Austar Coal Mine Pty Limited

REPORT

on

THE PREDICTION OF SUBSIDENCE PARAMETERS AND THE ASSESSMENT OF MINE SUBSIDENCE IMPACTS ON NATURAL FEATURES AND SURFACE INFRASTRUCTURE RESULTING FROM THE EXTRACTION OF PROPOSED AUSTAR LONGWALLS A3 TO A5 IN SUPPORT OF A SMP APPLICATION

Mine Subsidence Engineering Consultants
Level 1, 228 Victoria Avenue – Chatswood – NSW 2067
PO Box 3047 – Willoughby North – NSW 2068
Tel. (02) 9413 3777   Fax. (02) 9413 3822
Email: enquiries@minesubsidence.com

www.minesubsidence.com

Report Number MSEC275
Revision C
February 2007

DOCUMENT REGISTER

Revision	Description	Author	Reviewed	Date
A	DRAFT Subsidence Predictions and Impact Assessments Resulting from the Extraction of Proposed Longwalls A3 to A5	JB	-	21st Dec 06
B	Final Issue	JB	DRK	30th Jan 07
C	Minor revisions	JB	DRK	2nd Feb 07

Report produced for:- SMP Application to The Department of Primary Industries

EXECUTIVE SUMMARY

Austar Coal Mine Pty Limited (Austar) proposes to continue underground coal mining operations at Austar Coal Mine, which is located in the Newcastle Coalfield of New South Wales, by extracting coal from the Greta Seam using Longwall Top Coal Caving (LTCC) mining techniques. The locations of the proposed Austar Longwalls A3 to A5 are shown in Drawing No. MSEC275-01, which together with all other drawings is included in Appendix J at the end of this report.

Mine Subsidence Engineering Consultants Pty Limited (MSEC) has been commissioned by Austar to study the mining proposals, identify all natural features and surface infrastructure above the proposed longwalls, and to prepare subsidence predictions and impact assessments in support of a SMP Application.

The proposed longwalls are located east of the township of Ellalong, at a distance of 2 kilometres, at their closest point. A number of natural features and items of surface infrastructure have been identified in the vicinity of the proposed longwalls, including creeks, steep slopes, roads, water services, electrical services, telecommunication services, dams, water bores, archaeological sites, survey control marks, and building structures.

The predicted systematic subsidence parameters for the proposed longwalls have been made using the Incremental Profile Method. The subsidence model was calibrated to local data by comparing observed and back-predicted subsidence profiles along the monitoring lines above the previously extracted longwalls at the Colliery.

It was concluded from the back-analysis that the maximum observed incremental subsidence for the previously extracted longwalls at the Colliery were all less than the maximum back-predicted incremental subsidence, based on the standard Newcastle Coalfield subsidence profiles. The shapes of the observed incremental subsidence profiles, however, were slightly wider, and the points of maximum observed incremental subsidence were located closer to the longwall tailgates, than for the back-predicted incremental subsidence profiles, based on the standard Newcastle Coalfield subsidence profiles.

The shapes of the back-predicted incremental subsidence profiles were made to more closely match the observed incremental subsidence profiles by adopting the standard Newcastle Coalfield subsidence profiles based on a panel width-to-depth ratio of 0.3, rather than adopting the actual panel width-to-depth ratios, which varied between 0.38 and 0.65. No modifications were made to the magnitudes of the maximum back-predicted incremental subsidence for each longwall.

Austar Longwalls A3 to A5 are proposed to be extracted from the Greta Seam, which has an overall height varying between 4.8 metres and 6.8 metres at the proposed longwalls. A maximum seam height of 6.5 metres is proposed to be extracted. The LTCC equipment is proposed to mine the bottom 3 metres of the seam, and recover only about 85 % of the top coal in the seam.

The predicted systematic subsidence parameters resulting from the extraction of the proposed longwalls were determined using a combination of two subsidence models both using the calibrated Incremental Profile Method. The first model predicted the systematic subsidence parameters resulting from the extraction of the bottom coal, and a second model predicted the systematic subsidence parameters resulting from the recovery of the top coal.

It has been recognised that the extraction heights for proposed Austar Longwalls A3 to A5 are greater than those in the empirical database of the Incremental Profile Method, and greater than those at the previously extracted longwalls at the Colliery. A conservative upperbound case has also been assessed for the proposed longwalls, therefore, where the predictions and impact assessments have been undertaken assuming that the maximum possible total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls.

Chapter 1 of this report provides a general introduction to the study, which also includes a description of the mining geometry and geological details of the proposed mining area.

Chapter 2 identifies all the natural features and items of surface infrastructure above the proposed longwalls.

Chapter 3 includes a brief overview of longwall top coal caving, the development of mine subsidence, the back-calibration of the Incremental Profile Method to local data, and the subsidence models used to predict the systematic subsidence parameters for the proposed longwalls.

Chapter 4 provides the maximum predicted and maximum upperbound systematic subsidence parameters resulting from the extraction of the proposed longwalls.

Chapter 5 provides the predicted and upperbound subsidence parameters for each natural feature and item of surface infrastructure which was described in Chapter 2. The impact assessments for each of these features have been undertaken based on the predicted and the upperbound subsidence parameters.

Chapter 6 provides recommendations for ground monitoring.

Appendix C provides an introduction to longwall mining and subsidence.

Appendix D provides an introduction to methods of subsidence prediction.

The assessments provided in this report indicate that the levels of impact on the natural features and surface infrastructure can be managed by the preparation and implementation of subsidence management strategies. It is recommended, however, that a structural engineer inspect the building structures above the proposed longwalls, to assess their existing conditions, and to recommend any preventive measures, as required, prior to each structure being mined beneath.

It should be noted that more detailed assessments of the impacts of mine subsidence on some natural features and surface infrastructure have been undertaken by other consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

Monitoring of ground movements is recommended, as subsidence occurs, so as to compare the observed ground movements with those predicted, and to periodically review the predictions and impact assessments in the light of measured data.

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CHAPTER 1. BACKGROUND

1.1. Introduction

Austar Coal Mine Pty Limited (Austar) proposes to continue underground coal mining operations at Austar Mine, which is located in the Newcastle Coalfield of New South Wales, by extracting coal from the Greta Seam using Longwall Top Coal Caving (LTCC) mining techniques. The locations of the proposed Longwalls A3 to A5 are shown in Drawing No. MSEC275-01, which together with all other drawings is included in Appendix J at the end of this report.

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The proposed longwalls are located east of the township of Ellalong, at a distance of 2 kilometres at their closest point. A number of natural features and items of surface infrastructure have been identified in the vicinity of the proposed longwalls, including creeks, steep slopes, roads, water services, electrical services, telecommunication services, dams, water bores, archaeological sites, survey control marks, and building structures.

The proposed longwalls are located 300 metres south-east of the previously extracted Longwalls SL2 to SL4 at the Colliery. The proposed longwalls are also located to the east of the previously extracted Longwalls 1 to 13A at the Colliery, which are at a distance of 950 metres, at their closest point. Austar have approval to mine Longwalls A1 and A2, which are located north-west of Longwalls SL2 to SL4, which are currently being extracted using LTCC mining techniques.

The proposed longwalls and the SMP Area, which is defined in Section 2.1, have been overlaid on an orthophoto of the area, which is shown in Fig. 1.1. The major natural features and surface infrastructure in the vicinity of the proposed longwalls can be seen in this figure.

This report provides information that will support a SMP Application to the Department of Primary Industries (DPI) in accordance with the Written Report, as described in Chapter 6 of the SMP Guideline, as summarised in Table 1.1.

Table 1.1 Information Provided in Support of a SMP Application

Information	Section of the Guideline for "Applications for Subsidence Management Plan Approvals"
The SMP Area or Application Area	Section 6.2
Site Conditions of the SMP Area	Section 6.4
Characterisation of Surface and Sub-Surface Features within the SMP Area	Section 6.6
Subsidence Prediction	Section 6.7
Subsidence Impacts	Section 6.10.1
Impact Assessment based on Increased Subsidence Predictions	Section 6.10.3

In some cases, the report will refer to other sources for information on specific surface and sub-surface features. The report will also provide information to assist the risk assessment section of the SMP Application (DPI SMP Guideline 2003, Section 6.10.2).

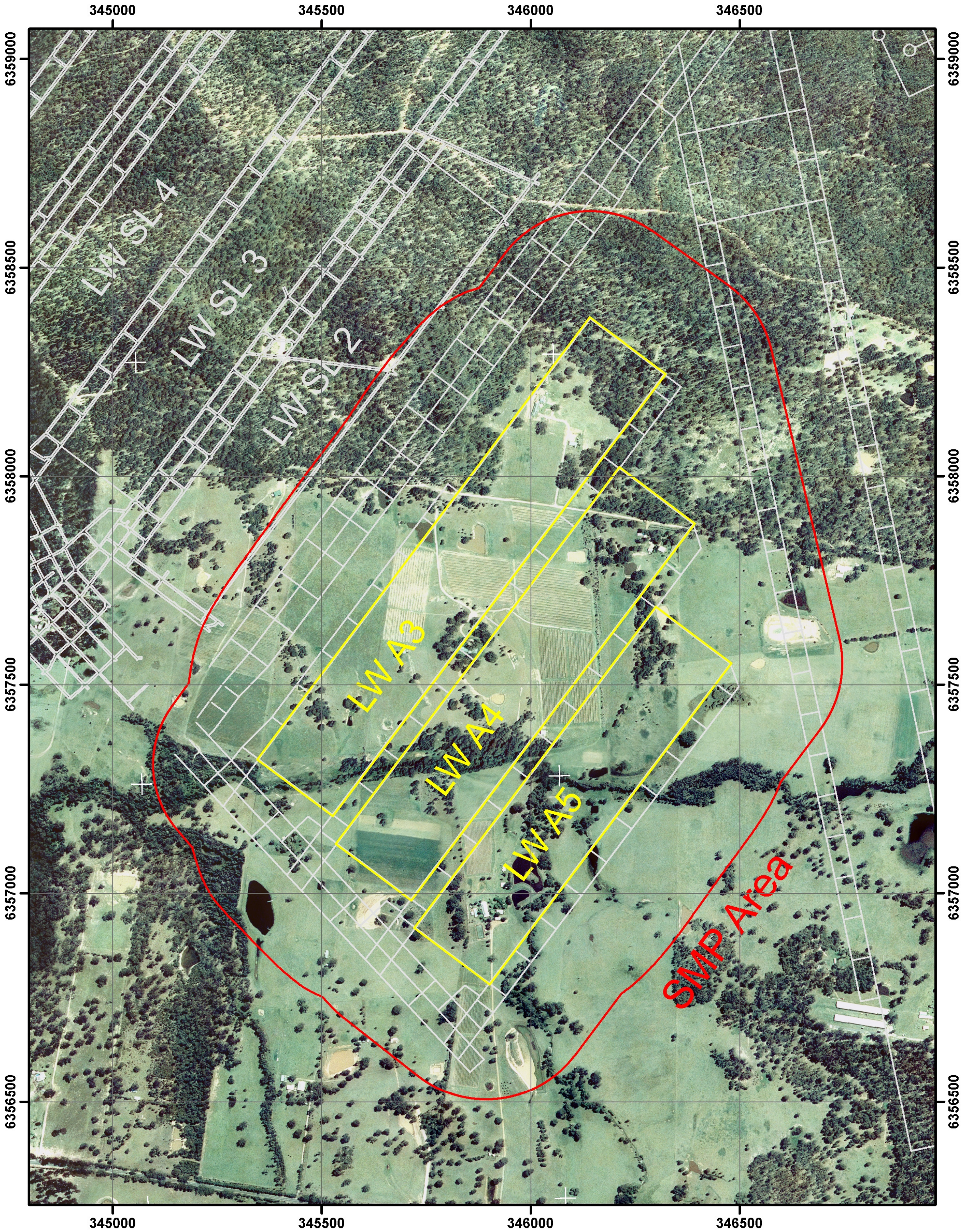

Fig. 1.1 Aerial Photograph Showing the Proposed Longwalls and the SMP Area

1.2. Mining Geometry

The layout of the proposed Austar Longwalls A3 to A5 within the Greta Seam is shown in Drawing No. MSEC275-01. A summary of the dimensions of the proposed longwalls is provided in Table 1.2.

Table 1.2 Geometry of Proposed Longwalls

Longwall	Length (m)	Void Width (m)	Solid Chain Pillar Width (m)
LWA3	1317	227	-
LWA4	1121	227	45
LWA5	954	227	45

The depth of cover to the Greta Seam above the proposed longwalls varies between a minimum of 485 metres, at the south-western end of proposed Longwall A3, and a maximum of 530 metres, above the middle of proposed Longwall A4. The seam floor at the proposed longwalls generally dips from the north-west to the south-east. The seam thickness at the proposed longwalls varies between a minimum of 4.8 metres, at the south-western end of proposed Longwall A5, and a maximum of 6.8 metres, at the north-eastern end of proposed Longwall A3. A maximum seam height of 6.5 metres is proposed to be extracted. The longwall top coal caving equipment is proposed to extract the bottom 3 metres of the seam, and recover approximately 85 % of the top coal in the seam.

The surface level contours, seam floor contours, seam thickness contours, and depth of cover contours are shown in Drawings Nos. MSEC275-02 to MSEC275-05. The known geological structures at seam level are shown in Drawing No. MSEC275-06.

1.3. Geological Details

The proposed longwalls lie in the Newcastle Coalfield within the Northern Sydney Basin. The typical stratigraphic section of the Newcastle Coalfield (after Ives et al, 1999, Moelle and Dean-Jones, 1995, Lohe and Dean-Jones, 1995, Sloan and Allman, 1995) is shown in Table 1.3. The strata shown in this table were laid down between the Early Permian to Middle Triassic Periods.

The longwalls are proposed to be extracted from the Greta Seam, which is located within the Kitchener Formation of the Greta Coal Measures. The overlying strata comprise the Paxton Formation, and the underlying strata comprise the Kurri Kurri Conglomerate and the Neath Sandstone. Strong and thick strata consisting of conglomerate and sandstone are typically observed within these formations.

The Newcastle region is characterised by a complex geological setting, with a great variety of rock types occurring over short lateral and vertical distances (Moelle and Dean-Jones, 1995). Folds, normal faults and dykes dominate the region and generally trend north-west to north-north-west (Lohe and Dean-Jones, 1995).

The major geological features within the vicinity of the proposed longwalls are shown in Drawing No. MSEC275-06. There are no identified major faults or dykes above the proposed longwalls. Two faults, identified as *Swamp Fault* on Drawing No. MSEC275-06, are located at a distance of 250 metres south-west of the proposed longwalls, at their closest point. The *Central Dyke* is located adjacent to the north-eastern ends of the proposed longwalls.

Table 1.3 Stratigraphy of the Newcastle Coalfield
(after Ives et al, 1999, Moelle & Dean-Jones, 1995, Lohe & Dean-Jones, 1995, Sloan & Allan, 1995)

STRATIGRAPHY			LITHOLOGY
Group	Formation	Coal Seams	
Narrabeen Group	Clifton		Sandstone, siltstone, mudstone, claystone
Newcastle Coal Measures	Moon Island Beach	Vales Point Wallarah Great Northern	Sandstone, shale, conglomerate, claystone, coal
	Awaba Tuff		Tuff, tuffaceous sandstone, tuffaceous siltstone, claystone, chert
	Boolaroo	Fassifern Upper Pilot Lower Pilot Hartley Hill	Conglomerate, sandstone, shale, claystone, coal
	Warners Bay Tuff		Tuff, tuffaceous sandstone, tuffaceous siltstone, claystone, chert
	Adamstown	Australasian Montrose Wave Hill Fern Valley Victoria Tunnel	Conglomerate, sandstone, shale, claystone, coal
	Nobbys Tuff		Tuff, tuffaceous sandstone, tuffaceous siltstone, claystone chert
	Lambton	Nobbys Dudley Yard Borehole	Sandstone, shale, minor conglomerate, claystone, coal
	Waratah Sandstone		Sandstone
Tomago Coal Measures	Dempsey		Shale, siltstone, fine sandstone, coal, and minor tuffaceous claystone
	Four Mile Creek		
	Wallis Creek		
Maitland Group	Mulbring Siltstone		Siltstone
	Muree Sandstone		Sandstone
	Braxton		Sandstone, and siltstone
Greta Coal Measures	Paxton	Pelton	Sandstone, conglomerate, and coal
	Kitchener	Greta	
	Kurri Kurri	Homeville	
	Neath Sandstone		Sandstone
Dalwood Group	Farley		Shale, siltstone, lithic sandstone, conglomerate, minor marl and coal, and interbedded basalts, volcanic breccia, and tuffs
	Rutherford		
	Allandale		
	Lochinvar		
Seaham Formation			

CHAPTER 2. IDENTIFICATION OF SURFACE FEATURES

2.1. Definition of the SMP Area

The "SMP Area" is defined as the surface area that is likely to be affected by the proposed mining of Longwalls A3 to A5 in the Greta Seam at Austar Coal Mine. The extent of the SMP Area has been calculated by combining the areas bounded by the following limits:-

- The 26½ degree angle of draw line,
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, and
- Features sensitive to far-field movements.

The 26½ degree angle of draw line is described as the "surface area defined by the cover depths, angle of draw of 26½ degrees, and the limit of the proposed extraction area in mining leases of (the Newcastle Coalfield)", as stated in Section 6.2 of the Department of Primary Industries SMP Guideline 2003. Given that the depth of cover above the proposed longwalls varies between 485 and 530 metres, the 26½ degree angle of draw line has been conservatively determined by drawing a line that is a horizontal distance varying between 245 and 265 metres around the limit of the proposed extraction area.

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, has been determined using the Incremental Profile Method, which is described in further detail in Section 3.4 and Appendix D. The angle of draw to the predicted total 20 mm subsidence contour has been calibrated to 30 degrees adjacent the longitudinal edges of the proposed longwalls, so as to match those observed over the previously extracted longwalls at the Colliery.

The predicted total 20 mm subsidence contour is, therefore, located outside the 26½ degree angle of draw line adjacent to the longitudinal edges of the proposed longwalls, and is located inside the 26½ degree angle of draw line adjacent to the commencing and finishing ends of the proposed longwalls. A line has therefore been drawn defining the general SMP Area, based upon the 26½ degree angle of draw line and the predicted total 20 mm subsidence contour, and is shown in Drawing No. MSEC275-01.

There are areas that lie outside the general SMP Area that are expected to experience either far-field movements, or valley related upsidence and closure movements. The surface features which are sensitive to such movements have been identified in this report and have been included as part of the SMP Area. These features are listed below and details are provided in later sections of the report.

- Cony and Quorrobolong Creeks, within the predicted limit of 20 mm total upsidence,
- Water Bores, and
- Survey Marks.

2.2. General Description of Surface Features and Infrastructure within the SMP Area

The major natural features and items of surface infrastructure within the SMP Area can be seen in the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA), numbered CESSNOCK 91322-N.

The following sections in this Chapter identify and describe all major natural features and surface infrastructure that lie within the SMP Area. A summary of these features is provided in Table 2.1, which follows the list included in Appendix B of the DPI SMP Guideline, 2003. Further details identifying areas of environmental sensitivity are provided in Section 2.3.

Table 2.1 Natural Features and Surface Improvements

Item	Within SMP Area	Environmentally Sensitive Area	Section Number Reference
NATURAL FEATURES			
Catchment Areas or Declared Special Areas			
Rivers or Creeks	✓		2.5.3
Aquifers or Known Groundwater Resources	✓		2.5.4
Springs			
Sea or Lake			
Shorelines			
Natural Dams			
Cliffs or Pagodas			
Steep Slopes	✓		2.5.10
Escarpments			
Land Prone to Flooding or Inundation	✓		2.5.12
Swamps, Wetlands or Water Related Ecosystems	✓		2.5.13
Threatened or Protected Species			
National Parks			
State Conservation Areas	✓		2.5.16
State Forests	✓		2.5.17
Natural Vegetation	✓		2.5.18
Areas of Significant Geological Interest			
Any Other Natural Features Considered Significant			
PUBLIC UTILITIES			
Railways			
Roads (All Types)	✓		2.6.2
Bridges			
Tunnels			
Culverts	✓		2.6.5
Water, Gas or Sewerage Infrastructure	✓		2.6.6
Liquid Fuel Pipelines			
Electricity Transmission Lines or Associated Plants	✓		2.6.10
Telecommunication Lines or Associated Plants	✓		2.6.11
Water Tanks, Water or Sewage Treatment Works			
Dams, Reservoirs or Associated Works			
Air Strips			
Any Other Public Utilities			
PUBLIC AMENITIES			
Hospitals			
Places of Worship			
Schools			
Shopping Centres			
Community Centres			
Office Buildings			
Swimming Pools			
Bowling Greens			
Ovals or Cricket Grounds			
Race Courses			
Golf Courses			
Tennis Courts			
Any Other Public Amenities			

Item	Within SMP Area	Environmentally Sensitive Area	Section Number Reference
FARM LAND AND FACILITIES			
Agricultural Utilisation or Agricultural Suitability of Farm Land	✓		2.8.1
Farm Buildings or Sheds	✓		2.8.2
Tanks	✓		2.8.3
Gas or Fuel Storages	✓		2.8.4
Poultry Sheds			
Glass Houses			
Hydroponic Systems			
Irrigation Systems	✓		2.8.8
Fences	✓		2.8.9
Farm Dams	✓		2.8.10
Wells or Bores	✓		2.8.11
Any Other Farm Features			
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS			
Factories			
Workshops			
Business or Commercial Establishments or Improvements	✓		2.9.3
Gas or Fuel Storages or Associated Plants			
Waste Storages or Associated Plants			
Buildings, Equipment or Operations that are Sensitive to Surface Movements			
Surface Mining (Open Cut) Voids or Rehabilitated Areas			
Mine Infrastructure Including Tailings Dams or Emplacement Areas			
Any Other Industrial, Commercial or Business Features			
AREAS OF ARCHAEOLOGICAL OR HERITAGE SIGNIFICANCE	✓		2.10.1
ITEMS OF ARCHITECTURAL SIGNIFICANCE			
PERMANENT SURVEY CONTROL MARKS	✓		2.12
RESIDENTIAL ESTABLISHMENTS			
Houses	✓		2.13.1
Flats or Units			
Caravan Parks			
Retirement or Aged Care Villages			
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	✓		2.13.5
Any Other Residential Features	✓		2.13.5
ANY OTHER ITEM OF SIGNIFICANCE			
ANY KNOWN FUTURE DEVELOPMENTS			

2.3. Areas of Environmental Sensitivity

This section provides a brief summary of features identified as areas of environmental sensitivity within the SMP Area, as defined in Section 6.6.3 of the DPI SMP Guideline, 2003. Further details on each of these features are provided in subsequent sections of this report.

Table 2.2 Summary of Areas of Environmental Sensitivity within the SMP Area

No.	Description	Within SMP Area	Details	Section No. Ref.
1	Land reserved as a State conservation area under the *National Parks and Wildlife Act 1974*	✓	Aberdare State Forest to become the Wereakata State Conservation Area	2.5.17
2	Land declared as an Aboriginal place under the *National Parks and Wildlife Act 1974*	None		
3	Land identified as wilderness by the Director, National Parks and Wildlife under the *Wilderness Act 1987*	None		
4	Land subject to a 'conservation agreement' under the *National Parks and Wildlife Act 1974*	None		
5	Land acquired by the Minister for the Environment under Part 11 of the *National Parks and Wildlife Act 1974*	None		
6	Land within State forests mapped as Forestry Management Zone 1, 2 or 3	None		
7	Wetlands mapped under SEPP 14 – Coastal Wetlands	None		
8	Wetlands listed under the Ramsar Wetlands Convention	None		
9	Lands mapped under SEPP 26 – Coastal Rainforests	None		
10	Areas listed on the Register of the National Estate	None		
11	Areas listed under the *Heritage Act 1977* for which a plan of management has been prepared	None		
12	Land declared as critical habitat under the *Threatened Species Conservation Act 1995*	None		
13	Land within a restricted area prescribed by a controlling water authority	None		
14	Land reserved or dedicated under the *Crown Lands Act 1989* for the preservation of flora, fauna, geological formations or other environmental protection purpose	None		
15	Important surface watercourses and groundwater resources identified through consultation with relevant government agencies	✓	Cony and Quorrobolong Creeks	2.5.3
16	Lake foreshores and flood prone areas	✓	Flood prone areas	2.5.12
17	Cliffs, escarpments and other important natural features	None		
18	Areas containing major ecological values	None		
19	Major surface infrastructure	None		
20	Surface features of community significance (including cultural, heritage or archaeological significance)	None		
21	Any other land identified by the Department to the titleholder	None		

2.4. Surface Topography

The surface level contours in the vicinity of the proposed longwalls are shown in Drawing No. MSEC275-02. The surface of the land within the SMP Area is generally flat to undulating, with the major topological feature being the hill located above the middle of proposed Longwalls A3 and A4. The surface levels within the SMP Area vary from a low point of approximately 120 metres AHD, in the base of Quorrobolong Creek, to a high point of approximately 160 metres AHD, at the top of the hill.

2.5. Natural Features

2.5.1. Catchment Areas and Declared Special Areas

There are no drinking water catchment areas, or declared special areas within the SMP Area.

2.5.2. Rivers

There are no rivers within the SMP Area.

2.5.3. Creeks

The locations of the major watercourses within the SMP Area are shown in Drawing No. MSEC275-07. The major watercourses within the SMP Area are briefly described below, with further details provided in the report by Umwelt (2007).

Cony Creek commences to the east of the SMP Area, and generally flows in a westerly direction, to where it drains into Quorrobolong Creek above proposed Longwall A5. **Quorrobolong Creek** commences to the south of the SMP Area, and generally flows in a northerly direction, to where it joins Cony Creek above proposed Longwall A5, and then generally flows in a westerly direction above proposed Longwalls A3 and A4. Quorrobolong Creek drains into Ellalong Lagoon, which is located at a distance of over 5 kilometres west of the SMP Area. Cony and Quorrobolong Creeks are alluvial based ephemeral creeks, having average natural gradients of less than 1 mm/m within the SMP Area.

There are numerous ephemeral drainage lines around and between the hills within the SMP Area, which are also shown in Drawing No. MSEC275-07. The drainage lines within the SMP Area flow into Cony and Quorrobolong Creeks.

2.5.4. Aquifers and Known Groundwater Resources

The ground water resources within the SMP Area occur in the shallow alluvial aquifers of Cony and Quorrobolong Creeks, and within the deeper Newcastle Coal Measures. Further descriptions of the aquifers within the SMP Area are provided in the report by Umwelt (2007).

2.5.5. Springs

There are no known springs within the SMP Area.

2.5.6. Sea or Lake

There are no seas, or lakes within the SMP Area.

2.5.7. Shorelines

There are no shorelines within the SMP Area.

2.5.8. Natural Dams

There are no natural dams within the SMP Area. There are, however, a number of farm dams within the SMP Area, which are described in Section 2.8.10.

2.5.9. Cliffs or Pagodas

There are no cliffs, or pagodas within the SMP Area.

2.5.10. Steep Slopes

For the purposes of this report, a steep slope has been defined as an area of land having a natural gradient greater than 1 in 3 (ie: a grade of 33 %, or an angle to the horizontal of 18°). The reason for identifying steep slopes is to highlight areas in which existing ground slopes are considered to be marginally stable.

The minimum grade of 1 to 3 represents a slope that would generally be considered stable for slopes consisting of rocky soils or loose rock fragments. Clearly the stability of natural slopes varies depending on their soil or rock types, and in many cases, natural slopes are stable at much higher gradients than 1 to 3.

The steep slopes within the SMP Area were identified from the 1 metre surface contours which were generated from an aerial laser scan of the area. There were two areas identified as having steep slopes which are shown in Drawing No. MSEC275-07. The steep slopes are located on the southern side of the hill above proposed Longwalls A3 and A4, and on the south-eastern side of the hill north of proposed Longwall A3.

2.5.11. Escarpments

There are no escarpments within the SMP Area.

2.5.12. Land Prone to Flooding or Inundation

The natural gradients along the alignments of Cony and Quorrobolong Creeks are very flat and are prone to flooding and inundation. A detailed flood study of the area has been undertaken and is described in the report by Umwelt (2007).

2.5.13. Swamps, Wetlands and Water-Related Ecosystems

There are no swamps or wetlands within the SMP Area. There are, however, a number of ponding areas along the alignments of Cony and Quorrobolong Creeks within the SMP Area, which are described in the report by Umwelt (2007).

2.5.14. Threatened, Protected Species or Critical Habitats

There are no lands within the SMP Area that have been declared as critical habitat under the *Threatened Species Conservation Act 1995*.

2.5.15. National Parks or Wilderness Areas

There are no National Parks, or any land identified as wilderness under the *Wilderness Act 1987* within the SMP Area.

2.5.16. State Recreation Areas or State Conservation Areas

At the time of this report, there were no State Recreation Areas, or State Conservation Areas within the SMP Area. It is planned, however, for the Aberdare State Forest to become a State Conservation Area, which is described in Section 2.5.17.

2.5.17. State Forests

The SMP Area is partly located within the **Aberdare State Forest**, which is located on the northern side of Nash Lane. It is planned for the Aberdare State Forest to become the **Wereakata State Conservation Area**. The National Parks Estate (Lower Hunter Region Reservations) Bill 2006 has been passed through both houses of parliament, and is currently awaiting assent, which is likely to occur prior to the extraction of the proposed longwalls.

2.5.18. Natural Vegetation

There is undisturbed native bushland within the SMP Area on the northern side of Nash Lane, within the *Aberdare State Forrest*. The land within the SMP Area on the southern side of Nash Lane has generally been cleared for agricultural utilisation, however, there is native bush along the alignments of Cony and Quorrobolong Creeks.

2.5.19. Areas of Significant Geological Interest

There are no areas of significant geological interest within the SMP Area.

2.5.20. Any Other Natural Feature Considered Significant

There are no other natural features considered significant within the SMP Area.

2.6. Public Utilities

2.6.1. Railways

There are no railways within the SMP Area.

2.6.2. Roads

The locations of the public roads within the vicinity of the proposed longwalls are shown in Drawing No. MSEC275-08. There are two public roads within the SMP Area, both of which are unsealed.

Nash Lane crosses directly above the proposed Longwalls A3 and A4, and provides access from the rural properties within the SMP Area to Quorrobolong Road, which is located 500 metres east of the SMP Area. Nash Lane is closed to public access just to the west of the SMP Area. **Pelton Fire Trail** crosses the northern corner of the SMP Area, which is an unsealed trail used for fire fighting purposes within the Aberdare State Forest. The private driveways on the rural properties within the SMP Area are all unsealed.

Sandy Creek Road and **Quorrobolong Road** are located just outside the SMP Area, at distances of 290 metres south and 440 metres east of the SMP Area, respectively, and will not be subjected to any systematic subsidence impacts.

2.6.3. Bridges

There are no bridges within the SMP Area.

2.6.4. Tunnels

There are no tunnels within the SMP Area.

2.6.5. Drainage Culverts

There is one identified drainage culvert on public land within the SMP Area. The 300 mm diameter concrete culvert is located under a private driveway, adjacent to Nash Lane, the location of which is shown in Drawing No. MSEC275-08. The culverts on private land within the SMP Area are described in the Property Subsidence Management Plans (PSMP) for each rural property.

2.6.6. Water Services

There is a privately owned water pipeline which follows the alignment of Nash Lane within the SMP Area, the location of which is shown in Drawing No. MSEC275-08. The extent of the pipeline within the SMP Area is not known and, therefore, the pipeline has been assumed to follow the full extent of Nash Lane within the SMP Area. The type of construction is not known, however, the pipeline is likely to be a Polyvinyl-Chloride (PVC) or Polyethylene (PE) pipeline.

The rural properties within the SMP Area also have local water pipelines to the dams and private rainwater tanks, which are described in the Property Subsidence Management Plans (PSMP).

2.6.7. Sewerage Pipelines and Sewerage Treatment Works

There are no sewerage pipelines, or sewage treatment works within the SMP Area. The properties within the SMP Area have local sewer connections to septic tanks, or package treatment plants, which are described in the Property Subsidence Management Plans (PSMP).

2.6.8. Gas Pipelines

There are no gas pipelines within the SMP Area.

2.6.9. Liquid Fuel Pipelines

There are no liquid fuel pipelines within the SMP Area.

2.6.10. Electricity Transmission Lines and Associated Plants

The locations of the electrical services within the SMP Area are shown in Drawing No. MSEC275-08. The electrical services, which are owned by Energy Australia, comprise of above ground 11 kV powerlines supported by timber poles. The poles have unique identification numbers which have been shown in Drawing No. MSEC275-08.

2.6.11. Telecommunication Lines and Associated Plants

The locations of the telecommunications services within the SMP Area are shown in Drawing No. MSEC275-08. The telecommunication services, which are owned by Telstra, comprise of direct buried local copper cables. There are no main copper cables, or optical fibre cables within the SMP Area.

2.6.12. Water Tanks, Water and Sewerage Treatment Works

There are no public water or sewerage treatment works within the SMP Area.

2.6.13. Dams, Reservoirs or Associated Works

There are no public dams, reservoirs, or associated works within the SMP Area.

2.6.14. Air Strips

There are no air strips within the SMP Area.

2.6.15. Any Other Public Utilities

There are no other public utilities within the SMP Area.

2.7. Public Amenities

2.7.1. Hospitals

There are no hospitals within the SMP Area.

2.7.2. Places of Worship

There are no places of worship within the SMP Area.

2.7.3. Schools

There are no schools within the SMP Area.

2.7.4. Shopping Centres

There are no shopping centres within the SMP Area.

2.7.5. Community Centres

There are no community centres within the SMP Area.

2.7.6. Office Buildings

There are no office buildings within the SMP Area.

2.7.7. Swimming Pools

There are no public swimming pools within the SMP Area.

2.7.8. Bowling Greens

There are no bowling greens within the SMP Area.

2.7.9. Ovals or Cricket Grounds

There are no ovals or cricket grounds within the SMP Area.

2.7.10. Race Courses

There are no race courses within the SMP Area.

2.7.11. Golf Courses

There are no golf courses within the SMP Area.

2.7.12. Tennis Courts

There are no public tennis courts within the SMP Area. There is, however, one privately owned tennis court which is described in Section 2.13.5.

2.7.13. Any Other Public Amenities

There are no other public amenities within the SMP Area.

2.8. Farm Land and Facilities

2.8.1. Agriculture Utilisation and Agriculture Improvements

The land within the SMP Area, south of Nash Lane, has predominately been cleared for agricultural utilisation. There are a number of vineyards and crops on the rural properties within the SMP Area which are shown in Drawing No. MSEC275-09. The vineyards contain trellises and drip irrigation systems, which are described in the Property Subsidence Management Plans (PSMP).

2.8.2. Farm Buildings and Sheds

There are 16 rural building structures (Structure Type R) that have been identified within the SMP Area, which include sheds, garages, and other non-residential building structures. There are a further 14 rural building structures which are on land partially located within the SMP Area, however, the structures themselves are located outside the SMP Area.

The locations of the rural building structures within the SMP Area are shown in Drawing No. MSEC275-09 and details are provided in Table G.01 in Appendix G. The locations, sizes, and details of the rural building structures were determined from an aerial photograph of the area and from site investigations.

2.8.3. Tanks

There are a number of tanks (Structure Type T) located on the rural properties within the SMP Area. The locations of the larger tanks within the SMP Area are shown in Drawing No. MSEC275-09 and details provided in Table 2.3.

Table 2.3 Details of the Larger Tanks within the SMP Area

Structure ID	Approximate MGA Easting (m)	Approximate MGA Northing (m)	Description
A02t01	345660	6356935	Concrete Water Tank
A02t02	345510	6356830	Elevated Water Tank Stand
A04t01	345935	6357565	Concrete Water Tank
A04t02	345933	6357550	Concrete Water Tank
A04t03	345885	6357590	Elevated Fuel Tank
A11t01	346040	6358200	Concrete Water Tank

There are also rainwater tanks associated with the residences on each rural property. The locations and details of the rainwater tanks are provided in the Property Subsidence Management Plans (PSMP) for each rural property.

2.8.4. Gas and/or Fuel Storages

There is one identified fuel tank within the SMP Area, details of which are provided in Section 2.8.3.

2.8.5. Poultry Sheds

There are no known poultry sheds within the SMP Area.

2.8.6. Glass Houses

There are no known glass houses within the SMP Area.

2.8.7. Hydroponic Systems

There are no known hydroponic systems within the SMP Area.

2.8.8. Irrigation Systems

There are irrigation systems within the SMP Area associated with the vineyards on the rural properties. The irrigation systems are described in the Property Subsidence Management Plans (PSMP).

2.8.9. Fences

A number of fences have been identified within the SMP Area. The majority of fences mark property boundaries and are constructed with timber or steel posts and with fencing wire or timber railings.

2.8.10. Farm Dams

A total of 23 farm dams (Structure Type D) have been identified within the SMP Area. The locations of the farm dams within the SMP Area are shown in Drawing No. MSEC275-09 and the details of each farm dam are provided in Table G.04 in Appendix G.

The maximum lengths of the farm dams vary between 17 and 185 metres, and the surface areas of the farm dams vary between 120 and 9300 m^2. The dams are generally of earthen construction, and have been established by localised cut and fill operations within the natural drainage lines. The farm dams are generally shallow, with the dam wall heights generally being less than 3 metres.

2.8.11. Wells and Bores

There are no registered water bores within the general SMP Area. There is, however, one registered water bore (Ref. GW054676) which is located just outside the general SMP Area, which is shown in Drawing No. MSEC275-08. The bore is 40 metres deep and the authorised use of the bore is for stock. The location and details of the water bore was provided by the Department of Natural Resources (DNR).

Discussions between Austar and the private owner of Bore GW054676 indicates that the bore is low yielding (approx. 1 L/sec) and poor quality (appox. 14,000 ~ 16,000 µS/cm), and is only left open for DNR baseline monitoring. The water is unsuitable for domestic or stock use.

2.8.12. Any Other Farm Features

There are no other significant farm features within the SMP Area.

2.9. Industrial, Commercial and Business Establishments

2.9.1. Factories

There are no factories within the SMP Area.

2.9.2. Workshops

There are no workshops within the SMP Area.

2.9.3. Business or Commercial Establishments or Improvements

The rural properties Refs. A01 and A02 are cattle breeders which are discussed in the Property Subsidence Management Plans (PSMP) of these properties. There are also vineyards located on the rural properties within the SMP Area which are described in Section 2.8.1 and in the Property Subsidence Management Plans (PSMP). There are no other known businesses or commercial establishments within the SMP Area.

2.9.4. Gas or Fuel Storages and Associated Plant

There are no known gas or fuel storages, or associated plant within the SMP Area.

2.9.5. Waste Storages and Associated Plant

There are no waste storages, or associated plant within the SMP Area.

2.9.6. Buildings, Equipment or Operations that are Sensitive to Surface Movements

There are no known buildings, equipment or operations that are sensitive to surface movements within the SMP Area.

2.9.7. Surface Mining (Open Cut) Voids and Rehabilitated Areas

There are no surface mining, or rehabilitation areas within the SMP Area.

2.9.8. Mine Infrastructure Including Tailings Dams or Emplacement Areas

There is no mine infrastructure within the SMP Area.

2.9.9. Any Other Industrial, Commercial or Business Features

There are no other industrial, or commercial, or business features within the SMP Area.

2.10. Areas of Archaeological or Heritage Significance

2.10.1. Items of Archaeological Significance

Descriptions of archaeological sites within the SMP Area are provided in the reports by HLA (1995) and by Umwelt (2007).

2.10.2. Items of Heritage Significance

Descriptions of any heritage sites within the SMP Area are provided in the reports by HLA (1995) and by Umwelt (2007).

2.10.3. Items on the Register of the National Estate

There are no items on the Register of National Estate within the SMP Area.

2.11. Items of Architectural Significance

There are no items of architectural significance within the SMP Area.

2.12. Permanent Survey Control Marks

There are no survey control marks within the general SMP Area. There are, however, a number of survey control marks located just outside the general SMP Area, primarily along Sandy Creek Road, which are shown in Drawing No. MSEC275-08. The survey control marks adjacent to the general SMP Area could be subjected to far-field movements and have, therefore, been included as part of the SMP Area.

2.13. Residential Establishments

2.13.1. Houses

There are seven houses located within the SMP Area, of which four are single-storey houses with lengths less than 30 metres (Type H1), and three are single-storey houses with lengths greater than 30 metres (Type H2). There are no double-storey houses (Types H3 and H4) within the SMP Area. The locations of the houses are shown in Drawing No. MSEC275-09 and the details of each house are provided in Table G.01 in Appendix G.

2.13.2. Flats or Units

There are no flats or units within the SMP Area.

2.13.3. Caravan Parks

There are no caravan parks within the SMP Area.

2.13.4. Retirement or Aged Care Villages

There are no retirement or aged care villages within the SMP Area.

2.13.5. Any Other Associated Structures

Refer to Sections 2.8.2 and 2.8.3 for the descriptions of rural building structures and tanks. There are two privately owned swimming pools within the SMP Area, being Structures Refs. A01p01 and A11p01, the locations of which are shown in Drawing No. MSEC275-09. There is one privately owned tennis court within the SMP Area, being Structure Ref. A01i, the location of which is also shown in Drawing No. MSEC275-09.

The houses on each rural property within the SMP Area have septic tanks. There are also private pipelines on the rural properties within the SMP Area connecting with the farm dams and private water tanks which are described in the Property Subsidence Management Plans (PSMP).

2.13.6. Any Other Residential Feature

There are no other significant residential features within the SMP Area.

2.14. Any Other Items

There are no other significant items within the SMP Area.

2.15. Any Known Future Developments

There are no known future developments within the SMP Area.

CHAPTER 3. OVERVIEW OF LONGWALL TOP COAL CAVING, THE DEVELOPMENT OF SUBSIDENCE, AND THE METHOD USED TO PREDICT THE MINE SUBSIDENCE PARAMETERS FOR THE PROPOSED LONGWALLS

3.1. Introduction

This chapter provides a brief overview of longwall top coal caving, the development of mine subsidence, and the method that has been used to predict the subsidence movements for the proposed Longwalls A3 to A5 at the project. Detailed descriptions of longwall mining and the development of subsidence are provided in Appendix C of this report. Detailed descriptions of methods used to predict mine subsidence movements are provided in Appendix D of this report.

The maximum predicted and maximum upperbound systematic subsidence parameters within the SMP Area resulting from the extraction of the proposed longwalls are provided in Chapter 4. The predicted and upperbound subsidence parameters and impact assessments for the natural features and items of surface infrastructure within the SMP Area are provided in Chapter 5.

3.1.1. Overview of Longwall Top Coal Caving

Longwall Top Coal Caving (LTCC) has been developed in China over the past 20 years, and is capable of extracting seam thicknesses between 4.5 and 12.5 metres. Austar Longwalls A1 and A2 have been approved to use LTCC mining techniques, and are the first in Australia to use such technology. Austar Longwalls A3 to A5 are also proposed to be extracted using LTCC mining techniques.

Austar Longwalls A3 to A5 are proposed to be extracted from the Greta Seam, where the seam thickness locally varies between 4.8 and 6.8 metres. The LTCC equipment, however, is proposed to extract a maximum seam height of 6.5 metres. A typical cross-section through one of the proposed Austar Longwalls A3 to A5 is shown in Fig. 3.1.

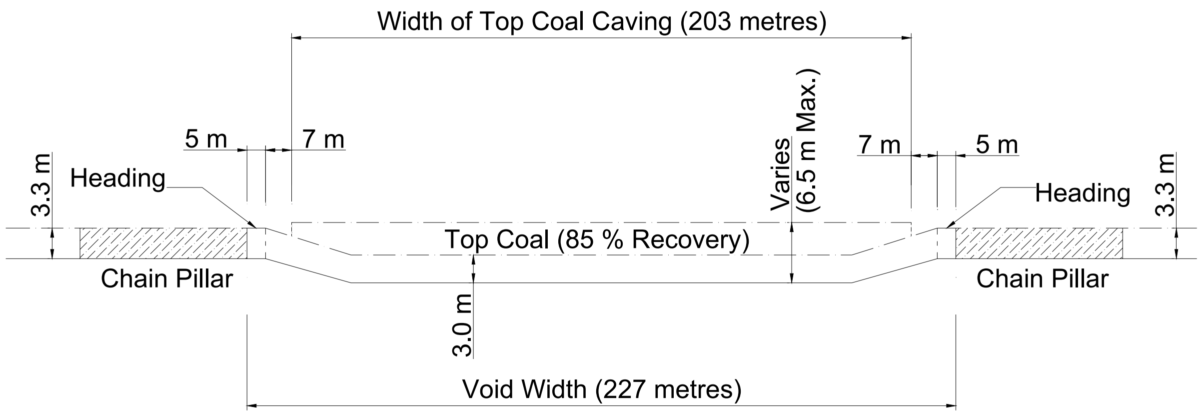

Fig. 3.1 Cross-Section through a Typical Proposed Austar Longwall A3 to A5

The development headings are initially extracted using continuous miners, and are 5 metres wide and 3.3 metres high. The headings are extracted above the seam floor, so that the floor of the longwall panel can be tapered down, as shown in the above figure, having a 1.3 metre drop over a horizontal distance of 23 metres from the headings.

The LTCC equipment uses a conventional longwall shearer to extract the bottom 3 metres of the coal seam, which is transported from the coal face by a face conveyor. The LTCC equipment uses specially designed shields with retractable flippers to allow the coal in the roof to cave behind the shields, which is transported by a second conveyor located behind the shields. A recovery of approximately 85 % of the top coal is generally achieved within the void width which is 12 metres clear of each chain pillar. Although it is proposed to extract a seam height of between 4.8 and 6.5 metres, the extracted seam height adjacent to the proposed chain pillars is only 3.3 metres.

The strata behind the shields, immediately above the coal seam, is allowed to collapse into the void that is left as the coal face retreats. The collapsed zone comprises of loose blocks and can contain large voids. Immediately above the collapsed zone, the strata remains relatively intact and bends into the void, resulting in new vertical factures, opening up of existing vertical fractures, and bed separation. The amount of strata sagging, fracturing, and bed separation reduces towards the surface.

At the surface, the ground subsides vertically as well as moves horizontally towards the centre of the mined goaf area. The maximum subsidence at the surface varies, depends on a number of factors including longwall geometry, depth of cover, extracted seam thickness, and geology. The maximum possible subsidence in the Newcastle Coalfield is typically between 55 to 65 % of the extracted seam thickness.

3.2. Overview of Systematic Subsidence Parameters

The normal ground movements resulting from the extraction of pillars or longwalls are referred to as systematic subsidence movements. These movements are described by the following parameters:-

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.
- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres (1/km)*, but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.
- **Strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile Strains** occur where the distance between two points increases and **Compressive Strains** occur when the distance between two points decreases. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

A cross-section through a typical single longwall panel showing typical profiles of subsidence, tilt, curvature and strain is provided in Fig. 3.2.

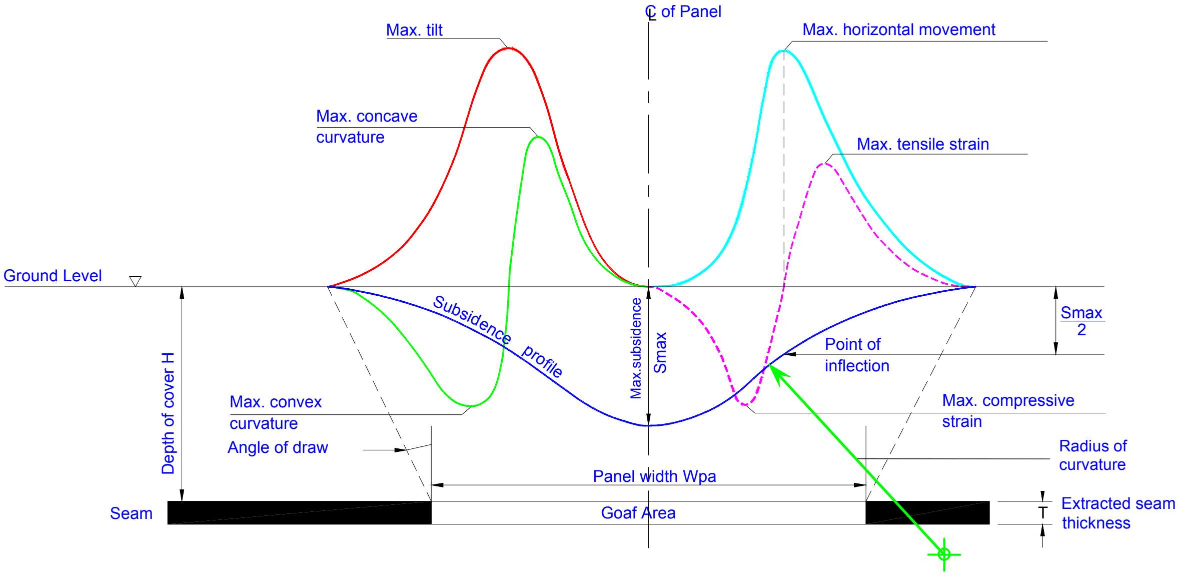

Fig. 3.2 Typical Profiles of Systematic Subsidence Parameters for a Single Longwall Panel

The predicted incremental subsidence, tilts, curvatures and strains are the additional parameters which result from the extraction of each longwall. The predicted cumulative subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of a series of longwalls.

3.3. Overview of Non-Systematic Subsidence Movements

Non-systematic subsidence movements include regional horizontal movements, irregular subsidence movements, and valley related movements. These movements are briefly described below, with more detailed descriptions provided in Appendix D.

3.3.1. Regional Horizontal Movements

In addition to the systematic horizontal movements which occur above and adjacent to extracted longwalls, regional horizontal movements have been observed at considerable distances from extracted longwalls. Such movements are predictable and occur whenever significant excavations occur at the surface or underground.

Regional horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain. These movements generally do not result in impact, except where they occur at large structures which are very sensitive to differential horizontal movements.

Detailed descriptions of regional horizontal movements, and the method used to predict such movements, are provided in Section 5.19.2 and Appendix D.5.9.

3.3.2. Irregular Subsidence Movements

Irregular subsidence movements can result from near surface geological structures, including faults, dykes, and abrupt changes in geology. The presence of these features near the surface can result in a bump in the subsidence profile, which is accompanied by locally higher tilts and strains.

Irregular subsidence movements can also occur at shallow depths of cover, where the collapsed zone above the extracted longwalls extends near to the surface. In this situation, the resulting subsidence profile become very erratic, which is accompanied by higher tilts and strains. This type of irregular subsidence movement is generally only seen where the depth of cover is less than 100 metres and is unlikely to occur above the proposed longwalls, as the depth of cover generally exceeds 500 metres.

The non-systematic tilts and strains resulting from irregular subsidence movements can be much greater than those resulting from the normal systematic subsidence movements. Irregular subsidence movements, and the impacts resulting from such movements, are described in Section 5.19.7 and Appendices D.5.8 and D.6.

3.3.3. Valley Related Movements

The creeks and tributaries within the SMP Area may also be subjected to valley related movements, which are commonly observed along river and creek alignments in the Southern Coalfield, but less commonly observed in the Newcastle Coalfield. The reason that valley related movements are less commonly observed in the Newcastle Coalfield could be that systematic subsidence movements are typically much larger than those observed in the Southern Coalfield which tend to mask any smaller valley related movements which may occur.

Valley related movements are a natural phenomenon, resulting from the formation and ongoing development of the valley, as illustrated in Fig. 3.3.

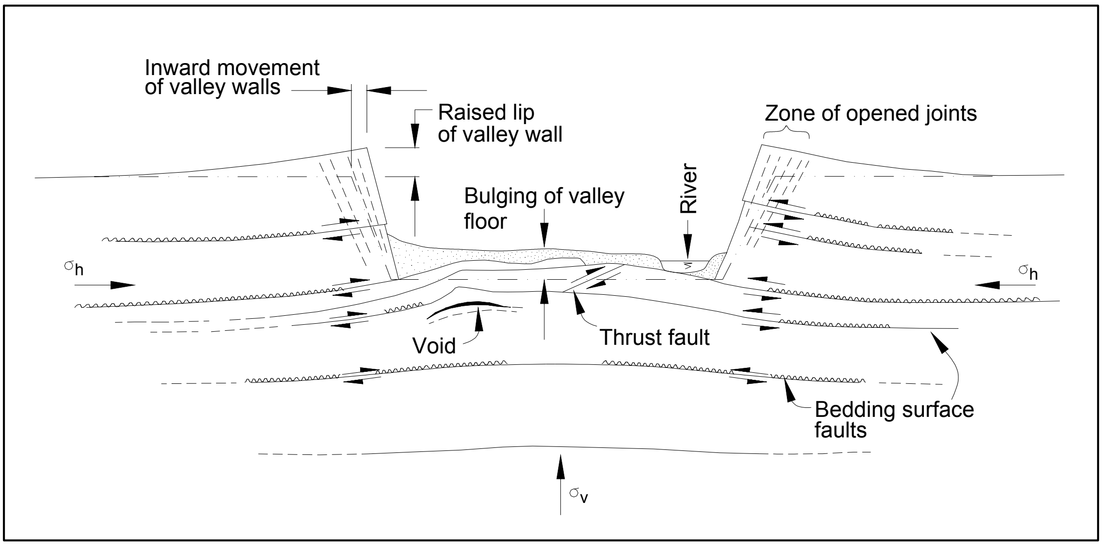

Fig. 3.3 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

Valley related movements can be accelerated by mine subsidence, and are described by the following parameters:-

- **Upsidence** is the reduced subsidence, or the net vertical movement within the base of a valley, and is typically expressed in units of *millimetres (mm)*. Upsidence results from the buckling of near surface strata in the base of the valley which results from the redistribution of, and increase in the horizontal stresses around the collapsed zones above extracted longwalls.
- **Closure** is the reduction in horizontal distance between the valley sides, and is expressed in units of *millimetres (mm)*. Closure also results from the redistribution of, and increase in the horizontal stresses around the collapsed zones above extracted longwalls.
- **Compressive Strains** occur within the valley as the result of valley closure and are calculated as the decrease in horizontal distance over a standard bay length, divided by the original bay length. **Tensile Strains** also occur adjacent to the valley as the result of valley closure, and are calculated as the increase in horizontal distance over a standard bay length, divided by the original bay length. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20. Compressive and tensile strains due to valley closure are typically expressed in units of *millimetres per metre (mm/m)*.

The predicted valley related movements resulting from the extraction of the proposed longwalls at the project were made using the empirical method outlined in ACARP Research Project No. C9067 (Waddington 2004). A detailed description of valley related movements, and the method used to predict such movements, are provided in Appendices D.5.3 to D.5.7.

3.4. The Incremental Profile Method

The predicted systematic subsidence parameters for the proposed Austar Longwalls A3 to A5 were made using the Incremental Profile Method. The Incremental Profile Method is an empirical model which was developed by MSEC, when previously trading as Waddington Kay and Associates. The standard Incremental Profile Method is briefly described below, with further details provided in Appendix D.

The standard Incremental Profile Method is based on a large database of observed monitoring data from previously extracted longwalls within the Southern, Newcastle, Hunter and Western Coalfields of New South Wales. The database consists of detailed subsidence monitoring data from Collieries including: Angus Place, Appin, Baal Bone, Bellambi, Beltana, Bulli, Chain Valley, Clarence, Coalcliff, Cooranbong, Cordeaux, Corrimal, Cumnock, Dartbrook, Delta, Dendrobium, Eastern Main, Ellalong (now Austar), Fernbrook, Glennies Creek, Gretley, Invincible, John Darling, Kemira, Lambton, Liddell, Metropolitan, Mt. Kembla, Munmorah, Nardell, Newpac, Newstan, Newvale, Newvale 2, South Bulga, South Bulli, Stockton Borehole, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, West Cliff, West Wallsend and Wyee.

The empirical database includes observed subsidence profiles based on extraction heights varying from less than 2 metres up to 5 metres. Of these observed subsidence profiles, 7 % are for cases having seam extraction heights of less than 2 metres, 74 % are for cases having seam extraction heights between 2 and 3 metres, 15 % are for cases having seam extraction heights between 3 and 4 metres, and 4 % are for cases having seam extraction heights between 4 and 5 metres.

Using the observed monitoring data, MSEC has developed a large database of observed incremental subsidence profiles, which are the additional observed subsidence profiles which resulted from the extraction of each longwall within a series of longwalls. It can be seen from the normalised incremental subsidence profiles within the database, that the observed shapes and magnitudes are reasonably consistent where the mining geometry and local geology are similar.

Subsidence predictions made using the Incremental Profile Method use the database of observed incremental subsidence profiles, the proposed longwall geometries, local surface and seam information, and geology. The method has a tendency to over-predict the systematic subsidence parameters, ie: is slightly conservative, where the proposed mining geometry and geology are within the range of the empirical database. The predictions are often tailored to local conditions where observed monitoring data is available close to the proposed mining area.

There is detailed survey monitoring data over the previously extracted longwalls at the Colliery and, hence, the Incremental Profile Method was calibrated to the local monitoring data, which is described in the following section.

3.4.1. Calibration of the Incremental Profile Method

Austar and Strata Control Technology (SCT) provided local monitoring data over the previously extracted longwalls at the Colliery, which includes Longwalls SL1 to SL4 and Longwalls 1 to 13A. The locations of the previously extracted longwalls at the Colliery and the subsidence monitoring lines are shown in Drawing No. MSEC275-01.

The previously extracted longwalls at the Colliery have void widths varying between 155 and 225 metres, depths of cover varying between 350 and 510 metres, and extracted seam thicknesses varying between 3.1 and 3.5 metres at the monitoring line locations.

Two meetings between Austar, MSEC, and SCT occurred on the 1st August and 26th September 2006. At the meetings and in subsequent discussions, SCT provided additional background information on the project, and were involved in the discussions on potential subsidence mechanisms, methods of prediction for top coal caving, shapes of predicted subsidence profiles, and experience of subsidence modelling for Austar Longwalls A1 and A2 and for thick seam extractions on other projects.

Initially, the magnitudes and shapes of the observed incremental subsidence profiles along each monitoring line were compared with the back-predicted subsidence profiles obtained using the standard Incremental Profile Method, which is based on the typical Newcastle Coalfield subsidence profiles.

The back-predictions made using the standard Incremental Profile Method used the longwall void widths and solid chain pillar widths, and used the local depths of cover and extracted seam thicknesses at the locations of the monitoring lines. The standard Incremental Profile Method was not modified for the presence of any thick massive strata units, or for the presence of other known geological structures at seam level.

It is possible to further refine the predictions made using the Incremental Profile Method based on the performance of the chain pillars, where the pillars behave differently from those within the empirical database, and where advice is provided by the relevant experts in pillar design. The predictions made using the standard Incremental Profile Method were not modified for varying strengths of coal in the chain pillars, or for varying strengths of the seam floor and seam roof. These refinements were not made in the model, as the refined predictions would not exceed those obtained for the upperbound case, as described in Section 3.6, which were used in the impact assessments for the natural features and surface infrastructure above the proposed longwalls.

It was found that the maximum observed incremental subsidence for the previously extracted longwalls along each monitoring line were less than the maximum back-predicted incremental subsidence obtained using the standard Incremental Profile Method, as shown in Fig. F.09 in Appendix F. That is, the back-predictions made for the longwalls along each monitoring line made using the standard Incremental Profile Method were greater than those observed.

It was also found that the observed incremental subsidence profiles along the monitoring lines were slightly wider, and that the points of maximum observed subsidence were located closer to the longwall tailgates, than for the back-predicted incremental subsidence profiles obtained using the standard Incremental Profile Method. Similar changes in the widths of the predicted subsidence profiles, and similar shifts in the positions of maximum predicted subsidence occur when comparing the shapes of predicted incremental subsidence profiles for varying panel width-to-depth ratios, which is illustrated in Fig. 3.4.

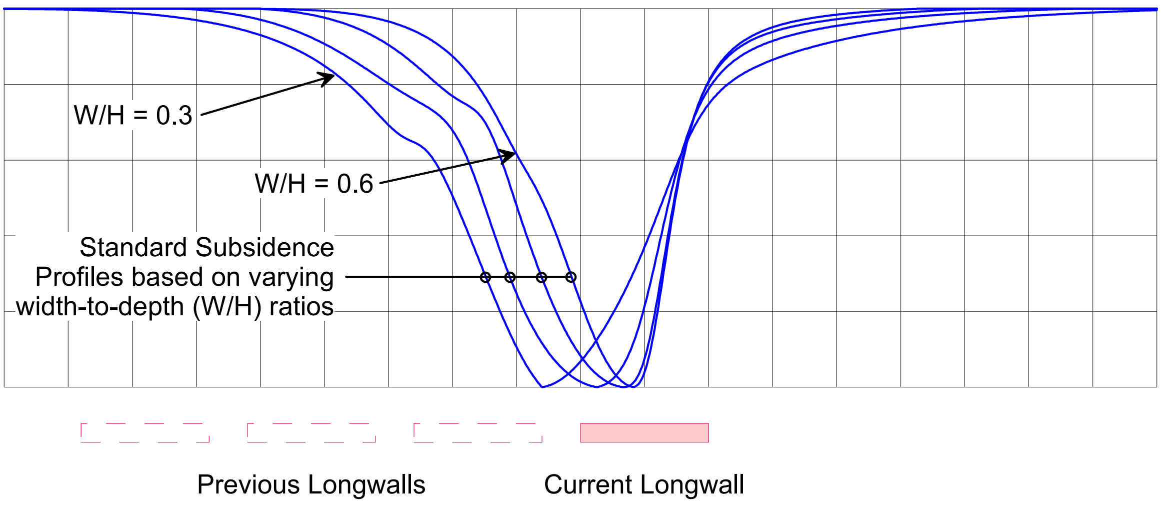

Fig. 3.4 Standard Normalised Profiles based on Varying Width-to-Depth Ratios

It was found, therefore, that the shapes of the back-predicted incremental subsidence profiles along each monitoring line could be made to more closely match those observed, by adopting the standard Newcastle Coalfield subsidence profiles based on smaller panel width-to-depth ratios. The observed incremental subsidence profiles along each monitoring line were then compared with a range of back-predicted incremental subsidence profiles using the standard Newcastle Coalfield profiles using varying panel width-to-depth ratios. No modifications were made to the magnitudes of the maximum back-predicted incremental subsidence for each longwall.

It was found that the shapes of the back-predicted incremental subsidence profiles closely matched the observed incremental subsidence profiles by adopting the standard Newcastle Coalfield subsidence profiles based on a panel width-to-depth ratio of 0.3, rather than adopting the actual panel width-to-depth ratios, which varied between 0.38 and 0.65.

The angle of draw to the predicted total 20 mm subsidence contour, obtained using the Incremental Profile Method, was also calibrated to 30 degrees adjacent the longitudinal edges of the longwalls, so as to match those observed over the previously extracted longwalls at the Colliery.

The comparisons between the observed subsidence profiles along each monitoring line, and the back-predicted subsidence profiles obtained using the standard Newcastle Coalfield profiles based on a width-to-depth ratio of 0.3, are shown in Figs. F.01 to F.08 in Appendix F. It can be seen from these figures, that the shapes of the back-predicted profiles closely match those observed along each monitoring line.

It can also be seen from these figures that the maximum back-predicted incremental subsidence for each longwall is greater than the maximum observed incremental subsidence. A comparison between maximum back-predicted and maximum observed incremental subsidence for each longwall is provided in Fig. F.09 in Appendix F.

The maximum observed incremental subsidence is generally between 45 % and 100 % of the maximum back-predicted incremental subsidence. In no case did the maximum observed incremental subsidence, or maximum observed total subsidence exceed the maximum back-predicted incremental subsidence, or the maximum back-predicted total subsidence, respectively. The variations in the ratios of maximum observed versus maximum predicted subsidence, as shown in Fig. F.09, are due to the varying longwall geometries, depths of cover, extracted seam heights, and geologies at the locations of each monitoring line.

3.5. Systematic Subsidence Predictions for the Proposed Longwalls A3 to A5

The predicted systematic subsidence parameters for the proposed Austar Longwalls A3 to A5 were made using the calibrated Incremental Profile Method, which adopts the standard Newcastle Coalfield subsidence profiles based on a panel width-to-depth ratio of 0.3. No subsidence reduction factors were applied to the predictions due to the presence of any thick massive strata units.

Predictions were made at points on a regular grid orientated north-south and east-west across the SMP Area. A grid spacing of 10 metres in each direction was adopted, which provides sufficient resolution for the generation of systematic subsidence, tilt and strain contours.

Two separate subsidence models were combined to predict the systematic subsidence parameters for the proposed longwalls. The first model predicted the systematic subsidence parameters resulting from the extraction of the bottom coal, and a second model predicted the systematic subsidence parameters resulting from the recovery of the top coal.

The subsidence models use the mining geometry, surface level contours, seam floor contours, and seam thickness contours to make predictions across the SMP Area. The surface level, seam floor and seam thickness contours were provided by Austar and are shown in Drawings Nos. MSEC275-02, MSEC275-03, and MSEC275-04, respectively.

The bottom coal subsidence model adopted longwall void widths of 227 metres, chain pillar widths of 45 metres, and an extraction height of 3 metres. The top coal subsidence model adopted longwall void widths of 203 metres, effective chain pillar widths of 45 metres, and an extraction height varying between 1.8 and 3.5 metres, of which only 85 % of the top coal is recovered.

Although the overall extraction height varies up to 6.5 metres, the height of the chain pillars are 3.3 metres, giving a slenderness (height-to-width) ratio of 1 in 14, which is within the range of the empirical database. The maximum equivalent extraction height of 6.0 metres (ie: 3 metres of bottom coal plus 85 % of 3.5 metres of top coal) is greater than the extraction heights for the cases within the empirical database, which includes extraction heights up to 5 metres.

As the maximum proposed equivalent extraction height is slightly greater than those within the empirical database, the relationship between chain pillar squashing and goafing may be different to the cases within the empirical database. An additional subsidence factor has, therefore, been applied to the top coal subsidence model which increases the maximum predicted incremental subsidence to that which is achieved for the extraction of the full void width of 227 metres. A summary of the subsidence factors for the top coal subsidence model are provided in Table 3.1.

Table 3.1 Additional Subsidence Factors for the Top Coal Subsidence Model

Subsidence Model	Longwall	Additional Subsidence Factor
Top Coal Caving	LWA3	1.5
	LWA4	1.2
	LWA5	1.2

The predicted systematic subsidence parameters for the proposed longwalls are the addition of the parameters obtained from the bottom coal subsidence model and the top coal subsidence model.

It has been recognised that the maximum equivalent extraction height for proposed longwalls is greater than those in the empirical database, and greater than those at the previously extracted longwalls at the Colliery. A conservative upperbound case has also been assessed in this report for risk management purposes, therefore, which is described in the following section.

3.6. Upperbound Case for the Proposed Longwalls

The thickness of the Greta Seam at the proposed longwalls varies between a minimum of 4.8 metres, at the south-western corner of proposed Longwall A5, and a maximum of 6.8 metres, at the north-eastern end of proposed Longwall A3. The LTCC equipment is proposed to extract a maximum seam height of 6.5 metres. It should also be noted, that the LTCC equipment is proposed to mine the bottom 3 metres of the seam, and recover only about 85 % of the top coal in the seam.

The maximum predicted total subsidence does not occur at the north-eastern end of proposed Longwall A3, where the seam thickness is the greatest, due to the longitudinal end effect of the longwall, and due to commencing ends of Longwalls A4 and A5 being staggered south of the end of Longwall A3. The maximum predicted total subsidence occurs midway along Longwalls A3 and A4, at the north-eastern most cross-section where Longwall A5 achieves the maximum re-activation of the goaf above Longwalls A3 and A4.

The seam thickness at the location of maximum predicted total subsidence is 6.0 metres, of which, only 85 % of the top coal is recovered. The equivalent extracted seam thickness at the location of maximum predicted total subsidence is, therefore, 5.55 metres (ie: 3 metres of bottom coal plus 85 % of 3 metres of top coal).

The empirical database for the Incremental Profile Method has 13 cases where the extracted seam height is greater than 4 metres, which includes one case where the extracted seam height was 4.8 metres, which occurred at West Wallsend Colliery, and another case where the extracted seam height was 5.0 metres, which occurred at Mandalong Colliery. It should also be noted that the extracted seam heights for the previously extracted longwalls at the Colliery, which were used to calibrate the Incremental Profile Method, varied between 3.1 metres and 3.5 metres.

It has been recognised, therefore, that the maximum equivalent extraction height for proposed Austar Longwalls A3 to A5 are greater than those in the empirical database, and greater than those at the previously extracted longwalls at the Colliery. A conservative Upperbound Case has also been assessed for the proposed longwalls, therefore, where the predictions and impact assessments have been undertaken assuming that the maximum possible total subsidence is achieved above the proposed longwalls. The maximum possible total subsidence at the surface resulting from longwall mining is less than extracted seam thickness, due to the formation of voids within the collapsed zone, dilation between spanning strata within the fractured zone, and the presence of the chain pillars.

The maximum observed subsidence at various Collieries within the New South Wales Coalfields are shown as the points in Fig. 3.5. All the points above 65 % seam thickness are for multi-seam extraction cases, where the re-activation of overlying goafs result in subsidence of up to 90 % of seam thickness. The multi-seam extraction cases are not relevant to the proposed Austar Longwalls A3 to A5, which are single-seam extractions. All the points below 65 % seam thickness are for single-seam extractions, which are relevant to proposed Austar Longwalls A3 to A5.

The blue lines in Fig. 3.5 are the National Coal Board prediction curves including multi-seam extraction cases and, therefore, are not relevant to proposed Austar Longwalls A3 to A5, which are single-seam extractions. The thick green and red lines are the Department's prediction curves for the Southern and Western Coalfields, which have a maximum subsidence of 65 % of seam thickness for supercritical conditions. The thick magenta line is the Department's prediction curve for the Newcastle Coalfield, which has a maximum subsidence of 58 % of seam thickness for supercritical conditions. The thin red and purple lines are the prediction curves used by the Incremental Profile Method for the Southern and Newcastle Coalfields, which have a maximum subsidence of 65 % of seam thickness for supercritical conditions.

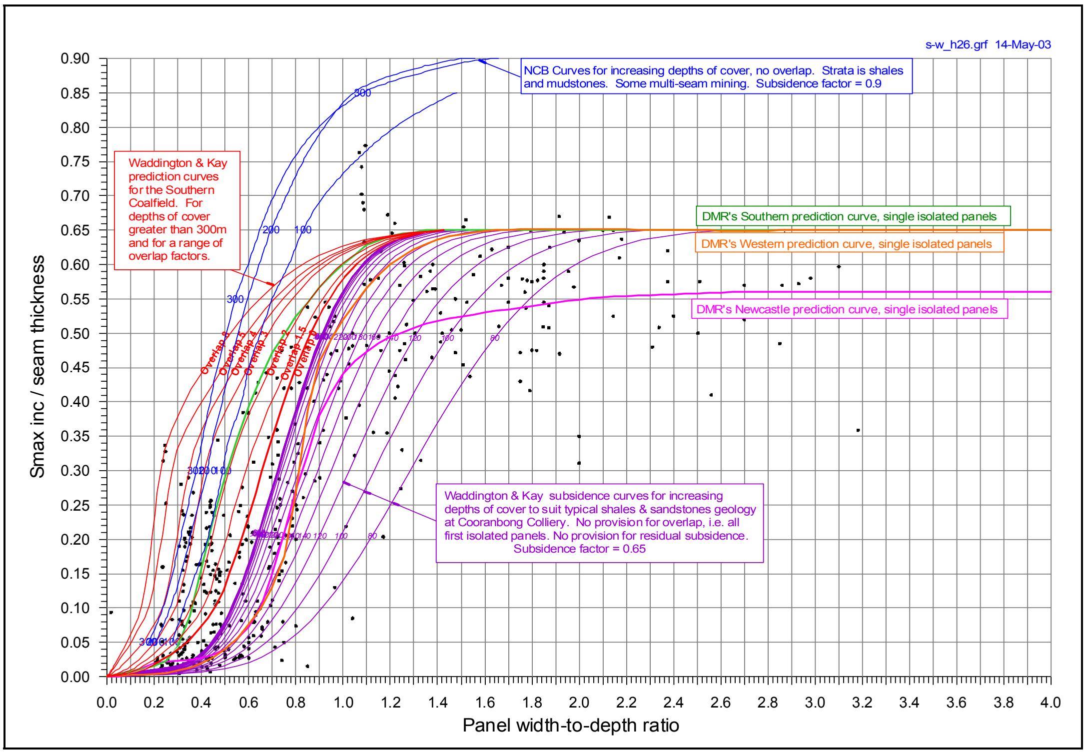

Fig. 3.5 Maximum Observed Subsidence in the New South Wales Coalfields

The Department's methods for the Southern and Western Coalfields, and the Incremental Profile Method prediction curves all have a maximum subsidence of 65 % of seam thickness for supercritical conditions. The Upperbound Case has, therefore, been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of the effective extracted seam thickness is achieved above the proposed longwalls. The effective extracted seam thickness is taken as the overall void area (ie: volume of the extracted coal), divided by the overall width of extraction. A cross-section through the proposed longwalls is shown in Fig. 3.6.

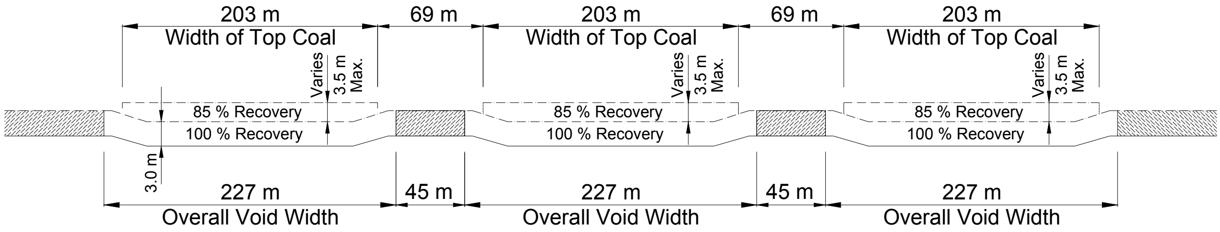

Fig. 3.6 Cross-section through the Proposed Longwalls A3 to A5

The effective extracted seam thickness is, therefore, calculated as follows:-

$$T_{eff} = \frac{100\% \times T_{BC} \times (227m + 227m + 227m) + 85\% \times T_{TC} \times (203m + 203m + 203m)}{227m + 45m + 227m + 45m + 227m}$$

where T_{BC} = 3.0 metres (Thickness of bottom coal)
T_{TC} = 1.8 ~ 3.5 metres (Thickness of top coal)

Using the above equation, the effective extracted seam thickness above the proposed longwalls varies between a minimum of 3.86 metres, at the south-western end of proposed Longwall A5, and a maximum of 5.0 metres, at the north-eastern end of proposed Longwall A3. The Upperbound Case has been determined by scaling up the predicted systematic subsidence parameters, such that a maximum subsidence of 65 % of effective extracted seam thickness is achieved above the proposed longwalls.

Predictions and impact assessments for the natural features and items of infrastructure have been made in this report for both the Predicted and the Upperbound Cases. Based on all the observed monitoring data within the New South Wales Coalfields, it is unlikely that the maximum total upperbound subsidence of 65 % of effective extracted seam thickness would be exceeded for the proposed longwalls.

CHAPTER 4. MAXIMUM PREDICTED AND UPPERBOUND SYSTEMATIC SUBSIDENCE PARAMETERS FOR THE PROPOSED LONGWALLS

4.1. Introduction

The following sections provide the maximum predicted and maximum upperbound systematic subsidence parameters resulting from the extraction of the proposed Austar Longwalls A3 to A5. The predicted and upperbound subsidence parameters and the impact assessments for the natural features and items of surface infrastructure are provided in Chapter 5.

The maximum predicted and maximum upperbound subsidence parameters, and the predicted and upperbound subsidence contours provided in this report show the systematic movements, and do not include the valley related upsidence and closure movements, or the effects of faults and other geological structures. Such effects have been addressed separately in the impact assessments for each feature provided in Sections 5.2 to 5.18, and in Section 5.19.

4.2. Maximum Predicted Systematic Subsidence Parameters for the Proposed Longwalls

The maximum predicted systematic subsidence parameters resulting from the extraction of the proposed longwalls were determined using the calibrated Incremental Profile Method, as described in Sections 3.4 and 3.5. The predicted cumulative systematic subsidence contours, after the extraction of each proposed longwall, are shown in Drawings Nos. MSEC275-10 to MSEC275-12 in Appendix J.

A summary of the maximum predicted incremental systematic subsidence parameters, due to the extraction of each proposed longwall, is provided in Table 4.1. A summary of the maximum predicted cumulative systematic subsidence parameters, after the extraction of each proposed longwall, is provided in Table 4.2. A summary of the maximum predicted travelling tilts and strains, during the extraction of each proposed longwall, is provided in Table 4.3.

Table 4.1 Maximum Predicted Incremental Systematic Subsidence Parameters due to the Extraction of Each Proposed Longwall

Longwall	Maximum Predicted Incremental Subsidence (mm)	Maximum Predicted Incremental Tilt (mm/m)	Maximum Predicted Incremental Tensile Strain (mm/m)	Maximum Predicted Incremental Compressive Strain (mm/m)
LWA3	295	1.5	0.2	0.4
LWA4	935	4.8	0.6	1.7
LWA5	865	4.1	0.8	1.4

Table 4.2 Maximum Predicted Cumulative Systematic Subsidence Parameters after the Extraction of Each Proposed Longwall

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Tilt (mm/m)	Maximum Predicted Cumulative Tensile Strain (mm/m)	Maximum Predicted Cumulative Compressive Strain (mm/m)
After LWA3	295	1.5	0.2	0.4
After LWA4	1130	5.1	0.7	1.7
After LWA5	1390	5.8	0.7	1.9

Table 4.3 Maximum Predicted Travelling Subsidence Parameters during the Extraction of Each Proposed Longwall

Longwall	Maximum Predicted Travelling Tilt (mm/m)	Maximum Predicted Travelling Tensile Strain (mm/m)	Maximum Predicted Travelling Compressive Strain (mm/m)
During LWA3	0.8	0.1	0.1
During LWA4	2.5	0.2	0.3
During LWA5	2.3	0.2	0.3

The maximum predicted incremental systematic tilt of 4.8 mm/m (ie: 0.5 %) represents a change in grade of 1 in 210. The maximum predicted cumulative systematic tilt of 5.8 mm/m (ie: 0.6 %) represents a change in grade of 1 in 170. The maximum predicted travelling tilt of 2.5 mm/m (ie: 0.3 %) represents a change in grade of 1 in 400.

The minimum radii of curvatures associated with the maximum predicted incremental systematic tensile and compressive strains of 0.8 mm/m and 1.7 mm/m, are 19 kilometres and 8.8 kilometres, respectively. The minimum radii of curvatures associated with the maximum predicted cumulative systematic tensile and compressive strains of 0.7 mm/m and 1.9 mm/m, are 21 kilometres and 7.9 kilometres, respectively. The minimum radii of curvatures associated with the maximum predicted travelling tensile and compressive strains of 0.2 mm/m and 0.3 mm/m, are 75 kilometres and 50 kilometres, respectively.

4.3. Maximum Upperbound Systematic Subsidence Parameters for the Proposed Longwalls

The upperbound systematic subsidence parameters resulting from the extraction of the proposed longwalls were determined by scaling up the predicted systematic subsidence parameters, such that a maximum subsidence of 65 % of effective extracted seam thickness was achieved above the proposed longwalls, as described in Section 3.6. The upperbound cumulative systematic subsidence contours, after the extraction of each proposed longwall, are shown in Drawings Nos. MSEC275-13 to MSEC275-15 in Appendix J.

A summary of the maximum upperbound incremental systematic subsidence parameters, due to the extraction of each proposed longwall, is provided in Table 4.4. A summary of the maximum upperbound cumulative systematic subsidence parameters, after the extraction of each proposed longwall, is provided in Table 4.5. A summary of the maximum upperbound travelling tilts and strains, during the extraction of each proposed longwall, is provided in Table 4.6.

Table 4.4 Maximum Upperbound Incremental Systematic Subsidence Parameters due to the Extraction of Each Proposed Longwall

Longwall	Maximum Upperbound Incremental Subsidence (mm)	Maximum Upperbound Incremental Tilt (mm/m)	Maximum Upperbound Incremental Tensile Strain (mm/m)	Maximum Upperbound Incremental Compressive Strain (mm/m)
LWA3	630	2.9	0.4	0.8
LWA4	1895	9.2	1.2	3.1
LWA5	1750	8.3	1.4	2.5

Table 4.5 Maximum Upperbound Cumulative Systematic Subsidence Parameters after the Extraction of Each Proposed Longwall

Longwall	Maximum Upperbound Cumulative Subsidence (mm)	Maximum Upperbound Cumulative Tilt (mm/m)	Maximum Upperbound Cumulative Tensile Strain (mm/m)	Maximum Upperbound Cumulative Compressive Strain (mm/m)
After LWA3	630	2.9	0.4	0.8
After LWA4	2335	9.4	1.1	3.1
After LWA5	2955	10.9	1.2	3.7

Table 4.6 Maximum Upperbound Travelling Subsidence Parameters during the Extraction of Each Proposed Longwall

Longwall	Maximum Upperbound Travelling Tilt (mm/m)	Maximum Upperbound Travelling Tensile Strain (mm/m)	Maximum Upperbound Travelling Compressive Strain (mm/m)
During LWA3	1.7	0.1	0.2
During LWA4	5.1	0.4	0.6
During LWA5	4.7	0.3	0.6

The maximum upperbound incremental systematic tilt of 9.2 mm/m (ie: 0.9 %) represents a change in grade of 1 in 110. The maximum upperbound cumulative systematic tilt of 10.9 mm/m (ie: 1.1 %) represents a change in grade of 1 in 90. The maximum upperbound travelling tilt of 5.1 mm/m (ie: 0.5 %) represents a change in grade of 1 in 195.

The minimum radii of curvatures associated with the maximum upperbound incremental systematic tensile and compressive strains of 1.4 mm/m and 3.1 mm/m, are 11 kilometres and 4.8 kilometres, respectively. The minimum radii of curvatures associated with the maximum upperbound cumulative systematic tensile and compressive strains of 1.2 mm/m and 3.7 mm/m, are 13 kilometres and 4.1 kilometres, respectively. The minimum radii of curvatures associated with the maximum upperbound travelling tensile and compressive strains of 0.4 mm/m and 0.6 mm/m, are 38 kilometres and 25 kilometres, respectively.

4.4. Predicted and Upperbound Systematic Subsidence Parameters along Prediction Line A

The location of Prediction Line A is shown in Drawings Nos. MSEC275-10 to MSEC275-15.

The profiles of predicted incremental and cumulative systematic subsidence, tilt and strain along Prediction Line A, at the completion of each proposed longwall, are shown in Fig. H.01 in Appendix H. A summary of the maximum predicted cumulative systematic subsidence parameters, after the extraction of each proposed longwall, is provided in Table 4.7.

Table 4.7 Maximum Predicted Cumulative Systematic Subsidence Parameters along Prediction Line A after the Extraction of Each Proposed Longwall

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Tilt (mm/m)	Maximum Predicted Cumulative Tensile Strain (mm/m)	Maximum Predicted Cumulative Compressive Strain (mm/m)
After LWA3	245	0.8	< 0.1	0.3
After LWA4	1035	4.1	0.5	1.3
After LWA5	1325	5.0	0.5	1.5

The maximum predicted cumulative systematic tilt of 5.0 mm/m (ie: 0.5 %) represents a change in grade of 1 in 200. The minimum radii of curvatures associated with the maximum predicted cumulative systematic tensile and compressive strains of 0.5 mm/m and 1.5 mm/m, are 30 kilometres and 10 kilometres, respectively.

The profiles of upperbound incremental and cumulative systematic subsidence, tilt and strain along Prediction Line A, at the completion of each proposed longwall, are shown in Fig. I.01 in Appendix I. A summary of the maximum upperbound cumulative systematic subsidence parameters, after the extraction of each proposed longwall, is provided in Table 4.8.

Table 4.8 Maximum Upperbound Cumulative Systematic Subsidence Parameters along Prediction Line A after the Extraction of Each Proposed Longwall

Longwall	Maximum Upperbound Cumulative Subsidence (mm)	Maximum Upperbound Cumulative Tilt (mm/m)	Maximum Upperbound Cumulative Tensile Strain (mm/m)	Maximum Upperbound Cumulative Compressive Strain (mm/m)
After LWA3	530	1.7	0.1	0.6
After LWA4	2155	8.5	1.0	2.7
After LWA5	2775	10.6	1.0	3.3

The maximum upperbound cumulative systematic tilt of 10.6 mm/m (ie: 1.1 %) represents a change in grade of 1 in 95. The minimum radii of curvatures associated with the maximum upperbound cumulative systematic tensile and compressive strains of 1.0 mm/m and 3.3 mm/m, are 15 kilometres and 4.5 kilometres, respectively.

CHAPTER 5. PREDICTED AND UPPERBOUND SUBSIDENCE PARAMETERS AND IMPACT ASSESSMENTS FOR THE NATURAL FEATURES AND ITEMS OF SURFACE INFRASTRUCTURE

5.1. Introduction

The following sections provide the predicted and upperbound subsidence parameters, resulting from the extraction of the proposed longwalls, for the natural features and items of surface infrastructure within the SMP Area. The impact assessments have been made for each natural feature and item of surface infrastructure, based on the predicted and on the upperbound subsidence parameters. Significant natural features and items of surface infrastructure located outside the SMP Area, which may be subjected to far-field movements and may be sensitive to these movements, have also been included as part of these assessments.

In the case of isolated natural features or items of surface infrastructure, it is possible that the actual subsidence parameters may be greater or less than those predicted, depending on their position within the subsidence trough. For the purposes of this report, however, the predictions provide the best available indication of the overall subsidence parameters that are likely to be experienced by each feature.

In determining specific predictions for isolated features, an additional factor of safety has been applied by taking the maximum predicted values of subsidence, tilt, curvature and strain within 20 metres of the perimeter of each isolated feature.

5.2. Quorrobolong and Cony Creeks

Quorrobolong and Cony Creeks are located directly above the proposed longwalls and are shown in Drawing No. MSEC275-07. The predicted and upperbound subsidence parameters and the impact assessments for these creeks are provided in the following sections.

5.2.1. Predicted Systematic Subsidence and Valley Related Movements

The predicted profiles of incremental and cumulative subsidence, upsidence and closure along Quorrobolong and Cony Creeks, at the completion of each proposed longwall, are shown in Figs. H.02 and H.03, respectively, in Appendix H. A summary of the maximum predicted cumulative subsidence, upsidence and closure at the creeks, after the extraction of each proposed longwall, is provided in Table 5.1.

Table 5.1 Maximum Predicted Cumulative Subsidence, Upsidence and Closure at Quorrobolong and Cony Creeks after the Extraction of Each Proposed Longwall

Creek	Longwall	Maximum Predicted Cumulative Subsidence at Creek (mm)	Equiv. Valley Height (m)	Maximum Predicted Cumulative Upsidence at Creek (mm)	Maximum Predicted Cumulative Closure at Creek (mm)
Quorrobolong Creek	After LWA3	120	1.5 ~ 12	30	20
	After LWA4	750	1.5 ~ 12	100	70
	After LWA5	1140	1.5 ~ 12	185	125
Cony Creek	After LWA3	< 20	2.5 ~ 10	< 20	< 20
	After LWA4	100	2.5 ~ 10	30	45
	After LWA5	850	2.5 ~ 10	105	90

The equivalent valley height is calculated by multiplying the measured overall valley height by a factor which reflects the shape of the valley. The overall valley height is measured after examining the terrain across the valley within a radius of half the depth of cover. The factor varies from 1.0, for steeply sided valleys in flat terrain, to less than 0.5, for valleys of flatter profile in undulating terrain. An equivalent valley height factor of 0.5 has been adopted for the creeks. This factor is consistent with the upsidence movements observed in the valleys along the monitoring lines above the previously extracted longwalls at the Colliery.

The predicted changes in surface levels along the creeks are illustrated by the predicted net vertical movement profiles shown in Figs. H.02 and H.03, which have been determined by the addition of the subsidence and upsidence movements. A summary of the maximum predicted cumulative net vertical movements, the resulting changes in gradient, and the resulting strains along the alignments of the creeks, after the extraction of each proposed longwall, is provided in Table 5.2.

Table 5.2 Maximum Predicted Cumulative Net Vertical Movements, Changes in Grade and Strains along Quorrobolong and Cony Creeks after the Extraction of Each Proposed Longwall

Creek	Longwall	Maximum Predicted Cumulative Net Subsidence (mm)	Maximum Predicted Cumulative Net Uplift (mm)	Maximum Predicted Cumulative Increase in Creek Gradient (mm/m)	Maximum Predicted Cumulative Decrease in Creek Gradient (mm/m)	Maximum Predicted Cumulative Tensile Strain due to Net Vertical Movement (mm/m)	Maximum Predicted Cumulative Compressive Strain due to Net Vertical Movement (mm/m)
Quorr-bolong Creek	After LWA3	100	< 20	0.4	0.7	0.2	0.3
	After LWA4	675	< 20	2.7	3.6	0.6	1.0
	After LWA5	980	< 20	3.4	4.6	0.7	1.5
Cony Creek	After LWA3	< 20	< 20	0.1	< 0.1	< 0.1	< 0.1
	After LWA4	65	< 20	0.8	< 0.1	0.1	< 0.1
	After LWA5	745	< 20	3.4	< 0.1	0.6	0.2

The creeks will also be subjected to travelling tilts and strains where the extraction faces of the proposed longwalls pass beneath them. The travelling tilts and strains are typically aligned along the longitudinal axes of the longwalls with the maximum values typically occurring in the locations of maximum incremental subsidence for each longwall. A summary of the maximum predicted travelling tilts and strains at the creeks, during the extraction of each proposed longwall, is provided in Table 5.3.

Table 5.3 Maximum Predicted Travelling Tilts and Strains at Quorrobolong and Cony Creeks during the Extraction of Each Proposed Longwall

Creek	Longwall	Maximum Predicted Travelling Tilt (mm/m)	Maximum Predicted Travelling Tensile Strain (mm/m)	Maximum Predicted Travelling Compressive Strain (mm/m)
Quorrobolong Creek	During LWA3	0.8	0.1	0.1
	During LWA4	2.5	0.2	0.3
	During LWA5	2.3	0.2	0.3
Cony Creek	During LWA3	< 0.1	< 0.1	< 0.1
	During LWA4	< 0.1	< 0.1	< 0.1
	During LWA5	2.3	0.2	0.3

5.2.2. Upperbound Systematic Subsidence and Valley Related Movements

The upperbound systematic subsidence parameters at the creeks have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as described in Section 3.6. The upperbound valley related movements at the creeks have been determined using the maximum upperbound incremental subsidence resulting from the extraction of each proposed longwall.

The upperbound profiles of incremental and cumulative subsidence, upsidence and closure along Quorrobolong and Cony Creeks, at the completion of each proposed longwall, are shown in Figs. I.02 and I.03, respectively, in Appendix I. A summary of the maximum upperbound cumulative subsidence, upsidence and closure at the creeks, after the extraction of each proposed longwall, is provided in Table 5.4.

Table 5.4 Maximum Upperbound Cumulative Subsidence, Upsidence and Closure at Quorrobolong and Cony Creeks after the Extraction of Each Proposed Longwall

Creek	Longwall	Maximum Upperbound Cumulative Subsidence at Creek (mm)	Equiv. Valley Height (m)	Maximum Upperbound Cumulative Upsidence at Creek (mm)	Maximum Upperbound Cumulative Closure at Creek (mm)
Quorrobolong Creek	After LWA3	265	1.5 ~ 12	40	25
	After LWA4	1565	1.5 ~ 12	105	75
	After LWA5	2420	1.5 ~ 12	190	130
Cony Creek	After LWA3	25	2.5 ~ 10	< 20	< 20
	After LWA4	220	2.5 ~ 10	35	45
	After LWA5	1745	2.5 ~ 10	110	95

The upperbound changes in surface levels along the creeks are illustrated by the upperbound net vertical movement profiles shown in Figs. I.02 and I.03, which have been determined by the addition of the subsidence and upsidence movements. A summary of the maximum upperbound cumulative net vertical movements, the resulting changes in gradient, and the resulting strains along the alignments of the creeks, after the extraction of each proposed longwall, is provided in Table 5.5.

Table 5.5 Maximum Upperbound Cumulative Net Vertical Movements, Changes in Grade and Strains along Quorrobolong and Cony Creeks after the Extraction of Each Proposed Longwall

Creek	Longwall	Maximum Upperbnd. Cumulative Net Subsidence (mm)	Maximum Upperbnd. Cumulative Net Uplift (mm)	Maximum Upperbnd. Cumulative Increase in Creek Gradient (mm/m)	Maximum Upperbnd. Cumulative Decrease in Creek Gradient (mm/m)	Maximum Upperbnd. Cumulative Tensile Strain due to Net Vertical Movement (mm/m)	Maximum Upperbnd. Cumulative Compressive Strain due to Net Vertical Movement (mm/m)
Quorr-bolong Creek	After LWA3	240	< 20	0.9	1.4	0.4	0.7
	After LWA4	1480	< 20	5.5	7.5	1.1	2.2
	After LWA5	2230	< 20	6.8	9.5	1.2	3.0
Cony Creek	After LWA3	20	< 20	0.2	< 0.1	< 0.1	< 0.1
	After LWA4	185	< 20	1.9	< 0.1	0.3	< 0.1
	After LWA5	1635	< 20	6.9	< 0.1	1.0	0.5

A summary of the maximum upperbound travelling tilts and strains at the creeks, during the extraction of each proposed longwall, is provided in Table 5.6.

Table 5.6 Maximum Upperbound Travelling Tilts and Strains at Quorrobolong and Cony Creeks during the Extraction of Each Proposed Longwall

Creek	Longwall	Maximum Upperbound Travelling Tilt (mm/m)	Maximum Upperbound Travelling Tensile Strain (mm/m)	Maximum Upperbound Travelling Compressive Strain (mm/m)
Quorrobolong Creek	During LWA3	1.7	0.1	0.2
	During LWA4	5.1	0.4	0.6
	During LWA5	4.7	0.3	0.6
Cony Creek	During LWA3	< 0.1	< 0.1	< 0.1
	During LWA4	< 0.1	< 0.1	< 0.1
	During LWA5	4.7	0.3	0.6

5.2.3. Impact Assessments for the Quorrobolong and Cony Creeks

The impact assessments for Quorrobolong and Cony Creeks, based on the predicted and the upperbound subsidence parameters, are provided in the following sections. The findings in this report should be read in conjunction with the findings from the flood model which are provided in the report by Umwelt (2007).

5.2.3.1. The Increased Likelihoods of Ponding and Flooding

A detailed flood model of the creeks has been undertaken by Umwelt using the predicted and the upperbound subsidence movements resulting from the extraction of the proposed longwalls, which were provided by MSEC. The increased likelihoods of ponding and flooding along the creeks have been assessed in the flood model and are provided in the report by Umwelt (2007).

5.2.3.2. The Likelihood of Cracking in the Alluvial Creek Beds

The maximum predicted tensile and compressive strains along the alignment of the Quorrobolong Creek, at any time during or after the extraction of the proposed longwalls, are 0.7 mm/m and 1.5 mm/m, respectively. The maximum predicted tensile and compressive strains along the alignment of the Cony Creek, at any time during or after the extraction of the proposed longwalls, are 0.6 mm/m and 0.3 mm/m, respectively.

The maximum upperbound tensile and compressive strains along the alignment of the Quorrobolong Creek, at any time during or after the extraction of the proposed longwalls, are 1.2 mm/m and 3.0 mm/m, respectively. The maximum upperbound tensile and compressive strains along the alignment of the Cony Creek, at any time during or after the extraction of the proposed longwalls, are 1.0 mm/m and 0.6 mm/m, respectively.

Surface tensile cracking in alluvial creek beds has generally not been observed in the past where the tensile strains have been less than 0.5 mm/m. It is likely, therefore, that some minor surface tensile cracking will occur within the beds of Quorrobolong and Cony Creeks as a result of the extraction of the proposed longwalls, based on both the predicted and upperbound tensile strains along the alignments of these creeks.

The maximum width of potential surface tensile cracking in the alluvial creek beds can be predicted from Fig. D.8 in Appendix D, which shows the relationship between maximum observed crack width and depth of cover, based upon measured data in the NSW Coalfields and observations over mines in the United Kingdom. The depth of cover above the proposed longwalls is generally greater than 500 metres and, therefore, the maximum predicted crack width resulting from the extraction of the proposed longwalls is approximately 25 mm. It is more likely, however, that a number of narrower cracks, rather than a single larger crack, would develop in the creek beds as the result of the systematic tensile strains.

Surface cracking could potentially occur within the tensile zones around the perimeters of the proposed longwalls, which are located within 0.1 to 0.4 times the depth of cover from the extracted longwall goaf edges. Smaller surface cracks could also occur behind the extraction faces of the proposed longwalls where they mine beneath the creeks. The surface cracks behind the longwall extraction faces tend to be transient, however, as the travelling tensile phase, which causes the cracks, is generally followed by a travelling compressive phase, which tends to partially reclose these cracks.

Surface tensile cracking occurs only within the top few metres of the surface soils, and would be expected to be filled with the alluvial materials during subsequent flow events. If any significant cracking were to be left untreated, however, erosion channels could develop along the alignments of the creeks. Any significant surface cracking in the alluvial creek beds can be easily remediated by infilling with alluvial or other suitable materials, or by locally regrading and recompacting the surface.

The buckling and dilation of underlying strata has generally not been observed in the past where the compressive strains have been less than 2 mm/m. The predicted compressive strains along the alignments of Quorrobolong and Cony Creeks, and the upperbound compressive strain along the alignment of Cony Creek are all less than 2 mm/m and are unlikely, therefore, to result in the buckling and dilation of the underlying strata along these creeks. The upperbound compressive strain along the alignment of Quorrobolong Creek, adjacent to the chain pillar between Longwalls A3 and A4, is greater than 2 mm/m and, therefore, if realised, could result in the buckling and dilation of the underlying strata.

The closure movements across the valleys of the creeks are also likely to result in elevated compressive strains in the beds of the creeks. The maximum predicted closure movements at Quorrobolong and Cony Creeks are 125 mm and 90 mm, respectively. The maximum upperbound closure movements at Quorrobolong and Cony Creeks are 130 mm and 95 mm, respectively. Compressive strains greater than 2 mm/m have been observed in creek beds in the past at these magnitudes of closure movements and where the creeks have been directly mined beneath, as can be seen in Fig. D.22 in Appendix D.

Compressive strains due to valley closure movements greater than 2 mm/m are generally not observed more than 250 metres outside extracted longwall goaf areas, as can be seen in Fig. D.23 and Fig. D.24 in Appendix D. It is possible, therefore, that some compressive buckling and dilation of the underlying strata could occur along the alignments of Quorrobolong and Cony Creeks above, and within 250 metres of the proposed longwalls. It has been observed in the past that the depth of buckling and dilation of underlying strata, resulting from valley closure movements, is generally less than 10 to 15 metres.

Surface tensile cracking can potentially occur in the locations where the underlying strata buckles and the depth of the overlying alluvials are shallow. In these cases, however, the surface cracks are likely to be filled with the alluvials during subsequent flow events.

In times of heavy rainfall, the dilated strata beneath the creek beds would become water charged, and the surface water would flow over any surface cracking. Any surface water that is diverted into the dilated strata beneath the creeks during times of high flow is unlikely to significantly affect the quality or quantity of the surface water flow, as the cross-sectional area of dilated strata is very small when compared to the cross-sectional area of the creek channels. In times of low flow, however, the surface water that is diverted into the dilated strata beneath the creek beds could temporarily affect the quality and quantity of the water flowing along the creeks.

The surface tensile cracking and the underlying dilated strata would tend to be naturally filled with alluvials during subsequent flow events, especially during times of heavy rainfall. If the surface tensile cracking and fractures in the underlying strata were found to not heal naturally, some remediation measures may be required at the completion of mining. Where necessary, any significant surface cracks in the alluvial creek beds can be easily remediated by infilling with alluvials or other suitable materials, or by locally regrading and recompacting the surface, and any significant fracturing and dilation in the underlying strata could be sealed by grouting or by other suitable methods.

As described in Section 5.19.8, the likely height of the fractured zone is 225 metres to 265 metres above the proposed longwalls. The depth of cover above the proposed longwalls is generally greater than 500 metres and, therefore, the predicted height of the constrained zone, which is located above the fractured zone, is 235 metres to 275 metres.

The constrained zone, also known as the continuous deformation zone, is illustrated in Fig. D.28 and Fig. D.29 in Appendix D. The constrained zone contains confined rock strata above the fractured zone which has sagged slightly but, because they are constrained, have absorbed most of the strain energy without suffering significant fracturing or alteration to the original physical properties. Some bed separation or slippage can be present as well as discontinuous vertical cracks, usually on the underside of thick strong beds. Weak or soft beds in this zone may suffer plastic deformation.

The Hawkesbury Sandstone forms the upper section of the constrained zone, which is relatively homogeneous and contains relatively thick beds. Vertical fracturing within the constrained zone is generally discontinuous and is unlikely, therefore, to result in increase hydraulic conductivity. It is unlikely, therefore, that there would be any net loss of water from the creeks resulting from the extraction of the proposed longwalls.

Quorrobolong Creek has been previously mined beneath by Longwalls 1 to 6 and Longwall SL1 at the Colliery, where the depths of cover vary between 310 and 370 metres, and there was no reported loss of water from the creek and no reported surface cracking in the creek bed.

Further discussion on the potential impacts of surface cracking and changes in surface water flows are provided in the report by Umwelt (2007).

5.2.3.3. Impact Assessments for Increase Predictions

If the predicted systematic subsidence parameters at the creeks were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound parameters at the creeks. It is unlikely that the upperbound systematic subsidence parameters at the creeks would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

The maximum upperbound tensile strain at Quorrobolong Creek is 1.2 mm/m, which is equal to the maximum upperbound systematic tensile strain above the proposed longwalls and is unlikely, therefore, to be exceeded. The maximum upperbound tensile strain at Cony Creek is 1.0 mm/m, which is only slightly less than the maximum upperbound systematic tensile strain above the proposed longwalls. If the maximum upperbound systematic tensile strain above the proposed longwalls of 1.2 mm/m were to occur at Cony Creek, the likelihood and extent of surface cracking in the alluvial bed would only slightly increase.

If the maximum upperbound systematic compressive strain above the proposed longwalls of 3.7 mm/m were to occur at Quorrobolong and Cony Creeks, the likelihood and extent of buckling and dilation of the underlying strata would increase accordingly. Any surface tensile cracking in the alluvial beds resulting from the buckling of the underlying strata could be remediated by infilling with alluvial or other suitable materials.

5.2.4. Recommendations for the Creeks

The assessed impacts on Quorrobolong and Cony Creeks resulting from the predicted and upperbound systematic subsidence and valley related movements can be managed with the implementation of suitable management strategies.

It is recommended that the creek beds are visually monitored during the extraction of the proposed longwalls, and that any significant surface tensile cracking is remediated by infilling with alluvials or other suitable materials, or by locally regrading and recompacting the surface.

5.3. Drainage Lines

There are a number of drainage lines around and between the hills within the SMP Area which are shown in Drawing No. MSEC275-07. These drainage lines have been included in the flood modelling which has been undertaken by Umwelt using the predicted and upperbound subsidence movements resulting from the extraction of the proposed longwalls, which were provided by MSEC. An assessment of the changes in surface level at the drainage lines are provided in the report by Umwelt (2007).

Surface tensile cracking could occur where the drainage lines cross the tensile zones around the perimeters of the proposed longwalls, which are located within 0.1 to 0.4 times the depth of cover from the extracted longwall goaf edges. Smaller surface cracks could also occur behind the extraction faces of the proposed longwalls where they mine beneath the drainage lines. The surface cracks behind the longwall extraction faces tend to be transient, however, as the travelling tensile phase, which causes the cracks, is generally followed by a travelling compressive phase, which tends to partially reclose these cracks.

Surface tensile cracking occurs only within the top few metres of the surface soils, and would be expected to be filled with the alluvial materials during subsequent flow events. If any significant cracking were to be left untreated, however, erosion channels could develop along the drainage lines.

It is recommended, therefore, that the drainage lines are visually monitored during the extraction of the proposed longwalls, and that any significant surface tensile cracking is remediated by infilling with alluvials or other suitable materials, or by locally regrading and recompacting the surface.

5.4. Steep Slopes

The locations of steep slopes within the SMP Area are shown in Drawing No. MSEC275-07. For the purposes of this report, steep slopes have been defined as areas of land having a natural gradient greater than 1 in 3 (ie: a grade of 33 %, or an angle to the horizontal of 18°). Steep slopes within the SMP Area have only been identified on the southern side of the hill located above proposed Longwall A4, and on the south-eastern side of the hill north of proposed Longwall A3.

5.4.1. Predicted Subsidence Parameters for the Steep Slopes

A summary of the maximum predicted systematic subsidence parameters at the steep slopes, during or after the extraction of each proposed longwall, which ever is the greater, is provided in Table 5.7.

Table 5.7 Maximum Predicted Systematic Subsidence Parameters at the Steep Slopes Resulting from the Extraction of the Proposed Longwalls

Longwall	Maximum Predicted Subsidence (mm)	Maximum Predicted Tilt (mm/m)	Maximum Predicted Tensile Strain (mm/m)	Maximum Predicted Compressive Strain (mm/m)
During or After LWA3	90	0.6	< 0.1	< 0.1
During or After LWA4	740	4.0	0.5	0.2
During or After LWA5	1210	3.4	0.2	1.0

The maximum predicted systematic tilt at the steep slopes, at any time during or after the extraction of the proposed longwalls, is 4.0 mm/m (ie: 0.4 %), or a change in grade of 1 in 250, which occurs after the extraction of proposed Longwall A4.

The maximum predicted systematic tensile and compressive strains at the steep slopes, at any time during or after the extraction of the proposed longwalls, are 0.5 mm/m and 1.0 mm/m, respectively, and the associated minimum radii of curvatures are 30 kilometres and 15 kilometres, respectively. The maximum predicted systematic tensile strain at the steep slopes occurs after the extraction of proposed Longwall A4, and the maximum predicted systematic compressive strain occurs after the extraction of proposed Longwall A5.

5.4.2. Upperbound Subsidence Parameters for the Steep Slopes

The upperbound systematic subsidence parameters at the steep slopes have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as discussed in Section 3.6.

A summary of the maximum upperbound systematic subsidence parameters at the steep slopes, during or after the extraction of each proposed longwall, which ever is the greater, is provided in Table 5.8.

Table 5.8 Maximum Upperbound Systematic Subsidence Parameters at the Steep Slopes Resulting from the Extraction of the Proposed Longwalls

Longwall	Maximum Upperbound Subsidence (mm)	Maximum Upperbound Tilt (mm/m)	Maximum Upperbound Tensile Strain (mm/m)	Maximum Upperbound Compressive Strain (mm/m)
During or After LWA3	200	1.4	0.1	< 0.1
During or After LWA4	1525	7.9	1.0	0.4
During or After LWA5	2570	7.9	0.1	1.8

The maximum upperbound systematic tilt at the steep slopes, at any time during or after the extraction of the proposed longwalls, is 7.9 mm/m (ie: 0.8 %), or a change in grade of 1 in 125, which occurs after the extraction of proposed Longwall A4.

The maximum upperbound systematic tensile and compressive strains at the steep slopes, at any time during or after the extraction of the proposed longwalls, are 1.0 mm/m and 1.8 mm/m, respectively, and the associated minimum radii of curvatures are 15 kilometres and 8.3 kilometres, respectively. The maximum upperbound systematic tensile strain at the steep slopes occurs after the extraction of proposed Longwall A4, and the maximum upperbound systematic compressive strain occurs after the extraction of proposed Longwall A5.

5.4.3. Impact Assessments for the Steep Slopes

The steep slopes are more likely to be impacted by ground strains, rather than tilt, as the maximum upperbound tilt of 7.9 mm/m represents a change in surface gradient of only 0.8 %, or 1 in 125, which is very small when compared to the natural gradients of the steep slopes.

Surface tensile cracking in the natural ground has generally not been observed in the past where the tensile strains have been less than 0.5 mm/m. It is likely, therefore, that the maximum upperbound tensile strain of 1.0 mm/m would result in some minor tensile cracking in the surface soils at the steep slopes. Any surface cracking is expected to be of a minor nature, due to the relatively low levels of predicted and upperbound systematic tensile strains, and due to the relatively high depth of cover. Surface tensile cracking is generally limited to the top few metres of the surface soils.

The maximum width of potential surface tensile cracking at the steep slopes can be predicted from Fig. D.8 in Appendix D, which shows the relationship between maximum observed crack width and depth of cover, based upon measured data in the NSW Coalfields and observations over mines in the United Kingdom. The depth of cover at the steep slopes is greater than 500 metres and, therefore, the maximum predicted crack width resulting from the extraction of the proposed longwalls is 25 mm. It is more likely, however, that a number of narrower cracks, rather than a single larger crack, would develop at the steep slopes as the result of the systematic tensile strains.

Minor surface tensile cracking tends to heal naturally, especially during rain events. If any significant cracking were to be left untreated, however, erosion channels could develop within the drainage lines. In this case, it is recommended that appropriate mitigation measures be undertaken, including infilling of surface cracks with soil or other suitable materials, so as to prevent the formation of soil erosion channels. With these mitigation measures in place, it is unlikely that any significant impact on the environment would occur as a result of surface tensile cracking at the steep slopes.

The buckling of underlying strata has generally not been observed in the past where the compressive strains have been less than 2 mm/m. The predicted and upperbound compressive strains at the steep slopes are both less than 2 mm/m and are unlikely, therefore, to result in the compressive buckling of underlying strata.

The steep slopes within the SMP Area are relatively flat, having natural gradients of less than 1 in 2, and the depths of cover at the steep slopes are greater than 500 metres, and it is unlikely, therefore, that the predicted and upperbound magnitudes of systematic strain would result in the slippage of soils down the steep slopes. If movement of the surface soils were to occur during the extraction of the proposed longwalls, minor tension cracks at the tops of slopes and minor compression ridges at the bottoms of slopes may form. In this case, minor mitigation measures might be required, including infilling of surface cracks with soil or other suitable materials, and minor regrading and recompacting of compression bumps. With these mitigation measures in place, it is unlikely that any significant impact on the environment would occur as a result of soil slumping at the steep slopes.

5.4.4. Impact Assessments for Increase Predictions

If the predicted systematic subsidence parameters at the steep slopes were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the steep slopes. It is unlikely that the upperbound systematic subsidence parameters at the steep slopes would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

If the maximum upperbound systematic tilt above the proposed longwalls of 10.9 mm/m were to occur at the steep slopes, it would still be unlikely to result in any significant impact, as the change in surface gradient of only 1.1 %, or 1 in 90, is still very small when compared to the natural gradients of the steep slopes.

If the maximum upperbound systematic tensile strain above the proposed longwalls of 1.2 mm/m were to occur at the steep slopes, the likelihood and extent of surface cracking would increase accordingly. Any surface cracking would still expected to be of a minor nature, and could be remediated by infilling with soil or other suitable materials.

If the maximum upperbound systematic compressive strain above the proposed longwalls of 3.7 mm/m were to occur at the steep slopes, it is possible that the underlying strata could buckling and result in surface tensile cracking. Any surface cracking would be expected to be of a minor nature, and could be remediated by infilling with soil or other suitable materials.

With these mitigation measures in place, it is unlikely that any significant impact would occur on the steep slopes, resulting from the extraction of the proposed longwalls.

5.4.5. Recommendations for the Steep Slopes

The assessed impacts on the steep slopes resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies.

It is recommended that the surface is visually monitored during the extraction of the proposed longwalls. Appropriate management strategies should be developed, in liaison with the property owners, so that any surface tensile cracking can be remediated, as required, throughout the mining period.

5.5. Nash Lane

The location of Nash Lane within the SMP Area is shown in Drawing No. MSEC275-08. The road is located directly above proposed Longwalls A3 and A4, and is located to the east of proposed Longwall A5.

5.5.1. Predicted Subsidence Parameters for Nash Lane

The predicted profiles of incremental and cumulative systematic subsidence, tilt and strain along the alignment of Nash Lane, at the completion of each proposed longwall, are shown in Fig. H.04 in Appendix H. A summary of the maximum predicted cumulative systematic subsidence parameters along the alignment of the road, after the extraction of each proposed longwall, is provided in Table 5.9.

Table 5.9 Maximum Predicted Cumulative Systematic Subsidence Parameters along the Alignment of Nash Lane after the Extraction of Each Proposed Longwall

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Tilt (mm/m)	Maximum Predicted Cumulative Tensile Strain (mm/m)	Maximum Predicted Cumulative Compressive Strain (mm/m)
After LWA3	290	0.9	< 0.1	0.3
After LWA4	955	3.7	0.3	1.0
After LWA5	1000	3.7	0.3	1.0

The road will also be subjected to travelling tilts and strains where the extraction faces of proposed Longwalls A3 and A4 pass beneath it. The travelling tilts and strains are typically aligned along the longitudinal axes of the longwalls with the maximum values typically occurring in the locations of maximum incremental subsidence for each longwall. A summary of the maximum predicted travelling tilts and strains at the road, during the extraction of proposed Longwalls A3 and A4, is provided in Table 5.10.

Table 5.10 Maximum Predicted Travelling Tilts and Strains at Nash Lane during the Extraction of Proposed Longwalls A3 and A4

Longwall	Maximum Predicted Travelling Tilt (mm/m)	Maximum Predicted Travelling Tensile Strain (mm/m)	Maximum Predicted Travelling Compressive Strain (mm/m)
During LWA3	0.8	0.1	0.1
During LWA4	0.5	0.1	0.1

The maximum predicted systematic subsidence at the road is 1000 mm, which occurs above the maingate of proposed Longwall A3, after the extraction of proposed Longwall A5.

The maximum predicted systematic tilt along the alignment of the road, at any time during or after the extraction of the proposed longwalls, is 3.7 mm/m (ie: 0.4 %), or a change in grade of 1 in 270, which occurs after the extraction of proposed Longwall A4. The maximum predicted systematic tilt across the alignment of the road, at any time during or after the extraction of the proposed longwalls, is 0.8 mm/m (ie: < 0.1 %), or a change in grade of 1 in 1250, which occurs during the extraction of proposed Longwall A4.

The maximum predicted systematic tensile and compressive strains at the road, at any time during or after the extraction of the proposed longwalls, are 0.3 mm/m and 1.0 mm/m, respectively, and the associated minimum radii of curvatures are 50 kilometres and 15 kilometres, respectively. The maximum predicted systematic tensile strain at the road occurs above the commencing end of proposed Longwall A4, and the maximum predicted systematic compressive strain occurs above the chain pillar between proposed Longwalls A3 and A4.

5.5.2. Upperbound Subsidence Parameters for Nash Lane

The upperbound systematic subsidence parameters at Nash Lane have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as discussed in Section 3.6.

The upperbound profiles of incremental and cumulative systematic subsidence, tilt and strain along the alignment of Nash Lane, at the completion of each proposed longwall, are shown in Fig. I.04 in Appendix I. A summary of the maximum upperbound cumulative systematic subsidence parameters along the alignment of the road, after the extraction of each proposed longwall, is provided in Table 5.11.

Table 5.11 Maximum Upperbound Cumulative Systematic Subsidence Parameters along the Alignment of Nash Lane after the Extraction of Each Proposed Longwall

Longwall	Maximum Upperbound Cumulative Subsidence (mm)	Maximum Upperbound Cumulative Tilt (mm/m)	Maximum Upperbound Cumulative Tensile Strain (mm/m)	Maximum Upperbound Cumulative Compressive Strain (mm/m)
After LWA3	625	1.8	0.1	0.6
After LWA4	2060	7.6	0.7	2.1
After LWA5	2160	7.5	0.7	2.0

A summary of the maximum upperbound travelling tilts and strains at the road, during the extraction of proposed Longwalls A3 and A4, is provided in Table 5.12

Table 5.12 Maximum Upperbound Travelling Tilts and Strains at Nash Lane during the Extraction of Proposed Longwalls A3 and A4

Longwall	Maximum Upperbound Travelling Tilt (mm/m)	Maximum Upperbound Travelling Tensile Strain (mm/m)	Maximum Upperbound Travelling Compressive Strain (mm/m)
During LWA3	1.7	0.2	0.2
During LWA4	1.1	0.2	0.2

The maximum upperbound systematic subsidence at the road is 2160 mm, which occurs above the maingate of proposed Longwall A3, after the extraction of proposed Longwall A5.

The maximum upperbound systematic tilt along the alignment of the road, at any time during or after the extraction of the proposed longwalls, is 7.6 mm/m (ie: 0.8 %), or a change in grade of 1 in 130, which occurs after the extraction of proposed Longwall A4. The maximum upperbound systematic tilt across the alignment of the road, at any time during or after the extraction of the proposed longwalls, is 1.7 mm/m (ie: 0.2 %), or a change in grade of 1 in 590, which occurs during the extraction of proposed Longwall A4.

The maximum upperbound systematic tensile and compressive strains at the road, at any time during or after the extraction of the proposed longwalls, are 0.7 mm/m and 2.1 mm/m, respectively, and the associated minimum radii of curvatures are 21 kilometres and 7.1 kilometres, respectively. The maximum upperbound systematic tensile strain at the road occurs above the commencing end of proposed Longwall A4, and the maximum upperbound compressive strain occurs above the chain pillar between proposed Longwalls A3 and A4.

5.5.3. Impact Assessments for Nash Lane

The maximum upperbound systematic tilt at the road of 7.6 mm/m (ie: 0.8 %) represents a change in grade of less than 1 % and, therefore, is unlikely to have any significant impact on the serviceability or the drainage of water at the road.

Nash Lane is an unsealed road and systematic tensile strains of less than 0.5 mm/m are unlikely to result in any significant surface cracking. It is possible, therefore, that the upperbound systematic tensile strain of 0.7 mm/m could result in minor tensile cracking in the unsealed road surface. Any cracking is expected to be of a minor nature, however, due to the relatively low levels of predicted and upperbound systematic tensile strains, and due to the relatively high depth of cover.

The maximum width of potential surface tensile cracking along Nash Lane can be predicted from Fig. D.8 in Appendix D, which shows the relationship between maximum observed crack width and depth of cover, based upon measured data in the NSW Coalfields and observations over mines in the United Kingdom. The depth of cover along the road is generally greater than 500 metres and, therefore, the maximum predicted crack width resulting from the extraction of the proposed longwalls is 25 mm. It is more likely, however, that a number of narrower cracks, rather than a single larger crack, would develop at the road as the result of the systematic tensile strains.

The buckling of underlying strata has generally not been observed in the past where the compressive strains have been less than 2 mm/m. It is possible, therefore, that the upperbound systematic compressive strain of 2.1 mm/m could be of sufficient magnitude to result in the buckling of the underlying strata, resulting in tensile cracking in the unsealed road surface.

Any tensile cracking or compressive rippling of the unsealed road surface, resulting from the extraction of the proposed longwalls, could be remediated by regrading and recompacting the surface using normal road maintenance techniques. With the implementation of suitable remediation measures, the road can be maintained in a safe and serviceable condition throughout the mining period.

5.5.4. Impact Assessments for Increased Predictions

If the predicted systematic subsidence parameters at Nash Lane were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at Nash Lane. It is unlikely that the upperbound systematic subsidence parameters at Nash Lane would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

If the maximum upperbound systematic tilt above the proposed longwalls of 10.9 mm/m were to occur at Nash Lane, the maximum change in grade at the road would only be 1.1 % and unlikely, therefore, to result in any significant impact on the serviceability or the drainage of water at the road.

If the maximum upperbound systematic tensile strain above the proposed longwalls of 1.2 mm/m were to occur at Nash Lane, the likelihood and extent of surface cracking would increase accordingly. Any surface cracking, however, would still be expected to be of a minor nature and easily remediated by regarding and recompacting the surface using normal road maintenance techniques.

If the maximum upperbound systematic compressive strain above the proposed longwalls of 3.7 mm/m were to occur at Nash Lane, the likelihood and extent of surface cracking resulting from the underlying strata buckling would increase accordingly. Any surface cracking, however, would still be expected to be of a minor nature and easily remediated by regarding and recompacting the surface using normal road maintenance techniques.

With these mitigation measures in place, it is likely that the road can be maintained in a safe and serviceable condition throughout the mining period.

5.5.5. Recommendations for Nash Lane

The assessed impacts on Nash Lane resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies.

It is recommended that Nash Lane should be visually monitored as each proposed longwall mines beneath it, such that any impacts can be identified and remediated accordingly. It is also recommended that management strategies are developed, in consultation with Cessnock City Council, so that the road can be maintained in a safe and serviceable condition throughout the mining period.

5.6. Pelton Fire Trail

Pelton Fire Trail crosses the northern corner of the SMP Area and is located outside the total predicted and total upperbound 20 mm subsidence contours. It is unlikely, therefore, that the Pelton Fire Trail would experience any significant impacts resulting from the extraction of the proposed longwalls.

If the predicted systematic subsidence parameters were to be increased by factors of 1.25 to 2 times, or the upperbound systematic subsidence parameters were to be increased by a factor of 1.25 times, it would still be unlikely that the road would experience any significant impacts resulting from the extraction of the proposed longwalls.

5.7. The Drainage Culvert

There is one identified drainage culvert on public land within the SMP Area. The culvert is located under a private driveway, adjacent to Nash Lane, the location of which is shown in Drawing No. MSEC275-08.

5.7.1. Predicted Subsidence Parameters for the Drainage Culvert

A summary of the maximum predicted systematic subsidence parameters at the drainage culvert, at any time during or after the extraction of the proposed longwalls, which ever is the greatest, is provided in Table 5.13.

Table 5.13 Maximum Predicted Systematic Subsidence Parameters at the Drainage Culvert Resulting from the Extraction of the Proposed Longwalls

Longwalls	Maximum Predicted Subsidence (mm)	Maximum Predicted Tilt (mm/m)	Maximum Predicted Tensile Strain (mm/m)	Maximum Predicted Compressive Strain (mm/m)
LWA3 to LWA5	990	1.4	0.1	0.9

The culvert is not located within a drainage line and will not, therefore, experience any valley related upsidence or closure movements.

The maximum predicted systematic tilt at the drainage culvert, at any time during or after the extraction of the proposed longwalls, is 1.4 mm/m (ie: 0.1 %), or a change in grade of 1 in 715, which occurs after the extraction of proposed Longwall A4.

The maximum predicted systematic tensile and compressive strains at the drainage culvert, at any time during or after the extraction of the proposed longwalls, are 0.1 mm/m and 0.9 mm/m, respectively, and the associated minimum radii of curvatures are 150 kilometres and 17 kilometres, respectively.

5.7.2. Upperbound Subsidence Parameters for the Drainage Culvert

The upperbound systematic subsidence parameters at the drainage culvert have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as discussed in Section 3.6.

A summary of the maximum upperbound systematic subsidence parameters at the drainage culvert, at any time during or after the extraction of the proposed longwalls, whichever is the greatest, is provided in Table 5.14.

Table 5.14 Maximum Upperbound Systematic Subsidence Parameters at the Drainage Culvert Resulting from the Extraction of the Proposed Longwalls

Longwalls	Maximum Upperbound Cumulative Subsidence (mm)	Maximum Upperbound Cumulative Tilt (mm/m)	Maximum Upperbound Cumulative Tensile Strain (mm/m)	Maximum Upperbound Cumulative Compressive Strain (mm/m)
LWA3 to LWA5	2080	2.9	0.2	1.9

The maximum upperbound systematic tilt at the drainage culvert, at any time during or after the extraction of the proposed longwalls, is 2.9 mm/m (ie: 0.3 %), or a change in grade of 1 in 345, which occurs after the extraction of proposed Longwall A4.

The maximum upperbound systematic tensile and compressive strains at the drainage culvert, at any time during or after the extraction of the proposed longwalls, are 0.2 mm/m and 1.9 mm/m, respectively, and the associated minimum radii of curvatures are 75 kilometres and 7.9 kilometres, respectively.

5.7.3. Impact Assessments for the Drainage Culvert

The maximum upperbound systematic tilt at the drainage culvert of 2.9 mm/m (ie: 0.3 %) represents a change in grade of less than 1 % and is unlikely, therefore, to have any significant impact on the serviceability of the culvert.

Concrete culverts can typically experience systematic tensile and compressive strains of up to 0.5 mm/m and 2 mm/m, respectively, along their main axes without impact. The drainage culvert is orientated at an angle of approximately 60 degrees to the goaf edges of the proposed longwalls and, therefore, the maximum upperbound systematic tensile and compressive strains along the main axis of the culvert are less than those shown in Table 5.14. It is unlikely, therefore, that the drainage culvert would be impacted as a result of the extraction of the proposed longwalls. If the culvert were to be impacted as a result of the extraction of the proposed longwalls, it could be easily repaired or replaced, as required.

5.7.4. Impact Assessments for Increased Predictions

If the predicted systematic subsidence parameters at the drainage culvert were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the culvert. It is unlikely that the upperbound systematic subsidence parameters at the culvert would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

If the maximum upperbound systematic tilt above the proposed longwalls of 10.9 mm/m were to occur at the drainage culvert, the maximum change in grade at the culvert would only be 1.1 % and unlikely, therefore, to result in any significant impact on the serviceability of the culvert.

If the maximum upperbound systematic tensile and compressive strains above the proposed longwalls of 1.2 mm/m and 3.7 mm/m, respectively, were to occur at the drainage culvert, it is likely that the culvert would be significantly impacted. If the drainage culvert were to be impacted, it could be easily repaired or replaced, as required.

5.7.5. Recommendations for the Drainage Culvert

The assessed impacts on the drainage culvert resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies. It is recommended that the drainage culvert should be visually monitored during the mining period.

5.8. Water Services

A privately owned water pipeline follows the alignment of Nash Lane within the SMP Area, the location of which is shown in Drawing No. MSEC275-08. The extent of the pipeline within the SMP Area is not known and, therefore, the pipeline has been assumed to follow the full extent of Nash Lane within the SMP Area.

5.8.1. Predicted Subsidence Parameters for the Water Pipeline

The predicted profiles of systematic subsidence, tilt and strain along the water pipeline are the same as those along Nash Road, which are shown in Fig. H.04 in Appendix H. A summary of the maximum predicted cumulative systematic subsidence parameters along the pipeline, after the extraction of each proposed longwall, is provided in Table 5.15.

Table 5.15 Maximum Predicted Cumulative Systematic Subsidence Parameters along the Water Pipeline after the Extraction of Each Proposed Longwall

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Tilt (mm/m)	Maximum Predicted Cumulative Tensile Strain (mm/m)	Maximum Predicted Cumulative Compressive Strain (mm/m)
After LWA3	290	0.9	< 0.1	0.3
After LWA4	955	3.7	0.3	1.0
After LWA5	1000	3.7	0.3	1.0

The pipeline will also be subjected to travelling tilts and strains where the extraction faces of proposed Longwalls A3 and A4 pass beneath it. The travelling tilts and strains are typically aligned along the longitudinal axes of the longwalls with the maximum values typically occurring in the locations of maximum incremental subsidence for each longwall. A summary of the maximum predicted travelling tilts and strains at the pipeline, during the extraction of proposed Longwalls A3 and A4, is provided in Table 5.16.

Table 5.16 Maximum Predicted Travelling Tilts and Strains at the Water Pipeline during the Extraction of Proposed Longwalls A3 and A4

Longwall	Maximum Predicted Travelling Tilt (mm/m)	Maximum Predicted Travelling Tensile Strain (mm/m)	Maximum Predicted Travelling Compressive Strain (mm/m)
During LWA3	0.8	0.1	0.1
During LWA4	0.5	0.1	0.1

The maximum predicted systematic subsidence at the pipeline is 1000 mm, which occurs above the maingate of proposed Longwall A3, after the extraction of proposed Longwall A5.

The maximum predicted systematic tilt along the pipeline, at any time during or after the extraction of the proposed longwalls, is 3.7 mm/m (ie: 0.4 %), or a change in grade of 1 in 270, which occurs after the extraction of proposed Longwall A4.

The maximum predicted systematic tensile and compressive strains at the pipeline, at any time during or after the extraction of the proposed longwalls, are 0.3 mm/m and 1.0 mm/m, respectively, and the associated minimum radii of curvatures are 50 kilometres and 15 kilometres, respectively. The maximum predicted systematic tensile strain at the pipeline occurs above the commencing end of proposed Longwall A4, and the maximum predicted systematic compressive strain occurs above the chain pillar between proposed Longwalls A3 and A4.

5.8.2. Upperbound Subsidence Parameters for the Water Pipeline

The upperbound systematic subsidence parameters at the water pipeline have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as discussed in Section 3.6.

The upperbound profiles of systematic subsidence, tilt and strain along the water pipeline are the same as those along Nash Road, which are shown in Fig. I.04 in Appendix I. A summary of the maximum upperbound cumulative systematic subsidence parameters along the pipeline, after the extraction of each proposed longwall, is provided in Table 5.17.

Table 5.17 Maximum Upperbound Cumulative Systematic Subsidence Parameters along the Water Pipeline after the Extraction of Each Proposed Longwall

Longwall	Maximum Upperbound Cumulative Subsidence (mm)	Maximum Upperbound Cumulative Tilt (mm/m)	Maximum Upperbound Cumulative Tensile Strain (mm/m)	Maximum Upperbound Cumulative Compressive Strain (mm/m)
After LWA3	625	1.8	0.1	0.6
After LWA4	2060	7.6	0.7	2.1
After LWA5	2160	7.5	0.7	2.0

A summary of the maximum upperbound travelling tilts and strains at the pipeline, during the extraction of proposed Longwalls A3 and A4, is provided in Table 5.18.

Table 5.18 Maximum Upperbound Travelling Tilts and Strains at the Water Pipeline during the Extraction of Proposed Longwalls A3 and A4

Longwall	Maximum Upperbound Travelling Tilt (mm/m)	Maximum Upperbound Travelling Tensile Strain (mm/m)	Maximum Upperbound Travelling Compressive Strain (mm/m)
During LWA3	1.7	0.2	0.2
During LWA4	1.1	0.2	0.2

The maximum upperbound systematic tilt along the pipeline, at any time during or after the extraction of the proposed longwalls, is 7.6 mm/m (ie: 0.8 %), or a change in grade of 1 in 130, which occurs after the extraction of proposed Longwall A4.

The maximum upperbound systematic tensile and compressive strains at the pipeline, at any time during or after the extraction of the proposed longwalls, are 0.7 mm/m and 2.1 mm/m, respectively, and the associated minimum radii of curvatures are 21 kilometres and 7.1 kilometres, respectively. The maximum upperbound systematic tensile strain at the pipeline occurs above the commencing end of proposed Longwall A4, and the maximum upperbound compressive strain occurs above the chain pillar between proposed Longwalls A3 and A4.

5.8.3. Impact Assessments for the Water Pipeline

The water pipeline is a gravity pipeline and is unlikely, therefore, to be impacted by the predicted or upperbound differential subsidence and tilt resulting from the extraction of the proposed longwalls.

The maximum upperbound systematic tensile and compressive strains at the pipeline are 0.7 mm/m and 2.0 mm/m, respectively. The type of construction is not known, however, the pipeline is likely to be a Polyvinyl-Chloride (PVC) or Polyethylene (PE) pipeline. These types of pipelines are flexible and can typically tolerate ground strains greater than 10 mm/m and radii of curvatures less than 0.1 kilometres. It is unlikely, therefore, that a PVC or PE pipeline would be impacted by the predicted and upperbound systematic strains and curvatures, resulting from the extraction of the proposed longwalls. It is recommended, however, that the pipeline is inspected on site, to confirm the location, extent, type of construction and existing condition of the pipeline.

The pipeline may be subjected to higher strains where it is anchored to the ground by associated infrastructure, or by tree roots. It is possible that the pipeline could be locally impacted where it is anchored to the ground, as a result of the extraction of the proposed longwalls, which could result in the leakage of water. In the event that the pipeline looses water, the Colliery would provide an alternative water supply until the Mine Subsidence Board repairs the pipeline.

5.8.4. Impact Assessments for Increased Predictions

If the predicted systematic subsidence parameters at the water pipeline were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the pipeline. It is unlikely that the upperbound systematic subsidence parameters at the pipeline would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

If the maximum upperbound systematic tilt above the proposed longwalls of 10.9 mm/m were to occur at the pipeline, it would still unlikely to result in any impact on the pipeline, as it is a gravity pipeline.

If the maximum upperbound systematic tensile and compressive strains above the proposed longwalls of 1.2 mm/m and 3.7 mm/m, respectively, were to occur at the pipeline, it would still be unlikely to result in any impact on a PVC or PE pipeline. The likelihood of impact on the pipeline where it is anchored to the ground by associated structures or by tree roots would increase accordingly.

5.8.5. Recommendations for the Water Pipeline

The assessed impacts on the water pipeline resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies. It is recommended that the pipeline is inspected on site, to confirm the location, extent, type of construction and existing condition of the pipeline. It is recommended that management strategies are developed, in consultation with the private owner, so that the pipeline can be maintained in a safe and serviceable condition throughout the mining period.

5.9. Electrical Services

There are three branches of an 11 kV powerline which cross the proposed Longwalls A3 to A5. The first branch (Branch 1) follows the alignment of Nash Lane, the second branch (Branch 2) crosses proposed Longwalls A4 and A5 in a north-south direction, and the third branch (Branch 3) crosses the south-western corner of proposed Longwall A5. The locations of the powerlines and the pole ID numbers are shown in Drawing No. MSEC275-08.

The cables will not be directly affected by the ground strains, as they are supported by the poles above ground level. The cables may, however, be affected by changes in the bay lengths, ie: the distance between the poles at the level of the cables, resulting from differential subsidence, systematic horizontal movements, and systematic tilt at the pole locations. The stabilities of the poles are also affected by systematic tilt, and by the changes in the catenary profiles of the cables.

5.9.1. Predicted Subsidence Parameters for the Powerlines

Summaries of the predicted cumulative systematic subsidence, tilt along and tilt across the alignments of the powerlines at each pole location, after the extraction of each proposed longwall, are provided in Table 5.19, Table 5.20, and Table 5.21.

Table 5.19 Predicted Cumulative Systematic Subsidence, Tilt Along and Tilt Across the Alignment of Powerline Branch 1 at the Pole Locations after the Extraction of Each Proposed LW

Pole ID	Maximum Predicted Cumulative Systematic Subsidence (mm)			Maximum Predicted Cumulative Systematic Tilt Along the Alignment of the Powerline (mm/m)			Maximum Predicted Cumulative Systematic Tilt Across the Alignment of the Powerline (mm/m)		
	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5
FT-80072	< 20	< 20	< 20	0.1	0.1	0.1	0.1	0.1	0.1
FT-80071	35	40	45	0.3	0.4	0.4	0.1	0.2	0.3
FT-80070	140	215	235	0.8	1.5	1.6	0.4	0.9	1.1
FT-80069	285	700	740	0.2	3.2	3.2	0.1	2.6	3.1
FT-98007	160	775	820	0.8	3.4	3.4	0.4	2.1	2.5
FT-98009	25	90	125	0.2	1.1	1.2	0.1	0.2	0.5

Table 5.20 Predicted Cumulative Systematic Subsidence, Tilt Along and Tilt Across the Alignment of Powerline Branch 2 at the Pole Locations after the Extraction of Each Proposed LW

Pole ID	Maximum Predicted Cumulative Systematic Subsidence (mm)			Maximum Predicted Cumulative Systematic Tilt Along the Alignment of the Powerline (mm/m)			Maximum Predicted Cumulative Systematic Tilt Across the Alignment of the Powerline (mm/m)		
	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5
FT-98008	240	440	455	0.4	1.8	1.9	0.9	1.6	1.6
FT-98007	160	775	820	0.6	1.6	2.0	0.8	3.7	3.7
FU-34114	35	355	1120	0.2	-2.1	0.5	0.2	2.9	2.3
FU-34112	30	310	695	0.2	1.7	1.8	0.2	2.6	4.7
FU-34111	< 20	60	640	< 0.1	0.4	1.0	0.1	0.6	3.5
FU-34110	< 20	< 20	135	< 0.1	< 0.1	0.5	< 0.1	< 0.1	0.7
FU-34109	< 20	< 20	45	< 0.1	< 0.1	0.2	< 0.1	< 0.1	0.3
FU-34102	< 20	< 20	< 20	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1

Table 5.21 Predicted Cumulative Systematic Subsidence, Tilt Along and Tilt Across the Alignment of Powerline Branch 3 at the Pole Locations after the Extraction of Each Proposed LW

Pole ID	Maximum Predicted Cumulative Systematic Subsidence (mm)			Maximum Predicted Cumulative Systematic Tilt Along the Alignment of the Powerline (mm/m)			Maximum Predicted Cumulative Systematic Tilt Across the Alignment of the Powerline (mm/m)		
	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5
FU-24107	< 20	< 20	< 20	< 0.1	< 0.1	0.1	< 0.1	< 0.1	0.1
FU-24106	< 20	< 20	25	< 0.1	< 0.1	0.2	< 0.1	< 0.1	0.2
FU-24105	< 20	< 20	85	< 0.1	0.1	1.0	< 0.1	0.1	0.6
FU-24102	< 20	< 20	170	< 0.1	0.1	1.4	< 0.1	0.1	1.4
FU-24103	< 20	< 20	255	< 0.1	0.1	1.1	< 0.1	0.2	2.3

The maximum predicted systematic subsidence at the pole locations is 1120 mm, which occurs at Pole FU-34114 (Branch 2) after the extraction of proposed Longwall A5. The maximum predicted differential systematic subsidence between adjacent poles is 695 mm, which occurs between Poles FT-98007 and FT-98009 (Branch 1) after the extraction of proposed Longwall A5.

The maximum predicted systematic tilt in any direction at the pole locations is 4.7 mm/m (ie: 0.5 %), or a change in verticality of 1 in 215, which occurs at Pole FU-34112 (Branch 2) after the extraction of proposed Longwall A5. The maximum predicted systematic horizontal movement at the locations of the poles is 70 mm which occurs at Pole FU-34112 (Branch 2 after the extraction of proposed Longwall A5.

5.9.2. Upperbound Subsidence Parameters for the Powerlines

The upperbound systematic subsidence parameters at the powerlines have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as discussed in Section 3.6.

Summaries of the upperbound systematic subsidence, tilt along and tilt across the alignments of the powerlines at each pole location, after the extraction of each proposed longwall, are provided in Table 5.22, Table 5.23, and Table 5.24.

Table 5.22 Upperbound Cumulative Systematic Subsidence, Tilt Along and Tilt Across the Alignment of Powerline Branch 1 at the Pole Locations after the Extraction of Each Proposed LW

Pole ID	Maximum Upperbound Cumulative Systematic Subsidence (mm)			Maximum Upperbound Cumulative Systematic Tilt Along the Alignment of the Powerline (mm/m)			Maximum Upperbound Cumulative Systematic Tilt Across the Alignment of the Powerline (mm/m)		
	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5
FT-80072	25	25	35	0.2	0.2	0.3	0.1	0.1	0.2
FT-80071	75	80	100	0.6	0.8	0.9	0.3	0.4	0.6
FT-80070	290	450	500	1.6	3.2	3.3	0.9	1.8	2.3
FT-80069	605	1470	1555	0.5	6.7	6.7	0.3	5.4	6.4
FT-98007	330	1630	1720	1.7	7.2	7.1	0.9	4.4	5.3
FT-98009	55	195	265	0.5	2.3	2.6	0.2	0.5	1.0

Table 5.23 Upperbound Cumulative Systematic Subsidence, Tilt Along and Tilt Across the Alignment of Powerline Branch 2 at the Pole Locations after the Extraction of Each Proposed LW

Pole ID	Maximum Upperbound Cumulative Systematic Subsidence (mm)			Maximum Upperbound Cumulative Systematic Tilt Along the Alignment of the Powerline (mm/m)			Maximum Upperbound Cumulative Systematic Tilt Across the Alignment of the Powerline (mm/m)		
	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5
FT-98008	500	920	950	0.7	3.8	4.1	1.8	3.4	3.4
FT-98007	330	1630	1720	1.2	3.3	4.2	1.6	7.8	7.8
FU-34114	70	750	2345	0.4	4.5	1.0	0.5	6.0	4.9
FU-34112	65	650	1455	0.4	3.5	3.8	0.5	5.4	9.8
FU-34111	< 20	125	1345	0.1	0.9	2.1	0.1	1.2	7.4
FU-34110	< 20	< 20	280	< 0.1	< 0.1	1.1	< 0.1	< 0.1	1.5
FU-34109	< 20	< 20	90	< 0.1	< 0.1	0.5	< 0.1	< 0.1	0.5
FU-34102	< 20	< 20	< 20	< 0.1	< 0.1	0.2	< 0.1	< 0.1	0.1

Table 5.24 Upperbound Cumulative Systematic Subsidence, Tilt Along and Tilt Across the Alignment of Powerline Branch 3 at the Pole Locations after the Extraction of Each Proposed LW

Pole ID	Maximum Upperbound Cumulative Systematic Subsidence (mm)			Maximum Upperbound Cumulative Systematic Tilt Along the Alignment of the Powerline (mm/m)			Maximum Upperbound Cumulative Systematic Tilt Across the Alignment of the Powerline (mm/m)		
	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5	LWA3	LWA4	LWA5
FU-24107	< 20	< 20	25	< 0.1	< 0.1	0.2	< 0.1	< 0.1	0.2
FU-24106	< 20	< 20	50	< 0.1	< 0.1	0.4	< 0.1	< 0.1	0.4
FU-24105	< 20	< 20	180	< 0.1	0.1	2.1	< 0.1	0.1	1.4
FU-24102	< 20	< 20	355	< 0.1	0.2	3.0	< 0.1	0.2	3.0
FU-24103	< 20	25	540	< 0.1	0.2	2.2	< 0.1	0.4	4.8

The maximum upperbound systematic subsidence at the pole locations is 2345 mm, which occurs at Pole FU-34114 (Branch 2) after the extraction of proposed Longwall A5. The maximum upperbound differential systematic subsidence between adjacent poles is 1455 mm, which occurs between Poles FT-98007 and FT-98009 (Branch 1) after the extraction of proposed Longwall A5.

The maximum upperbound systematic tilt in any direction at the pole locations is 9.8 mm/m (ie: 1.0 %), or a change in verticality of 1 in 100, which occurs at Pole FU-34112 (Branch 2) after the extraction of proposed Longwall A5. The maximum upperbound systematic horizontal movement at the locations of the poles is 150 mm, which occurs at Pole FU-34112 (Branch 2) after the extraction of proposed Longwall A5.

5.9.3. Impact Assessments for the Powerlines

The maximum upperbound differential systematic subsidence between adjacent poles of 1455 mm, which occurs between Poles FT-98007 and FT-98009 (Branch 2), occurs over a bay length of 240 metres, and the resulting increase in bay length is approximately 4 mm, or less than 0.1 % of the original bay length. It is unlikely, therefore, that the maximum predicted or the maximum upperbound differential systematic subsidence between adjacent poles would result in any significant impact on the powerlines.

High tilts at the locations of poles can adversely impact the stability of the poles, especially the tension poles that are supported by guy ropes. The maximum upperbound systematic tilt at the locations of the poles is 9.8 mm/m, which occurs at Pole FU-34112 (Branch 2). Powerlines can typically experience tilts of up to 20 mm/m at the locations of the poles without impact. It is unlikely, therefore, that the maximum predicted or the maximum upperbound systematic tilt at the locations of the poles would result in any significant impact on the powerlines.

The maximum upperbound systematic horizontal movement at the locations of the poles is 150 mm, which occurs at Pole FU-34112 (Branch 2). The original bay length between Poles FU-34112 and FU-34111 is 200 metres and, therefore, the upperbound systematic horizontal movement equates to a change in bay length of less than 0.1 % of the original bay length. It is unlikely, therefore, that the maximum predicted or the maximum upperbound systematic horizontal movements at the locations of the poles would result in any significant impact on the powerlines.

5.9.4. Impact Assessments for Increased Predictions

If the predicted systematic subsidence parameters at the powerlines were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the powerlines. It is unlikely that the upperbound systematic subsidence parameters at the powerlines would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

If the maximum upperbound systematic tilt above the proposed longwalls of 10.9 mm/m were to occur at the poles, the changes in bay lengths would still be much less than 0.1 % of the original bay lengths and unlikely, therefore, to result in any significant impact on the powerlines.

If the maximum upperbound systematic horizontal movement above the proposed longwalls of 165 mm were to occur at the poles, the changes in bay lengths would still be much less than 0.1 % of the original bay lengths and unlikely, therefore, to result in any significant impact on the powerlines.

5.9.5. Recommendations for the Powerlines

The assessed impacts on the 11 kV powerlines resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies.

It is recommended that the 11 kV powerlines should be inspected by a suitably qualified person prior to being mined beneath, to assess the existing conditions of the powerlines, and to determine whether any preventive measures are required. The powerlines should be visually monitored as each longwall mines beneath them, so that any impacts can be identified and rectified immediately. It is also recommended that management strategies are developed, in consultation with Energy Australia, so that the powerlines can be maintained in a safe and serviceable condition throughout the mining period.

5.10. Telecommunication Services

The local underground copper telecommunications cables within the SMP Area follow Nash Lane, the locations of which are shown in Drawing No. MSEC275-08. Consumer underground copper cables connect the local copper cables along Nash Lane with the rural properties along this road.

The copper cables are direct buried and are unlikely, therefore, to be impacted by tilt. The copper cables, however, are likely to experience the ground strains resulting from the extraction of the proposed longwalls.

5.10.1. Predicted Subsidence Parameters for the Copper Cables

The predicted profiles of systematic subsidence and strain along the local copper cables are the same as those along Nash Road, which are shown in Fig. H.04 in Appendix H. A summary of the maximum predicted cumulative systematic subsidence parameters along the local copper cables, after the extraction of each proposed longwall, is provided in Table 5.25.

Table 5.25 Maximum Predicted Cumulative Systematic Subsidence Parameters along the Local Copper Cables Resulting from the Extraction of Each Proposed Longwall

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Tensile Strain (mm/m)	Maximum Predicted Cumulative Compressive Strain (mm/m)
After LWA3	290	< 0.1	0.3
After LWA4	955	0.3	1.0
After LWA5	1000	0.3	1.0

The cables will also be subjected to travelling strains where the extraction faces of proposed Longwalls A3 and A4 pass beneath them. A summary of the maximum predicted travelling strains at the copper cables, during the extraction of proposed Longwalls A3 and A4, is provided in Table 5.26.

Table 5.26 Maximum Predicted Travelling Strains at the Local Copper Cables during the Extraction of Proposed Longwall A3 and A4

Longwall	Maximum Predicted Travelling Tensile Strain (mm/m)	Maximum Predicted Travelling Compressive Strain (mm/m)
During LWA3	0.1	0.1
During LWA4	0.1	0.1

The maximum predicted systematic tensile and compressive strains at the local copper cables, at any time during or after the extraction of the proposed longwalls, are 0.3 mm/m and 1.0 mm/m, respectively, and the associated minimum radii of curvatures are 50 kilometres and 15 kilometres, respectively. The maximum predicted systematic tensile strain at the copper cables occurs above the commencing end of proposed Longwall A4, and the maximum predicted systematic compressive strain occurs above the chain pillar between proposed Longwalls A3 and A4.

5.10.2. Upperbound Subsidence Parameters for the Copper Cables

The upperbound systematic subsidence parameters at the local copper cables have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as discussed in Section 3.6.

The upperbound profiles of systematic subsidence and strain along the local copper cables are the same as those along Nash Road, which are shown in Fig. I.04 in Appendix I. A summary of the maximum upperbound cumulative systematic subsidence parameters along the local copper cables, after the extraction of each proposed longwall, is provided in Table 5.27.

Table 5.27 Maximum Upperbound Cumulative Systematic Subsidence Parameters along the Local Copper Cables after the Extraction of Each Proposed Longwall

Longwall	Maximum Upperbound Cumulative Subsidence (mm)	Maximum Upperbound Cumulative Tensile Strain (mm/m)	Maximum Upperbound Cumulative Compressive Strain (mm/m)
After LWA3	625	0.1	0.6
After LWA4	2060	0.7	2.1
After LWA5	2160	0.7	2.0

A summary of the maximum upperbound travelling strains at the local copper cables, during the extraction of proposed Longwalls A3 and A4, is provided in Table 5.28.

Table 5.28 Maximum Upperbound Travelling Strains at the Local Copper Cables during the Extraction of Proposed Longwalls A3 and A4

Longwall	Maximum Upperbound Travelling Tensile Strain (mm/m)	Maximum Upperbound Travelling Compressive Strain (mm/m)
During LWA3	0.2	0.2
During LWA4	0.2	0.2

The maximum upperbound systematic tensile and compressive strains at the local copper cables, at any time during or after the extraction of the proposed longwalls, are 0.7 mm/m and 2.1 mm/m, respectively, and the associated minimum radii of curvatures are 21 kilometres and 7.1 kilometres, respectively. The maximum upperbound systematic tensile strain at the cables occurs above the commencing end of proposed Longwall A4, and the maximum upperbound systematic compressive strain occurs above the chain pillar between proposed Longwalls A3 and A4.

5.10.3. Impact Assessments for the Copper Cables

The maximum upperbound systematic tensile or compressive strain at the local copper cables, at any during or after the extraction of the proposed longwalls, is 2.1 mm/m. Modern copper cables can, in some cases, tolerate tensile strains of up to 20 mm/m, without impact.

It is unlikely, therefore, that the local copper cables would be impacted as a result of the extraction of the proposed longwalls, based on the predicted and on the upperbound systematic strains. It is possible, however, that the cables could experience locally elevated strains where they are anchored to the ground by associated infrastructure, or by tree roots. It is unlikely at the magnitudes of the predicted and upperbound systematic strains, however, that there would be any significant impact on the copper cables at any anchor points.

5.10.4. Impact Assessments for Increased Predictions

If the predicted systematic subsidence parameters at the copper cables were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the cables. It is unlikely that the upperbound systematic subsidence parameters at the cables would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

If the maximum upperbound systematic tensile and compressive strains above the proposed longwalls of 1.2 mm/m and 3.7 mm/m, respectively, were to occur at the copper cables, it would still be unlikely to result in any impact on the cables, as the strains would still be much less than 20 mm/m.

5.10.5. Recommendations for the Copper Telecommunication Cables

The assessed impacts on the copper telecommunication cables resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies.

It is recommended that management strategies are developed, in consultation with Telstra, so that the serviceability of the local copper cables can be maintained throughout the mining period.

5.11. Rural Building Structures

A total of 16 rural building structures (Structure Type R) have been identified within the SMP Area, which include farm sheds, garages and other non-residential structures. The locations of the rural building structures are shown in Drawing No. MSEC275-09 and details are provided in Table G.01 in Appendix G.

5.11.1. Predicted Subsidence Parameters for the Rural Building Structures

Predictions of systematic subsidence, tilt and strain have been made at the centroid and at the vertices of each rural building structure, as well as eight equally spaced points radially placed around the centroid and vertices at a distance of 20 metres. In the case of a rectangular shaped structure, predictions have been made at a minimum of 45 points within and around the structure.

At these points, the maximum predicted values of systematic subsidence, tilt and strain have been determined during, and after the extraction of each proposed longwall, for each rural building structure. An additional strain of 0.2 mm/m has been added to the magnitude of the predicted strains, where the predicted subsidence is greater than 20 mm, to account for the scatter which is generally observed in strain profiles.

The maximum predicted subsidence, and the tilt and strain impact assessments for each rural building structure within the SMP Area are provided in Table G.01. A summary of the tilt and strain impact assessments for the rural building structures within the SMP Area, after the extraction of each proposed longwall, is provided in Table 5.29.

Table 5.29 Summary of Predicted Tilt and Strain Impact Assessments for the Rural Building Structures within the SMP Area after the Extraction of Each Proposed Longwall

Longwall	Tilt Impact Categories				Strain Impact Categories					
	Cat A	Cat B	Cat C	Cat D	Cat 0	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
After LWA3	16	0	0	0	16	0	0	0	0	0
After LWA4	16	0	0	0	15	1	0	0	0	0
After LWA5	16	0	0	0	14	2	0	0	0	0

It can be seen from the above table, that no rural building structures are assessed to experience a tilt impact greater than Category A. It can also be seen from the above table that two rural building structures are assessed to experience a Category 1 strain impact, and no rural building structures are assessed to experience a strain impact of Category 2, or greater.

5.11.2. Upperbound Subsidence Parameters for the Rural Building Structures

The upperbound systematic subsidence parameters at the rural building structures have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as discussed in Section 3.6.

The maximum upperbound subsidence, and the upperbound tilt and strain impact assessments for each rural building structure within the SMP Area are provided in Table G.02. A summary of the upperbound tilt and strain impact assessments for the rural building structures within the SMP Area, after the extraction of each proposed longwall, is provided in Table 5.30.

Table 5.30 Summary of Upperbound Tilt and Strain Impact Assessments for the Rural Building Structures within the SMP Area after the Extraction of Each Proposed Longwall

Longwall	Tilt Impact Categories				Strain Impact Categories					
	Cat A	Cat B	Cat C	Cat D	Cat 0	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
After LWA3	16	0	0	0	16	0	0	0	0	0
After LWA4	10	1	5	0	13	2	1	0	0	0
After LWA5	3	8	4	1	13	2	1	0	0	0

It can be seen from the above table, that one rural building structure is assessed to experience an upperbound Category D tilt impact, and four rural building structures are assessed to experience an upperbound Category C tilt impact at the completion of the proposed longwalls. It can also be seen from the above table that one rural building structure is assessed to experience an upperbound Category 2 strain impact, and two rural building structures are assessed to experience an upperbound Category 1 strain impact.

5.11.3. Impact Assessments for the Rural Building Structures

Preventive measures are generally not recommended for rural building structures unless the impact assessments are Category D for Tilt or Category 4 for strain, or greater. This is due to the flexible types of construction of these structures.

There is one rural building structure, being Structure Ref. A04c, which is assessed to experience an upperbound Category D tilt impact. This structure is a small shed and the maximum upperbound tilt of 10.3 mm/m is unlikely to result in any significant impact on the serviceability, or structural integrity of the shed. It is recommended that the Structure Ref. A04c should be inspected by a structural engineer prior to the extraction of proposed Longwall A4, to assess its existing condition, and to recommend any required preventive measures for tilt. The remaining rural building structures are assessed to experience an upperbound Category C tilt impact, or less.

There are no rural building structures which are assessed to experience an upperbound Category 3 strain impact, or greater. Provided that the rural building structures are in a sound condition, they are expected to remain in a safe and serviceable condition throughout the mining period. No preventive measures are recommended for the rural building structures for strain impacts.

Any impacts on the rural building structures that might occur as a result of the extraction of the proposed longwalls are expected to be of a minor nature, and be easily remediated using well established building techniques. With these remedial measures in place, it is unlikely that there will be any significant long term impact on rural building structures resulting from the extraction of the proposed longwalls.

5.11.4. Impact Assessments for Increased Predictions

If the predicted systematic subsidence parameters were to be increased by factors of 1.25 to 2 times, the potential impacts on the rural structures would increase accordingly. The tilt and strain impact assessments for increased predictions are provided in Table G.03, and are summarised in Table 5.31.

Table 5.31 Summary of the Tilt and Strain Impact Assessments for the Rural Building Structures within the SMP Area for Increased Predictions

Increased Prediction	Number of Rural Structures with Tilt Impact Assessment for Increased Predictions				Number of Rural Structures with Strain Impact Assessment for Increased Predictions					
	Cat A	Cat B	Cat C	Cat D	Cat 0	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
x 1.25	15	1	0	0	14	1	1	0	0	0
x 1.50	10	5	1	0	14	1	1	0	0	0
x 1.75	6	9	1	0	13	2	1	0	0	0
x 2.00	3	7	6	0	12	3	1	0	0	0

If the predictions were to be increased by a factor of 2 times, the maximum tilt and strain impacts on the rural building structures are Category C and Category 2, respectively. It would be expected, therefore, that remediation measures would not be required for the rural building structures, even if the predictions were to be exceeded by a factor of up to 2 times.

It is unlikely that the upperbound systematic subsidence parameters at the rural building structures would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as described in Section 3.6.

5.11.5. Recommendations for the Rural Building Structures

The assessed impacts on the rural building structures resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies.

It is recommended that all rural building above the proposed longwalls should be inspected by a structural engineer, prior to being mined beneath, to assess the existing conditions of the structures and to recommend any preventive measures, as required. It is recommended that the rural building structures are visually monitored during the extraction of the proposed longwalls.

5.12. Tanks

There are a number of tanks (Structure Type T) located within the SMP Area including rainwater tanks and fuel storage tanks. The locations of the larger tanks are shown in Drawing No. MSEC275-09 and detail provided in Table 2.3. There are also rainwater tanks associated with the residences on each rural property.

5.12.1. Predicted Subsidence Parameters for the Tanks

Predictions of subsidence, tilt and strain have been made at the centroid of each tank, as well as eight equally spaced points radially placed around the perimeter of each tank at a distance of 20 metres. Predictions have been made at a minimum of 45 points within and around the tanks.

The maximum predicted systematic tilt at the tanks is 3.3 mm/m (ie: 0.3 %), or a change in grade of 1 in 300. The maximum predicted systematic tensile strain at the tanks is 0.8 mm/m, and the associated minimum radius of curvature is 19 kilometres. The maximum predicted systematic compressive strain at the tanks is 1.8 mm/m, and the associated minimum radius of curvature is 8.3 kilometres

5.12.2. Upperbound Subsidence Parameters for the Tanks

The upperbound systematic subsidence parameters at the tanks have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as discussed in Section 3.6.

The maximum upperbound systematic tilt at the tanks is 7.0 mm/m (ie: 0.7 %), or a change in grade of 1 in 145. The maximum upperbound systematic tensile strain at the tanks is 1.5 mm/m, and the associated minimum radius of curvature is 10 kilometres. The maximum upperbound systematic compressive strain at the tanks is 3.3 mm/m, and the associated minimum radius of curvature is 4.5 kilometres.

5.12.3. Impact Assessments for the Tanks

Tilt can affect the serviceability of tanks by altering the water or fuel levels in the tanks, which can in turn affect the minimum level of water or fuel which can be released from the taps. The maximum upperbound systematic tilt at the tanks within the SMP Area represents a change in grade of less than 1 % and is unlikely, therefore, to have any significant impact on the serviceability of the tanks.

Tanks A02t02 and A04t03 are elevated tanks on supporting structures. High tilts can potentially induce eccentricities and, hence, increased the loads within the supporting structures. The maximum upperbound systematic tilt at the tanks represents a change in grade of less than 1 % and is unlikely, therefore, to have any significant impact on the supporting structures.

The maximum upperbound systematic tensile and compressive strains at the tanks are 1.5 mm/m and 3.3 mm/m, respectively. The ground strains are unlikely to be fully transferred into the tanks where the tanks are founded on a ground slab or the natural ground. In these cases, it is unlikely that the tanks would be impacted by the predicted or upperbound systematic strains.

The ground strains are unlikely to be transferred into the supporting structures of elevated Tanks A02t02 and A04t03 if the structures are founded on base slabs. If the predicted or upperbound systematic strains were to be fully transferred into the supporting structures of these tanks, however, it could result in increased loads in the structural members which could result in an adverse impact on the strength of these structures. It is recommended, therefore, that a structural engineer should inspect the footings of the supporting structures to the elevated tanks and recommend any preventive measures, as required.

It is also possible that buried water pipelines associated with the tanks within the SMP Area could be impacted by the predicted and upperbound systematic strains if they are anchored by the tanks, or by other structures in the ground. Any impacts are expected to be of a minor nature, including leaking pipe joints, and could be easily repaired. With these remedial measures in place, it would be unlikely that there would be any long term impact on the pipelines associated with the tanks.

5.12.4. Impact Assessments for Increased Predictions

If the predicted systematic subsidence parameters at the tanks were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the tanks. It is unlikely that the upperbound systematic subsidence parameters at the tanks would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

If the maximum upperbound systematic tilt above the proposed longwalls of 10.9 mm/m were to occur at the tanks, the maximum change in grade at the tanks would be approximately 1 % and unlikely, therefore, to have any significant impact on the serviceability of the tanks, or on the structural integrity of the supporting structures to the elevated tanks.

If the maximum upperbound systematic tensile and compressive strains above the proposed longwalls of 1.2 mm/m and 3.7 mm/m, respectively, were to occur at the tanks, the potential impacts on the supporting structures to the elevated tanks and the potential impacts on the buried water pipelines associated with the tanks would increase accordingly. If the upperbound systematic strains were realised at the tanks, the preventive measures for the supporting structures to the elevated tanks, and the remedial measures for the buried pipelines would not significantly change. It would still be unlikely that there would be any significant impact to the tanks themselves, where the tanks are founded on a ground slab or on the natural ground.

5.12.5. Recommendations for the Tanks

The assessed impacts on the tanks resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies.

It is recommended that the tanks above the proposed longwalls should be inspected by a structural engineer, prior to being mined beneath, to assess the existing condition of the tanks and supporting structures, and to recommend any preventive measures, as required. It is recommended that the tanks are visually monitored during the mining period.

5.13. Fences

There are a number of fences within the SMP Area which are constructed in a variety of ways, generally using either timber or metal materials. Wire fences could be affected by tilting of the fence posts and changes of tension in the fence wires due to strain as mining occurs. Wire fences are generally flexible in construction and can usually tolerate tilts of up to 10 mm/m and strains of up to 5 mm/m without any significant impact.

The fences are located across the SMP Area and are likely to be subjected to the full range of systematic subsidence parameters. The maximum predicted systematic subsidence parameters within the SMP Area are summarised in Table 4.2 and Table 4.3. The maximum upperbound systematic subsidence parameters within the SMP Area are summarised in Table 4.4 and Table 4.5.

The maximum upperbound systematic tilt within the SMP Area is 10.9 mm/m (ie: 1.1 %), or a change in gradient of 1 in 90, which occurs above proposed Longwall A3 after the extraction of proposed Longwall A5. It is possible that the fences above proposed Longwall A3 could be impacted by the upperbound systematic tilts. It is also possible that the fences above proposed Longwalls A4 and A5 could be impacted by the upperbound systematic tilts, where the fence posts have high existing tilts.

The maximum upperbound systematic tensile and compressive strains within the SMP Area are 1.2 mm/m and 3.7 mm/m, respectively. The maximum upperbound systematic tensile strain occurs above the maingate of proposed Longwall A5, and the maximum upperbound systematic compressive strain occurs adjacent to the maingate of proposed Longwall A3. The maximum upperbound systematic strains are less than 5 mm/m and are unlikely, therefore, to have a significant impact on the fences.

Any impacts on the fences which occur as the result of mining are likely to be of a minor nature and relatively easy to rectify by re-tensioning the fencing wire, straightening the fence posts, and if necessary, replacing some sections of fencing.

If the predicted systematic subsidence parameters at the fences were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the fences. It is unlikely that the upperbound systematic subsidence parameters at the fences would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

The assessed impacts on the fences resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies.

5.14. Farm Dams

There are 23 farms dams identified within the SMP Area, the locations of which are shown in Drawing No. MSEC275-09 and details are provided in Table G.04 in Appendix G. The identified farm dams are typically earth dams established within the surface soils along the lines of natural watercourses.

5.14.1. Predicted Subsidence Parameters for the Farm Dams

Predictions of systematic subsidence, tilt and strain have been made at the centroid and at the corners of each farm dam, as well as eight equally spaced points radially placed around the centroid and corners at a distance of 20 metres. An additional strain of 0.2 mm/m has been added to the magnitude of the predicted strains, where the predicted subsidence is greater than 20 mm, to account for the scatter that is generally observed in strain profiles.

The maximum predicted values of systematic subsidence, tilt and strain have been determined during, and after the extraction of each proposed longwall. The maximum predicted systematic subsidence parameters at each farm dam are provided in Table G.04, and are summarised in Fig. 5.1, Fig. 5.2 and Fig. 5.3.

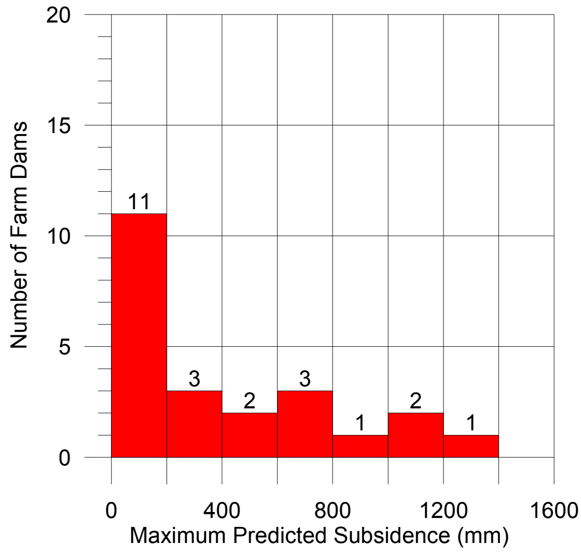

Fig. 5.1 Maximum Predicted Systematic Subsidence at the Farm Dams after the Extraction of the Proposed Longwalls A3 to A5

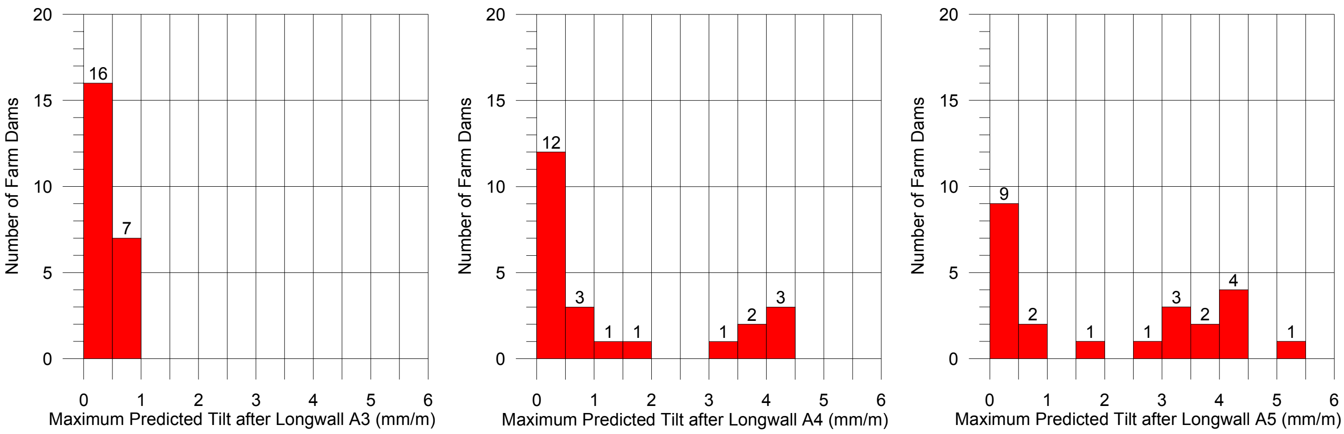

Fig. 5.2 Maximum Predicted Systematic Tilt at the Farm Dams after the Extraction of Proposed Longwall A3 (Left), Proposed Longwall A4 (Middle), and Proposed Longwall A5 (Right)

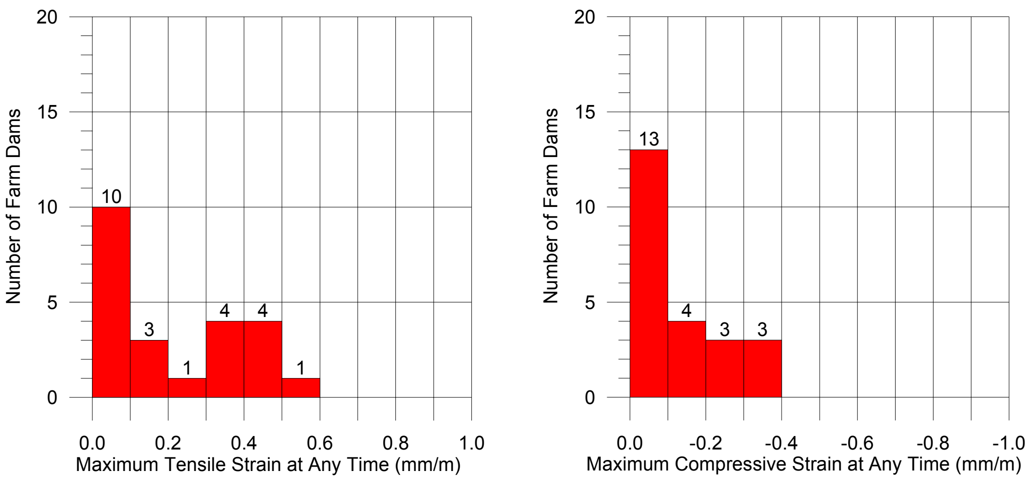

Fig. 5.3 Maximum Predicted Systematic Tensile Strain (Left) and Compressive Strain (Right) at the Farm Dams Resulting from the Extraction of Proposed Longwalls A3 to A5

The maximum predicted systematic tilt at the farm dams, at any time during or after the extraction of the proposed longwalls, is 5.2 mm/m (ie: 0.5 %), or a change in grade in 1 in 195, which occurs a Dam A04d02 after the extraction of proposed Longwall A5.

The maximum predicted systematic tensile and compressive strains at the farm dams are 0.5 mm/m and 0.4 mm/m, respectively, and the associated minimum radii of curvatures are 30 kilometres and 38 kilometres, respectively.

The dams have typically been constructed within drainage lines and, therefore, may be subjected to valley related movements resulting from the extraction of the proposed longwalls. The equivalent valley heights at the dams are very small and the predicted valley related upsidence and closure movements at the dam walls are likely to be much less than the predicted systematic subsidence movements.

5.14.2. Upperbound Subsidence Parameters for the Farm Dams

The upperbound systematic subsidence parameters at the farm dams have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as discussed in Section 3.6.

The maximum upperbound values of systematic subsidence, tilt and strain have been determined during, and after the extraction of each proposed longwall. The maximum upperbound systematic subsidence parameters at each farm dam are provided in Table G.05, and are summarised in Fig. 5.4, Fig. 5.5 and Fig. 5.6.

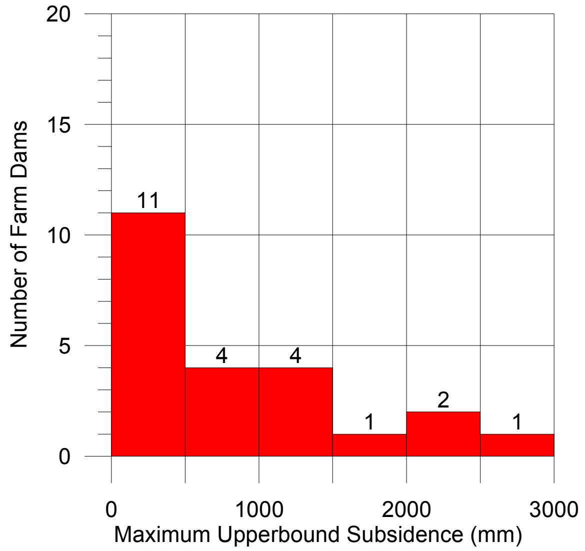

Fig. 5.4 Maximum Upperbound Systematic Subsidence at the Farm Dams after the Extraction of the Proposed Longwalls A3 to A5

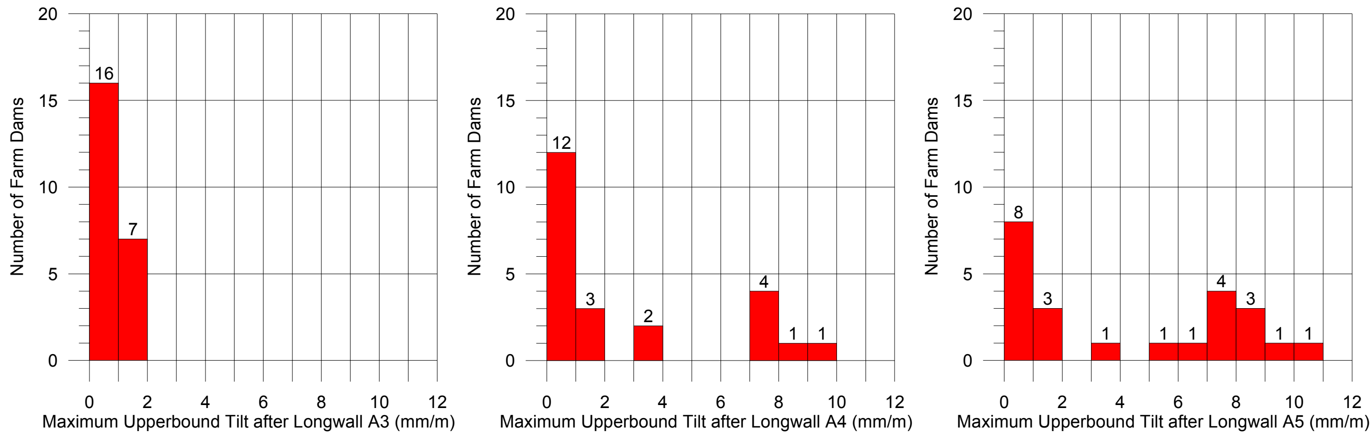

Fig. 5.5 Maximum Upperbound Systematic Tilt at the Farm Dams after the Extraction of Proposed Longwall A3 (Left), Proposed Longwall A4 (Middle), and Proposed Longwall A5 (Right)

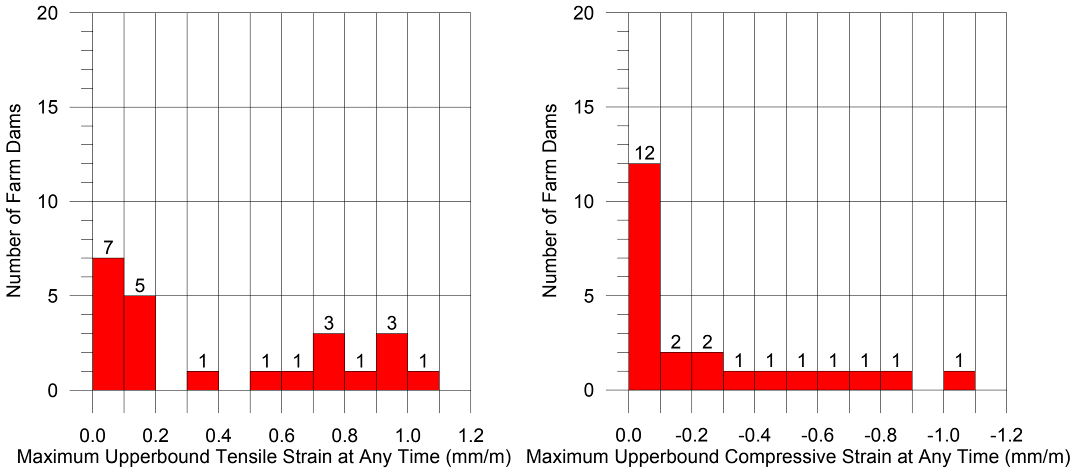

Fig. 5.6 Maximum Upperbound Systematic Tensile Strain (Left) and Compressive Strain (Right) at the Farm Dams Resulting from the Extraction of Proposed Longwalls A3 to A5

The maximum upperbound systematic tilt at the farm dams, at any time during or after the extraction of the proposed longwalls, is 10.9 mm/m (ie: 1.1 %), or a change in grade of 1 in 90, which occurs at Dam A04d02 after the extraction of proposed Longwall A5.

The maximum upperbound systematic tensile and compressive strains at the farm dams are 1.1 mm/m and 1.0 mm/m, respectively, and the associated minimum radii of curvatures are 14 kilometres and 15 kilometres, respectively.

5.14.3. Impact Assessments for the Farm Dams

Mining induced tilts can affect the water levels around the perimeters of farm dams, with the freeboard increasing on one side, and decreasing on the other. Tilt can potentially reduce the storage capacity of farm dams, resulting in them to overflow, or affect the stability of the dam walls.

The maximum predicted changes in freeboard at the farm dams within the SMP Area were conservatively determined by applying the maximum predicted systematic tilts along the longest sides of the dams. The maximum upperbound changes in freeboard at the farm dams within the SMP Area were conservatively determined by applying the maximum upperbound systematic tilts along the longest sides of the dams. The maximum predicted and maximum upperbound changes in freeboard at the farm dams are summarised in Tables G.04 and G.05, respectively.

The maximum predicted change in freeboard at the farm dams is 190 mm, which occurs at Dam A04d02 after the extraction of proposed Longwall A5. The maximum upperbound change in freeboard at the farm dams is 400 mm, which also occurs at Dam A04d02 after the extraction of proposed Longwall A5. The maximum predicted and upperbound changes in freeboard are less than 500 mm and are unlikely, therefore, to have a significant impact on the stability of the dam walls. It is possible, however, that the larger changes in freeboard could result in a reduction in the capacities of the farm dams, where the maximum tilts increase the water levels at the dam walls.

The maximum upperbound systematic tensile and compressive strains at the farm dams, at any time during or after the extraction of the proposed longwalls, are 1.1 mm/m and 1.0 mm/m, respectively. Farm dams, such as those identified within the SMP Area, are typically constructed of cohesive soils with reasonably high clay content. The walls of the farm dams should be capable of withstanding tensile strains of up to 3 mm/m without damage, because of their inherent elasticity. It is unlikely, therefore, that the maximum predicted and maximum upperbound systematic strains would result in any significant impact on the farm dams.

It is possible, however, that some minor cracking and leakage of water may occur in the farm dam walls which are subjected to the higher upperbound strains, though any minor cracking or leakages can be easily identified and repaired as required. It is not expected that any significant loss of water will occur from the farm dams, and that any loss would flow into the tributary in which the dam was formed.

There is a possibility that high concentrations of strain could occur at faults, fissures and other geological features, or points of weaknesses in the strata, and such occurrences could be coupled with localised stepping in the surface. If this type of phenomenon coincided with a farm dam wall, then, there is a possibility that an impact on the dam could occur, but the likelihood of this occurring is very small.

5.14.4. Impact Assessments for Increased Predictions

If the predicted systematic subsidence parameters at the farm dams were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the farm dams. It is unlikely that the upperbound systematic subsidence parameters at the farm dams would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

If the maximum upperbound tilt above the proposed longwalls of 10.9 mm/m were to occur at the farm dams, the changes in freeboard at the dam walls would increase accordingly. The maximum change in grade at the dam walls would be approximately 1 % and unlikely, therefore, to result in any significant impact on the stability of the dam walls.

If the maximum upperbound systematic tensile and compressive strains above the proposed longwalls of 1.2 mm/m and 3.7 mm/m, respectively, were to occur at the farm dams, the likelihood and extent of cracking in the dam walls would increase accordingly. As the maximum systematic tensile strain is still less than 3 mm/m, any cracking in the dam walls would still expected to be of a minor nature, and would be expected to be easily repaired.

With these remediation measures in place, it is unlikely that any significant long term impact on the farm dams would occur resulting from the extraction of the proposed longwalls.

5.14.5. Recommendations for the Farm Dams

The assessed impacts on the farm dams resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies.

All water retaining structures should be visually monitored during the extraction of the proposed longwalls, to ensure that they remain in a safe and serviceable condition. In the event that any of the farm dams within the SMP Area loses water as the result of mine subsidence, the Colliery would provide an alternative water supply to the affected property for the duration of the mining period, and the Mine Subsidence Board would repair the farm dam following the completion of mining. The management strategies for the farm dams should be incorporated in the Property Subsidence Management Plans (PSMP) for each rural property.

5.15. Wells and Bores

There are no registered water bores within the general SMP Area. There is, however, one registered water bore adjacent to the general SMP Area, being Bore GW054676, which is shown in Drawing No. MSEC275-08. The bore is located outside the total predicted and total upperbound 20 mm subsidence contours and is unlikely, therefore, to be subjected to any significant systematic subsidence, tilts, or strains as a result of the extraction of the proposed longwalls.

The bores in the vicinity of the SMP Area may be affected by regional horizontal movements, which can occur up to 2 or 3 kilometres from the proposed longwalls. Differential horizontal movements at different strata horizons can reduce the capacities of the bores in the vicinity of proposed longwalls, or increase the ingress of water into the bores at different strata horizons.

The water obtained from Bore GW054676 is low yielding (approx. 1 L/sec) and poor quality (approx. 14,000 ~ 16,000 μS/cm) and is unsuitable for domestic or stock use. The bore is solely used by the DNR as a baseline groundwater monitoring bore. There are no known bores yielding water that is used by the property holders within the SMP Area.

If the capacities of any bores within the vicinity of the SMP Area were affected by far-field movements, the Colliery would provide alternative supplies of water until such time as the Mine Subsidence Board could re-establish a water supply. Normally this would occur when mining in the area had been completed, at which time the Board would either repair the existing bore and its equipment, extend the bore to a greater depth, or establish a new bore. With these mitigation measures in place, it is unlikely there would be any significant long term impact on water supplies from the bores resulting from the extraction of the proposed longwalls, based on both the predicted and the upperbound systematic subsidence parameters.

5.16. Archaeological Sites

The impact assessments for archaeological sites are provided in the report by Umwelt (2007).

5.17. Survey Control Marks

There are no survey control marks within the general SMP Area. There are, however, survey control marks in the vicinity of the general SMP Area, which are shown in Drawing No. MSEC275-08.

The survey control marks in the vicinity of the proposed longwalls may experience either small amounts of subsidence and / or some small regional horizontal movements as the proposed longwalls are mined. It is possible that other marks outside the immediate area could also be affected by regional horizontal movements, up to 3 kilometres outside the general SMP Area.

It will be necessary on completion of the proposed longwalls, when the ground has stabilised, to re-establish these marks. Consultation between Austar and the Department of Lands will be required throughout the mining period to ensure that these survey marks are reinstated at an appropriate time, as required.

5.18. Houses

There are seven houses located within the SMP Area, of which four are single-storey houses with lengths less than 30 metres (Type H1), and three are single-storey houses with lengths greater than 30 metres (Type H2). There are no double-storey houses (Types H3 and H4) within the SMP Area. The locations of the houses within the SMP Area are shown in Drawing No. MSEC275-09 and details are provided in Table G.01 in Appendix G.

5.18.1. Predicted Subsidence Parameters for the Houses

Predictions of systematic subsidence, tilt and strain have been made at the centroid and at the vertices of each house, as well as eight equally spaced points radially placed around the centroid and vertices at a distance of 20 metres. In the case of a rectangular shaped structure, predictions have been made at a minimum of 45 points within and around the structure.

At these points, the maximum predicted values of systematic subsidence, tilt and strain have been determined during, and after the extraction of each proposed longwall, for each house. An additional strain of 0.2 mm/m has been added to the magnitude of the predicted strains, when the predicted subsidence is greater than 20 mm, to account for the scatter in observed strain profiles.

The maximum predicted subsidence, and the tilt and strain impact assessments for each house within the SMP Area are provided in Table G.01. A summary of the tilt and strain impact assessments for the houses within the SMP Area, after the extraction of each proposed longwall, is provided in Table 5.32.

Table 5.32 Summary of Predicted Tilt and Strain Impact Assessments for the Houses within the SMP Area after the Extraction of Each Proposed Longwall

Longwall	Tilt Impact Categories				Strain Impact Categories					
	Cat A	Cat B	Cat C	Cat D	Cat 0	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
After LWA3	7	0	0	0	7	0	0	0	0	0
After LWA4	7	0	0	0	4	2	0	1	0	0
After LWA5	7	0	0	0	3	3	0	1	0	0

It can be seen from the above table, that no houses are assessed to experience a tilt impact greater than Category A. It can also be seen from the above table that one house (Ref. A04a) is assessed to experience a Category 3 strain impact, and three houses (Refs. A01a, A11a, and A11c) are assessed to experience Category 1 strain impacts.

5.18.2. Upperbound Subsidence Parameters for the Houses

The upperbound systematic subsidence parameters at the houses have been determined by scaling up the predicted systematic subsidence parameters, such that a maximum total subsidence of 65 % of effective extracted seam height is achieved above the proposed longwalls, as discussed in Section 3.6.

The maximum upperbound subsidence, and the upperbound tilt and strain impact assessments for each house within the SMP Area are provided in Table G.02. A summary of the upperbound tilt and strain impact assessments for houses within the SMP Area, after the extraction of each proposed longwall, is provided in Table 5.33.

Table 5.33 Summary of Upperbound Tilt and Strain Impact Assessments for the Houses within the SMP Area after the Extraction of Each Proposed Longwall

Longwall	Tilt Impact Categories				Strain Impact Categories					
	Cat A	Cat B	Cat C	Cat D	Cat 0	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
After LWA3	7	0	0	0	5	2	0	0	0	0
After LWA4	4	3	0	0	3	3	0	0	1	0
After LWA5	3	3	1	0	2	3	1	0	1	0

It can be seen from the above table, that one house (Ref. A03a) is assessed to experience an upperbound Category C tilt impact, and three houses (Refs. A01a, A11a, and A11c) are assessed to experience an upperbound Category B tilt impact at the completion of the proposed longwalls. It can also be seen from the above table that one house (Ref. A04a) is assessed to experience an upperbound Category 4 strain impact, and one house (Ref. A11a) is assessed to experience an upperbound Category 2 strain impact.

5.18.3. Impact Assessments for the Houses

Preventive measures are generally not recommended for houses unless the impact assessments are Category C for Tilt or Category 3 for Strain, or greater.

There are no houses assessed to experience at Category B tilt impact, or higher. There is, however, one house, being Structure Ref. A03a, which is assessed to experience an upperbound Category C tilt impact. Tilt does not have any significant impact on the stability of houses, unless the tilts are significantly greater than those predicted within the SMP Area.

The upperbound systematic tilt at Structure Ref. A03a, however, could affect the serviceability of the house, including door swings, and issues with gutter and wet area drainage. No preventive measures are recommended for the houses within the SMP Area for tilt prior to mining. Minor remedial measures may be required for tilt after the houses are mined beneath, including the correction of door swings, gutters, and wet area drainage.

Based on the predicted systematic subsidence parameters, there is one house, being Structure Ref. A04a, which is assessed to experience a Category 3 strain impact, and no houses are assessed to experience a Category 4 or 5 strain impact. If the upperbound systematic subsidence parameters were realised, Structure Ref. A04a is assessed to experience an upperbound Category 4 strain impact. The remaining houses are assessed to experience upperbound strain impacts of Category 2, or less.

It should be noted that a great deal of conservatism has been used in the strain impact assessments for the houses, which includes the following:-

- The predicted and upperbound systematic strains at each house have been taken as the maximum values at the centroid, at the vertices, or at eight points radially placed around each centroid and vertex at a distance of 20 metres. This is conservative as the maximum strains generally occur at one of the points located 20 metres from the perimeter of the houses, and the strains at the remaining points are less.

- The maximum predicted and maximum upperbound systematic strains have been assumed to be orientated along the main axes, ie: longest sides, of the houses. This is conservative as the maximum strains are generally orientated obliquely to the houses within the SMP Area, and the strains along the main axes of the houses are less.
- The strain impact assessments have been determined by applying the maximum predicted and maximum upperbound systematic strains along the maximum lengths of the houses. This is conservative for long houses, as the peak strains occur over relatively short distances, and reduce in magnitude away from these locations.

The predicted and upperbound strain impact assessments for Structure Ref. A04a could be shown to be less than those provided in Tables G.01 and G.02 by removing some of the conservatism described above. This conservatism is considered appropriate, however, given the less certain nature of strain predictions and the necessity for providing conservative predictions for houses.

Preventive measures may be required to Structure Ref. A04a, prior to the extraction of proposed Longwall A4. It is recommended that a structural engineer should inspect Structure Ref. A04a, prior to the house being mined beneath, to assess the existing condition and to recommend any required preventive measures, such that the house can be maintained in a safe and serviceable condition throughout the mining period.

Preventive measures are not recommended for the remaining houses. Provided that these houses are in a sound existing condition, they are expected to remain safe and serviceable during and after the extraction of the proposed longwalls. It is recommended that all houses should be inspected by a structural engineer, prior to each house being mined beneath, to assess the existing conditions of the houses, and to recommend any preventive measures, as required.

In the event that impacts occur on the houses, they can be remediated through well established building techniques. With these remediation measures in place, it is unlikely that there would be any significant long term impact on houses resulting from the extraction of the proposed longwalls.

5.18.4. Impact Assessments for Increased Predictions

If the predicted systematic subsidence parameters were to be increased by factors of 1.25 to 2 times, the potential impacts on the houses would increase accordingly. The tilt and strain impact assessments for increased predictions are provided in Table G.03 and are summarised in Table 5.34.

Table 5.34 Summary of Tilt and Strain Impact Assessments for the Houses within the SMP Area for Increased Predictions

Increased Prediction	Number of Houses with Tilt Impact Assessment for Increased Predictions				Number of Houses with Strain Impact Assessment for Increased Predictions					
	Cat A	Cat B	Cat C	Cat D	Cat 0	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
x 1.25	7	0	0	0	2	4	0	1	0	0
x 1.50	7	0	0	0	2	4	0	1	0	0
x 1.75	4	3	0	0	2	4	0	0	1	0
x 2.00	3	4	0	0	2	1	3	0	1	0

If the predictions were to be increased by a factor of 2 times, all houses would be assessed to experience a Category B tilt impact, or less. One house, being Structure Ref. A04a, would be assessed to experience a Category 4 strain impact, and the remaining houses would be assessed to experience a Category 2 strain impact, or less. Remediation measures might be required for Structure Ref. A04a, after the extraction of Longwall A4, if the predictions were exceeded by a factor of 2 times. With these remediation measures implemented, it is unlikely that there would be any significant long term impact on the houses resulting from the extraction of the proposed longwalls.

It is unlikely that the upperbound systematic subsidence parameters at the houses would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as described in Section 3.6.

5.18.5. Recommendations for the Houses

The assessed impacts on the houses resulting from the predicted and upperbound systematic subsidence parameters can be managed with the implementation of suitable management strategies.

It is recommended that all houses above the proposed longwalls should be inspected by a structural engineer, prior to each house being mined beneath, to assess the existing conditions of the houses, and to recommend any preventive measures, as required. It is recommended that the houses are visually monitored during the extraction of the proposed longwalls. It is also recommended that the houses directly above the proposed longwalls are surveyed during the mining period, where agreements can be made between Austar and the owners.

5.18.6. Non-Residential Building Structures

The predictions and impact assessments for the rural building structures and tanks are provided in Sections 5.11 and 5.12, respectively. The predictions and impact assessments for the swimming pools, tennis court and on-site waste water systems are provided in the following sections.

5.18.6.1. Swimming Pools

There are two swimming pools within the SMP Area, being Structures Refs. A01p01 and A11p01. The locations of the pools are shown in Drawing No. MSEC275-09 and details are provided in Table G.01 in Appendix G.

Predictions of systematic subsidence, tilt and strain have been made at the centroid and at the corners of each pool, as well as eight equally spaced points radially placed around the centroid and corners at a distance of 20 metres. The maximum predicted and maximum upperbound systematic subsidence, tilt and strains at each pool are provided in Tables G.01 and G.02, respectively

The maximum upperbound systematic tilt at the pools is 5.9 mm/m (ie: 0.6 %), or a change in grade of 1 in 170. The maximum predicted and maximum upperbound changes in gradient at the pools are less than 1 % and are unlikely, therefore, to result in any significant impacts on the serviceability of the pools. While the predicted and upperbound systematic tilts are not expected to result in a loss of capacity for the polls, it is noted that tilts are more readily noticeable to property owners, particularly if the walls of the pools are tiled, as the height of the freeboard will vary along the length of the pool.

The maximum upperbound systematic tensile or compressive strain at the pools is 0.4 mm/m, and the associated minimum radius of curvature is 38 kilometres. It is unlikely that the maximum predicted or maximum upperbound systematic strains would be fully transferred into the pool structures and is unlikely, therefore, to result in any significant systematic subsidence impacts on the pool structures.

While the predicted and upperbound systematic strain impacts on the pool structures have been assessed as not significant, it is noted that pools and the associated infrastructure can be more susceptible to systematic subsidence movements than for other structures.

If the predicted systematic subsidence parameters at the pools were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the pools. It is unlikely that the upperbound systematic subsidence parameters at the pools would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

5.18.6.2. Tennis Court

There is one tennis court within the SMP Area, being Structure Ref. A01i. The location of the tennis court is shown in Drawing No. MSEC275-09 and details are provided in Table G.01 in Appendix G.

Predictions of systematic subsidence, tilt and strain have been made at the centroid and at the corners of the tennis court, as well as eight equally spaced points radially placed around the centroid and corners at a distance of 20 metres. The maximum predicted and maximum upperbound systematic subsidence, tilt and strains at the tennis court are provided in Tables G.01 and G.02, respectively.

The maximum upperbound systematic tilt at the tennis court is 5.6 mm/m (ie: 0.6 %), or a change in grade of 1 in 180, which represents a change in grade of less than 1 % and is unlikely, therefore, to result in any significant impact on the serviceability of the tennis court.

The maximum upperbound systematic tensile strain at the tennis court is 0.6 mm/m, and the associated minimum radius of curvature is 25 kilometres. It possible that the upperbound tensile strain could result in cracking in the natural surface of the tennis court. Any cracking in the natural surface of the tennis court is expected to be of a minor nature and easily repaired.

If the predicted systematic subsidence parameters at the tennis court were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the tennis court. It is unlikely that the upperbound systematic subsidence parameters at the tennis court would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

5.18.6.3. On-Site Waste Water Systems

The residences on the rural properties within the SMP Area have on-site waste water systems. The predicted and upperbound systematic subsidence parameters at the on-site waste water systems are similar to those at the houses which they serve, which are summarised in Tables G.01 and G.02, respectively, as these are the maximum values which occur within 20 metres of the houses.

A summary of the maximum predicted systematic subsidence parameters at the on-site waste water systems, at any time during or after the extraction of the proposed longwalls, whichever is the greater, is provided in Table 5.35.

Table 5.35 Maximum Predicted Systematic Subsidence Parameters at the On-Site Waste Water Systems due to the Extraction of the Proposed Longwalls

Location	Maximum Predicted Subsidence (mm)	Maximum Predicted Tilt (mm/m)	Maximum Predicted Systematic Tensile Strain (mm/m)	Maximum Predicted Systematic Compressive Strain (mm/m)
On-site Waste Water Systems	1355	3.3	0.8	1.8

A summary of the maximum upperbound systematic subsidence parameters at the on-site waste water systems, at any time during or after the extraction of the proposed longwalls, whichever is the greater, is provided in Table 5.36.

Table 5.36 Maximum Upperbound Systematic Subsidence Parameters at the On-Site Waste Water Systems due to the Extraction of the Proposed Longwalls

Location	Maximum Upperbound Subsidence (mm)	Maximum Upperbound Tilt (mm/m)	Maximum Upperbound Systematic Tensile Strain (mm/m)	Maximum Upperbound Systematic Compressive Strain (mm/m)
On-site Waste Water Systems	2810	7.0	1.5	3.3

The maximum upperbound systematic tilt at the on-site waste water systems is 7.0 mm/m (ie: 0.7 %), or a change in grade of 1 in 145, which represents a change in grade of less than 1 % and is unlikely, therefore, to have any significant impact on the systems.

The maximum upperbound systematic tensile and compressive strains at the on-site waste water systems are 1.5 mm/m and 3.3 mm/m, respectively, and the associated minimum radii of curvatures are 10 kilometres and 4.5 kilometres, respectively. The on-site waste water system tanks are generally small, typically less than 3 metres in diameter, and are constructed from reinforced concrete, and are usually bedded in sand and backfilled. It is unlikely, therefore, that the maximum predicted or maximum upperbound systematic strains would result in any significant impacts on the tank structures themselves.

It is possible, however, that the buried pipelines associated with the on-site waste water tanks could be impacted by the upperbound systematic strains if they are anchored by the tanks or other structures in the ground. Any impacts are expected to be of a minor nature, including leaking pipe joints, and could be easily repaired. With these remediation measures in place, it would be unlikely that there would be any long term impact on the pipelines associated with the on-site waste water systems.

If the predicted systematic subsidence parameters at the on-site waste water systems were to be increased by factors of 1.25 to 2 times, the predicted parameters would still be less than the upperbound systematic subsidence parameters at the systems. It is unlikely that the upperbound systematic subsidence parameters at the systems would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness above the proposed longwalls, as discussed in Section 3.6.

5.18.7. Fences

The predictions and impact assessments for fences are provided in Section 5.13.

5.19. Other Potential Subsidence Movements and Impacts

The following sections provide discussions on other potential subsidence movements and impacts resulting from the extraction of the proposed Longwalls A3 to A5.

5.19.1. Predicted Systematic Horizontal Movements

The predicted systematic horizontal movements over the proposed longwalls are calculated by applying a factor to the predicted systematic tilt values. In the Newcastle Coalfield a factor of 10 is generally adopted, being the same factor as that used to determine strains from curvatures, and this has been found to give a reasonable correlation with measured data.

The comparisons between observed and back-predicted strains along the monitoring lines above the previously extracted longwalls at the Colliery, as described in Section 3.4.1, indicates that a factor of 15 provides a better correlation for prediction systematic horizontal movements. The factor will in fact vary and will be higher at low tilt values and lower at high tilt values. The application of this factor will therefore lead to over-prediction of horizontal movements where the tilts are high and under-prediction of the movements where the tilts are low.

The maximum predicted systematic tilt within the SMP Area, at any time during or after the extraction of the proposed longwalls, is 5.8 mm/m, which occurs above proposed Longwall A3 after the extraction of proposed Longwall A5. This area will experience the greatest predicted systematic horizontal movement towards the centre of the overall goaf area resulting from the extraction of the proposed longwalls. The maximum predicted systematic horizontal movement is, therefore, approximately 90 mm, i.e. 5.8 mm/m multiplied by a factor of 15.

The maximum upperbound systematic tilt within the SMP Area, at any time during or after the extraction of the proposed longwalls, is 10.9 mm/m, which also occurs above proposed Longwall A3 after the extraction of proposed Longwall A5. The maximum upperbound systematic horizontal movement is, therefore, approximately 165 mm, i.e. 10.9 mm/m multiplied by a factor of 15.

Systematic horizontal movements do not directly impact on natural features or items of surface infrastructure, rather impacts occur as the result of differential horizontal movements. Systematic strain is the rate of change of systematic horizontal movement. The impacts of systematic strain on the natural features and items of surface infrastructure are addressed in impact assessments for each feature, which are provided in Sections 5.2 to 5.18.

5.19.2. Predicted Regional Horizontal Movements

In addition to the systematic subsidence movements that have been predicted above and adjacent the proposed longwalls, and the predicted valley related movements along the creeks, it is also likely that some regional horizontal movements will be experienced during the extraction of the proposed longwalls.

Regional horizontal movements result from the redistribution of horizontal in situ stresses in the strata around the collapsed and fractures zones above longwall extractions. Such movements are to some extent predictable and occur whenever significant excavations occur at the surface or underground.

The horizontal in situ stresses in the strata within the SMP Area have already been affected by the previously extracted Longwalls SL2 to SL4 to the north of the proposed longwalls, and by the previously extracted Longwalls SL1 and 1 to 13A to the west of the proposed longwalls. As the proposed Longwalls A3 to A5 are mined, it is likely that the redistribution of the horizontal in situ stresses would result in regional horizontal movements towards the new goaf area.

An empirical database of observed incremental regional horizontal movements has been compiled using monitoring data primarily from the Southern Coalfield, from Collieries including Appin, Bellambi, Dendrobium, Douglas, Newstan, Tower and West Cliff. The regional horizontal movements resulting from longwall mining were generally observed to be orientated towards the extracted longwall. At very low levels of regional horizontal movements, however, there was a high scatter in the orientation of the observed movements.

The observed incremental regional horizontal movements, resulting from the extraction of a single longwall, for all monitoring points within the database, is provided in Fig. D.26 in Appendix D. The observed incremental regional horizontal movements, resulting from the extraction of a single longwall, for monitoring points within the database where there was solid coal between the longwall and monitoring points, is provided in Fig. D.27 in Appendix D.

It can be seen from these figures, that incremental regional horizontal movements of up to 20 mm have been observed at distances of 2000 metres from extracted longwalls. As successive longwalls within a series of longwalls are mined, the magnitudes of the incremental regional horizontal movements decrease. This is possibly due to the fact that once the in situ stresses within the strata in the collapsed zones above the first few extracted longwalls has been redistributed, the potential for further movement is reduced. The total regional horizontal movement is not, therefore, the sum of the incremental regional horizontal movements for the individual longwalls.

The predicted regional horizontal movements resulting from the extraction of the proposed longwalls are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than 0.1 mm/m. The impacts of regional horizontal movements on the natural features and items of surface infrastructure within the vicinity of the SMP Area is expected to be insignificant.

5.19.3. The Potential Impacts of Ground Vibration on Structures due to Mining

The settlement of the ground resulting from systematic subsidence is generally a series of gradual and progressive movements, the effect of which is not apparent to an observer at the surface. The major breakage and collapse of strata into the voids left by the extraction of the seam occur in the strata layers immediately above the seam. Above that level, the breakage and collapse of the strata reduces to become a bending and sagging of the upper layers of rock with less sudden and much smaller movements occurring. In some instances, the movements can be concentrated at faults or other points of weakness in the strata with minor stepping at the surface.

Where the strata layers immediately above the seam are thick, massive, and competent, then any major collapse below ground would result in some vibration in the layers of rock above it, which might be felt as a minor effect at the surface. However, these effects would normally be associated with mining at shallow depths of cover and would not generally be expected to occur at deeper mines, such as for the proposed longwalls where the depth of cover generally exceeds 500 metres.

Higher ground vibrations and noise were observed during the extraction of previous longwalls at the Colliery which resulted in some minor structural impacts. The peak particle velocities (PPV) at the surface were monitoring during the extraction of Longwalls 6 to 9. The maximum measured PPV were 22 mm/sec and 26 mm/m, which occurred in early 1991 during the extraction of Longwall 7, and 28 mm/sec, which occurred in early 1992 during the extraction of Longwall 8. The remaining measured PPV were all less than 8 mm/sec. PPV above 6 mm/sec are clearly noticeably and PPV above 13 mm/m can potentially result in minor structural impacts. The high PPV measured at the Colliery were believed to be the result of a dyke which is located above the previously extracted longwalls at the Colliery.

It is possible, therefore, as the proposed longwalls are mined and the strata subsides, for some vibrations to be felt at the surface, though these are more likely to occur directly above, or close to the proposed longwalls. As there are no identified significant geological features above the proposed longwalls, the levels of vibration would generally be expected to be low and would not be of sufficient amplitude to result in any significant structural impact. Any structural impact which occurs due to vibration, resulting from the extraction of the proposed longwalls, is expected to be of a minor nature, and easily repaired using normal building maintenance techniques.

5.19.4. The Potential for Noise at the Surface due to Mining

It is very unusual for noise to be noticed at the surface due to longwall mining at depths of cover of 500 metres, such as for the proposed longwalls. As discussed in Section 5.19.3, however, noise resulting from strata collapsing into the goaf was observed at the surface during the extraction of previous longwalls at the Colliery.

As systematic subsidence occurs and the near surface rocks are affected by tensile and compressive strains, the rocks open up at joints and planes of weakness, and displace due to rotation and shear. Generally the movements are gradual and cannot be detected by an observer at the surface. These movements are also generally shielded by the more plastic surface soils which tend to distribute the strains more evenly and insulate against any sounds from below.

In some cases, the stresses in the rock can build up to the point that the rock suddenly shears to form a new fracture and if the rock is exposed or has only a thin covering of surface soil, the noise resulting from the fracturing can be heard at the surface. Normally the background level of noise in the countryside is such that the sound is not noticed, although in the stillness of night, it might occasionally be noticed when it occurs in close proximity. The structural impact due to noise at the surface, resulting from the extraction of the proposed longwall, is predicted to be insignificant.

5.19.5. The Potential for Increased Subsidence due to Earthquake

It is unlikely that a seismic event would result in additional subsidence to occur above the proposed longwalls, as this has not been observed in the past. After the 1989 Newcastle earthquake, there was no recorded significant damage to mine workings and no additional subsidence measured above mined areas within the Newcastle Coalfield.

After the 1989 Newcastle earthquake, no movement could be detected in any of the fault zones and along joint plane traces outcropping in the Newcastle City district. There were no convincing evidence for liquefaction processes in the Newcastle district, nor were significant changes of surface levels observed. Operating mines suffered negligible structural damage as a result of the earthquake but several reported changes in hydrological regimes lasting 4 to 6 months (Moelle 1995).

Although subsidence due to longwall mining results in voids to be formed within the collapsed zone and bedding separations to be formed within the fractured zone, the consolidation of these zones occur shortly after mining and the strata reaches a state of equilibrium, after which no further significant movement occurs. Following the original subsidence event, residual subsidence of up to 10 % occurs, but usually movement ceases within a period of 5 to 10 years. Once this equilibrium forms, it is unlikely that any further consolidation would occur as a result of an earthquake event.

It should also be noted that the impact assessments for the natural features and items of surface infrastructure provided in this report have been made for an upperbound case, which assumes that the maximum possible subsidence of 65 % of effective extracted seam thickness is achieved, as described in Section 3.6. Any small additional consolidation resulting from an earthquake event is unlikely to result in the maximum upperbound systematic subsidence parameters to be exceeded.

The impacts on buildings and surface infrastructure resulting from earthquake events occur when the structures are set in motion, starting with the foundations, which then propagates up through the structures. The differential movement, or sway, of the structures induce forces within the structures which can then result in impact. Below the surface, at the level of underground mine workings, the strata are confined and move en masse, which does not result in differential movements between the different horizons and, hence, does not result in impact. The movements resulting from earthquake events in the past have generally only been observed at the surface, rather than underground. It has also been reported, in the past, that miners working underground during earthquake events were totally unaware of the events.

5.19.6. The Likelihood of Surface Cracking in Soils and Fracturing of Bedrock

As subsidence occurs, surface cracks will generally appear in the tensile zone, i.e. within 0.1 to 0.4 times the depth of cover from the longwall perimeter. Most of the cracks will occur within a radius of approximately 0.1 times the depth of cover from the longwall perimeter. The cracks will generally be parallel to the longitudinal edges of the longwalls.

It is also possible that surface cracks could occur above and parallel to the moving longwall extraction faces, ie: at right angles to the longitudinal edges of the longwalls, as the subsidence trough develops. This cracking is, however, likely to be transient, since the tensile phase, which causes the cracks to open up, is generally followed by a compressive phase, that partially closes them. Fractures are less likely to be observed in exposed bedrock where tensile strain levels are low, typically less than 2 mm/m, as has been predicted within the SMP Area.

Surface tensile fracturing in near surface sandstone is likely to occur coincident with the maximum tensile strains, but open fractures could also occur due to buckling of surface beds that are subject to compressive strains. Fracture widths tend to increase as the depth of cover reduces, and only minor fracturing is expected for the proposed longwalls, where the depth of cover generally exceeds 500 metres.

The incidence of cracks on the surface due to mine subsidence is additionally dependent on the thickness and inherent plasticity of the soils that overlie the bedrock. Surface soils above the proposed longwalls are generally weathered to some degree. The widths and frequencies of any cracks are also dependent upon the pre-existing jointing patterns in the bedrock. Large joint spacing can lead to concentrations of strain and possibly the development of fissures at the rockhead, which are not necessarily coincident with the joints.

A joint spacing of ten metres is not unusual for sandstone and, therefore, fractures at joints could be as wide as 10 mm, based the maximum upperbound systematic tensile strain of 1.2 mm/m resulting from the extraction of the proposed longwalls. Based on the graph in Fig. D.8 in Appendix D, it is unlikely that surface cracks from systematic subsidence movements would exceed 25 mm in width above the proposed longwalls, where the depth of cover generally exceeds 500 metres. If a reasonable thickness of surface soil exists, it is more likely that the surface soil would exhibit a number of narrower cracks, rather than a single larger crack.

Cracking is found more often in the bases of creek and river valleys due to the compressive strains associated with upsidence and closure movements. The likelihood and extent of cracking along the creeks within the SMP Area are discussed in Section 5.2.

The surface cracking resulting from the extraction of the proposed longwalls is expected to be of a minor nature, which is expected to be easily remediated by infilling with soil or other suitable materials, or by locally regrading and recompacting the surface.

5.19.7. The Likelihood of Irregular Profiles

Wherever faults, dykes, or abrupt changes in geology are present at the surface, it is possible that irregularities in the subsidence profiles could occur. Similarly, where surface rocks are thinly bedded, and where cross-bedded strata exist close to the surface, it is possible for surface buckling to occur, leading to irregular movements. Most irregularities in subsidence profiles, however, can be explained by the presence of surface incisions such as gorges, river valleys, and creeks.

Several geological structures have been identified at seam level in the vicinity of the proposed longwalls, and these are shown in Drawing No. MSEC275-06. The major geological features identified at seam level are the faults located south-west of the proposed longwalls, and the dyke located to the north-east of the proposed longwalls. There are no identified significant geological structures above the proposed longwalls.

Irregularities also occur in shallow mining situations, where the collapsed zone, which develops above the extracted seam, extends near to the surface. This type of irregularity is generally only seen where the depth of cover is less than 100 metres, and is unlikely to occur above the proposed longwalls, where the depth of cover generally exceeds 500 metres.

Irregular subsidence profiles can also occur where longwall mining is carried out beneath previous workings, especially beneath bord and pillar extractions which have extensive stooks preventing immediate subsidence. In such situations, the pillars or stooks left in the upper seam can collapse, when mining occurs beneath them, leading to local increased subsidence and irregular subsidence profiles. There are no existing workings above the proposed longwalls, and this kind of irregularity will not occur in this case.

It is also possible that anomalous movements could also occur at unknown geological structures above the proposed longwalls. These have occurred in the past within the NSW Coalfields, and are discussed in Appendix D.5.8. Given the relatively low density of surface features within the SMP Area, the probability of an anomalous movement coinciding with a surface feature is assessed as low.

5.19.8. Likely Height of the Fractured Zone above the Proposed Longwalls

The background to sub-surface strata movements has been discussed in Appendix D.6, and the following conclusions should be read in that context.

The height of the collapsed zone, which forms immediately above extracted longwalls, is generally between 21 to 33 times the extracted seam thickness. The effective extracted seam thickness for the proposed longwalls varies between 3.86 and 5.0 metres, as discussed in Section 3.6, and the predicted height of the collapsed zone for the proposed longwalls, therefore, varies between 80 and 165 metres.

The height of the fractured zone is dependent upon the angle of break (a), the width of the panel (W) and the spanning capacity of a competent stratum at the top of the fracture zone, span (w). These are illustrated in Fig. 5.7. From the mining geometry it can be shown that the height of the fractured zone equals the panel width (W) minus the span (w) divided by twice the tangent of the angle of break.

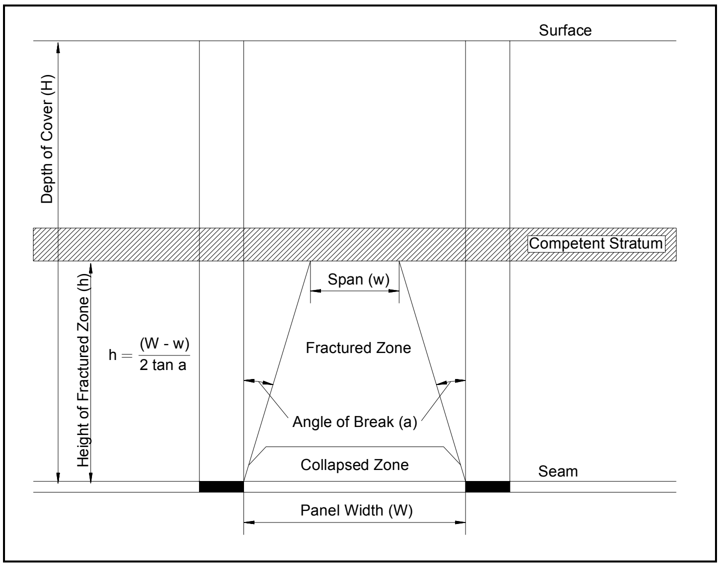

Fig. 5.7 Theoretical Model illustrating the Development and Limit of the Fractured Zone

Using this relationship, the theoretical height of the fractured zone, as a proportion of the width of the extracted panel, has been determined for a range of panel width-to-depth ratios. These values have been plotted in the graph shown in Fig. 5.8, together with the values that have been reported in literature. The red data points are those which have been reported in literature whilst the theoretical values are shown in green, magenta and blue for angles of break of 17°, 20° and 23°, respectively.

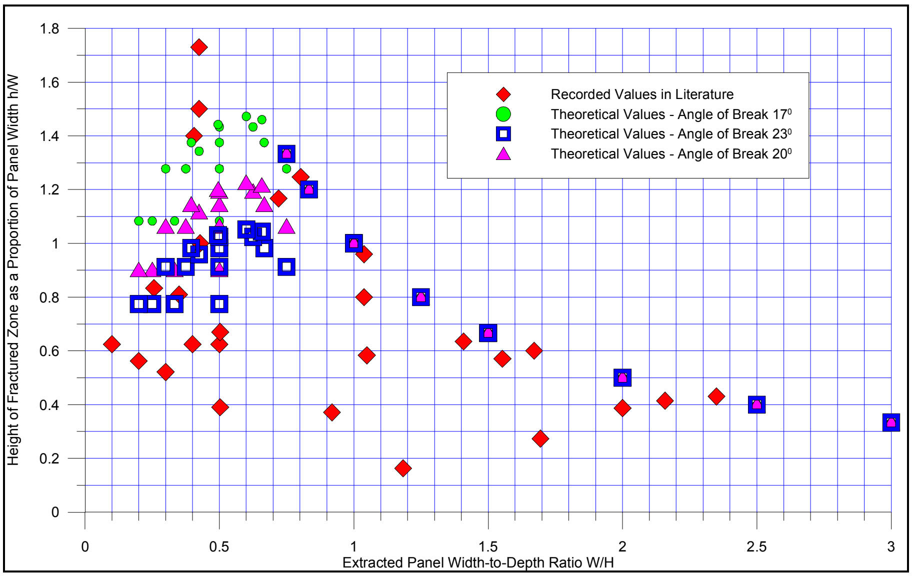

Fig. 5.8 Graph showing Height of Fractured Zone as a Proportion of Panel Width for different Width-to-Depth Ratios

It can be seen that the height of the fractured zone in the database is reasonably represented by the theoretical model using an angle of draw of 20°. Only three red data points appear above the magenta data points and these are the heights of the fractured zone over Longwall 2 at Ellalong Colliery (now Austar), and over Longwall 3 at Tahmoor Colliery, which were given by Holla (1986) and Holla and Buizen (1991).

In both of these cases, the apparent heights of the fractured zone were determined from extensometer readings which could have included horizontal shear as well as vertical dilation. The stated heights of the fractured zone at Tahmoor, which are the highest data points in the graph, are not supported by the measured vertical strains, which averaged only 0.6 mm/m in the top 160 metres of the overburden. A more realistic assessment is that the fractured zone extended only to the Bald Hill Claystone.

In some cases, it is likely that the upwards progression of the fractured zone was limited by the levels of vertical strain that could be developed, which is dependent upon the extracted seam thickness, the surface subsidence and the depth of cover.

The upper limit of the fractured zone will be reached when the strata above that zone are sufficiently strong to span the goaf area without significant bending or shear strains being developed. In the Newcastle Coalfield, the upper layers in the overburden strata are relatively strong sandstones. These sandstone strata are particularly strong and would be expected to be capable of spanning at least 35 metres. If an average angle of break of 20° is assumed, with an extracted panel width of 227 metres, then a height of 265 metres would be required above the seam to reduce the effective span to 35 metres. If an angle of break of 23° is assumed, then a height of 225 metres would be required above the seam to reduce the effective span to 35 metres.

The depth of cover above the proposed longwall generally exceeds 500 metres and it is unlikely, therefore, that the fractured zone would extend up to the surface. It is expected that a *Constrained Zone*, also called a *Continuous Deformation Zone*, would occur between the fractured zone and the surface, which is illustrated in Fig. D.28 and Fig. D.29 in Appendix D.

The constrained zone comprises confined rock strata which have sagged slightly but, because they are constrained, have absorbed most of the strain energy without suffering significant fracturing or alteration to the original physical properties. Some bed separation or slippage can be present as well as discontinuous vertical cracks (usually on the underside of thick strong beds). Weak or soft beds in this zone may suffer plastic deformation.

5.20. Comparison of Predicted Subsidence Parameters Obtained using the Holla Series and Department's Handbook Methods

For comparison, the maximum predicted systematic subsidence parameters along Prediction Line A were also determined using the Holla Series Method (Holla 1988) and the Department's Handbook Method (DMR 1987). These methods only allow for the prediction of the maximum values of systematic subsidence, tilt, curvature and strain, and do not precisely indicate where these maxima will occur.

It should be noted that the proposed extraction heights for the proposed longwalls are greater than those which the Holla Series and Department's Handbook Methods were based. It should also be noted that the Holla Series Method was based on observed subsidence monitoring data from the Southern Coalfield only. Dr. Holla advised verbally, however, that this method could be applied to the Newcastle Coalfield, and that the method would over predict subsidence in the Newcastle Coalfield. The predicted systematic subsidence parameters obtained using these methods, therefore, can only be used as a general comparison.

The overall void widths of the proposed longwalls are 227 metres and the chain pillar widths are 45 metres. Along Prediction Line A, the depth of cover varies between 505 metres and 530 metres, with an average depth of cover of 520 metres. Along Prediction Line A, the overall seam thickness varies between 5.45 metres and 6.15 metres, with an average overall seam thickness of 5.7 metres. The effective extracted seam thickness, based on 85 % recovery of the top coal, is 5.3 metres (ie: 3 metres of bottom coal plus 85 % of 2.7 metres of top coal).

The maximum predicted subsidence using the Holla Series Method (Holla 1988) is determined from Fig. 4 of a published paper which has been reproduced in Fig. 5.9. This figure provides the maximum predicted subsidence, as a ratio of the extracted seam thickness, for varying panel width-to-depth ratios and varying pillar width-to-depth ratios, based on critical extraction conditions.

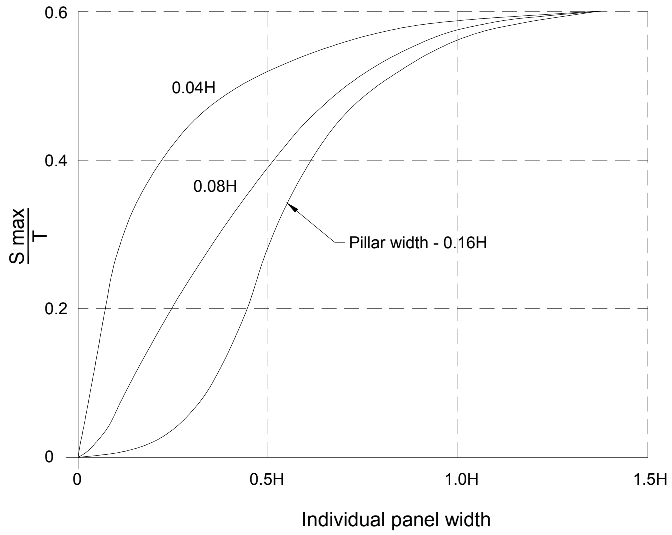

Fig. 5.9 Graph for the Prediction of Maximum Subsidence over a Series of Panels for Critical Extraction Conditions (after Holla, 1988)

Based on an individual panel width-to-depth ratio of 0.44 (ie: 227 metres / 520 metres) and a chain pillar width-to-depth ratio of 0.087 (ie: 45 metres / 520 metres), the maximum predicted total subsidence obtained using Fig. 5.9 is 0.34 times the effective extracted seam thickness, giving a maximum total subsidence of 1800 mm. It should be noted that the maximum predicted total subsidence obtained using the Holla Series Method is based on achieving critical extraction conditions.

The systematic tilts and strains can be predicted using the Department's Handbook Method (DMR 1987) and are obtained by multiplying various factors by the maximum subsidence in millimetres and dividing the result by the depth of cover in metres. The factors for tensile strain, compressive strain and tilt are given in Figs. 10, 11 and 13 of the handbook. The curvatures are determined from the strains using the graph in Fig. 14 of the handbook.

For equivalent panel width-to-depth ratios above 1.4, i.e. for critical extraction conditions, the factors are 0.4 for tensile strain, 0.6 for compressive strain and 1.8 for tilt. In the original handbook, these factors were only applicable to single panels, but Dr. Holla verbally advised that the Department's Method can be used to determine the tilts and strains over a series of longwall panels, using the overall width of the series in the width-to-depth ratio.

The tilts and strains have been determined for critical extraction conditions, ie: adopting an overall panel width-to-depth ratio of greater than 1.4, using the Department's Handbook Method. The maximum predicted systematic tilt, tensile strain, and compressive strain are 6.2 mm/m, 1.4 mm/m, and 2.1 mm/m, respectively.

The predictions made using the Incremental Profile Method are based on three longwalls, having an overall width-to-depth ratio of 1.5, ie: (3 x 227m plus 2 x 45m) / 520m. Although the overall width-to-depth ratio is greater than 1.4, which is typically the critical extraction width, the maximum subsidence for critical extraction conditions may not have been achieved for the proposed longwalls.

To make comparisons between the two methods, the maximum predicted total subsidence obtained using the Incremental Profile Method has been determined by providing additional longwalls until critical extraction conditions are achieved, which is illustrated in Fig. 5.10.

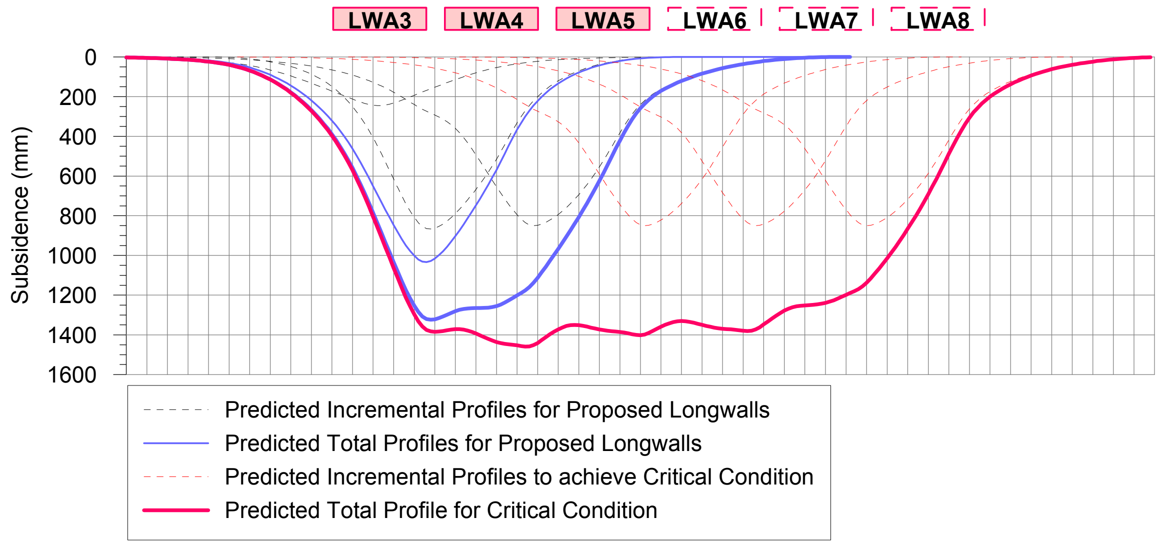

Fig. 5.10 Maximum Predicted Total Subsidence for Critical Conditions Obtained Using the Incremental Profile Method

The maximum predicted total subsidence for critical extraction conditions, obtained using the Incremental Profile Method, is 1460 mm. The maximum predicted tilt, tensile strain and compressive strain for critical extraction conditions, obtained using the Incremental Profile Method are, therefore, 5.5 mm/m, 0.7 mm/m, and 1.7 mm/m, respectively.

The upperbound total systematic subsidence parameters, obtained using the Incremental Profile Method, are based on a maximum total subsidence of 65 % of effective extracted seam thickness is achieved and, therefore, critical extraction conditions are achieved.

A comparison between the predicted total systematic subsidence parameters obtained using the Holla Series and Department's Handbook Methods, and the Incremental Profile Method, is provided in Table 5.37 .

Table 5.37 Comparison of Maximum Predicted Parameters Obtained using Alternative Methods

Predicted Parameter	Holla Series and Department's Handbook Methods	Incremental Profile Method (Predictions for Critical Extraction Conditions)	Incremental Profile Method (Upperbound)
Subsidence (mm)	1800	1460	2855
Tilt (mm/m)	6.2	5.5	10.9
Hogging Curvature (1/km)	0.14	0.05	0.08
Sagging Curvature (1/km)	0.20	0.11	0.25
Tensile Strain (mm/m)	1.4	0.7	1.2
Compressive Strain (mm/m)	2.1	1.7	3.7

It can be seen from the above table that the predictions obtained using the Holla Series and Department's Handbook Methods are greater than those obtained using the Incremental Profile Method, for critical extraction conditions, but much less than those obtained using the Incremental Profile Method based on the upperbound case.

5.21. Testing of the Incremental Profile Method against Previously Extracted Longwalls

The Incremental Profile Method was calibrated to local monitoring data above the previously extracted longwalls at the Colliery, which is described in Section 3.4.1.

5.22. Estimation of the Reliability of Systematic Subsidence Predictions

As described in Section 3.4.1, the Incremental Profile Method has been calibrated to local data using the monitoring data above the previously extracted longwalls at the Colliery. It was found that the shapes of the back-predicted incremental subsidence profiles could be made to closely match the shapes of the observed incremental subsidence profiles by adopting the standard Newcastle Coalfield subsidence profiles based on a panel width-to-depth ratio of 0.3, rather than adopting the actual panel width-to-depth ratios, which varied between 0.38 and 0.65.

No modifications were made to the magnitudes of the maximum back-predicted incremental subsidence in the comparisons for the previously extracted longwall at the Colliery. It was found that the maximum observed incremental subsidence was generally between 45 % and 100 % of the maximum back-predicted incremental subsidence. In no case did the maximum observed incremental subsidence or maximum observed total subsidence exceed the maximum back-predicted incremental subsidence or the maximum back-predicted total subsidence, respectively.

The calibrated Incremental Profile Method should, therefore, provide realistic, if not conservative predictions where the longwall and mining geometries are within the range of the empirical database. It has been recognised, however, that the extraction heights for the proposed longwalls are greater than those in the empirical database, and greater than those at the previously extracted longwalls at the Colliery.

Predictions and impact assessments for a conservative upperbound case were also undertaken, therefore, which assumed that a maximum total subsidence of 65 % of effective extracted seam thickness is achieved above the proposed longwalls, as described in Section 3.6. Based on all the monitoring data throughout the NSW Coalfields, it is unlikely that the maximum upperbound systematic subsidence parameters would be exceeded.

Empirical methods of subsidence prediction are generally accepted as providing predictions of maximum subsidence to an accuracy of ±10% to ±15%, where the longwall and mining geometries are within the ranges of the empirical databases. It was indicated by Dr Lax Holla, in his paper entitled, "Reliability of Subsidence Prediction Methods for use in Mining Decisions in New South Wales" (Holla 1991c), that the accuracy of predictions of maximum subsidence, made using the Department's Empirical Method, generally ranged from +8% to -11%. Of the 14 examples, referred to in the paper, from longwalls at seven different collieries in the Southern and Newcastle Coalfields, the predicted maximum subsidence was less than the measured maximum subsidence in only four cases. Where empirical models have been calibrated to local data, even greater accuracies have been found to be possible in predicting the maximum values of the subsidence parameters.

The prediction of systematic subsidence parameters at a specific point is more difficult, but, based upon a large number of comparative analyses, it is concluded that the vertical subsidence predictions at any point, using the Incremental Profile Method, should generally be accurate within ±15%, where the longwall and mining geometries are within the range of the empirical database, and where the model has been calibrated to local data. Where subsidence is predicted at points beyond the goaf edge, which are likely to experience very low values of subsidence, the predictions should generally be accurate to within 50 mm of subsidence.

The systematic tilts can be predicted to the same level of accuracy as subsidence, but the measured curvatures and strains can vary considerably from the predicted systematic values for the following reasons:-

- Variations in local geology can affect the way in which the near surface rocks are displaced as subsidence occurs. In the compression zone, the surface strata can buckle upwards or can fail by shearing and sliding over their neighbours. If localised cross bedding exists, this shearing can occur at relatively low values of stress. This can result in fluctuations in the local strains, which can range from tensile to compressive. In the tensile zone, existing joints can be opened up and new fractures can be formed at random, leading to localised concentrations of tensile strain.

- Where a thick surface layer of soil, clay or rock exists, the underlying movements in the bedrock are often transferred to the surface at reduced levels and the measured strains are, therefore, more evenly distributed and hence more systematic in nature than they would be if they were measured at rockhead.
- Strain measurements can sometimes give a false impression of the state of stress in the ground. For example:
  - buckling of the near-surface strata can result in localised cracking and apparent tensile strain in areas where overall, the ground is in fact being compressed, because the actual values of the measured strains are dependent on the locations of the survey pegs.
  - where joints open up or cracks develop in the tensile phase and fail to close in the compressive phase, as they sometimes do if they are subsequently filled, the ground can appear to be in tension when it is actually in compression.
- Sometimes, survey errors can also affect the measured strain values and these can result from movement in the benchmarks, inaccurate instrument readings, or disturbed survey pegs. In these circumstances it is not surprising that the predicted systematic strain at a point does not match the measured strain.
- In sandstone dominated environments, much of the earlier ground movements can be concentrated at the existing natural joints, which have been found to be at an average spacing of 7 to 15 metres.

It is also recognised that the ground movements above a longwall panel can be affected by the gradient of the coal seam, the direction of mining and the presence of faults and dykes above the panel, which can result in a lateral shift in the subsidence profile.

A comparative analysis along the line of the Cataract Tunnel over Longwalls 401 to 403 at Appin Colliery revealed that the predicted strains at points along the surface over a length of 1.1 kilometres were exceeded in only eight cases. In six of these cases, the measured strain in a particular bay was immediately preceded or followed by a strain of equal amplitude, but of opposite sign, in the adjoining bay.

The two highest values of measured strain were 1.9 mm/m, tensile, and 2.1 mm/m, compressive, but all other strains were within the range 1.2 mm/m, tensile, to 1.4 mm/m, compressive. In five out of the eight cases, the measured strains exceeded the maximum predicted values. In many cases, the measured strains at particular points were less than predicted.

The prediction of strain at a point must be considered within an appropriate confidence interval, but the Incremental Profile Method approach does allow a more realistic assessment of the subsidence impacts. An assessment based upon applying the maximum predicted strains at every point would be overly conservative and would yield an excessively overstated assessment of the potential subsidence impacts.

5.23. Estimation of the Reliability of Upsidence and Closure Predictions

It should be noted that the development of the predictive methods for upsidence and closure are the result of recent research and the methods do not, at this stage, have the same confidence level as systematic subsidence prediction techniques. As further case histories are studied, the method is being improved, but it can be used in the meantime, so long as suitable factors of safety are applied. This is particularly important where the predicted levels of movement are small, and the potential errors, expressed as percentages, can be higher.

Whilst the major factors that determine the levels of movement have been identified, there are some factors that are difficult to isolate. One factor that is thought to influence the upsidence and closure movements is the level of in situ horizontal stress that exists within the strata. In situ stresses are difficult to obtain and not regularly measured, and the limited availability of data makes it difficult to be definitive about the influence of the in situ stress on the upsidence and closure movements. The methods are, however, based predominantly upon the measured data from Tower Colliery, where the in situ stresses are high. The methods will, therefore, tend to over-predict the movements in areas of lower stress.

It should be noted, that the method used to predict upsidence and closure was not adjusted for any local changes in the geology within the creek and river beds. The database for upsidence and closure is mainly based on creeks and rivers which predominantly have sandstone beds. It has been observed where creeks or rivers are founded on thinly bedded shales, the observed closure is higher and the observed upsidence is smaller than what would be predicted using the upsidence and closure model.

CHAPTER 6. RECOMMENDED GROUND MONITORING

6.1. Objectives of Ground Monitoring

The objectives of a ground monitoring program are envisaged as follows:-

- Provide general information on the magnitude and extent of subsidence over the longwalls,
- Compare actual ground movements with predicted ground movements,
- Monitor ground movements at or near surface infrastructure at greater risk,
- Provide an indication of any non-systematic movements within the subsidence zone (however, given the low density of surface features above the proposed longwalls, the risk of adverse impacts from non-systematic movements, ie: anomalies, is low. If the density was high, the purpose would be to provide early detection),
- Satisfy the objectives of the proposed subsidence management strategies, and
- Meet the expectations of the community with regard to monitoring subsidence.

It should be noted that ground monitoring is only one part of an overall management strategy. Other forms of monitoring include visual monitoring, and specific monitoring related to items of infrastructure. It has often been found that these other forms of monitoring are more effective in identifying impacts, or the potential for impacts, than traditional ground movement monitoring.

6.2. Recommended Ground Monitoring for the Proposed Longwalls

It is recommended that a ground monitoring line should be installed along Nash Lane, and should be monitored during the mining period. The timing and frequency of ground monitoring should be determined in consultation with the Cessnock City Council.

Ideally, a ground monitoring line perpendicular to the proposed longwalls, near the location of maximum predicted subsidence, would provide the best monitoring data for the proposed longwalls. However, any such monitoring line would require agreements between Austar and the land owners on which the line would be located.

It is also recommended, where agreements can be made between Austar and the owners, that the ground movements at the houses above the proposed longwalls should be monitored during the mining period. The monitoring could include the installation of four survey pegs at each house, one near each corner of each house, and additional pegs located along the lengths of the longer houses.

Visual monitoring of the land surface, building structures, and infrastructure should also be undertaken throughout the mining period.

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

Glossary of Terms and Definitions

Some of the mining terms used in the report are defined below:

Angle of draw	The angle of inclination from the vertical of the line connecting the goaf edge of the workings and the limit of subsidence (which is usually taken as 20 mm of subsidence).
Chain pillar	A block of coal left unmined between the longwall extraction panels.
Cover depth (H)	The depth from the surface to the top of the seam. Cover depth is normally provided as an average over the area of the panel.
Critical area	The area of extraction at which the maximum possible subsidence of one point on the surface occurs.
Curvature	The change in tilt between two adjacent sections of the tilt profile divided by the average horizontal length of those sections.
Extracted seam	The thickness of coal that is extracted. The extracted seam thickness is thickness normally given as an average over the area of the panel.
Effective extracted seam thickness (T)	The extracted seam thickness modified to account for the percentage of coal left as pillars within the panel. Refer to Section 3.4.
Face length	The width of the coalface measured across the longwall panel.
Goaf	The void created by the extraction of the coal into which the immediate roof layers collapse.
Goaf end factor	A factor applied to reduce the predicted incremental subsidence at points lying close to the commencing or finishing ribs of a panel.
Horizontal displacement	The horizontal movement of a point on the surface of the ground as it settles above an extracted panel.
Inflection point	The point on the subsidence profile where the profile changes from a convex curvature to a concave curvature. At this point the strain changes sign and subsidence is approximately one half of S max.
Incremental subsidence	The difference between the subsidence at a point before and after a panel is mined. It is therefore the additional subsidence at a point resulting from the excavation of a panel.
Overlap adjustment factor	A factor that defines the ratio between the maximum incremental subsidence of a panel and the maximum incremental subsidence of that panel if it were the first panel in a series.
Panel	The plan area of coal extraction.
Panel length (L)	The longitudinal distance along a panel measured in the direction of (mining from the commencing rib to the finishing rib.
Panel width (Wv)	The transverse distance across a panel, usually equal to the face length plus the widths of the roadways on each side.
Panel centre line	An imaginary line drawn down the middle of the panel.
Pillar	A block of coal left unmined.
Pillar width (Wpi)	The shortest dimension of a pillar measured from the vertical edges of the coal pillar.
Strain	The change in the horizontal distance between two points divided by the original horizontal distance between the points.
Sub-critical area	An area of panel smaller than the critical area.
Subsidence	The vertical movement of a point on the surface of the ground as it settles above an extracted panel.
Super-critical area	An area of panel greater than the critical area.
Tilt	The difference in subsidence between two points divided by the horizontal distance between the points.
Uplift	An increase in the level of a point relative to its original position.
Upsidence	A reduction in the expected subsidence at a point, being the difference between the predicted subsidence and the subsidence actually measured.

The structure classifications used in this report are defined below:

C	Commercial
D	Dams
H1	Single storey houses with a maximum plan dimension less than 30 metres
H2	Single storey houses with a maximum plan dimension greater than 30 metres
H3	Double storey houses with a maximum plan dimension less than 30 metres
H4	Double storey houses with a maximum plan dimension greater than 30 metres
P	Pools
PA	Public amenities
PU	Public utilities
R	Other non-residential structures
T	Tanks

APPENDIX B. REFERENCES

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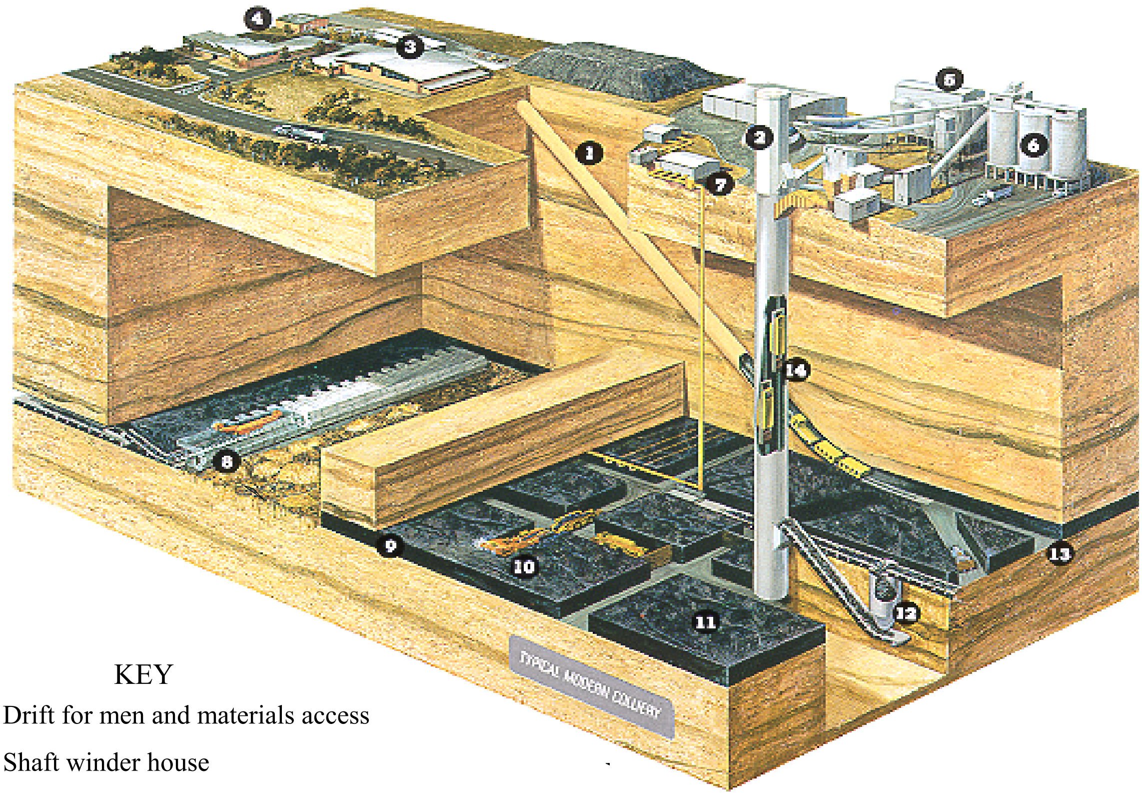
APPENDIX C. INTRODUCTION TO LONGWALL MINING AND SUBSIDENCE

C.1. The Longwall Mining Process

Fig. C.1, below, shows a cutaway diagram of a typical longwall mine. The main features of the mine are indicated in the key below the diagram. The longwall face is indicated by the number 8 in the diagram.



KEY

1. Drift for men and materials access
2. Shaft winder house
3. Bathhouse and administration building
4. Workshops
5. Coal preparation plant
6. Coal storage bins
7. Gas drainage system
8. Longwall face equipment
9. Coal seam
10. Continuous miner unit
11. Coal pillar
12. Underground coal bin
13. Main roadway or heading
14. Coal skips to carry coal to the surface

Fig. C.1 Cutaway View of a Typical Longwall Mine

In longwall mining, a panel of coal, typically around 150 to 300 metres wide, 1000 to 3500 metres long and 2 to 5 metres thick, is totally removed by longwall shearing machinery, which travels back and forth across the coalface. A typical section through a coal face is shown in Fig. C.2 and a photograph of typical longwall face equipment is shown in Fig. C.3. The shearer cuts a slice of coal from the coalface on each pass and a face conveyor, running along the full length of the coalface, carries this away to discharge onto a belt conveyor, which carries the coal out of the mine.

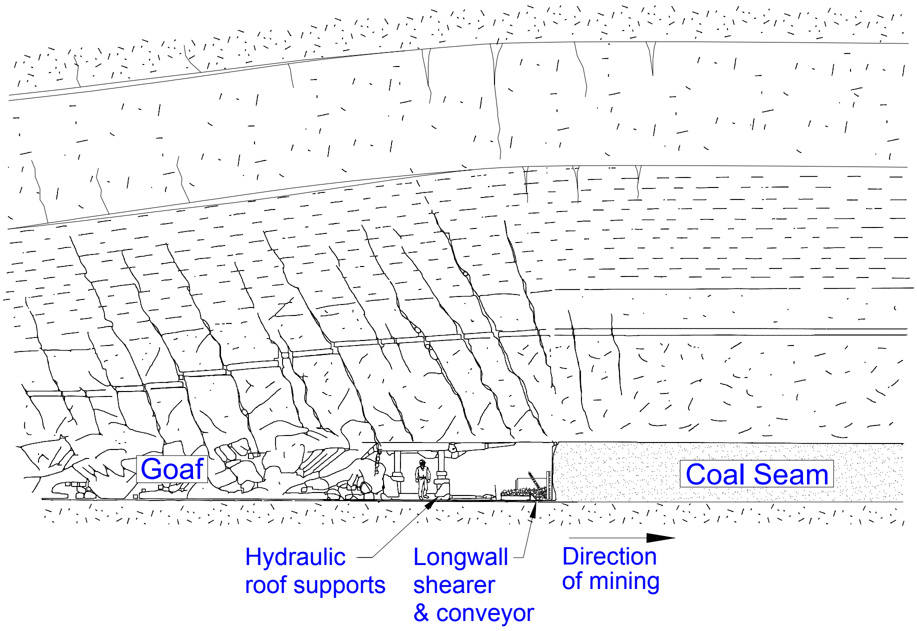


Fig. C.2 Cross Section of a Typical Longwall Face

The area immediately in front of the coalface is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata and provide a working space for the shearing machinery and face conveyor. After each slice of coal is removed, the hydraulic roof supports, the face conveyor and the shearing machinery are moved forward. Fig. C.3 shows the arrangement of machinery on a typical longwall face, with the hydraulic roof supports on the left hand side and the coal face on the right hand side of the picture. The drum in the background is the rotating cutting head of the coal shearer and the chain conveyor can be seen in the foreground.

Fig. C.3 Typical Longwall Face Equipment

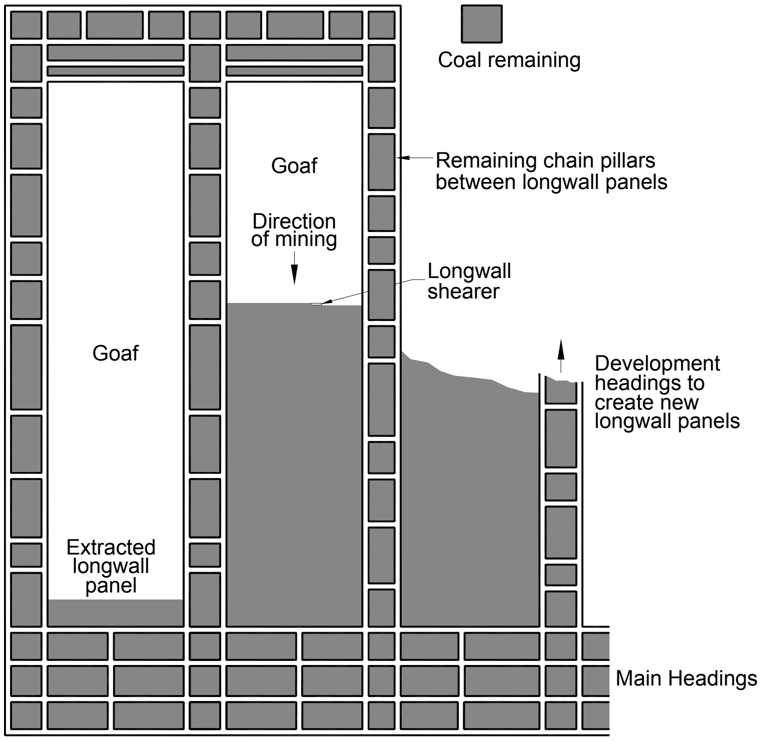


Fig. C.4 Typical Plan View of a Series of Longwall Panels

Fig. C.4 shows a typical layout of a group of longwalls. Before the extraction of a longwall panel commences, continuous mining equipment extracts coal to form roadways (known as headings) around the longwall panel. These roadways form the mine ventilation passages and provide access for people, machinery, electrical supply, communication systems, water pump out lines, compressed air lines and gas drainage lines. The roadways, which provide access from the mine entrance to the longwalls, are referred to as the main headings. Once the main headings have been established additional roadways, known as development headings, are driven on both sides of the longwall panel and are connected together across the end of the longwall.

The longwall face equipment is established at the end of the panel that is remote from the main headings and coal is extracted within the panel as the longwall equipment moves towards the main headings. This configuration is known as retreat mining. Typically, a longwall face retreats at a rate of 50 metres to 100 metres per week, depending on the seam thickness and mining conditions. The coal between the development headings and between the main headings is left in place as pillars to protect the roadways as mining proceeds. The pillars between the development headings are referred to as chain pillars.

When coal is extracted using this method, the roof immediately above the seam is allowed to collapse into the void that is left as the face retreats. This void is referred to as the goaf. Miners working along the coalface, operating the machinery, are shielded from the collapsing strata by the canopy of the hydraulic roof supports. As the roof collapses into the goaf behind the roof supports, the fracturing and settlement of the rocks progresses through the overlying strata and results in sagging and bending of the near surface rocks and subsidence of the ground above, as illustrated in Fig. C.2.

If the width of an extracted panel of coal is small and the rocks above the seam are sufficiently strong, it is possible that the roof will not collapse and hence no appreciable subsidence will occur at the surface. However, to maximise the utilisation of coal resources and for other economic reasons, wide panels of coal are generally extracted and, in most cases, the roof is unable to support itself.

Longwall panel widths between 250 metres and 300 metres are becoming common as collieries strive towards more cost-efficient production and some collieries are now considering longwall widths of 400 metres or more.

C.2. The Development of Subsidence.

C.2.1. Subsidence Mechanisms.

As the immediate roof strata, i.e. the rocks immediately above the seam, collapse into the goaf, the rocks above them lose support and sag to fill the void beneath them. The mechanism progresses towards the surface and the affected width increases so that at the surface, an area somewhat larger than the extracted panel of coal undergoes settlement. Fig. C.5 shows a typical subsidence profile above an extracted longwall panel and it can be seen that the majority of the subsidence occurs over the centre of the longwall and tapers off around the perimeter of the longwall. The subsidence is typically less than the thickness of coal extracted underground.

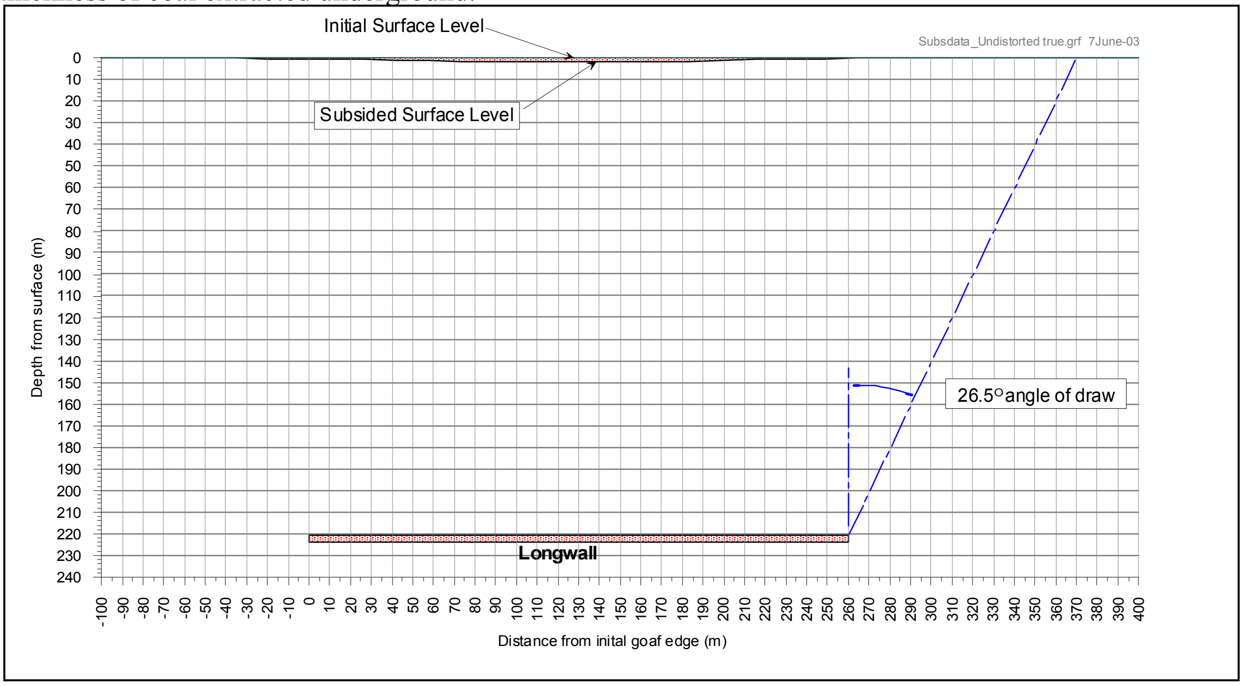


Fig. C.5 Typical Subsidence Profile Drawn to a True Scale

The angle at which the subsidence spreads out towards the limit of subsidence, at the surface, is referred to as the angle of draw. The angle of draw depends upon the strength of the strata and the depth of cover to the coal seam and typically lies between 10 and 35 degrees from the vertical, depending on how the limit of subsidence is defined.

It is generally accepted that subsidence of less than 20 mm will have negligible effect on surface infrastructure and this is generally adopted as the cut-off point for determination of the angle of draw. In the Coalfields of NSW, if local data is not available, the cut-off-point is taken as a point on the surface defined by an angle of draw of 26½ degrees from the edge of the extraction, i.e. a point on the surface at a distance of half the depth of cover from the goaf edge. Where local data exists and it can be shown that the angle is generally less than 26½ degrees, then, the lower angle of draw can be used.

The subsidence of the surface is considerably less than the thickness of coal removed, due to the voids that are left within the collapsed strata. The extent of the settlement at the surface is therefore dependent upon the strength and nature of the rocks overlying the coal seam and is a direct function of their capacity to bridge over the voids.

When a panel has a width that is small, relative to the depth of the seam below the surface, the fractured rocks have a tendency to bridge over the goaf by arching between the solid abutments on each side of the panel, thus reducing the amount of subsidence.

As the panel width is increased, however, the overlying rocks are less able to arch over the goaf and a limiting panel width is reached where no support is available and maximum subsidence occurs. This limiting panel width is referred to as the critical width and is usually taken to be 1.4 times the depth of cover. It does, however, depend upon the nature of the strata.

Where several panels are mined in a series and chain pillars are left between the panels, the maximum subsidence does not occur unless each panel is, at least, of critical width. The chain pillars crush and distort as the coal is removed from both sides of them, but, usually, they do not totally collapse and, hence, the pillars provide a considerable amount of support to the strata above them.

Where large supercritical areas are extracted, the maximum possible subsidence is typically 55% to 65% of the extracted seam thickness, but, because chain pillars are normally left in place, and provide some support, this maximum possible subsidence is rarely reached.

Research has shown that the incremental subsidence of a second or subsequent panel in a series is greater than the subsidence of an individual isolated panel of identical geometry. Because the subsidence effects above a panel extend beyond its goaf edges, these effects can overlap those of neighbouring panels.

Where the width to depth ratios of the panels in a series are sub-critical, which is normally the case in the Southern Coalfield, the amount of subsidence in each panel is determined by the extent of these overlaps, which are further influenced by the widths of the chain pillars. In this situation, the first panel in a series will generally exhibit the least subsidence and the second and subsequent panels will exhibit greater subsidence due to disturbance of the strata caused by mining the preceding panels and consequential redistribution of stresses within the strata.

The subsidence at the surface does not occur suddenly but develops progressively as the coal is extracted within the area of influence of the extracted panel. In many cases, when the cover over the coal seam is deep, a point on the surface will be affected by the extraction of several adjacent panels.

When extraction of coal from a panel is commenced, there is no immediate surface subsidence, but as the coal within the panel is extracted and the resulting void increases in size, subsidence develops gradually above the goaf area. As mining continues, a point is reached within the panel where a maximum value of subsidence occurs and despite further mining beyond this point, within the panel, this level of subsidence is not increased.

As further adjacent panels are extracted, additional subsidence is experienced, above the previously mined panel or panels. However, a point is also reached where a maximum value of subsidence is observed over the series of panels irrespective of whether more panels are later extracted.

The subsidence effect at the surface occurs in the form of a wave, which moves across the ground at approximately the same speed as the longwall face retreats within the longwall panel. The extraction of each panel creates its own wave as the panels are mined in sequence.

The development of subsidence at any point on the surface of the ground can be seen to be a very complex mechanism and the cumulative effect of a number of separate movements.

C.2.2. Subsidence Parameters

Subsidence, tilt, horizontal displacement, curvature and strain are the subsidence parameters normally used to define the extent of the surface movements that will occur as mining proceeds and generally form the basis for the assessment of the impacts of subsidence on surface infrastructure. These parameters are illustrated in Fig. C.6. which shows a typical subsidence profile drawn to an exaggerated vertical scale.

Subsidence

Subsidence usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements can in many cases be greater than the vertical subsidence, where the subsidence is small. The amplitude of subsidence is usually expressed in millimetres.

Tilt

Tilt is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. The sign of tilt is not important, but the convention usually adopted is for a positive tilt to indicate the ground increasing in subsidence in the direction of measurement.

The maximum tilt, or the steepest portion of the subsidence profile, occurs at the point of inflection in the subsidence trough, where the subsidence is roughly equal to one half of the maximum subsidence. Tilt is usually expressed in millimetres per metre.

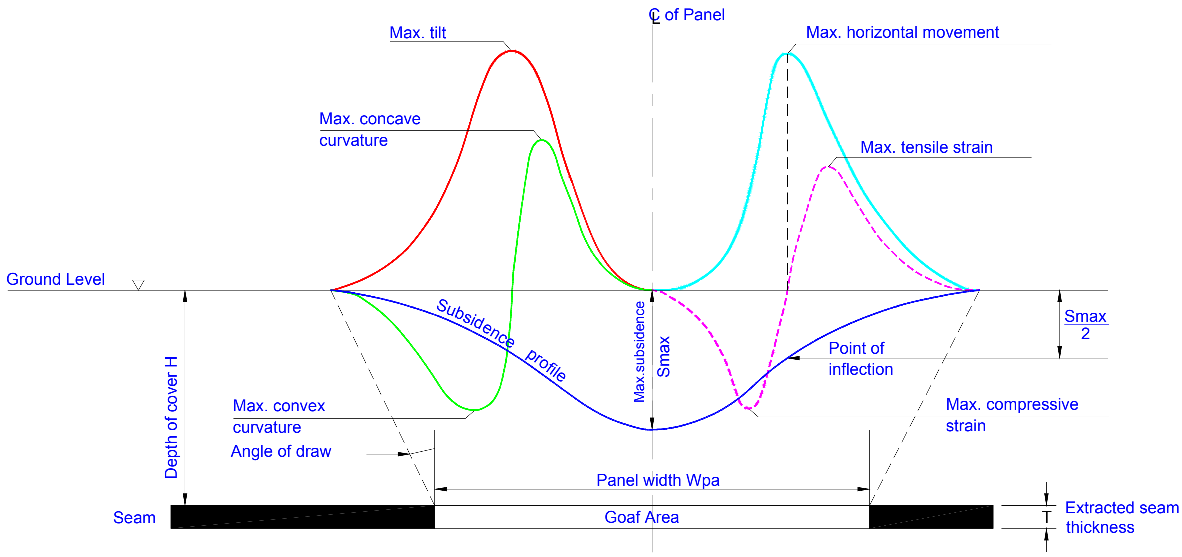


Fig. C.6 Subsidence Parameter Profiles above a Single Longwall Panel

Horizontal Displacement

The horizontal component of subsidence, or horizontal displacement, is greatest at the point of maximum tilt and declines to zero at the limit of subsidence and at the point of maximum subsidence. Horizontal displacement is usually expressed in millimetres.

Curvature

Curvature is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the radius of curvature with the units of 1/km, or km^{-1}, but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in kilometres.

Curvature is convex or ‘hogging’ over the goaf edges and concave or ‘sagging’ toward the bottom of the subsidence trough. The convention usually adopted is for convex curvature to be positive and concave curvature to be negative.

Strain

Strain is caused by bending and differential horizontal movements in the strata. Measured strain is determined from monitored survey data by calculating the horizontal change in length of a section of a subsidence profile and dividing this by the initial horizontal length of that section.

If the section has been extended, the ground is in tension and the change in length and the resulting strain are positive. If the section has been shortened, the ground is in compression and the change in length and the resulting strain are negative.

The unit of measurement adopted for strain is millimetres per metre. The maximum strains coincide with the maximum curvature and hence the maximum tensile strains occur towards the sides of the panel whilst the maximum compressive strains occur towards the bottom of the subsidence trough.

C.2.3. Subsidence Impacts at the Surface

The most significant impacts on surface infrastructure are experienced during the development of the subsidence trough, when maximum ground movements normally occur.

As the subsidence wave approaches a point on the surface, the ground starts to settle, is displaced horizontally towards the mined void and is subjected to tensile strains, which build from zero to a maximum over the length of convex or hogging curvature, as shown in Fig. C.7.

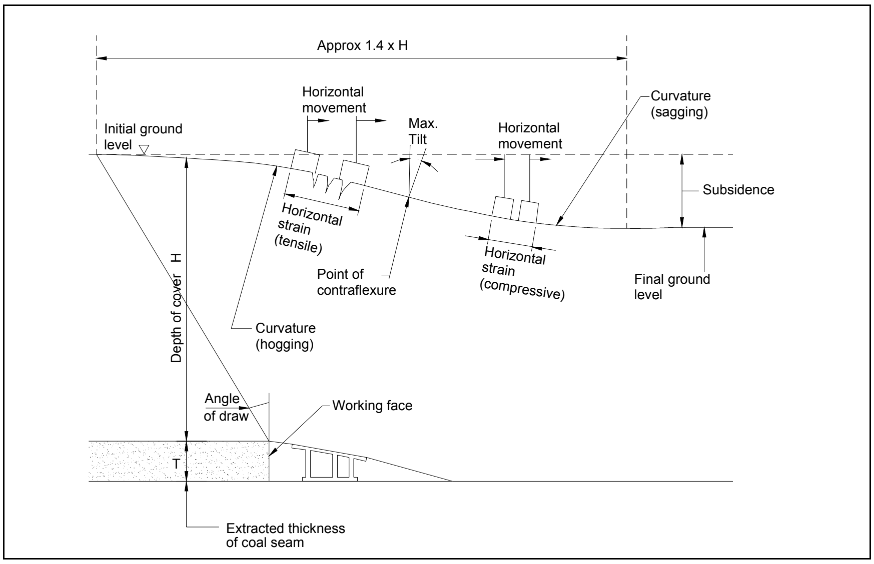


Fig. C.7 Development of a Subsidence Trough (to an exaggerated vertical scale)

The position of maximum hogging curvature is the position of maximum tensile strain. When vertical subsidence is approximately half of the maximum subsidence, i.e., as the face passes under the surface point, the ground reaches its maximum horizontal displacement and the strain reduces to zero again.

As the longwall face moves further away from the surface point the settlement continues, horizontal displacement reduces and the ground is subjected to compressive strains, which build from zero to a maximum over the length of concave or sagging curvature and then decline to zero as maximum subsidence is reached. The position of maximum sagging curvature is the position of maximum compressive strain. When the subsidence is complete, the ground is commonly left with no horizontal displacement and little residual tilt or strain.

Between the tensile and compressive zones is the point of inflection, which is the point at which maximum tilt and maximum horizontal displacement occurs. For critical extraction conditions, it is also the point at which the subsidence is, approximately, equal to half the maximum subsidence.

As the longitudinal wave passes, the transverse subsidence profile gradually develops and is completed as maximum subsidence is reached. The transverse subsidence profiles over each side of the panel are similar in shape to the longitudinal subsidence profile and have the same distribution of tilts, curvatures and strains. Most of the points on the surface will thus be subjected to three-dimensional movements, with tilt, curvature and strain in both the transverse and longitudinal directions. The impact of subsidence on surface infrastructure is therefore dependent upon its position within the trough.

The above sequence of ground movements, along the length of a panel, only applies to surface structures if they are located at a point where the maximum subsidence is likely to occur. Elsewhere, the impacts, in the both the transverse and longitudinal direction are reduced.

If a structure is located on the perimeter of the subsidence trough, it will only be slightly affected, will suffer little settlement and will have little residual tilt or strain.

A structure or surface feature on the side of the trough between the tension and compression zones will experience some subsidence, and will be left with residual horizontal displacement and tilt, but will be subjected to lower curvatures and strains. Structures or surface features located at the positions of maximum curvature and strain would generally suffer the greatest impact.

As each panel within a series is extracted in turn, an incremental subsidence trough is formed above it. If the width-to-depth ratios of the panels are low, the incremental subsidence troughs overlap at the surface and the resulting subsidence at any point, in these circumstances, is a combination of the effects of a number of panels.

A point on the surface may then be subjected to a series of subsidence waves, which occur as each panel is extracted, and the duration of these impacts will depend upon the position of the point relative to each of the subsidence troughs that are formed.

APPENDIX D. METHODS OF SUBSIDENCE PREDICTION

D.1. The Prediction of Subsidence Parameters

D.1.1. Alternative Methods of Prediction

Several alternative methods have been used in the past to predict subsidence parameters, including:

- Graphical Methods, such as the National Coal Board Method used in the U.K.
- Profile Function Methods.
- Influence Function Methods.
- Numerical Modelling Methods.
- Empirical Methods.

Profile function methods seek to define the shape of the subsidence profile using a single mathematical formula. These are generally only applicable to single panels, since they assume the profiles to be symmetrical and fail to recognise the way in which subsidence profile shapes are modified over adjacent and previously longwall goaf areas.

Influence function methods predict subsidence profiles based on the theory of an area of influence around a point of extraction. These methods can be applied to a wide range of mining geometries, but are more difficult to calibrate and check than profile function methods.

Numerical modelling techniques have been developed in recent years using finite element and discrete element models such as FLAC, UDEC and FLOMEC. These are particularly useful tools for investigating strata mechanisms and hydrological impacts, but have not been found to produce sufficiently accurate predictions of mine subsidence parameters.

Empirical methods can be developed for the prediction of subsidence parameters whenever a large database of measured subsidence parameters is available. These methods can be advantageously employed over a wide range of mining geometries, taking into account local variations in strata lithology. Other modelling methods can also be successful where sufficient local data is available for model calibration. To be successful, all methods of prediction have to be checked against measured data and calibrated to reflect local geology.

An empirical approach has generally been adopted in the coalfields of New South Wales, and this has been expanded in recent years by the development of the Incremental Profile Method. The Standard Empirical methods and the Incremental Profile Method are described in the following sections. Further information on alternative methods of subsidence prediction can be found in Kratzsch (1983) and Whittaker and Reddish (1989).

D.1.2. Standard Empirical Methods

At collieries in New South Wales, the maximum subsidence of the surface has generally been predicted using empirical methods. In the past, subsidence predictions were based upon the methods outlined in the Subsidence Engineers Handbook, first published by the National Coal Board of the United Kingdom in 1965 and revised in 1975. This involved the use of a series of graphs derived from numerous field observations in British mines, which allowed the shapes of the subsidence, tilt and strain profiles to be predicted.

The method gave good results when applied to British mining situations, but when the method was adopted in Australia, it became clear that the field observations differed considerably from predicted values and were generally much less than theory would suggest.

This is because the strata that overlie the coal seams in British coalfields differ from those that occur in the coalfields of Australia and because the subsidence measurements in British coalfields were in some cases affected by multi-seam mining. The rocks in Britain are generally less competent and less able to bridge the extracted voids and, therefore, for a given seam thickness, the maximum subsidence is greater than it would normally be for the same mining geometry in Australian conditions.

An intensive research program was therefore undertaken by the then New South Wales Department of Mineral Resources (DMR) to develop a predictive model that was more appropriate for Australian conditions. It was noted that the subsidence behaviour varied significantly between the Southern Coalfield, the Newcastle Coalfield and the Western Coalfield of New South Wales. Subsidence data from collieries in New South Wales were therefore studied separately for the three coalfields. The work resulted in three publications which provide guidelines for the prediction of mine subsidence parameters in each coalfield. The handbook for the Southern Coalfield was completed in 1975 (Holla, 1975) and the handbooks for the Newcastle and Western Coalfields were completed in 1987 (Holla, 1987a) and 1991 (Holla, 1991a) respectively. It should be noted that the method of prediction given in the New South Wales handbooks is only applicable to single, isolated panels.

Additional research by Dr L. Holla of the DMR led to the publishing of a paper (Holla, 1988) which included a graph which can be used to predict the maximum subsidence above a series of longwall panels, for critical extraction conditions. This graph is reproduced as Fig. D.1, where S_{max} is the maximum subsidence, T is the seam thickness and H is the depth of cover.

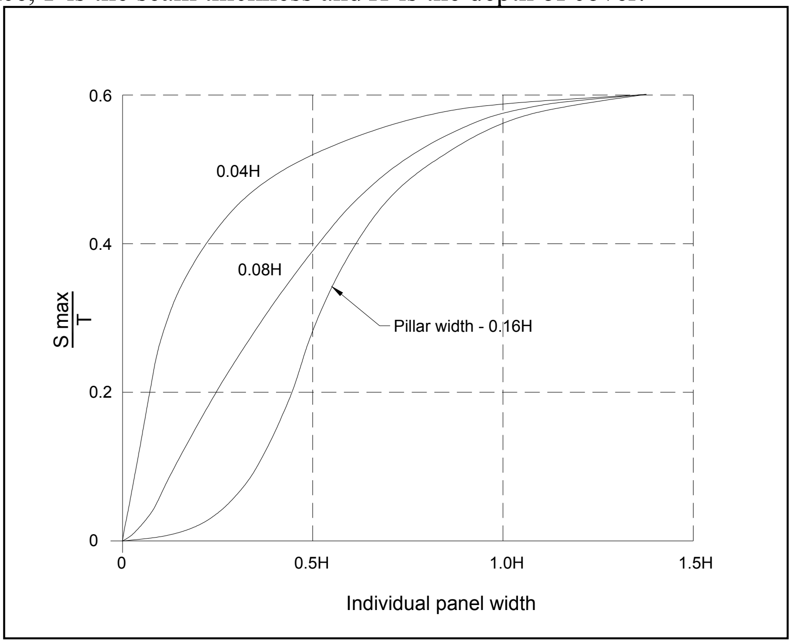


Fig. D.1 Graph for the Prediction of Maximum Subsidence over a Series of Panels for Critical Extraction Conditions (after Holla, 1988)

Following further study, a revised handbook was produced by the DMR for the Southern Coalfield in 2000 (Holla and Barclay). This later handbook included graphs that allow prediction of the maximum subsidence over a series of longwall panels. The handbook can also be used to establish an approximate subsidence profile and to predict the maximum tilt, curvature and strain above a mined area, for single panels.

When the width of an extracted panel, the depth of cover, and the extracted seam thickness are known, the following parameters can be predicted:

- The maximum subsidence value
- The location of the inflection point
- The average goaf edge subsidence
- The limit of subsidence

Once these parameters have been determined, an appropriate subsidence profile can be produced as a line of best fit between the points of maximum subsidence, inflection, goaf edge subsidence and limit of subsidence. This method thus allows the approximate shape of subsidence profile to be determined for a single isolated panel.

The predicted maximum tensile strain, compressive strain and tilt can be determined from the maximum subsidence and depth of cover, using, respectively, factors obtained from the graphs shown in Figs. 4.6, 4.7 and 4.10 of the DMR handbook (Holla and Barclay, 2000). The predicted maximum curvatures can be derived from the predicted maximum strains using the graph shown in Fig. 4.9 of the handbook.

The limit of subsidence is determined from the depth of cover and the angle of draw. The DMR recommends a practical angle of draw of 26½ degrees for general use in the Southern Coalfield, and hence the limit of subsidence would generally be positioned at half the depth of cover from the perimeter of the extracted area.

Whilst the DMR method normally provides reasonable predictions of the maximum subsidence above a series of longwall panels, it does not predict the subsidence profiles across a series of panels and does not allow the variations in tilt, curvature and strain to be determined across a series of longwalls. This method therefore could not be used to provide the detailed predictions required for this study. However, it was used to provide a check on the accuracy of the maximum predicted subsidence parameters which have been obtained using the Incremental Profile Method.

D.1.3. The Incremental Profile Method

The Incremental Profile Method was developed by Mr A.A. Waddington and Mr. D.R. Kay during the course of a study for BHP Collieries Division, the Water Board and AGL during the latter part of 1994 (Waddington and Kay, 1995). The purpose of the study was to develop an empirical method which could be used to predict the subsidence, tilts, curvatures and strains likely to be experienced as longwall mining occurred at Appin and Tower Collieries, and to assess the likely effects of mining on surface infrastructure.

The first step in the development of the model was to study detailed records of subsidence movements which had been observed over previous longwalls at Appin and Tower Collieries and over longwalls at neighbouring mines, including Tahmoor, West Cliff, Cordeaux and South Bulli Collieries. The measured subsidence data was plotted in a variety of ways to establish whether or not any regular patterns of ground behaviour could be found. The most significant patterns were illustrated in the shapes of the observed incremental subsidence profiles measured along survey lines located transversely across the longwalls.

The incremental subsidence profile for each longwall was derived by subtracting the initial subsidence profile (measured prior to mining the longwall) from the final subsidence profile (measured after mining the longwall). The incremental subsidence profile for a longwall therefore shows the change in the subsidence profile caused by the mining of the individual longwall.

The consistency in the shapes of the incremental subsidence profiles led to the development of the Incremental Profile Method. This consistency can be observed in the typical incremental subsidence profiles presented in Fig. D.2.

The Incremental Profile Method of prediction is based upon predicting the incremental subsidence profile for each longwall in a series of longwalls and then adding the respective incremental profiles to show the cumulative subsidence profile at any stage in the development of a series of longwalls.

The incremental subsidence profiles are also used to derive incremental tilts, systematic curvatures and systematic strains which can be added to show the transient and final values of each parameter as a series of longwalls are mined.

Profiles can be predicted in both the transverse and longitudinal directions, thus allowing the subsidence, tilts, systematic curvatures and systematic strains to be predicted at any point on the surface above a series of longwalls. The method also explains the development of undulations that occur within the subsidence trough and allows the magnitude of both transient and residual tilts and curvatures within the trough to be determined.

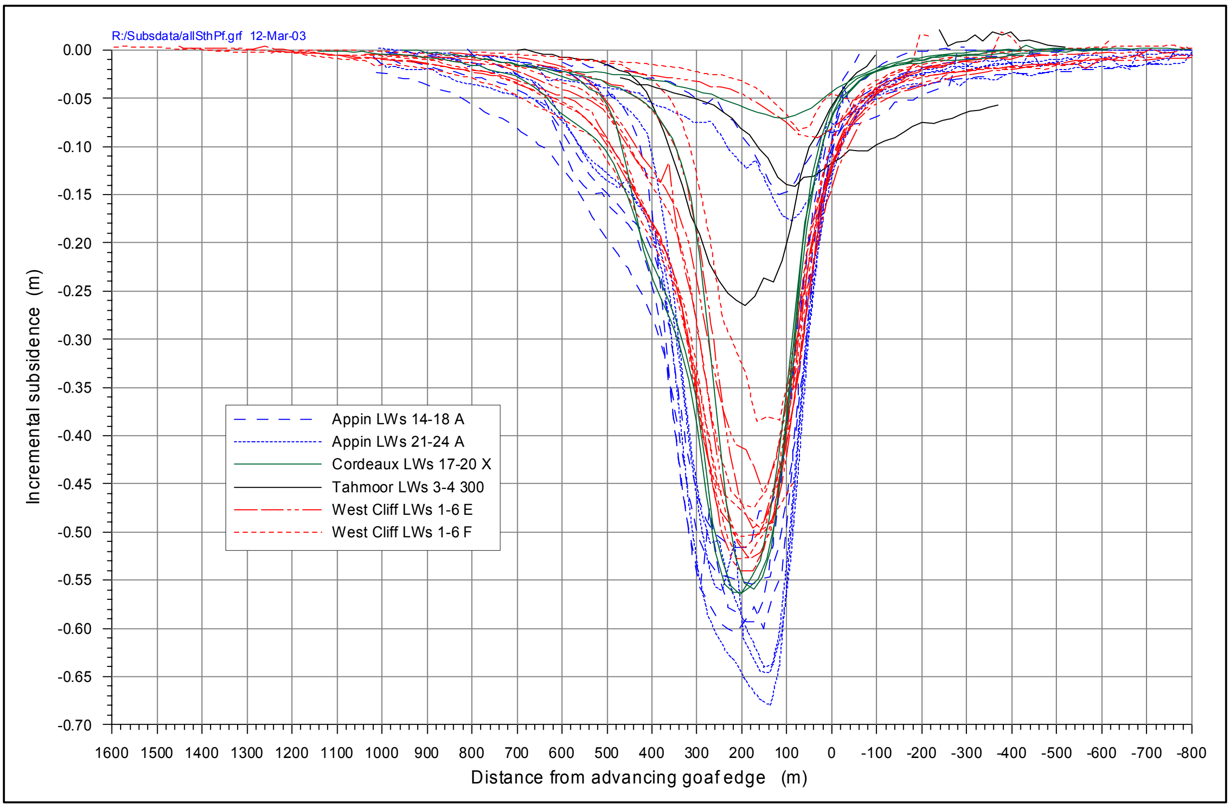


Fig. D.2 Typical Incremental Subsidence Profiles – NSW Southern Coalfield

The model was initially tested by comparing the predicted values of subsidence, tilt, curvature and strain against the measured values for a number of longwalls at Appin, Cordeaux, Tahmoor and West Cliff Collieries. Following that study, the method was used to analyse and predict subsidence over other longwall panels at Appin, South Bulli, Bulli, Corrimal, Tahmoor, Teralba, North Cliff, Metropolitan, Tower and West Cliff Collieries. These studies found that the shapes of the measured incremental profiles conformed to the patterns and magnitudes observed during the initial 1994 study.

During 1996 and 1997, the method was extended for use in the Newcastle Coalfield. The shapes of incremental profiles over extracted longwall panels at Cooranbong, West Wallsend, Newstan, Teralba, and Wyee Collieries were studied and a subsidence model was developed for the Cooranbong Life Extension Project. These studies have shown that the shapes of the incremental profiles in the southern part of the Newcastle Coalfield conform to the patterns observed in the Southern Coalfield. Since that study, the method has been used to analyse and predict subsidence over other longwall panels at West Wallsend, Cooranbong, Wyong and South Bulga Collieries.

The collection of additional data has allowed further refinement of the method and the database now includes more than 475 measured examples. A wide range of longwall panel and pillar widths and depths of cover is included within the database and hence, the shapes of the observed incremental profiles in the database reflect the behaviour of typical strata over a broad spectrum.

Further research during the last few years has identified the shapes of the incremental profiles in a number of multi-seam situations. These profiles are generally greater in amplitude than the single seam profiles and differ in shape from the standard profiles over single seams.

The incremental profiles have been modelled in two halves, the point of maximum subsidence being the point at which the two halves of the profile meet. A library of mathematically defined profile shapes has been established, which allows the incremental profiles to be modelled, depending on the width to depth ratio of the longwall and the position of the longwall in the series.

The mathematical formulae that define the profile shapes are of the form given in Equation 1 below. The library of profile shapes simply comprises the values *a* to *k* in these formulae.

$$y = \frac{a + cx + ex^2 + gx^3 + ix^4 + kx^5}{1 + bx + dx^2 + fx^3 + hx^4 + jx^5} \qquad \text{Equation 1}$$

Different formulae apply, with unique *a* to *k* values, for first, second, third, fourth, and fifth or subsequent panels in a series, and for different width-to-depth ratios, within the range 0.3 to 5.0. For second, third, fourth and fifth or subsequent panels, the left and right hand sides of the profiles have different formulae.

The library of profile shapes thus contains a to k values for 693 different half-profile shapes for single-seam mining situations. In addition the library contains 236 different half-profile shapes for a range of multi-seam mining situations. A selection of model incremental subsidence profiles for various width-to-depth ratios is shown in Fig. D.3, below.

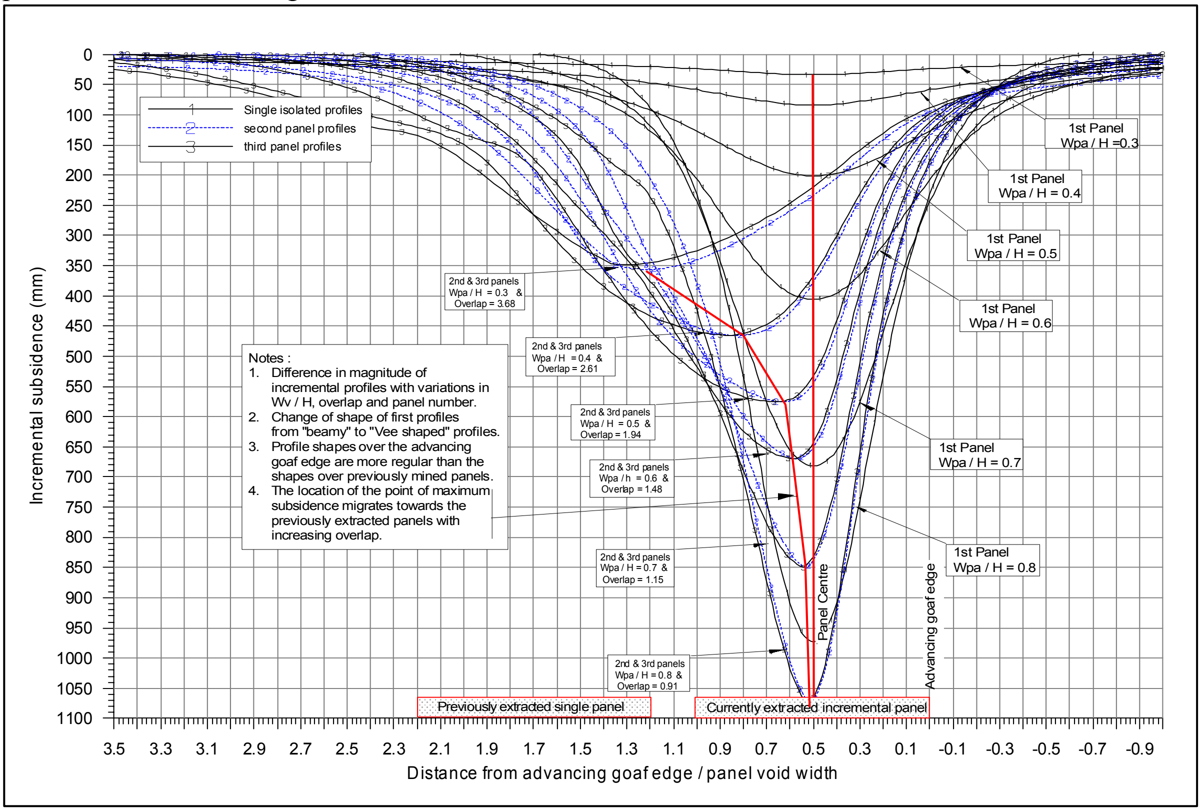


Fig. D.3 Incremental Subsidence Profiles obtained using the Incremental Profile Method

The method has a tendency to over-predict the subsidence parameters because a conservative approach was adopted in preparing the graph that is used for predicting the maximum incremental subsidence. Fig. D.4 shows the maximum incremental subsidence, expressed as a proportion of seam thickness, versus panel width-to-depth ratio.

Since this graph is used to determine the amplitude of the incremental subsidence profile, any over-prediction of the maximum subsidence value also leads to over-predictions of the tilt, curvature and strain values. Once the geometry of a longwall panel is known, the shapes of the two halves of the incremental subsidence profile of the panel can be determined from the appropriate formulae to provide a smooth non-dimensional subsidence profile across the longwall.

The actual incremental profile is obtained by multiplying vertical dimensions by the maximum incremental subsidence value and horizontal dimensions by the local depth of cover. Smooth tilt and curvature profiles are obtained by taking the first and second derivatives of the subsidence profile. Strain profiles are obtained directly from the curvature profiles.

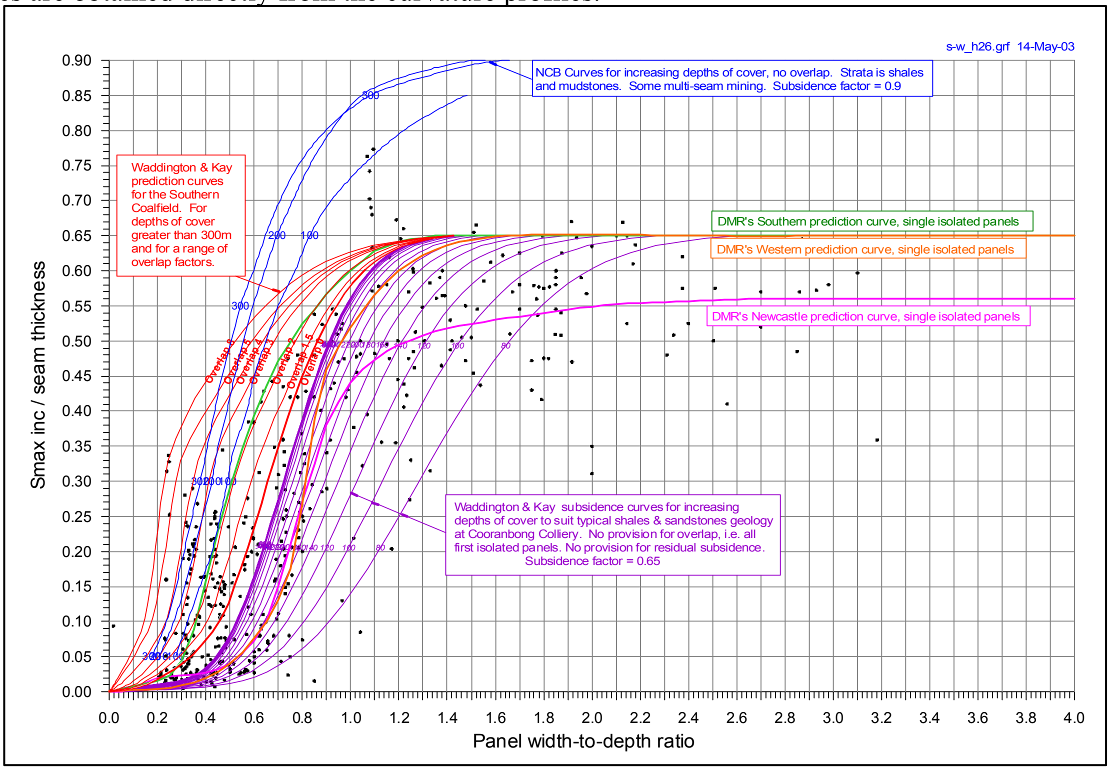


Fig. D.4 Prediction Curves for Maximum Incremental Subsidence

It can be seen from Fig. D.3 and Fig. D.4 that, as panel width to depth ratio (W/H) decreases, the magnitude of the incremental subsidence profile is reduced and the position of the point of maximum subsidence moves closer to the previously extracted panels. It has been found that the amplitude and position of the incremental profile relative to the advancing goaf edge of the longwall is determined by a factor known as the overlap factor. This overlap factor is derived empirically as a function of the panel width, pillar width and depth of cover.

In order to determine strain values from the curvature profiles, it is necessary to select an empirical relationship that will generally provide conservative results. The NCB Subsidence Engineers Handbook (1975) adopts a relationship in which the reciprocal radius of curvature, K, is equal to strain squared divided by 0.024.

This relationship does not provide a good fit when strains derived from predicted curvatures, are compared with measured values. However, if a linear relationship of strain = 15 × curvature is chosen, then a closer fit is achieved between predicted and observed data from the Southern Coalfield. This equates to the bending strain in a beam of 30 metres depth, bending about its centre line. The relationship of 15 × curvature is also reasonably close to the graph of radius of curvature versus maximum strain given in Fig. 4.9 of the DMR's handbook for the Southern Coalfield (Holla and Barclay, 2000), for depths of cover between 300 metres and 400 metres. It will, however, give lower values of strain for greater depths. A factor of 10 has been found to be more applicable in the Newcastle and Hunter Coalfields.

Predicted horizontal displacements in the direction of the prediction line (normal to the longwall), can be derived by accumulating the predicted strains multiplied by the bay lengths, after distributing any displacement closure errors over all bay lengths in proportion to the predicted strains. Alternatively, the predicted horizontal ground movement profiles can be derived by applying a proportionality factor to the predicted tilt profiles, which they resemble in both magnitude and direction.

Experience has shown that the subsidence and tilt profiles predicted using the Incremental Profile Method usually match the systematic observed profiles reasonably accurately. It is not possible to match the predicted and observed curvature and strain profiles to the same standard, due to the large amount of scatter generally found in the measured data. The range of systematic strains is, however, adequately predicted.

The scatter in the strains is caused by random variations in stratigraphy, rock strength, fracture characteristics and spacing of joints which dictate the way in which the near surface rocks will respond as subsidence occurs. The scatter sometimes results in anomalous peaks of strain, though in many cases these peaks can be predicted.

It should be remembered that the predicted strains obtained using the Incremental Profile Method are the systematic strains, which can, in some cases, be exceeded by local anomalous peaks of strain. In the Incremental Profile Method, such anomalous peaks of strain are dealt with statistically.

The Incremental Profile Method provides a greater understanding of the mechanism of subsidence over a series of panels and allows a detailed prediction of subsidence parameters to be made for any point on the subsidence profile.

Other benefits of the Incremental Profile Method are as follows:

- The method can be used even where the seam thicknesses, pillar and panel widths and depths of cover vary from panel to panel across a series of longwalls. This is possible because the total subsidence predictions are an accumulation of incremental subsidence profiles for each longwall, based on their individual panel and pillar widths, the seam thickness and depth of cover and the position of each longwall within the series of longwalls.
- After superimposing the influence of the incremental subsidence profiles for each longwall it has been found, in the syntheses carried out to date, that the total subsidence profiles are predicted quite accurately.
- Because the total subsidence profiles are well represented, this method provides improved predictions of tilts, and general background or 'systematic' curvatures and strains.
- The method can be used to model the effects of alternative mine layouts with different pillar and panel configurations and to compare the impact of tilts, curvatures and strains for each alternative.
- By varying the proposed widths of panels and pillars, it is possible to show the variations in the predicted magnitude of the maximum total subsidence and the shape of the subsidence trough.

Because of the inherent advantages of the Incremental Profile Method, this method has been used to make the detailed subsidence predictions for this project.

D.1.4. Typical Subsidence Predictions

Typical predicted incremental and cumulative total subsidence, tilt and strain profiles over a series of longwalls are shown in Fig. D.5. It can be seen that the subsidence parameters vary throughout the subsidence trough.

Subsidence profiles are generally prepared along a series of parallel prediction lines, orientated at right angles to the centrelines of the longwalls. The prediction lines are generally positioned 25 metres to 100 metres apart, depending on the depth of cover and generally cover the full area of the longwalls, extending outwards as far as the limit of subsidence.

When the predicted subsidence profiles have been developed along each of the prediction lines, the predicted subsidence data is used to develop a three-dimensional model of the subsidence trough, from which subsidence contours are derived.

A typical longwall layout showing predicted subsidence contours over a series of four longwalls is illustrated in Fig. D.6. The variations in these contours reflect the changes in seam thickness and depths of cover from place to place over the area of the longwalls.

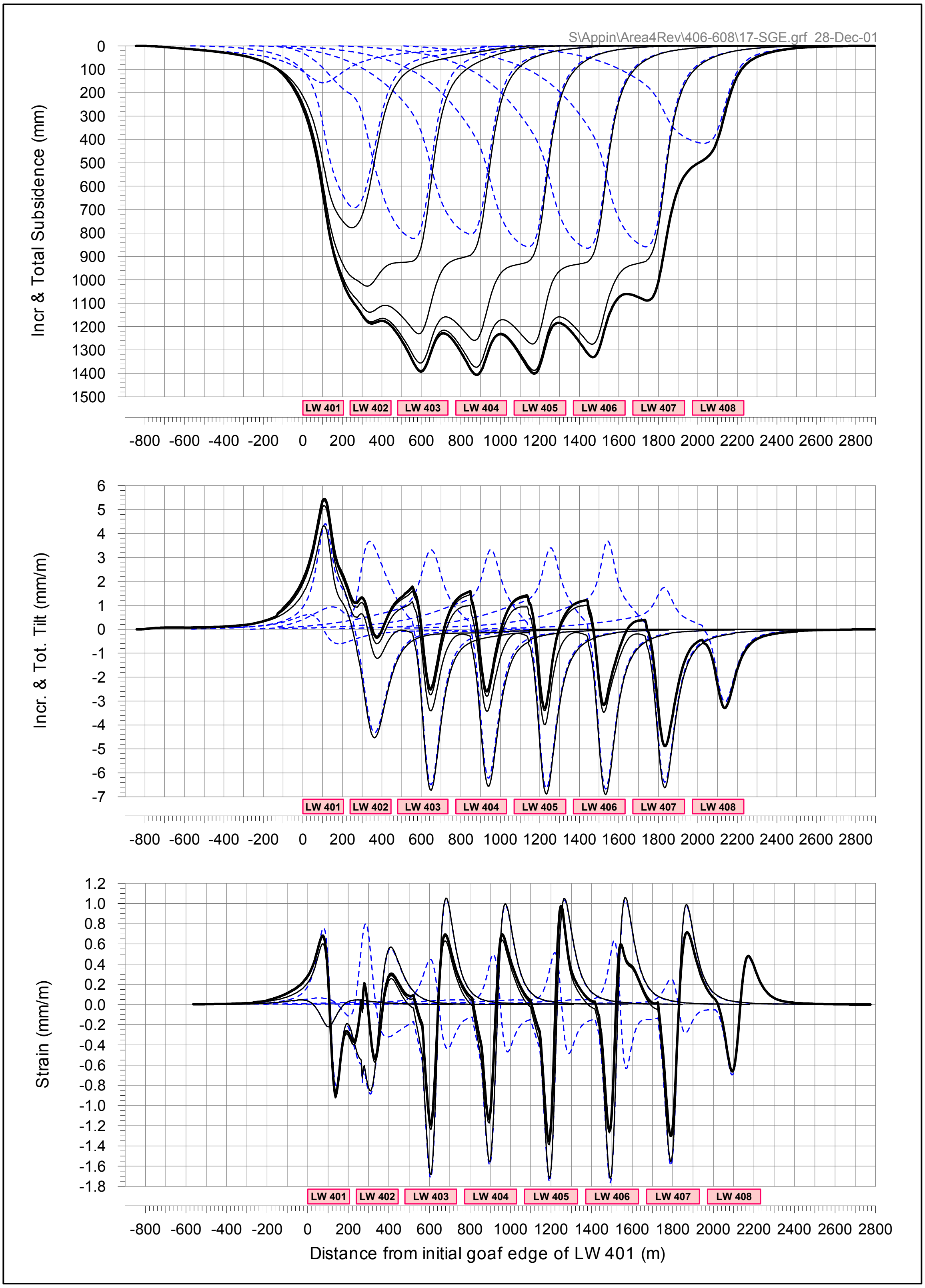


Fig. D.5 Typical Predicted Incremental and Total Subsidence, Tilt and Strain Profiles

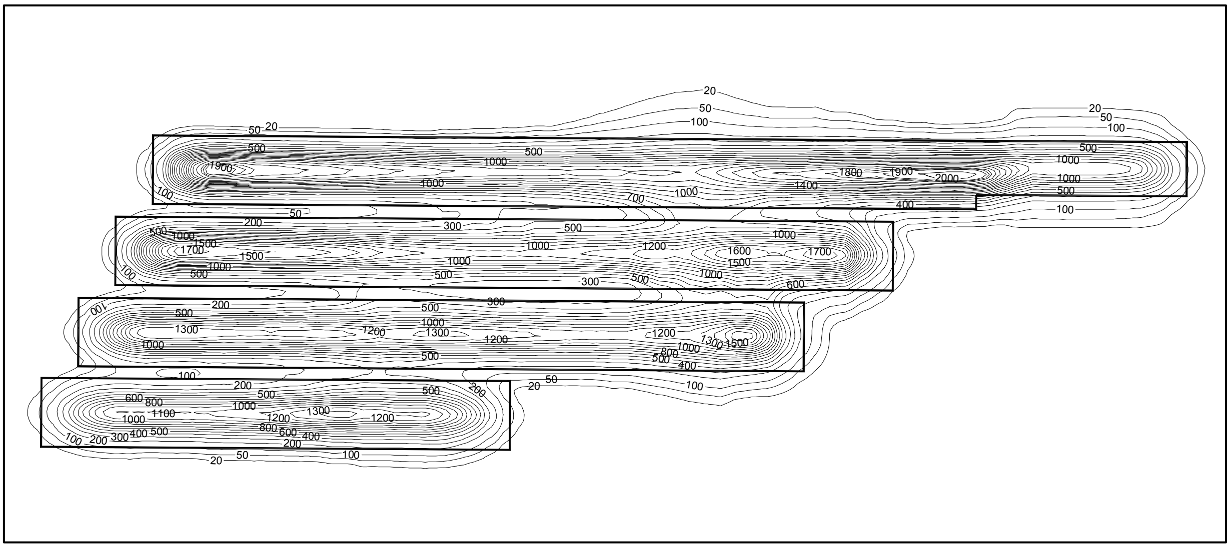


Fig. D.6 Typical Predicted Subsidence Contours over a Series of Longwalls

D.2. Timing and Direction of Predicted Tilts and Strains

It is generally found that the maximum tilts and strains at any point within a mined area are aligned in the transverse direction across the longwalls and occur after the longwalls are extracted. However, there are cases when the maximum tilts and strains are not aligned in the transverse directions. There are also instances where the maximum tilts and strains at a particular point occur during the extraction of a particular longwall and are later reduced by extraction of subsequent longwalls. Treatment of these cases is discussed below.

D.2.1. Travelling, Transient and Final Subsidence Parameters

The Incremental Profile Method allows subsidence parameters to be predicted at any point on the surface when the longwall face is at any position in a panel, and hence for any:

- **travelling** scenario, *during* extraction of a longwall,
- **transient** scenario, *following* the extraction of *each* longwall, or
- **final scenario, following the extraction of all longwalls in a series.**

This is particularly relevant for assessing the impacts of curvature and strain on an item of surface infrastructure, which can be greater at a travelling stage than on completion of mining a particular longwall or all longwalls in a series.

A review of subsidence data from several collieries in the Southern Coalfields, in particular West Cliff Colliery, has indicated that the magnitude of the observed travelling strains in the longitudinal direction are generally smaller than the observed transient or final longitudinal strains over the ends of the longwalls. Using the Incremental Profile Method, the travelling strains at any point in the subsidence trough can be determined by taking into account the maximum predicted longitudinal strains over the ends of each longwall, the maximum predicted incremental subsidence value for the longwall and the predicted subsidence at the point of interest.

D.2.2. Tilts and Strains in the Transverse and Longitudinal Directions

The predicted maximum tilts and strains within the mined areas are, generally, those which are aligned in the transverse direction across the longwalls. However, at the ends of the longwalls, the maximum tilts and strains are at right angles to the subsidence contours, which can be aligned in various directions relative to the longwalls. Also, in some cases, the travelling wave that occurs during the extraction of each longwall can produce travelling longitudinal tilts and strains which can be greater than the transverse values. These cases typically occur at those points within the subsidence trough at which maximum subsidence is developed.

At points where it is found that longitudinal tilts and strains are greater than those in the transverse direction, it is extremely rare for these tilts and strains to be greater at a transient stage than on completion of mining. There may be isolated cases where the maximum tilts and strains are aligned in a diagonal direction to the orthogonal axes of the longwalls. In such cases, the magnitude of these tilts and strains will exceed the transverse and longitudinal values by a small proportion only and are unlikely to influence the final assessment of potential impact or development of management plans to mitigate this potential impact.

D.3. Statistical Analysis of Curvature and Strain

The peak values of curvature and strain that have frequently been noted along measured monitoring lines have generally been found to be localised effects associated with escarpments, river valleys, creek alignments or geological anomalies. Consequently, many of them are predictable.

Higher values of measured strain can also arise from buckling of near-surface strata at shallow depths of cover, from disturbance of survey pegs and from survey errors. There are, therefore, some anomalies that can not be predicted and it has to be accepted that there is a small risk of peak values of strain and curvature occurring, at some point, in addition to the predicted systematic background strains and the predictable local peaks. It is preferable to deal with such anomalies on a statistical basis and wherever measured records are available, frequency analyses should be prepared in order to determine the likely incidence of such occurrences.

A histogram of measured strains at South Bulga Colliery, where the depth of cover to the Whybrow Seam varies between 40 metres and 160 metres, is shown in Fig. D.7. It can be seen that 90% of the measured strains were between 1.0 mm/m, tensile, and 2.5 mm/m, compressive. Approximately 9% of tensile strains were in the range 2.5 mm/m to 17 mm/m, whilst 9% of compressive strains were in the range 1.0 mm/m to 12.5 mm/m. Only 1% of strains exceeded 17 mm/m, compressive, or 12.5 mm/m, tensile.

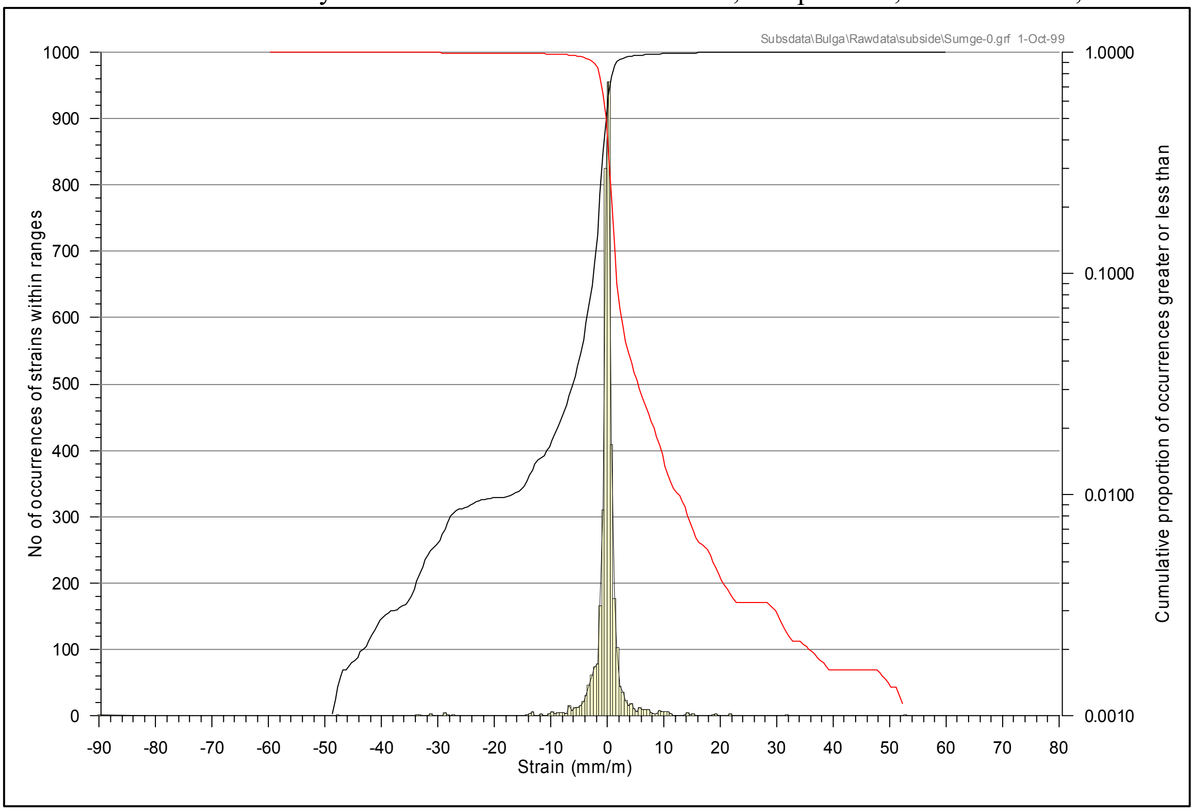


Fig. D.7 Graph showing Histogram of Strain Occurrences at South Bulga Colliery

D.4. Surface Cracking

As subsidence occurs, cracks will generally appear in the tensile zone, i.e. within 0.1 to 0.4 times the depth of cover from the longwall perimeter. It is also possible that cracking could occur in other locations at right angles to the longitudinal centreline of the longwall as the longwall is mined and the subsidence trough develops. However, this cracking is likely to be transient, since the tensile phase, which results in the cracks opening up, is generally followed by a compressive phase that closes them.

Surface tensile fracturing in exposed sandstone is likely to occur coincident with the maximum tensile strains, but fracturing could also occur due to buckling of surface beds that are subject to compressive strains. Fracture widths tend to increase as the depth of cover reduces and significant cracking would normally be expected where the depth of cover is less than 250 metres.

Noticeable cracks are less likely to occur at low levels of strain, i.e. where the strains are less than 2 mm/m. Kratzsch (1983) indicated that tension cracks had been recorded in Germany, at strains of 3 mm/m to 7 mm/m. Whittaker and Reddish (1989) indicated, however, that noticeable cracking had been recorded in the United Kingdom, in Triassic Sandstone, at strains less than 2 mm/m.

Fig. D.8 shows the relationship between the depth of cover and the width of surface cracks, based upon measured data in the NSW Coalfields and observations over mines in the United Kingdom. The line on the graph represents the upper bound limit of the data in flat terrain. It can be seen that the maximum crack width at a depth of cover of 400 to 500 metres, due to normal subsidence movements, would generally be expected to be around 20 to 30 mm. Where the depth of cover is less than 250 metres, however, larger crack widths can sometimes develop.

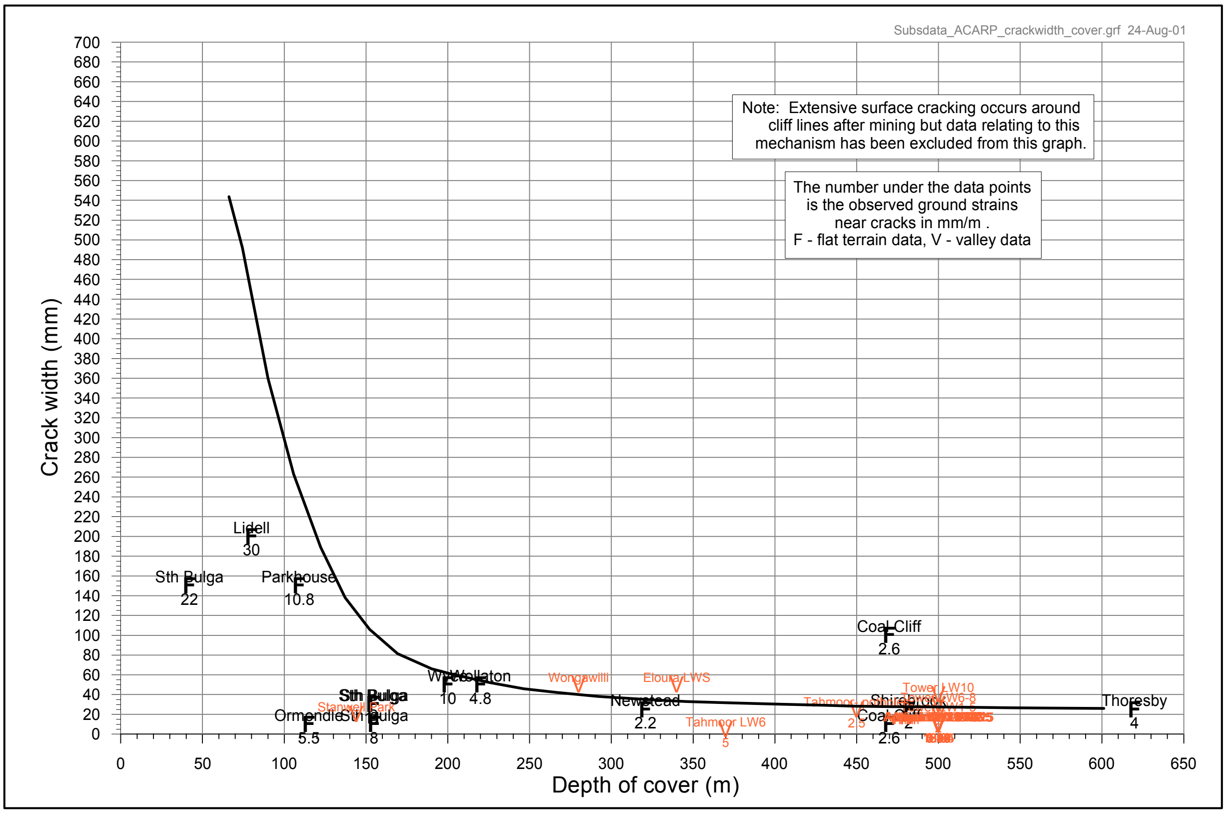


Fig. D.8 Relationship between Crack Width and Depth of Cover

The greater crack widths that have been recorded at depths of cover above 400 metres, occurred in exposed bedrock, and were mainly in the bottoms of valleys and gorges or associated with steep slopes.

D.5. Additional Mining-Induced Ground Movements caused by Topographic or Geological Factors

D.5.1. Analysis of Ground Displacements from Measured Survey Data

When longwalls are extracted beneath steeply incised terrain, the ground movements that occur around the longwalls are very complex, particularly within a high stress regime, and these complex movements result from a number of distinct mechanisms. During research by Mine Subsidence Engineering Consultants, previously known as Waddington Kay & Associates, it was found that measured movements were often a combination of some or all of the following components:

- Normal mining-induced horizontal movements of points on the surface, around an extracted panel, as subsidence occurs, which are generally directed towards the centre of the extracted goaf area.
- Upsidence and closure of creeks, gullies, river valleys and gorges due to valley bulging, which results from the redistribution of pre-existing in-situ stresses, as mine subsidence occurs.
- Predominantly horizontal displacements of surface strata due to release and redistribution of pre-existing regional in-situ stresses as the extracted goaf areas increase in size within a local mining area.
- Mass slippage movements in a downhill direction due to topographic factors.
- Differential movements of the strata on opposite sides of a fault line.
- Continental drift, which is known to change the positions of points on the Australian Plate by moving them approximately 70 mm each year towards the northeast.

Study of data collected over longwalls in the Southern Coalfield during the last twenty years has led to the development of methods that can now be used for the prediction of some of these components which are discussed in this section. Valley related movements are less obvious in the Newcastle and Hunter Coalfields and are usually more difficult to resolve from observed monitoring data. The reason for this is that the systematic movements in the Newcastle and Hunter Coalfields are generally much larger than those in the Southern Coalfield, and these movements tend to overshadow any valley related movements which may occur, especially in smaller, less incised valleys.

In developing predictive methods, it is advantageous if the measured data can be broken down into its various components prior to analysis. This is not an easy task, however, because in most cases the measured survey movements are relative movements rather than absolute movements and in all cases they are total movements. When analysing the closures that have been measured in creeks and river valleys due to valley bulging, however, it appears that many of the other components have little or no effect on the closure measurements.

Mass slippage down steep slopes, due to mining is a relatively rare occurrence and is due to the instability of surface soils in particular locations. Where steep slopes exist and can be affected by mining it is prudent to study the geology of the site and the nature of the surface soils so that any unstable areas can be identified. It is possible that some of the data studied by Waddington Kay & Associates could have been affected by this mechanism, but if so it will have led to overstatement of closure movements.

Differential movements on opposite sides of a fault line are equally rare occurrences and there are only a few known major faults in the study areas. There is no evidence to indicate that any of the measured data used in developing the predictive methods have been affected by differential movements at faults.

In analysing the valley closure data, no allowance was made for differential movements caused by regional horizontal stress redistribution or continental drift, because the differential movements in the two sides of a valley, as a result of these mechanisms, would be negligible.

In the steep-sided Cataract and Nepean River Gorges it was found that the closures in the sides of the gorges were almost mass movements with little differential shear displacement between different horizons in the strata. Almost all of the closure, therefore, occurred in the bases of the gorges. Because the gorge bases are relatively narrow, the differential mining-induced horizontal movement, due to differential tilting in the sides of the gorges, was relatively small in comparison with the closure movements.

In the vee-shaped valleys, a large proportion of the closure occurred in the bases of the valleys, coupled with localised concentration of compressive strain, but in some cases, part of the closure was noted to occur at horizons above the bases of the valleys.

This observation from measured data was supported by numerical modelling work by CSIRO, which indicates that in vee-shaped valleys some of the shearing occurs along weaker horizons in the valley sides. The closure movements are, therefore, spread over a greater width than those measured in the gorges.

It is possible that some of the measured closure data from vee-shaped valleys could have been affected by differential systematic mining-induced horizontal movements in the valley sides. In some cases these differential movements could have caused the sides of the valley to open and the measured closure, being the sum of the two movements, could, therefore, be less than the actual closure caused by valley bulging.

The extent to which the data might have been affected in this way is difficult to determine. This is because many of the surveys that were carried out in the past did not measure the absolute movements of the ground in three dimensions. In these cases the closures have been calculated from the strains.

The method that has been developed for the prediction of closure is, therefore, based upon the overall closure of the valley recognising that, in the case of vee-shaped valleys, some of the movement will occur in the valley sides.

When predicting closures in vee-shaped valleys it would be prudent to ignore the impacts of differential mining-induced horizontal movements in the valley sides, if those movements result in a reduction in the predicted closures.

D.5.2. Normal Mining Induced Horizontal Ground Movements

The 'normal' horizontal component of subsidence, sometimes referred to as horizontal displacement, can be predicted, in flat terrain, i.e. where steep slopes or surface incisions do not influence ground movement patterns. As discussed in Section D.1.3, the magnitude and direction of horizontal displacements can be determined, approximately, from the predicted tilt profiles, by applying the strain-curvature factor. These subsidence induced horizontal displacements are generally directed towards the centre of the mined longwall panel as shown in Fig. D.9.

As also discussed in Section D.1.3, the appropriate strain-curvature factor for the Newcastle Coalfield is 10. If the predicted tilt at a point is 2 mm/m, for example, then the predicted horizontal ground displacement will be approximately 20 mm, directed towards the centre of the mined goaf.

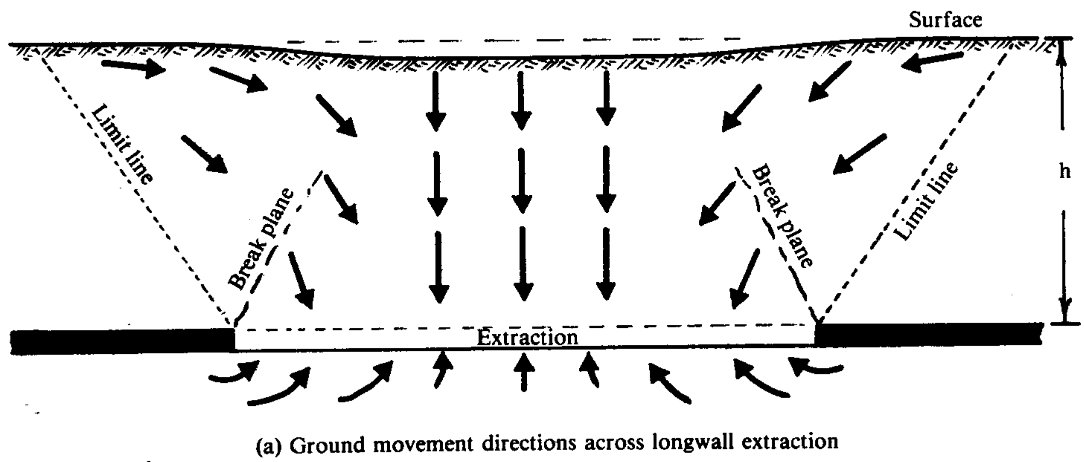


Fig. D.9 Normal Mining Induced Movements above an Extracted Area (after Whittaker, Reddish and Fitzpatrick, 1985)

This method is only approximate and, whilst it tends to be conservative where the tilts are high, it tends to underestimate the horizontal movements where the tilts are low. Where the tilt is low, however, the 'normal' horizontal displacement is generally very small, even though it could be many times greater than the vertical subsidence at the same point. The tilts reduce with increasing distance from the goaf edge of the longwall, and at the edge of the subsidence trough, where the tilts approach zero, any small horizontal displacement at that point could be infinitely greater than the tilt. When large horizontal displacements are measured outside the goaf area, they are more likely to be a result of regional movements, as discussed in Section D.5.9.

D.5.3. Upsidence and Closure due to Mining beneath Gorges, River Valleys and Creeks

When creeks and river valleys are affected by mine subsidence, the observed subsidence in the base of the creek or river is generally less than the level that would normally be expected in flat terrain. This reduced subsidence is due to the floor of the valley buckling upwards. This phenomenon is referred to as valley bulging and results from the redistribution of, and increase in, the horizontal stresses in the strata immediately below the base of the valley as mining occurs. Valley bulging is a natural phenomenon, resulting from the formation and ongoing development of the valley, as indicated in Fig. D.10, but the process is accelerated by mine subsidence. The phenomenon appears to be triggered, to varying degrees, whenever mining occurs beneath or adjacent to escarpments, gorges, river valleys, creeks or other surface incisions.

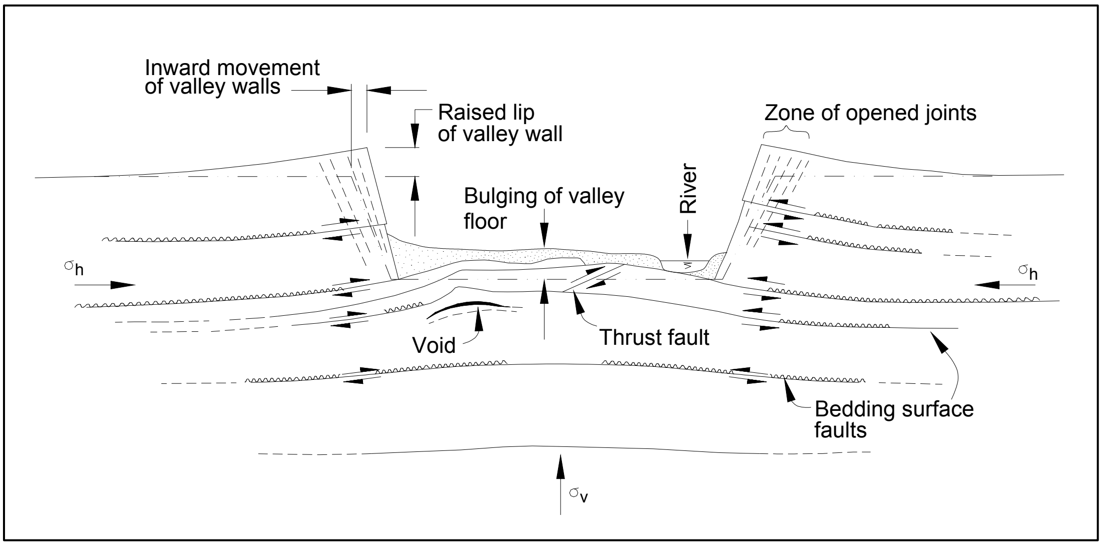


Fig. D.10 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

The local reduction in subsidence, which is referred to as 'upsidence', is generally accompanied by localised changes in tilt and curvature leading to high compressive strain in the centre of the valley and horizontal closure of the valley sides. In the case of escarpments and wide river gorges the movements may be limited to the cliffs that are closest to the extracted area.

The phenomenon is clearly seen when subsidence profiles are plotted to an exaggerated vertical scale, when the upsidence can be seen as a localised upwards spike in an otherwise smooth subsidence profile, coincident with a creek alignment. A typical example is illustrated in Fig. D.11, which shows the measured subsidence profiles over Longwalls 1 to 6 at West Cliff Colliery, along a survey line known as the E-Line. The upsidence spike in the subsidence profile, between Longwalls 2 and 3, can be seen to coincide with the alignment of a local creek, leading to a reduced subsidence of approximately 200 mm coupled with a local concentration of compressive strain.

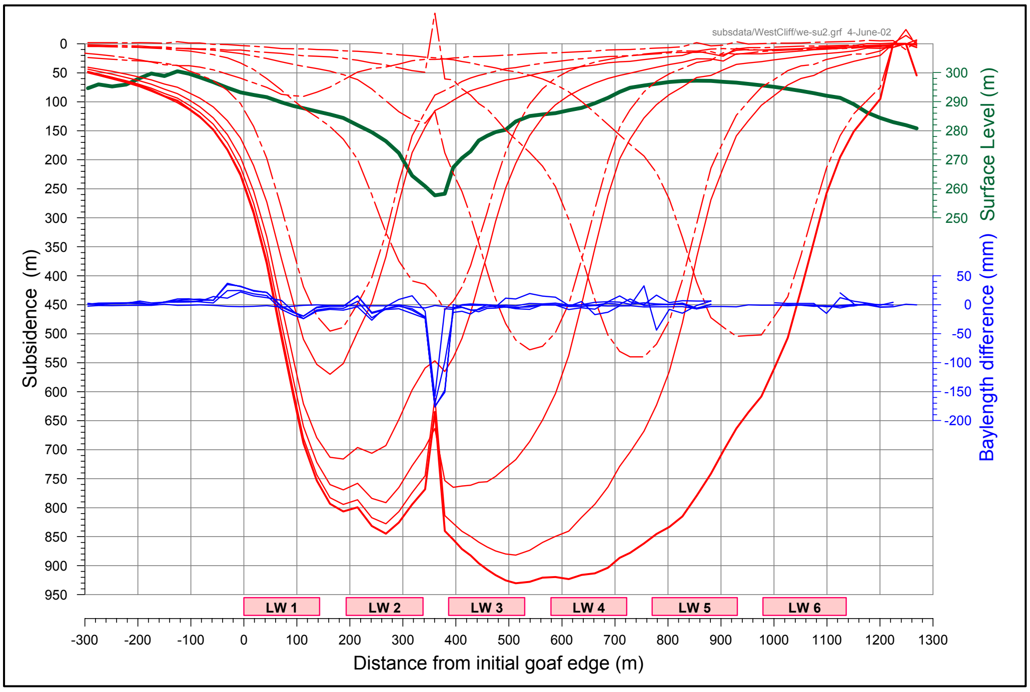


Fig. D.11 Measured Subsidence Profiles over Longwalls 1 to 6 at West Cliff Colliery

In most cases studied, the upsidence effects extend outside the valley and include the immediate cliff lines and the ground beyond them. For example, monitoring within the Cataract Gorge, at Tower Colliery, as Longwalls 8 and 10 were mined, revealed that the upsidence extended up to 300 metres from the centre of the Gorge, on both sides of the Gorge. In that case, the magnitude of the upsidence was greater than the subsidence leading to an overall uplift in the base of the Gorge, consequently leaving it above its original pre-mining level.

In other cases, within creek alignments, upsidence has been observed well outside an extracted panel, apparently due to a beam within the near-surface strata rotating and pivoting as a seesaw, as one end of it rises and the other subsides. However, in these cases, the measured upsidence and strains were less than would be expected to arise from the compressive buckling mechanism described above.

Based upon the empirical evidence, upsidence and closure movements can be expected in cliffs and in the sides of valleys, whenever longwalls are mined beneath or adjacent to them. Such movements, however, tend to be smaller outside the goaf areas and tend to reduce with increasing distance outside the goaf edge. The movements are incremental and increase as each longwall is mined in sequence, and consequently the movements resulting from the mining of one longwall can be spread over several longwalls.

Methods of prediction have been developed for closure and upsidence, as detailed in the ACARP *Management Information Handbook on the Undermining of Cliffs, Gorges and River Systems* (Waddington Kay and Associates, 2002).

The methods used to determine the predicted upsidence and closure for gorges, creek and river valleys were developed using empirical data from the Southern Coalfield. The data was mainly taken from the Nepean and Cataract River Valleys, which are large and steeply incised when compared to many of the valleys within the Newcastle and Hunter Coalfields. It is expected, therefore, that the methods used to determine predicted upsidence and closure movements will provide conservative results for smaller, less incised creek and river valleys within the Newcastle and Hunter Coalfields.

D.5.4. The Prediction of Closure in Creeks and River Valleys

A method has been developed for prediction of closure across creeks and river valleys which is based upon measured data over a wide range of cases, with valley depths varying from 27 metres to 74 metres. This data was mainly collected from collieries in the Southern Coalfield where the valleys are incised into flat lying sedimentary deposits and where the in-situ horizontal stresses are high. However, valley closure has also been observed in other locations and with lower valley depths.

The method is expected to give superior results in areas with geology and stress regimes similar to those from which it was derived. The method is based upon upper-bound measured values and it is anticipated that the method will over-predict in most cases, especially in areas of lower stress. Further research is required to determine how pre-existing in-situ horizontal stress and variations of local geology specifically influence the closure movements.

The method of valley closure prediction was first fully described in the report tilted "Report on ACARP Research Project No C9067 Research into the Impacts of Mine Subsidence on the Strata and Hydrology of River Valleys and Development of Management Guidelines for Undermining Cliffs, Gorges and River Systems" that was published by Waddington Kay & Associates in 2002. Since then new observations of closure have permitted minor improvements to the method of prediction that allow for the detailed prediction of distribution of closure movement profiles across a valley and allow more realistic upper bound predictions when predicting closure and upsidence at large distances from the lateral and longitudinal edges of longwall panels. The minor modifications in the prediction curves are shown on the following figures.

The method for the prediction of closure is based upon a series of graphs that show the interrelationships between closure and a number of contributory factors. The interrelationships between the factors are illustrated in the following figures.

- Fig. D.12 shows a graph of closure plotted against the transverse distance from a point in the bottom of the valley to the advancing goaf edge of the longwall divided by the width of the panel plus the width of the pillar.
- Fig. D.13 shows a longitudinal distance adjustment factor plotted against the longitudinal distance from a point in the bottom of the valley to the nearest end of the longwall in metres.
- Fig. D.14 shows a valley depth adjustment factor plotted against valley depth.
- Fig. D.15 shows an incremental subsidence adjustment factor plotted against the maximum incremental subsidence of the panel.

The graphs provide the original and the revised upper bound prediction curves, which are predominantly based upon closure data from the Cataract and Nepean Gorges, where the maximum incremental subsidence was approximately 410 mm and the depth of gorge was approximately 68 metres. The observed raw data values were "normalised" to account for variations in positions of the monitored creeks with respect to the panel edges and for variations in the magnitude of the maximum incremental subsidence over the mined panel and for variations in the valley depths. Large adjustment factors had to be applied to some of the raw observed data points and, where the raw data point is smaller than the survey tolerance, this magnification is also applied to the survey errors. Accordingly judgement was required to determine where to fit the new prediction curves, which are found to be above 90% of the adjusted observed closure data.

The closure is initially predicted from the graph shown in Fig. D.12 and the value so obtained is adjusted with reference to the graphs shown in Fig. D.13 to Fig. D.15, depending on the position of the bottom of the valley relative to the end of the longwall, the valley depth and the maximum incremental subsidence of the longwall.

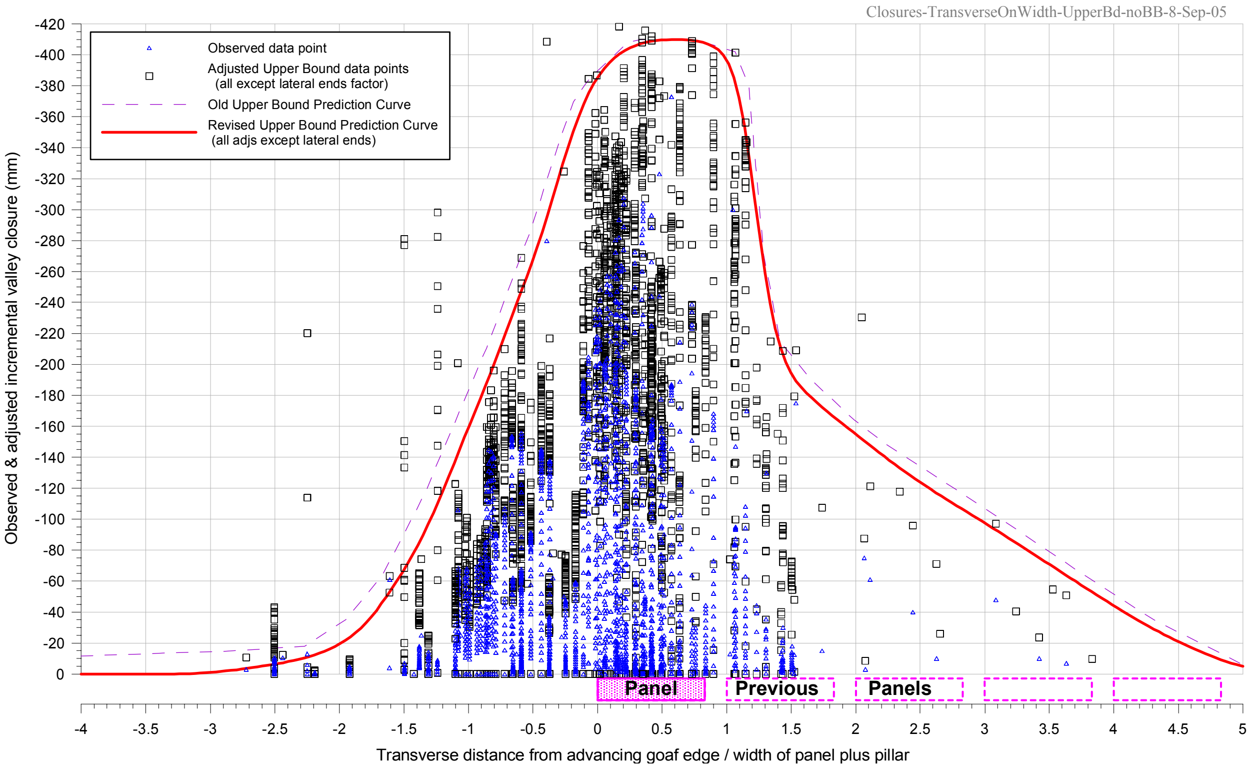


Fig. D.12 Valley Closure versus Distance from the Advancing Goaf Edge of the Longwall relative to the Width of the Panel plus the Width of the Pillar

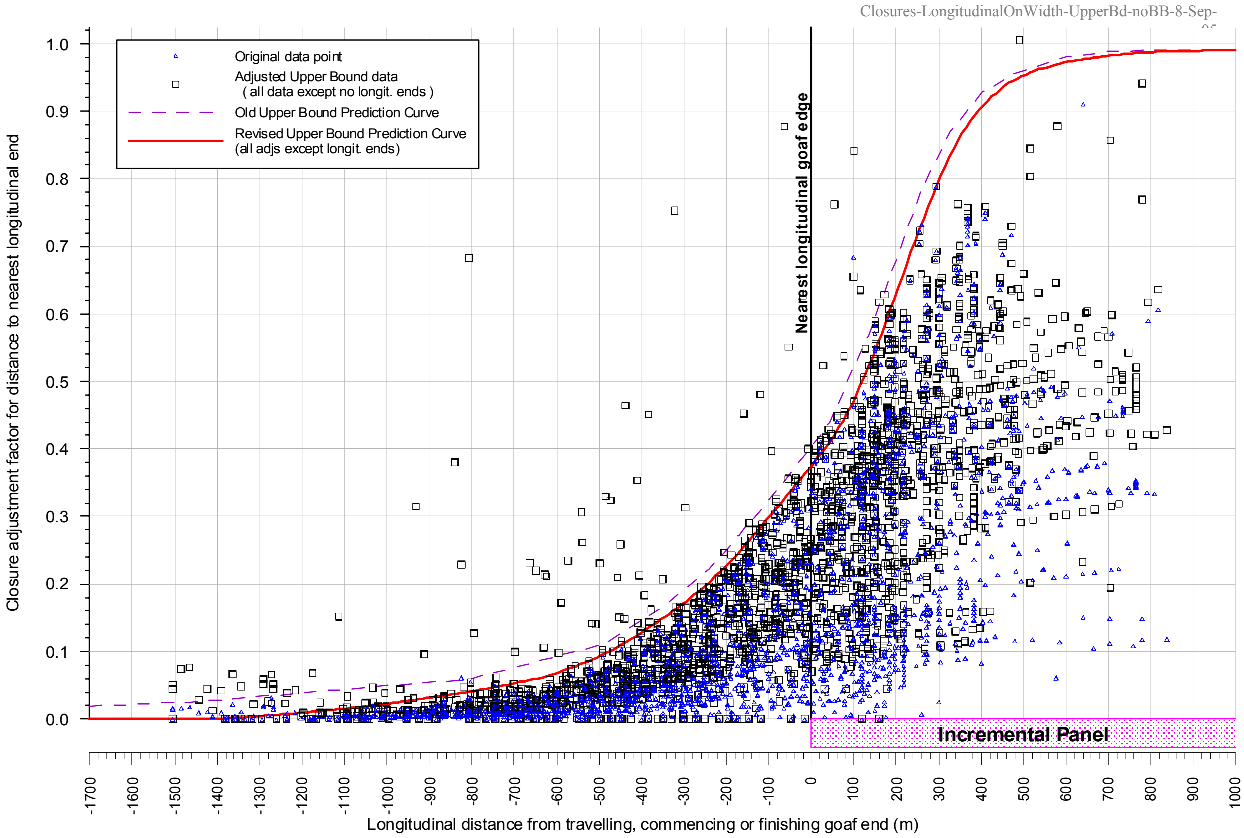


Fig. D.13 Valley Closure Adjustment Factor versus Longitudinal Distance

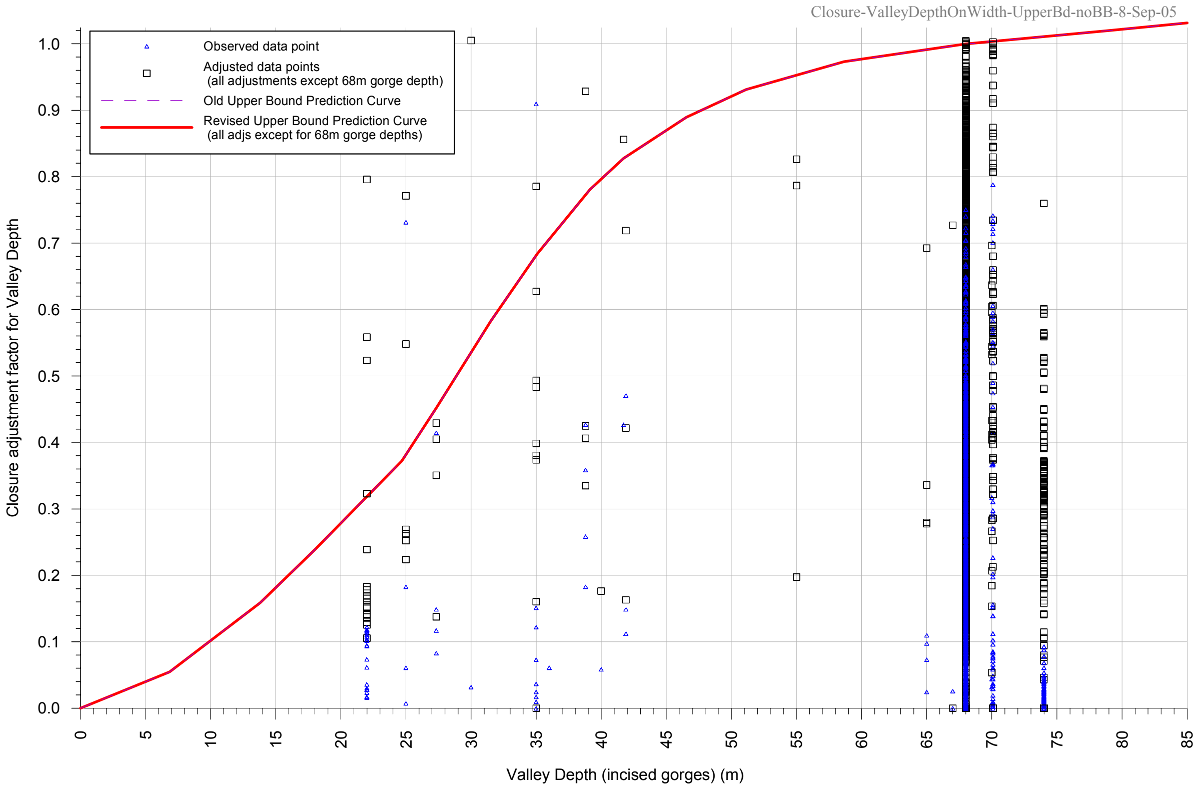


Fig. D.14 Valley Closure Adjustment Factor versus Valley Depth

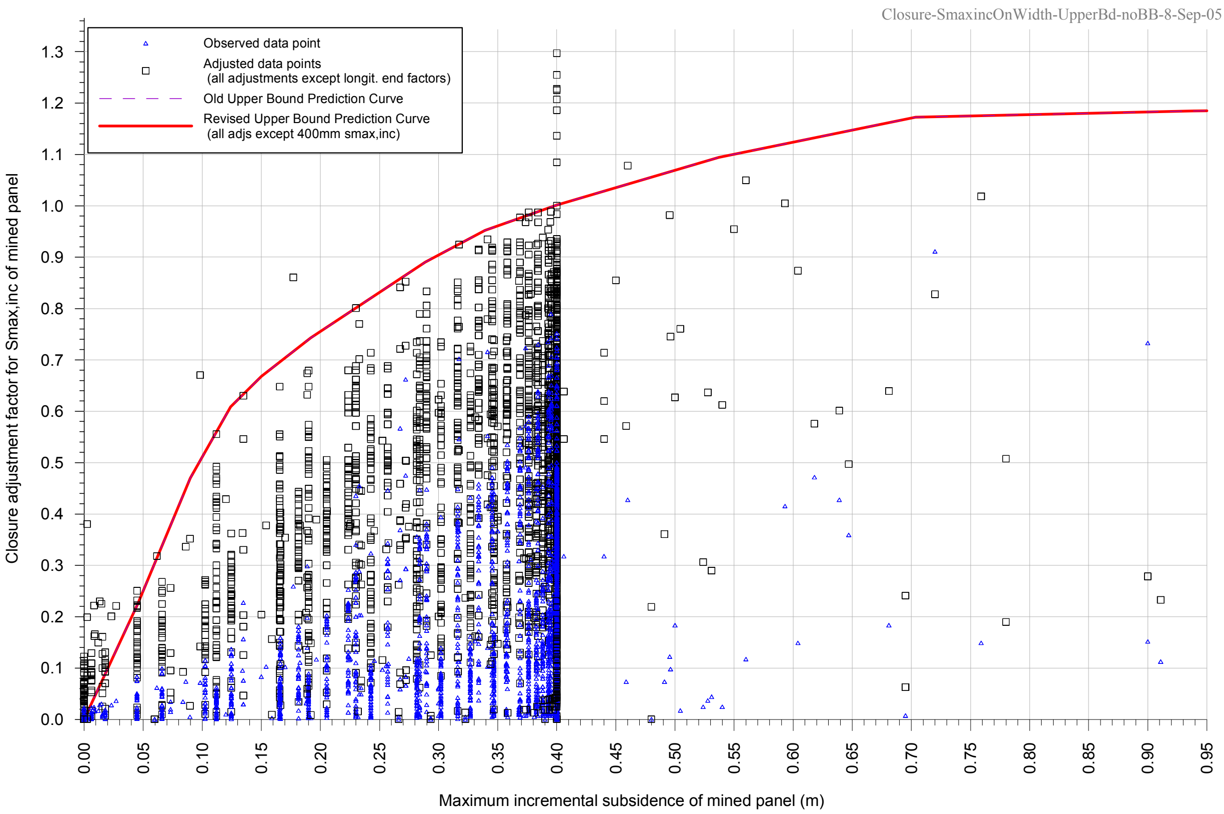


Fig. D.15 Valley Closure Adjustment Factor versus Maximum Incremental Subsidence

Fig. D.16 shows the distance measurement convention used to define the location of the point in the creek for which closure and upsidence predictions are required.

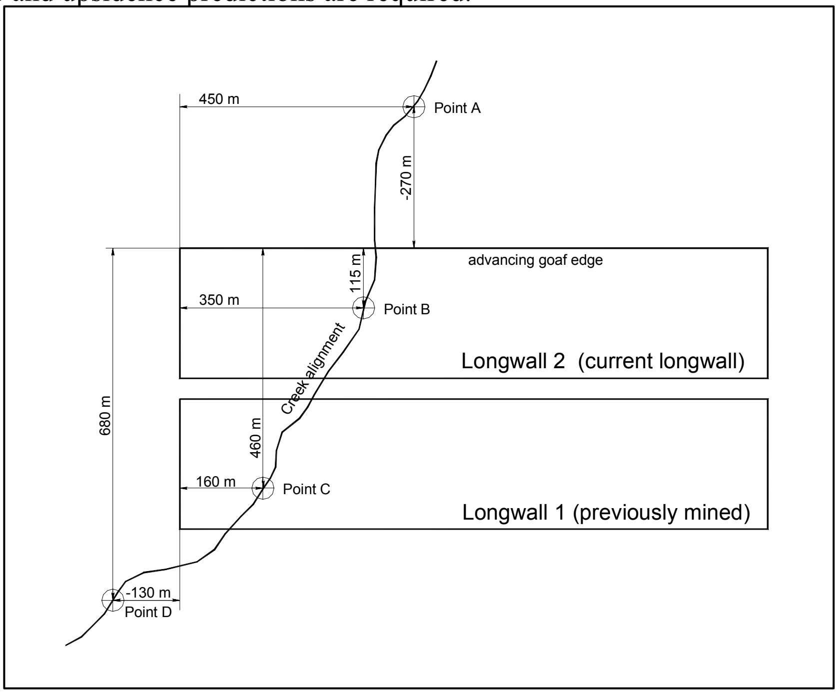


Fig. D.16 Distance Measurement Convention for Closure and Upsidence Predictions

The transverse distances plotted in Fig. D.12 are the distances measured at right angles to the advancing goaf edge of the longwall expressed as a proportion of the width of the panel plus the width of the pillar. The transverse distances for points A, B, C and D in Fig. D.16 are -270 metres, 115 metres, 460 metres and 680 metres, respectively, distances outside the goaf being negative.

The longitudinal distances plotted in Fig. D.13 are the distances from the nearest end of the longwall, measured parallel to the longitudinal centreline of the longwall. These distances for points A, B, C and D in Fig. D.16 are 450 metres, 350 metres, 160 metres and -130 metres, respectively, distances outside the goaf again being negative.

To make a prediction of closure at a point in the base of a creek or river valley, it is necessary to know the distance of the point from the advancing edge of the longwall, the longitudinal distance from the nearest end of the longwall, the valley depth, the maximum incremental subsidence of the panel that is being mined and the panel and pillar widths.

D.5.5. The Prediction of Upsidence in Creeks and River Valleys

The method developed for the prediction of upsidence in creeks and river valleys is similar to that described above for the prediction of closure. The method is based upon measured data over a wide range of cases, with valley depths varying from 8 metres to 87 metres. The data was mainly collected from collieries in the Southern Coalfield where the valleys are incised into flat lying sedimentary deposits and where the in-situ horizontal stresses are high.

The method of prediction would therefore be expected to give superior results in areas with similar geology and similar stress regimes. The method has also been modified based on new data received since the ACARP report was published in 2002. The method is based upon upper-bound measured values and it is anticipated that the method will over-predict in most cases, especially in areas of lower stress. Again, further research is required to determine how pre-existing in-situ horizontal stress and local variations in geology specifically influence the upsidence movements.

The prediction of upsidence is based upon a series of graphs that show the interrelationships between upsidence and a number of contributory factors. The interrelationships between the factors are illustrated in the following figures.

- Fig. D.17 shows the graph of upsidence plotted against the transverse distance from a point in the bottom of the valley to the advancing goaf edge of the longwall divided by the width of the panel plus the width of the pillar.
- Fig. D.18 shows a longitudinal distance adjustment factor plotted against the longitudinal distance from a point in the bottom of the valley to the nearest end of the longwall in metres.
- Fig. D.19 shows a valley depth adjustment factor plotted against valley depth.
- Fig. D.20 shows an incremental subsidence adjustment factor plotted against the maximum incremental subsidence of the panel.

The graphs provide the original and the revised upper bound values, which are mainly based upon upsidence data from the Cataract Gorge, where the maximum incremental subsidence was approximately 350 mm and the depth of gorge was approximately 70 metres.

The transverse distances plotted in Fig. D.17 are the distances measured at right angles to the advancing goaf edge of the longwall, expressed as a proportion of the width of the panel plus the width of the pillar. Fig. D.16 shows the distance measurement convention used to define the location of the point in the creek for which closure and upsidence predictions are required.

To make a prediction of upsidence at a point in the base of a creek or river valley, it is necessary to know the distance of the point from the advancing edge of the longwall, the longitudinal distance from the nearest end of the longwall, the valley depth, the maximum incremental subsidence of the panel that is being mined and the panel and pillar widths.

The initial prediction of upsidence is made using the upper-bound curve in Fig. D.17, for the relevant transverse distance divided by panel plus pillar width. The value of upsidence is then adjusted by multiplying it by the factors obtained from the upper-bound graphs from Fig. D.18 to Fig. D.20.

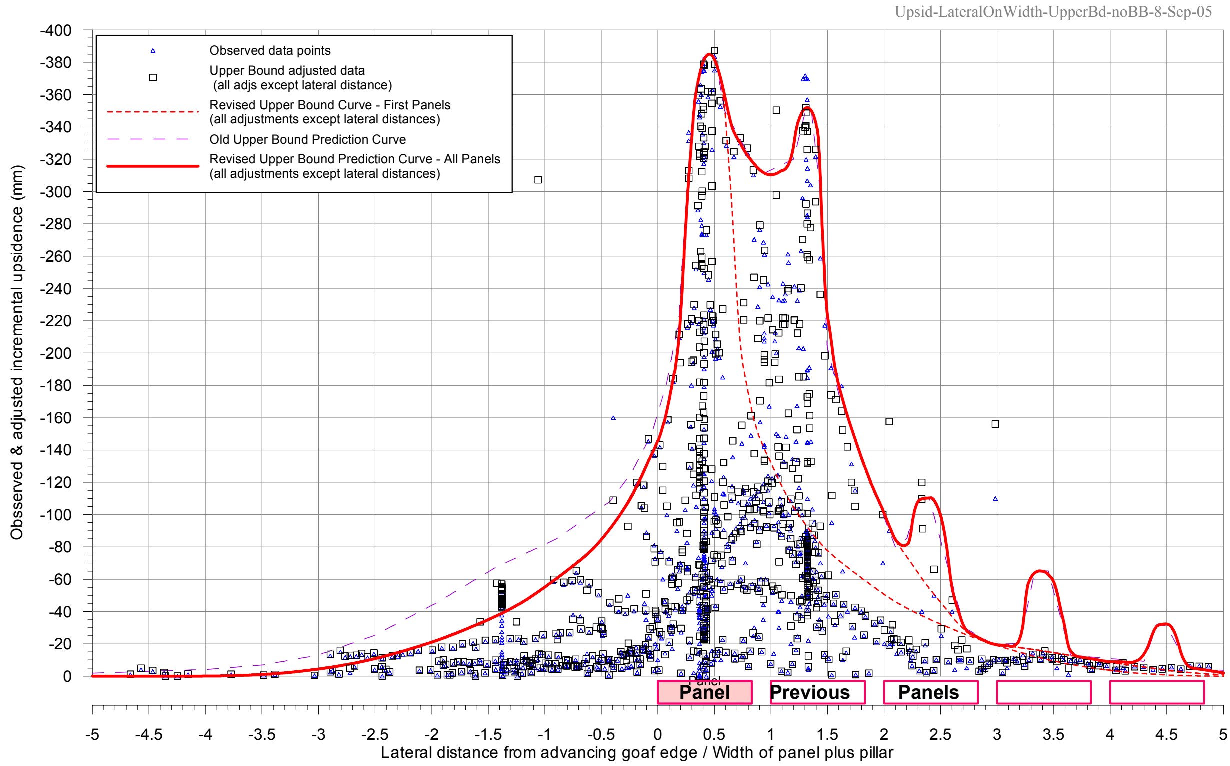


Fig. D.17 Upsidence versus Distance from the Advancing Goaf Edge of the Longwall relative to the Width of the Panel plus the Width of the Pillar

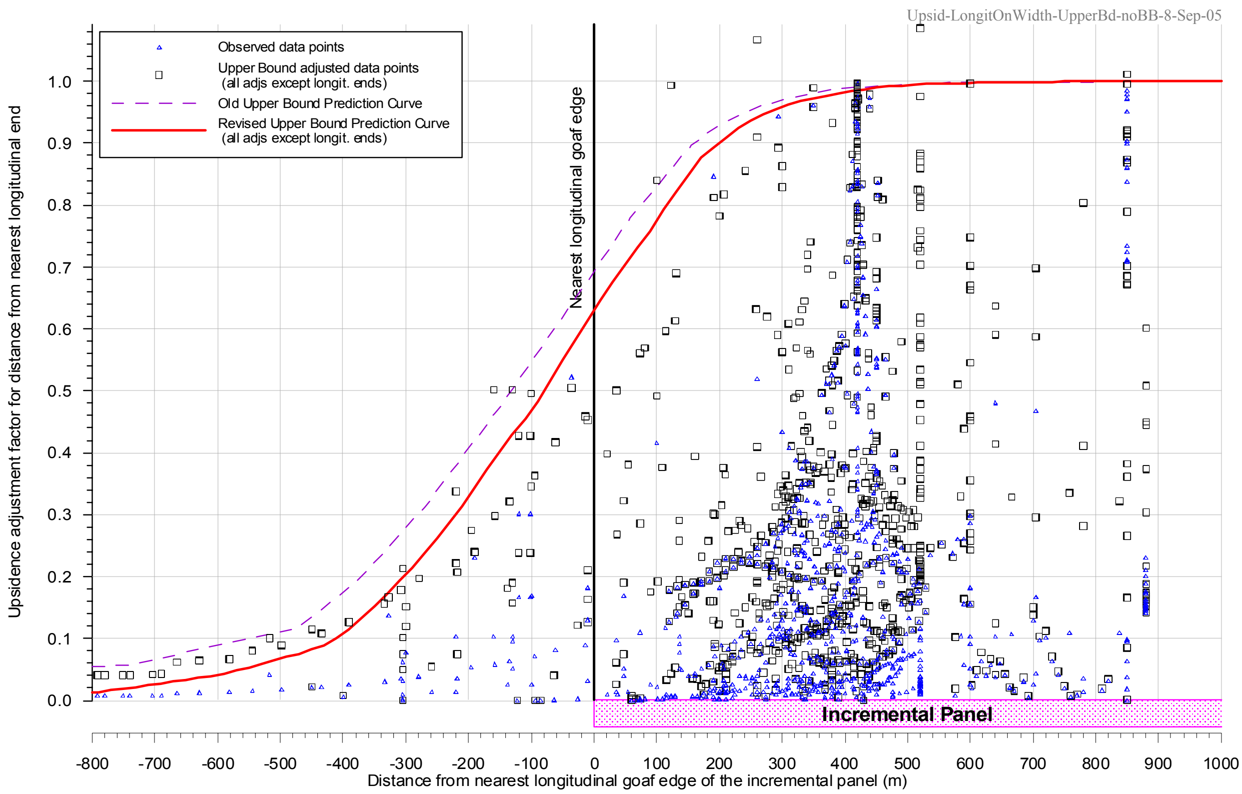


Fig. D.18 Upsidence Adjustment Factor versus Longitudinal Distance

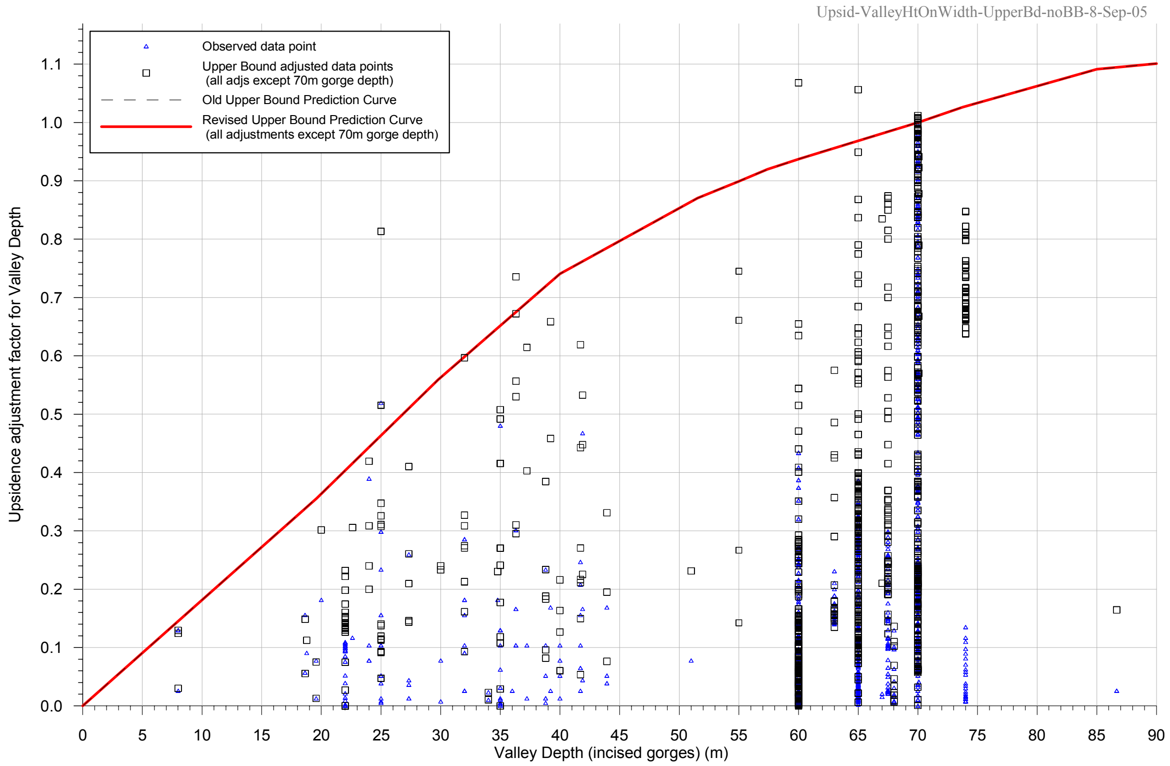


Fig. D.19 Upsidence Adjustment Factor versus Valley Depth

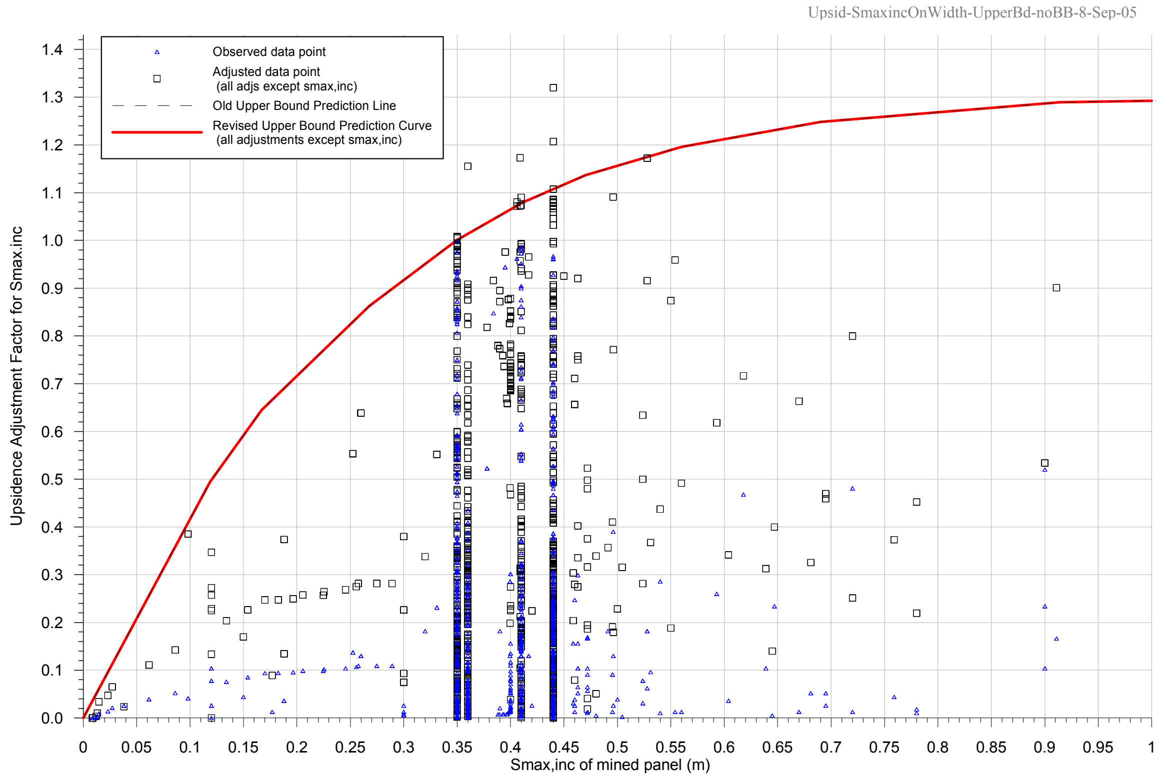


Fig. D.20 Upsidence Adjustment Factor versus Maximum Incremental Subsidence

D.5.6. The Lateral Distribution of Upsidence

Upsidence is the result of two separate mechanisms, namely, valley bulging and buckling of the strata in the base of the valley. The maximum upsidence occurs in the base of a creek or river valley, where the strata buckling occurs, but the upsidence effect spreads outwards under the sides of the valley for a considerable distance due to valley bulging.

For example, in the Cataract Gorge above Longwall 8 at Tower Colliery, whilst the upsidence in the base of the gorge was 350 mm, the upsidence in the clifflines was around 100 mm and the upsidence effect extended for a distance of 300 metres on each side of the gorge.

Fig. D.21 shows idealised profiles of upsidence across the Cataract gorge, both along the goaf edge of a longwall and along the centreline of the longwall. It can be seen that the lateral spread of the upsidence was greater where the amplitude of the upsidence was greater. Further research is required in order to develop a more definitive method for the prediction of upsidence profiles, but in the meantime it seems reasonable to model the profiles on the upper measured profile shown in Fig. D.21. An approximate profile can be obtained by scaling both the width and amplitude of the profile in proportion to the predicted upsidence value. It should be noted, however, that the predicted profile can only be approximated since the actual buckling will depend upon local geology and might not be centrally positioned in the bottom of the valley or gorge.

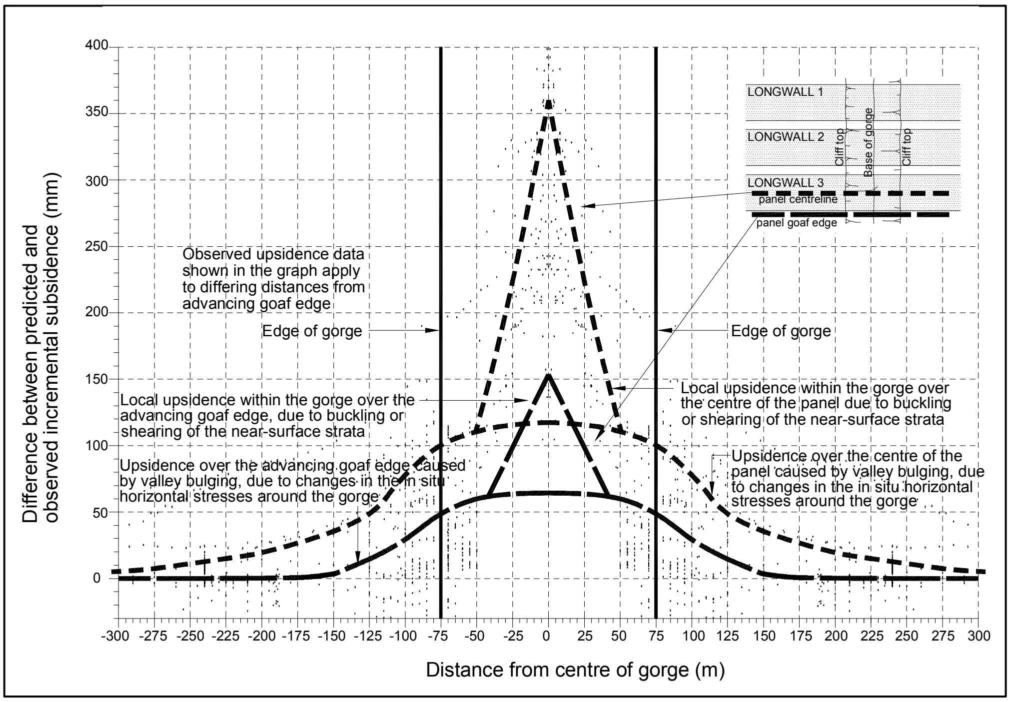


Fig. D.21 Idealised Upsidence Profiles across the Cataract Gorge

D.5.7. The Prediction of Compressive Strains in Creeks and River Valleys

The method of prediction for compressive strain due to closure was developed as part of the ACARP study (2002). The method provides an indication of the maximum compressive strains that might be experienced as a result of mining by adopting an upper bound relationship between observed closure and maximum compressive strain. This relationship is shown in Fig. D.22. The predicted closure, obtained using the method described in Section D.5.4, is the overall closure across the valley.

The predicted strain is the average strain over a bay length of 20 metres and is assumed to occur within the lowest part of the valley. The closure of this bay can, therefore, be determined from the predicted strain. The closure over this bay length can be greater than the overall closure of the valley, due to expansion in the valley sides as the horizontal stresses are relieved.

It is believed that the closure and strain are both driven by the in-situ horizontal stress and it is reasonable to assume that the compressive strains will reduce as the in-situ stress reduces. Since the graph in Fig. D.22 has been based on data that is primarily from observations at Tower Colliery, where the in-situ stress is particularly high, it is expected that the graph will generally be conservative and could over-predict strains by 100% in some cases, particularly where the predicted levels of strain are low. The data spread in the graph shows the variations that have occurred in practice and provides a guide to the potential range of strains that might occur in a particular case.

Since the completion of the ACARP study, an examination of observed ground movements suggest that the predictive method is mainly applicable for creeks and valleys that are located directly above extracted longwalls. However, it has been found that observed maximum compressive strains are substantially less in locations that are not directly above extracted longwalls. An upper bound relationship between compressive strain and lateral and longitudinal distance from longwalls is provided in Fig. D.23 and Fig. D.24. It is hoped that further analysis of observed ground movements will be conducted in the future, so that the method for predicting maximum compressive strains can be improved.

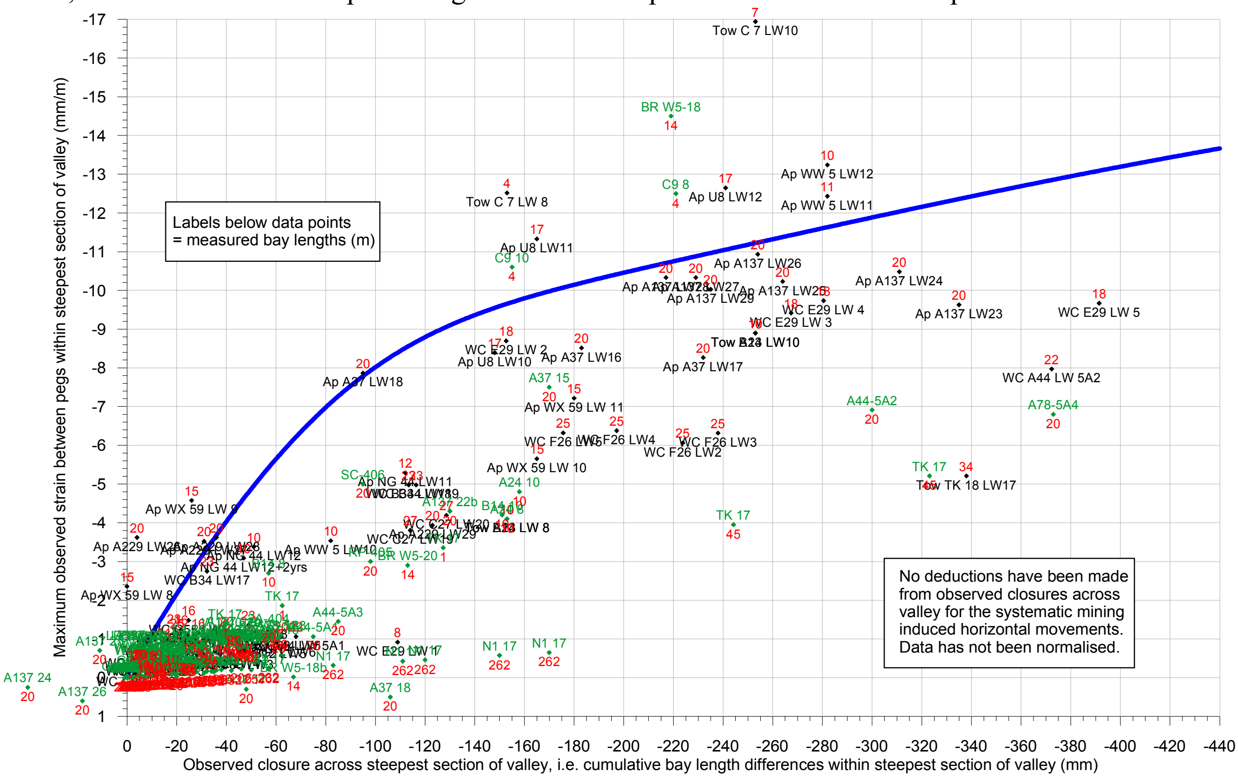


Fig. D.22 Graph of Maximum Compressive Strain versus Valley Closure

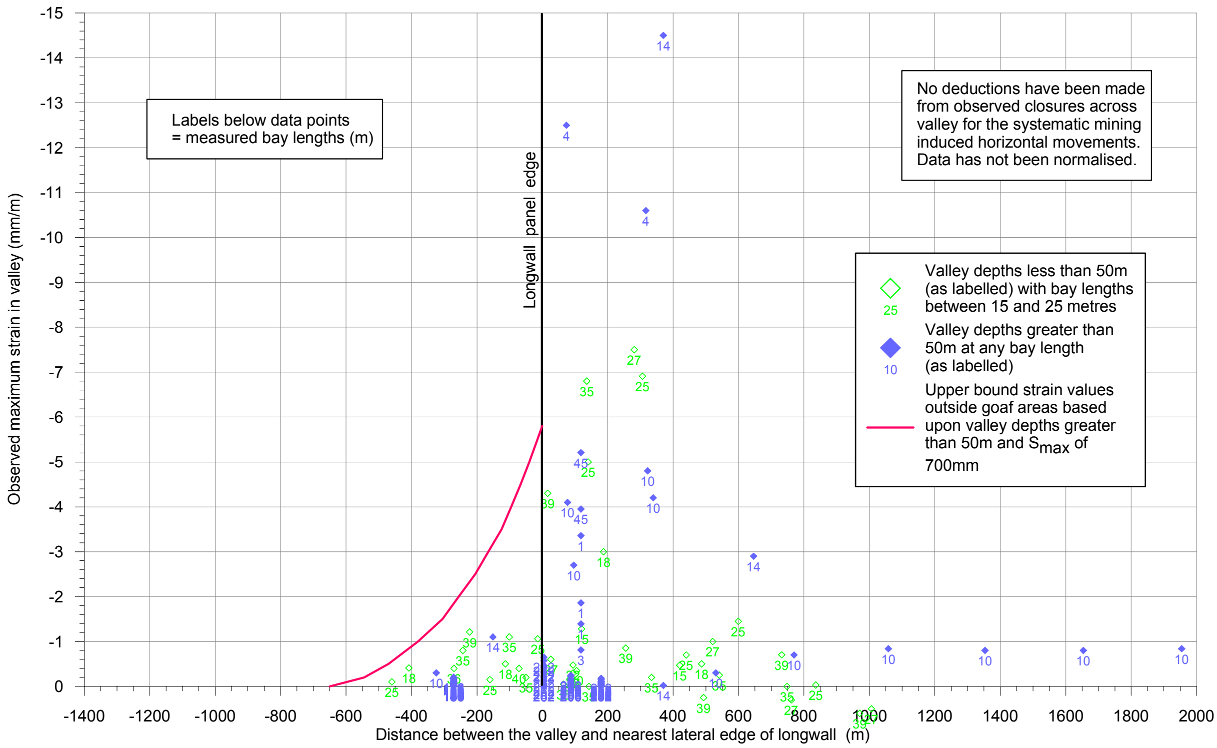


Fig. D.23 Graph of Maximum Compressive Strain versus Lateral Distance

Strain vs LongitDist

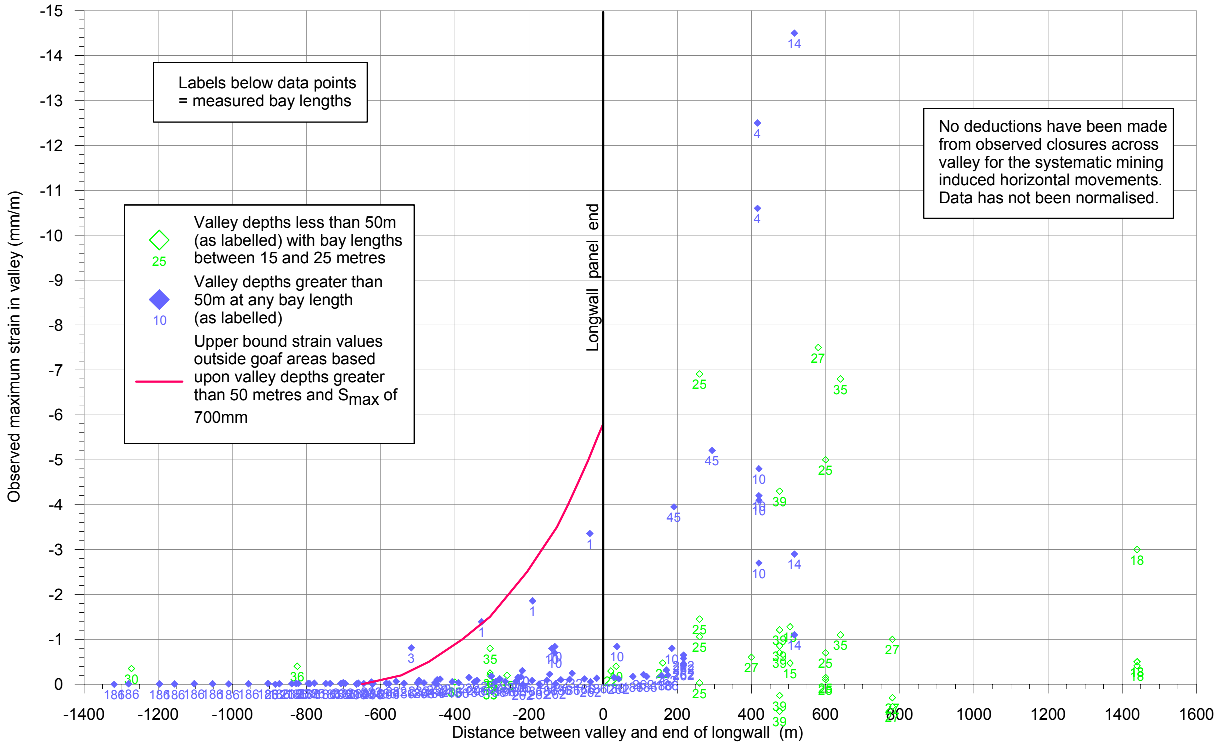


Fig. D.24 Graph of Maximum Compressive Strain versus Longitudinal Distance

D.5.8. Other Surface Anomalies

D.5.8.1. Definition of an Anomaly

An anomaly is defined as a significant irregular or non-systematic ground movement, which was not expected to occur. Small fluctuations in survey lines are not categorised as anomalies as these rarely affect surface features and are often within survey tolerance.

Systematic subsidence movements due to longwall extraction are particularly easy to identify as longwalls are regular in shape and the extracted coal seams are relatively uniform in thickness. Systematic subsidence profiles are typically smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata collapsing into a void.

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden. Where the depth of cover is greater than 400 metres, such as in the Southern Coalfield, the subsidence profiles along monitoring lines are generally smooth. Where the depth of cover is less than 100 metres, such as in the Newcastle and Hunter Coalfields, the subsidence profiles along monitoring lines are not generally smooth.

Even where the subsidence profiles are smooth, at locations with a high depth of cover, however, localised non-systematic ground movements have been observed along monitoring lines on some occasions. The causes behind the majority of these movements can be interpreted and are outlined in Section D.5.8.2. These include valley upsidence and closure, the influence of geological structures and issues related to the installation or surveying of monitoring lines.

Even though it is possible to attribute a reason behind most non-systematic ground movements, there remain some movements that still cannot be explained. These are termed “anomalies”, and their presence can sometimes impact surface features. Suggested reasons for some of these movements are discussed later in the report. In summary, it is believed that these anomalies are a result of the reaction of near-surface strata to increased horizontal compressive stress due to mine subsidence.

While the causes of anomalies are not yet fully understood, it is hoped that they will be better understood as the development of mine subsidence knowledge progresses. This may then allow these movements to be predicted, so that surface features can be better protected in the future.

D.5.8.2. Method of Identification of Anomalies along Monitoring Lines

Anomalies have been identified from observed subsidence profiles by a process of elimination. If a cause behind an irregularity in a subsidence, tilt or strain profile cannot be determined, the irregularity is recorded as an anomaly. All significant irregularities in the subsidence, tilt and strain profiles have been identified along each monitoring line, and the cause of each irregularity has been described and recorded. The most common causes of irregular or non-systematic movements are listed below.

- Valley upsidence and closure
- Geological Structures
- Change in direction of monitoring line
- Bumped pegs
- Damaged pegs
- Survey Line Discontinuities
- Survey Errors

D.5.8.3. Potential Causes of Anomalies

There are a number of possible causes of anomalies, the majority of which are due to local near-surface geology.

- Upsidence and closure in unknown "hidden" creeks which have been filled in by geological processes or by infrastructure development. This cause could be eliminated by examination of topography and lithology records.
- The possible presence of an unknown fault, dyke or other geological structure.
- Buckling due to increased horizontal stress concentrations, similar to those experienced in valleys.
- Buckling due to cross bedding or blocky behaviour of the near surface strata.
- Rotation of near-surface strata over the goaf edge.
- The presence of a stronger stratum capable of forming a natural corbel at the goaf edge.

It is observed that the major observed anomalies have behaved in a similar manner. The anomalies show an upwards bulge, or upsidence in the subsidence profile, coupled with a local concentration of compressive strain. In some cases, a localised surface "wrinkle" has formed at the point of maximum compression.

It is generally considered that the ground within the subsidence trough is in tension close to the edge of the longwall and in compression close to the centre of the longwall. This, however, is only true for the immediate surface of the bedrock. The strata behaves as a series of distinct beds of varying strengths that separate due to shearing along planes of weakness as subsidence occurs. The strata can therefore be looked upon as a series of relatively thin slabs laying one upon the other.

The underside of the uppermost stratum, following subsidence, is in compression close to the goaf edge and in tension close to the centre of the longwall, contrary to what the upper surface of the stratum is experiencing. It is these changes in stress between the upper surface of one layer and the lower surface of the layer above it that results in the shearing between the beds and the resulting bed separation.

In the Newcastle and Hunter Coalfields, the in-situ horizontal stresses in the strata can be greater than the vertical stresses, even close to the surface. The strata are being compressed on all sides, with the exception of the surface, which is not vertically constrained. As subsidence occurs and the normal collapse mechanisms initiate, the strata above and close to the longwall move inwards to fill the void. This allows the strata outside the subsidence trough to expand towards the goaf area.

At the same time, the horizontal stresses in the strata are redistributed above and below the seam causing increases in stress above the collapse zone, which results in elastic shortening, horizontally, and elastic expansion, vertically. The strata on each side of the collapse zone expands towards the goaf and are partially stress relieved resulting in vertical shortening of the strata and increased subsidence movements well outside the angle of draw.

This redistribution of horizontal stress extends for a considerable distance outside the goaf area, with measurable displacements almost three kilometres away. It is believed that this expansion towards the longwall goaf areas, due to the relaxation of in-situ horizontal stress in the strata is the cause both of the regional horizontal displacements and the unusually high vertical subsidence displacements that sometimes occur beyond the angle of draw.

All of the subsidence mechanisms are driven by in-situ stresses and gravitational forces, which are compressive. None of the driving forces behind the subsidence-induced movements are tensile. Generally, when the strata are vertically confined, they behave systematically. The irregularities that occur in subsidence profiles are therefore a surface phenomenon that is driven by compressive forces.

The surface strata can be likened to an ice flow, in which the individual blocks of ice are displaced due to the pressures exerted on them by their neighbours and by the underlying currents in the water beneath them. The blocks can buckle upwards or one block can shear and ride over the top of its neighbour. In some cases the blocks can be forced upwards to form arches or ridges. Not all movements are in the vertical plane and in some circumstances horizontal shearing can occur as one block slides past another, being propelled by a greater force and facing less resistance than its neighbour.

It is conjectured that the major anomalies that have been recorded were due to arching and buckling of near-surface strata as mining resulted in bed separation. It is also possible that shearing in underlying cross-bedded strata could initiate the anomaly, but there has been no stepping in the surface, which suggests that the near-surface strata have buckled rather than sheared.

It is interesting to note that the most likely place for compressive buckling to occur at the surface is where the surface is convex, or hogging. This is because the tendency in that situation is for the rocks to buckle upwards when compressed horizontally and to fail in bending tension or in shear. Where the strata are concave, or sagging, the underlying strata restrain the buckling and, generally, failure would occur only when the applied horizontal stresses exceeded the compressive strength of the strata, which is much greater than its tensile or shear resistance.

The in-situ horizontal stress increases in intensity with depth, but the stresses still exist close to the surface. The stresses are distributed throughout the strata according to the stiffness of each unit and the weaker strata attract a smaller proportion of the stress than the stronger strata. The way in which the surface strata will behave is, therefore, dependent upon the nature of the surface and near-surface rocks.

As mining occurs, subsidence and redistribution of in-situ horizontal stress results in bed separation and each stratum, particularly those at the surface, which are less confined by the weight of the rocks above them, becomes an independent and relatively slender compression member.

In this situation, very little eccentricity of loading or curvature of the member is required to initiate arching, followed by buckling. The initial buckling is a result of the in-situ horizontal stress and the movement is exacerbated as subsequent longwalls are mined and the longwalls get closer to the anomaly.

The increased subsidence over the goaf was initially difficult to understand, because it was anticipated that subsidence would be reduced in the high stress regime. A possible explanation, for the increased subsidence, is that the strata in the collapse zone had already been partially stress relieved by the adjacent goaf areas and thus offered less horizontal confinement, therefore allowing greater subsidence to occur.

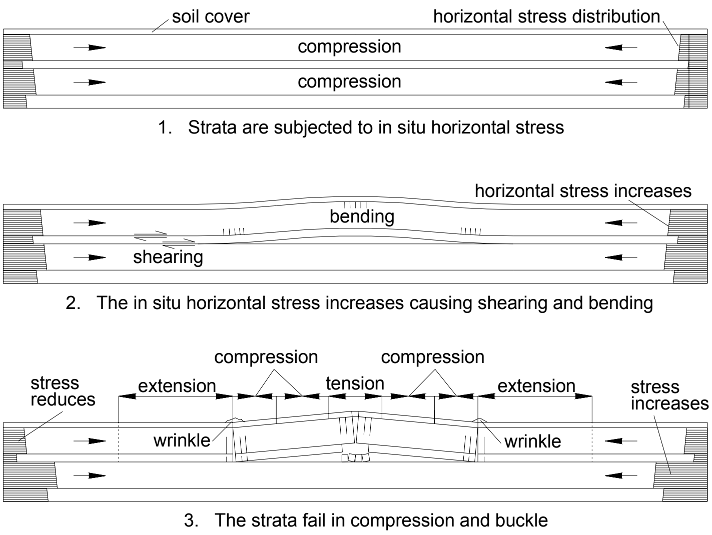


Fig. D.25 Strata Buckling Mechanism due to In-situ Horizontal Stress

The way in which buckling develops is illustrated in Fig. D.25. The phenomenon starts as bed separation occurs in the near-surface strata, due to shearing between beds as the in-situ stresses in the strata are redistributed. The stress in a particular stratum results in bending occurring, either due to eccentricity of loading or curvature of the stratum and the stratum arches upwards.

As the subsidence impact increases, the stratum starts to crack on its convex surfaces as the rock fails in bending tension. If the mining-induced stress continues to increase and the tensile fractures continue to develop to the full depth of the stratum, the stratum eventually fails in compression and buckles upwards. The buckling releases the horizontal confining stress in the stratum on both sides of the buckle and allows the stratum to expand horizontally and locally relieve the compressive stress. The stress relief in the surface stratum transfers additional stress into the strata below it and this can result in progressive failure and buckling through a number of strata, until the buckling of a stratum is prevented by the weight of the rocks above it.

When buckling occurs, the resultant strains measured at the surface can vary considerably from the predicted systematic strains and can alternate between compressive and tensile, even though the strata are consistently being compressed. It is this erratic behaviour of the surface strata that results in the scatter in measured strain profiles. The measurement of strain does not differentiate between a real extension of an unstressed stratum under applied bending stress and the expansion of a stratum due to compressive stress relief. The measured strains can therefore give a false impression of the state of stress in the surface strata.

It is probable that the most substantial impact to building structures in the Southern Coalfield is due to the buckling of surface strata under the influence of in-situ horizontal stress. Generally the underlying systematic levels of tensile and compressive strain are too low to result in significant impact and the worst impact has been associated with anomalous behaviour of the strata, where curvatures, strains and tilts have been increased.

D.5.9. The Prediction of Incremental Regional Horizontal Movements

In addition to the ‘normal’ and topographically related movements, far-field regional movements have also been recorded in a number of cases, at considerable distances from the longwall goaf areas. Such movements have often been several times higher than the vertical subsidence movements measured at the same locations.

It has been conjectured that these regional movements are caused by redistribution of the stresses in the strata between the seam and the surface due to the regional mining activity. The direction of such movements would tend to be towards the active mining, but the direction of movement could also be dependent upon the scale and proximity of adjacent goaf areas.

It has been suggested by some authors that the regional movements are generally aligned with the principal horizontal in-situ stress direction. However, it seems more reasonable to suggest that the movements will be directed from areas of high stress towards areas where the confining stresses have been reduced by mining activity, thus allowing expansion of the strata to occur. The stresses within the strata are generally compressive in all directions and until mining occurs the stresses are in equilibrium, the balance being controlled by the shear resistance within and between strata units. As mining occurs, the equilibrium is disturbed and the stresses have to achieve a new balance by shearing through the weaker strata units and by expanding into areas of greatest dilation, i.e. towards the goaf areas, where the confining stresses have been relieved.

An empirical database of observed regional horizontal movements has been compiled using monitoring data primarily from the Southern Coalfield of New South Wales in Australia. The monitoring data was collected from Collieries including Appin, Bellambi, Dendrobium, Tower and West Cliff. The regional horizontal movements resulting from longwall mining were generally observed to be orientated towards the extracted longwall. At low levels of regional horizontal movements, however, there was a high scatter in the orientation of the observed movements.

Fig. D.26 shows the observed incremental regional horizontal movements, resulting from the extraction of a single longwall, relative to the distance from the longwall. It can be seen from this figure that incremental regional horizontal movements of up to 20 mm have been observed at distances of 2000 metres from extracted longwalls.

Fig. D.27 shows the observed incremental regional horizontal movements, resulting from the extraction of a single longwall, relative to the distance from the longwall, for cases where there was solid coal between the longwall and the monitoring points. It can be seen by comparing Fig. D.26 and Fig. D.27, that the magnitudes of observed incremental regional horizontal movements are generally less where there is solid coal between the longwalls and monitoring points.

The maximum movements tend to occur when the second and third longwalls are mined in a series, and tends to decline as subsequent longwalls are mined. This is possibly due to the fact that once the strata has been stress relieved by the first few longwalls, the potential for further movement is reduced.

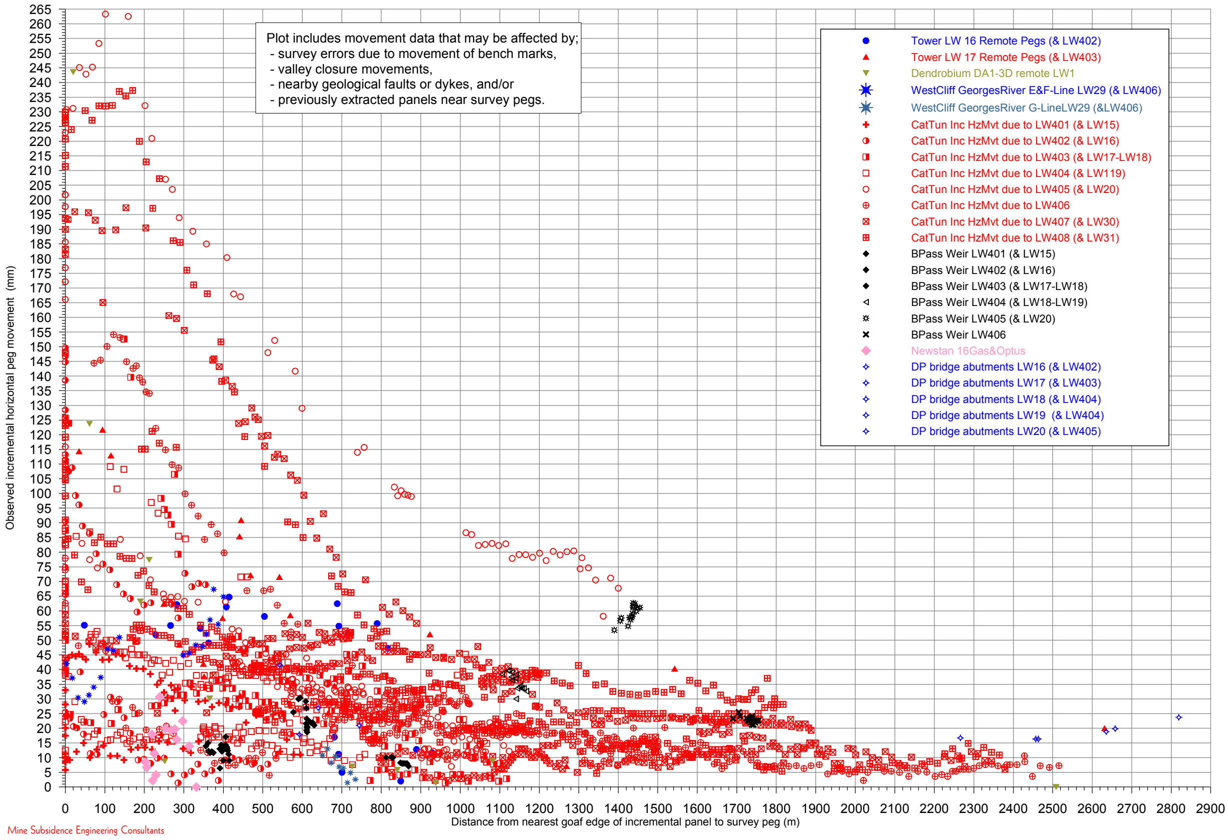


Fig. D.26 Observed Incremental Regional Horizontal Movements

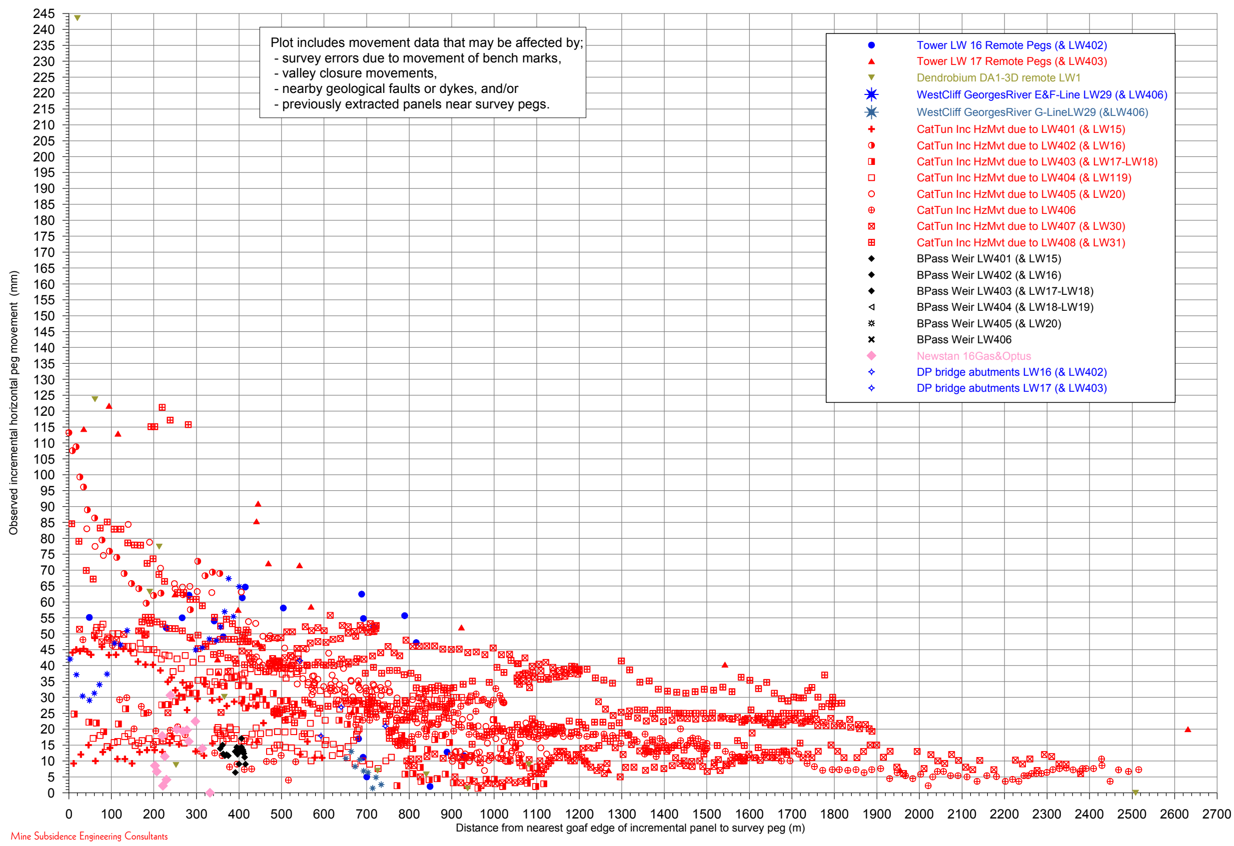


Fig. D.27 Observed Incremental Regional Horizontal Movements with Solid Coal between the Monitoring Points and Mined Longwall

D.6. Sub-Surface Strata Movements above Extracted Panels of Coal

D.6.1. Collapse Mechanisms

Before the strata above an underground excavation are disturbed, all points beneath the surface are under compression from the weight of the overburden, and from pre-existing in-situ horizontal stresses, and are in a state of equilibrium. The extraction of panels of coal, by continuous miner or longwall mining operations, creates voids, which upset the balance of forces in the strata, causing displacements to occur until a new state of equilibrium is reached.

The overall force field in the strata, outside and around the extracted void, remains unchanged and the stresses have to readjust locally around the void to achieve this new state of equilibrium. The void provides the compressed rock with a space into which it can expand, and in so doing relieve the stresses that initiated the movement.

Because the extracted voids are generally much wider than the height of the seam, the initial movements tend to be vertical displacements of the roof and floor of the void, movements of the roof being assisted to a greater extent by gravity. Once the vertical movement occurs, generally by failure of the immediate roof strata, the strata outside the void, which are no longer constrained by the roof strata can relieve some of their stress by expanding horizontally into the goaf area. A state of equilibrium is achieved when the desire of the strata to expand is balanced by the frictional shear forces, developed by the weight of the overburden, which tend to resist the expansion.

The collapse of the immediate roof strata will generally be followed by the collapse of the rocks above them, unless the remaining overburden strata are sufficiently strong and homogeneous to span over the width of the void. Failure generally occurs due to the separation of an individual stratum along a bedding plane, which, being unable to carry the loads imposed by the weight of the overburden and the horizontal compressive stress, shears or buckles in bending and falls into the goaf.

The collapse progresses upwards until a stronger and more homogeneous strata beam is reached with the capacity to bridge the void. Such strata beam could be a thicker homogeneous rock of a particular type, such as a massive sandstone or conglomerate layer, or could be a combination of rock strata, which, acting together as a laminated beam, have sufficient strength to span the void. The height at which the progressive collapse of the strata towards the surface is arrested, i.e. the height of the fractured zone, is dictated by the width of the extracted void and the nature of the overburden strata.

The mechanism of collapse and the subsidence at the surface is further complicated by the cantilevering of the strata from the abutments on each side of the void and the elastic compression of the coal pillars and the strata above and below them.

After failure of the immediate roof, the lateral expansion of the strata at the abutments into the extracted void tends to form natural corbels, which support the strata above them and reduce the effective span. As the collapse progresses upwards the corbels extend further and further towards the centre of the goaf and form an irregular cantilever of strata at each abutment which transfer the weight of the overburden strata above the collapsed zone into the abutments. The angle, measured from the vertical, at which these corbels extend into the goaf area, is referred to as the angle of break.

The cantilevering strata and the overburden above the collapse zone span between the abutments and sag across the void and are partially supported by the collapsed rocks beneath them. At the same time, because the loads on the abutments are increased by the spanning strata, elastic compression occurs in the abutment coal pillars and in the strata above and below the pillars, causing settlement over the pillars. This settlement above the pillars is greatest where the depth of cover is high and the width to depth ratio of the extracted panel is relatively small. At higher width to depth ratios the settlement over the pillars reduces, because the strata collapses more freely into the goaf and less load is shed to the abutments. Additional settlement over the pillars occurs due to the lateral expansion of the strata at the abutments and the resultant vertical dilation caused by horizontal stress relief.

These separate mechanisms combine to cause subsidence at the surface, which extends over the extracted void and beyond the edges of the void to the limit of subsidence. Vertical subsidence at the surface is generally less than the thickness of the extracted coal seam, because the collapsed strata and the sagging strata above the collapsed zone contain a significant number of voids.

Rocks within the collapsed zone tend to fail by blocky delamination from the strata above them and collapse into the void in an irregular manner, which causes bulking of the collapsed strata to occur. Sometimes this can be sufficient to choke off the collapsed zone and prevent further progression of the collapsed zone towards the surface. In other cases it is possible that significant voids could be left at the top of the collapsed zone beneath a competent strata beam.

Above the collapsed zone is the fractured zone in which the strata are subject to significant vertical displacement and bending, which result in fracturing, joint opening, shearing on bedding planes and bed separation. The more competent rocks tend to span over the gaps beneath them, whilst weaker rocks tend to sag onto the stronger rocks beneath them. This results in vertical bed separation and void formation beneath the more competent strata with increased horizontal permeability. In this zone, it is possible that cracks could extend for the full depth of a stratum, thus increasing vertical permeability and connectivity between near surface aquifers and the mine workings.

Above the fractured zone is the constrained zone, in which the strata tend to sag and bend without failing and are laterally constrained by the horizontal in-situ stresses within the strata. In this zone, the bending of the strata results in the development of shear stresses at the interfaces between adjacent beds, causing horizontal displacements along the bedding planes and increased horizontal permeability. At low curvatures it is likely that some strata would crack on their convex surfaces, though the tension cracks would not penetrate the full depth of a stratum and hence would not provide hydraulic connectivity to the underlying strata. In the constrained zone, it is therefore possible that the horizontal permeability could increase due to subsidence, without an increase in vertical permeability.

Above the constrained zone is the surface zone, which comprises vertically unconfined strata and alluvial soils that essentially follow the bedrock movements downwards, but can still experience tensile cracking and surface buckling due to ground curvatures and strains.

D.6.2. Angle of break

The extent to which the corbels develop at the abutments and cantilever into the collapse zone is dependent upon the strength and thickness of the strata in the immediate roof and overburden, the locations of pre-existing joints and faults and the level of in-situ horizontal stress. The units that are thicker, stronger and more homogeneous will tend to cantilever further than those which are thinly bedded, weaker and more frequently jointed. The angle of break is therefore dependent upon local geology. It can also be affected by the choice of mining method and the speed of mining.

In a sequence of rocks comprising sandstones, conglomerates, shales, claystones and mudstones of moderate thickness it would appear, from the literature that has been reviewed, that the angle of break will be somewhere between 17^0 and 23^0. Based upon an angle of break of 17^0 the collapse zone would only extend through to the surface if the width to depth ratio was greater than 0.6 and if there was no significant stratum to span the void and arrest the upward development of the collapse zone at some horizon in the sequence. At an angle of break of 23^0, the width to depth ratio would have to exceed 0.84.

D.6.3. Variations in Terminology used to describe Strata Displacement Zones

A study of the various papers and texts that are listed in the references in Appendix B, reveals that the terminology used by different authors to describe the strata displacement zones above an extracted panel is inconsistent. Forster (1995) noted that most studies had recognised four separate zones, with some variations in the definitions of each zone. Peng and Chiang (1984) as illustrated in Fig 8.4.1 of the text book by Peng, which is reproduced in Fig. D.28, below, had recognised only three zones, namely the caved zone, the fractured zone and the continuous deformation zone. McNally et al (1996) also recognised three zones, which they referred to as the caved zone, the fractured zone and the elastic zone.

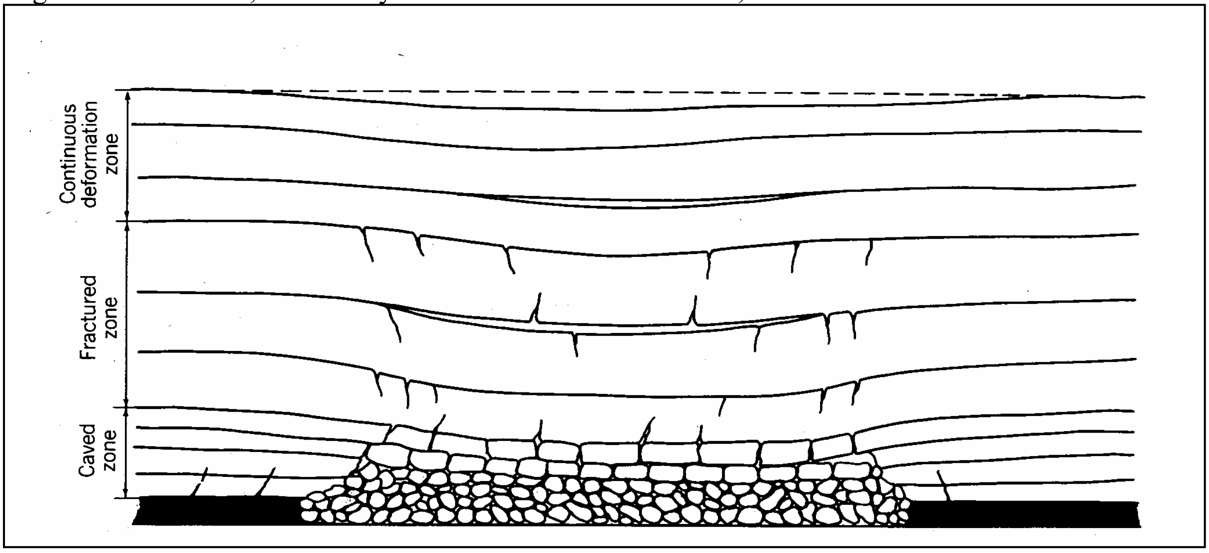


Fig. D.28 Zones in the Overburden According to Peng and Chiang (1984)

Kratzsch (1983) identified four zones, namely the immediate roof, the main roof, the intermediate zone and the surface zone. For the purpose of this study, the following zones, as described by Singh and Kendorski (1981) and proposed by Forster (1995), have been adopted. These are further illustrated in Fig. D.29, below.

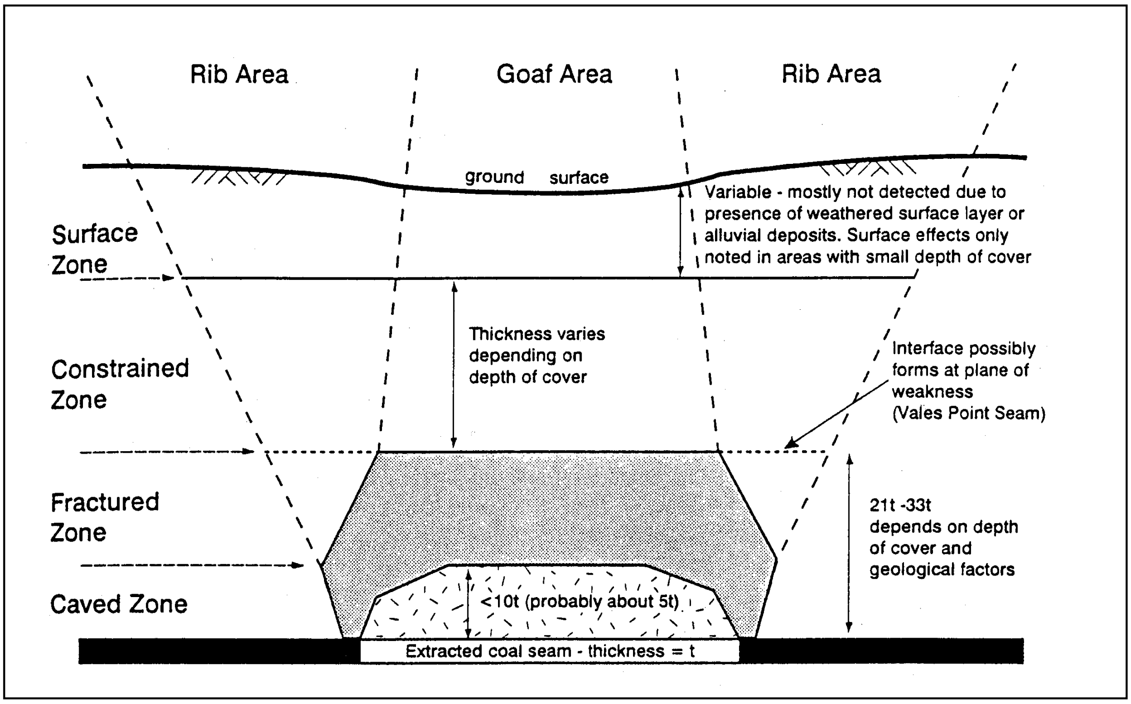


Fig. D.29 Zones in the Overburden according to Forster (1995)

- *Caved or collapsed Zone*. (Some authors note primary and secondary caving zones.) Comprises loose blocks of rock detached from the roof and occupying the cavity formed by mining. Can contain large voids
- *Disturbed or Fractured Zone*. (Some authors include the secondary caving zone.) Basically in-situ material lying immediately above the caved zone which has sagged downwards and consequently suffered significant bending, fracturing, joint opening and bed separation.
- *Constrained or Aquiclude Zone*. (Also called the Intermediate Zone.) Comprises confined rock strata above the disturbed zone which have sagged slightly but, because they are constrained, have absorbed most of the strain energy without suffering significant fracturing or alteration to the original physical properties. Some bed separation or slippage can be present as well as discontinuous vertical cracks (usually on the underside of thick strong beds). Weak or soft beds in this zone may suffer plastic deformation.
- *Surface Zone*. Unconfined strata at the ground surface in which mining induced tensile and compressive strains may result in the formation of surface cracking or ground heaving.

D.6.4. Permeability, Vertical Dilation and Collapse and Fracture Zones

The likely heights of the collapsed, fractured and constrained zones have been provided by various authors and these have been reviewed during the course of preparing this report. Generally, the height of the caved zone has been indicated to fall within the range 1.5 to 14 times the extraction height, with the majority of cases in the range 5 to 10 times the extracted height. Forster concluded that the maximum height would be less than 10 times and probably around 5 times the extraction height.

The height of the fractured zone has been indicated to lie within the range 10 to 105 times the extracted height, though Holla and Buizen (1991) indicated that the height of the fractured zone over Longwall 3 at Tahmoor Colliery extended to a height of 143 times the extracted seam thickness, based upon extensometer readings. Forster (1995) concluded that the height of the fractured zone should be taken as 21 to 33 times the extracted height of the seam.

An alternative method of measuring the heights of the collapsed and fractured zones is to express the height as a function of the extracted width. This method appears to be favoured by some authors, though definitive relationships have yet to be determined. The height of the disturbed zone, being the overall height of the collapsed and fractured zones, has generally been found to vary from 0.16 to 1.4 times the extracted width. A height of 1.73 times the extracted width was indicated by Holla and Buizen (1991) over Longwall 3 at Tahmoor Colliery, based upon extensometer readings.

Some of the difficulties in establishing the heights of the various zones of disturbance above an extracted panel stem from the imprecise definitions of the fracture and constrained zones and the interpretation of extensometer readings. The definition of constrained zone is based upon the assumption that bed separation in this zone will increase horizontal permeability without increasing vertical permeability. It is possible for considerable dilation to occur as differential bending of the strata layers occurs, but this is not considered to be the same kind or extent of fracturing that is to be found in the fractured zone, where vertical permeability is likely to be affected by bending or shear induced vertical fractures.

Where vertical dilation is measured by extensometer readings, it is possible that bed separation in the constrained zone could be misinterpreted as fracturing in the fractured zone. The measurement of vertical tensile strain is of some assistance in identifying the extent of the strata disturbance at different horizons, but where bed separation occurs in the constrained zone a large vertical strain at that point can be confined by low vertical strains above and below the point.

The interpretation of extensometer readings has to be undertaken with care, particularly where the extensometers are limited in depth and do not penetrate the full depth of the overburden. The researchers at the University of New South Wales (1984) noted that since there had been no direct permeability measurements, it was difficult to establish a relationship between the vertical strain variation and the permeability of the strata.

Another issue with regard to extensometer readings that should be highlighted is that the extensometers were affected by horizontal shear and displacement, which resulted in total extension readings that were greater than the extracted thickness of coal. Quite clearly the extensions included horizontal movements between strata units at particular horizons and such movements would give a totally wrong impression of the vertical strains between anchors.

D.6.5. Relationship between Vertical Dilation Heights and Mining Geometry

The effect of mining geometry on the heights of the collapse and fractured zones is not well documented. Theory would suggest that the height of the collapse zone would be directly related to the width of the extraction, the height of extraction, the depth of cover and the nature of the rocks in the overburden. Where the panel width-to-depth ratio is high and the depth of cover is shallow, it is clear that the fractured zone can extend from seam to surface. This is clearly indicated in the extensometer readings from boreholes above shallow areas of extraction, where the vertical strains close to the surface are as high as they are close to seam level.

This was apparent in the results of the extensometer readings above Longwall 2 at Invincible Colliery, where the longwall width was 135 metres, the height of extraction was 2.7 metres and the depth of cover was 116 metres. The width-to-depth ratio of the panel was, therefore, 1.16. In this case, the collapsed zone extended to approximately 9 times the extracted seam thickness above the seam roof. Above the collapsed zone, the vertical strain was almost linear through to the surface at approximately 8 mm/m, indicating that the fractured zone extended to the full depth of the overburden.

It was also apparent in the movements of the strata above Longwall 11 at Angus Place Colliery. In that case, the longwall width was 211 metres, the height of extraction was 2.47 metres and the depth of cover was 263 metres. The width-to-depth ratio of the panel was, therefore, 0.8. Bhattacharyya and Zang (1993) estimated that the height of the collapsed zone was 25 metres, or 10 times the extracted seam height. Above the collapsed zone, the vertical strain was almost linear through to the surface at approximately 5.6 mm/m, indicating that the fractured zone extended to the full depth of the overburden.

The extent of the collapsed zone has generally been defined with reference to the extracted seam thickness and the height to which collapse occurs before the bulking of the collapsed rocks chokes off further vertical progression of the collapsed zone. The extent of the fractured zone above the collapsed zone would appear to be more dependent upon the width of the extraction and the angle of break. The vertical strain would appear to be dependent upon the extracted seam thickness, the amount of subsidence and the depth of cover.

It is reasonable to suppose that as the width to depth ratio reduces, the height of the fractured zone would also reduce. Conversely, the height of the fractured zone would be expected to increase as the width-to-depth ratio increased.

APPENDIX E. CLASSIFICATION OF DAMAGE TO BUILDING STRUCTURES

E.1. Introduction

The major mining-induced ground movements and subsidence parameters that are used to assess the impacts of subsidence on building structures are discussed in the following sections. The classification system for impact levels due to subsidence induced ground movements are also explained.

E.2. Mining Induced Ground Movements

E.2.1. Vertical Subsidence

Vertical, rigid body, subsidence has little or no effect on buildings or other surface structures where the subsidence occurs uniformly. The structures are, naturally, left at a lower level but normally this has little or no adverse effect upon them. Drainage systems and services to a building normally subside with the building and impact only results when differential subsidence occurs.

E.2.2. Horizontal Displacement

Horizontal displacements due to mining subsidence occur in such a way that points on the surface generally move towards the centre of the subsidence trough. Where one part of a structure is moved differently relative to other parts, then the structure experiences tensile stretching or compressive squashing. Differential horizontal movements give rise to strains but uniform horizontal movement of a surface structure would not normally have any adverse effect as the ground and structure move together.

E.2.3. Tilt

Ground tilt does not generally lead to structural impact. Severe tilts, however, may cause serviceability problems, such as doors tending to close themselves, or drainage problems, resulting from changes in the slopes of roof gutters, wet area floors and external paved areas. Single storey buildings usually remain serviceable when the residual tilts are less than 7 mm/m, although taller structures can be more sensitive to tilt. Swimming pools and large water storage tanks are also sensitive to tilting and, in some cases, are more sensitive than residential buildings.

E.2.4. Curvature

Curvature resulting from differential tilting is one of the major causes of impact to buildings and structures. Normally, curvature is defined as the reciprocal of the radius of curvature but it can also be defined by a deflection ratio for a particular length of structure, or by the radius of curvature itself. The deflection ratio is the maximum vertical displacement occurring between two points along a structure, expressed as a fraction of the horizontal distance between them.

An acceptable, or allowable, deflection ratio is that which can be tolerated by a structure without impairing its structural adequacy or serviceability, despite visible cracking that may occur in the superstructure. It is therefore a measure of the resistance of a structure to bending and shear strain.

Allowable deflection ratios are given in the Australian Standard AS 2870 (1996) for different types of construction and these, together with ratios established in research by various authors, are discussed in Sections 4.5 to 4.8. Cracking in rendered walls will normally be more apparent than in face brickwork and the allowable deflection ratios are therefore reduced for structures with rendered walls.

Modern brick structures are generally built with vertical joints at frequent intervals to allow for thermal expansion and other building movements. These structures can normally accommodate some curvature without damage but older brick structures, which were not designed to accommodate such movements, are more likely to be adversely affected.

E.2.5. Horizontal Strain

As discussed in Section 4.2.2, differential horizontal movements give rise to ground strains, however, most of the horizontal movements are proportional to ground curvature. Within the subsidence trough, convex or hogging curvature is accompanied by tensile strain and concave or sagging curvature is accompanied by compressive strain. Both tensile and compressive strains can cause cracking in a building structure but tensile strains are more difficult to accommodate since almost all components of a structure are weaker in tension than compression.

High levels of tensile strain cause stepped cracking in brickwork and masonry, cracking in plaster wall linings, pulled joints in plumbing and separation at joints in paving and roadways. High levels of compressive strain are characterised by crushing and spalling of faces in brickwork and masonry, closure of door and window openings, shear fractures, buckling of pipes, wall linings, floors, ceilings and external paving.

The transfer of ground strains into the structure occurs through friction on the underside of the foundations and ground pressure on the sides of the foundations. The transfer is thus dependent upon the configuration and type of foundation and its orientation to the subsidence trough.

The transfer of strain is also dependent upon the types of soil that are immediately below the foundation. Buildings founded on rock can, in some cases, experience a full transfer of strain whilst those founded on clay or sandy soils generally only attract a proportion of the ground strain. The transfer is a function of soil to foundation interaction and, in many cases, shearing of the soil layers reduces the transfer of strain.

Colwell and Thorne (1991), in their paper that referred to the monitoring of subsidence movements at a house above Longwall 3 at West Wallsend Colliery, indicated that the strains transferred into the walls of a brick veneer home were an order of magnitude less than those measured in the ground.

Horizontal tensile strains will affect all types of structure to the same degree once they have been cracked, since any increase in strain will tend to increase the width of the existing cracks rather than develop new ones.

E.2.6. Strain and Curvature Combinations

In practice, structural impact results from combinations of ground curvature and strain. The ground movements are generally three dimensional, adding the further complication of twisting in a structure. As subsidence occurs, the foundations settle and deform to match the subsided shape of the ground, the deformations being concentrated mainly at weak joints in the structure.

New cracks are generally formed where the shear or tensile strength of structural elements is exceeded. The cracking patterns depend upon the extent of the vertical displacements, the length to height ratio of the walls, the structural capacity of the building elements, and the shear strength and stiffness of the foundations.

In masonry and brickwork, the cracks generally follow the mortar joints either vertically or diagonally in steps. Bending and shear cracks can also occur due to curvature and strain along a wall. Once the cracks have formed, further ground deformations and extensions will be consumed in extending or expanding the cracks.

Where buildings are founded on sandy soils or clays and the ground strains are not fully transmitted into the structure, the level of impact is mostly dictated by curvature rather than horizontal strain.

Generally, the worst impacts will result from a combination of convex (hogging) curvature and tensile strain, rather than concave (sagging) curvature and compressive strain. The impact assessments, given in Chapter 6, have reviewed each combination, but are based upon the worst combination of the bending and horizontal tensile strains, which have been predicted to occur at each structure as the longwalls are mined. For each longwall panel, the travelling and transient strains at each structure have both been considered, and the maximum of these strains was used in the impact assessment for the structure.

E.3. Effect of Building Structure Type

The design and configuration of buildings and the materials of which they are built will determine the effects which mining subsidence will have upon them and the extent to which they will be affected. The bending strains resulting from ground curvature will affect different types of buildings in different ways.

A full masonry building of, for example, 15 metres in length, can tolerate a maximum differential foundation movement of 10 mm before damage occurs, whilst a timber framed building can tolerate a differential movement of 50 mm due to its greater flexibility.

A well designed building on foundations that allow for differential movement of the superstructure, constructed of flexible materials, with proper attention to the design of movement joints, will suffer less than a rigid brick structure on concrete strip foundations.

Buildings founded upon clay strata will not, normally, be subjected to the total horizontal ground strain. Buildings on piled foundations, on the other hand, would be affected to a greater extent due to lateral earth pressure on the piles and if the piles are rigidly connected to the building foundations this could result in a greater level of strain being applied to the building superstructure. Foundations built directly onto bedrock are more likely to transmit the total amount of ground strain into the building causing greater levels of impact.

Buildings that have raft foundations, built on a layer of sand and provided with a sliding membrane, often allow the ground to move without causing damage to the superstructure. Other buildings that are founded on stumps or short brick piers will generally allow the ground to move with only slight impact to the building above. These buildings also provide easy access for temporary and permanent adjustment of the piers and the structure.

The length of the building is also an important factor, since longer buildings will experience greater extension due to direct ground strain and bending strain, and the levels of impact will consequently be increased.

For many long structures, however, the maximum predicted strain will only apply over part of the length of the structure. In normal circumstances, therefore, the movements caused by mine subsidence will not be fully transmitted to the buildings and structures on the surface. However, a cautious approach is normally adopted and impact assessments are generally carried out assuming full transfer of displacements and strains from the ground into the structures. This approach was adopted in the present study.

E.4. Damage Thresholds on Building Structures

Much has been written on the subject of impact to buildings resulting from ground movements and the way in which different types of building, with different forms of construction, are likely to respond to applied curvatures and strains.

In 1974, Burland and Wroth prepared a thorough review of published papers to that date and recorded the findings of various researchers, which are summarised below. They presented the results to a conference of the British Geotechnical Society on the Settlement of Structures. Most of the literature referred to by the authors related to impact resulting from differential settlement or curvature rather than horizontally induced mining strains but it is nevertheless useful in establishing guidelines for determination of the effects of mine subsidence.

Burland and Wroth concluded that for brickwork and blockwork, in cement mortar, the critical tensile strain lay in the range 0.5 mm/m to 1.0 mm/m and for reinforced concrete in the range 0.3 mm/m to 0.5 mm/m. Below these levels, no cracking was apparent.

To place this in context with normal building movements, it is worth noting that strains likely to occur in clay brickwork, due to thermal expansion and contraction, can be of the order of 0.2 mm/m to 0.3 mm/m for a temperature differential of 30°C. Expansion of brickwork due to brick growth can also be of this order of magnitude.

The expansion and contraction of concrete structures, due to changes in temperature or moisture content, can be twice as high as for clay bricks. British Standards permit shrinkage strains of 0.3 mm/m to 0.9 mm/m in walls and panels.

Fig. 11 of the paper by Burland and Wroth compares the relative sag and hog for load-bearing walls and frame buildings, as determined by various researchers, and provides further guidance on the relationship between impact levels, deflection ratios and length to height ratios. The authors' view was that allowable deflection ratios for hogging structures should be less than for sagging structures.

The methods used to define the threshold levels for differential movement and strain varied from author to author and Burland and Wroth clarified the terminology, to enable direct comparisons to be made. Some statements concerning levels of impact were rather subjective and it was not easy to compare 'severe' by Littlejohn, with 'substantial' from Cheney and Burford and 'considerable' from Bjerrum. The relative values of strain provided some assistance in making comparisons.

It is clear that mining induced curvatures and strains will in some cases cause significant impact to building structures unless they are designed to accommodate these movements.

E.5. Allowable Deflection Ratios

Various authors in Australia have considered the effects of differential movement of buildings and many papers have been published which contain valuable data. This information has been incorporated in compiling Table E.1, which shows allowable deflection ratios for various types of building. The table has been extended to show the equivalent radii of curvature, for buildings of different length, at the allowable deflection ratios.

Bray and Branch (1988) provided a table showing allowable deflection ratios and limiting radii of curvature for different types of construction. Dr Lax Holla (1987b) also published a table of allowable deflection ratios, which was derived from a paper by Woodburn (1979), entitled Interaction of Soils, Footings and Structures.

Australian Standard, AS 2870 - 1996, provides guidance on the allowable deflection ratios for various types of structure, to be used in the design of foundations for domestic buildings and also gives tolerable levels of differential vertical movement in foundations.

Granger (1991) gives tolerable values of deflection ratio and maximum acceptable deflections for reinforced and articulated brick walls. The deflection ratio for brick veneer of 1:600 has been assumed to apply to normal face brickwork and the lower allowable deflection ratio of 1:800 has been adopted for rendered masonry, which is more susceptible to impact.

Where different authors have stated slightly different values, the lower ratio has been assumed in compiling Table E.1. Allowable deflection ratio, for a particular type of building, has been taken to mean the deflection ratio which would cause only slight impact if applied to a building of that type.

Not all structures, however, will be situated at the position of maximum curvature. The curvature and strain will vary considerably throughout the longwall area and the levels of impact on buildings and structures will be dependent upon their positions within the subsidence troughs.

E.6. Classification of Impact Levels to Walls

The 'National Coal Board Classification of Subsidence Damage' for building structures, was given in Table 8 of the *Subsidence Engineers Handbook*, which was published by the National Coal Board, in 1975. The scale of damage was classified by description and was related to specific changes in the lengths of building structures.

The National Coal Board classification would appear to have been in use in 1962, when it was referred to, in a slightly amended form, in a paper presented to the Institution of Structural Engineers by J.D. Geddes (1962). This descriptive classification of impact was adopted and extended by the Department of the Environment, of the U.K., in 1981, at which time the impact categories were linked to crack width, rather than to specific changes in the length of a structure. The classification, in this form, was shown in Table 8.5 of a book titled *Ground Movements and their Effect on Structures* (Geddes, 1984).

Table E.1 Allowable Deflection Ratios for Building Structures

Form of Construction		Allowable Deflection Ratio	Length in Metres			
			10	20	30	40
Loadbearing walls			**Acceptable Radius of Curvature in Kilometres**			
1	Solid masonry, rendered	1:4000	5.00	10.00	15.00	20.00
2	Solid masonry	1:3000	3.75	7.50	11.25	15.00
Non-loadbearing or lightly loaded walls			**Acceptable Radius of Curvature in Kilometres**			
3	Solid masonry, rendered	1:2000	2.50	5.00	7.50	10.00
4	Solid masonry	1:1500	1.87	3.75	5.62	7.50
5	Articulated masonry, rendered	1:800	1.00	2.00	3.00	4.00
6	Articulated masonry	1:600	0.75	1.50	2.25	3.00
7	Reinforced articulated masonry, rendered	1:600	0.75	1.50	2.25	3.00
8	Reinforced articulated masonry	1:400	0.50	1.00	1.50	2.00
9	Masonry veneer, rendered	1:800	1.00	2.00	3.00	4.00
10	Masonry veneer	1:600	0.75	1.50	2.25	3.00
11	Articulated masonry veneer, rendered	1:600	0.75	1.50	2.25	3.00
12	Articulated masonry veneer	1:500	0.62	1.25	1.87	2.50
13	Reinforced articulated masonry veneer, rendered	1:400	0.50	1.00	1.50	2.00
14	Reinforced articulated masonry veneer	1:300	0.38	0.75	1.12	1.50
15	Timber or steel clad in fibro or weatherboard	1:300	0.38	0.75	1.12	1.50
16	Steel or concrete frame with brick infill	1:1000	1.25	2.50	3.75	5.00
17	Steel or concrete frame without infill	1:500	0.62	1.25	1.87	2.50

The same classification has been incorporated, with some minor revisions to the wording, within Appendix C of Australian Standard, AS 2870 - 1996. Table C1 in the standard shows the classification of impact with reference to walls, related to crack width, and Table C2 gives a classification of impact with reference to concrete floors, related to both crack width and differential vertical movement.

The Australian Standard Classification, reproduced from Table C1, is presented in Table E.2 and has been used in this report as the basis for describing levels of impact to building structures, resulting from mine subsidence. The classification has, however, been extended to include a Category 5, which corresponds to the Very Severe Damage Category of the National Coal Board Classification and represents crack widths greater than 25 mm.

Table E.2 Classification of Impact with Reference to Walls

Impact Category	Description of typical impact to walls and required repair	Approximate crack width limit
0	Hairline cracks.	< 0.1 mm
1	Fine cracks which do not need repair.	0.1 mm to 1.0 mm
2	Cracks noticeable but easily filled. Doors and windows stick slightly.	1 mm to 5 mm
3	Cracks can be repaired and possibly a small amount of wall will need to be replaced. Doors and windows stick. Service pipes can fracture. Weather-tightness often impaired	5 mm to 15 mm, or a number of cracks 3 mm to 5 mm in one group
4	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Window or door frames distort. Walls lean or bulge noticeably. Some loss of bearing in beams. Service pipes disrupted.	15 mm to 25 mm but also depends on number of cracks
5	As above but worse, and requiring partial or complete rebuilding. Roof and floor beams lose bearing and need shoring up. Windows broken with distortion. If compressive damage, severe buckling and bulging of the roof and walls.	> 25 mm

E.7. Classification of Impact Levels due to Tilt

There is no standard method for classifying the level of impact caused by tilt. However, Australian Standard AS 2870 - 1996 indicates that local deviations in vertical or horizontal slope of more than 1 in 100, (10 mm/m), will normally be clearly visible and that slopes greater than 1 in 150 (approximately 7 mm/m) are undesirable.

However, it is recognised that structures are constructed to varying levels of accuracy. As reported by Burton (1995), research commissioned by the Mine Subsidence Board in 1991 indicated that a sample of 83 dwellings built at Woodrising in the preceding ten years in areas unaffected by mining, had a mean deviation from level of 2.39 mm/m, with a maximum deviation of 8.7 mm/m. The Mine Subsidence Board, in its *Annual Review* (1992), published further details of the research project. Fig. E.1 shows the distribution of measured tilts arising from this and other pre-mining surveys, and indicates that 21% of 156 houses had tilts of more than 4 mm. The maximum tilt measured at a building prior to mining was 15 mm/m, with nine cases being reported between 9 mm/m and 15 mm/m. The acceptable change in tilt, due to mining, will thus vary from case to case and will be dependent upon the tilts existing before mining occurs.

The Mine Subsidence Board has adopted the policy that tilts caused by mine subsidence, which affect serviceability, constitute impact that is to be compensated. When the tilts are between 4 mm/m and 7 mm/m, the Board recognises that the tilt, in some instances, could cause problems to roof drainage and wet area floors and, in those circumstances, would expect to carry out remedial works. It is also possible that some adjustment could be required to doors and windows.

Where the tilt is greater than 7 mm/m and the roof drainage, wet area floors or pools can not be correctly graded or levelled without major structural work, then the Board would consider jacking the building to level. If, in extreme cases, the tilt caused impact to a building structure that could not be repaired economically, the Board, depending on the merits of each case, may be prepared to demolish the structure and rebuild it, or negotiate with the owner to pay monetary compensation, or purchase the property.

There appears to be a consensus that final overall tilts in buildings which are less than 7 mm/m are tolerable and that tilts above 10 mm/m are undesirable. Overall tilts in buildings less than 5 mm/m would generally have negligible impact on building structures though this level of tilt could affect swimming pools and could possibly affect roof, floor or land drainage systems, where existing gradients are less than normal design requirements.

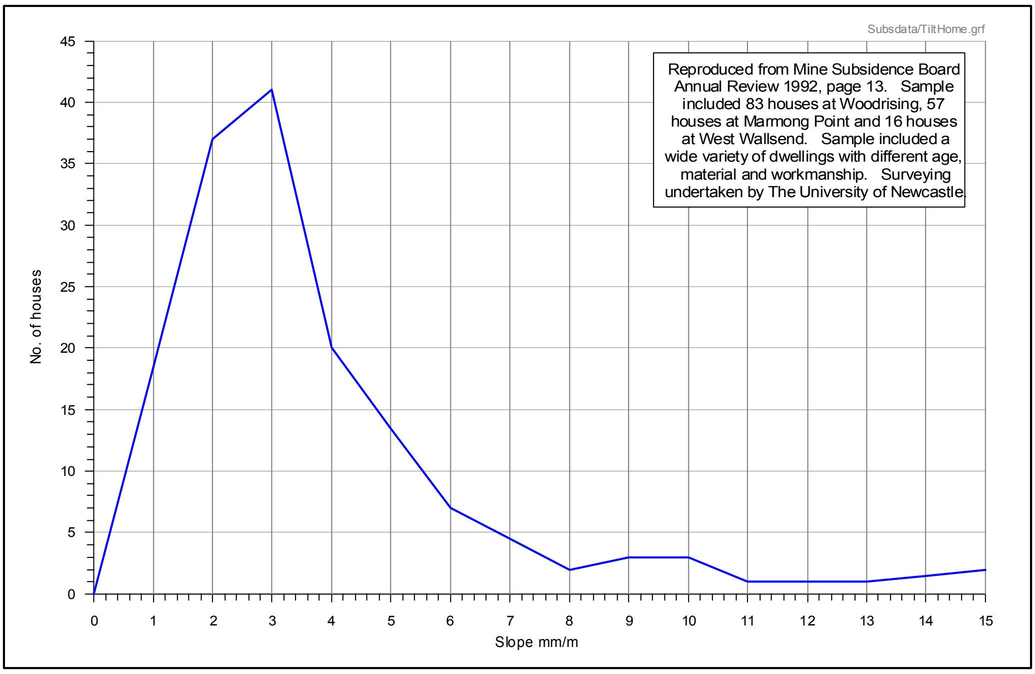


Fig. E.1 Tilts of Surveyed Dwellings located outside Mine Subsidence Areas

The impact classification shown in Table E.3, was developed by Waddington Kay & Associates. This has generally been accepted for a number of previous projects and Commissions of Inquiry. It is noted, however, that the Mine Subsidence Board consider jacking houses for Category C levels of tilt.

Table E.3 Classification of Impact with Reference to Tilt

Impact Category	Mining Induced Ground Tilt (mm/m)	Description
A	< 5	Unlikely that remedial work will be required.
B	5 to 7	Adjustment to roof drainage and wet area floors might be required.
C	7 to 10	Minor structural work might be required to rectify tilt. Adjustments to roof drainage and wet area floors will probably be required and remedial work to surface water drainage and sewerage systems might be necessary.
D	> 10	Considerable structural work might be required to rectify tilt. Jacking to level or rebuilding could be necessary in the worst cases. Remedial work to surface water drainage and sewerage systems might be necessary.

E.8. Classification of Impact due to Ground Strains

In 1975, the National Coal Board, in the *Subsidence Engineers Handbook*, published a graph showing the relationship between impact, horizontal ground strain and the length of a building structure. It was based upon empirical data obtained from studying the effects of subsidence along 165 observation lines at numerous collieries in the U.K.

It has been generally accepted as providing a reasonable basis for assessing the levels of impact that are likely to result from mining subsidence and has been adopted in other countries around the world. When used in Australia for the prediction of impact, it has been shown to provide reasonable agreement with observed impact levels (Holla, 1988 and 1995; Bray and Branch, 1988).

The graph is reproduced, in an extended form, in Fig. E.2 and illustrates the various impact categories, shown in Table E.2. These are separated by lines that represent specific extensions to the length of a structure. These extensions, which define the various categories of impact, were originally published in Table 8 of the *Subsidence Engineers Handbook* (NCB, 1975). It follows that the strain values referred to in Fig. E.2, should be seen as those occurring in the building structure. Normally these are taken to be the mining-induced horizontal ground strains. However, ground strains should be converted into structure strains by adding or subtracting the effect of mining-induced hogging or sagging curvature in the structure.

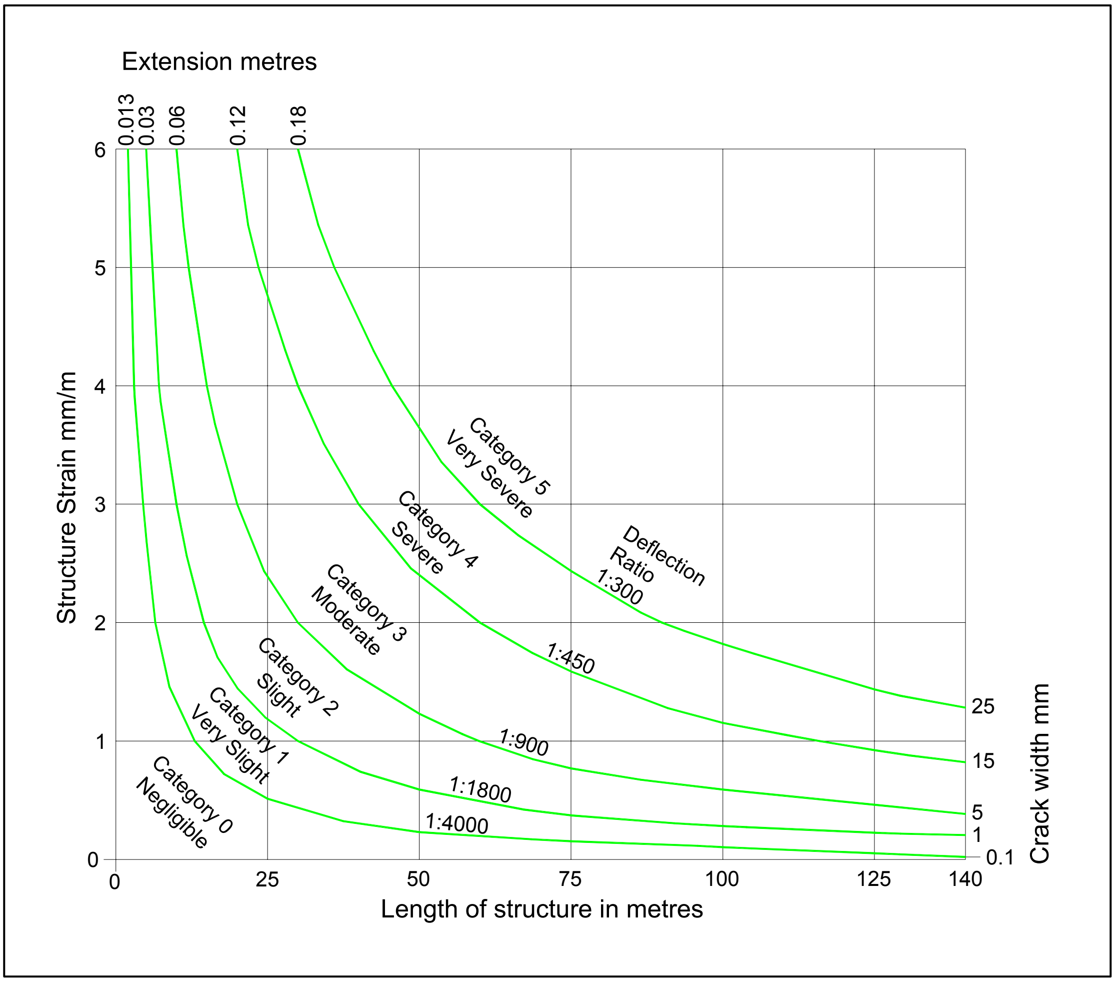


Fig. E.2 Impact Classification with Deflection Ratios for Two Storey Brick Structures

The impact categories shown in Fig. E.2 relate to typical two-storey brick or masonry building structures, which were the norm in mining areas in the U.K. Brick veneer homes and timber framed structures, with fibro or weatherboard cladding, which are commonly built in Australia, are not normally found in the mining areas of the U.K. The impact classifications are, therefore, somewhat conservative for these more typical Australian structures.

As previously discussed, the horizontal ground strains are associated with ground curvatures and both contribute to the strain which is experienced by a building structure. Often the horizontal strain is only partially transferred into the building and the curvature, which causes bending strain, provides the greater contribution to the total strain.

The bending strain in a building structure, resulting from hogging curvature of the ground, is dependent upon the height of the building, *H*, and the radius of curvature of the ground, *R*, and can be expressed simply as strain = *H/R*, as shown in Fig. E.3.

In this calculation, it is assumed that the curvature of the ground, at foundation level, is transferred into the structure by differential settlement of the foundations and that the structure bends to accommodate the curvature. It is assumed that hogging curvature will result in bending about the underside of the foundation. In practice, some shearing may take place in the structure and the calculated bending strain might not be fully developed.

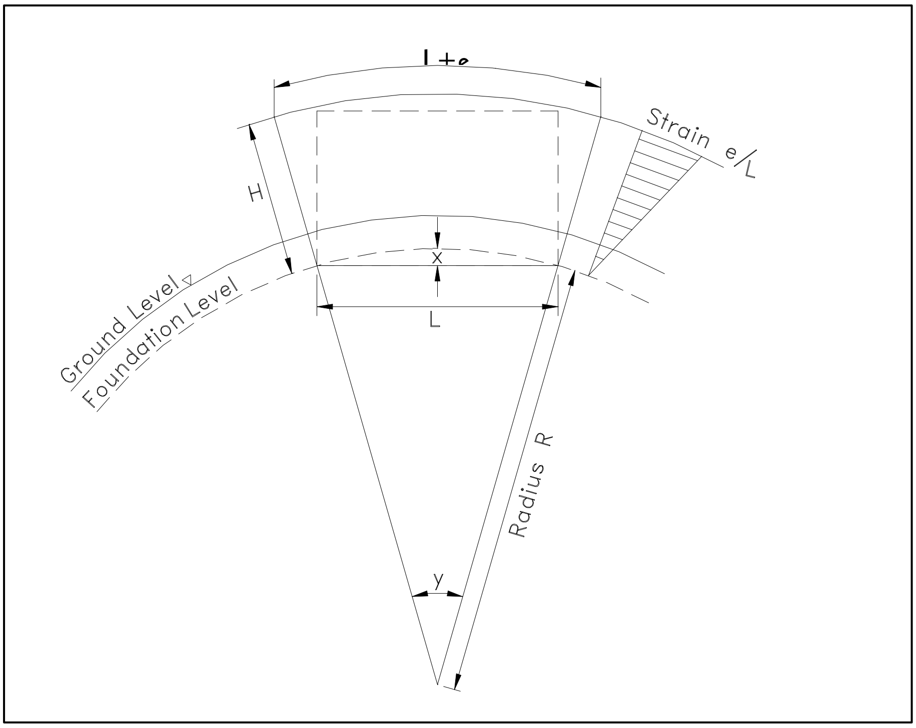
In the sagging mode, some resistance to bending will occur in the lower part of the wall. Normally slippage will occur at damp course level but, if no damp course exists, the foundations or ground slab will provide resistance. The effective neutral axis will therefore be in the lower part of the wall but its location will vary from structure to structure. In general, it seems reasonable to assume that walls, subjected to concave, or sagging, curvature, will bend about their centre line.

To determine the tensile strains in a building structure, the horizontal tensile ground strains have been added to the tensile bending strains, which are determined from a structure height measured from the underside of the foundation. To determine the compressive strains in a building structure, the compressive bending strains, determined from the mid-height of a structure, have been deducted from the horizontal compressive ground strains. This combined strain has then been used in predicting impact intensity from Fig. E.2.

In practice, much of the horizontal ground strain could be lost in the transfer. The impact assessments, provided in Chapter 6, are therefore cautious assessments that represent the worst possible scenario based upon the predicted subsidence parameters.

E.9. The Relationship between Impact Classification and Allowable Deflection Ratio

The elongation of a structure, due to curvature of the ground is directly related to the deflection ratio of a structure, as shown in Fig. E.3.



Note: Curvature exaggerated for clarity

Fig. E.3 Symbols used in the Analysis of Structures Bending by Hogging

From the geometry of a circle it can be shown that:

elongation of structure, e = deflection ratio × 8 H Equation 2

The relationship between the elongation of a structure, due to bending, and the deflection ratio is therefore dependent upon the height of the structure.

From the curve shown in Fig. E.2, a two-storey building with a height of 6.75 metres represents an extension of 0.03 metres for an impact category between 1 and 2. This can be related to a deflection ratio using the formula given above.

Hence, Deflection Ratio $= \frac{\text{elongation}}{8H} = \frac{0.03}{54} = \frac{1}{1800}$ Equation 3

Using the method above, the deflection ratios have been calculated for other values of extension and these have been shown in Fig. E.2. The calculations indicate that for two-storey brick structures, with a height of 6.75 metres, the upper limit of impact for Category 2 represents a deflection ratio of 1:900. Similarly, the upper limits of Impact Categories 3 and 4 are represented by deflection ratios of 1:450 and 1:300, respectively.

It is reasonable to assume that the level of impact at a deflection ratio of less than 1:4000 would be negligible for a two storey brick structure. A curve has been included in Fig. E.2, based upon this value of deflection ratio, in order to provide a division between Impact Categories 0 and 1.

E.10. Relationship between Impact Classification and Crack Width

The deflection ratios and maximum crack widths which separate each Impact Category, for two-storey brick structures of 6.75 metres height, are shown in Fig. E.2. Based upon these factors, Fig. E.4 has been produced, to show the relationship between the inverse of deflection ratio and the maximum crack width.

The impact categories given in Table E.2 are related to maximum crack widths and these have been shown for each of the categories in Fig. E.2. Impact Category 0 relates to a maximum crack width of less than 0.1 mm, which would not be visible, and hence represents negligible impact. Categories 1 to 4 relate to maximum crack widths of 1 mm, 5 mm, 15 mm and 25 mm respectively. Category 5 has been added to represent crack widths greater than 25 mm.

In a paper presented by P.F. Walsh (1991), a graph was published showing the relationship between crack widths and inverse deflection ratios for single storey, brick veneer houses, subject to reactive clay movements. The graph was reproduced from a paper which was published in 1981 by D.A. Cameron and P.F. Walsh, and is based upon actual deflections and crack widths.

This graph has been added to Fig. E.4 to show the comparison between the theoretical relationships and measured results and a very close agreement can be seen. The classification of impact with reference to both extension and crack width would, therefore, appear to have some scientific basis.

It can be seen from Table E.1, that all other types of building structure have an allowable deflection ratio greater than that of brick structures. A timber-framed building, for example, has an allowable deflection ratio of 1:300 compared with 1:2000 for lightly loaded rendered brickwork. Rendered brick veneer structures have an allowable ratio of 1:800.

The effect of bending strains on building structures is dependent upon their flexibility and their capacity to absorb curvature by shearing. The level of impact caused to a building, by curvature of the ground, therefore reduces as the allowable deflection ratio increases.

The use of the graphs in Fig. E.2 to predict the levels of impact to buildings of flexible construction would, therefore, be an over-cautious approach and would result in excessively conservative assessments. The management strategies have therefore been adjusted for sheds and other light structures to compensate for this conservatism.

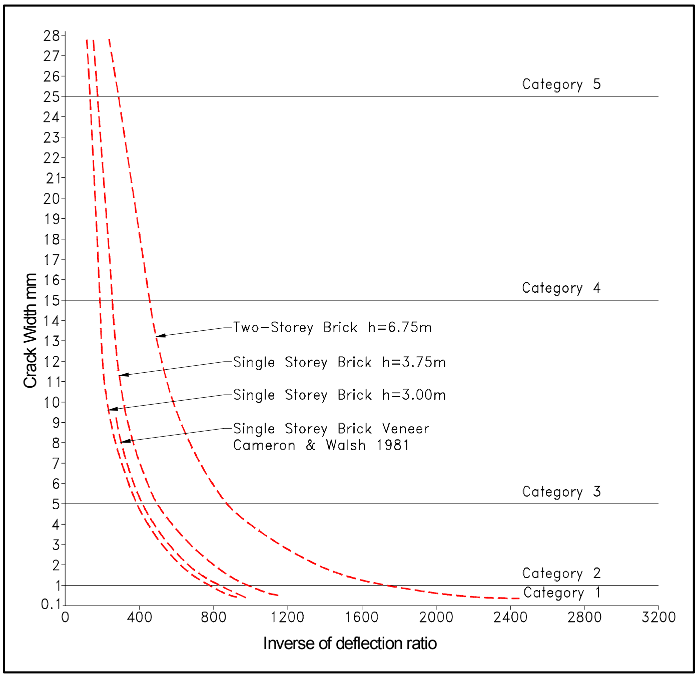


Fig. E.4 Variation of Crack Width with Deflection Ratio for Brick Structures

APPENDIX F. COMPARISONS BETWEEN OBSERVED AND BACK-PREDICTED SUBSIDENCE PROFILES FOR THE PREVIOUSLY EXTRACTED LONGWALLS

Comparison of Predicted and Observed Profiles along Sandy Creek Road Monitoring Line - LW2 to LW4

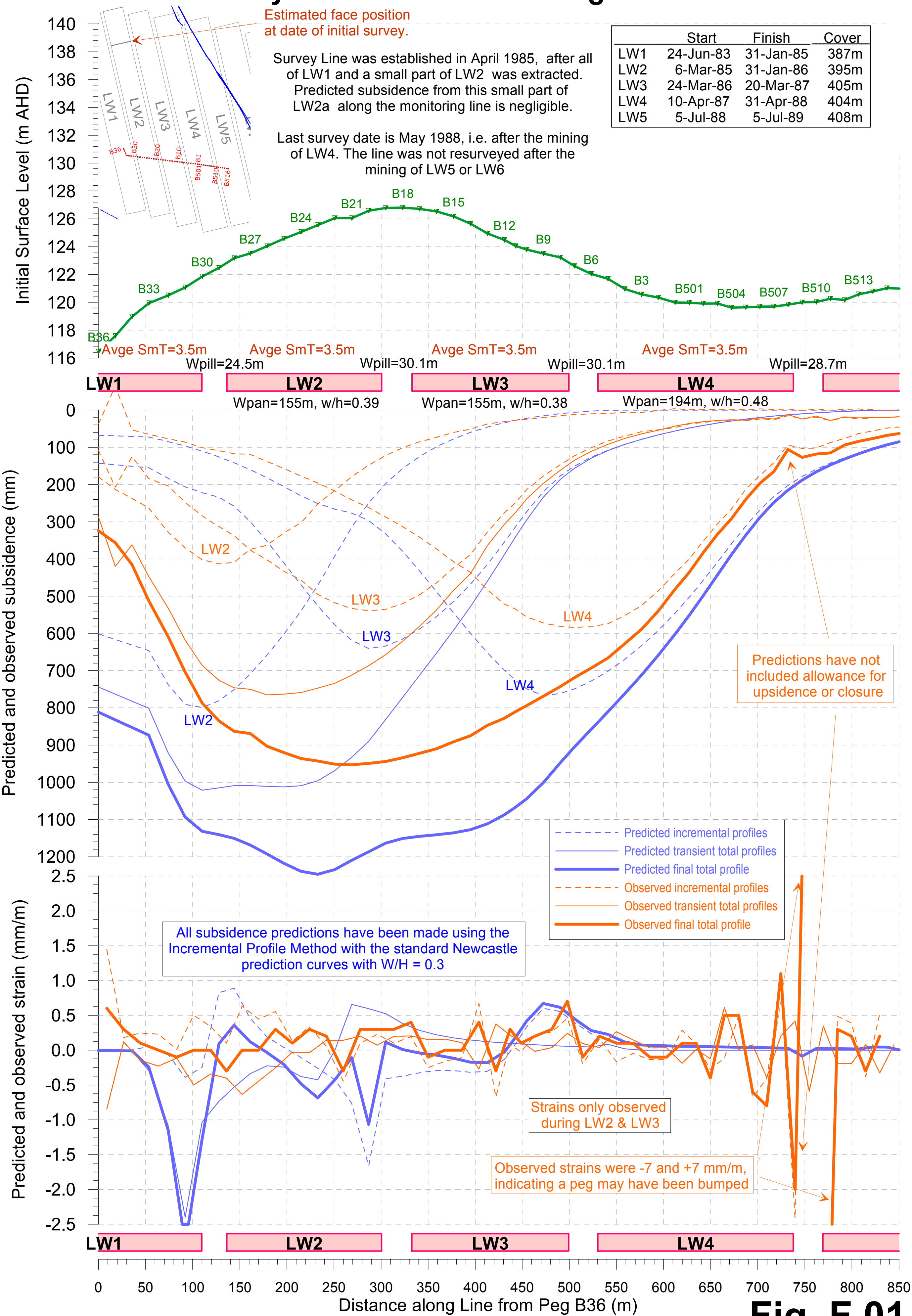


Fig. F.01

Comparison of Predicted and Observed Profiles along the Sandy Creek Road Monitoring Line - LW6 to LW9

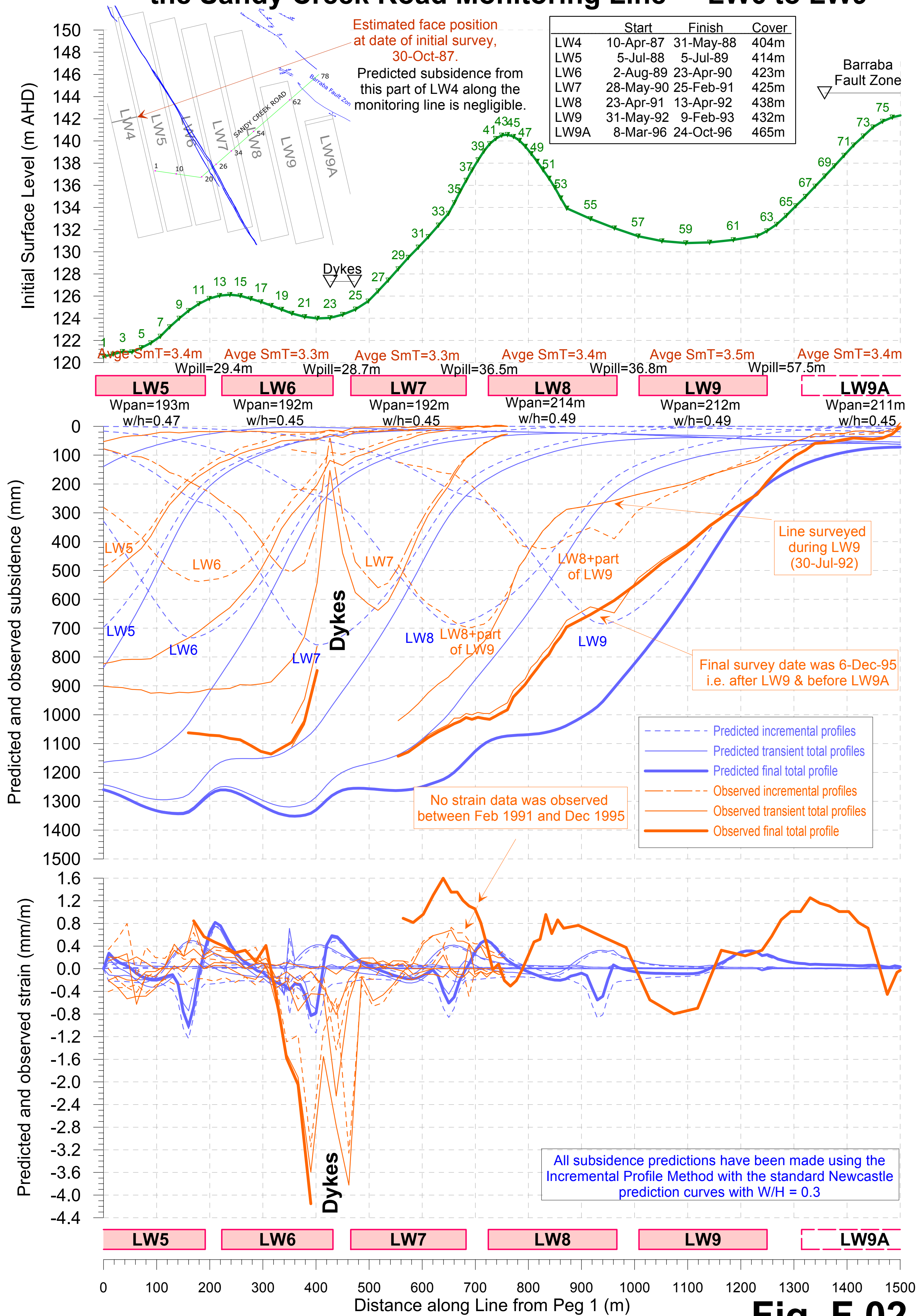
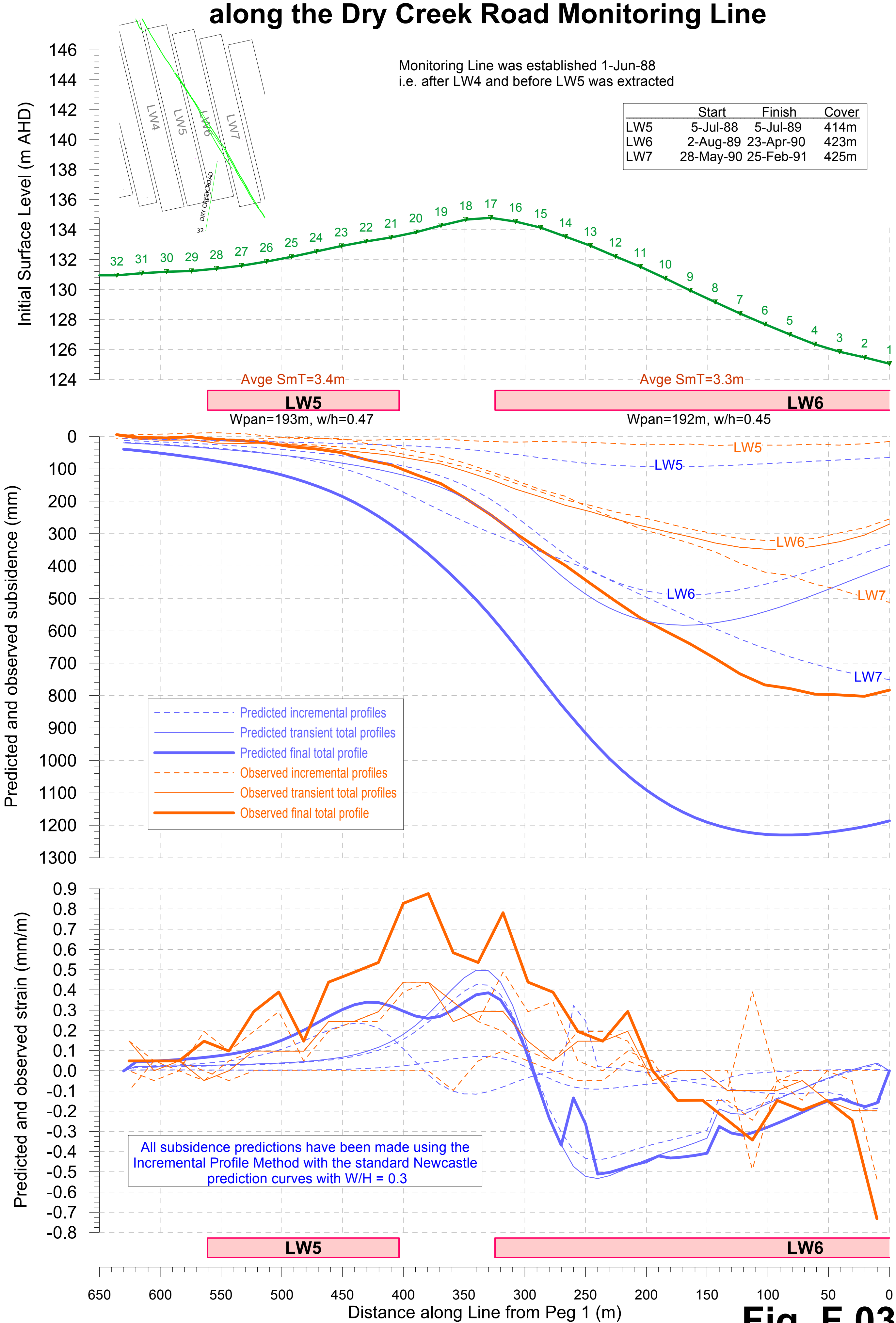


Fig. F.02

Comparison of Predicted and Observed Profiles along the Dry Creek Road Monitoring Line



	Start	Finish	Cover
LW5	5-Jul-88	5-Jul-89	414m
LW6	2-Aug-89	23-Apr-90	423m
LW7	28-May-90	25-Feb-91	425m

Fig. F.03

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Comparison of Predicted and Observed Profiles along Monitoring Line LW9A

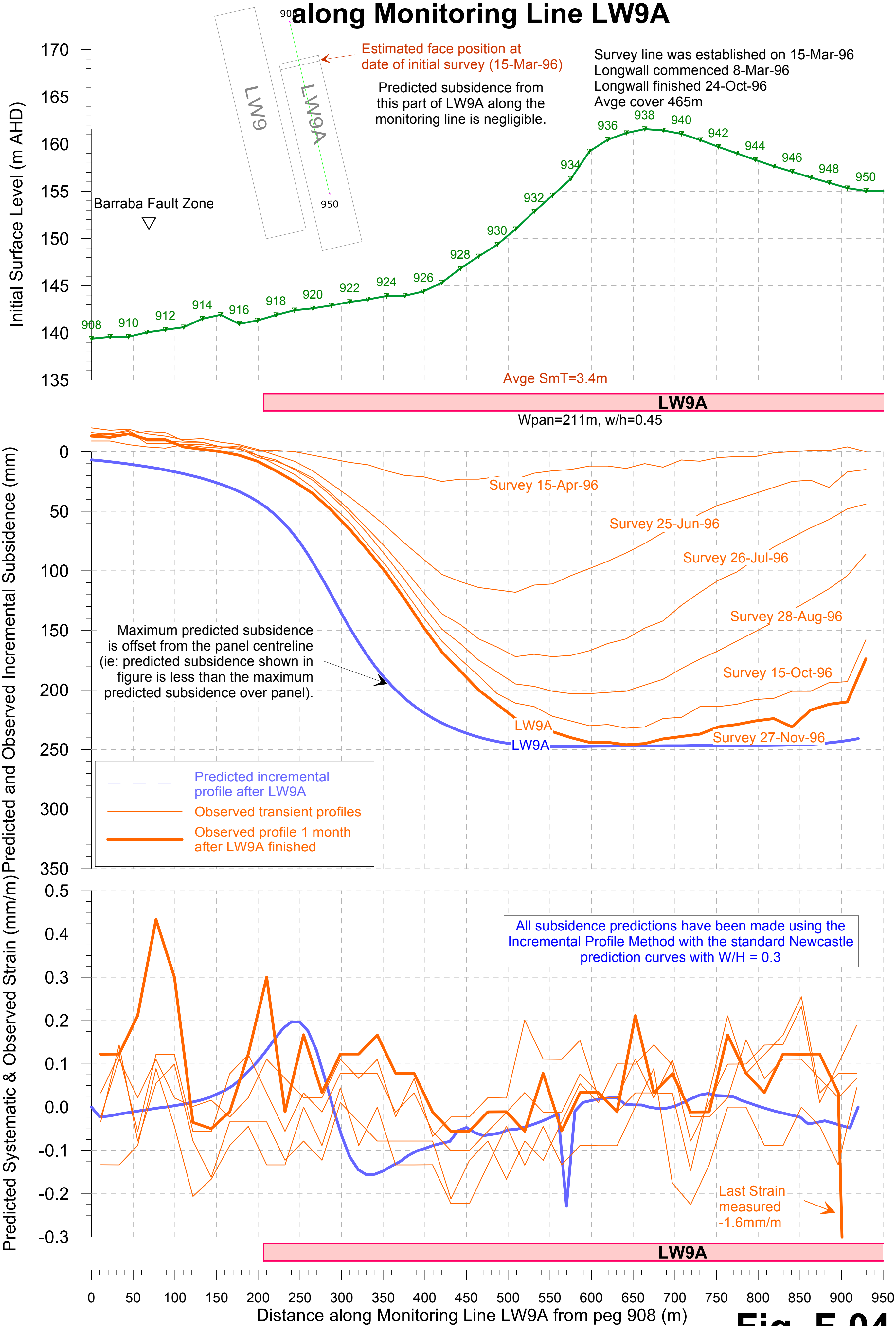


Fig. F.04

Comparison of Predicted and Observed Profiles across Monitoring Line LW10-12A

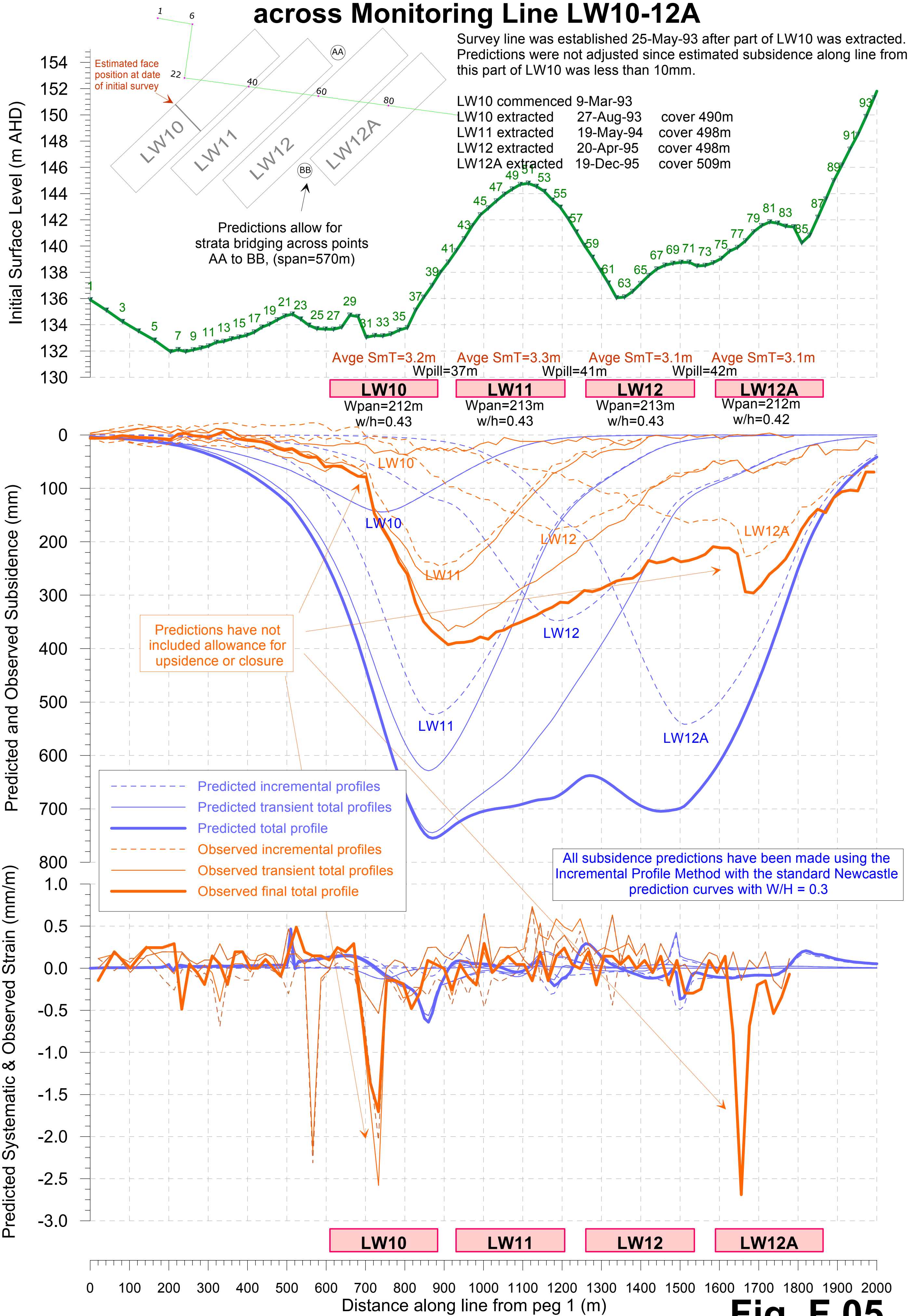


Fig. F.05

Comparison of Predicted and Observed Profiles along Monitoring Line LWSL1

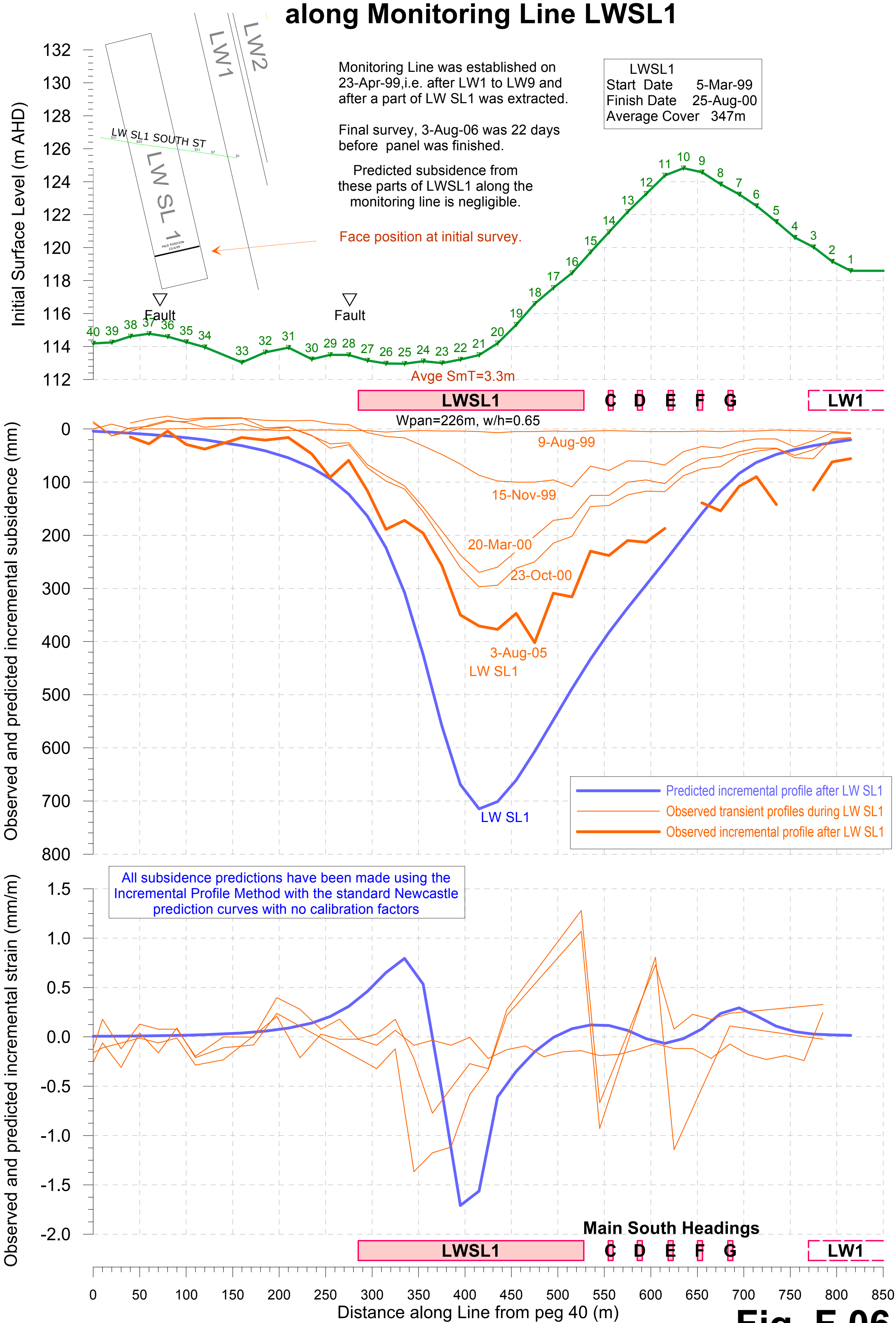


Fig. F.06

Comparison of Predicted and Observed Profiles along Monitoring Line LW13-Line2

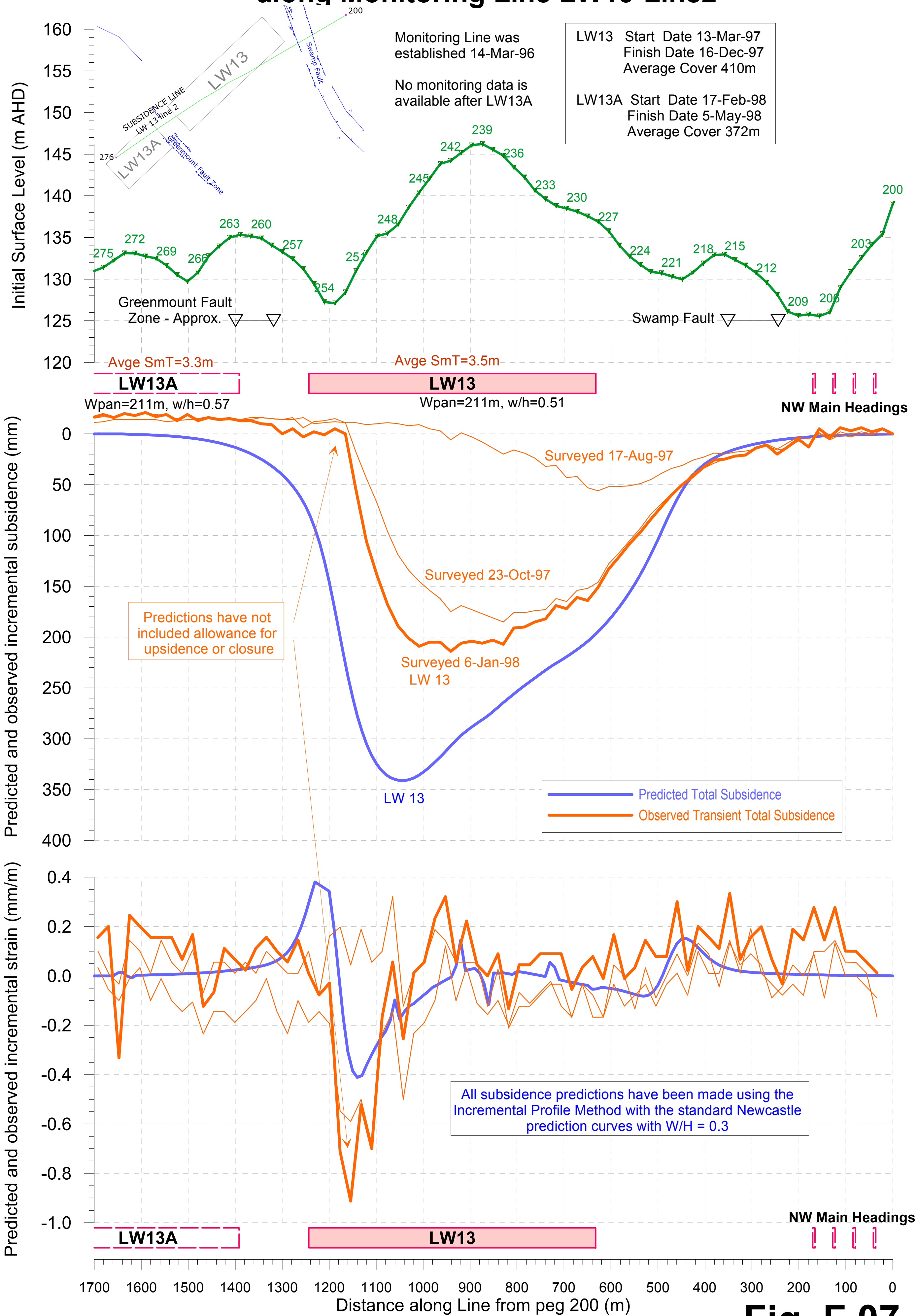


Fig. F.07

Comparison of Predicted and Observed Profiles along Monitoring Line LWSL2 - LWSL3

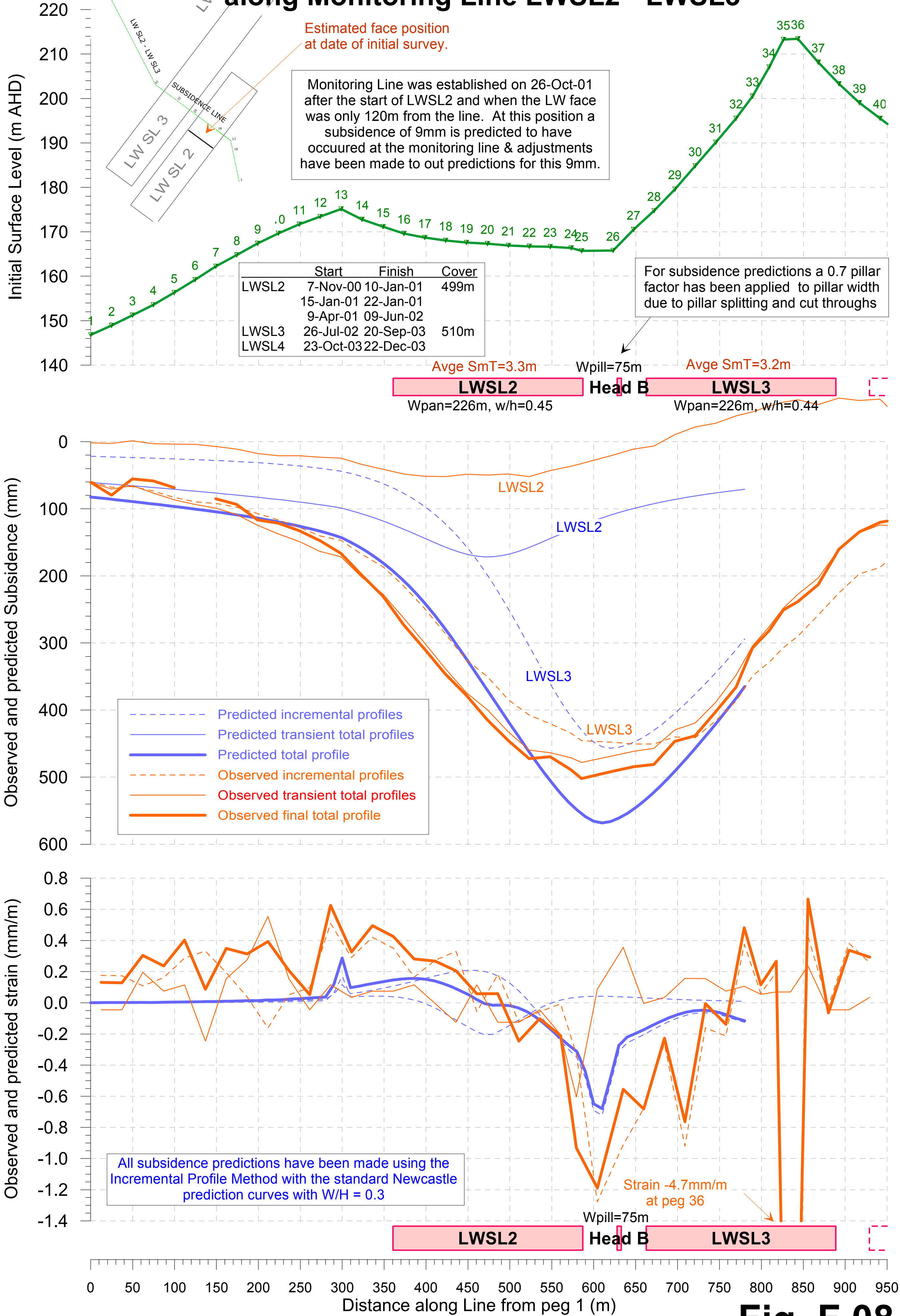
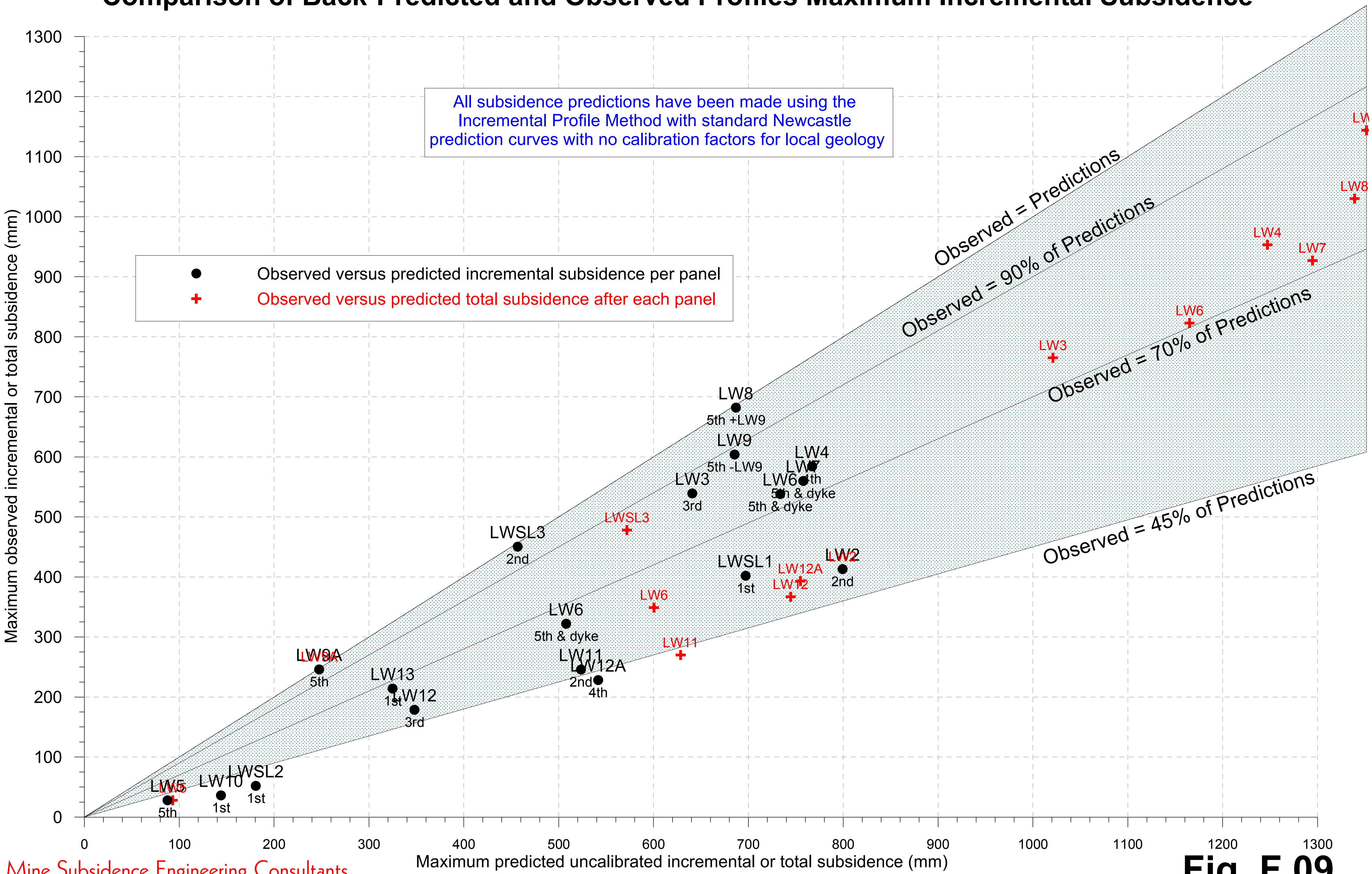


Fig. F.08

I:\Projects\Austar\Stage 2\MSEC275 - Longwalls A3 to A5\Subsdata\Monitoring\All Lines (12Oct06)\Plot of Smax Predicted and Observed (Dec06).grf.....15-Dec-06

Comparison of Back-Predicted and Observed Profiles Maximum Incremental Subsidence



Mine Subsidence Engineering Consultants

Fig. F.09

APPENDIX G. TABLES

Table G.01 - Austar Proposed Longwalls A3 to A5
Predicted Systematic Subsidence and Tilt and Strain Impact Assessments for Building Structures

Label	Easting	Northing	Type	Longest Side (m)	Height (m)	Total Predicted Subs after LWA3 (mm)	Total Predicted Subs after LWA3 and LWA4 (mm)	Total Predicted Subs after LWA3 to LWA5 (mm)	Total Predicted Tilt after LWA3 (mm/m)	Total Predicted Tilt after LWA3 and LWA4 (mm/m)	Total Predicted Tilt after LWA3 to LWA5 (mm/m)	Maximum Predicted Travelling Tilt LWA3 to LWA5 (mm/m)	Tilt Impact Assessment after LWA3	Tilt Impact Assessment after LWA3 and LWA4	Tilt Impact Assessment after LWA3 to LWA5	Impact Assessment Strain during or after LWA3 (mm/m)	Strain Impact Assessment for LWA3	Impact Assessment Strain during or after LWA3 and LWA4 (mm/m)	Strain Impact Assessment for LWA3 and LWA4	Impact Assessment Strain during or after LWA3 to LWA5 (mm/m)	Strain Impact Assessment for LWA3 to LWA5
A01a	345890.5	6356961.1	H2	37.0	3.75	3	35	456	0.0	0.5	2.8	1.8	Category A	Category A	Category A	0.1	Category 0	0.3	Category 0	-0.4	Category 1
A01b	345860.2	6356951.5	R	7.0	3.00	3	29	397	0.0	0.4	2.9	1.6	Category A	Category A	Category A	0.1	Category 0	0.2	Category 0	-0.4	Category 0
A01c	345926.3	6356955.2	R	15.0	3.00	2	24	376	0.0	0.3	2.8	1.7	Category A	Category A	Category A	0.1	Category 0	0.2	Category 0	0.5	Category 0
A01d	345921.3	6356939.7	R	14.0	3.00	2	20	335	0.0	0.3	2.7	1.6	Category A	Category A	Category A	0.1	Category 0	0.1	Category 0	0.5	Category 0
A01e	345934.3	6357020.5	R	12.0	3.00	5	44	537	0.1	0.5	3.1	2.1	Category A	Category A	Category A	0.1	Category 0	0.3	Category 0	-0.4	Category 0
A01f	345892.2	6356910.2	R	4.0	3.00	2	15	270	0.0	0.2	2.6	1.3	Category A	Category A	Category A	0.1	Category 0	0.1	Category 0	-0.3	Category 0
A01g	345935.3	6357056.7	R	9.0	3.00	6	58	621	0.1	0.6	3.1	2.2	Category A	Category A	Category A	0.1	Category 0	0.3	Category 0	-0.4	Category 0
A01p01	345869	6356953.5	P	13.2	-	3	30	409	0.0	0.4	2.9	1.6	-	-	-	-	-	-	-	-	-
A01i	345879.3	6356907.2	O	34.0	-	2	19	308	0.0	0.3	2.7	1.4	-	-	-	-	-	-	-	-	-
A01j	345912.9	6356372.8	R	5.0	3.00	0	0	1	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A01k	345902.6	6356374.1	R	5.0	3.00	0	0	1	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A02a	345512.6	6356852.9	H1	18.0	3.75	2	17	55	0.0	0.2	0.4	0.2	Category A	Category A	Category A	0.1	Category 0	0.1	Category 0	0.3	Category 0
A02b	345512.2	6356828.7	R	6.0	3.00	1	12	45	0.0	0.1	0.4	0.2	Category A	Category A	Category A	0.1	Category 0	0.1	Category 0	0.2	Category 0
A02c	345425.6	6356534.2	H1	16.0	3.75	0	0	2	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A02d	345451.6	6356537.7	R	23.0	3.00	0	0	3	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A02e	345406.5	6356556.1	R	14.0	3.00	0	0	3	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A02f	345424.4	6356524.8	R	11.0	3.00	0	0	2	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A03a	346314.9	6357825.7	H1	17.0	3.75	41	256	328	0.4	3.0	3.3	2.9	Category A	Category A	Category A	0.3	Category 0	0.6	Category 0	0.6	Category 0
A03b	346286.2	6357822.5	R	12.0	3.00	49	338	418	0.4	3.5	3.8	3.4	Category A	Category A	Category A	0.3	Category 0	0.7	Category 0	0.7	Category 0
A03c	346274.1	6357856	R	8.0	3.00	62	374	440	0.5	3.6	3.9	3.5	Category A	Category A	Category A	0.3	Category 0	0.5	Category 0	0.5	Category 0
A03d	346262.1	6357860.4	R	12.0	3.00	70	423	489	0.6	3.7	4.0	3.6	Category A	Category A	Category A	0.3	Category 0	0.4	Category 0	0.5	Category 0
A03e	346284	6357814.7	R	4.0	3.00	45	326	409	0.4	3.5	3.7	3.3	Category A	Category A	Category A	0.3	Category 0	0.7	Category 0	0.7	Category 0
A04a	345850.7	6357583.1	H2	44.0	3.75	190	1056	1355	0.8	2.6	3.2	2.8	Category A	Category A	Category A	-0.3	Category 0	-1.6	Category 3	-1.8	Category 3
A04b	345867.3	6357638.7	R	14.0	3.00	201	1080	1367	0.9	2.3	3.6	3.0	Category A	Category A	Category A	-0.3	Category 0	-1.7	Category 1	-1.9	Category 1
A04c	345697.6	6357578.7	R	8.0	3.00	244	829	1012	0.7	4.0	5.0	4.5	Category A	Category A	Category A	-0.5	Category 0	-0.5	Category 0	-0.5	Category 0
A04d	346030.2	6357385.3	R	13.0	3.00	26	266	1150	0.2	2.7	2.9	3.4	Category A	Category A	Category A	0.2	Category 0	0.7	Category 0	-1.0	Category 1
A05a	346748.6	6357778.7	H2	35.0	3.75	0	1	4	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A05b	346738.5	6357761.9	R	17.0	3.00	0	1	4	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A05c	346782	6357786.4	R	9.0	3.00	0	1	2	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A05d	346673.5	6357777.9	R	12.0	3.00	1	3	8	0.0	0.1	0.1	0.1	Category A	Category A	Category A	0.1	Category 0	0.1	Category 0	0.1	Category 0
A06a	345673.6	6356646.7	H1	16.0	3.75	0	2	16	0.0	0.0	0.2	0.1	Category A	Category A	Category A	0.1	Category 0	0.1	Category 0	0.1	Category 0
A06b	345610.9	6356646.1	R	5.0	3.00	0	2	14	0.0	0.0	0.1	0.1	-	-	-	-	-	-	-	-	-
A06c	345601	6356644.8	R	8.0	3.00	0	2	13	0.0	0.0	0.1	0.1	-	-	-	-	-	-	-	-	-
A06d	345589.1	6356644.3	R	9.0	3.00	0	2	13	0.0	0.0	0.1	0.1	-	-	-	-	-	-	-	-	-
A07a	345395.1	6357959.4	H1	19.0	3.75	16	16	21	0.1	0.1	0.2	0.2	-	-	-	-	-	-	-	-	-
A07b	345381.5	6357954	R	7.0	3.00	14	14	18	0.1	0.1	0.2	0.2	-	-	-	-	-	-	-	-	-
A07c	345328.5	6357882.5	R	7.0	3.00	14	14	18	0.1	0.1	0.2	0.2	-	-	-	-	-	-	-	-	-
A09a	347041.2	6357598.4	H2	33.0	3.75	0	0	0	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A09b	347021.9	6357639.5	R	37.0	3.00	0	0	0	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A10a	346728.3	6356837.8	R	12.0	3.00	0	0	0	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A11a	346012.3	6358161.4	H2	39.0	3.75	248	343	353	1.0	2.2	2.3	2.2	Category A	Category A	Category A	-0.3	Category 0	0.4	Category 1	0.4	Category 1
A11b	346028.6	6358180.9	R	13.0	3.00	234	304	311	1.0	1.8	1.9	1.8	Category A	Category A	Category A	-0.3	Category 0	0.3	Category 0	0.3	Category 0
A11c	346101.7	6358076.9	H1	19.0	3.75	279	489	504	1.0	2.9	3.0	2.8	Category A	Category A	Category A	-0.5	Category 0	0.8	Category 1	0.8	Category 1
A11p01	346025.8	6358168.1	P	7.5	2.00	240	317	325	1.0	1.9	2.0	1.9	-	-	-	-0.3	-	0.3	-	0.4	-

Table G.02 - Austar Proposed Longwalls A3 to A5
Upperbound Systematic Subsidence and Upperbound Tilt and Strain Impact Assessments for Building Structures

Label	Easting	Northing	Type	Longest Side (m)	Height (m)	Upperbound Subs after LWA3 (mm)	Upperbound Subs after LWA3 and LWA4 (mm)	Upperbound Subs after LWA3 to LWA5 (mm)	Upperbound Tilt after LWA3 (mm/m)	Upperbound Tilt after LWA3 and LWA4 (mm/m)	Upperbound Tilt after LWA3 to LWA5 (mm/m)	Upperbound Travelling Tilt LWA3 to LWA5 (mm/m)	Upperbound Tilt Impact Assessment after LWA3	Upperbound Tilt Impact Assessment after LWA3 and LWA4	Upperbound Tilt Impact Assessment after LWA3 to LWA5	Upperbound Assessment Strain during or after LWA3 (mm/m)	Upperbound Impact Assessment for LWA3	Upperbound Assessment Strain during or after LWA3 and LWA4 (mm/m)	Upperbound Impact Assessment for LWA3 and LWA4	Upperbound Assessment Strain during or after LWA3 to LWA5 (mm/m)	Upperbound Impact Assessment for LWA3 to LWA5
A01a	345890.5	6356961.1	H2	37.0	3.75	8	79	948	0.1	1.0	5.7	1.0	Category A	Category A	Category B	0.2	Category 0	0.3	Category 0	-0.6	Category 1
A01b	345860.2	6356951.5	R	7.0	3.00	7	66	831	0.1	0.9	6.0	0.9	Category A	Category A	Category B	0.2	Category 0	0.3	Category 0	-0.6	Category 0
A01c	345926.3	6356955.2	R	15.0	3.00	6	54	785	0.1	0.7	5.8	0.7	Category A	Category A	Category B	0.2	Category 0	0.3	Category 0	0.7	Category 0
A01d	345921.3	6356939.7	R	14.0	3.00	5	45	703	0.1	0.6	5.5	0.6	Category A	Category A	Category B	0.2	Category 0	0.3	Category 0	0.7	Category 0
A01e	345934.3	6357020.5	R	12.0	3.00	11	100	1113	0.1	1.1	6.3	1.1	Category A	Category A	Category B	0.2	Category 0	0.4	Category 0	-0.5	Category 0
A01f	345892.2	6356910.2	R	4.0	3.00	4	34	571	0.1	0.5	5.3	0.5	Category A	Category A	Category B	0.2	Category 0	0.3	Category 0	-0.5	Category 0
A01g	345935.3	6357056.7	R	9.0	3.00	15	131	1282	0.2	1.4	6.3	1.4	Category A	Category A	Category B	0.2	Category 0	0.4	Category 0	-0.5	Category 0
A01p01	345869	6356953.5	P	13.2	-	7	68	856	0.1	0.9	5.9	0.9	-	-	-	-	-	-	-	-	-
A01i	345879.3	6356907.2	O	34.0	-	5	42	648	0.1	0.6	5.6	0.6	-	-	-	-	-	-	-	-	-
A01j	345912.9	6356372.8	R	5.0	3.00	0	0	2	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A01k	345902.6	6356374.1	R	5.0	3.00	0	0	2	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A02a	345512.6	6356852.9	H1	18.0	3.75	5	35	116	0.0	0.3	0.9	0.3	Category A	Category A	Category A	0.2	Category 0	0.2	Category 0	0.3	Category 0
A02b	345512.2	6356828.7	R	6.0	3.00	3	26	93	0.0	0.3	0.8	0.3	Category A	Category A	Category A	0.2	Category 0	0.2	Category 0	0.3	Category 0
A02c	345425.6	6356534.2	H1	16.0	3.75	0	0	5	0.0	0.0	0.1	0.0	-	-	-	-	-	-	-	-	-
A02d	345451.6	6356537.7	R	23.0	3.00	0	1	6	0.0	0.0	0.1	0.0	-	-	-	-	-	-	-	-	-
A02e	345406.5	6356556.1	R	14.0	3.00	0	1	6	0.0	0.0	0.1	0.0	-	-	-	-	-	-	-	-	-
A02f	345424.4	6356524.8	R	11.0	3.00	0	0	4	0.0	0.0	0.1	0.0	-	-	-	-	-	-	-	-	-
A03a	346314.9	6357825.7	H1	17.0	3.75	103	574	727	0.9	6.3	7.0	6.3	Category A	Category B	Category C	0.3	Category 0	1.1	Category 1	1.1	Category 1
A03b	346286.2	6357822.5	R	12.0	3.00	121	742	916	1.0	7.2	7.8	7.2	Category A	Category C	Category C	0.3	Category 0	1.1	Category 1	1.1	Category 1
A03c	346274.1	6357856	R	8.0	3.00	153	819	962	1.2	7.4	8.0	7.4	Category A	Category C	Category C	0.3	Category 0	0.7	Category 0	0.7	Category 0
A03d	346262.1	6357860.4	R	12.0	3.00	171	921	1065	1.4	7.6	8.2	7.6	Category A	Category C	Category C	0.3	Category 0	-0.7	Category 0	0.7	Category 0
A03e	346284	6357814.7	R	4.0	3.00	114	718	896	1.0	7.1	7.7	7.1	Category A	Category C	Category C	0.3	Category 0	1.1	Category 0	1.1	Category 0
A04a	345850.7	6357583.1	H2	44.0	3.75	417	2178	2809	1.7	5.4	4.9	5.4	Category A	Category B	Category A	0.2	Category 0	-2.8	Category 4	-3.3	Category 4
A04b	345867.3	6357638.7	R	14.0	3.00	441	2241	2848	1.8	3.8	5.9	3.8	Category A	Category A	Category B	0.2	Category 0	-2.9	Category 2	-3.5	Category 2
A04c	345697.6	6357578.7	R	8.0	3.00	519	1806	2233	1.3	8.2	10.3	8.2	Category A	Category C	Category D	-0.8	Category 0	-0.9	Category 0	-0.9	Category 0
A04d	346030.2	6357385.3	R	13.0	3.00	64	574	2391	0.6	5.5	6.2	5.5	Category A	Category B	Category B	0.3	Category 0	1.1	Category 1	-1.6	Category 1
A05a	346748.6	6357778.7	H2	35.0	3.75	2	4	9	0.0	0.1	0.1	0.1	-	-	-	-	-	-	-	-	-
A05b	346738.5	6357761.9	R	17.0	3.00	1	4	9	0.0	0.1	0.1	0.1	-	-	-	-	-	-	-	-	-
A05c	346782	6357786.4	R	9.0	3.00	1	2	5	0.0	0.0	0.1	0.0	-	-	-	-	-	-	-	-	-
A05d	346673.5	6357777.9	R	12.0	3.00	4	9	20	0.0	0.1	0.2	0.1	Category A	Category A	Category A	0.1	Category 0	0.1	Category 0	0.1	Category 0
A06a	345673.6	6356646.7	H1	16.0	3.75	1	4	34	0.0	0.0	0.3	0.0	Category A	Category A	Category A	0.2	Category 0	0.2	Category 0	0.2	Category 0
A06b	345610.9	6356646.1	R	5.0	3.00	0	3	29	0.0	0.0	0.3	0.0	-	-	-	-	-	-	-	-	-
A06c	345601	6356644.8	R	8.0	3.00	0	3	28	0.0	0.0	0.3	0.0	-	-	-	-	-	-	-	-	-
A06d	345589.1	6356644.3	R	9.0	3.00	0	3	27	0.0	0.0	0.3	0.0	-	-	-	-	-	-	-	-	-
A07a	345395.1	6357959.4	H1	19.0	3.75	40	40	55	0.4	0.4	0.5	0.4	-	-	-	-	-	-	-	-	-
A07b	345381.5	6357954	R	7.0	3.00	35	35	48	0.3	0.3	0.5	0.3	-	-	-	-	-	-	-	-	-
A07c	345328.5	6357882.5	R	7.0	3.00	35	35	47	0.3	0.3	0.4	0.3	-	-	-	-	-	-	-	-	-
A09a	347041.2	6357598.4	H2	33.0	3.75	0	0	1	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A09b	347021.9	6357639.5	R	37.0	3.00	0	0	1	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A10a	346728.3	6356837.8	R	12.0	3.00	0	0	0	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-
A11a	346012.3	6358161.4	H2	39.0	3.75	547	775	799	2.0	5.0	5.2	5.0	Category A	Category A	Category B	-0.3	Category 1	0.7	Category 1	0.8	Category 2
A11b	346028.6	6358180.9	R	13.0	3.00	518	685	703	2.0	4.0	4.1	4.0	Category A	Category A	Category A	-0.3	Category 0	0.5	Category 0	0.5	Category 0
A11c	346101.7	6358076.9	H1	19.0	3.75	607	1095	1127	2.0	6.5	6.7	6.5	Category A	Category B	Category B	-0.8	Category 1	1.5	Category 1	1.5	Category 1
A11p01	346025.8	6358168.1	P	7.5	2.00	530	715	734	2.0	4.3	4.4	4.3	-	-	-	-0.3	-	0.6	-	0.6	-

Table G.03 - Austar Proposed Longwalls A3 to A5

Tilt and Strain Impact Assessments for Increased Predictions for Building Structures

Label	Easting	Northing	Type	Longest Side (m)	Height (m)	Tilt Impact Assessment after LWA3 to LWA5 with Increased Prediction x1.25	Tilt Impact Assessment after LWA3 to LWA5 with Increased Prediction x1.5	Tilt Impact Assessment after LWA3 to LWA5 with Increased Prediction x1.75	Tilt Impact Assessment after LWA3 to LWA5 with Increased Prediction x2.0	Strain Impact Assessment for LWA3 to LWA5 with Increased Prediction x1.25	Strain Impact Assessment for LWA3 to LWA5 with Increased Prediction x1.5	Strain Impact Assessment for LWA3 to LWA5 with Increased Prediction x1.75	Strain Impact Assessment for LWA3 to LWA5 with Increased Prediction x2.0
A01a	345890.5	6356961.1	H2	37.0	3.75	Category A	Category A	Category A	Category B	Category 1	Category 1	Category 1	Category 2
A01b	345860.2	6356951.5	R	7.0	3.00	Category A	Category A	Category B	Category B	Category 0	Category 0	Category 0	Category 0
A01c	345926.3	6356955.2	R	15.0	3.00	Category A	Category A	Category A	Category B	Category 0	Category 0	Category 0	Category 1
A01d	345921.3	6356939.7	R	14.0	3.00	Category A	Category A	Category A	Category B	Category 0	Category 0	Category 0	Category 0
A01e	345934.3	6357020.5	R	12.0	3.00	Category A	Category A	Category B	Category B	Category 0	Category 0	Category 0	Category 0
A01f	345892.2	6356910.2	R	4.0	3.00	Category A	Category A	Category A	Category B	Category 0	Category 0	Category 0	Category 0
A01g	345935.3	6357056.7	R	9.0	3.00	Category A	Category A	Category B	Category B	Category 0	Category 0	Category 0	Category 0
A01p01	345869	6356953.5	P	13.2	-	-	-	-	-	-	-	-	-
A01i	345879.3	6356907.2	O	34.0	-	-	-	-	-	-	-	-	-
A01j	345912.9	6356372.8	R	5.0	3.00	-	-	-	-	-	-	-	-
A01k	345902.6	6356374.1	R	5.0	3.00	-	-	-	-	-	-	-	-
A02a	345512.6	6356852.9	H1	18.0	3.75	Category A	Category A	Category A	Category A	Category 0	Category 0	Category 0	Category 0
A02b	345512.2	6356828.7	R	6.0	3.00	Category A	Category A	Category A	Category A	Category 0	Category 0	Category 0	Category 0
A02c	345425.6	6356534.2	H1	16.0	3.75	-	-	-	-	-	-	-	-
A02d	345451.6	6356537.7	R	23.0	3.00	-	-	-	-	-	-	-	-
A02e	345406.5	6356556.1	R	14.0	3.00	-	-	-	-	-	-	-	-
A02f	345424.4	6356524.8	R	11.0	3.00	-	-	-	-	-	-	-	-
A03a	346314.9	6357825.7	H1	17.0	3.75	Category A	Category A	Category B	Category B	Category 1	Category 1	Category 1	Category 1
A03b	346286.2	6357822.5	R	12.0	3.00	Category A	Category B	Category B	Category C	Category 0	Category 0	Category 1	Category 1
A03c	346274.1	6357856	R	8.0	3.00	Category A	Category B	Category B	Category C	Category 0	Category 0	Category 0	Category 0
A03d	346262.1	6357860.4	R	12.0	3.00	Category A	Category B	Category B	Category C	Category 0	Category 0	Category 0	Category 0
A03e	346284	6357814.7	R	4.0	3.00	Category A	Category B	Category B	Category C	Category 0	Category 0	Category 0	Category 0
A04a	345850.7	6357583.1	H2	44.0	3.75	Category A	Category A	Category B	Category B	Category 3	Category 3	Category 4	Category 4
A04b	345867.3	6357638.7	R	14.0	3.00	Category A	Category B	Category B	Category C	Category 2	Category 2	Category 2	Category 2
A04c	345697.6	6357578.7	R	8.0	3.00	Category B	Category C	Category C	Category C	Category 0	Category 0	Category 0	Category 0
A04d	346030.2	6357385.3	R	13.0	3.00	Category A	Category A	Category B	Category B	Category 1	Category 1	Category 1	Category 1
A05a	346748.6	6357778.7	H2	35.0	3.75	-	-	-	-	-	-	-	-
A05b	346738.5	6357761.9	R	17.0	3.00	-	-	-	-	-	-	-	-
A05c	346782	6357786.4	R	9.0	3.00	-	-	-	-	-	-	-	-
A05d	346673.5	6357777.9	R	12.0	3.00	Category A	Category A	Category A	Category A	Category 0	Category 0	Category 0	Category 0
A06a	345673.6	6356646.7	H1	16.0	3.75	Category A	Category A	Category A	Category A	Category 0	Category 0	Category 0	Category 0
A06b	345610.9	6356646.1	R	5.0	3.00	-	-	-	-	-	-	-	-
A06c	345601	6356644.8	R	8.0	3.00	-	-	-	-	-	-	-	-
A06d	345589.1	6356644.3	R	9.0	3.00	-	-	-	-	-	-	-	-
A07a	345395.1	6357959.4	H1	19.0	3.75	-	-	-	-	-	-	-	-
A07b	345381.5	6357954	R	7.0	3.00	-	-	-	-	-	-	-	-
A07c	345328.5	6357882.5	R	7.0	3.00	-	-	-	-	-	-	-	-
A09a	347041.2	6357598.4	H2	33.0	3.75	-	-	-	-	-	-	-	-
A09b	347021.9	6357639.5	R	37.0	3.00	-	-	-	-	-	-	-	-
A10a	346728.3	6356837.8	R	12.0	3.00	-	-	-	-	-	-	-	-
A11a	346012.3	6358161.4	H2	39.0	3.75	Category A	Category A	Category A	Category A	Category 1	Category 1	Category 1	Category 2
A11b	346028.6	6358180.9	R	13.0	3.00	Category A	Category A	Category A	Category A	Category 0	Category 0	Category 0	Category 0
A11c	346101.7	6358076.9	H1	19.0	3.75	Category A	Category A	Category B	Category B	Category 1	Category 1	Category 1	Category 2
A11p01	346025.8	6358168.1	P	7.5	2.00	-	-	-	-	-	-	-	-

Table G.04 - Austar Proposed Longwalls A3 to A5
Predicted Systematic Subsidence Parameters for Farm Dams

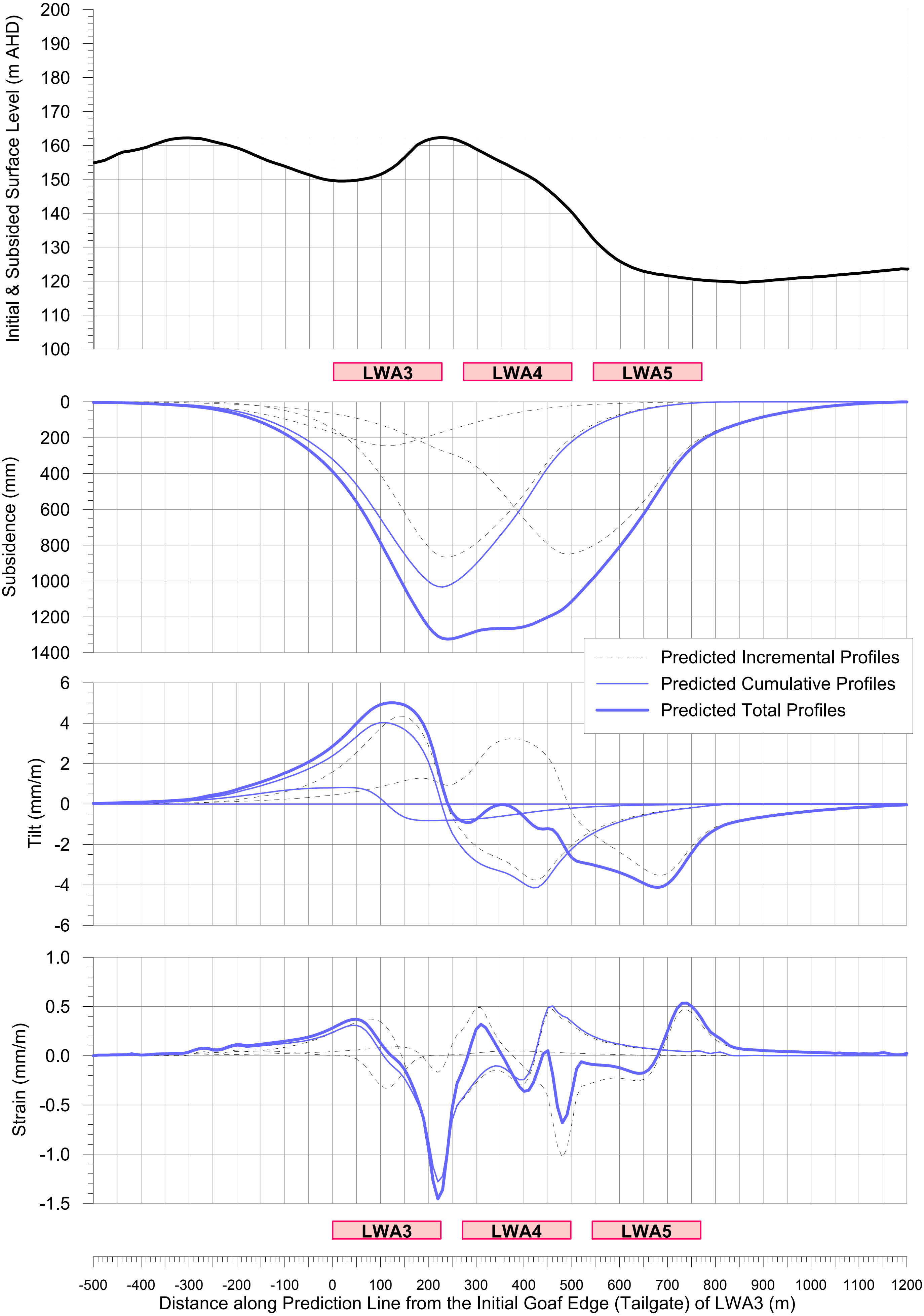
Label	Easting	Northing	Type	Longest Side (m)	Total Predicted Subs after LWA3 to LWA3 (mm)	Total Predicted Subs after LWA3 to LWA4 (mm)	Total Predicted Subs after LWA3 to LWA5 (mm)	Total Predicted Tilt after LWA3 to LWA3 (mm/m)	Total Predicted Tilt after LWA3 to LWA4 (mm/m)	Total Predicted Tilt after LWA3 to LWA5 (mm/m)	Maximum Predicted Travelling Tilt LWA3 to LWA5 (mm/m)	Maximum Upperbound Change in Freeboard (mm)	Total Predicted Tensile Strain during or after LWA3	Total Predicted Comp. Strain during or after LWA3	Total Predicted Tensile Strain during or after LWA3 and LWA4	Total Predicted Comp. Strain during or after LWA3 and LWA4	Total Predicted Tensile Strain during or after LWA3 to LWA5	Total Predicted Comp. Strain during or after LWA3 to LWA5
A01d01	345973.4	6356989.5	D	49.6	3	28	426	0.0	0.4	3.2	2.0	80	0.0	0.0	0.0	0.0	0.4	-0.1
A01d02	345991.7	6357049.4	D	97.9	6	55	625	0.1	0.6	3.5	2.3	170	0.0	0.0	0.1	0.0	0.4	-0.2
A01d03	346149.7	6357078.2	D	89.6	2	10	270	0.0	0.2	2.6	1.5	120	0.0	0.0	0.1	0.0	0.5	-0.1
A01d04	346145.3	6356892.4	D	18.6	0	0	87	0.0	0.0	0.6	0.4	10	0.0	0.0	0.0	0.0	0.0	0.0
A01d05	345985.8	6356607	D	165.1	0	1	17	0.0	0.0	0.2	0.1	20	0.0	0.0	0.0	0.0	0.0	0.0
A01d06	345904.3	6356288.2	D	64.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A02d01	345352	6356965.3	D	133.2	7	38	57	0.1	0.3	0.5	0.4	30	0.0	0.0	0.0	0.0	0.1	0.0
A02d02	345346.8	6356848	D	98.6	2	14	28	0.0	0.1	0.3	0.2	10	0.0	0.0	0.0	0.0	0.0	0.0
A02d03	345568.1	6357412.6	D	27.5	224	721	878	0.7	3.5	4.3	3.9	60	0.0	-0.3	0.1	-0.3	0.1	-0.3
A02d04	345649	6357949.7	D	50.9	108	162	190	0.8	1.4	1.6	1.5	40	0.1	0.0	0.1	0.0	0.2	0.0
A03d01	346236.6	6357778.9	D	34.3	62	526	646	0.5	4.1	4.3	3.8	70	0.1	0.0	0.5	-0.2	0.5	-0.3
A03d02	346319.1	6357663.3	D	49.7	18	168	355	0.2	1.7	3.4	1.8	80	0.0	0.0	0.2	0.0	0.5	-0.1
A04d01	345745	6357868.6	D	77.6	230	482	559	0.9	3.5	4.0	3.7	160	0.0	-0.1	0.3	-0.1	0.4	-0.1
A04d02	345867.8	6357841.7	D	73.6	285	959	1100	0.9	4.4	5.2	4.8	190	0.1	-0.4	0.3	-0.4	0.4	-0.4
A04d03	346111.4	6357806.6	D	42.9	151	981	1093	0.9	3.6	3.8	3.3	80	0.1	-0.1	0.2	-0.4	0.2	-0.4
A04d04	345922	6357465.6	D	30.9	86	771	1266	0.6	4.0	0.8	3.1	60	0.0	0.0	0.1	-0.3	0.1	-0.4
A04d05	346161.2	6357288.6	D	47.2	6	51	677	0.1	0.7	4.2	2.6	100	0.0	0.0	0.1	0.0	0.4	-0.2
A04d06	345619.8	6356959.9	D	92.4	8	71	309	0.1	0.9	3.4	1.3	160	0.0	0.0	0.2	0.0	0.5	-0.3
A05d01	346636.5	6357703.8	D	71.6	1	5	18	0.0	0.1	0.2	0.1	10	0.0	0.0	0.0	0.0	0.0	0.0
A06d01	345547.3	6356597.8	D	77.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A06d02	345775.8	6356576	D	19.8	0	1	7	0.0	0.0	0.1	0.0	< 10	0.0	0.0	0.0	0.0	0.0	0.0
A06d03	345702.2	6356449.2	D	63.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A07d01	345183.1	6356840.1	D	75.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A07d02	345159.2	6357459.6	D	27.8	13	18	24	0.2	0.3	0.4	0.3	10	0.0	0.0	0.0	0.0	0.0	0.0
A07d03	345216.3	6357754.6	D	39.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A08d01	345022.3	6357022.3	D	64.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A08d02	344950.4	6357451.9	D	38.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A08d03	345042.8	6357733.1	D	61.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A09d01	346622.2	6357632.5	D	136.0	1	6	26	0.0	0.1	0.4	0.2	20	0.0	0.0	0.0	0.0	0.1	0.0
A09d02	346545.6	6357550.6	D	33.1	1	3	36	0.0	0.1	0.4	0.2	10	0.0	0.0	0.1	0.0	0.1	0.0
A09d03	346816.7	6357588.6	D	32.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A09d04	347023.1	6357668.4	D	19.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A09d05	347116.3	6357679.5	D	21.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A09d06	347118.4	6357620.9	D	24.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A09d07	347112.4	6357548.4	D	16.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A10d01	346373.2	6356935.7	D	65.0	0	0	34	0.0	0.0	0.3	0.2	10	0.0	0.0	0.0	0.0	0.1	-0.1
A10d02	347005.5	6356791.6	D	45.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A10d03	346957.9	6357116.8	D	184.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A10d04	346772	6357245.5	D	130.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table G.05 - Austar Proposed Longwalls A3 to A5
Upperbound Systematic Subsidence Parameters for Farm Dams

Label	Easting	Northing	Type	Longest Side (m)	Upperbound Subs after LWA3 to LWA3 (mm)	Upperbound Subs after LWA3 to LWA4 (mm)	Upperbound Subs after LWA3 to LWA5 (mm)	Upperbound Tilt after LWA3 to LWA3 (mm/m)	Upperbound Tilt after LWA3 to LWA4 (mm/m)	Upperbound Tilt after LWA3 to LWA5 (mm/m)	Upperbound Travelling Tilt LWA3 to LWA5 (mm/m)	Maximum Upperbound Change in Freeboard (mm)	Upperbound Tensile Strain during or after LWA3	Upperbound Comp. Strain during or after LWA3	Upperbound Tensile Strain during or after LWA3 to LWA4	Upperbound Comp. Strain during or after LWA3 to LWA4	Upperbound Tensile Strain during or after LWA3 to LWA5	Upperbound Comp. Strain during or after LWA3 to LWA5
A01d01	345973.4	6356989.5	D	49.6	7	64	889	0.1	0.8	6.5	0.8	160	0.0	0.0	0.1	0.0	0.8	-0.3
A01d02	345991.7	6357049.4	D	97.9	15	124	1289	0.2	1.3	7.1	1.3	350	0.0	0.0	0.2	0.0	0.8	-0.3
A01d03	346149.7	6357078.2	D	89.6	5	26	575	0.1	0.5	5.4	0.5	240	0.0	0.0	0.1	0.0	0.9	0.0
A01d04	346145.3	6356892.4	D	18.6	0	0	188	0.0	0.0	1.2	0.0	10	0.0	0.0	0.0	0.0	0.1	0.0
A01d05	345985.8	6356607	D	165.1	0	1	37	0.0	0.0	0.4	0.0	40	0.0	0.0	0.0	0.0	0.1	0.0
A01d06	345904.3	6356288.2	D	64.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A02d01	345352	6356965.3	D	133.2	14	79	120	0.1	0.7	1.0	0.7	70	0.0	0.0	0.1	-0.1	0.1	-0.1
A02d02	345346.8	6356848	D	98.6	4	29	59	0.1	0.3	0.5	0.3	30	0.0	0.0	0.0	0.0	0.1	0.0
A02d03	345568.1	6357412.6	D	27.5	484	1568	1925	1.4	7.3	9.1	7.3	130	0.0	-0.6	0.0	-0.7	0.2	-0.7
A02d04	345649	6357949.7	D	50.9	252	391	464	1.6	3.2	3.7	3.2	90	0.1	0.0	0.3	0.0	0.3	0.0
A03d01	346236.6	6357778.9	D	34.3	151	1115	1381	1.2	8.2	8.9	8.1	150	0.1	0.0	0.9	-0.5	0.9	-0.5
A03d02	346319.1	6357663.3	D	49.7	48	379	775	0.5	3.6	7.3	3.6	180	0.1	0.0	0.5	-0.1	1.0	-0.1
A04d01	345745	6357868.6	D	77.6	504	1102	1293	1.9	7.6	8.9	7.6	350	0.0	-0.1	0.7	-0.1	0.8	-0.1
A04d02	345867.8	6357841.7	D	73.6	616	2096	2435	1.8	9.2	10.9	9.2	400	0.0	-0.8	0.6	-1.0	0.7	-1.0
A04d03	346111.4	6357806.6	D	42.9	344	2028	2288	1.9	7.3	7.9	7.2	170	0.1	0.0	0.1	-0.6	0.5	-0.6
A04d04	345922	6357465.6	D	30.9	198	1584	2687	1.4	7.9	1.9	7.9	120	0.1	0.0	0.1	-0.5	0.1	-0.8
A04d05	346161.2	6357288.6	D	47.2	16	121	1393	0.2	1.4	8.2	1.4	190	0.0	0.0	0.2	0.0	0.6	-0.3
A04d06	345619.8	6356959.9	D	92.4	18	152	659	0.2	1.9	7.2	1.9	330	0.0	0.0	0.3	0.0	1.1	-0.6
A05d01	346636.5	6357703.8	D	71.6	5	15	43	0.1	0.3	0.6	0.3	20	0.0	0.0	0.0	0.0	0.1	0.0
A06d01	345547.3	6356597.8	D	77.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A06d02	345775.8	6356576	D	19.8	0	1	16	0.0	0.0	0.2	0.0	< 10	0.0	0.0	0.0	0.0	0.0	0.0
A06d03	345702.2	6356449.2	D	63.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A07d01	345183.1	6356840.1	D	75.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A07d02	345159.2	6357459.6	D	27.8	31	42	58	0.4	0.7	0.8	0.7	10	0.1	0.0	0.1	0.0	0.1	0.0
A07d03	345216.3	6357754.6	D	39.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A08d01	345022.3	6357022.3	D	64.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A08d02	344950.4	6357451.9	D	38.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A08d03	345042.8	6357733.1	D	61.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A09d01	346622.2	6357632.5	D	136.0	5	18	62	0.1	0.3	0.8	0.3	50	0.0	0.0	0.1	0.0	0.1	0.0
A09d02	346545.6	6357550.6	D	33.1	3	10	83	0.1	0.3	1.1	0.3	20	0.0	0.0	0.1	0.0	0.2	0.0
A09d03	346816.7	6357588.6	D	32.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A09d04	347023.1	6357668.4	D	19.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A09d05	347116.3	6357679.5	D	21.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A09d06	347118.4	6357620.9	D	24.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A09d07	347112.4	6357548.4	D	16.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A10d01	346373.2	6356935.7	D	65.0	0	0	78	0.0	0.0	0.7	0.0	20	0.0	0.0	0.0	0.0	0.1	0.0
A10d02	347005.5	6356791.6	D	45.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A10d03	346957.9	6357116.8	D	184.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A10d04	346772	6357245.5	D	130.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX H. FIGURES (PREDICTED SUBSIDENCE PARAMETERS)

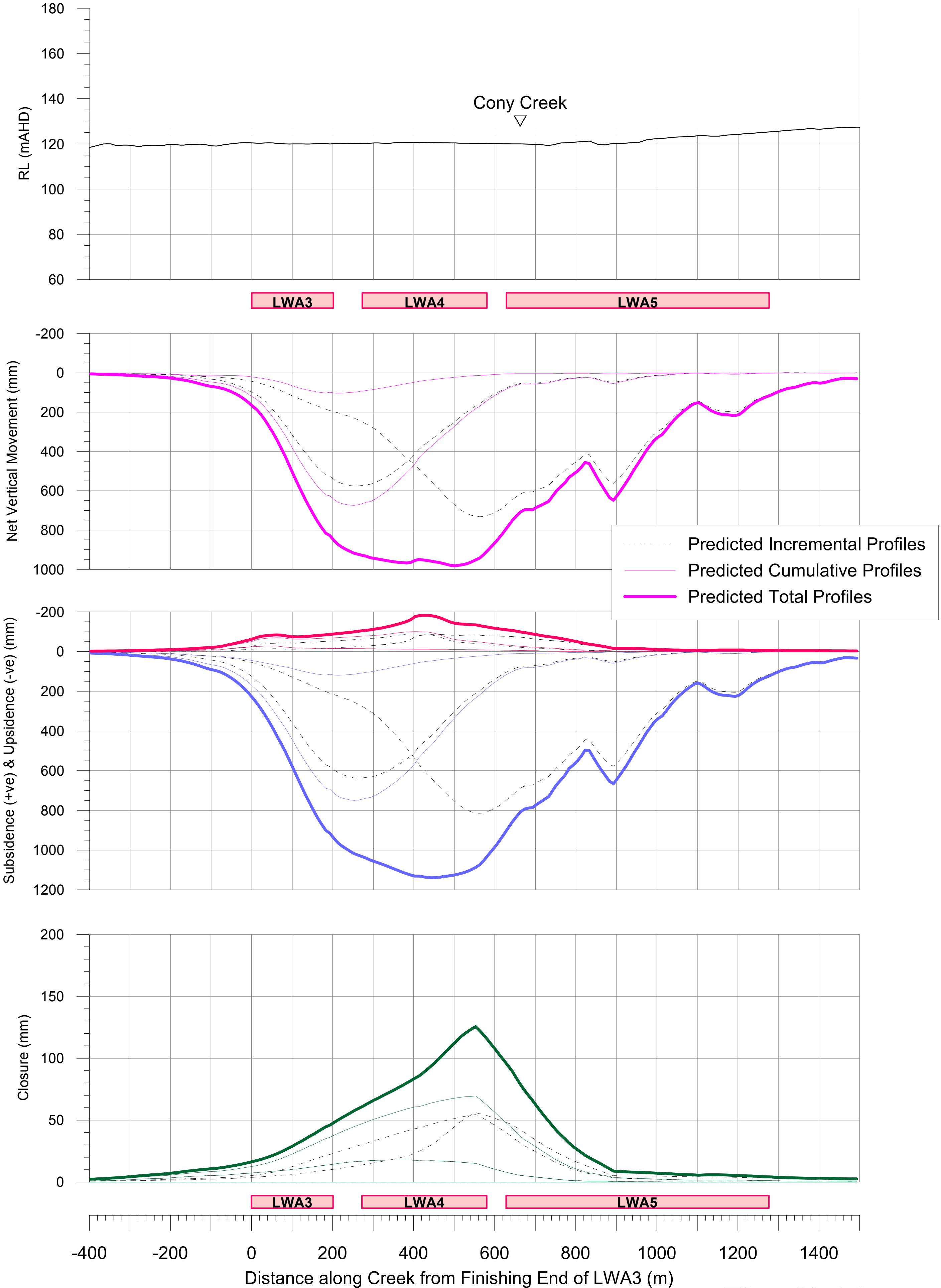
Predicted Systematic Subsidence, Tilt and Strain Profiles along Prediction Line A



Mine Subsidence Engineering Consultants

Fig. H.01

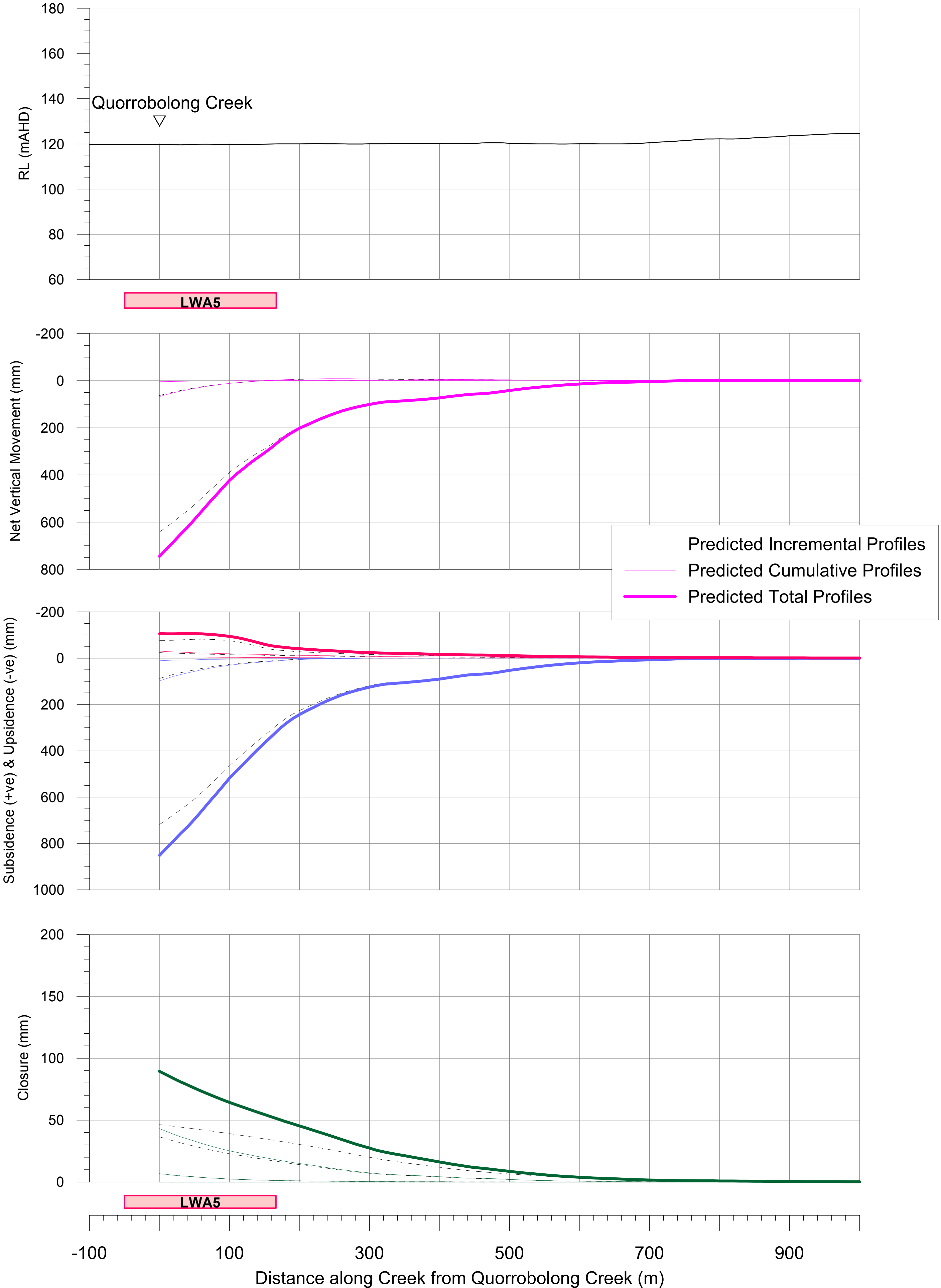
Quorrobolong Creek Long Section
Predicted Subsidence, Upsidence and Closure



Mine Subsidence Engineering Consultants

Fig. H.02

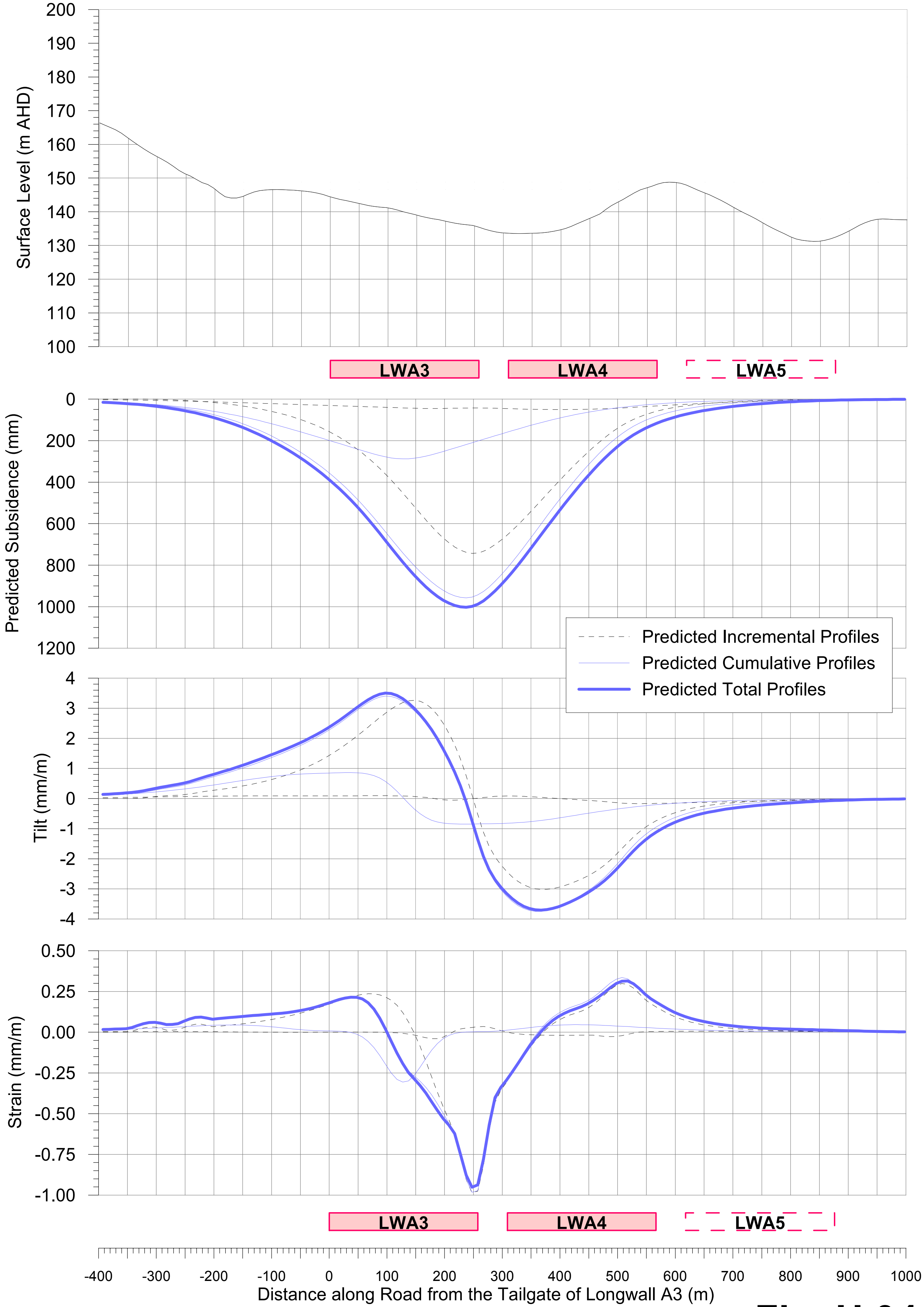
Cony Creek Long Section
Predicted Subsidence, Upsidence and Closure



Mine Subsidence Engineering Consultants

Fig. H.03

Predicted Systematic Subsidence, Tilt and Strain Profiles along Nash Lane



Mine Subsidence Engineering Consultants

Fig. H.04

APPENDIX I. FIGURES (UPPERBOUND SUBSIDENCE PARAMETERS)

Upperbound Systematic Subsidence, Tilt and Strain Profiles along Prediction Line A

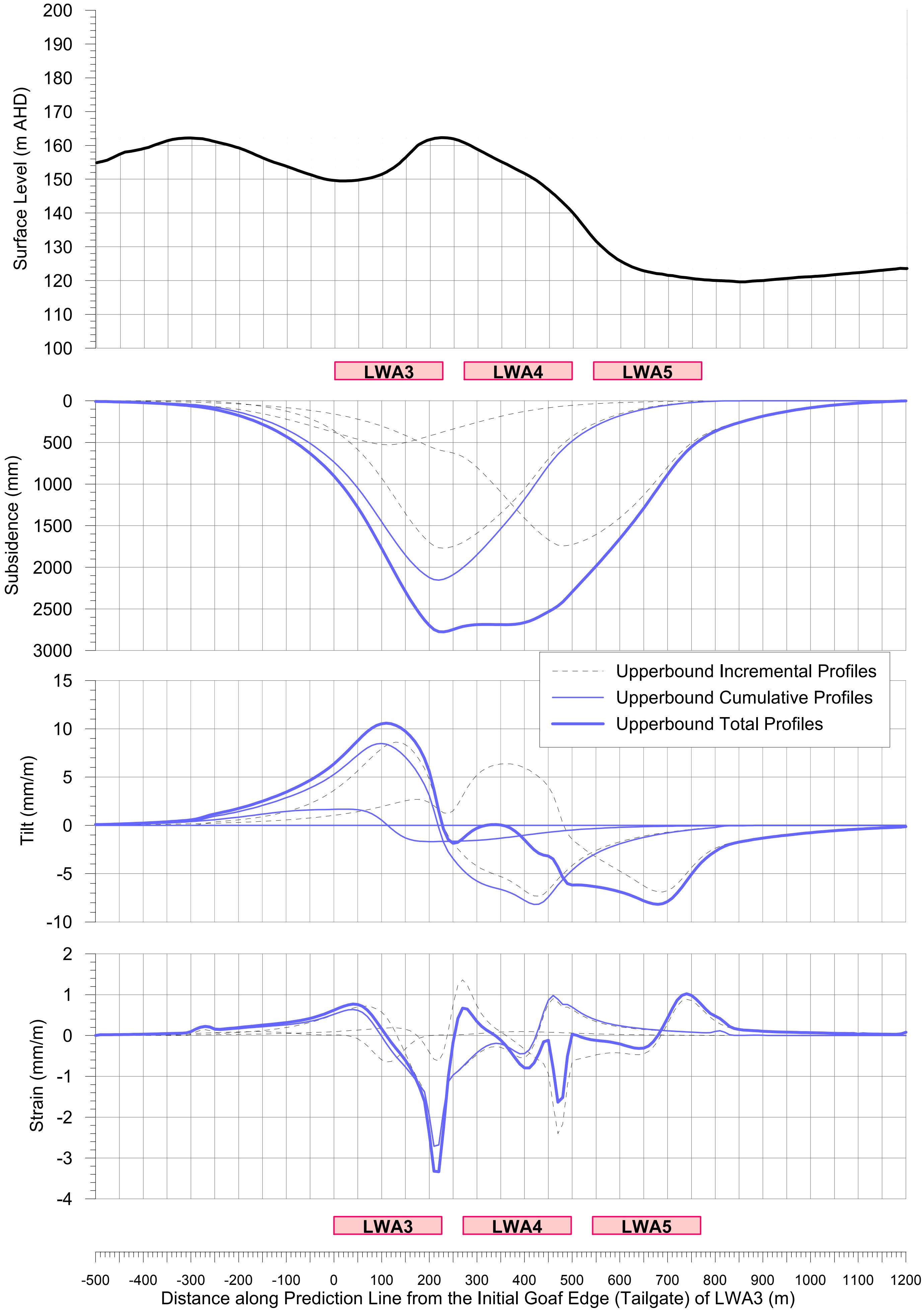


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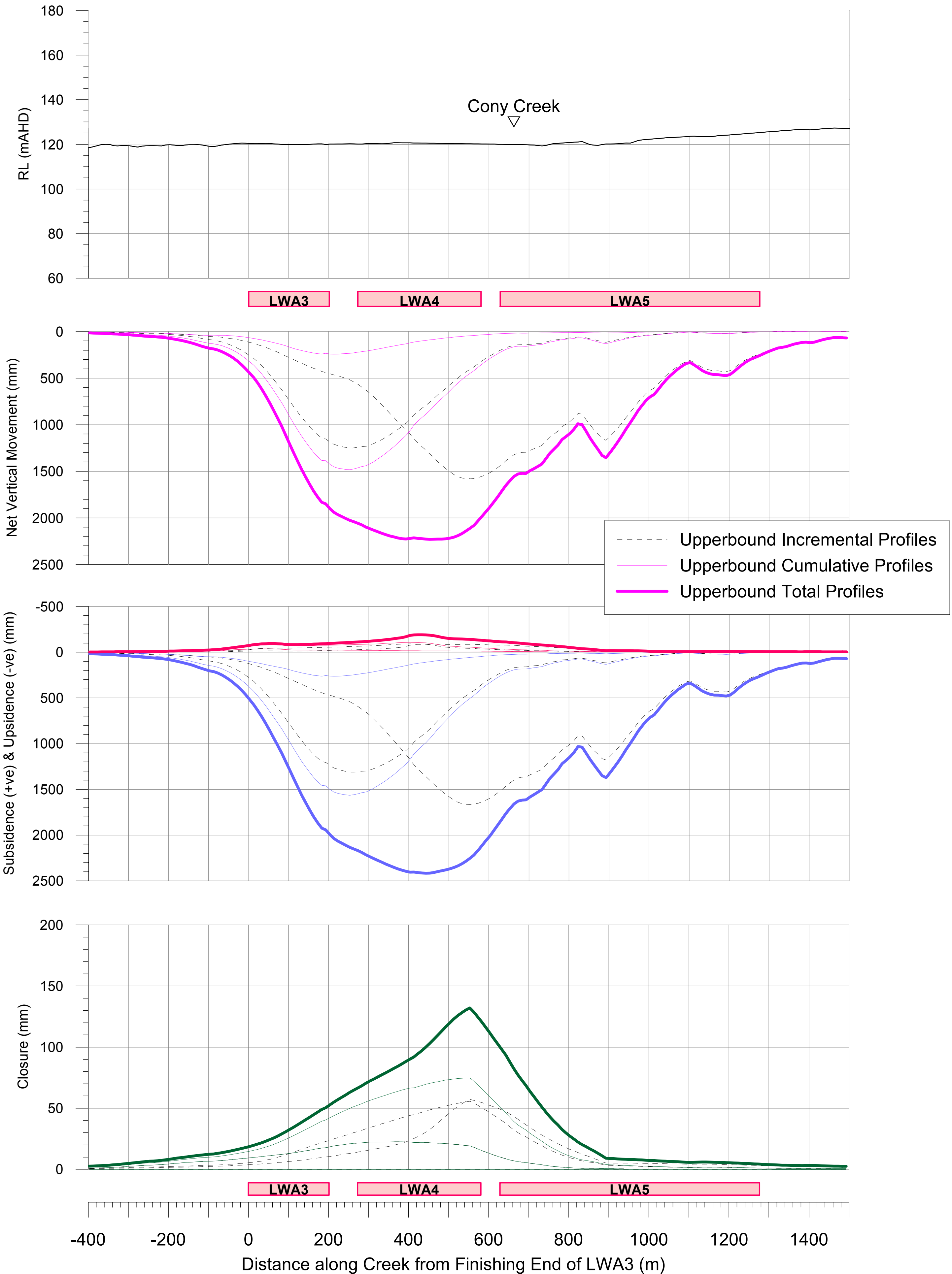
Fig. I.01

Quorrobolong Creek Long Section
Upperbound Subsidence, Upsidence and Closure



Mine Subsidence Engineering Consultants

Fig. I.02

Cony Creek Long Section
Upperbound Subsidence, Upsidence and Closure

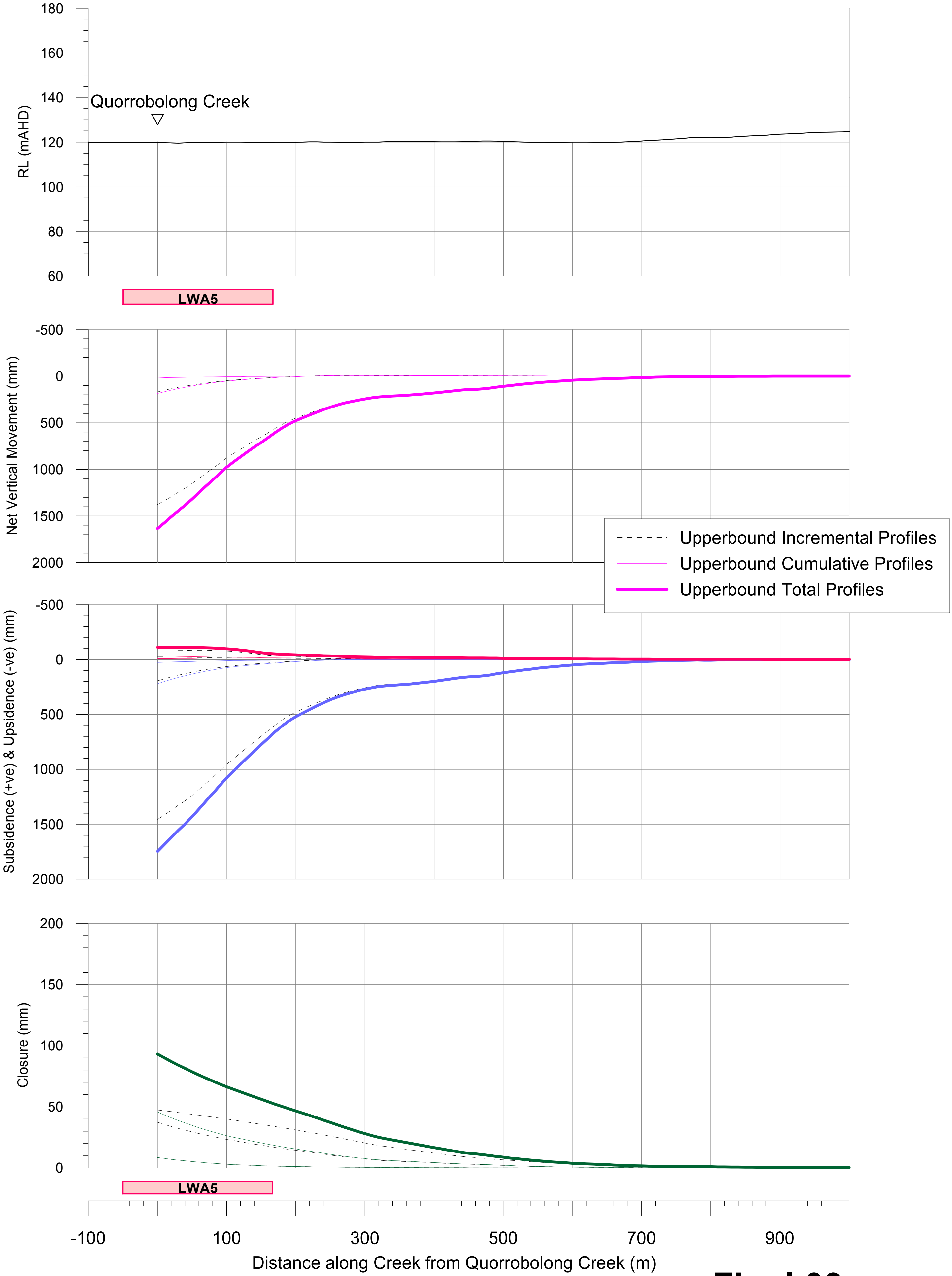
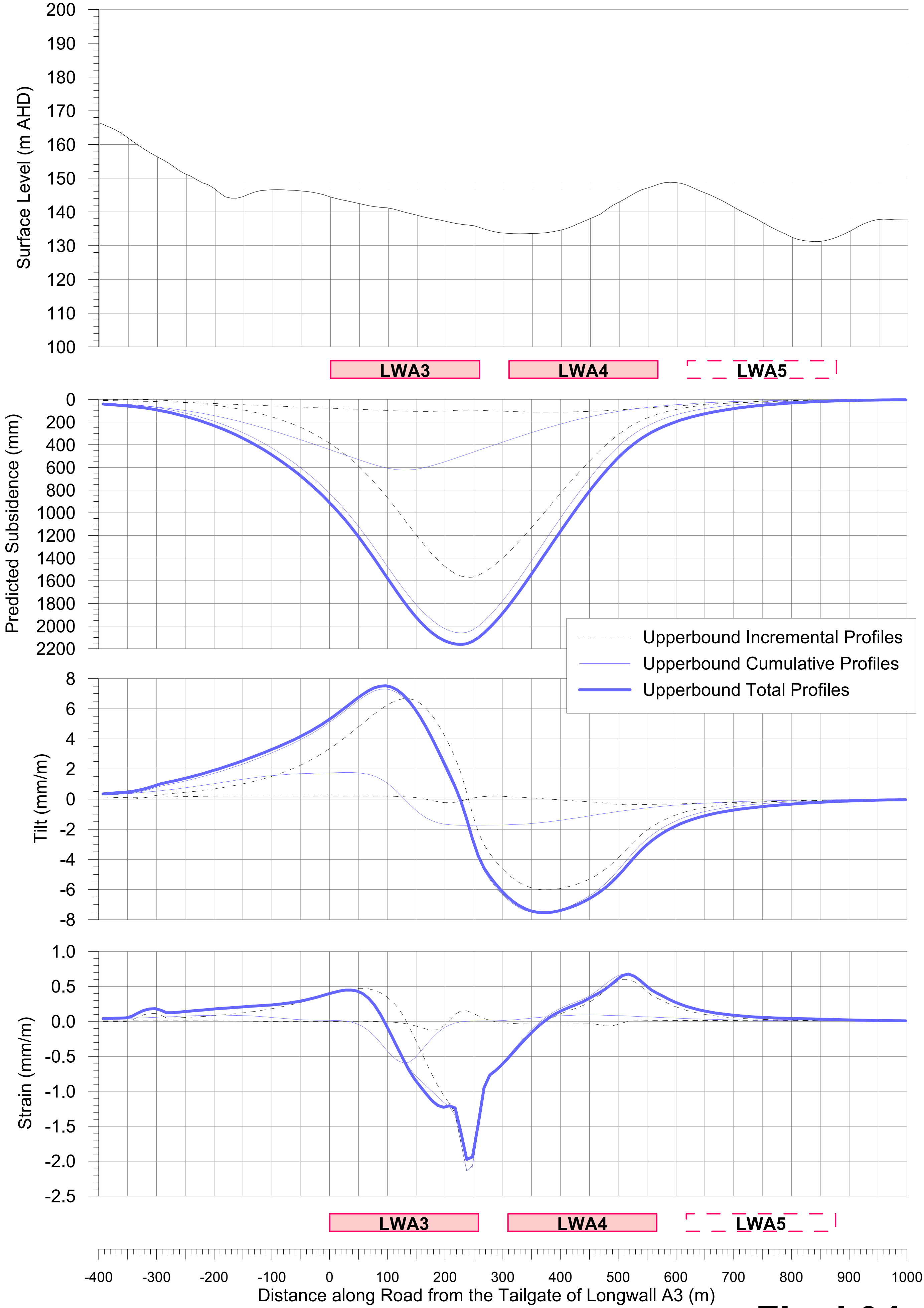


Fig. I.03

Upperbound Systematic Subsidence, Tilt and Strain Profiles along Nash Lane



Mine Subsidence Engineering Consultants

Fig. I.04

APPENDIX J. DRAWINGS

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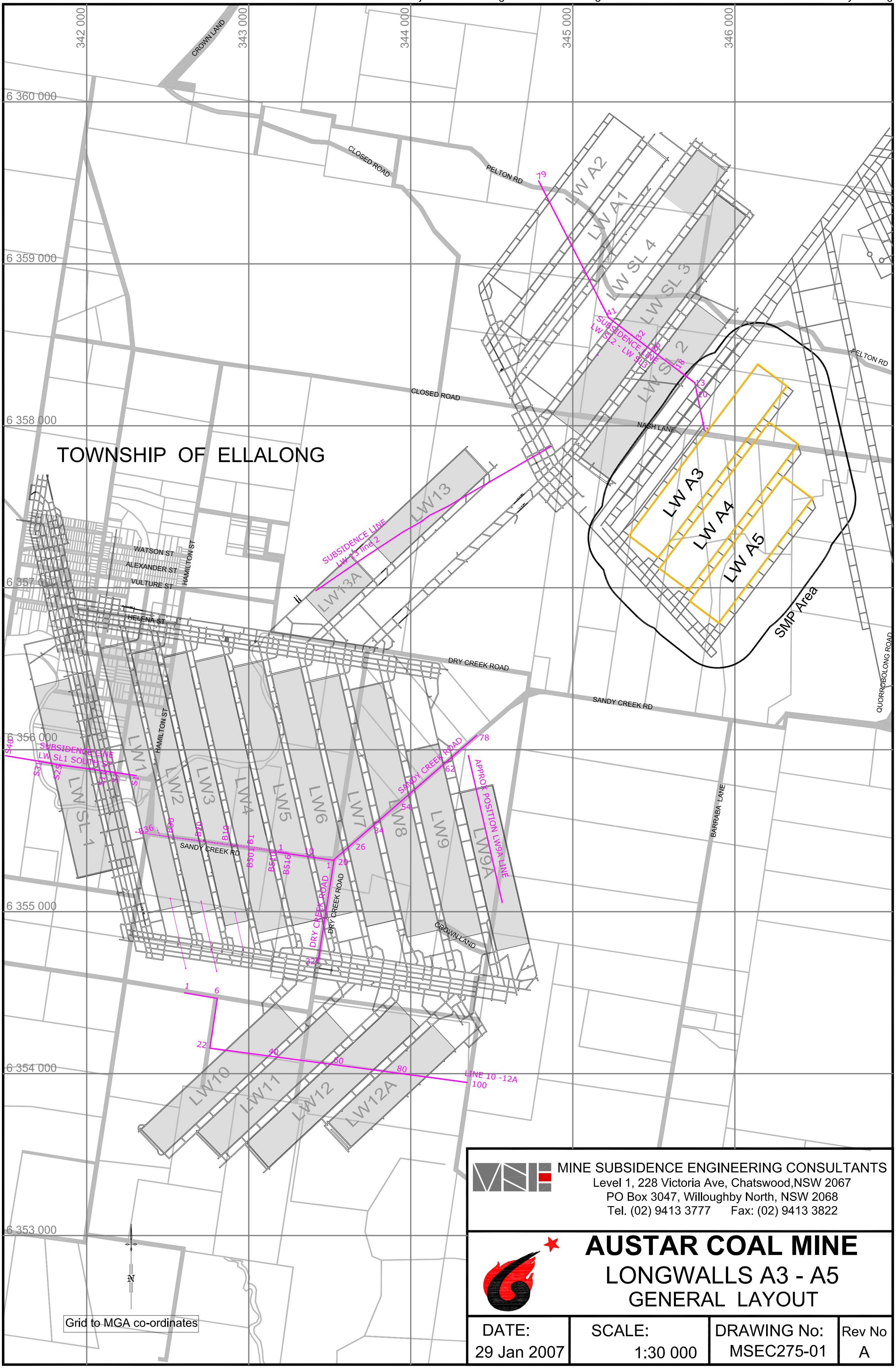

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AUSTAR COAL MINE
LONGWALLS A3 - A5
GENERAL LAYOUT

DATE:	SCALE:	DRAWING No:	Rev No
29 Jan 2007	1:30 000	MSEC275-01	A

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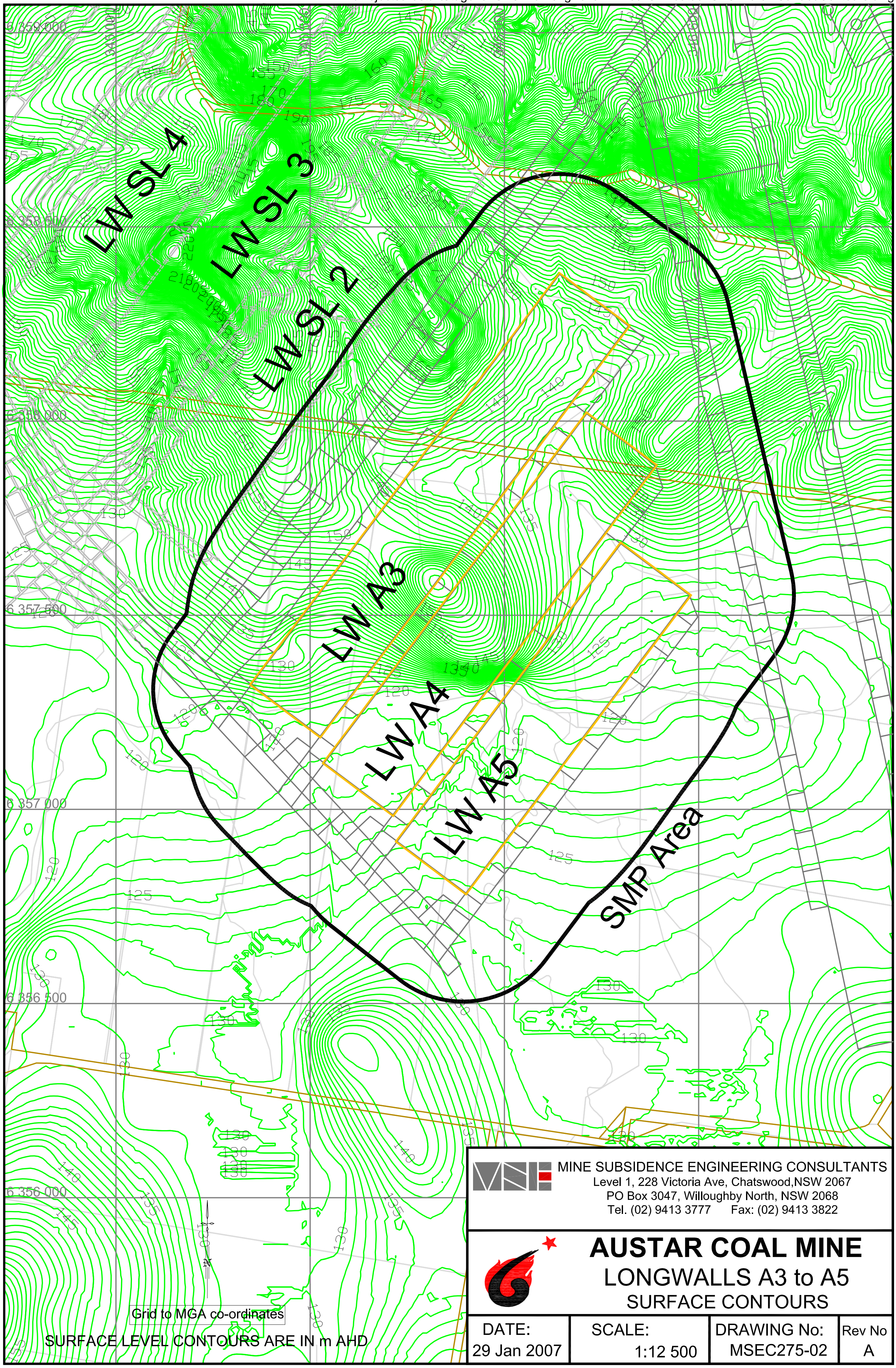

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AUSTAR COAL MINE
LONGWALLS A3 to A5
SURFACE CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
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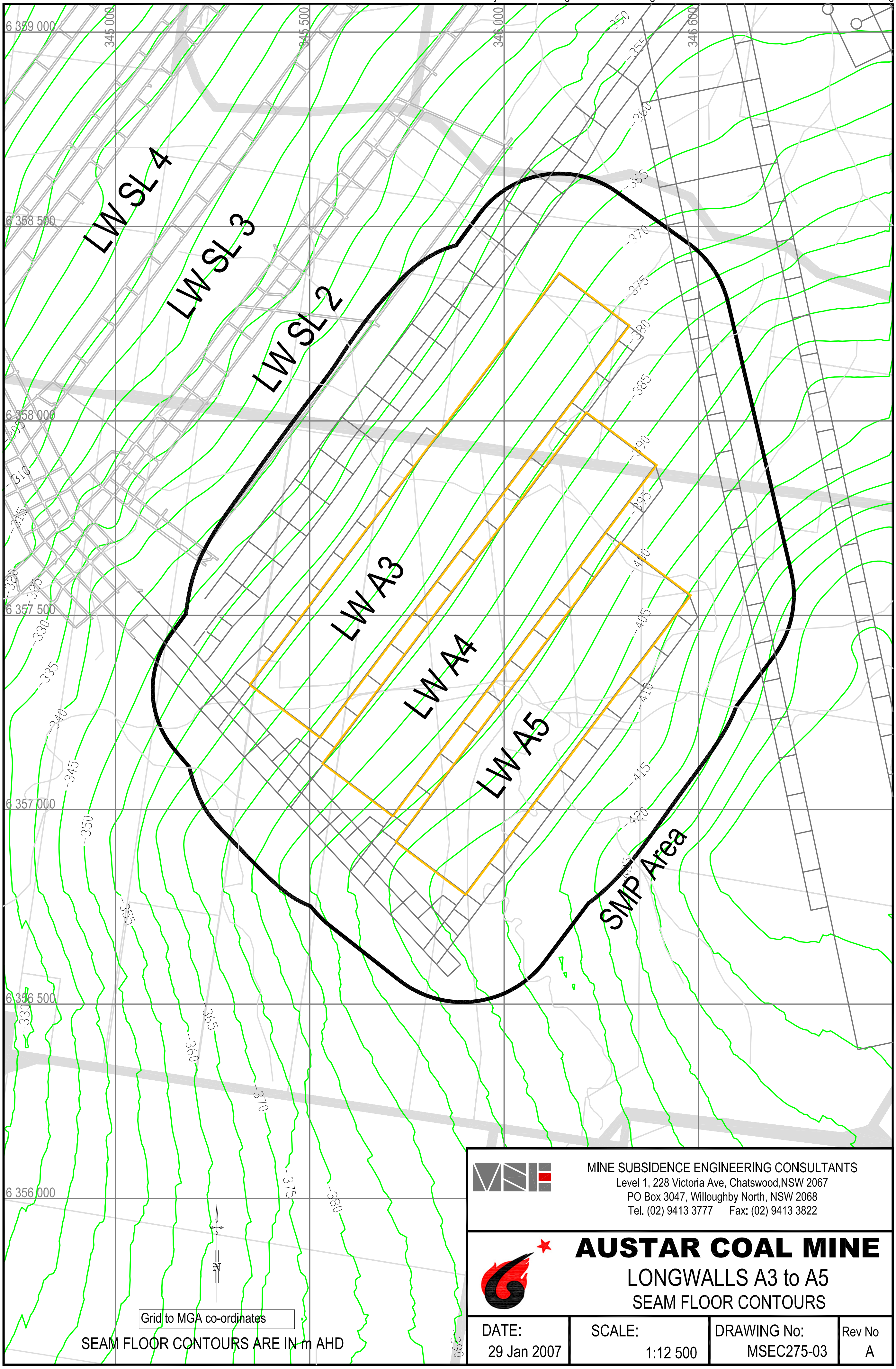

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AUSTAR COAL MINE

LONGWALLS A3 to A5

SEAM FLOOR CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
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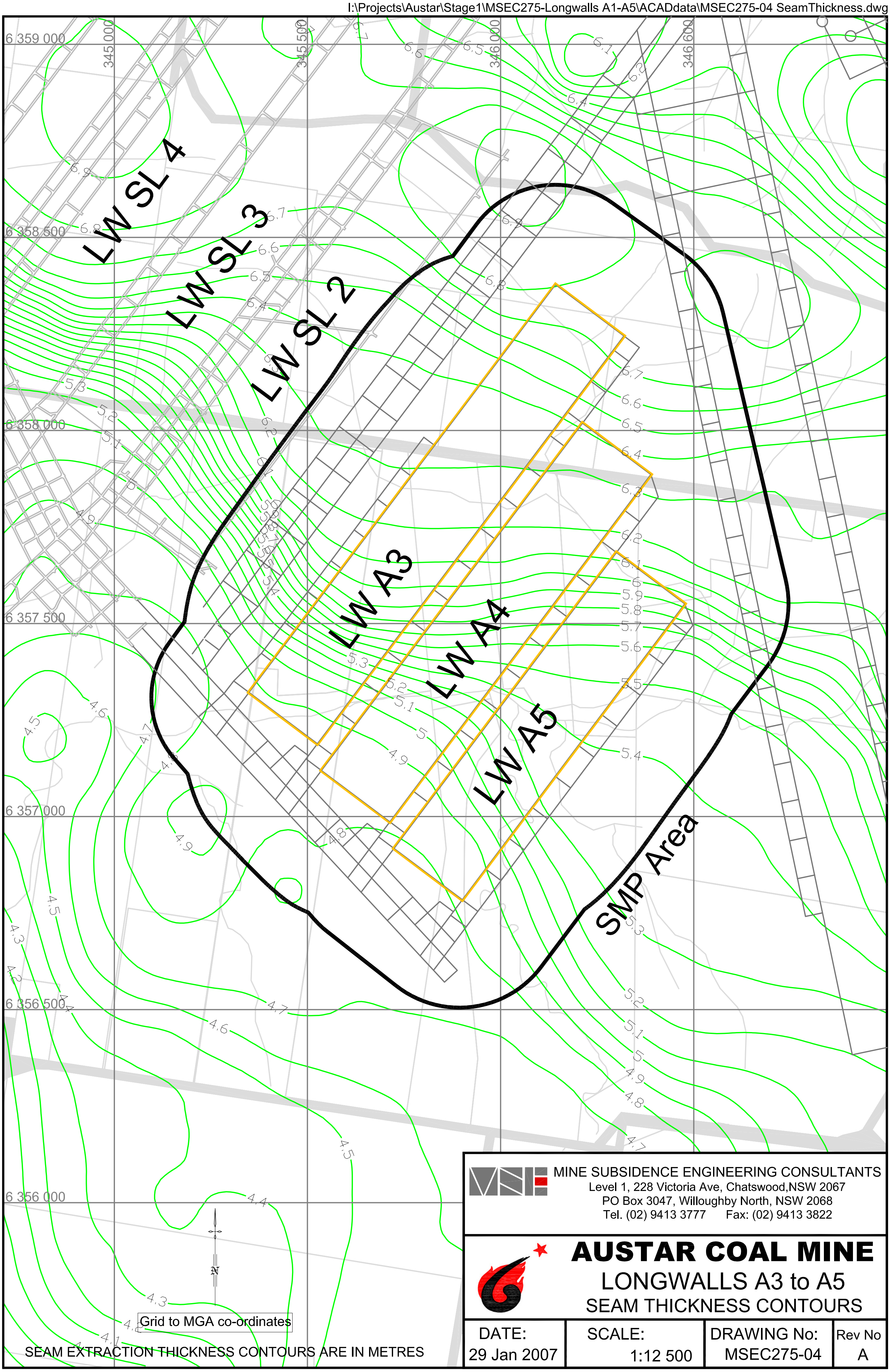

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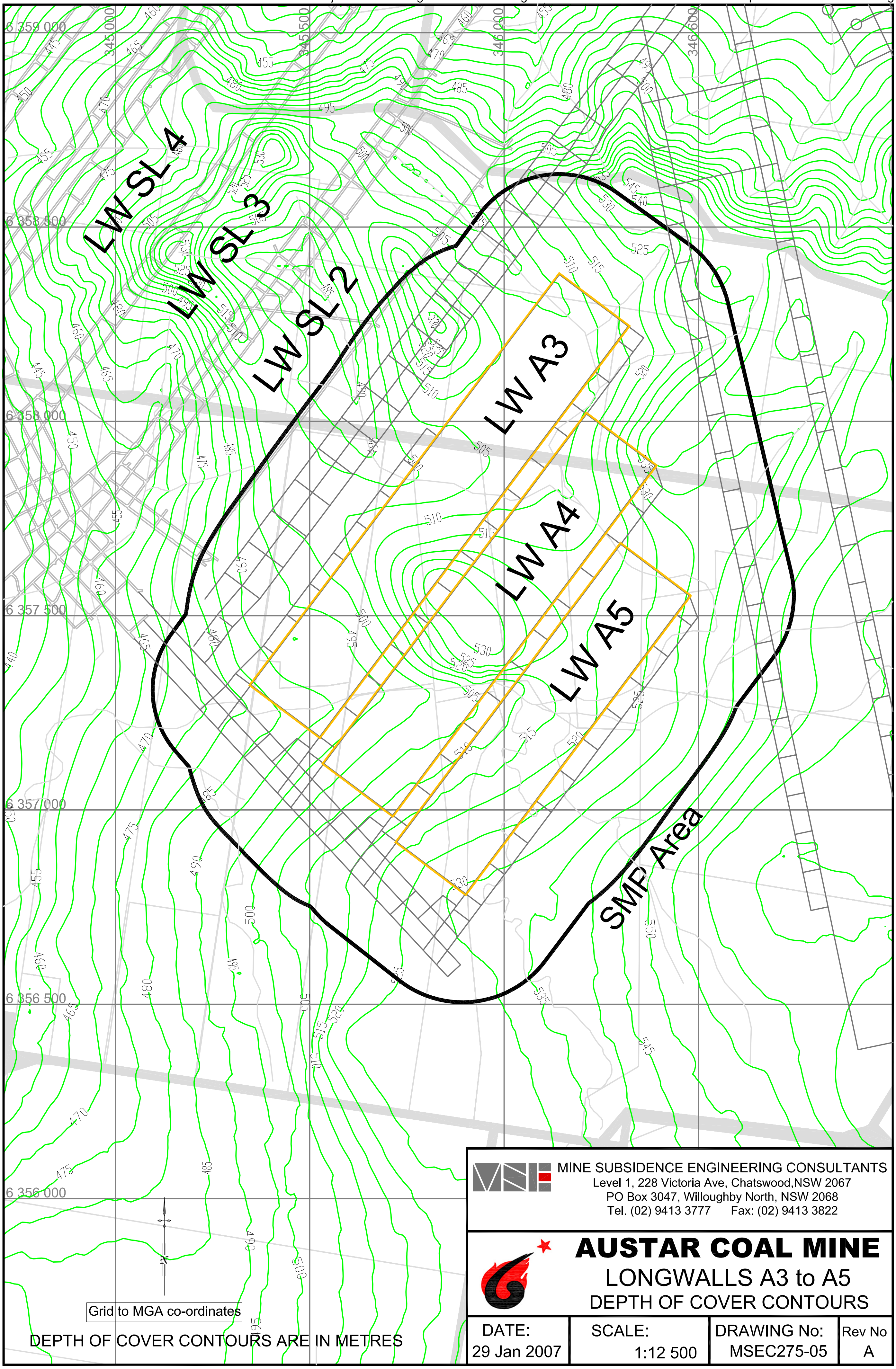

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AUSTAR COAL MINE

LONGWALLS A3 to A5

DEPTH OF COVER CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
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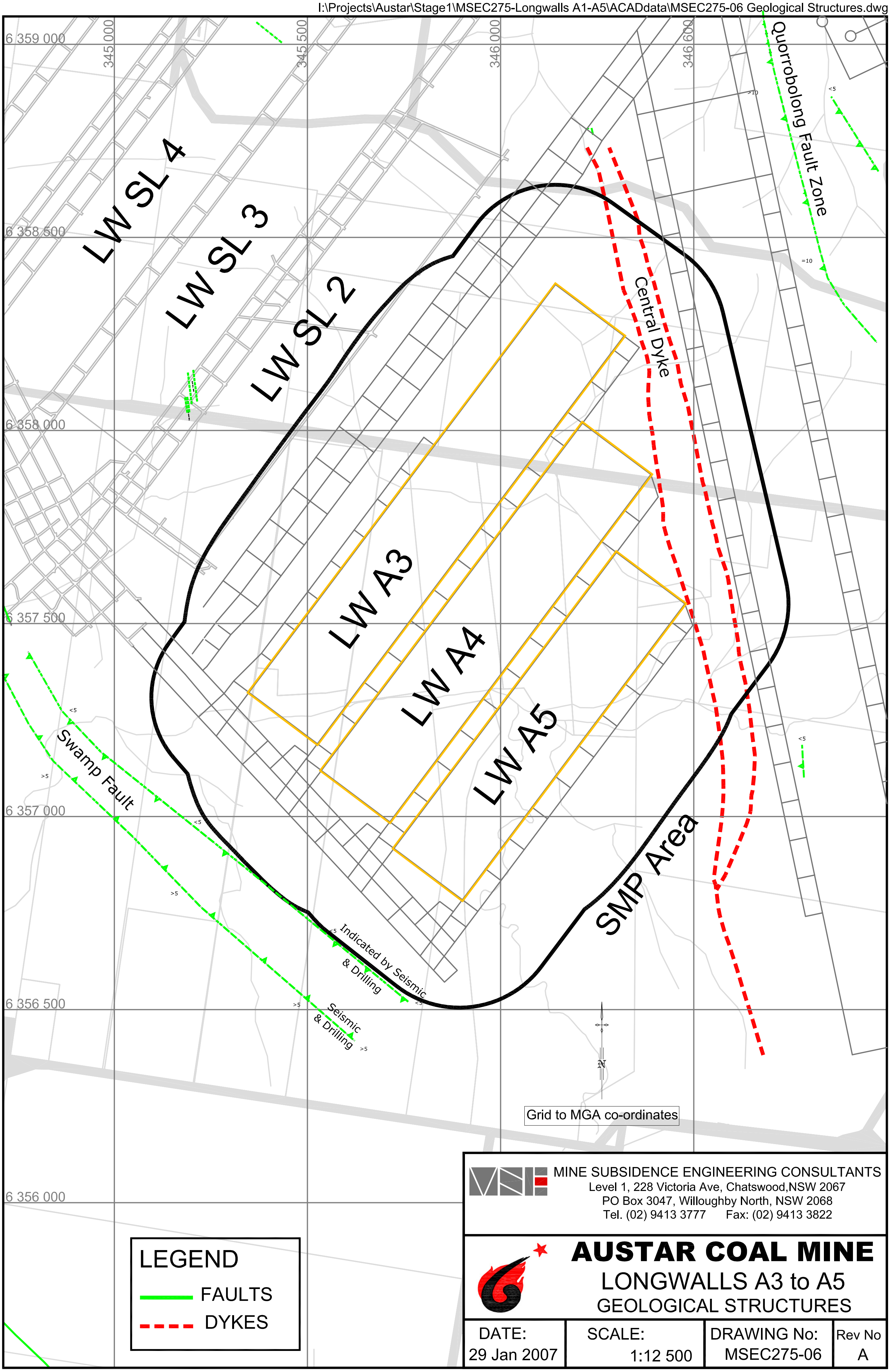

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AUSTAR COAL MINE
LONGWALLS A3 to A5
GEOLOGICAL STRUCTURES

DATE:	SCALE:	DRAWING No:	Rev No
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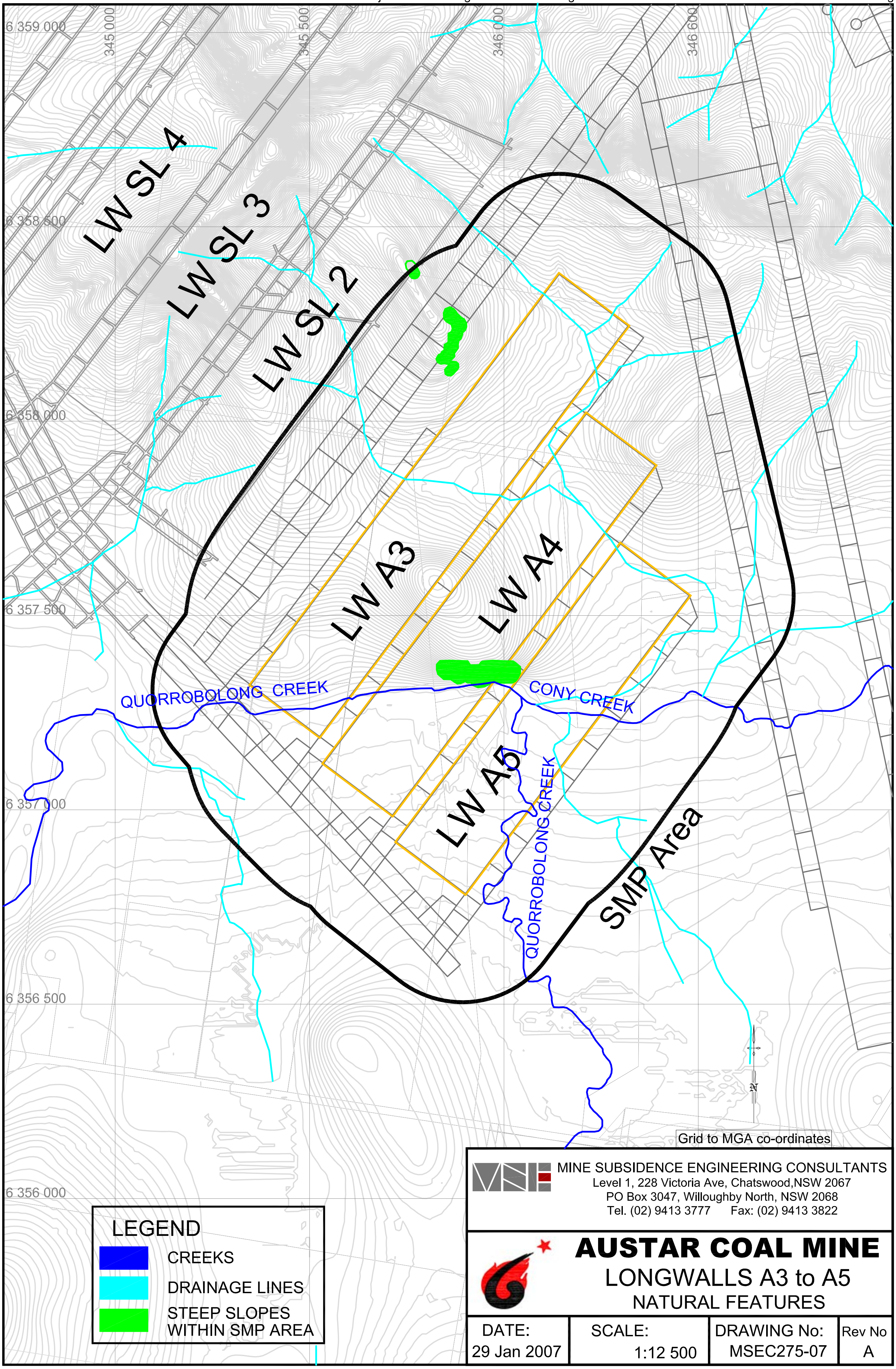

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AUSTAR COAL MINE
LONGWALLS A3 to A5
NATURAL FEATURES

DATE:	SCALE:	Drawing No:	Rev No
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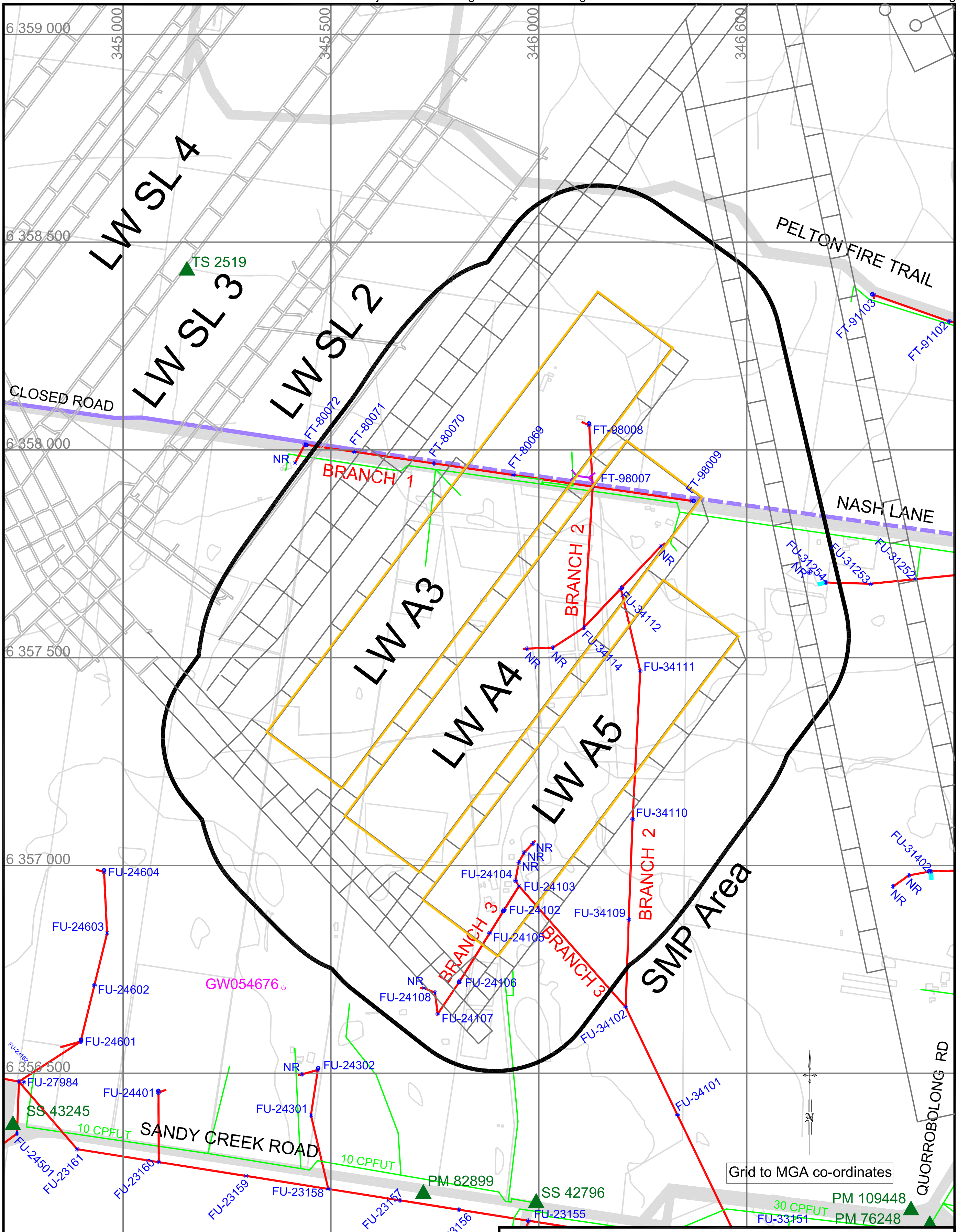

Legend

Registered Groundwater Bores
Survey Control Marks
Culvert

Telstra
Local Underground Copper Cables

Energy Australia
Above Ground Services
Power Poles & IDs
Underground Services

Water Pipeline (Private)
Approximate location from Hunter Water
Unconfirmed location

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AUSTAR COAL MINE
LONGWALLS A3 to A5
SURFACE INFRASTRUCTURE

DATE:	SCALE:	DRAWING No:	Rev No
29 Jan 2007	1:12 500	MSEC275-08	A

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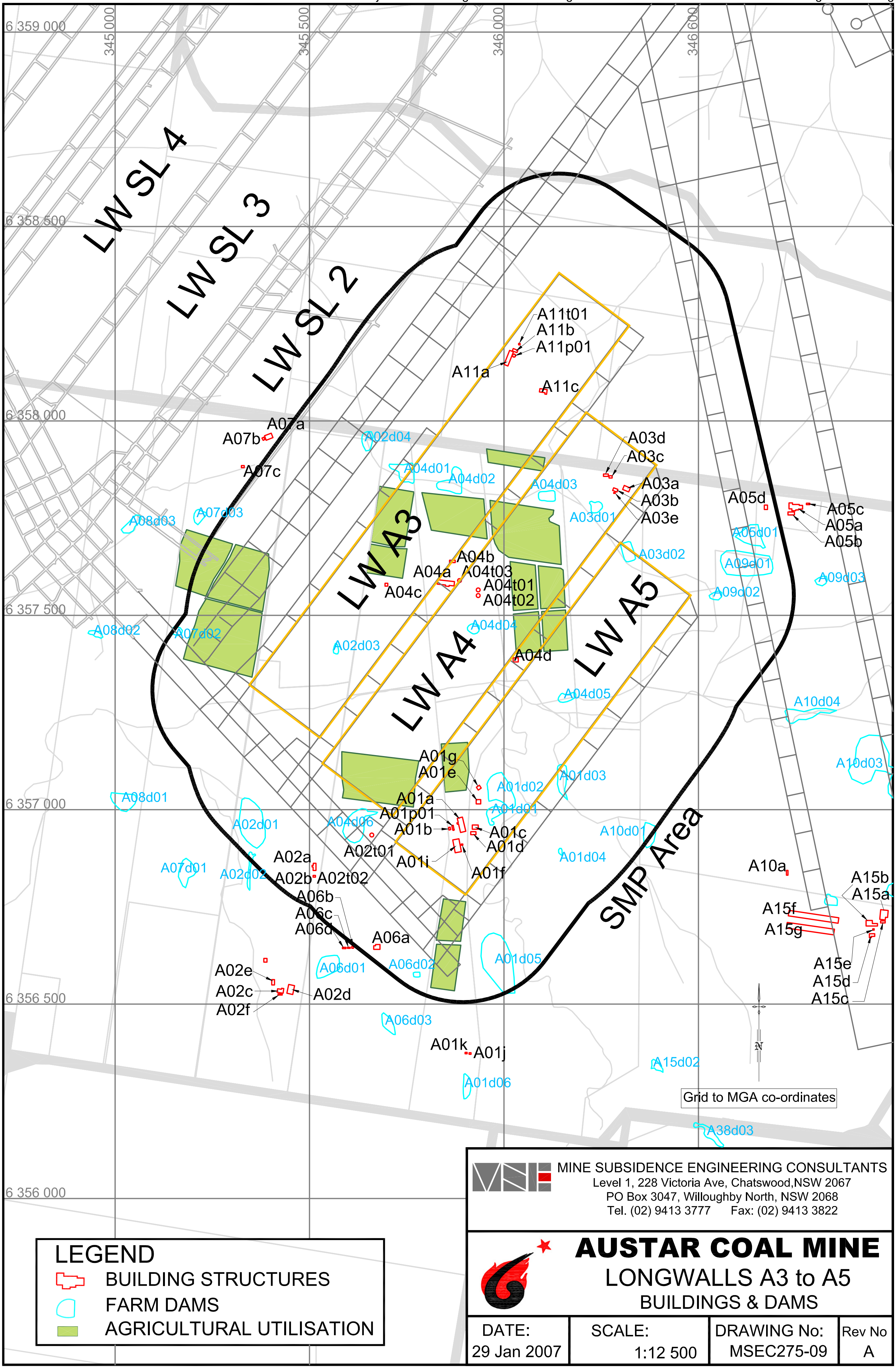

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AUSTAR COAL MINE
LONGWALLS A3 to A5
BUILDINGS & DAMS

DATE:	SCALE:	DRAWING No:	Rev No
29 Jan 2007	1:12 500	MSEC275-09	A

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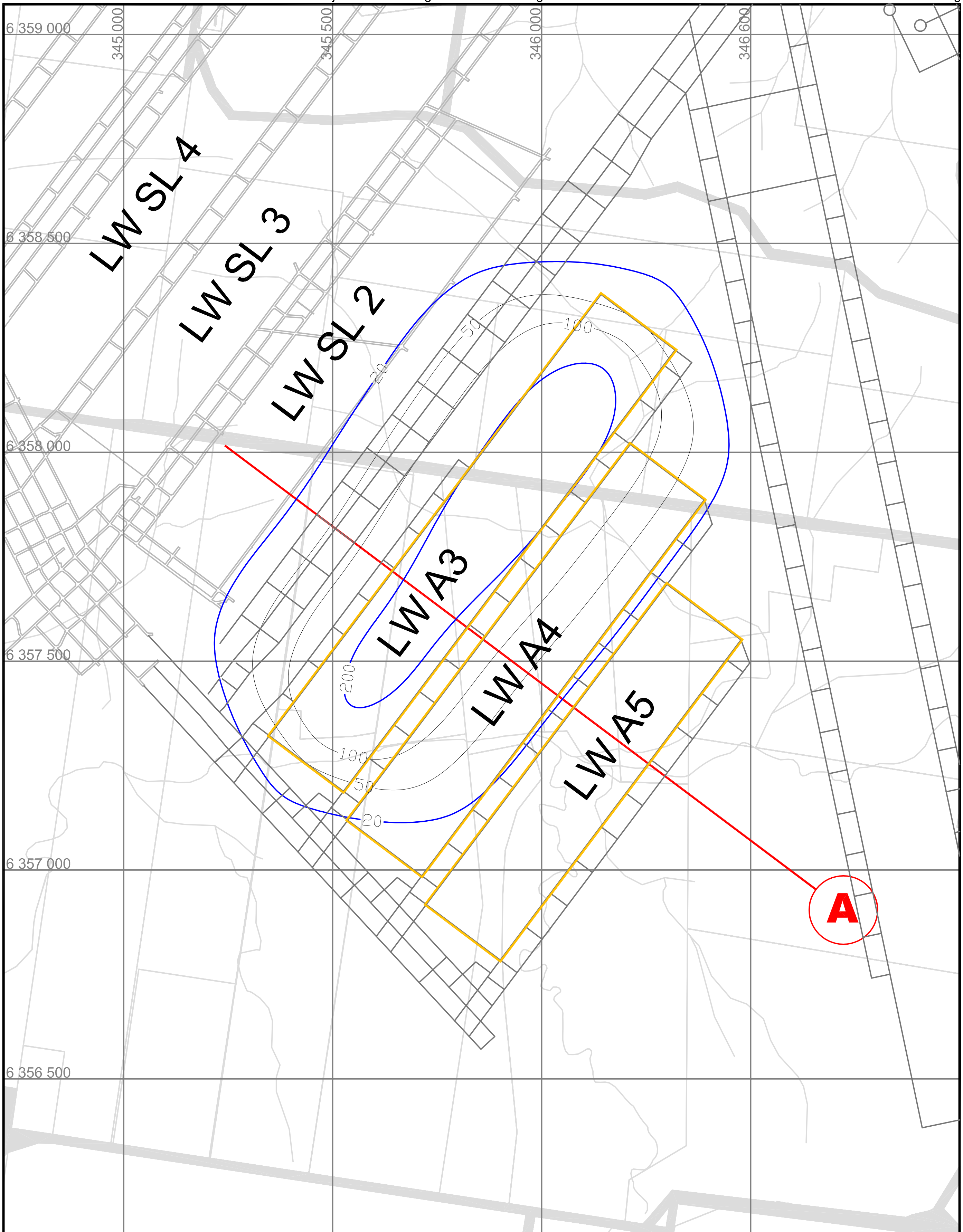

Grid to MGA co-ordinates

PREDICTED SUBSIDENCE CONTOURS ARE IN MILLIMETRES

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AUSTAR COAL MINE
LONGWALLS A3 to A5
PREDICTED SUBSIDENCE CONTOURS
DUE TO LONGWALL A3

DATE:	SCALE:	DRAWING No:	Rev No
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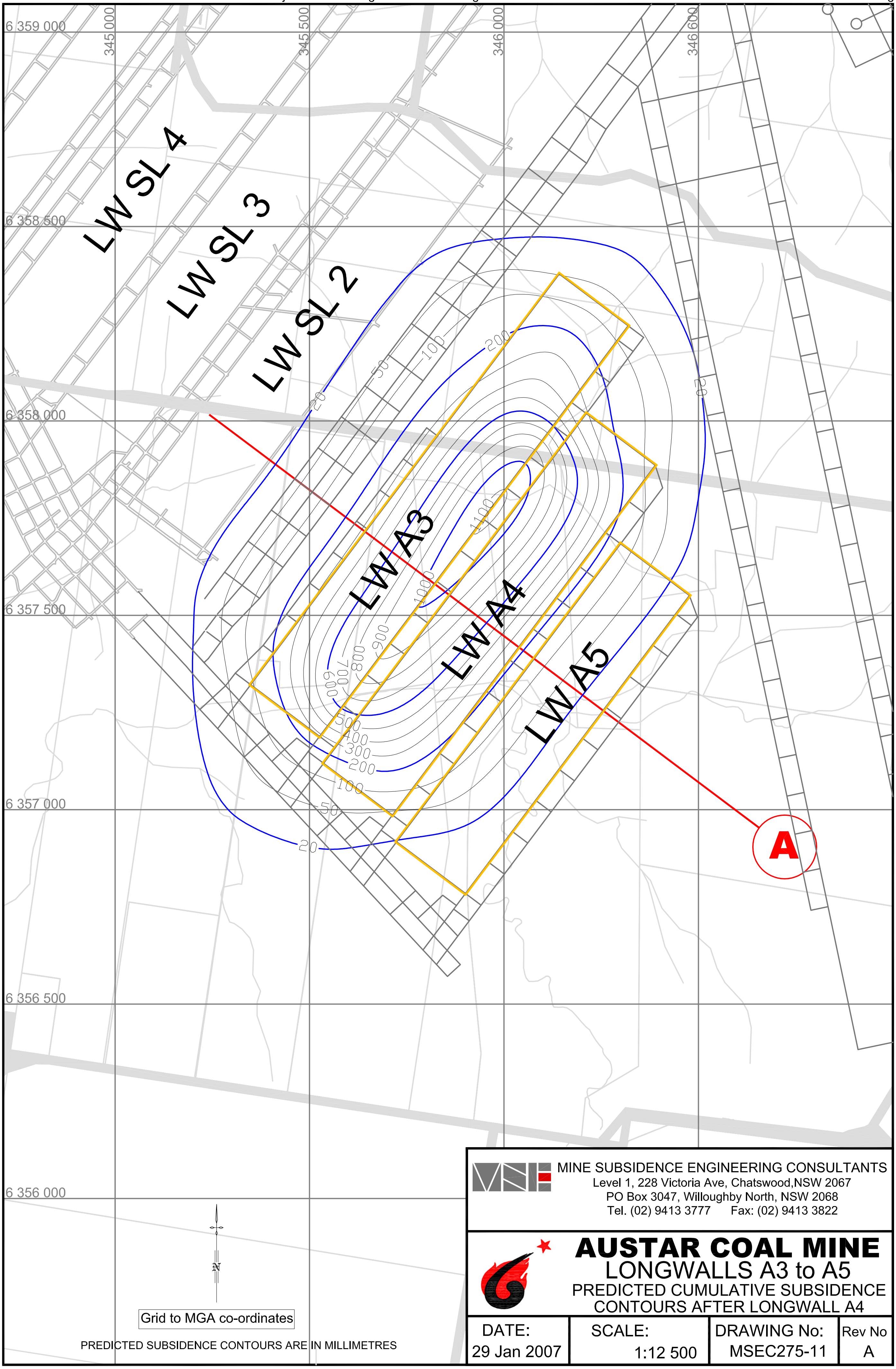

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LONGWALLS A3 to A5
PREDICTED CUMULATIVE SUBSIDENCE CONTOURS AFTER LONGWALL A4

DATE:	SCALE:	DRAWING No:	Rev No
29 Jan 2007	1:12 500	MSEC275-11	A

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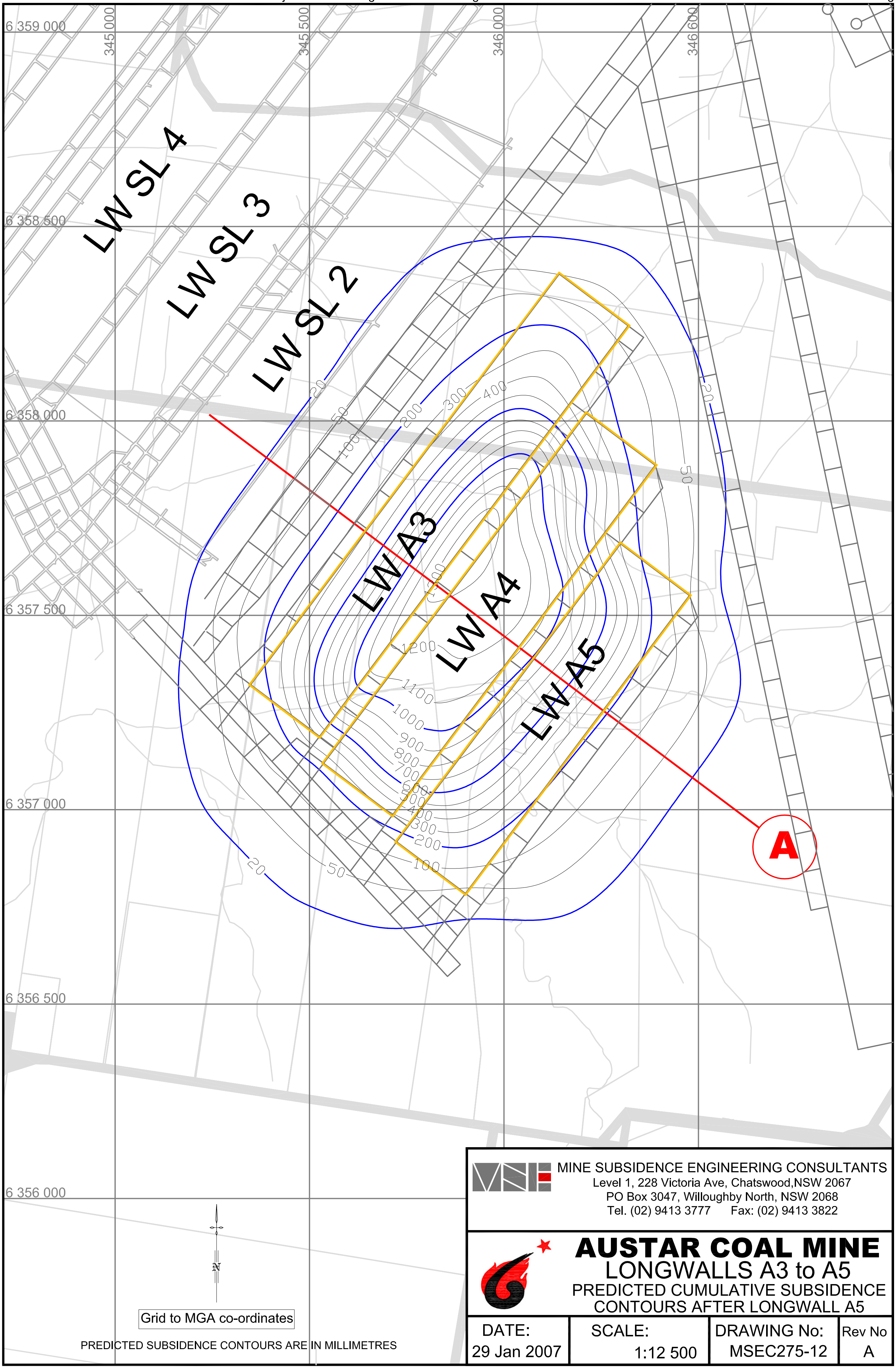

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AUSTAR COAL MINE
LONGWALLS A3 to A5
PREDICTED CUMULATIVE SUBSIDENCE
CONTOURS AFTER LONGWALL A5

DATE:	SCALE:	DRAWING No:	Rev No
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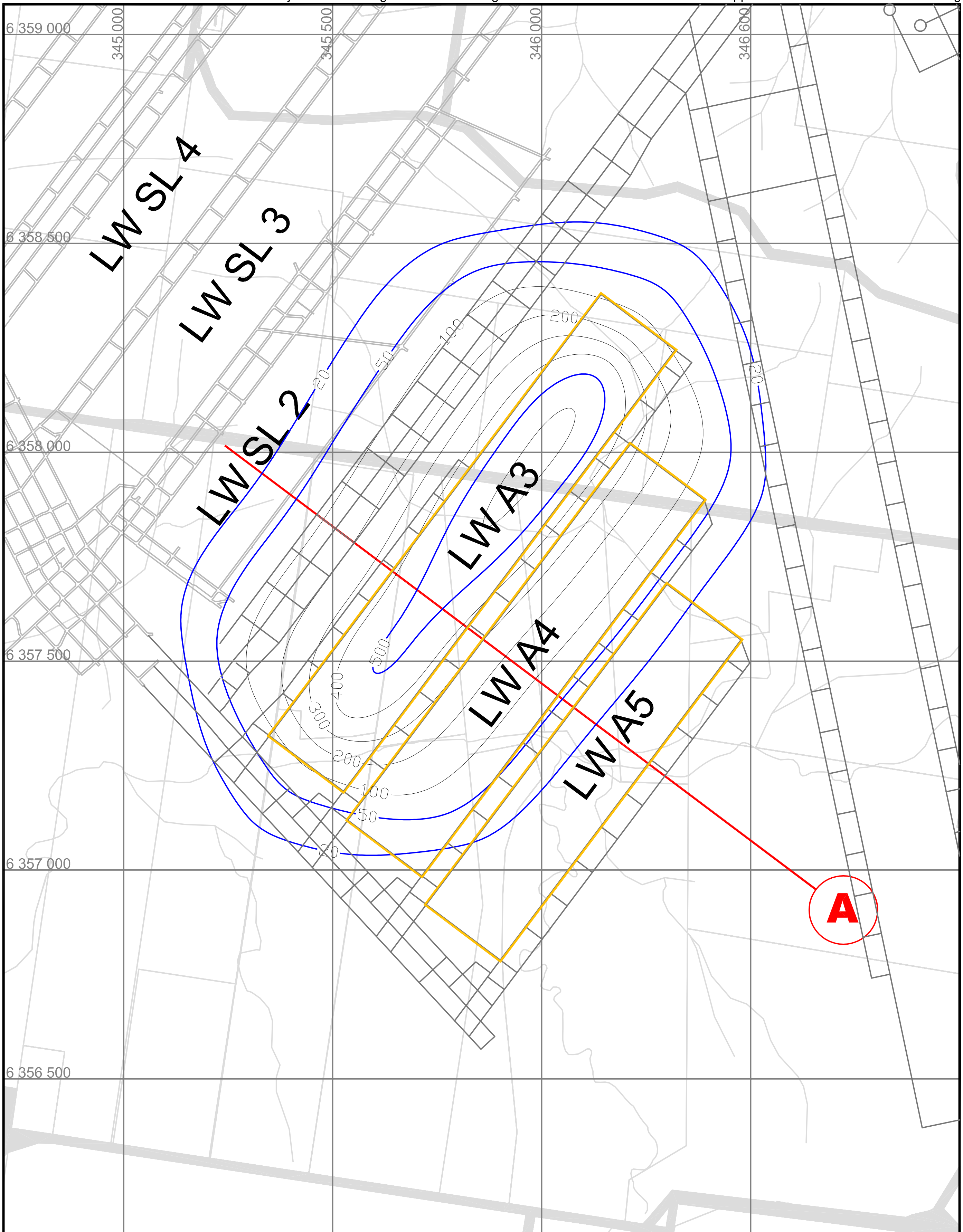

Grid to MGA co-ordinates

PREDICTED SUBSIDENCE CONTOURS ARE IN MILLIMETRES

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AUSTAR COAL MINE
LONGWALLS A3 to A5
UPPERBOUND CUMULATIVE SUBSIDENCE CONTOURS DUE TO LONGWALL A3

DATE:	SCALE:	DRAWING No:	Rev No
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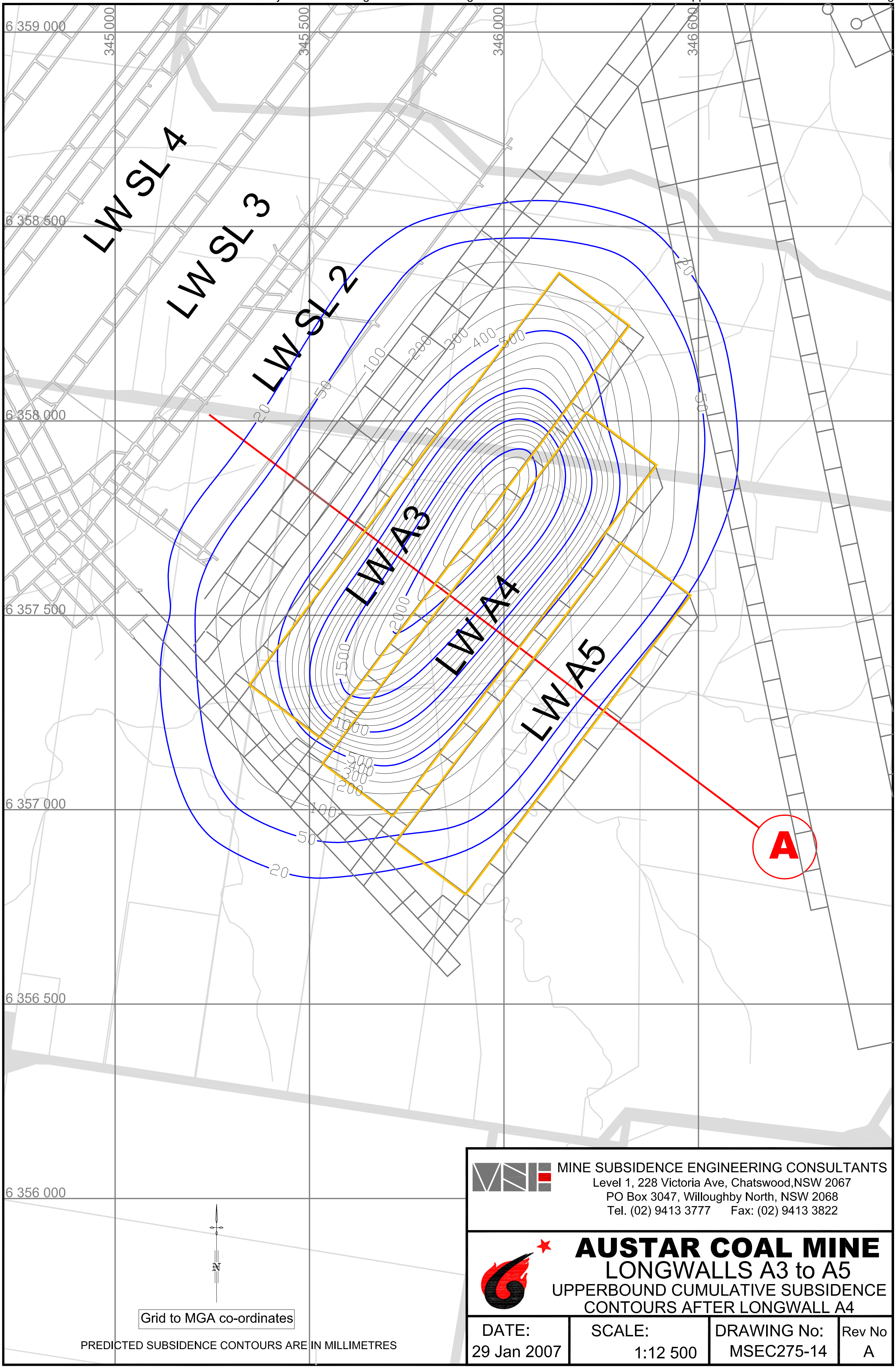

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LONGWALLS A3 to A5
UPPERBOUND CUMULATIVE SUBSIDENCE CONTOURS AFTER LONGWALL A4

DATE:	SCALE:	DRAWING No:	Rev No
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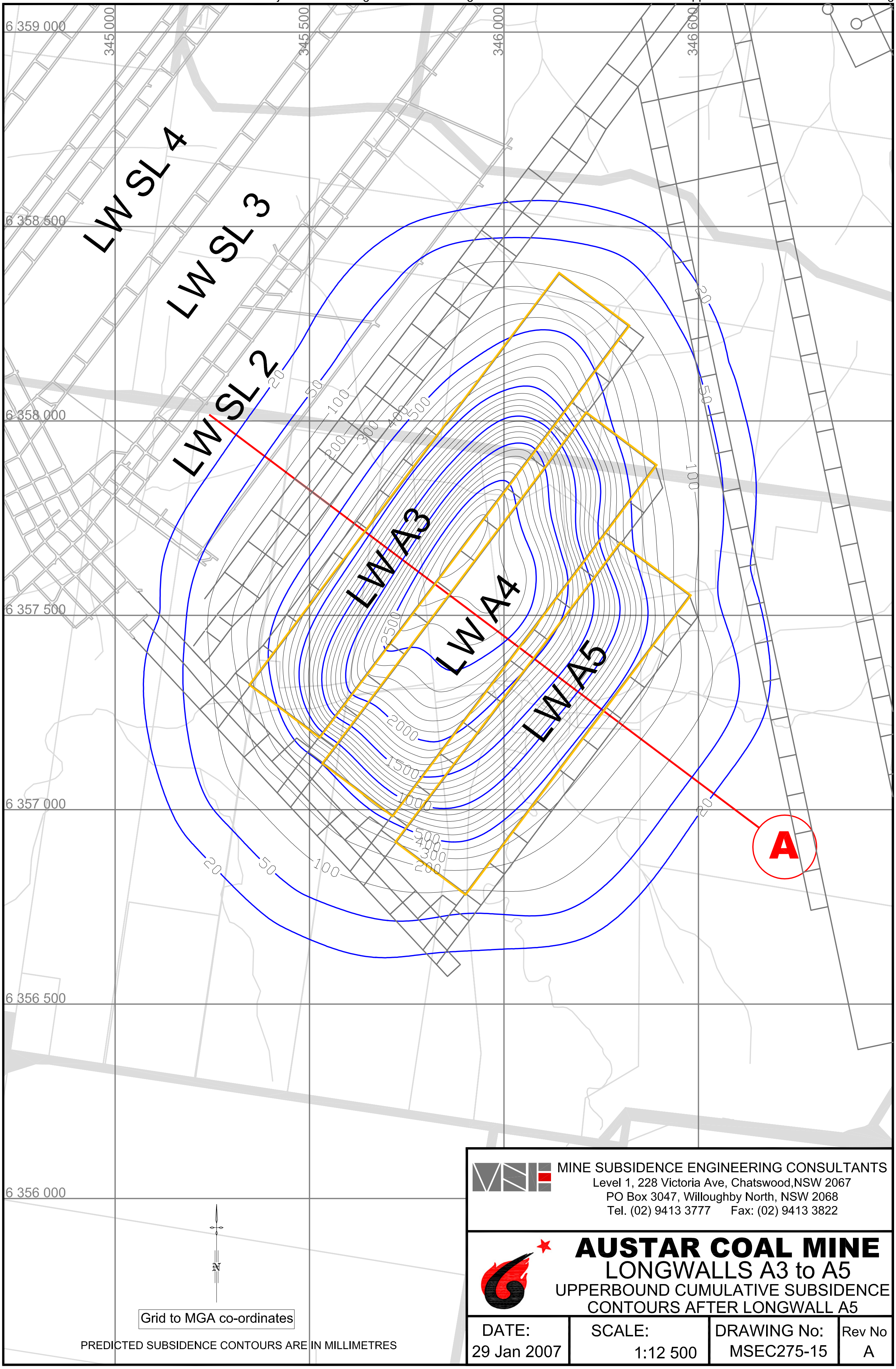

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AUSTAR COAL MINE
LONGWALLS A3 to A5
UPPERBOUND CUMULATIVE SUBSIDENCE CONTOURS AFTER LONGWALL A5

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