longwall 1 was 0.67 metres, which represents 'a_1' = 25 % of the extracted seam thickness at this point. The maximum observed subsidence 'S_T' at Peg 230, after the extraction of both seams, was 3.19 metres represents an 'a_T' value at this point of 60%.

Hence in this case 'a_1' = 60 %, 'a_2' = 96 % and 'a_T' = 67 %. From the above review it can be noted that the maximum observed 'S_1' and 'a_1' did not occur at the same location as the maximum observed 'S_2', and 'a_2', values.

It can also be noted that the extracted seam thickness of Longwall 1 where it overlies Longwall 3 was 2.72m and the seam thickness of Longwall 3 under LW1 was 2.65m as shown in the above Fig. 4.11 and these seam thickness values are different from the values (2.4 metres and 2.0 metres), as published in the paper by Li et al (2007) and (2010). This may be important as it is this case at Liddell Colliery that yielded the maximum 'a_T' result of 83% as discussed in the Li et al (2007) and (2010) analyses, see their Table 1 below in Fig. 4.17, and, as discussed above with new data supplied by the Liddell Colliery, this maximum 'a_T' value should have been 67%.

Blakefield South Mine partially extracted Longwall BSLW1 during 2010 within the Blakefield Seam under the South Bulga Colliery Longwalls 3 to 6 that were extracted within the Whybrow Seam, between 1996 to 1999, as shown below in Fig. 4.19.

The South Bulga Longwalls 3 to 6 (Whybrow Seam) were 260 metres wide and the Blakefield South Mine Longwall BSLW1 (Blakefield Seam) was 330 metres wide. The depth of cover to the Whybrow Seam, within the extent of the extracted BSLW1, varied from 90 metres to 120 metres and the depth of cover to the Blakefield Seam along the centreline of BSLW1, within the extent of extraction, varied from 170 metres to 210 metres.

The ML1 Line is a longitudinal monitoring line located directly above BSLW1, as shown in Fig. 4.20. Along the monitoring line and the seam thickness varies between 2.3 metres and 2.9 metres. Also along the monitoring line, the interburden thickness between the Blakefield and Whybrow Seams varies between 70 metres and 80 metres as shown in Fig. 4.21.

Fig. 4.19 Mine layout for Blakefield South Mine Longwalls 1 to 6 under the South Bulga Colliery Longwalls 3 to 6 plus the Locations of Various Subsidence Monitoring Lines

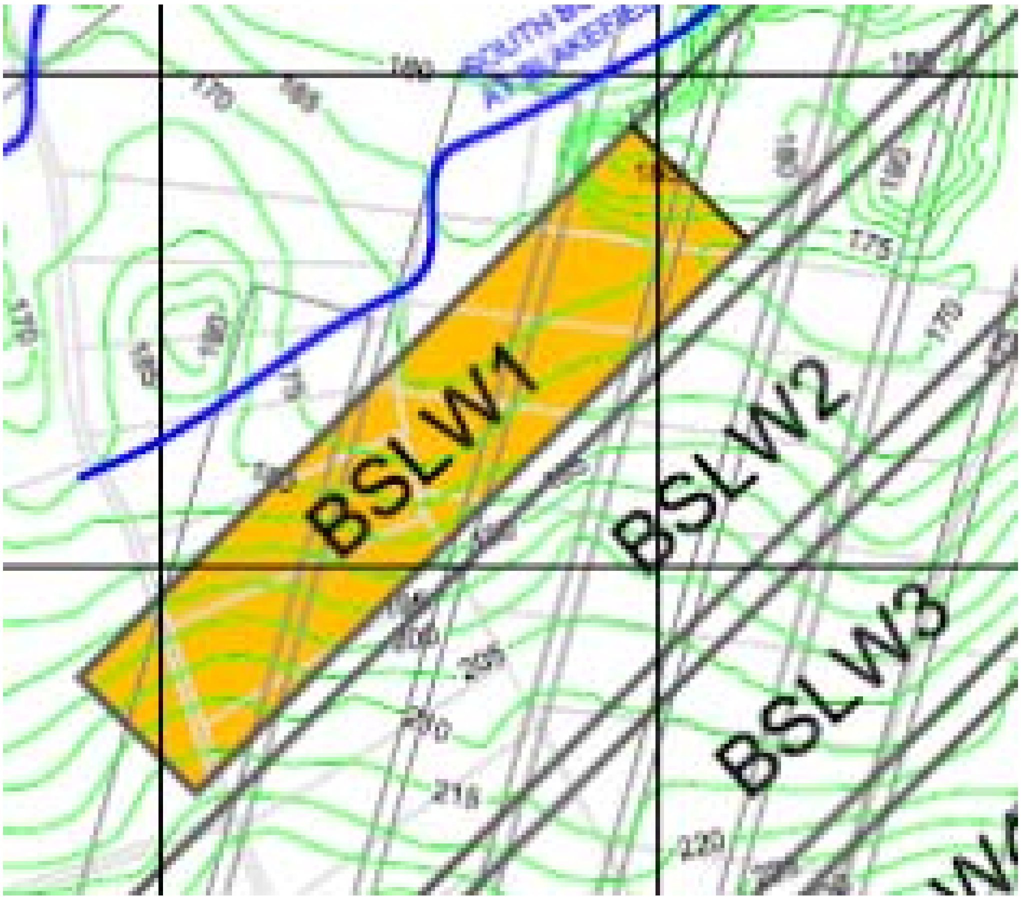

Fig. 4.20 Depth of Cover to Blakefield Seam for Blakefield South Mine Longwall BSLW1

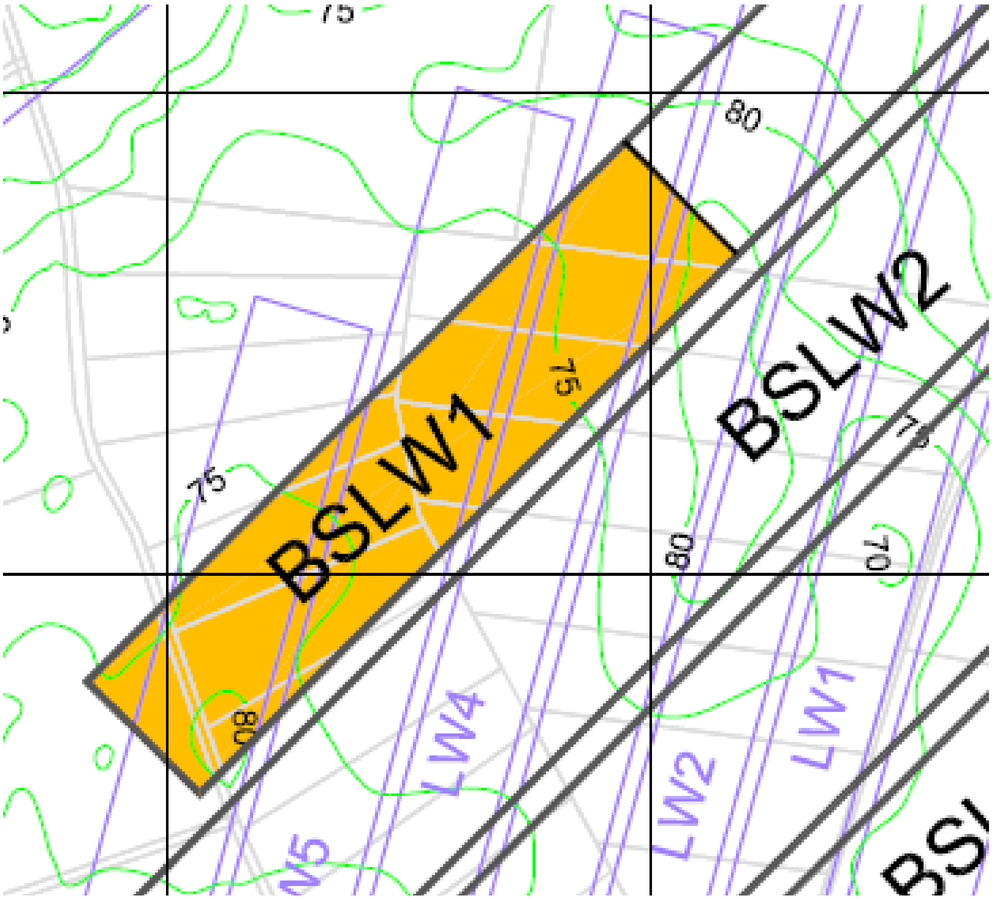

Fig. 4.21 Interburden Thickness between Whybrow Seam and Blakefield Seam for Blakefield South Mine Longwall BSLW1

As shown in Fig. 4.22, the maximum observed subsidence 'S_2' due to the extraction of the Blakefield Seam, was 2.68 metres which occurred at peg ML40 over the centre of BSLW1 and near the edge of Longwall 5 in the Whybrow Seam, which represents 'a_2' value of 110% of the extracted Blakefield Seam thickness at this point.

No monitoring was undertaken at this point during the extraction of the Whybrow Seam Longwalls 3 to 6. However we can provide an approximate subsidence prediction, 'S_1', for the extraction of the Whybrow Seam Longwalls 3 to 6 at this point, i.e. Peg ML40, of 0.54 metres based on the calibrated MSEC IPM single seam subsidence prediction model. The maximum predicted subsidence-on-seam proportion, 'a_1', at this point is therefore 23%. The total subsidence at this point, i.e. Peg ML40, 'S_T' is 3.22 metres and, hence, in this location 'a_T' = 68%.

The maximum predicted value for 'S_1' along the ML1 line is 1.23 metres at Peg ML3 near the commencing end of BSLW1 and over the centre of the South Bulga Longwall 6 and this value at this point represents an 'a_1' value of 50%. At this point, i.e. Peg ML3, 'S_2' is 2.40 metres, 'a_2' is 84%, 'S_T' is 3.63 metres, 'a_T' is 68%. The maximum observed plus predicted 'S_T' value is 3.66 metres at peg ML9 which represents an 'a_T' value of 68% at this point.

The maximum observed plus predicted 'a_T' proportion is 73% at peg ML46, where the observed plus predicted 'S_T' value is 3.40 metres. At this point the predicted S_1', for the extraction of the Whybrow Seam Longwalls 3 to 6 was 1.11 metres and the 'a_1' value, at this point was 47%. The maximum observed 'S_2' value at this point was 2.29 metres and the 'a_2' value, at this point was 99%.

Hence in this case 'a_1' = 50 %, 'a_2' = 110 % and 'a_T' = 73 % and from this review, it can be concluded that the maximum 'S_1', 'S_2', 'S_T', 'a_1', 'a_2', and 'a_T' values do not necessarily occur at the same point.

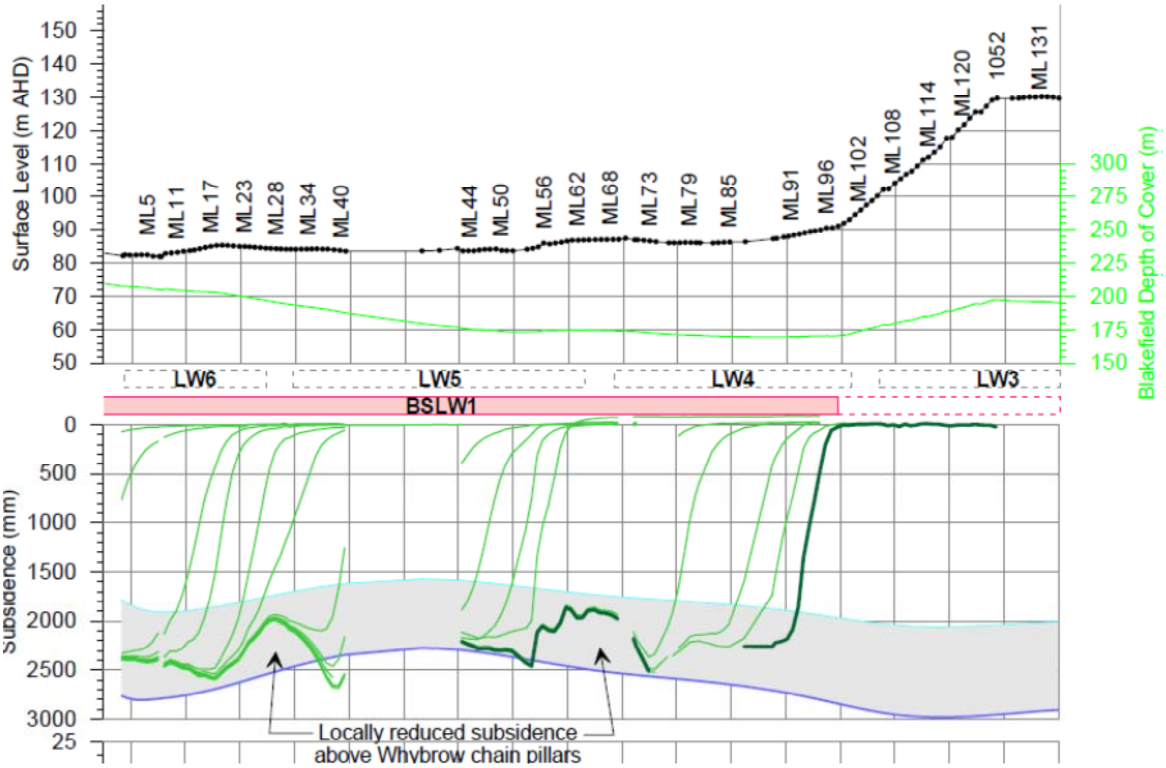

Fig. 4.22 Observed and Predicted Profiles of Incremental Subsidence along the ML1 Line due to the Extraction of Longwall BSLW1 in the Blakefield Seam at Blakefield South Mine

The predictions shown above in Fig. 4.22 for Blakefield South were made based on both a Stacked Case (i.e. chain pillar above chain pillar, shown as the blue) and a Staggered Case (i.e. chain pillar above goaf, shown as the cyan line). The reason both predictions were made was the complex mining geometry, as the longwalls in the Blakefield Seam are oblique to the longwalls in the Whybrow Seam, which meant that there was greater uncertainty associated with the multi-seam movements. The predicted profiles were calibrated using the results of an SCT numerical model but it is important to recognise that the predicted magnitudes for this project were all calibrated using the recommendations by Li et al (2010).

It can be seen from this figure, that the observed subsidence was typically within the range of those predicted, based on predictions using the Stacked and Staggered Cases, however, it did exceed the predicted maxima in two locations, albeit only slightly in some locations. The profile of observed subsidence varied along the length of the monitoring line, with locally increased subsidence adjacent to the chain pillars in the overlying Whybrow Seam, and locally reduced subsidence directly above the chain pillars in the Whybrow Seam.

The multi-seam factor 'a_T' should therefore be seen as varying depending on the subsidence proportions from the mined overlying (i.e. single-seam) and underlying (i.e. multi-seam) longwalls, the actual seam thicknesses of the overlying and underlying seams, the interburden thickness between the overlying and underlying seams and the extent of voids in the previously mined panels and the stability of the remaining pillars.

Most of the available NSW multi-seam monitoring cases that have been reviewed the panels widths are relatively wide with respect to the depths of cover and the values of 'a_T' are varying from 60 to 73%. However, it should be noted that in sub-critical panel width cases this multi-seam subsidence-on-seam thickness factor 'a_T' can be low as 20% and each case should be reviewed on its merits rather than assuming a set maximum 'a_T' value of 80 or 85%.

4.5. General Comment on the Influence of Interburden Thickness in Multi-Seam Subsidence Predictions

Li et al (2007) and (2010) noted that the interburden thickness between the seams varies in the cases that were studied by up to 75 metres. Nevertheless, in the above formulas in Li et al (2007) and in Li et al (2010), no allowance is provided in these equations for the influence or effects of variations in the interburden thickness between the proposed seams.

It seems logical that where the interburden thickness is small, then there is far greater strata interaction between workings in the two seams, including greater likelihood of the collapse of previously stable pillars, etc. Where the interburden thickness between the seams is very large, then far less multi-seam effects and strata interactions would be expected. That is, the multi-seam factor 'a_T' should be greatest for the cases where the interburden thicknesses are the lowest and where the proportions of subsidence of the extracted seam thicknesses in the overlying seam (i.e. a_1) and underlying seam (i.e. a_2) are the lowest.

It should also be noted that the extent of this strata interaction from the lower panel can also be affected by not only the interburden thickness but also by the widths of longwall panels in the lower seam. Where the interburden thickness is much greater than panel width, then less interaction would be expected than where the panel widths were much greater than the interburden thickness. All of the currently available multi-seam longwall over longwall monitoring data is from cases where the interburden thickness is much less than the width of the lower mined panel as was discussed above. However, it seems logical that with more and more monitoring data, cases will become available where the interburden thickness is much greater than the panel widths and then less multi-seam interaction would be expected.

4.6. Review of SCT Multi-Seam Subsidence Predictions for Ashton Coal Project

The preliminary MSEC multi-seam subsidence predictions for this ACOL review study have been produced using the standard MSEC IPM model, which is based on the available empirical multi-seam data and the recommendations by Li et al (2010).

The MSEC predictions were compared with those provided in SCT Report ASH3657, which were based on conservative empirical equations and the recommendations of Li et al (2010), and in SCT Report ASH3852, which were based on the 3D extrapolation of the FLAC 2D numerical modelling.

The predicted values of maximum total subsidence, 'S_T', for the ACOL study, after the extraction of both the PG and ULD Seams, ranges from;

- 3.0 metres (Fig. 4.5) for the 3D extrapolation of the FLAC 2D numerical modelling as presented in the SCT Report ASH3852, to
- 3.7 metres as reported in the SCT Report ASH3584 (2009), to
- 4.3 metres for the 85% cumulative modified version of SCT Report ASH3852 (Fig. 4.6), to
- 4.5 metres for the MSEC modified empirical IPM model (Fig. 4.4), and to
- 4.5 metres as predicted in the SCT Report ASH3657 (Fig. 4.7).

It can be noted that the numerical model provided lower levels of subsidence than the empirical methods and that there is close similarity between the levels of predicted subsidence between the empirical methods.

The SCT Report ASH3852 concludes that;

> *"Multi-seam subsidence at the Liddell Colliery was estimated at 83% of total seam thickness for the Upper Liddell and Middle Liddell multi-seam extraction (Li et al, 2010). This is greater than suggested in the FLAC numerical modelling for the Ashton Mine, however confidence is gained from the numerical modelling of the Blakefield South multi-seam extraction which proved to be correct within the predicted range."*
>
> *"Although the empirical data suggests there are examples where the maximum subsidence is up to 85% of total seam thickness, the numerical modelling in FLAC 2D suggests that for the geology and panel geometries at Ashton, the maximum subsidence may be significantly lower."*

MSEC notices that there have been several case studies with 'a_T' values higher than those proposed in this numerical modelling report and concludes that the observed values could be higher than those in this SCT Report ASH3852.

The SCT Report ASH3657 advises that;

> *"These subsidence estimates are higher than previous estimates of subsidence associated with mining the PG and ULD Seams presented in the EIS (2.7m to 3.4m) and in SCT Report ASH3584 (3.7m). The increase is partly due to differences in geometry and an increase in the seam thickness proposed to be mined, but primarily because a more conservative approach has been taken in this current assessment to estimating the maximum subsidence (based on 85% of combined seam thickness) for impact assessment purposes given recent work by Li et al (2010) and the uncertainties that are now recognised to exist around predicting subsidence in a multi-seam environment."*
>
> *"A conservative approach has been adopted for estimating subsidence in both the stacked geometry previously and the offset geometry assessed in this report. More accurate estimates of the actual subsidence behaviour are anticipated in future, with lower values of subsidence expected, once results of subsidence monitoring become available from the first few ULD Seam longwall panels mined below existing longwall panels in the PG Seam."*

It is agreed that these predictions are most likely overly conservative and these conservative predictions will most likely be found to be higher than the actual monitored movements. But based on the above reviews of the recently reviewed multi-seam monitoring cases, the actual monitored movements after the extraction of the Ashton PG and ULD Longwalls will probably be closer to a maximum predicted 4.5 metres value than to a maximum predicted value of 3 metres.

The most recent monitoring of multi-seam subsidence at Blakefield South Mine revealed that the observed multi-seam subsidence-on-seam proportions, 'a_2', along the ML1 Line, which is a longitudinal line located directly above BSLW1, ranged from 76 % to 112 % and averaged 89 %. This monitoring case involved longwalls that had a complex layout, (see Fig. 4.19), with the lower wider longwalls oblique to the upper longwalls at an angle of approximately 30 degrees, which resulted in the undermining of several longwall panels and chain pillars in the overlying Whybrow Seam. As discussed in Section 4.4, the South Blakefield multi-seam monitoring data shows that the maximum observed value of 'a_T' was 73% and if this level of multi-seam subsidence occurred at Ashton the maximum subsidence value at the Ashton Project after the extraction of the PG and ULD Seams would be 3.8 metres.

The Liddell Colliery multi-seam monitoring data, after allowing for the extracted seam thicknesses that were provided by the Colliery, indicates that the maximum observed values of 'a_T' was 67%, and if this level of multi-seam subsidence occurred at Ashton the maximum subsidence value at the Ashton Project after the extraction of the PG and ULD Seams would be 3.6 metres. The Newstan Colliery multi-seam monitoring data indicates that the maximum observed values of 'a_T' was 76%, and if this level of multi-seam subsidence occurred at Ashton the maximum subsidence value at the Ashton Project after the extraction of the PG and ULD Seams would be 4 metres.

On reviewing these monitoring cases, MSEC is therefore in general agreement with the range of multi-seam mine subsidence predictions that have been provided for the extraction of the PG and ULD Seams at the Ashton Project.

5.0 REVIEW OF ASHTON COAL PROJECT IMPACT ASSESSMENT REPORT FOR PROPOSED EXTRACTION OF THE ULD SEAM LONGWALLS

We have reviewed the sections in the SCT Report ASH3657 that identified the surface features and infrastructure that are over and near the Ashton Coal Project. We have also reviewed the impact assessments that were prepared by Ken Mills in the SCT Report ASH3657 that are based on conservative empirical subsidence predictions that are presented in the SCT Report ASH3657.

MSEC is in general agreement with the assessed impacts provided in the SCT Report ASH3657.

MSEC supports the SCT recommendation that additional subsidence monitoring be provided during mining of the ULD Seam because of the unique opportunity afforded by the proposed mining layouts in the PG and ULD Seams.

We understand that the proposed mining area is predominantly cattle grazing land located between Glennies Creek and the western side of the Bowmans Creek flood plain. This land is predominantly owned by ACOL and much of it has previously been subsided by mining in the Pikes Gully (PG) Seam.

The major natural features in the area include; Bowmans Creek, the Hunter River, Glennies Creek, the New England Highway, including a bridge over Bowmans Creek, varied electricity powerlines, a fibre optic cable, various local roads and Narama Dam.

We understand that the ULD Seam longwall panel layout has been designed so that the maximum total subsidence below the alignment of the proposed diversion of Bowmans Creek is less than 100 mm and in most areas is less than 20 mm. Should the monitoring over the first two longwall ULD panels reveal higher than expected multi-seam subsidence than is being predicted then adjustments can be provided to the mine layout before any longwalls mine near the Bowmans Creek.

6.0 REFERENCES

Holla, L. and Thompson, K.G. (1992). A Study of Ground Movement in Three Orthogonal Directions due to Shallow Multi-Seam Longwall Mining. The Australian Coal Journal, No. 38, 3-13.

Holla, L. and Thompson, K.G. (1988). Ground Movement in Multi-Seam Coal Mining, Civ. Eng. Trans., Vol. CE30, No. 5, December, 299-306.

Holt, G. (Oct 2001). Ashton Coal Project - Assessment of the Impact of Subsidence from Longwall Mining.

Kapp, W.A. (1982). Subsidence from Deep Longwall Mining of Coal Overlain by Massive Sandstones. Proc. Australasian Ins. Min. Met., 7/1 – 7/9.

Li, G., Steuart, P., Pâquet, R. (2007). A Case Study on Multi-Seam Subsidence with Specific Reference to Longwall Mining under Existing Longwall Goaf. Mine Subsidence Technological Society Seventh Triennial Conference. The University of Wollongong, November 2007. pp111 ~ 125.

Li G, Steuart P, Paquet, R, and Ramage, R (2010), A Cast Study on Mine Subsidence Due to Multi-Seam Longwall Extraction Proceedings of Second Australasian Ground Control in Mining Conference Sydney N.S.W. 23-24 November 2010 pp 191-200.

SCT Report ASH2963A, Winton Gale, (Mar 2008). Assessment of Longwall Panel Widths and Potential Hydraulic Connection to Bowmans Creek - Ashton Mine.

SCT Report ASH3084, Ken Mills, (Aug 2008). Subsidence Assessment for Ashton Coal Mine Longwalls 1 to 4.

SCT Report ASH3305, Yvette Heritage, (Jan 2008). Ashton Field Investigations – Aquiclude Study.

SCT Report ASH3342a, Ken Mills, (Feb 2008). Ashton Review of Longwall 1 Subsidence Monitoring and Comparison with Predictions.

SCT Report ASH3485, Ken Mills, (Aug 2009). Review of Subsidence Monitoring and Comparison with Predictions of Longwall 2 and Longwall 3 at Completion of Longwall 3.

SCT Report ASH3584, Ken Mills, (Oct 2009). Multi-Seam Subsidence Assessment for Ashton Coal Mine Longwalls 5 to 8.

SCT Report ASH3602, Ken Mills, (Dec 2009). Longwall 4 - End of Panel Subsidence Report

SCT Report ASH3657, Ken Mills, (Dec 2011). Subsidence Assessment for Upper Liddell Seam, Longwalls 1 to 8 Extraction Plan, Draft for Consideration.

SCT Report ASH3852, Yvette Lewis, (Oct 2011). Ashton Multi-Seam Subsidence Predictions 3D Extrapolations.