Austar Coal Mine

Austar Coal Mine
ENVIRONMENTAL ASSESSMENT

Stage 3 Modification

VOLUME 2
Appendices 9 - 11

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Environmental Consultants

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APPENDIX 9

Subsidence Analysis and Assessment (MSEC)

mine subsidence ENGINEERING CONSULTANTS

Austar Coal Mine:

Stage 3 – Longwalls A7 to A19

Subsidence Predictions and Impact Assessments for Natural Features and Surface Infrastructure in Support of a Modification to the Development Consent

DOCUMENT REGISTER

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01	Draft Issue	JB	-	17th Mar 11
A	Final Issue	JB	AAW	13th May 11

Report produced to:- Support a Modification to the Development Consent for submission to the Department of Planning.

Associated reports:- MSEC309 (Revision D) – 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 A6 to A17 in Support of a Part 3A Application (September 2008).

MSEC389 (Revision B) – End of Panel Subsidence Monitoring Report for Austar Longwalls A1 and A2 (January 2009).

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

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

Austar Coal Mine Pty Limited (Austar) has completed the extraction of Longwalls A1 and A2 in Stage 1 and Longwall A3 in Stage 2 of the Austar Coal Mine (the Mine) using Longwall Top Coal Caving (LTCC) mining techniques. At the time of this report, Austar was in the process of extracting Longwall A4 in Stage 2 of the Mine. Austar also proposes to extract Longwalls A5 and A5a within Stage 2, which are the subject of separate approvals.

Austar proposes to continue underground coal mining operations by extracting longwalls in Stage 3, which is located to the east of Stage 2. Austar submitted a Part 3A Application for the extraction of the proposed Longwalls A6 to A17 in Stage 3 in October 2008. Report No. MSEC309 (Revision D) was issued on the 18th September 2008 in support of that application. The Department of Planning granted Austar approval under the Part 3A approval process on the 6th September 2009.

Austar now proposes to modify the longwalls in Stage 3. The longwall layout adopted in the original Part 3A Application and in Report No. MSEC309 is referred to as the *Previous Layout* in this report. The proposed modified longwall layout is referred to as the *Modified Layout* in this report.

The Modified Layout in Stage 3 comprises 13 proposed longwalls, referred to as Longwalls A7 to A19. The locations of the proposed Longwalls A7 to A19 in the Modified Layout are shown in Drawing No. MSEC484-01, in Appendix G, at the end of this report.

Mine Subsidence Engineering Consultants (MSEC) has been commissioned by Austar to study the modified 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 Modification to the original Development Consent to be assessed by the Department of Planning.

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

Austar proposes to extract Longwalls A7 to A19 from the Greta Seam, which has an overall height varying between 4.0 metres and 8.0 metres within the proposed extents of the longwalls. The LTCC equipment will fully mine the bottom 3 metres of the seam, and recover approximately 85 % of the top coal in the seam.

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 using local data, and the subsidence model used to predict the conventional subsidence parameters for the proposed longwalls.

Chapter 4 provides the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed longwalls, based on the Modified Layout. Comparisons of these maximum predicted subsidence parameters with those obtained based on the Previous Layout (i.e. Report No. MSEC309) are also provided in this chapter.

Chapters 5 through to 9 provide the descriptions and the predicted subsidence parameters for each of the natural features and items of surface infrastructure, based on the Modified Layout. Comparisons of these predicted subsidence parameters with those obtained based on the Previous Layout (i.e. Report No. MSEC309) are also provided in these chapters. The impact assessments for each of these features have also been carried out based on the predicted subsidence parameters, for the Modified Layout.

Comparisons between the maximum predicted subsidence parameters resulting from the extraction of the Stage 3 longwalls, based on the Previous and Modified Layouts, is provided in Table 1.

Table 1 Maximum Predicted Total Conventional Subsidence Parameters Resulting from the Extraction of the Stage 3 Longwalls

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Report No. MSEC309)	1925	6.7	0.06	0.12
Modified Layout (Report No. MSEC484)	1800	6.5	0.05	0.09

It can be seen from the above table, that the maximum predicted subsidence parameters, based on the Modified Layout, are similar to but slightly less than those predicted based on the Previous Layout. The reason for this is that, although the longwall void widths are proposed to be increased from 227 metres to 237 metres, the chain pillars are also proposed to be increased from 45 metres to 55 metres. The maximum predicted subsidence is governed by pillar compression, due to the high depths of cover above the proposed longwalls and, therefore, the reduction in subsidence resulting from the larger chain pillar widths outweighs the increased subsidence resulting from the larger void widths.

A summary of the changes to the maximum predicted subsidence parameters for each natural feature and item of surface infrastructure, resulting from the proposed longwall modifications, is provided in Table 2.

Table 2 Changes in the Maximum Predicted Subsidence Parameters for Each Natural Feature and Item of Surface Infrastructure Resulting from the Proposed Longwall Modifications

Feature	Description of Changes in Maximum Predicted Subsidence Parameters
Cony Creek	Predictions based on the Modified Layout are similar to but slightly less than those predicted based on the Previous Layout
Sandy Creek	Predictions based on the Modified Layout are of a similar order of magnitude to but slightly greater than those predicted based on the Previous Layout
Steep Slopes	Predictions based on the Modified Layout are similar to or slightly less than those predicted based on the Previous Layout
Roads	Predictions based on the Modified Layout are similar to or slightly less than those predicted based on the Previous Layout
Road Bridges	Predictions based on the both the Modified and Previous Layouts are small, with the maximum predicted subsidence being less than 50 mm
Drainage Culverts	Predictions based on the Modified Layout are similar to or slightly less than those predicted based on the Previous Layout
Electrical Infrastructure	Predictions based on the Modified Layout are similar to or slightly less than those predicted based on the Previous Layout
Telecommunications Infrastructure	Predictions based on the Modified Layout are similar to or slightly less than those predicted based on the Previous Layout
Survey Control Marks	The overall levels of predicted movement based on the Modified Layout are similar to or slightly less than those predicted based on the Previous Layout
Rural Building Structures, Tanks, Pools and Farm Dams	The overall levels of predicted movement based on the Modified Layout are similar to or slightly less than those predicted based on the Previous Layout. The predicted movements for each individual structure slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each structure relative to the proposed longwalls
Archaeological Sites	Predictions for the Grinding Groove Site based on the Modified Layout are much less than those predicted based on the Previous Layout. Predictions for the remaining sites based on the Modified Layout are similar to or slightly less than those predicted based on the Previous Layout
Historical Sites	The overall levels of predicted movement based on the Modified Layout are similar to or slightly less than those predicted based on the Previous Layout. The predicted movements for each individual site slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each structure relative to the proposed longwalls.
Houses	The overall levels of predicted movement based on the Modified Layout are similar to or slightly less than those predicted based on the Previous Layout. The predicted movements for each individual house slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each structure relative to the proposed longwalls.

It can be seen from the above table, that the predicted mine subsidence movements at the natural features and items of surface infrastructure, based on the Modified Layout, are of a similar order of magnitude to those predicted based on the Previous Layout. In some cases the predicted movements slightly increase and in other cases the predicted movements slightly decrease, as a result of the proposed longwall modifications, depending on the locations of each feature relative to the proposed longwalls.

In all cases, the potential impacts on the natural features and items of surface infrastructure are not expected to change significantly as a result of the proposed longwall modifications. The proposed management strategies for all the features, therefore, are the same as those previously recommended in Report No. MSEC309 and the Part 3A Application.

The assessments provided in this report indicate that the levels of impact on the natural features and the items of surface infrastructure can be managed by the preparation and implementation of subsidence management strategies. It should be noted that more detailed assessments of the impacts of mine subsidence on some natural features and items of surface infrastructure have been prepared by other consultants, experts in their fields, 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, to compare the observed ground movements with those predicted, and to periodically review the predictions and impact assessments in the light of measured data.

CONTENTS

Tables

Tables are prefixed by the number of the chapter or the letter of the appendix in which they are presented.

Figures

Figures are prefixed by the number of the chapter or the letter of the appendix in which they are presented.

Drawings

Drawings referred to in this report are included in Appendix G at the end of this report.

1.1. Background

Austar Coal Mine Pty Limited (Austar) has completed the extraction of Longwalls A1 and A2 in Stage 1 and Longwall A3 in Stage 2 of the Austar Coal Mine (the Mine) using Longwall Top Coal Caving (LTCC) mining techniques. At the time of this report, Austar was in the process of extracting Longwall A4 in Stage 2 of the Mine. Austar also proposes to extract Longwalls A5 and A5a within Stage 2, which are the subject of separate approvals.

Austar proposes to continue underground coal mining operations by extracting longwalls in Stage 3 of the Mine, which is located to the east of Stage 2. Austar submitted a Part 3A Application for the extraction of the proposed Longwalls A6 to A17 in Stage 3 in October 2008. Report No. MSEC309 (Revision D) was issued on the 18th September 2008 in support of that application. The Department of Planning granted Austar approval under the Part 3A approval process on the 6th September 2009.

Austar now proposes to modify the longwalls in Stage 3. The longwall layout adopted in the original Part 3A Application and in Report No. MSEC309 is referred to as the *Previous Layout* in the remainder of this report. The proposed modified longwall layout is referred to as the *Modified Layout* in the remainder of this report. A comparison of the longwall layouts based on the Previous and Modified Layouts is provided in Fig. 1.1.

Fig. 1.1 Comparison of the Previous and Modified Layouts of the Proposed Longwalls in Stage 3

The Modified Layout in Stage 3 comprises 13 proposed longwalls, referred to as Longwalls A7 to A19. The locations of the proposed Longwalls A7 to A19 in the Modified Layout are also shown in Drawing No. MSEC484-01, in Appendix G, at the end of this report.

Mine Subsidence Engineering Consultants (MSEC) has been commissioned by Austar to study the proposed longwalls in the Modified Layout, identify all natural features and items of surface infrastructure above the proposed longwalls, and to prepare subsidence predictions and impact assessments for the features that could be affected by the extraction of the proposed modified longwalls. Comparisons of the predicted mine subsidence movements with those obtained based on the Previous Layout have also been undertaken.

The Modified Layout of the proposed longwalls and the Study Area, as defined in Section 2.2, have been overlaid on an orthophoto of the area, which is shown in Fig. 1.2. The major natural features and surface infrastructure in the vicinity of the proposed longwalls can be seen in this figure.

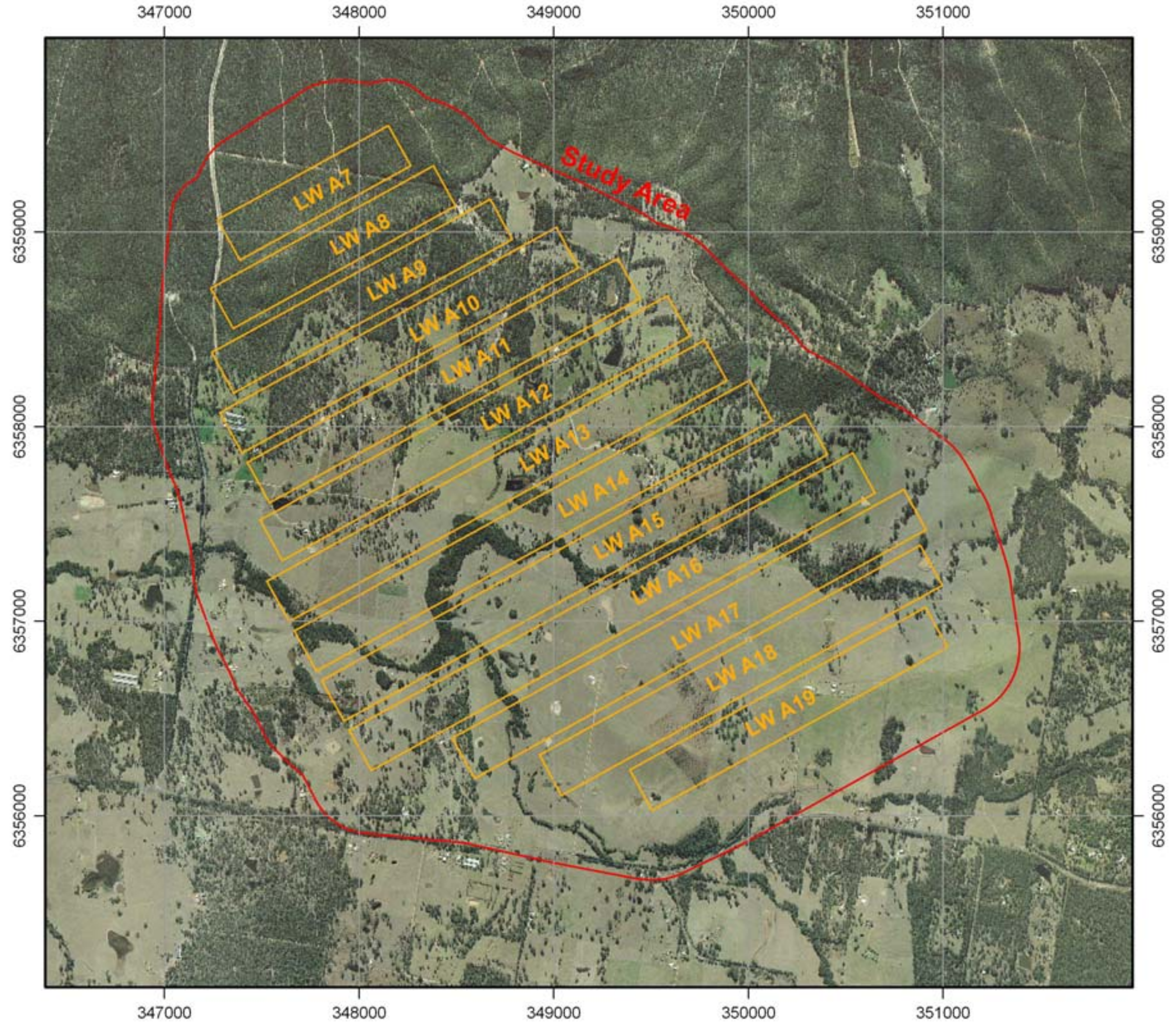

Fig. 1.2 Aerial Photograph Showing the Modified Layout and the Study Area

This report provides information that will support a Modification to the Development Consent to be submitted to the Department of Planning. In some cases, this report will refer to other sources of information on specific natural features and items of surface infrastructure, and these reports should be read in conjunction with this report.

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 using local data, and the subsidence model used to predict the conventional subsidence parameters for the proposed longwalls.

Chapter 4 provides the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed longwalls, based on the Modified Layout. Comparisons of these maximum predicted subsidence parameters with those obtained based on the Previous Layout (i.e. Report No. MSEC309) are also provided in this chapter.

Chapters 5 through to 9 provide the descriptions and the predicted subsidence parameters for each of the natural features and items of surface infrastructure, based on the Modified Layout. Comparisons of these predicted subsidence parameters with those obtained based on the Previous Layout (i.e. Report No. MSEC309) are also provided in these chapters. The impact assessments for each of these features have also been carried out based on the predicted subsidence parameters, for the Modified Layout.

1.2. Mining Geometry

The Modified Layout of the proposed Longwalls A7 to A19 within the Greta Seam is shown in Drawing No. MSEC484-01, in Appendix G. A summary of the dimensions of the proposed longwalls in the Modified Layout is provided in Table 1.1.

Table 1.1 Geometry of the Proposed Stage 3 Longwalls Based on the Modified Layout

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
LWA7	1,000	237	-
LWA8	1,300	237	55
LWA9	1,635	237	55
LWA10	1,975	237	55
LWA11	2,175	237	55
LWA12	2,390	237	55
LWA13	2,565	237	55
LWA14	2,670	237	55
LWA15	2,835	237	55
LWA16	2,955	237	55
LWA17	2,650	237	55
LWA18	2,235	237	55
LWA19	1,735	237	55

The Previous Layout comprised longwalls having overall lengths varying between 1,450 metres and 3,200 metres, overall void widths of 227 metres and chain pillars of 45 metres.

The depth of cover to the Greta Seam directly above the proposed longwalls varies between a minimum of 455 metres, above the tailgate of Longwall A7, and a maximum of 760 metres, towards the south-western end of Longwall A19. The seam floor within Stage 3 generally dips from the north to the south.

The Greta Seam splits in the south-eastern corner of the mining area, the approximate location of which is shown in Drawings Nos. MSEC484-04 and MSEC484-06.

On the western side of the seam split line, the available seam thickness within the extents of the proposed longwalls varies between 5.5 metres and 8.0 metres, which is proposed to be extracted using LTCC mining techniques. It is proposed that the LTCC equipment will be used to fully extract the bottom 3 metres of the seam and recover approximately 85 % of the remaining top coal.

On the eastern side of the seam split line, the available seam thickness within the extents of the proposed longwalls is approximately 4 metres, which is proposed to be extracted using conventional longwall mining techniques. It is proposed that the conventional longwall mining will extract the full seam thickness.

The surface level contours, seam floor contours, seam thickness contours and depth of cover contours are shown in Drawings Nos. MSEC484-02, MSEC484-03, MSEC484-04 and MSEC484-05, respectively. The known geological structures at seam level are shown in Drawing No. MSEC484-06.

1.3. Surface Topography

The surface level contours in the vicinity of the proposed longwalls are shown in Drawing No. MSEC484-02. The surface of the land within the central and southern parts of the Study Area is generally flat to undulating.

The major topographical feature within the Study Area is the **Broken Back Range** which is located directly above Longwalls A7 to A9 and above the commencing (north-eastern) ends of Longwalls A14 to A16. There is also a hill located in the southern part of the Study Area above the middle of the proposed Longwall A19.

The surface levels directly above the proposed longwalls vary from a low point of approximately 120 metres AHD, above the tailgate of Longwall A7, to a high point of approximately 210 metres AHD, above the commencing (north-eastern) end of Longwall A15.

1.4. Geological Details

The Austar Coal Mine lies in the Newcastle Coalfield, within the Northern Sydney Basin. A 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 1.2. The strata shown in this table were laid down between the Early Permian and the Middle Triassic Periods.

Longwalls A7 to A19 are proposed to be extracted within the Greta Seam, which is located within the Kitchener Formation of the Greta Coal Measures. The overlying strata comprise the Paxton Formation, which consists of interbedded sandstone and siltstone layers up to 20 metres thick. The uppermost layer in the Greta Coal Measures is the Pelton Seam, which is less than 0.5 metres thick. 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 main sequence overlying the Greta Coal Measures is the Branxton Formation, which is part of the Maitland Group sediments from the mid Permian period. The Maitland Group comprises, in order of deposition, the Branxton Formation, Muree Sandstone and Mulbring Siltstone. The Branxton Formation immediately overlies the Greta Coal Measures and is made up of a substantial thickness of sedimentary rocks. The lithology of the Branxton Formation generally consists of the coarser sandstone and conglomerate rocks at the base of the formation, grading to finer deposits of silty sandstone and siltstone at the top of the formation. The upper part of the formation contains a unit known as *Fenestella Shale* that contains numerous fossils of marine invertebrate fauna.

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 known to exist in the vicinity of the proposed longwalls are shown in Drawing No. MSEC484-06. There are no major faults or dykes that have been identified within the extents of the proposed longwalls. The *Quorrobolong Fault Zone* is located to the west of the proposed longwalls. The *Abernethy Fault Zone* is located to the north of the proposed longwalls.

Table 1.2 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			

The surface lithology within the Study Area is shown in Fig. 1.3, which shows the proposed longwalls overlaid on Geological Series Sheet Quorrobolong 9132-2-S, which is published by Industry and Investment NSW (I&I). It can be seen from this figure, that the surface lithology within the Study Area comprises predominately of areas derived from the Branxton Formation (Pmb) and Quaternary soils (Qa).

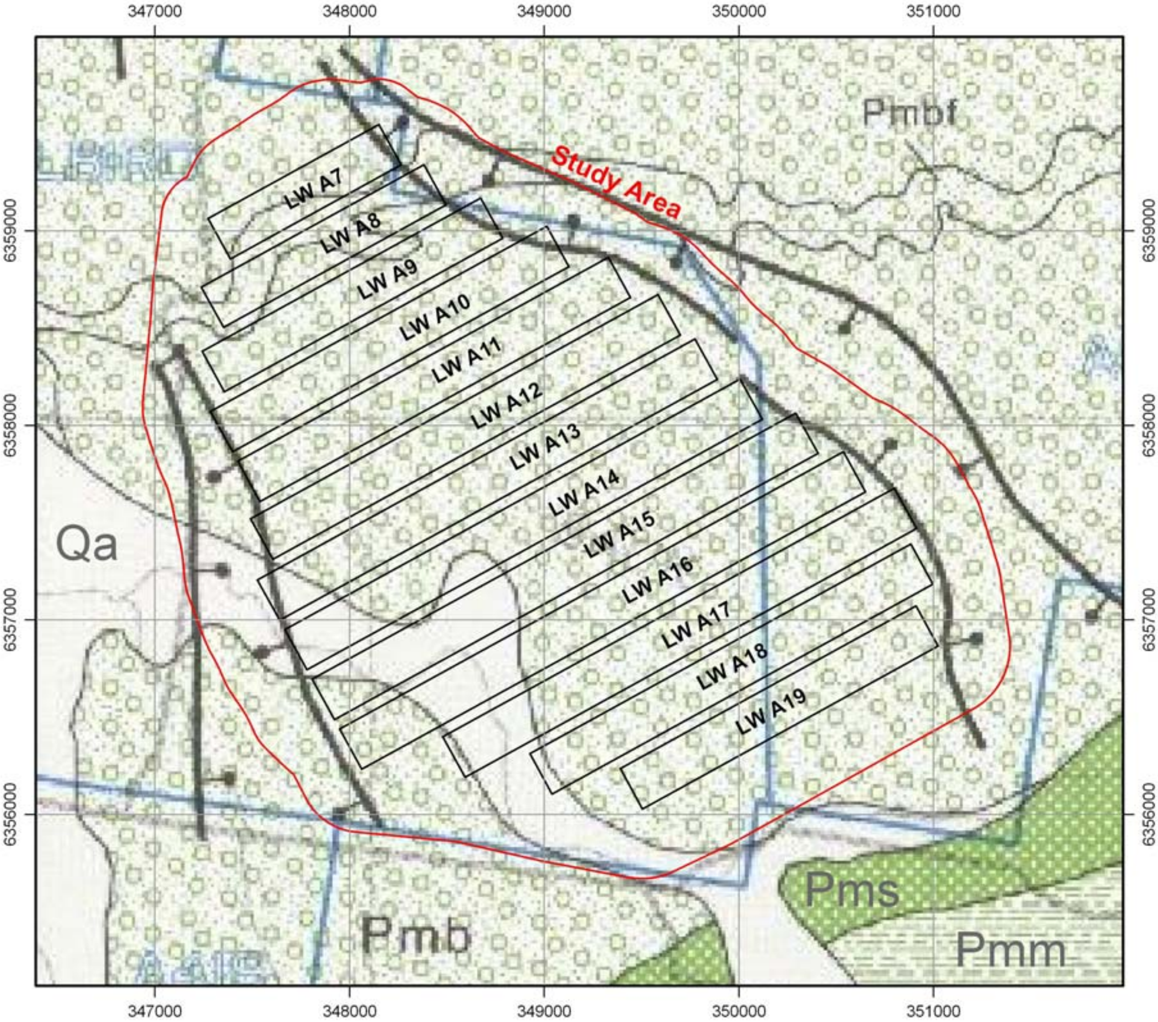

Fig. 1.3 Surface Lithology within the Study Area
Geological Series Sheet Quorrobolong 9132-2-S (I&I)

2.1. Definition of the Extent of the Longwall Mining Area

The *Extent of the Longwall Mining Area* is defined as the maximum extents of the proposed longwalls (i.e. second workings) that are shown in Drawing No. MSEC484-01.

2.2. Definition of the Study Area

The *Study Area* is defined as the surface area that is likely to be affected by the proposed mining of Longwalls A7 to A19 in the Greta Seam at Austar Coal Mine, based on the Modified Layout. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:-

- The 26.5 degree angle of draw line from the proposed extents of Longwalls A7 to A19, and
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour resulting from the extraction of the proposed Longwalls A7 to A19.

The depth of cover contours are shown in Drawing No. MSEC484-05. It can be seen from this drawing, that the depth of cover varies between 455 metres and 760 metres directly above the proposed longwalls. The 26.5 degree angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 230 metres and 380 metres around the limits of the proposed extraction areas.

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 Sections 3.6 and 3.7. The angle of draw to the predicted total 20 mm subsidence contour has been calibrated to 30 degrees adjacent to the maingates and tailgates of the proposed longwalls, in order to match those observed over the previously extracted longwalls at the colliery.

The predicted total 20 mm subsidence contour, therefore, is generally located outside the 26.5 degree angle of draw line adjacent to the longitudinal edges of the proposed longwalls, and is generally located inside the 26.5 degree angle of draw line adjacent to the commencing and finishing ends of the proposed longwalls. A line has therefore been drawn defining the Study Area, based upon the 26.5 degree angle of draw line and the predicted total 20 mm subsidence contour, whichever is furthest from the longwalls, and is shown in Drawing No. MSEC484-01.

There are areas that lie outside the Study 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 in the assessments provided in this report. These features are listed below and details of these are provided in later sections of the report:-

- Watercourses, within the predicted limits of 20 mm total upsidence and 20 mm total closure,
- Groundwater bores, and
- Survey control marks.

2.3. Natural Features and Items of Surface Infrastructure within the Study Area

The major natural features and items of surface infrastructure within the Study Area can be seen in the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA), numbered QUORROBOLONG 9132-2-S. The Extent of the Longwall Mining Area and the Study Area have been overlaid on an extract of this CMA Map and are shown in Fig. 2.1.

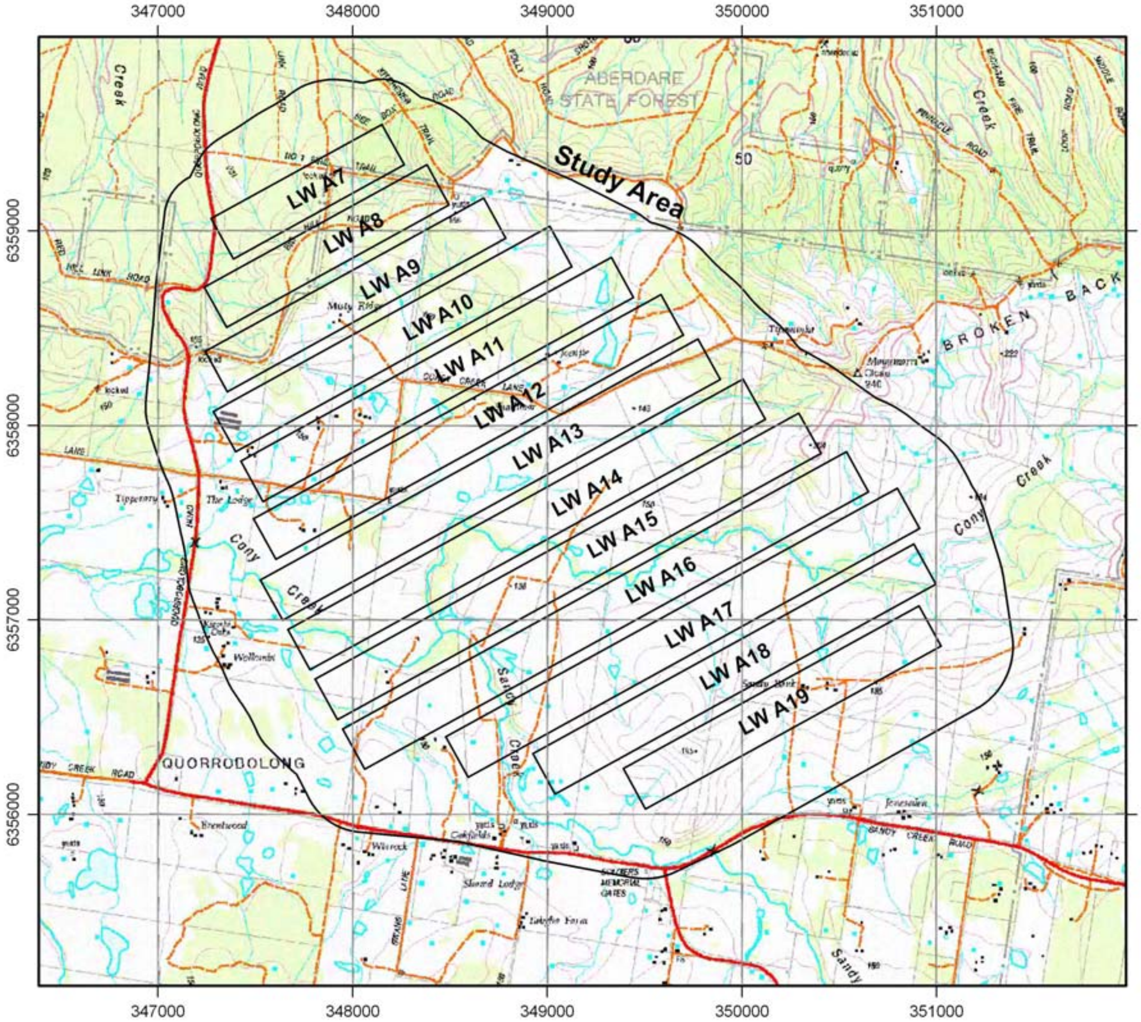

Fig. 2.1 Extent of the Longwall Mining Area and the Study Area Overlaid on CMA Map No. Quorrobolong 9132-2-S

A summary of the natural features and items of surface infrastructure within the Study Area is provided in Table 2.1. The locations of the natural features and items of surface infrastructure are shown in Drawings Nos. MSEC484-07 to MSEC484-17, in Appendix G. The descriptions of these features are provided in Chapters 5 through to 9, as indicated by the Section number in Table 2.1.

The predicted subsidence parameters for the natural features and items of surface infrastructure are provided in Chapters 5 through to 9. Comparisons of these predicted subsidence parameters with those obtained based on the Previous Layout (i.e. Report No. MSEC309) are also provided in these chapters.

Table 2.1 Natural Features and Surface Infrastructure

Item	Within Study Area	Section Number Reference
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	×	
Rivers or Creeks	✓	5.1
Aquifers or Known Groundwater Resources	✓	5.2
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	×	
Steep Slopes	✓	5.3
Escarpments	×	
Land Prone to Flooding or Inundation	✓	5.4
Swamps, Wetlands or Water Related Ecosystems	✓	5.5
Threatened or Protected Species	×	
National Parks	×	
State Forests	✓	5.6
State Conservation Areas	✓	5.7
Natural Vegetation	✓	5.8
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
	×	
PUBLIC UTILITIES	×	
Railways	×	
Roads (All Types)	✓	6.1
Bridges	✓	6.2
Tunnels	×	
Culverts	✓	6.3
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	✓	6.4
Telecommunication Lines or Associated Plants	✓	6.5
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 Study Area	Section Number Reference
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	✓	7.1
Farm Buildings or Sheds	✓	7.2
Tanks	✓	7.3
Gas or Fuel Storages	✓	7.4
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	✓	7.5
Farm Dams	✓	7.6
Wells or Bores	✓	7.7
Any Other Farm Features	×	
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Factories	×	
Workshops	×	
Business or Commercial Establishments or Improvements	×	
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	✓	8.1 & 8.2
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.6
RESIDENTIAL ESTABLISHMENTS		
Houses	✓	9.1
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	✓	9.2 9.3 9.4 9.5
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

3.0 OVERVIEW OF LONGWALL MINING, 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. Further details are provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

The maximum predicted conventional subsidence parameters within the Study Area, resulting from the extraction of the proposed longwalls, are provided in Chapter 4. The predicted subsidence parameters and impact assessments for the natural features and items of surface infrastructure within the Study Area are provided in Chapters 5 through to 9.

3.2. 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 in Stage 1 and Longwall A3 in Stage 2 have been extracted using LTCC mining techniques and Longwall A4 in Stage 2 is currently being extracted using LTCC mining techniques.

The Stage 3 longwalls are proposed to be extracted from the Greta Seam, where the seam thickness locally varies between 4.0 and 8.0 metres within the proposed extents of the longwalls. A typical cross-section through one of the Stage 3 longwalls is shown in Fig. 3.1.

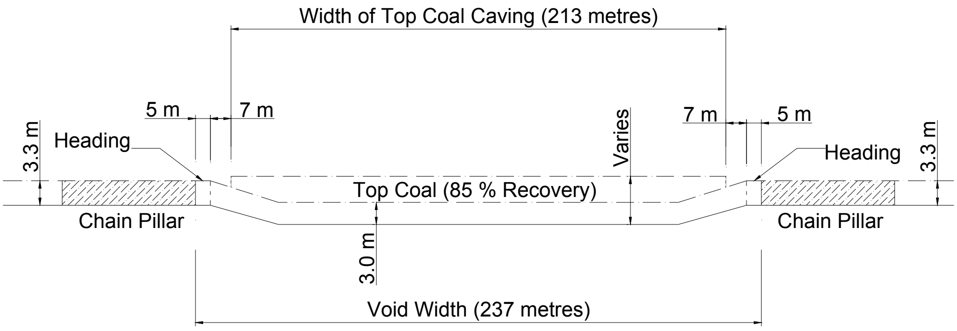

Fig. 3.1 Cross-Section through a Typical Stage 3 Longwall

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 the seam thickness varies between 4.0 and 8.0 metres within the proposed extents of the Stage 3 longwalls, the extracted seam thickness 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 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, depending on a number of factors including longwall geometry, depth of cover, extracted seam thickness and overburden geology. The maximum achievable subsidence in the Newcastle Coalfield, for single-seam super-critical conditions, is typically between 55 % and 60 % of the extracted seam thickness.

3.3. Overview of Conventional Subsidence Parameters

The normal ground movements resulting from the extraction of pillars or longwalls are referred to as conventional or 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 beyond the longwall goaf edges, 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 %, or 1 in 1000.

- **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* (km^{-1}), 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 the relative differential horizontal movements of the ground. **Normal 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.

  Whilst mining induced normal strains are measured along monitoring lines, ground shearing can also occur both vertically and horizontally across the directions of monitoring lines. Most of the published mine subsidence literature discusses the differential ground movements that are measured along subsidence monitoring lines, however, differential ground movements can also be measured across monitoring lines using 3D survey monitoring techniques.

- **Horizontal shear deformation** across monitoring lines can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. It is not possible, however, to determine the horizontal shear strain across a monitoring line using traditional 2D or 3D monitoring techniques.

  High deformations along monitoring lines (i.e. normal strains) are generally measured where high deformations have been measured across the monitoring line (i.e. shear deformations). Conversely, high deformations across monitoring lines are also generally measured where high normal strains have been measured along the monitoring line.

The **incremental** subsidence, tilts, curvatures and strains are the additional parameters which result from the extraction of each longwall. The **cumulative** subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of a series of longwalls. The **total** subsidence, tilts, curvatures and strains are the final parameters at the completion of a series of longwalls. The **travelling** tilts, curvatures and strains are the transient movements as the longwall extraction face mines directly beneath a given point

3.4. Far-field Movements

The measured horizontal movements at survey marks which are located beyond the longwall goaf edges and over solid unmined coal areas are often much greater than the observed vertical movements at those marks. These movements are often referred to as *far-field movements*.

Far-field 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 impacts on natural features or built environments, except where they are experienced by large structures which are very sensitive to differential horizontal movements.

In some cases, higher levels of far-field horizontal movements have been observed where steep slopes or surface incisions exist nearby, as these features influence both the magnitude and the direction of ground movement patterns. Similarly, increased horizontal movements are often observed around sudden changes in geology or where blocks of coal are left between longwalls or near other previously extracted series of longwalls. In these cases, the levels of observed subsidence can be slightly higher than normally predicted, but these increased movements are generally accompanied by very low levels of tilt, curvature and strain.

Far-field horizontal movements and the method used to predict such movements are described further in Section 4.7.

3.5. Overview of Non-Conventional Subsidence Movements

Conventional subsidence profiles are typically smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata spanning the extracted void. Normal conventional subsidence movements due to longwall extraction are easy to identify where longwalls are regular in shape, the extracted coal seams are relatively uniform in thickness, the geological conditions are consistent and surface topography is relatively flat.

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near surface strata layers. Where the depth of cover is greater than 400 metres, such as is the case within the Study Area, the observed subsidence profiles along monitoring survey lines are generally smooth. Where the depth of cover is less than 100 metres, the observed subsidence profiles along monitoring lines are generally irregular. Very irregular subsidence movements are observed with much higher tilts and strains at very shallow depths of cover where the collapsed zone above the extracted longwalls extends up to or near to the surface.

Irregular subsidence movements are occasionally observed at the deeper depths of cover along an otherwise smooth subsidence profile. The cause of these irregular subsidence movements can be associated with:-

- issues related to the timing and the method of the installation of monitoring lines,
- sudden or abrupt changes in geological conditions,
- steep topography, and
- valley related mechanisms.

Non-conventional movements due to geological conditions and valley related movements are discussed in the following sections.

3.5.1. Non-conventional Subsidence Movements due to Changes in Geological Conditions

It is believed that most non-conventional ground movements are a result of the reaction of near surface strata to increased horizontal compressive stresses due to mining operations. Some of the geological conditions that are believed to influence these irregular subsidence movements are the blocky nature of near surface sedimentary strata layers and the possible presence of unknown faults, dykes or other geological structures, cross bedded strata, thin and brittle near surface strata layers and pre-existing natural joints. The presence of these geological features near the surface can result in a bump in an otherwise smooth subsidence profile and these bumps are usually accompanied by locally increased tilts, curvatures and strains.

Even though it may be possible to attribute a reason behind most observed non-conventional ground movements, there remain some observed irregular ground movements that still cannot be explained with the available geological information. The term "*anomaly*" is therefore reserved for those non-conventional ground movement cases that were not expected to occur and cannot be explained by any of the above possible causes.

It is not possible to predict the locations and magnitudes of non-conventional anomalous movements. In some cases, approximate predictions for the non-conventional ground movements can be made where the underlying geological or topographic conditions are known in advance. It is expected that these methods will improve as further knowledge is gained through ongoing research and investigation.

In this report, non-conventional ground movements are being included statistically in the predictions and impact assessments, by basing these on the frequency of past occurrence of both the conventional and non-conventional ground movements and impacts. The analysis of strains provided in Section 4.5 includes those resulting from both conventional and non-conventional anomalous movements. The impact assessments for the natural features and items of surface infrastructure, which are provided in Chapters 5 through to 9, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

3.5.2. Non-conventional Subsidence Movements due to Steep Topography

Non-conventional movements can also result from downslope movements where longwalls are extracted beneath steep slopes. In these cases, elevated tensile strains develop near the tops of the steep slopes and elevated compressive strains develop near the bases of the steep slopes. The potential impacts resulting from down slope movements include the development of tension cracks at the tops of the steep slopes and compression ridges at the bottoms of the steep slopes.

Further discussions on the potential for down slope movements for the steep slopes within the Study Area are provided in Section 5.2.

3.5.3. Valley Related Movements

The watercourses within the Study 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 why valley related movements are less commonly observed in the Newcastle Coalfield could be that the conventional subsidence movements are typically much larger than those observed in the Southern Coalfield and tend to mask any smaller valley related movements which may occur.

Valley bulging movements are a natural phenomenon, resulting from the formation and ongoing development of the valley, as illustrated in Fig. 3.2. The potential for these natural movements are influenced by the geomorphology of the valley.

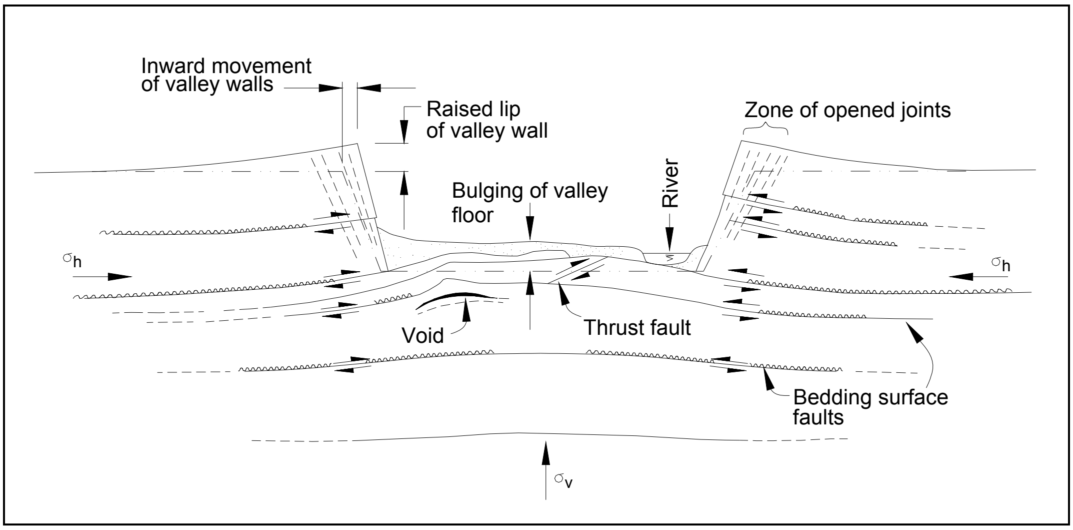

Fig. 3.2 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

Valley related movements can be caused by or accelerated by mine subsidence as the result of a number of factors, including the redistribution of horizontal in-situ stresses and down slope movements. Valley related movements are normally described by the following parameters:-

- **Upsidence** is the reduced subsidence, or the relative uplift within a valley which results from the dilation or buckling of near surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.

- **Closure** is the reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides.

- **Compressive Strains** occur within the bases of valleys as a result of valley closure and upsidence movements. **Tensile Strains** also occur in the sides and near the tops of the valleys as a result of valley closure movements. The magnitudes of these strains, which are typically expressed in the units of *millimetres per metre (mm/m)*, are calculated as the changes in horizontal distance over a standard bay length, divided by the original bay length.

The predicted valley related movements resulting from the extraction of the proposed longwalls were made using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002). Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*. There are other methods available to predict valley related movements, however, the ACARP method was adopted for this project as it is the most thoroughly used and tested method

3.6. The Incremental Profile Method

The predicted conventional subsidence parameters for the Stage 3 longwalls were obtained using the calibrated 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 and further details can be obtained from the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

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 and typically 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 metres and 3 metres, 15 % are for cases having seam extraction heights between 3 metres and 4 metres, and 4 % are for cases having seam extraction heights between 4 metres and 5 metres. The empirical database now also includes Longwalls A1 and A2 in Stage 1 and Longwall A3 in Stage 2 at Austar Coal Mine, which used LTCC mining techniques, and are discussed further in Section 3.8.

The Stage 3 longwalls are proposed to be extracted using LTCC mining techniques. The available seam thickness on the western side of the seam split line varies between 5.5 metres and 8.0 metres. The LTCC equipment will be used to extract the bottom 3 metres of the seam and recover approximately 85 % of the remaining top coal. That is, the effective extraction height for the Stage 3 longwalls varies between 5.1 metres and 7.3 metres on the western side of the seam split line. The available seam thickness on the eastern side of the seam split line is 4 metres, which is proposed to be extracted using conventional longwall mining techniques.

Although the effective extraction height for the Stage 3 longwalls varies up to 7.3 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 overburden is expected to be capable of spanning the extracted voids with minimal sag subsidence and then, based on a pillar height of 3.3 metres, the maximum achievable subsidence due to pillar compression alone would be in the order of 45 % of the maximum extracted seam thickness (i.e. 3.3 metre pillars / 7.3 metre extraction height), based on super-critical conditions.

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.

3.7. Calibration of the Incremental Profile Method

Austar and Strata Control Technology (SCT) provided local monitoring data over the previously extracted longwalls at the colliery, prior to extracting Longwalls A1 and A2 in Stage 1 and Longwall A3 in Stage 2, which included 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. MSEC484-01.

The previously extracted longwalls at the colliery (excluding Longwalls A1 to A3) have void widths varying between 155 metres and 225 metres, depths of cover varying between 350 metres and 510 metres and extracted seam thicknesses varying between 3.1 metres 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, which can reduce the sag subsidence directly above the extracted longwalls. The model was also not modified for the presence of geological structures, as no significant geological structures had been identified at seam level within the goaf areas of the proposed longwalls.

It was found that the values of maximum observed incremental subsidence for the previously extracted longwalls along each monitoring line were less than the values of 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 using the standard Incremental Profile Method were greater than those observed. Also, as described in Section 3.8, the maximum observed subsidence resulting from the extraction of Longwalls A1 and A2 in Stage 1 and Longwall A3 in Stage 2, were less than those predicted using the calibrated Incremental Profile Method.

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. 3.3.

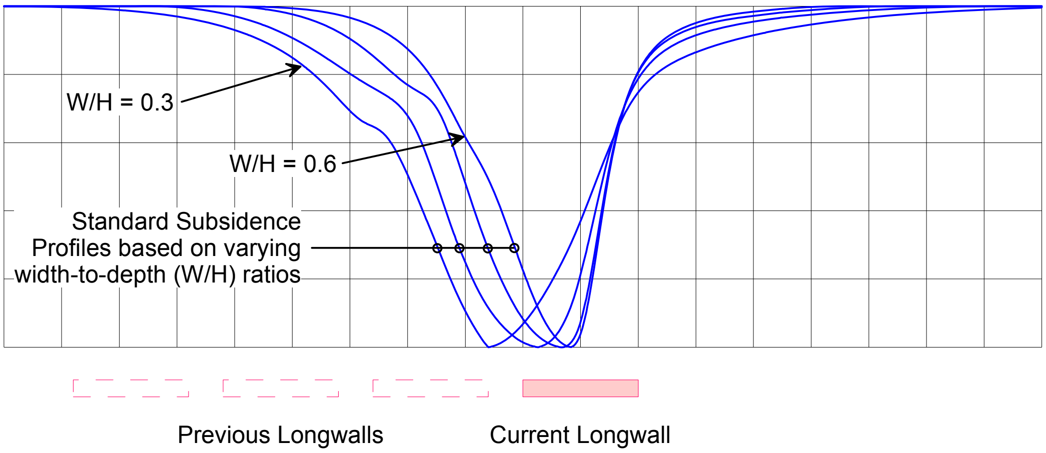

Fig. 3.3 Standard Normalised Profiles based on Varying Width-to-Depth Ratios

The reason that the observed subsidence profiles were wider or beamier than the predicted profiles and that the maximum observed subsidence was less than the maximum predicted subsidence was the result of the geology of the overburden. The massive sandstones in the overlying Branxton Formation were capable of spanning the extracted voids with minimal sag subsidence and, hence, the observed subsidence profiles and the magnitudes of the observed subsidence were governed, to a large extent, by pillar compression.

The shapes of the back-predicted incremental subsidence profiles along each monitoring line were adjusted to more closely match those observed, by adopting the standard Incremental Profile Method Newcastle Coalfield subsidence profiles, based on smaller panel width-to-depth ratios. 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. No adjustments were made to the magnitudes of the maximum back-predicted incremental subsidence for each longwall.

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 to the longitudinal edges of the longwalls, 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 reasonably 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 to maximum predicted subsidence, as shown in Fig. F.09, are due to the varying longwall geometries, depths of cover, extracted seam heights, and the local geology at each monitoring line.

3.8. Comparison of the Observed and Predicted Subsidence Profiles

3.8.1. Stage 1 Longwalls A1 and A2

Subsequent to the issue of Report No. MSEC309, the extraction of Longwalls A1 and A2 in Stage 1 were completed using LTCC mining techniques. The comparisons between the observed movements and those predicted using the calibrated Incremental Profile Method were provided in Report No. MSEC389 (Revision B), which was issued in January 2009. A brief overview of these comparisons is provided below.

The mine subsidence movements were monitored during the extraction of Longwalls A1 and A2. The comparisons between the observed and predicted movements along Line 1A, Line 1B and Line 2 are provided in Fig. F10, Fig. F11 and Fig. F12, respectively, in Appendix F.

It can be seen from these figures, that the maximum observed subsidence along the monitoring lines were typically less than those predicted using the calibrated Incremental Profile Method. The only exception was the maximum observed subsidence along Line 2, after the extraction of Longwall A1, of 75 mm which was slightly greater than the maximum predicted of 60 mm.

The observed tilts, tensile strains and compressive strains along the monitoring lines, after the extraction of Longwall A1, were generally in the order of survey tolerance. There were a number of spikes in the observed profiles which appear to have resulted from disturbed survey marks.

The maximum observed tilts, tensile strains and compressive strains along the monitoring lines, after the extraction of Longwall A2, were typically less than or similar to those predicted using the calibrated Incremental Profile Method. The only exceptions were the maximum observed tensile and compressive strains along Line 1B of 2.5 mm/m and 2.2 mm/m, respectively, which were greater than the predictions of 1.3 mm/m and 1.8 mm/m, respectively.

It is noted, however, that the maximum observed tensile strain occurred at the top of a ridge line and, therefore, could be influenced by down slope movements. It is also noted, that the maximum observed compressive strain occurred approximately 250 metres north of the active longwall and, therefore, was likely to be the result of a disturbed survey mark.

The seam thickness within the extracted goaf areas of the Longwalls A1 and A2 was approximately 6.5 metres. The LTCC equipment extracts the bottom 3 metres of the seam and recovers most of the remaining top coal. Based on the coal tonnages, the average extracted seam thickness for Longwalls A1 and A2 was approximately 5.5 metres (SCT, 2008), which equates to a recovery of approximately 70 % of the top coal.

3.8.2. Stage 2 Longwalls A3 and A4

The mine subsidence movements were monitored during the extraction of Longwalls A3 and A4 in Stage 2. The comparisons between the observed and predicted movements along Line A3, Line A3X and Line 4 are provided in Fig. F13, Fig. F14 and Fig. F15, respectively, in Appendix F. It is noted that, at the times of the latest surveys for these monitoring lines, Longwall A4 had around 350 metres of extraction remaining.

It can be seen from these figures, that the maximum observed subsidence along the monitoring lines were less than those predicted using the calibrated Incremental Profile Method. The maximum observed subsidence along Lines A3 and A3X were much less than the maximum predicted subsidence, which may indicate that the prediction model is conservative above the first longwall in a series.

The maximum observed subsidence along Line A4 represented around 70 % of the maximum predicted subsidence at the completion of mining. Additional subsidence is expected along this monitoring line, due to the remaining 350 metres of extraction and due to long term residual subsidence, however, the maximum observed subsidence is not expected to exceed that predicted.

The maximum observed tilts along the monitoring lines were generally less than the maximum predicted tilts. Localised and elevated tilts were observed in some locations, which exceeded the predictions, however, it is likely that these have occurred as the result of disturbed survey marks, as they occurred outside of the extents of the longwalls.

The maximum observed strains along the monitoring lines were generally less than 1.0 mm/m tensile and compressive. Two localised and elevated compressive strains were observed along Line A3 which were both around 3.5 mm/m. These localised strains were not accompanied by any bumps or steps in the observed subsidence profiles, which is usually an indicator for Irregular ground movements.

Elevated tensile and compressive strains were also observed along Line A3X and Line 4. It is likely that these strains have occurred as the result of disturbed survey marks, as they occurred outside of the extents of the longwalls.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed Longwalls A7 to A19, based on the Modified Layout. The predicted subsidence parameters and the impact assessments for the natural features and items of surface infrastructure are provided in Chapters 5 through to 9.

The subsidence predictions are based on the latest available surface level contours, seam floor contours and seam thickness contours, which were provided by Austar, and are shown in Drawings Nos. MSEC484-02, MSEC484-03 and MSEC484-04, respectively, in Appendix G. The predicted subsidence parameters are based on the LTCC equipment extracting the bottom 3 metres of the seam and recovering approximately 85 % of the remaining top coal.

The maximum predicted subsidence parameters and the predicted subsidence contours provided in this report show the conventional movements and do not include the valley related upsidence and closure movements, nor the effects of faults and other geological structures. Such effects have been addressed separately in the impact assessments for each feature provided in Chapters 5 through to 9.

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

The maximum predicted conventional subsidence parameters resulting from the extraction of the proposed longwalls were determined using the calibrated Incremental Profile Method, which was described in Chapter 3. A summary of the maximum predicted values of incremental conventional subsidence, tilt and curvature, due to the extraction of each of the proposed longwalls, is provided in Table 4.1.

Table 4.1 Maximum Predicted Incremental Conventional Subsidence, Tilt and Curvature Resulting from the Extraction of Each of the Proposed Longwalls

Longwall	Maximum Predicted Incremental Conventional Subsidence (mm)	Maximum Predicted Incremental Conventional Tilt (mm/m)	Maximum Predicted Incremental Conventional Hogging Curvature (km^{-1})	Maximum Predicted Incremental Conventional Sagging Curvature (km^{-1})
LWA7	475	2.5	0.01	0.04
LWA8	875	4.0	0.03	0.09
LWA9	850	3.5	0.04	0.08
LWA10	850	3.5	0.04	0.08
LWA11	850	3.5	0.04	0.07
LWA12	850	3.5	0.04	0.07
LWA13	850	4.0	0.03	0.07
LWA14	900	4.0	0.03	0.07
LWA15	950	4.0	0.03	0.08
LWA16	975	4.0	0.03	0.08
LWA17	1025	4.5	0.04	0.08
LWA18	1050	4.5	0.04	0.08
LWA19	925	4.0	0.03	0.08

The predicted total conventional subsidence contours, resulting from the extraction of Longwalls A7 to A19, based on the Modified Layout, are shown in Drawing No. MSEC484-18. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature, after the extraction of each of the proposed longwalls, based on the Modified Layout, is provided in Table 4.2.

Table 4.2 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature after the Extraction of Each of the Proposed Longwalls

Longwalls	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
LWA7	475	2.5	0.02	0.04
LWA8	1200	4.5	0.04	0.09
LWA9	1450	5.0	0.04	0.09
LWA10	1525	5.5	0.04	0.09
LWA11	1600	5.5	0.04	0.09
LWA12	1650	6.0	0.04	0.09
LWA13	1675	6.0	0.04	0.09
LWA14	1675	6.0	0.04	0.09
LWA15	1675	6.0	0.05	0.09
LWA16	1675	6.5	0.05	0.09
LWA17	1725	6.5	0.05	0.09
LWA18	1775	6.5	0.05	0.09
LWA19	1800	6.5	0.05	0.09

The predicted tilts provided in the above table are the maxima after the completion of each of the proposed longwalls. The predicted curvatures provided in the above table are the maxima at any time during or after the extraction of each of the proposed longwalls.

The maximum predicted conventional tilt is 6.5 mm/m (i.e. 0.7 %), which represents a change in grade of 1 in 155. The maximum predicted conventional hogging and sagging curvatures are 0.05 km^{-1} and 0.09 km^{-1}, respectively, which represent minimum radii of curvature of 20 kilometres and 11 kilometres, respectively. The maximum predicted conventional tilts and curvatures in the Study Area are less than those typically experienced on the Newcastle Coalfield and are closer to those typically experienced in the Southern Coalfield.

The predicted conventional subsidence parameters vary across the Study Area as the result of, amongst other factors, variations in the overburden geology, depths of cover, longwall geometry and extraction heights. To illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along Prediction Line A, the location of which is shown in Drawing No. MSEC484-18. The predicted profiles of conventional subsidence, tilt and curvature along this prediction line, resulting from the extraction of the proposed longwalls, based on the Modified Layout, are shown in Fig. E.01, in Appendix E.

4.3. Comparison of Maximum Predicted Conventional Subsidence, Tilt and Curvature

Comparisons between the maximum predicted subsidence parameters resulting from the extraction of the Stage 3 longwalls, based on the Previous and Modified Layouts, is provided in Table 4.3.

Table 4.3 Maximum Predicted Total Conventional Subsidence Parameters Resulting from the Extraction of the Stage 3 Longwalls Based on the Previous and Modified Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Report No. MSEC309)	1925	6.7	0.06	0.12
Modified Layout (Report No. MSEC484)	1800	6.5	0.05	0.09

It can be seen from the above table, that the maximum predicted subsidence parameters, based on the Modified Layout, are similar to but slightly less than those based on the Previous Layout. The reason for this is that, although the longwall void widths are proposed to be increased from 227 metres to 237 metres, the chain pillars are also proposed to be increased from 45 metres to 55 metres. The maximum predicted subsidence is governed by pillar compression, due to the high depths of cover above the proposed longwalls and, therefore, the reduction in subsidence resulting from the larger chain pillar widths outweighs the increased subsidence resulting from the larger void widths.

4.4. Maximum Upperbound Conventional Subsidence, Tilt and Curvature

The predicted conventional subsidence parameters for a second case, referred to as the *Upperbound Case*, were previously provided for the Stage 3 longwalls in Report No. MSEC309. The Upperbound Case was used for risk assessment purposes only and was determined by scaling up the predicted conventional subsidence parameters, such that a maximum total subsidence of 65 % of the effective extracted seam thickness was achieved above the proposed longwalls.

It is noted, that this provides some additional conservatism, as the maximum achievable subsidence in the Newcastle Coalfield is typically 55 % to 60 % of the extracted seam thickness, for single-seam super-critical mining conditions. Also, as described in Section 3.6, the overburden is expected to be capable of spanning the extracted goafs with minimal sag subsidence and then, based on a pillar height of 3.3 metres, the maximum achievable subsidence due to pillar compression alone would be in the order of 45 % of the maximum extracted seam thickness (i.e. 3.3 metre pillars / 7.3 metre extraction height), based on super-critical conditions.

The seam thickness typically varies between 5.5 metres to 8.0 metres on the western side of the seam split line. The effective extracted seam thickness for the LTCC mining has been taken as the overall void area (i.e. volume of the extracted coal), divided by the overall width of extraction. A cross-section through three of the proposed longwalls is shown in Fig. 4.1.

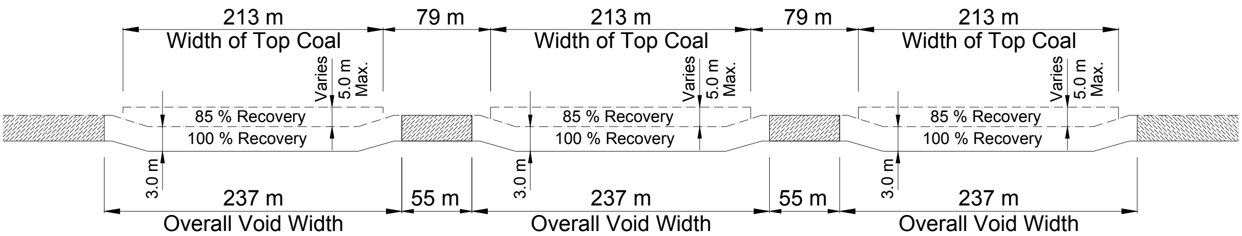

Fig. 4.1 Part Cross-section through Proposed Longwalls A7 to A19

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

$$T_{eff} = \frac{100\% \times T_{BC} \times 237m + 85\% \times T_{TC} \times 213m}{237m + 55m}$$

where T_{BC} = 3.0 metres (Thickness of bottom coal)
T_{TC} = 3.0 ~ 3.5 metres typically, 5.0 metres maximum (Thickness of top coal)

Using the above equation, the effective extracted seam thickness for the proposed longwalls typically varies between 4.3 metres and 4.6 metres, with a maximum effective extracted seam thickness of 5.5 metres. The Upperbound Case has, therefore, been determined by scaling up the predicted conventional subsidence parameters, such that a maximum subsidence of 65 % of effective extracted seam thickness is achieved above the proposed longwalls.

A summary of the maximum upperbound values of total conventional subsidence, tilt and curvature, resulting from the extraction of each of the proposed longwalls, based on the Modified Layout, is provided in Table 4.4.

Table 4.4 Maximum Upperbound Total Conventional Subsidence, Tilt and Curvature after the Extraction of Each of the Proposed Longwalls

Longwalls	Maximum Upperbound Total Conventional Subsidence (mm)	Maximum Upperbound Total Conventional Tilt (mm/m)	Maximum Upperbound Total Conventional Hogging Curvature (km^{-1})	Maximum Upperbound Total Conventional Sagging Curvature (km^{-1})
LWA7	825	4.0	0.04	0.06
LWA8	2050	7.5	0.07	0.15
LWA9	2450	9.0	0.06	0.15
LWA10	2575	9.0	0.06	0.15
LWA11	2700	9.0	0.07	0.15
LWA12	2800	9.5	0.07	0.15
LWA13	2825	10	0.07	0.15
LWA14	2825	10	0.07	0.15
LWA15	2825	11	0.08	0.15
LWA16	2825	11	0.09	0.15
LWA17	2925	11	0.09	0.15
LWA18	2975	11	0.09	0.15
LWA19	3000	11	0.09	0.15

The maximum upperbound conventional tilt is 11 mm/m (i.e. 1.1 %), which represents a change in grade of 1 in 90. The maximum upperbound conventional hogging and sagging curvatures are 0.09 km^{-1} and 0.15 km^{-1}, respectively, which represent minimum radii of curvature of 11 kilometres and 7 kilometres, respectively. The maximum upperbound conventional tilts and curvatures in the Study Area are less than those typically experienced in the Newcastle Coalfield, but are slightly greater than the maxima typically experienced in the Southern Coalfield.

It can be seen from Table 4.2 andTable 4.4, that the maximum upperbound conventional subsidence parameters, resulting from the extraction of all of the proposed longwalls, are approximately 1.6 times the maximum predicted conventional subsidence parameters.

The impact assessments based on increased predictions for the natural features and surface infrastructure, provided in Chapters 5 through to 9, have been based on the upperbound subsidence parameters. That is, the impact assessments based on increased predictions have considered the case where the actual subsidence parameters exceed those predicted by a factor of up to 1.6 times.

4.5. Predicted Strains

The prediction of strain is more difficult than the predictions of subsidence, tilt and curvature. The reason for this is that strain is affected by many factors, including ground curvature and horizontal movement, as well as local variations in the near surface geology, the locations of joints at bedrock, and the depth of bedrock. Survey tolerance can also represent a substantial portion of the measured strain, in cases where the strains are of a low order of magnitude. The profiles of observed strain, therefore, can be irregular even when the profiles of observed subsidence, tilt and curvature are relatively smooth.

In previous MSEC subsidence reports, including Report No. MSEC309, predictions of conventional strain were provided based on the best estimate of the average relationship between curvature and strain. Similar relationships have been proposed by other authors. The reliability of the strain predictions was highlighted in these reports, where it was stated that measured strains can vary considerably from the predicted conventional values.

Adopting a linear relationship between curvature and strain provides a reasonable estimate for the maximum conventional tensile and compressive strains. The locations that experience hogging curvature are more likely to experience tensile strains and locations that experience sagging curvature are more likely to experience compressive strains.

There is, however, considerable variation from the linear relationship. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strains for low curvatures. We have therefore provided a statistical approach to account for the variability, instead of providing a single predicted conventional strain.

The range of potential strains above the proposed longwalls has been determined using monitoring data from the previously extracted longwalls at the colliery. Longwalls A1 and A2 in Stage 1 and Longwalls A3 and A4 in Stage 2 were extracted using LTCC mining techniques. The range of strains measured during the extraction of these longwalls should, therefore, provide a good indication of the range of potential strains for the proposed longwalls.

The mine subsidence movements were measured along three monitoring lines during the extraction of Longwalls A1 and A2 in Stage 1, being the Line 1A, Line 1B and Line 2. Also, the mine subsidence movements were measured along three monitoring lines during the extraction of Longwalls A3 and A4 in Stage 2, being the Line A3, Line A3X and Line A4. Unfortunately, six monitoring lines over four longwalls do not provide a sufficient sample to undertake a statistical analysis of strain.

The monitoring lines above the previously extracted Longwalls SL1 to SL4 and Longwalls 1 to 13A at the colliery were also included in the analysis. These longwalls were extracted using conventional longwall mining techniques, where the mined seam thickness varied between 3 metres and 3.5 metres. The seam thickness for the proposed longwalls typically varies between 6 metres and 7 metres, of which only 85 % of the top coal is recovered and, hence, the effective extracted seam thickness is likely to range between 5.6 metres and 6.4 metres.

Although the extracted seam thickness for Longwalls S1 to SL4 and Longwalls 1 to 13A were less than the likely effective extracted seam thicknesses for the proposed longwalls, these previously extracted longwalls were mined at shallower depths of cover, typically ranging between 350 metres and 400 metres for Longwall SL1 and Longwalls 1 to 4, between 400 metres and 450 metres for Longwalls 5 to 9, and between 450 metres and 500 metres for Longwall 9A, Longwalls 10 to 12A and Longwalls SL2 and SL3.

The overall ground curvatures measured along the monitoring lines above Longwalls SL1 to SL4 and Longwalls 1 to 13A were similar to those predicted above the proposed longwalls. In addition to this, there were a number of elevated strains measured along the monitoring lines above these longwalls, due to the presence of dykes and other geological structures. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains for the proposed longwalls.

The data used in the analysis of observed strains included those resulting from both conventional and non-conventional anomalous movements, but did not include those resulting from valley related movements, which are addressed separately in this report. The strains resulting from damaged or disturbed survey marks have also been excluded.

4.5.1. Analysis of Strains Measured in Survey Bays

For features that are in discrete locations, such as building structures, farm dams and archaeological sites, it is appropriate to assess the frequency of the observed maximum strains for individual survey bays.

The survey database has been analysed to extract the maximum tensile and compressive strains that have been measured at any time during the extraction of the previous longwalls at the colliery, for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls.

The strain distributions were analysed with the assistance of the Centre of Excellence for Mathematics and Statistics of Complex Systems (MASCOS). A number of probability distribution functions were fitted to the empirical data. It was found that a *Generalised Pareto Distribution (GPD)* provided the best fit to the raw strain data.

The histogram of the maximum observed tensile and compressive strains measured in survey bays above goaf, for the monitoring lines at the colliery, is provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

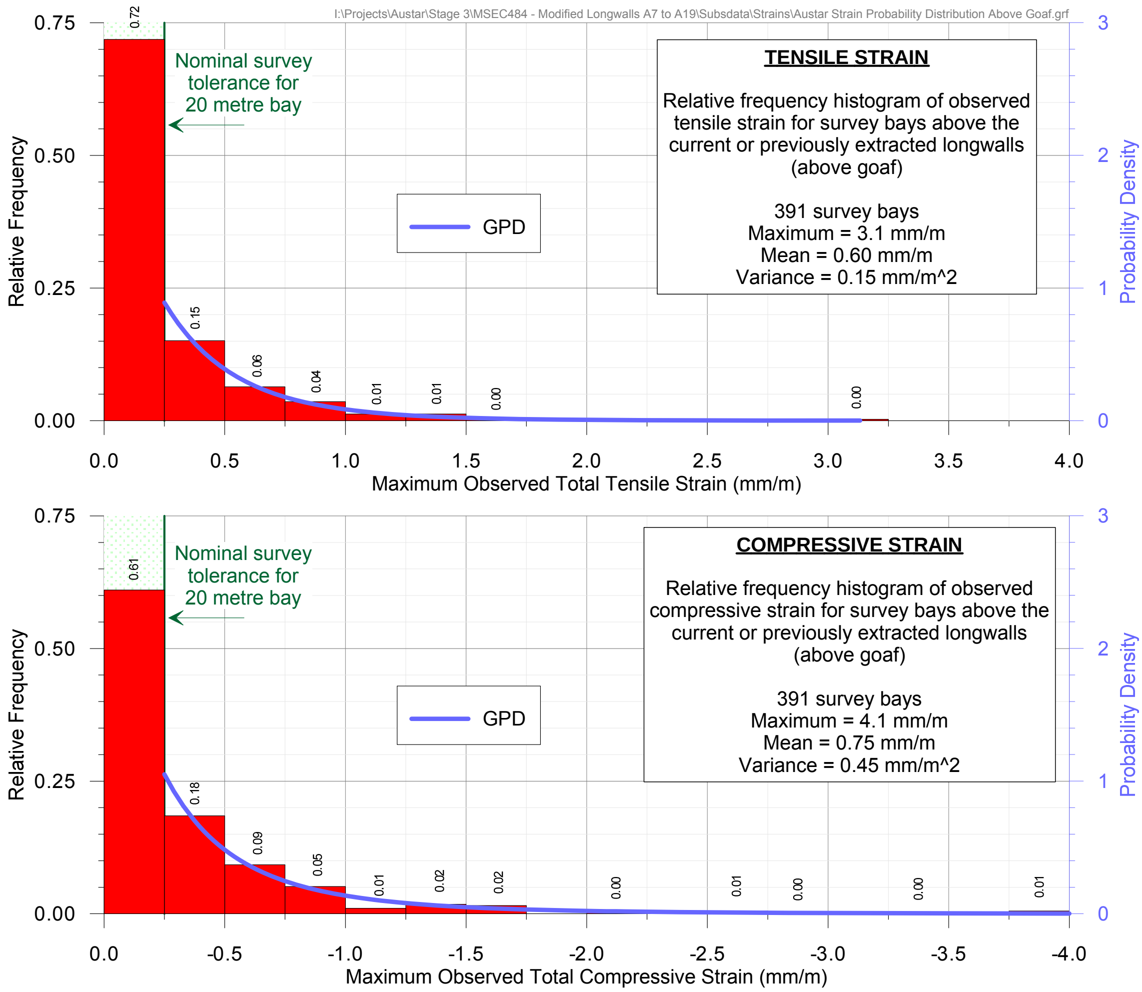

Fig. 4.2 Distributions of the Measured Maximum Tensile and Compressive Strains during the Extraction of Previous Longwalls at the Colliery for Bays Located Above Goaf

Confidence levels have been determined from the empirical strain data using the fitted GPDs. In the cases where survey bays were measured multiple times during the longwall extraction, the maximum tensile strain and the maximum compressive strain were used in the analysis (i.e. single tensile strain and single compressive strain measurement per survey bay).

The 95 % confidence levels for the maximum strains that the individual survey bays experienced above goaf, at any time during mining, were 0.8 mm/m tensile and 1.3 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced above goaf, at any time during mining, were 1.5 mm/m tensile and 2.5 mm/m compressive.

The survey database has also been analysed to extract the maximum tensile and compressive strains that have been measured at any time during the extraction of the previous longwalls at the colliery, for survey bays that were located directly above solid coal and within 250 metres of the nearest longwall goaf edge. Solid coal is defined as the coal that has not been extracted by longwalls.

The histogram of the maximum observed tensile and compressive strains measured in survey bays above solid coal, for monitoring lines at the colliery, is provided in Fig. 4.3. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

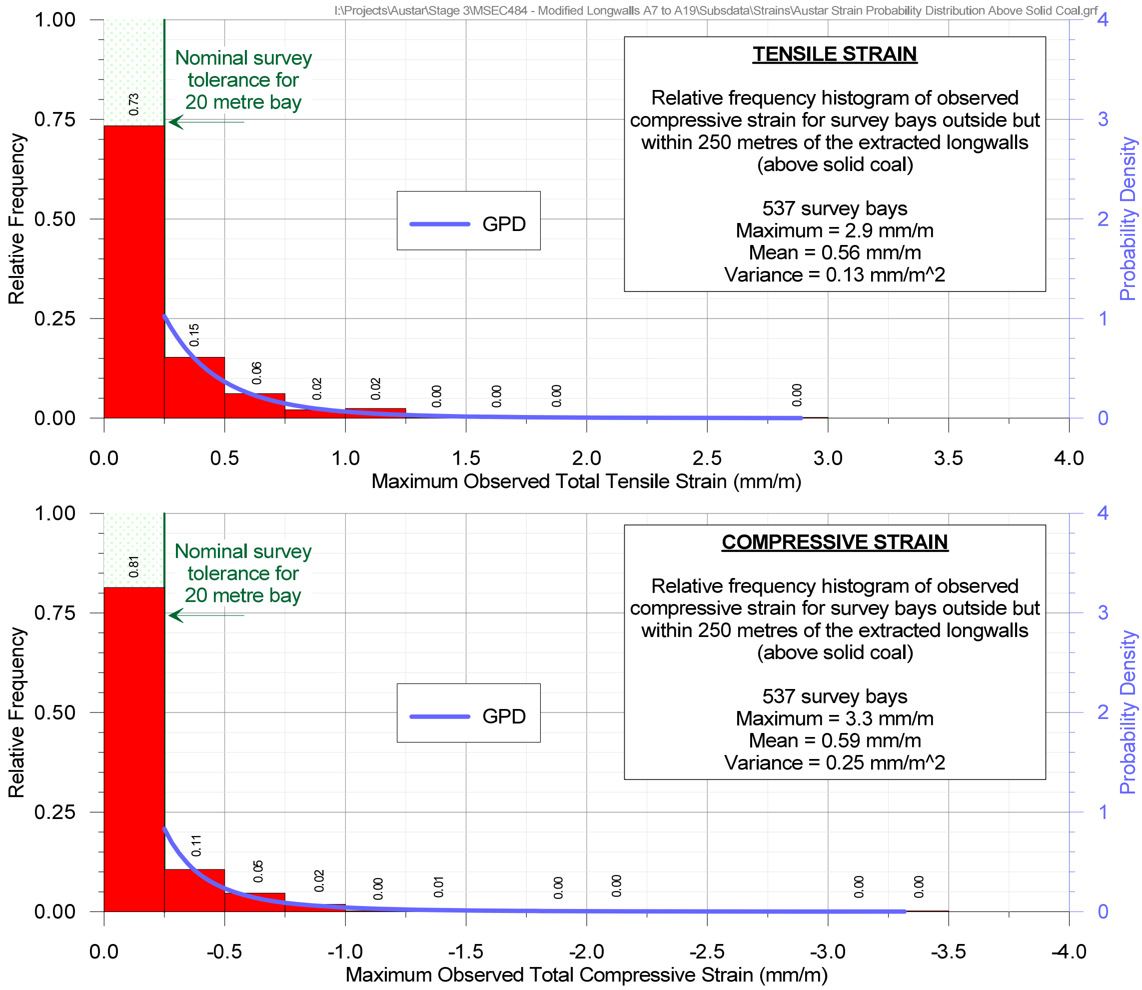

Fig. 4.3 Distributions of the Measured Maximum Tensile and Compressive Strains during the Extraction of Previous Longwalls at the Colliery for Bays Located Above Solid Coal

Confidence levels have been determined from the empirical strain data using the fitted GPDs. In the cases where survey bays were measured multiple times during the longwall extraction, the maximum tensile strain and the maximum compressive strain were used in the analysis (i.e. single tensile strain and single compressive strain measurement per survey bay).

The 95 % confidence levels for the maximum strains that the individual survey bays experienced above solid coal, at any time during mining, were 0.7 mm/m tensile and 0.6 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced above solid coal, at any time during, mining were 1.1 mm/m tensile and 1.1 mm/m compressive.

4.5.2. Analysis of Strains Measured Along Whole Monitoring Lines

For linear features such as roads, cables and pipelines, it is more appropriate to assess the frequency of observed maximum strains along whole monitoring lines, rather than for individual survey bays. That is, an analysis of the maximum strains anywhere along the monitoring lines, regardless of where the strain actually occurs.

The histogram of maximum observed tensile and compressive strains measured anywhere along the monitoring lines, at any time during or after the extraction of the previous longwalls at the colliery, is provided in Fig. 4.4.

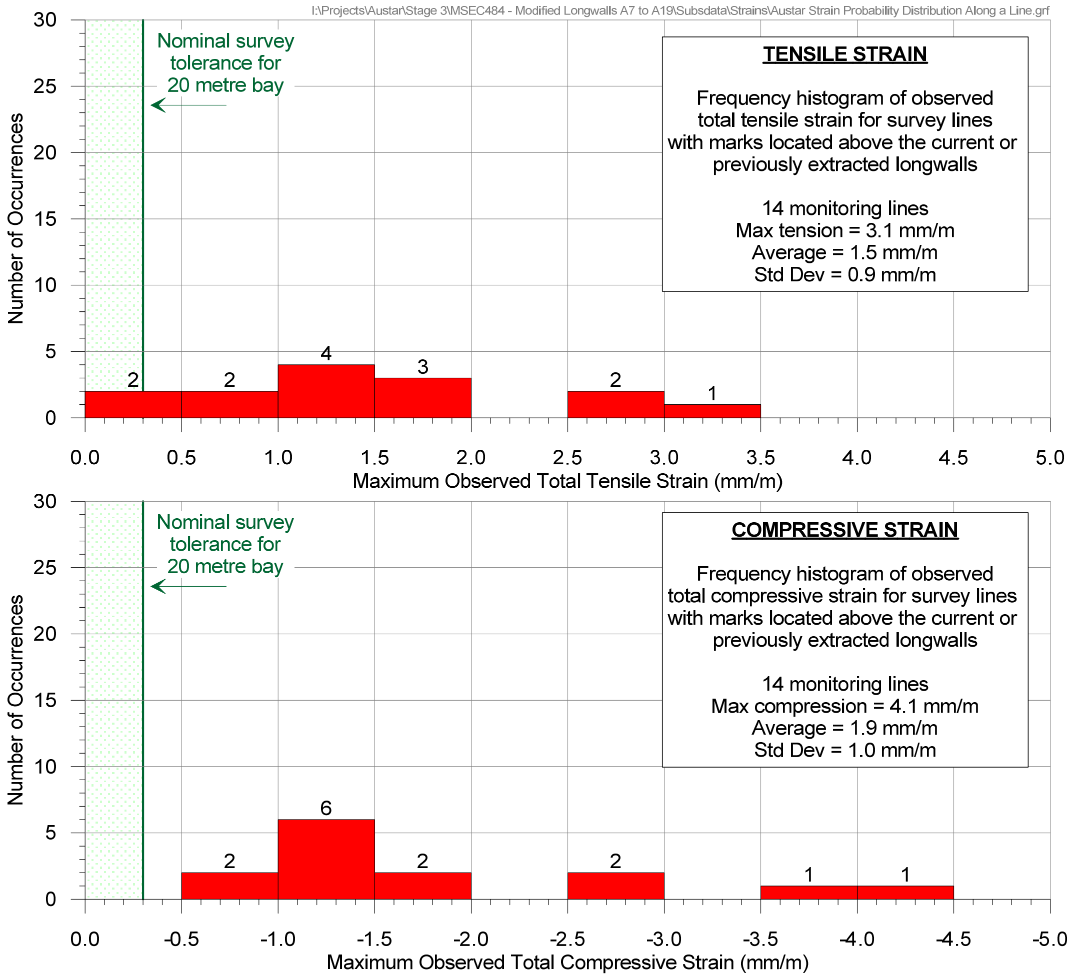

Fig. 4.4 Distributions of Measured Maximum Tensile and Compressive Strains along the Monitoring Lines during the Extraction of Previous Longwalls at the Colliery

It can be seen from Fig. 4.4, that 11 of the 14 monitoring lines have recorded maximum total tensile strains of 2 mm/m or less. It can also be seen, that 10 of the 14 monitoring lines have recorded maximum compressive strains of 2 mm/m or less. The maximum observed tensile strain was 3.1 mm/m and the maximum observed compressive strain was 4.1 mm/m.

4.5.3. Analysis of Shear Strains

As described in Section 3.3, ground strain comprises two components, being normal strain and shear strain, which can be interrelated using Mohr's Circle. The magnitudes of the normal strain and shear strain components are, therefore, dependant on the orientation in which they are measured. The maximum normal strains, referred to as the principal strains, are those in the direction where the corresponding shear strain is zero.

Normal strains along monitoring lines can be measured using 2D and 3D techniques, by taking the change in horizontal distance between two points on the ground and dividing by the original horizontal distance between them. This provides the magnitude of normal strain along the orientation of the monitoring line and, therefore, this strain may not necessarily be the maximum (i.e. principal) normal strain.

Shear deformations are more difficult to measure, as they are the relative horizontal movements perpendicular to the direction of measurement. However, 3D monitoring techniques provide data on the direction and the absolute displacement of survey pegs and, therefore, the shear deformations perpendicular to the monitoring line can be determined. But, in accordance with rigorous definitions and the principles of continuum mechanics, (e.g. Jaeger, 1969), it is not possible to determine horizontal shear strains in any direction relative to the monitoring line using 3D monitoring data from a straight line of survey marks.

As described in Section 3.3, shear deformations perpendicular to monitoring lines can be described using various parameters, including horizontal tilt, horizontal curvature, horizontal mid-ordinate deviation, angular distortion and shear index. In this report, horizontal mid-ordinate deviation has been used as the measure for shear deformation, which is defined as the differential horizontal movement of each survey mark, perpendicular to a line drawn between the two adjacent survey marks.

The frequency distribution of the maximum horizontal mid-ordinate deviation measured at survey marks above goaf, for previously extracted longwalls where the depths of cover were greater than 350 metres, is provided in Fig. 4.5. As the typical bay length was 20 metres, the calculated horizontal mid-ordinate deviations were over a chord length of 40 metres. The probability distribution function, based on the fitted GPD, has also been shown in this figure.

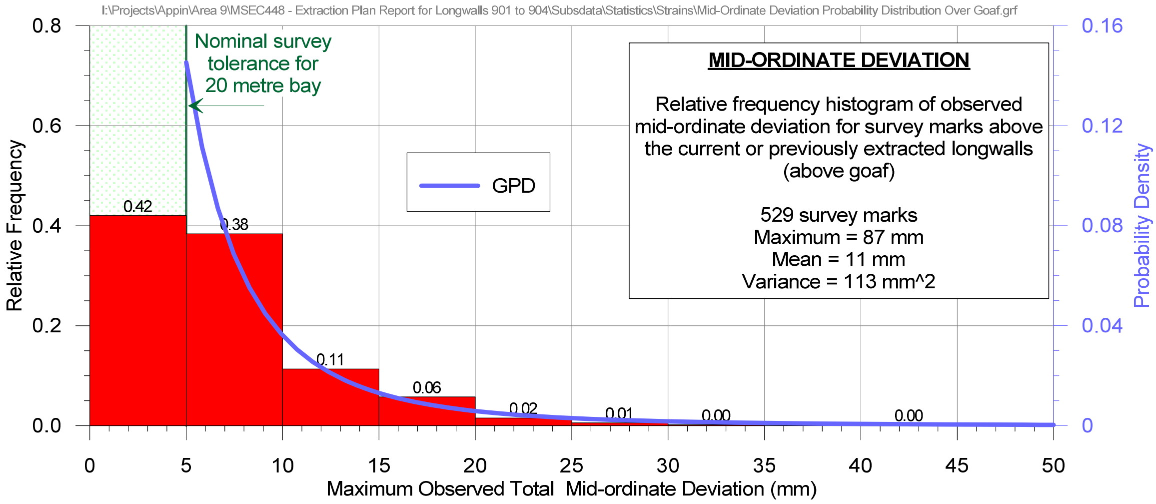

Fig. 4.5 Distribution of Measured Maximum Horizontal Mid-ordinate Deviation during the Extraction of Previous Longwalls for Marks Located Above Goaf

Confidence levels have been determined from the empirical strain data using the fitted GPD. In the cases where survey marks were measured multiple times during the longwall extraction, the maximum horizontal mid-ordinate deviation was used in the analysis (i.e. one measurement per survey mark).

The 95 % confidence levels for the maximum horizontal mid-ordinate deviations for individual survey marks experienced above goaf, at any time during mining, was 21 mm, which equates to a horizontal radius of curvature of 10 kilometres. The 99 % confidence levels for the maximum horizontal mid-ordinate deviation that the individual survey marks experienced above goaf, at any time during mining, was 42 mm, which equates to a horizontal radius of curvature of 5 kilometres

4.6. Predicted Conventional Horizontal Movements

The predicted conventional horizontal movements over the proposed longwalls are calculated by applying a factor to the predicted conventional tilt values. In the Newcastle Coalfield a factor of 10 is generally adopted, being the same factor as that used to determine average 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 Sections 3.7 and 3.8, indicates that a factor of 15 provides a better correlation for the prediction of conventional horizontal movements at Austar Coal Mine. This 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 conventional tilt within the Study Area, at any time during or after the extraction of the proposed longwalls, based on the Modified Layout, is 6.5 mm/m, which occurs near the finishing (south-western) end of Longwall A18. This area will experience the greatest predicted conventional horizontal movement towards the centre of the overall goaf area resulting from the extraction of the Stage 3 longwalls. The maximum predicted conventional horizontal movement is, therefore, approximately 100 mm, i.e. 6.5 mm/m multiplied by a factor of 15.

Conventional horizontal movements do not directly impact on natural features or items of surface infrastructure, rather impacts occur as the result of differential horizontal movements. Strain is the rate of change of horizontal movement. The impacts of strain on the natural features and items of surface infrastructure are addressed in the impact assessments for each feature, which have been provided in Chapters 5 through to 9.

4.7. Predicted Far-field Horizontal Movements

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

An empirical database of observed incremental far-field 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 far-field horizontal movements resulting from longwall mining were generally observed to be orientated towards the extracted longwall. At very low levels of far-field horizontal movements, however, there was a high scatter in the orientation of the observed movements.

The observed incremental far-field horizontal movements, resulting from the extraction of longwalls in the Southern Coalfield, is provided in Fig. 4.6. The confidence levels, based on fitted GPDs, have also been shown in this figure to illustrate the spread of the data.

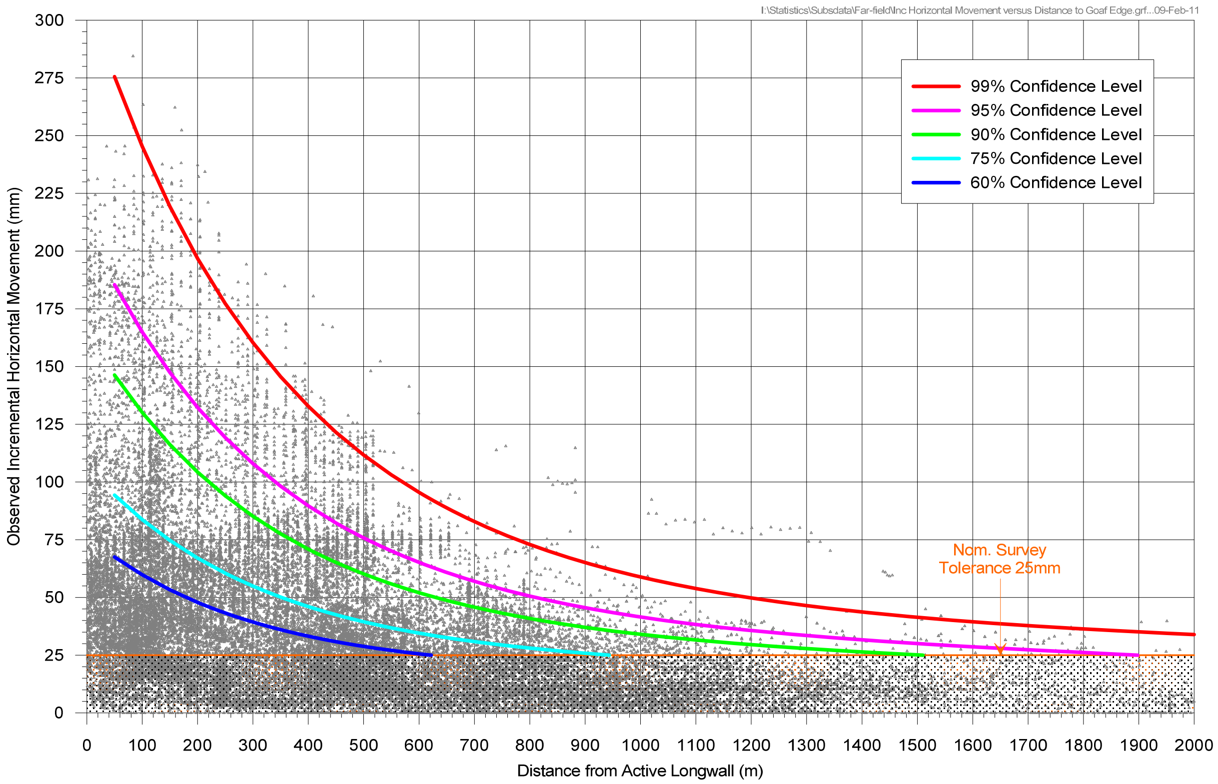

Fig. 4.6 Observed Incremental Far-Field Horizontal Movements from the Southern Coalfield

As successive longwalls within a series of longwalls are mined, the magnitudes of the incremental far-field horizontal movements decrease. This is possibly due to the fact that once the in-situ stresses within the strata has been redistributed around the collapsed zones above the first few extracted longwalls, the potential for further movement is reduced. The total far-field horizontal movement is not, therefore, the sum of the incremental far-field horizontal movements for the individual longwalls.

The predicted far-field 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 survey tolerance. The impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the vicinity of the Study Area is not expected to be significant, except where they occur at large structures which are sensitive to small differential movements.

4.8. Non-Conventional Ground Movements

It is likely that non-conventional ground movements will occur within the Study Area, due to near surface geological conditions, steep topography and valley related movements, which were discussed in Section 3.5. These non-conventional movements are often accompanied by elevated tilts, curvatures and strains which are likely to exceed the conventional predictions.

The major geological features within the vicinity of the proposed longwalls are shown in Drawing No. MSEC484-06. There are no identified major faults or dykes within the extents of the proposed longwalls. The *Quorrobolong Fault Zone* is located to the west of the proposed longwalls. The *Abernethy Fault Zone* is located to the north of the proposed longwalls.

Specific predictions of upsidence, closure and compressive strain due to the valley related movements are provided for the creeks in Section 5.1. The impact assessments for the streams are based on both the conventional and valley related movements. The potential for non-conventional movements associated with steep topography is discussed in the impact assessments for the steep slopes provided in Section 5.3.

In most cases, it is not possible to predict the exact locations or magnitudes of the non-conventional anomalous movements due to near surface geological conditions. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains where the depths of cover were greater than 400 metres, including both conventional and non-conventional anomalous strains, which is discussed in Section 4.5. In addition to this, the impact assessments for the natural features and items of surface infrastructure, which are provided in Chapters 5 through to 9, include historical impacts resulting from previous longwall mining which have occurred as a result of both conventional and non-conventional subsidence movements.

The largest known case of non-conventional movement, where the depth of cover was greater than 400 metres, occurred above Appin Longwall 408. In this case, a low angle thrust fault was re-activated in response to mine subsidence movements, resulting in differential vertical and horizontal movements across the fault. Observations at the site showed that the non-conventional movements developed gradually and over a period of time. Regular ground monitoring across the fault indicated that the rate of differential movement was less than 0.5 mm per day at the time non-conventional movements could first be detected. Subsequently as mining progressed, the rate of differential movement increased to a maximum of 28 mm per week.

The development of strain at the low angle thrust fault, as measured along the T-Line during the extraction of Longwall 408, is illustrated in Fig. 4.7. Photographs of the anomalous ground movements associated with this fault are provided in the photographs in Fig. 4.8 and Fig. 4.9.

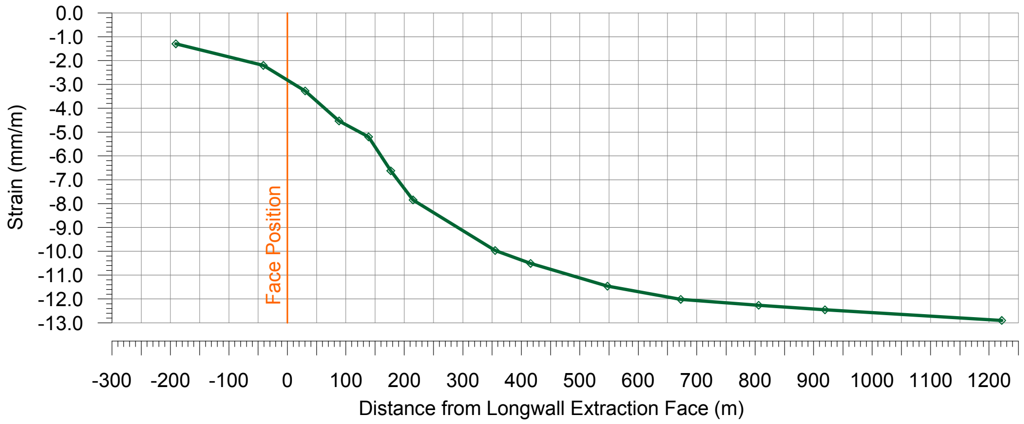

Fig. 4.7 Development of Strain at the Low Angle Thrust Fault Measured along the T-Line during the Extraction of Appin Longwall 408

Fig. 4.8 Surface Compression Humping due to Low Angle Thrust Fault (above Appin Longwall 408)

Fig. 4.9 Surface Compression Humping due to Low Angle Thrust Fault (above Appin Longwall 408)

The developments of strain at anomalies identified where the depths of cover were greater than 400 metres, excluding the low angle thrust fault discussed previously, are illustrated in Fig. 4.10. It can be seen from this figure, that the non-conventional movements develop gradually. For these cases, the maximum rate of development of anomalous strain was 1.1 mm/m per week, or 0.4 mm/m per 10 metres of longwall advance. Based on the previous experience of longwall mining where the depths of cover were greater than 400 metres, it has been found that non-conventional anomalous movements can be detected early by regular ground monitoring and visual inspections.

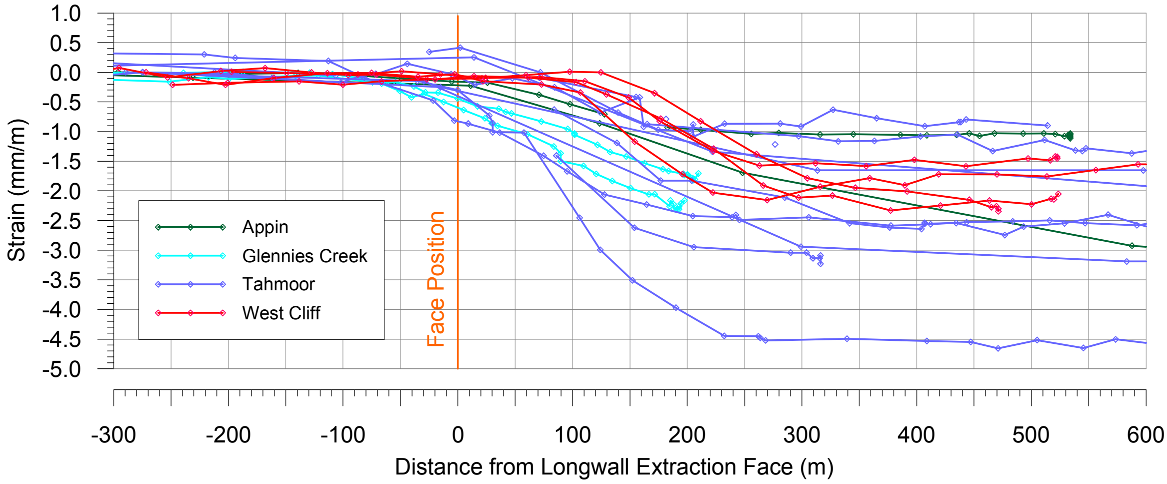

Fig. 4.10 Development of Non-Conventional Anomalous Strains where Depths of Cover were Greater than 400 metres

A study of the majority of ground survey data within the Southern Coalfield was undertaken in 2006 by MSEC. Forty-one monitoring lines were examined for anomalies, which represent a total of 58.2 kilometres of monitoring lines, and approximately 2,980 survey pegs. The monitoring lines crossed over 75 longwalls. The selected lines represented all the major lines over the subsided areas, and contained comprehensive information on subsidence, tilt and strain measurements. A total of 20 anomalies were detected, of which four were considered to be significant. The observed anomalies affected 41 of the approximately 2,980 survey pegs monitored. This represented a frequency of 1.4 %.

The above estimates are based on ground survey data that crossed only a small proportion of the total surface area affected by mine subsidence. Recent mining beneath urban and semi-rural areas at Tahmoor and Thirlmere by Tahmoor Colliery Longwalls 22 to 25 provides valuable “whole of panel” information. A total of approximately 35 locations (not including valleys) have been identified over the four extracted longwalls. The surface area directly above the longwalls is approximately 2.56 km^2. This equates to a frequency of 14 sites per square kilometre or one site for every 7 hectares.

4.9. General Discussion on Mining Induced Ground Deformations

Longwall mining can result in surface cracking, heaving, buckling, humping and stepping at the surface. The extent and severity of these mining induced ground deformations are dependent on a number of factors, including the mine geometry, depth of cover, overburden geology, locations of natural jointing in the bedrock and the presence of near surface geological structures.

Faults and joints in bedrock develop during the formation of the strata and from subsequent distressing associated with movement of the strata. Longwall mining can result in additional fracturing in the bedrock, which tends to occur in the tensile zones, but fractures can also occur due to buckling of the surface beds in the compressive zones. The incidence of visible cracking at the surface is dependent on the pre-existing jointing patterns in the bedrock as well as the thickness and inherent plasticity of the soils that overlie the bedrock.

Surface cracking in soils as the result of conventional subsidence movements is not commonly observed where the depths of cover are greater than 400 metres, such as is the case at Austar Coal Mine, and any cracking that has been observed has generally been isolated and of a minor nature.

Cracking is found more often in the bases of stream valleys due to the compressive strains associated with upsidence and closure movements. The likelihood and extent of cracking along the creeks within the Study Area are discussed in Section 5.1. Cracking can also occur at the tops of steep slopes as the result of downslope movements, which is discussed in Section 5.3.

Surface cracks are more readily observed in built infrastructure such as road pavements. In the majority of these cases no visible ground deformations can be seen in the natural ground adjacent to the cracks in the road pavements. In rare instances more noticeable ground deformations, such as humping or stepping of the ground can be observed at thrust faults.

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

Examples of surface tensile cracking and compression buckling are provided in the photographs in Fig. 4.11 and Fig. 4.12, respectively. These ground deformations were observed in the Southern Coalfield, where the depths of cover were similar to, but slightly less than those within the Study Area.

Fig. 4.11 Example of Surface Tensile Cracking in the Natural Ground Surface (Observed in the Southern Coalfield at a Similar Depth of Cover as the Study Area)

Fig. 4.12 Example of Surface Compression Buckling Observed in Road Pavement (Observed in the Southern Coalfield at a Similar Depth of Cover as the Study Area)

Localised ground buckling and shearing can occur wherever faults, dykes and abrupt changes in geology occur near the ground surface. The identified geological structures within the Study Area are discussed in Section 1.4. Discussions on irregular ground movements were provided in Section 4.8.

4.10. Estimated Height of the Fractured Zone

Some further information on sub-surface strata movements is provided in the report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*, and the following conclusions should be read in that context.

While there are many factors that may influence the height of fracturing and dilation, it is generally considered by various authors, e.g. Gale (ACARP C13013, 2008) and Guo et al (ACARP C14033, 2007), that an increase in panel width will likely result in an increase in the height of fracturing and dilation.

The theoretical height of the fractured zone can be estimated from the mining geometry, as being equal to the panel width (W) minus the span (w) divided by twice the tangent of the angle of break. These are illustrated in Fig. 4.13.

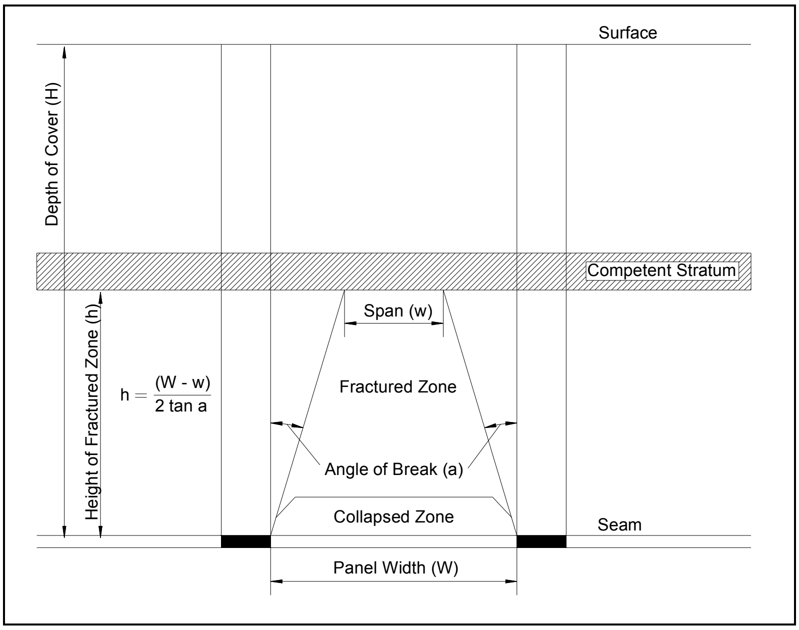

Fig. 4.13 Theoretical Model Illustrating the Development and Limit of the Fractured Zone

MSEC has gathered observed data sourced from a number of literature studies. The data points collected to date are shown in Fig. 4.14. The data points are compared with the results of the theoretical model developed by MSEC, using an angle of break of 20 degrees and spanning width of 30 metres. The results are also compared with lines representing factors of 1.0 times and 1.5 times the panel width, which was suggested by Gale (2008).

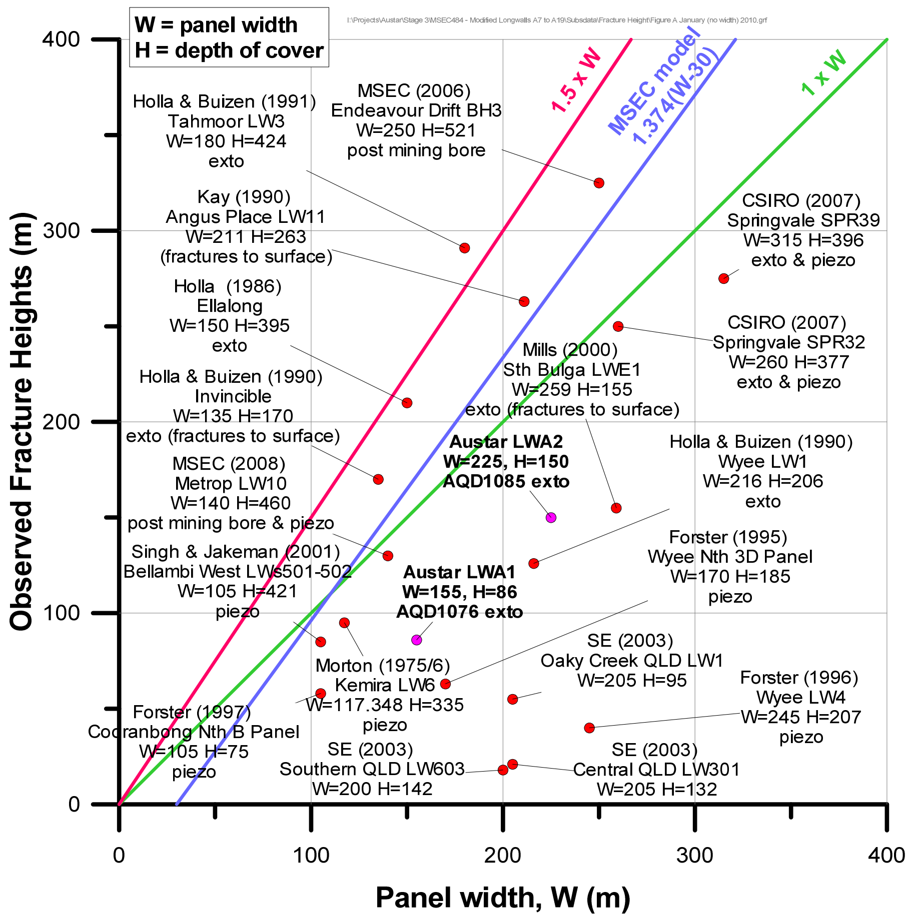

Fig. 4.14 Observed Fracture Heights versus Panel Width

It can seen from Fig. 4.14, that the MSEC model and Gale's suggested factors of 1.0 and 1.5 provide reasonable estimates for the observed heights of fracturing.

The results for extensometers AQD1076 and AQD1085 are shown in Fig. 4.14, which were located in the middle of Austar Stage 1 Longwalls A1 and A2, respectively. The measured heights of the fractured zones in these two locations are less than the MSEC model and less than the lines representing factors of 1.0 times and 1.5 times.

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 30 metres. If an average angle of break of 20° is assumed, with an extracted panel width of 237 metres, then a height of 285 metres would be required above the seam to reduce the effective span to 30 metres. If an angle of break of 23° is assumed, then a height of 245 metres would be required above the seam to reduce the effective span to 30 metres.

The depth of cover above the proposed longwalls varies between 455 metres and 760 metres and, therefore, it is unlikely that the fractured zone would extend up to the surface. It is expected that a *Constrained Zone* or *Continuous Deformation Zone* would occur between the fractured zone and the surface, as illustrated in Fig. 4.15 and Fig. 4.16.

It is noted, that the height of fracturing, based on significant bed separation and vertical dilation, measured by extensometers, does not imply that vertical permeability has increased. It simply means that bed separation and horizontal permeability has increased. The height of fracturing based on this approach may include part of the constrained zone, as defined by Forster (1995), which is shown in Fig. 4.16.

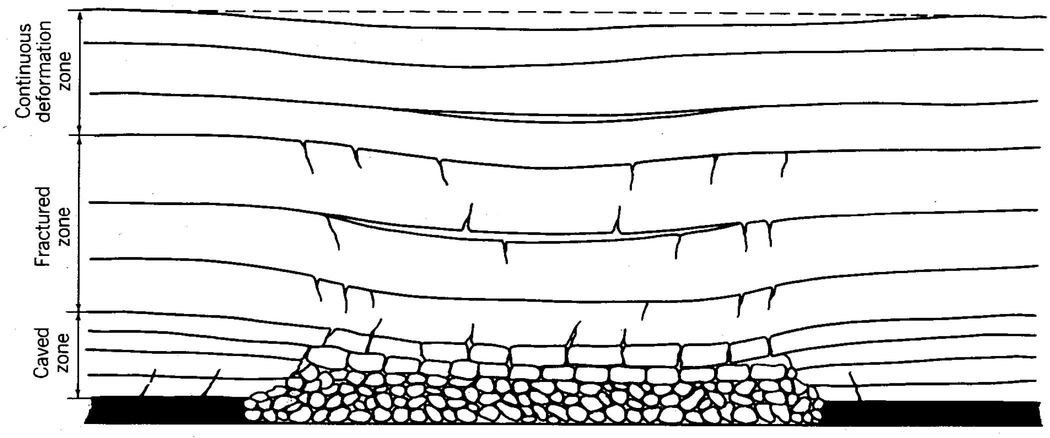

Fig. 4.15 Zones in the Overburden According to Peng and Chiang (1984)

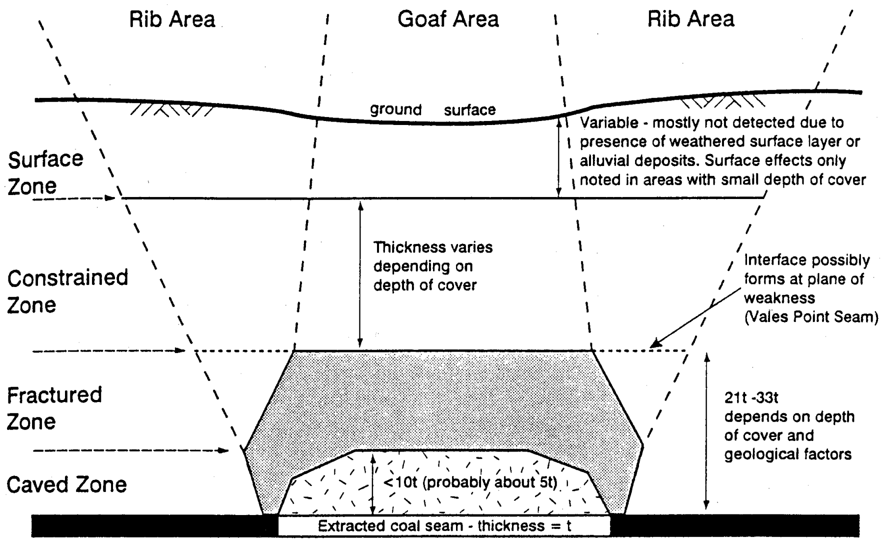

Fig. 4.16 Zones in the Overburden according to Forster (1995)

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.

5.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE NATURAL FEATURES WITHIN THE STUDY AREA

The following sections provide the descriptions, predictions and impact assessments for the natural features within the Study Area. The predictions based on the Modified Layout are compared to those based on the Previous Layout, which were provided in Report No. MSEC309. The impact assessments have been made for each natural feature based on the predicted subsidence parameters, based on the Modified Layout.

All significant natural features located outside the Study Area, which may be subjected to far-field movements or valley related movements and may be sensitive to these movements, have also been included as part of these assessments.

5.1. Watercourses

The location of the major watercourses within the Study Area are shown in Drawing No. MSEC484-07. The descriptions, predictions and impact assessments for these watercourses are provided in the following sections.

5.1.1. Descriptions of the Watercourses

The major watercourses within the Study Area are briefly described below, with further details provided in the report by Umwelt (2011a).

Cony Creek commences to the east of the proposed longwalls, and flows in a westerly direction, to where it drains into Quorrobolong Creek over 1 kilometre to the west of the proposed longwalls. **Sandy Creek** commences to the south of the Study Area, and flows in a north-westerly direction, to where it drains into Cony Creek above the proposed Longwall A15. Cony and Sandy Creeks are both ephemeral creeks with natural surface soil beds, having average natural gradients of less than 1 mm/m within the Study Area.

There are also a number of ephemeral drainage lines around and between the hills within the Study Area, which are also shown in Drawing No. MSEC484-07. The drainage lines within the Study Area flow into Cony and Sandy Creeks.

5.1.2. Predictions for the Watercourses

The predicted profiles of subsidence, upsidence and closure along Cony and Sandy Creeks, after the extraction of each of the proposed longwalls, are shown in Figs. E.02 and E.03, respectively, in Appendix E. A summary of the maximum predicted values of total subsidence, upsidence and closure along the creeks, after the extraction of each of the proposed longwalls, is provided in Table 5.1.

Table 5.1 Maximum Predicted Total Subsidence, Upsidence and Closure for Cony and Sandy Creeks Resulting from the Extraction of the Proposed Longwalls

Location	Longwall	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
Cony Creek	After LWA11	< 20	< 20	< 20
	After LWA12	50	< 20	< 20
	After LWA13	325	30	20
	After LWA14	1175	50	30
	After LWA15	1450	70	50
	After LWA16	1550	125	100
	After LWA17	1625	225	150
	After LWA18	1650	275	200
	After LWA19	1675	300	200
Sandy Creek	After LWA13	< 20	< 20	< 20
	After LWA14	100	< 20	< 20
	After LWA15	825	40	20
	After LWA16	1400	70	30
	After LWA17	1600	75	35
	After LWA18	1600	80	40
	After LWA19	1600	80	40

The profiles of equivalent valley height used to determine the predicted valley related upsidence and closure movements along Cony and Sandy Creeks are shown in Figs. E.02 and E.03, respectively. The equivalent valley height is calculated by multiplying the measured overall valley depth 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 0.7 has been adopted for Cony and Sandy Creeks. This factor is consistent with the observed valley related movements along monitoring lines at a number of collieries in the Newcastle and Hunter Coalfields.

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

Table 5.2 Maximum Predicted Total Net Vertical Movements and Changes in Grade for Cony and Sandy Creeks Resulting from the Extraction of the Proposed Longwalls

Location	Longwall	Maximum Predicted Total Net Subsidence (mm)	Maximum Predicted Total Net Uplift (mm)	Maximum Predicted Total Increase in Creek Gradient (mm/m)	Maximum Predicted Total Decrease in Creek Gradient (mm/m)
Cony Creek	After LWA11	< 20	< 20	< 0.5	< 0.5
	After LWA12	40	< 20	0.5	< 0.5
	After LWA13	325	< 20	2.0	1.5
	After LWA14	1150	< 20	3.5	3.5
	After LWA15	1400	< 20	3.5	4.5
	After LWA16	1500	< 20	4.0	5.0
	After LWA17	1575	< 20	3.0	5.0
	After LWA18	1575	50	3.0	5.0
	After LWA19	1600	40	3.0	5.0
Sandy Creek	After LWA13	< 20	< 20	< 0.5	< 0.5
	After LWA14	100	< 20	0.5	< 0.5
	After LWA15	775	< 20	3.5	< 0.5
	After LWA16	1325	< 20	4.0	< 0.5
	After LWA17	1525	< 20	3.5	0.5
	After LWA18	1550	< 20	3.5	1.0
	After LWA19	1550	< 20	3.5	1.0

The creeks are linear features and, therefore, the most relevant distribution of strain is the distribution of maximum strains measured along whole monitoring lines above previous longwall mining. The analysis of strains along whole monitoring lines during the mining of previous longwalls at the colliery is discussed in Section 4.5.2, which include conventional strains and strains resulting from non-conventional anomalous movements. The strains resulting from valley related movements are discussed separately in the impact assessments for the creeks.

The other drainage lines within the Study Area are located across the extents of the longwalls and, therefore, are expected to experience the full range of predicted movements. The maximum predicted conventional subsidence parameters within the Study Area are provided in Section 4.2.

5.1.3. Comparison of Predictions for the Creeks with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for watercourses with those provided in the Part 3A Application is provided in Table 5.3.

Table 5.3 Comparison of the Maximum Predicted Conventional Subsidence Parameters for Cony and Sandy Creeks Resulting from the Extraction of the Stage 3 Longwalls

Creek	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
Cony Creek	Previous Layout (Report No. MSEC309)	1865	320	250
	Modified Layout (Report No. MSEC484)	1675	300	200
Sandy Creek	Previous Layout (Report No. MSEC309)	1410	65	25
	Modified Layout (Report No. MSEC484)	1600	80	40

It can be seen from the above table, that the maximum predicted mine subsidence movements along Cony Creek, based on the Modified Layout, are similar to but slightly less than those predicted based on the Previous Layout. In consequence, the assessed level of impact for this creek reduces as a result of the proposed longwall modifications.

The maximum predicted mine subsidence movements along Sandy Creek, based on the Modified Layout, are a similar order of magnitude to but slightly greater than those predicted based on the Previous Layout. The potential impacts on this creek, therefore, are not expected to change significantly as a result of the proposed longwall modifications.

Further discussions on the potential impacts on the creeks resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

5.1.4. Impact Assessments for the Watercourses

The impact assessments for Cony and Sandy Creeks, based on the predicted subsidence parameters, are provided in the following sections. The findings in this report should be read in conjunction with the findings from the flood study which are provided in the report by Umwelt (2011a).

The Increased Likelihoods of Ponding and Flooding

A detailed flood model of the creeks has been developed by Umwelt, using the predicted 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 study and are provided in the report by Umwelt (2011a).

The Likelihood of Cracking in the Creek Beds

The maximum predicted hogging and sagging curvatures along Cony Creek, resulting from the extraction of the proposed longwalls, are both 0.04 km^{-1}, which equates to a minimum radius of curvature of 25 kilometres. The maximum predicted hogging and sagging curvatures along Sandy Creek, resulting from the extraction of the proposed longwalls, are 0.03 km^{-1} and 0.05 km^{-1}, respectively, which equate to minimum radii of curvature of 33 kilometres and 20 kilometres, respectively.

The range of ground strains above the proposed longwalls is expected to be similar to the range of strains measured during the previously extracted longwalls at the colliery, which is described in Section 4.5.2. It is possible, that the creeks could also experience elevated compressive strains as a result of valley closure movements.

The compressive strains resulting from valley related movements are more difficult to predict than conventional strains. It has been observed in the past, however, that compressive strains greater than 2 mm/m have occurred where the magnitudes of closure and upsidence were similar to those predicted along Cony and Sandy Creeks.

It is possible, therefore, that some compressive buckling and dilation of the uppermost bedrock could occur beneath the natural surface soils in Cony and Sandy Creeks above and within 250 metres of the longwalls. It has been observed in the past, that the depth of buckling and dilation of the uppermost bedrock, resulting from valley related movements, is generally less than 10 metres to 15 metres.

Surface cracking can potentially occur in the locations where the uppermost bedrock fractures or buckles and where the depths of cover to bedrock are shallow. Any surface cracking that occurs as a result of the extraction of the proposed longwalls is likely to be filled with the natural surface soils during subsequent flow events.

In times of heavy rainfall, any dilated bedrock beneath the creek beds would become water charged, and the surface water would flow over any surface cracks. Surface water that is diverted into the dilated bedrock beneath the creeks, during times of rainfall, is unlikely to significantly affect the overall quality or quantity of the surface water flow, as the cross-sectional area of dilated bedrock is very small when compared to the cross-sectional area of the creek channels.

Any surface cracking would tend to be naturally filled with the natural surface soils during subsequent flow events, especially during times of heavy rainfall. If any surface cracks were found not to seal naturally, some remedial measures may be required at the completion of mining. Where necessary, any significant surface cracks in the creek beds could be easily remediated by infilling with the natural surface soils or other suitable materials, or by locally regrading and recompacting the surface.

As described in Section 4.10, the likely height of the fractured zone is estimated to be between 245 metres to 285 metres above the proposed longwalls. The depths of cover directly above the proposed longwalls varies between 455 metres and 760 metres and, therefore, the depth of the constrained zone, which is located above the fractured zone, is estimated to be between 180 metres and 525 metres.

The continuous deformation zone and the constrained zone are illustrated in Fig. 4.15 and Fig. 4.16. 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.

At Austar Coal Mine, the Cessnock 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 increased 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.

Where Longwalls 1 to 6 and Longwall SL1 at the colliery were previously mined beneath Quorrobolong Creek, where the depths of cover vary between 310 metres and 370 metres, 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 (2011a).

5.1.5. Impact Assessments for the Watercourses Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the creeks, the potential for increased ponding, flooding and scouring would increase. The flood model has considered the upperbound subsidence movements and further discussions are provided in the report by Umwelt (2011a).

If the maximum upperbound conventional curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the creeks, the likelihood and extent of fracturing, buckling and dilation of the underlying bedrock would increase directly above the longwalls. Surface cracking could potentially occur in the locations where the depths of cover to bedrock are shallow. Any surface cracks that occur as a result of the extraction of the proposed longwalls are likely to be filled with the natural surface soils during subsequent flow events. It is noted, however, that any surface cracks could be remediated, if necessary, by infilling with the natural surface soils or other suitable materials, or by locally regrading and recompacting the surface.

5.1.6. Recommendations for the Watercourses

The assessed impacts on Cony and Sandy Creeks, resulting from the extraction of the proposed longwalls, can be managed by the implementation of suitable management strategies.

It is recommended that the creek beds are periodically visually monitored during the extraction of the proposed longwalls, and that any significant surface tensile cracking is remediated by infilling with the natural surface soils or other suitable materials, or by locally regrading and recompacting the surface, as required. With these management strategies in place, it is unlikely that there would be any significant long term impact on the creeks resulting from the extraction of the proposed longwalls

5.2. Aquifers and Known Groundwater Resources

The groundwater resources within the Study Area occur in the shallow alluvial aquifers of Cony and Sandy Creeks and within the deeper Newcastle Coal Measures. Further descriptions of the aquifers within the Study Area are provided in the report by Umwelt (2011a).

5.3. Steep Slopes

The locations of the steep slopes within the Study Area are shown in Drawing No. MSEC484-07. The descriptions, predictions and impact assessments for the steep slopes are provided in the following sections.

5.3.1. Descriptions of the 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 (i.e. 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 may be marginally stable.

The steep slopes within the Study Area were identified from the 1 metre surface contours which were generated from an airbourne laser scan of the area. There were a few areas identified as having steep slopes, which are shown in Drawing No. MSEC484-07.

The *Broken Back Range* crosses the northern part of the Study Area and is located directly above the proposed Longwalls A7 to A9 and above the commencing (north-eastern) ends of Longwalls A14 to A16. The natural surface gradients along the range, directly above the proposed longwalls, typically vary between 1 in 3 and 1 in 2 (i.e. a grade of 50 %, or an angle to the horizontal of 27°), with isolated areas having natural surface gradients of up to 1 in 1.5 (i.e. a grade of 67 %, or an angle to the horizontal of 34°).

There are also steep slopes located along the hill in the southern part of the Study Area, which is located directly above the proposed Longwall A19. The natural surface gradients along the southern side of the hill typically vary up to 1 in 1.5 and the natural surface gradients along the northern side of the hill typically vary up to 1 in 2.

5.3.2. Predictions for the Steep Slopes

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature at the steep slopes, resulting from the extraction of the proposed longwalls, is provided in Table 5.4.

Table 5.4 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature at the Steep Slopes Resulting from the Extraction of the Proposed Longwalls

Location	Longwall	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Broken Back Range	After LWA7	350	2.0	0.02	0.01
	After LWA8	1175	4.5	0.04	0.09
	After LWA9	1400	5.0	0.04	0.09
	After LWA10	1500	5.0	0.04	0.09
	After LWA19	1525	5.0	0.04	0.09
Hill above Longwall A19	After LWA16	< 20	< 0.5	< 0.01	< 0.01
	After LWA17	50	0.5	< 0.01	< 0.01
	After LWA18	325	2.5	0.02	< 0.01
	After LWA19	1275	4.5	0.03	0.02

The predicted tilts provided in the above table are the maxima after the completion of each of the proposed longwalls. The predicted curvatures provided in the above table are the maxima at any time during or after the extraction of each of the proposed longwalls.

The steep slopes are planar features and, therefore, the most relevant distribution of strain is the distribution of maximum strains measured along whole monitoring lines above previous longwall mining. The analysis of strains along whole monitoring lines during the mining of previous longwalls at the colliery is discussed in Section 4.5.2 and the results are provided in Fig. 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.3.3. Comparison of Predictions for the Steep Slopes with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for steep slopes with those provided in the Part 3A Application is provided in Table 5.5.

Table 5.5 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Steep Slopes Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Broken Back Range	Previous Layout (Report No. MSEC309)	1800	6.7	0.05	0.13
	Modified Layout (Report No. MSEC484)	1525	5.0	0.04	0.09
Hill above Longwall A19	Previous Layout (Report No. MSEC309)	1350	5.0	0.04	0.03
	Modified Layout (Report No. MSEC484)	1275	4.5	0.03	0.02

It can be seen from the above table, that the maximum predicted mine subsidence movements at the steep slopes, based on the Modified Layout, are similar to or slightly less than those predicted based on the Previous Layout. In consequence, the assessed levels of impact for the steep slopes reduce as a result of the proposed longwall modifications.

Further discussions on the potential impacts on the steep slopes resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

5.3.4. Impact Assessments for the Steep Slopes

The maximum predicted tilt for the steep slopes, resulting from the extraction of the proposed longwalls, is 5.0 mm/m (i.e. 0.5 %), which represents a change in grade of 1 in 200. The predicted changes in grade are small when compared to the natural grades of the steep slopes, which are greater than 1 in 3 and, therefore, are unlikely to result in any significant impact on the stability of the steep slopes.

The steep slopes are more likely to be impacted by ground curvatures and strains, than by tilt. The potential impacts would generally result from the down slope movement of soils, causing tension cracks to appear at the tops of the slopes and compression ridges to form at the bottoms of the slopes.

The maximum predicted ground curvatures for the steep slopes, resulting from the extraction of the proposed longwalls, are 0.04 km^{-1} hogging and 0.09 km^{-1} sagging, which represent minimum radii of curvature of 25 kilometres and 11 kilometres, respectively. The maximum predicted ground curvatures at the steep slopes are similar to those typically experienced in the Southern Coalfield. The potential impacts on the steep slopes within the Study Area, therefore, are expected to be similar to those previously observed in the Southern Coalfield.

There is extensive experience of mining beneath steep slopes in the Southern Coalfield. These include steep slopes along the Cataract, Nepean, Bargo and Georges Rivers. No large-scale slope failures have been observed along these slopes, even where longwalls have been mined directly beneath them. Although no large-scale slope failures have been observed in the Southern Coalfield, tension cracking has been observed at the tops of steep slopes as the result of downslope movements.

Cracks resulting from downslope movements at depths of cover greater than 400 metres, such as is the case in the Study Area, are generally isolated and narrow, typically having maximum widths in the order of 50 mm. Larger cracks have been observed at the tops of very steep slopes and adjacent to large rock formations, where maximum crack widths in the order of 100 mm to 150 mm have been observed at depths of cover greater than 400 metres, such as is the case in the Study Area.

If tension cracks were to develop, as a result of the extraction of the proposed longwalls, it is possible that soil erosion could occur if these cracks were left untreated. It is possible, therefore, that some remediation might be required, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the slopes in the longer term.

While in most cases, impacts on steep slopes are likely to consist of surface cracks, there remains a low probability of large-scale downslope movements. Experience indicates that the probability of mining induced large-scale slippages is extremely low due to the significant depth of cover within the Study Area.

While the risk is extremely low, some risk remains and attention must therefore be paid to any features or items of infrastructure that are located in the vicinity of steep slopes directly above the proposed longwalls, which include the:-

- Fire trails,
- Low voltage powerlines,
- The optical fibre cable and copper cables, and
- Survey control marks.

5.3.5. Impact Assessments for the Steep Slopes Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the steep slopes, the potential impacts would not significantly increase, as the maximum tilt would still be much less than the natural surface gradients of the steep slopes within the Study Area.

If the maximum upperbound curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the steep slopes, the extent of potential surface cracking would increase where the steep slopes are located directly above the proposed longwalls. It is expected, however, that any surface cracking could still be remediated by infilling with soil or other suitable materials, or by locally regrading and compacting the surface.

5.3.6. Recommendations for the Steep Slopes

It is recommended that the steep slopes are periodically visually monitored during the mining period and until any necessary remedial measures are completed. It is also recommended that management strategies be developed to ensure that these measures are implemented. With these management strategies in place, it is unlikely that there would be any significant long term impacts on the steep slopes resulting from the extraction of the proposed longwalls.

5.4. Land Prone to Flooding and Inundation

The natural gradients along the alignments of Cony and Sandy 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 (2011a).

5.5. Swamps, Wetlands and Water Related Ecosystems

There are no swamps or wetlands within the Study Area. There are, however, a number of ponding areas along the alignments of Cony and Sandy Creeks within the Study Area, which are described in the report by Umwelt (2011a).

5.6. State Forests

The Study Area is partly located within the former **Aberdare State Forest**, which is located on the northern sides of Big Hill Road and Nash Lane. Part of the forest became a conservation area which is described in Section 5.7.

5.7. State Recreational or Conservation Areas

As part of the Lower Hunter Region Reservations Bill, 2,257 hectares of the Aberdare State Forest became part of the **Werakata State Conservation Area** on the 1st July 2007. The conservation area is located on the northern sides of Big Hill Road and Nash Lane.

5.8. Natural Vegetation

There is undisturbed native bushland within the Study Area on the northern sides of Coney Creek Lane and Nash Lane, within the *Aberdare State Forest* and the *Werakata State Conservation Area*. The land within the Study Area, on the southern sides of Coney Creek Lane and Nash Lane, has generally been cleared for agricultural use, however, there are pockets of native bush, primarily along the alignments of Cony and Sandy Creeks.

The following sections provide the descriptions, predictions and impact assessments for the Public Utilities within the Study Area.

6.1. The Roads

The locations of public roads within the Study Area are shown in Drawing No. MSEC484-08. The descriptions, predictions and impact assessments for the roads within the Study Area are provided in the following sections.

6.1.1. Descriptions of the Roads

A brief description of the public roads is provided below.

Sandy Creek Road crosses the southern extent of the Study Area. The road is located at a distance of 285 metres south of the commencing (south-western) end of the proposed Longwall A19, at its closest point to the proposed longwalls. Sandy Creek Road provides access between the township of Ellalong, located west of the Study Area, and Freemans Drive and Lake Road, located east of the Study Area. Sandy Creek Road has a bitumen seal within the Study Area.

Quorrobolong Road crosses directly above the commencing (south-western) ends of the proposed Longwalls A7 and A8. The road provides access between the township of Kitchener, located north of the Study Area, and Sandy Creek Road in the southern part of the Study Area. Quorrobolong Road has a bitumen seal within the Study Area.

Coney Creek Lane crosses directly above the proposed Longwalls A11, A12 and A13. The road provides access between the rural properties within the Study Area and Quorrobolong Road. Coney Creek Lane is an unsealed road.

Big Hill Road crosses directly above the proposed Longwalls A8 and A9. The road is an unsealed trail which is used for fire fighting purposes within the Aberdare State Forest.

6.1.2. Predictions for the Roads

The predicted profiles of conventional subsidence, tilt and curvature along the alignments of Quorrobolong Road, Coney Creek Lane and Big Hill Road, resulting from the extraction of the proposed longwalls, are shown in Figs. E.04, E.05 and E.06, respectively, in Appendix E. A summary of the maximum predicted cumulative conventional subsidence parameters along the alignments of the roads, after the extraction of each of the proposed longwalls, is provided in Table 6.1.

Table 6.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Public Roads Resulting from the Extraction of the Proposed Longwalls

Location	Longwall	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Sandy Creek Road	After LWA18	< 20	< 0.5	< 0.01	< 0.01
	After LWA19	30	< 0.5	< 0.01	< 0.01
Quorrobolong Road	After LWA7	60	< 0.5	< 0.01	< 0.01
	After LWA8	200	1.0	0.01	< 0.01
	After LWA9	250	1.5	0.01	< 0.01
	After LWA10	300	1.5	0.01	< 0.01
	After LWA11	325	1.5	0.01	< 0.01
	After LWA19	325	2.0	0.01	< 0.01
Coney Creek Lane	After LWA9	< 20	< 0.5	< 0.01	< 0.01
	After LWA10	150	1.0	0.01	< 0.01
	After LWA11	900	3.0	0.02	0.01
	After LWA12	1275	4.0	0.02	0.02
	After LWA13	1450	5.0	0.02	0.03
	After LWA14	1500	5.0	0.02	0.03
	After LWA15	1550	5.0	0.02	0.03
	After LWA19	1550	5.0	0.02	0.03
Bill Hill Road	After LWA7	475	1.5	0.02	0.02
	After LWA8	1175	4.0	0.02	0.05
	After LWA9	1425	3.5	0.02	0.05
	After LWA10	1500	4.0	0.02	0.05
	After LWA11	1550	4.5	0.02	0.05
	After LWA12	1600	5.0	0.02	0.05
	After LWA19	1625	5.0	0.02	0.05

The predicted tilts provided in the above table are the maxima after the completion of each of the proposed longwalls. The predicted curvatures provided in the above table are the maxima at any time during or after the extraction of each of the proposed longwalls.

The roads are linear features and, therefore, the most relevant distribution of strain is the distribution of maximum strains measured along whole monitoring lines above previous longwall mining. The analysis of strains along whole monitoring lines during the mining of previous longwalls at the colliery is discussed in Section 4.5.2 and the results are provided in Fig. 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

6.1.3. Comparison of Predictions for the Roads with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the roads with those provided in the Part 3A Application is provided in Table 6.2.

Table 6.2 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Roads Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Hogging Curvature in Any Direction (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature in Any Direction (km^{-1})
Sandy Creek Road	Previous Layout (Report No. MSEC309)	140	< 0.5	< 0.01	< 0.01
	Modified Layout (Report No. MSEC484)	30	< 0.5	< 0.01	< 0.01
Quorrobolong Road	Previous Layout (Report No. MSEC309)	550	2.1	0.03	0.03
	Modified Layout (Report No. MSEC484)	325	2.0	0.01	< 0.01
Coney Creek Lane	Previous Layout (Report No. MSEC309)	1800	5.3	0.03	0.03
	Modified Layout (Report No. MSEC484)	1550	5.0	0.02	0.03
Bill Hill Road	Previous Layout (Report No. MSEC309)	1850	5.5	0.05	0.11
	Modified Layout (Report No. MSEC484)	1625	5.0	0.02	0.05

It can be seen from the above table, that the maximum predicted mine subsidence movements at the roads, based on the Modified Layout, are similar to or slightly less than those predicted based on the Previous Layout. In consequence, the assessed levels of impact for the roads reduce as a result of the proposed longwall modifications.

Further discussions on the potential impacts on the roads resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

6.1.4. Impact Assessments for the Local Roads

The maximum predicted conventional tilt for the roads, resulting from the extraction of the proposed longwalls, is 5 mm/m (i.e. 0.5 %), or a change in grade of 1 in 200. The predicted tilts are less than 1 % and are unlikely, therefore, to result in any significant impacts on the serviceability or surface water drainage of these roads. If any additional ponding or adverse changes in surface water drainage were to occur as a result of mining, the roads could be repaired using normal road maintenance techniques.

The maximum predicted conventional hogging and sagging curvatures for the roads, resulting from the extraction of the proposed longwalls, are 0.02 km^{-1} and 0.05 km^{-1}, respectively, which equate to minimum radii of curvatures of 50 kilometres and 20 kilometres, respectively. The range of potential strains above the longwalls is expected to be similar to the range of strains measured during the previously extracted longwalls at the colliery, which is discussed in Section 4.5.2 and illustrated in Fig. 4.4.

The maximum predicted ground curvatures and the range of potential strains for these roads are similar to those typically experienced in the Southern Coalfield. The potential impacts on the roads within the Study Area, therefore, are expected to be similar to those previously observed in the Southern Coalfield.

The most extensive experience has come from the extraction of Tahmoor Colliery Longwalls 22 to 25, where these longwalls have mined directly beneath approximately 10 kilometres of local roads. A total of 12 impacts have been observed, which equates to an average of one impact for every 860 metres of pavement. The impacts were minor and did not present a public safety risk.

Of these impacts, one was substantially greater than the other observed impacts, and this is illustrated in Fig. 6.1. Two additional sites with substantially greater impacts were recently observed during the mining of Tahmoor Colliery Longwall 25. One of the sites was located at a roundabout and a photograph of this site is also shown in Fig. 6.1. Photographs of other cracking and the buckling of a kerb and gutter are shown in Fig. 6.2.

More frequent impacts have been observed to concrete kerbs and gutters. The impacts are most commonly focussed around driveway laybacks and involve cracking, spalling or buckling. A typical buckling impact of a kerb is shown in Fig. 6.2.

A total of five drainage pits have been damaged during the mining of Tahmoor Colliery Longwalls 24A and 25. Investigations are currently underway to determine whether impacts have occurred to stormwater pipes in these areas.

Fig. 6.1 Cracking and Bump at Roundabout at Tahmoor Colliery

Fig. 6.2 Cracking and Buckling of Kerb at Tahmoor Colliery

It is expected that any impacts on the roads within the Study Area could be repaired using normal road maintenance techniques. With the necessary remedial measures implemented, it is expected that the roads would be maintained in safe and serviceable conditions throughout the mining period.

The potential impacts on the unsealed roads within the Study Area include cracking and heaving of the unsealed road surfaces. Any impacts on the unsealed roads could be repaired by infilling the cracks, or by regrading and recompacting the surface.

6.1.5. Impact Assessments for the Local Roads Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the roads, the potential impacts on the serviceability of the roads would not significantly increase, as the maximum change in grade would still be small, in the order of 1 %. Minor changes in the road surface water drainage could occur, in some locations, but these could be repaired using normal road maintenance techniques.

If the maximum upperbound curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the roads, the curvatures would be similar to the maxima typically experienced in the Southern Coalfield. The potential impacts would still be expected to be similar to those experienced in the Southern Coalfield, and these could be repaired using normal road maintenance techniques.

With the necessary remedial measures implemented, it is likely that the roads could be maintained in a safe and serviceable condition throughout the mining period.

6.1.6. Recommendations for the Roads

The assessed impacts on the roads within the Study Area, resulting from the extraction of the proposed longwalls, can be managed with the implementation of suitable management strategies.

It is recommended that the roads should be periodically visually monitored as each of the proposed longwalls are mined beneath them, 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, to ensure that the roads are maintained in a safe and serviceable condition throughout the mining period.

6.2. Road Bridges

The locations of road bridges in the vicinity of the proposed longwalls are shown in Drawing No. MSEC484-08. The descriptions, prediction and impact assessments for the road bridges are provided in the following sections.

6.2.1. Descriptions of the Road Bridges

There are two public road bridges which have been identified within the Study Area.

Bridge **BR-QR01** is situated near the western extent of the Study Area, where Quorrobolong Road crosses Cony Creek. The bridge is located 330 metres west of the finishing (south-western) end of Longwall A12, at its closest point to the proposed longwalls. Bridge BR-QR01 is a timber structure, with three intermediate timber supports, having an overall span of approximately 22 metres, a photograph of which is provided in Fig. 6.3. This bridge has historic significance, which is described in the report by Umwelt (2011c).

Fig. 6.3 Bridge BR-QR01 along Quorrobolong Road

Bridge **BR-SR01** is situated near the southern extent of the Study Area, where Sandy Creek Road crosses Sandy Creek. The bridge is located 350 metres south of Longwall A19, at its closest point to the proposed longwalls. Bridge BR-SR01 is a single span concrete structure having an overall span of approximately 12 metres, a photograph of which is provided in Fig. 6.4.

Fig. 6.4 Bridge BR-SR01 along Sandy Creek Road

6.2.2. Predictions for the Road Bridges

The proposed longwalls do not mine directly beneath Bridges BR-QR01 and BR-SR01. A summary of the maximum predicted total conventional subsidence, tilts and curvatures at the bridges, after the completion of the proposed longwalls, is provided in Table 6.3. The values provided in this table are the maximum predicted conventional subsidence parameters within 20 metres of each bridge.

Table 6.3 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Road Bridges Resulting from the Extraction of the Proposed Longwalls

Bridge	Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
BR-QR01	Quorrobolong Road and Coney Creek	40	< 0.5	< 0.01	< 0.01
BR-SC01	Sandy Creek Road and Sandy Creek	25	< 0.5	< 0.01	< 0.01

The bridges could also be subjected to valley related movements. A summary of the maximum predicted valley related upsidence and closure movements at the bridges, after the completion of the proposed longwalls, is provided in Table 6.4.

Table 6.4 Maximum Predicted Total Upsidence and Closure for the Road Bridges Resulting from the Extraction of the Proposed Longwalls

Bridge	Location	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
BR-QR01	Quorrobolong Road and Coney Creek	< 20	< 20
BR-SC01	Sandy Creek Road and Sandy Creek	20	20

The bridges are at discrete locations above solid coal and, therefore, the most relevant distribution of strain is the distribution of maximum strains measured in individual survey bays above solid coal from previous longwall mining. The analysis of strains for survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1 and the results for survey bays above solid coal are provided in Fig. 4.3.

6.2.3. Comparison of Predictions for the Road Bridges with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the road bridges with those provided in the Part 3A Application is provided in Table 6.5.

Table 6.5 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Road Bridges Based on the Previous and Modified Layouts

Layout		Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Hogging Curvature in Any Direction (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature in Any Direction (km^{-1})
BR-QR01	Previous Layout (Report No. MSEC309)	35	< 0.5	< 0.01	< 0.01
	Modified Layout (Report No. MSEC484)	40	< 0.5	< 0.01	< 0.01
BR-SC01	Previous Layout (Report No. MSEC309)	< 20	< 0.5	< 0.01	< 0.01
	Modified Layout (Report No. MSEC484)	25	< 0.5	< 0.01	< 0.01

It can be seen from the above table, that the maximum predicted mine subsidence movements at the road bridges, based on the Modified Layout, are similar to those predicted based on the Previous Layout. In consequence, the assessed level of impact for the bridges are not expected to change significantly as a result of the proposed longwall modifications.

Further discussions on the potential impacts on the bridges resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

6.2.4. Impact Assessments for the Road Bridges

It can be seen from Table 6.3, that the predicted magnitudes of subsidence at the bridges are small, being less than 50 mm. While it is possible that the bridges could experience subsidence slightly greater than 50 mm, as the result of far-field vertical movements, they would not be expected to experience any significant tilts, curvatures or strains.

The maximum predicted conventional tilt at the bridges, at any time during or after the extraction of the proposed longwalls, is less than 0.5 mm/m (i.e. < 0.1 %), or a change in grade less than 1 in 2000. The maximum predicted tilt is very small and is unlikely, therefore, to result in any significant impacts on the serviceability of the bridges.

The maximum predicted conventional hogging and sagging curvatures for the bridges, resulting from the extraction of the proposed longwalls, are less than 0.01 km^{-1}, which equates to minimum radius of curvature greater than 100 kilometres. The range of potential strains at the bridges is expected to be similar to the range of strains measured above solid coal for the previously extracted longwalls at the colliery, which are discussed in Section 4.5.2 and illustrated in Fig. 4.3.

Bridge BR-QR01 is a timber structure, with three intermediate timber supports, having an overall span of approximately 22 metres. The bridge is of flexible construction and is expected, therefore, to accommodate the very small predicted curvatures, the range of potential strains and the valley related upsidence and closure movements, without any significant impacts.

Bridge BR-SC01 is a single span concrete structure, having an overall span of approximately 12 metres. It is expected that the thermal expansion joints in the bridge would be able to accommodate the very small predicted curvatures, the range of potential strains and the valley related upsidence and closure movements, without any significant impacts.

6.2.5. Impact Assessments for the Road Bridges Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the predicted tilts were increased by factors of up to 5 times, the maximum predicted tilt at the bridges would be around 2 mm/m (i.e. 0.2 %), which represents a change in grade of 1 in 500. The maximum predicted tilts at the bridges would still be less than 1 % and unlikely, therefore, to result in any significant impacts on the serviceability or structural integrity of the bridges.

If the predicted curvatures were increased by factors of up to 5 times, the maximum predicted curvature at the bridges would be around 0.01 km^{-1}, which equates to minimum radius of curvature of 100 kilometres. It would still be expected that the bridges could accommodate these very small movements without any significant impacts.

6.2.6. Recommendations for the Road Bridges

It is recommended that the Bridges BR-SC01 and BR-QC01 be periodically visually monitored during the extraction of the proposed longwalls.

6.3. Road Drainage Culverts

The descriptions, predictions and impact assessments for the road drainage culverts are provided in the following sections.

6.3.1. Descriptions of the Drainage Culverts

A number of road drainage culverts have been identified within the Study Area, the locations of which are shown in Drawing No. MSEC484-08. The drainage culverts have been installed where the local roads cross the drainage lines and typically range in diameter between 275 mm and 600 mm. There are also three historical culverts within the Study Area, which are located immediately adjacent to the finishing (south-western) ends of Longwalls A7 and A8, which are discussed in Section 8.2.

6.3.2. Predictions for the Drainage Culverts

The drainage culverts are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4. If the longwalls were to be shifted or reoriented within the Extent of the Longwall Mining Area, the maximum predicted subsidence parameters would be expected to be similar to those provided in Chapter 4.

The drainage culverts are at discrete locations and, therefore, the most relevant distributions of strain are the distributions of maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains in survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1. The results for survey bays above goaf are illustrated in Fig. 4.2 and the results for survey bays above solid coal are illustrated in Fig. 4.3.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, valley related upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements. The strains resulting from valley related movements are discussed separately in the following sections.

6.3.3. Comparison of Predictions for the Drainage Culverts with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the drainage culverts with those provided in the Part 3A Application is provided in Table 6.6.

Table 6.6 Comparison of the Maximum Predicted Conventional Subsidence Parameters for Drainage Culverts Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Hogging Curvature in Any Direction (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature in Any Direction (km^{-1})
Drainage Culverts	Previous Layout (Report No. MSEC309)	1925	6.7	0.06	0.12
	Modified Layout (Report No. MSEC484)	1800	6.5	0.05	0.09

It can be seen from the above table, that the maximum predicted mine subsidence movements at the drainage culverts, based on the Modified Layout, are similar to or slightly less than those predicted based on the Previous Layout.

The predicted movements for each individual drainage culvert slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each structure relative to the proposed longwalls.

Further discussions on the potential impacts on the drainage culverts resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

6.3.4. Impact Assessments for the Drainage Culverts

The maximum predicted tilt within the Study Area is 6.5 mm/m (i.e. 0.7 %), which represents a change in grade of 1 in 150. It is expected that the culverts will generally experience tilts less than this maximum, as the result of the variations in the predicted tilts across the Study Area and the orientations of the culverts relative to the subsidence trough.

The predicted changes in grade are small, less than 1 % and, therefore, are unlikely to result in any significant impacts on the serviceability of the drainage culverts. If the flow of water through any drainage culverts were to be adversely affected, as a result of the extraction of the proposed longwalls, this could be easily remediated by relevelling the affected culverts.

The maximum predicted ground curvatures within the Study Area, resulting from the extraction of the proposed longwalls, are 0.05 km^{-1} hogging and 0.09 km^{-1} sagging, which represent minimum radii of curvature of 20 kilometres and 11 kilometres, respectively. It is expected that the culverts will generally experience curvatures less than these maxima, as the result of variations in the predicted curvatures across the Study Area and the orientations of the culverts relative to the subsidence trough.

The drainage culverts are located along drainage lines and could, therefore, experience valley related upsidence and closure movements. The drainage culverts are orientated along the alignments of the drainage lines and, therefore, the upsidence and closure movements are orientated perpendicular the main axes of the culverts and unlikely to result in any significant impacts.

Previously extracted longwalls throughout the NSW Coalfields have been mined directly beneath drainage culverts. The incidence of impacts on drainage culverts has been found to be low, where the depths of cover were greater than 400 metres, such as is the case within the Study Area. Impacts have generally been limited to cracking in the concrete headwalls which can be readily remediated. In some cases, however, cracking in the culvert pipes occurred which required the culverts to be replaced.

With remedial measures implemented, it is expected that the drainage culverts within the Study Area could be maintained in serviceable conditions throughout the mining period

6.3.5. Impact Assessments for the Local Drainage Culverts Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the drainage culverts, the potential impacts would still expected to be of a minor nature, as the maximum change in grade would still be small, in the order of 1 %. If the flow of water through any culverts were to be adversely affected, this could be readily remediated by relevelling the affected culverts.

If the maximum upperbound curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the drainage culverts, the likelihood of impacts would increase, however, the incidence of impact would still be expected to be relative low. Any culvert impacted by mining could be repaired or, if required, replaced.

6.3.6. Recommendations for the Drainage Culverts

The potential impacts on the drainage culverts within the Study Area can be managed by periodic visual monitoring and the implementation of any necessary remedial measures. The ground movements will occur gradually as mining progresses, which will provide adequate time to repair or replace the culverts at the appropriate time, should these works be required. With these remedial measures in place, it is unlikely that there would be any significant long term impacts on the serviceability of the culverts.

6.4. Electrical Infrastructure

The locations of the electrical infrastructure within the Study Area are shown in Drawing No. MSEC484-09. The descriptions, predictions and impact assessments for the electrical infrastructure are provided in the following sections.

6.4.1. Descriptions of the Electrical Infrastructure

The electrical services, which are owned by Energy Australia, comprise above ground 11 kV powerlines supported by timber poles. There are also low voltage powerlines which supply power to the rural properties within the Study Area.

6.4.2. Predictions for the Electrical Infrastructure

The powerlines will not be directly affected by the ground strains, as the cables are supported by poles above ground level. The cables may, however, be affected by changes in the bay lengths, i.e. the distances between the poles at the levels of the cables, resulting from differential subsidence, horizontal movements, and tilt at the pole locations. The stabilities of the poles may also be affected by conventional tilts, and by changes in the catenary profiles of the cables.

The powerlines are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4. If the longwalls were to be shifted or reoriented within the Extent of the Longwall Mining Area, the maximum predicted subsidence parameters would be expected to be similar to those provided in Chapter 4.

6.4.3. Comparison of Predictions for the Electrical Infrastructure with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the electrical infrastructure with those provided in the Part 3A Application is provided in Table 6.7.

Table 6.7 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Electrical Infrastructure Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Subsidence (mm)	Maximum Predicted Tilt (mm/m)
Electrical Infrastructure	Part 3A Layout (Report No. MSEC404)	1925	6.7
	Extraction Plan Layout (Report No. MSEC448)	1800	6.5

It can be seen from the above table, that the maximum predicted mine subsidence movements at the electrical infrastructure, based on the Modified Layout, are similar to or slightly less than those predicted based on the Previous Layout. In consequence, the assessed level of impact for the electrical infrastructure reduce as a result of the proposed longwall modifications.

Further discussions on the potential impacts on the electrical infrastructure resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

6.4.4. Impact Assessments for the Electrical Infrastructure

The maximum predicted tilt within the Study Area is 6.5 mm/m (i.e. 0.7 %), which represents a change in verticality of 1 in 150. It is expected that the power poles will generally experience tilts less than this maximum, as the result of the variations in the predicted tilts across the Study Area.

Longwalls at the colliery and elsewhere in the New South Wales Coalfields have successfully been mined directly beneath low voltage powerlines in the past, where the magnitudes of the predicted mine subsidence movements were similar to those predicted within the Study Area. This includes approximately 4 kilometres of low voltage powerlines above Longwalls 1 to 12A at the colliery. In addition to this, Tahmoor Colliery Longwalls 22 to 25 have mined directly beneath approximately 17 kilometres of electrical cables and 380 power poles and no significant impacts were reported.

Whilst significant impacts generally do not result, where the magnitudes of the predicted mine subsidence movements are similar to those predicted within the Study Area, there are some cases where tension adjustments have been required to some aerial connections to houses. This is understandable as the overhead cables are typically pulled tight between each house and the power pole.

The incidence of impacts on the powerlines within the Study Area, resulting from the extraction of the proposed longwalls, is expected to be low and it is anticipated that any impacts would be relatively minor and easily repaired.

6.4.5. Impact Assessments for the Electrical Infrastructure Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the powerlines, it is possible that some poles would require additional support, including the installation of guy wires, and that some cable catenaries would need to be adjusted. It would still be expected that these potential impacts could be managed by the implementation of suitable management strategies.

6.4.6. Recommendations for the Electrical Infrastructure

The assessed impacts on the 11 kV and low voltage powerlines, resulting from the extraction of the proposed longwalls, could be managed by the implementation of suitable management strategies.

It is recommended that the 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 periodically visually monitored as each longwall is mined 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.

6.5. Telecommunications Infrastructure

The locations of the telecommunications infrastructure within the Study Area are shown in Drawing No. MSEC484-10. The descriptions, predictions and impact assessments for the telecommunications infrastructure are provided in the following sections.

6.5.1. Description of the Telecommunications Infrastructure

The telecommunication infrastructure within the Study Area are owned by Telstra and comprise direct buried optical fibre cable and above ground and direct buried copper cables.

The **optical fibre cable** crosses directly above the proposed Longwalls A9 to A18. The cable runs between the Quorrobolong Telephone Exchange, which is located on Sandy Creek Road, south of the proposed longwalls, and the township of Cessnock, which is located north of the Study Area.

The **copper telecommunications cables** generally follow the alignments of Sandy Creek Road, Quorrobolong Road and Coney Creek Lane within the Study Area. The local cables are direct buried and the main cables are aerial cables supported by timber poles.

The **Quorrobolong Telephone Exchange** is located outside the Study Area. The building is located on Sandy Creek Road, at a distance of 285 metres south of the finishing (south-western) end of Longwall A18.

6.5.2. Predictions for the Telecommunications Infrastructure

The predicted profiles of conventional subsidence, tilt and curvature along the alignment of the optical fibre cable, resulting from the extraction of the proposed longwalls, are shown in Fig. E.07, in Appendix E. The predicted profiles of conventional subsidence, tilt and curvature along the copper telecommunications cables adjacent to Coney Creek Lane are similar to those predicted along that road, which are shown in Fig. E.05, in Appendix E.

A summary of the maximum predicted cumulative conventional subsidence parameters for the telecommunications infrastructure, after the extraction of each of the proposed longwalls, is provided in Table 6.8.

Table 6.8 Maximum Predicted Total Conventional Subsidence Parameters for the Optical Fibre Cable after the Extraction of Each of the Proposed Longwalls

Location	Longwall	Maximum Predicted Subsidence (mm)	Maximum Predicted Tilt (mm/m)	Maximum Predicted Hogging Curvature (km^{-1})	Maximum Predicted Sagging Curvature (km^{-1})
Optical Fibre Cable	After LWA7	< 20	< 0.5	< 0.01	< 0.01
	After LWA8	80	< 0.5	< 0.01	< 0.01
	After LWA9	500	2.0	0.02	0.03
	After LWA10	1150	3.0	0.02	0.03
	After LWA11	1425	3.5	0.02	0.03
	After LWA12	1500	4.0	0.02	0.03
	After LWA13	1575	4.0	0.03	0.04
	After LWA19	1575	4.0	0.03	0.04
Copper Cables adjacent to Coney Creek Lane	After LWA7	< 20	< 0.5	< 0.01	< 0.01
	After LWA8	< 20	< 0.5	< 0.01	< 0.01
	After LWA9	125	0.5	< 0.01	< 0.01
	After LWA10	950	3.0	0.02	0.02
	After LWA11	1325	3.0	0.02	0.02
	After LWA12	1475	4.0	0.02	0.02
	After LWA13	1525	4.5	0.02	0.03
	After LWA19	1575	5.0	0.02	0.03
Copper Cables adjacent to Sandy Creek Road	After LWA16	< 20	< 0.5	< 0.01	< 0.01
	After LWA17	40	< 0.5	< 0.01	< 0.01
	After LWA18	325	2.0	0.01	< 0.01
	After LWA19	1025	3.0	0.02	0.03
Quorrobolong Exchange	After LWA18	< 20	< 0.5	< 0.01	< 0.01
	After LWA19	20	< 0.5	< 0.01	< 0.01

The predicted tilts provided in the above table are the maxima after the completion of each of the proposed longwalls. The predicted curvatures provided in the above table are the maxima at any time during or after the extraction of each of the proposed longwalls. The predicted subsidence parameters for the telephone exchange are the maxima within 20 metres of the perimeter of the building.

The optical fibre and copper cables are linear features and, therefore, the most relevant distribution of strain is the distribution of maximum strains measured along whole monitoring lines above previous longwall mining. The analysis of strains along whole monitoring lines during the mining of previous longwalls at the colliery is discussed in Section 4.5.2 and the results are provided in Fig. 4.4.

The telephone exchange is at a discrete location above solid coal and, therefore, the most relevant distribution of strain is the distribution of maximum strains measured in individual survey bays above solid coal from previous longwall mining. The analysis of strains for survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1 and is illustrated in Fig. 4.3.

The optical fibre cable crosses Cony and Sandy Creeks and could experience valley related movements in these locations. A summary of the maximum predicted upsidence and closure movements at the creek crossings, resulting from the extraction of the proposed longwalls, is provided in Table 6.9.

Table 6.9 Maximum Predicted Upsidence and Closure Movements at the Creek Crossings for the Optical Fibre Cable Resulting from the Extraction of the Proposed Longwalls

Location	Longwall	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Cony Creek	Above LWA15	70	30
Sandy Creek	Above LWA17	50	25
	South of LWA18	< 20	< 20

The predicted upsidence and closure movements provided in the above table are the maxima after the completion of all of the proposed longwalls.

6.5.3. Comparison of Predictions for the Telecommunications Cables with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the telecommunications infrastructure with those provided in the Part 3A Application is provided in Table 6.10.

Table 6.10 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Telecommunications Infrastructure Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Hogging Curvature in Any Direction (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature in Any Direction (km^{-1})
Optical Fibre Cable	Previous Layout (Report No. MSEC309)	1900	5.5	0.04	0.09
	Modified Layout (Report No. MSEC484)	1575	4.0	0.03	0.04
Copper Cables	Previous Layout (Report No. MSEC309)	1900	5.0	0.04	0.07
	Modified Layout (Report No. MSEC484)	1575	5.0	0.02	0.03

It can be seen from the above table, that the maximum predicted mine subsidence movements at the telecommunications infrastructure, based on the Modified Layout, are similar to or slightly less than those predicted based on the Previous Layout. In consequence, the assessed level of impact for the telecommunications infrastructure reduce as a result of the proposed longwall modifications.

Further discussions on the potential impacts on the telecommunications infrastructure resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

6.5.4. Impact Assessments for the Optical Fibre Cable

The optical fibre cable is direct buried and is unlikely, therefore, to be impacted by tilt. The cable is also unlikely to be impacted by curvature, as the cable is flexible and would be expected to tolerate the predicted minimum radius of curvature within the Study Area of 11 kilometres.

The optical fibre cable could, however, be affected by the ground strains resulting from the extraction of the proposed longwalls. The greatest potential for impacts will occur as a result of localised ground strains due to non-conventional ground movements or valley related movements.

The tensile strains in the optical fibre cables could be higher than predicted, where the cables connect to the support structures, which may act as anchor points, preventing any differential movements that may have been allowed to occur in the ground. Tree roots have also been known to anchor cables to the ground. The extent to which the anchor points affect the ability of the cables to tolerate the mine subsidence movements depends on the cable size, type, age, installation method and ground conditions.

In addition to this, optical fibre cables contain additional fibre lengths over the sheath lengths, where the individual fibres are loosely contained within tubes. Compression of the sheaths can transfer to the loose tubes and fibres and result in "micro-bending" of the fibres constrained within the tubes, leading to higher attenuation of the transmitted signal. If the maximum predicted compressive strains were to be fully transferred into the optical fibre cables, the strains could be of sufficient magnitude to result in the reduction in capacities of the cables or transmission loss.

The strains transferred into the optical fibre cables can be monitored using Optical Time Domain Reflectometer (OTDR), which can be used to notify the infrastructure owners of strain concentrations due to non-conventional ground movements or valley related movements.

Longwalls in the Coalfields of New South Wales have been successfully mined directly beneath optical fibre cables in the past. A summary of some of these cases is provided in Table 6.11.

Table 6.11 Examples of Mining Beneath Optical Fibre Cables

Colliery and LWs	Length of Optical Fibre Cables Directly Mined Beneath (km)	Observed Maximum Movements at Optical Fibre Cables	Pre-Mining Mitigation, Monitoring and Observed Impacts
Appin LW301 and LW302	0.8	650 mm Subsidence 0.7 mm/m Tensile Strain 2.8 mm/m Comp. Strain	600 metre aerial cable on standby. Ground survey, visual, OTDR. No reported impacts.
Tahmoor LW22 to LW25	1.2	775 mm Subsidence 0.8 mm/m Tensile Strain 1.9 mm/m Comp. Strain	Ground survey, visual, OTDR, SBS. No reported impacts.
Tower LW1 to LW10	1.7	400 mm Subsidence 3 mm/m Tilt 0.5 mm/m Tensile Strain 1.0 mm/m Comp. Strain	No reported impacts
West Cliff LW5A3, LW5A4 and LW29 to LW33	2.3	950 mm Subsidence 1 mm/m Tensile Strain 5.5 mm/m Comp. Strain (Measured B-Line)	Survey, visual, OTDR, SBS. No reported impacts.
West Wallsend LW27	0.2	350 mm Subsidence 1.3 mm/m Tensile Strain 1.7 mm/m Comp. Strain	Cut over clear of Longwall 27. Ground survey, visual, OTDR. No reported impacts.

It can be seen from the above table, that longwalls in the coalfields of New South Wales have been successfully mined directly beneath optical fibre cables, with the implementation of suitable management strategies. For the optical fibre cable at Austar Coal Mine, it is recommended that the predicted movements are reviewed by the infrastructure owners, to assess the potential impacts and to develop the appropriate management strategies.

6.5.5. Impact Assessments for the Copper Telecommunications Cables

The direct buried copper telecommunications cables are unlikely to be impacted by tilt. The cables are also unlikely to be impacted by curvature, as the cables are flexible and would be expected to tolerate the predicted minimum radius of curvature within the Study Area of 11 kilometres.

The direct buried copper cables could, however, be affected by the ground strains resulting from the extraction of the proposed longwalls. The copper cables are more likely to be impacted by tensile strains rather than compressive strains. It is possible, that the direct buried cables could experience higher tensile strains where they are anchored to the ground by associated infrastructure, or by tree roots. The cables could also experience higher compressive strains at the creek crossings as the result of valley related movements.

Aerial copper telecommunications cables are generally not affected by ground strains, as they are supported by the poles above ground level. The aerial cables, however, could be affected by the changes in bay lengths, i.e. the distances between the poles at the levels of the cables, which result from mining induced differential subsidence, horizontal ground movements and lateral movements at the tops of the poles due to tilting of the poles. The stabilities of the poles can also be affected by mining induced tilts and by changes in the catenary profiles of the cables.

Longwalls in the Coalfields of New South Wales have been successfully mined directly beneath copper telecommunications cables in the past, where the magnitudes of the predicted mine subsidence movements were similar to those predicted within the Study Area. Some of these cases have been summarised in Table 6.12.

Table 6.12 Examples of Mining Beneath Copper Telecommunications Cables

Colliery and LWs	Copper Cables	Observed Maximum Movements at the Copper Cables	Observed Impacts
Appin LW401 to LW408	Longwalls have mined beneath 4 km of underground cables and 0.8 km of aerial cables	700 mm Subsidence 5 mm/m Tilt 1 mm/m Tensile Strain 2 mm/m Comp. Strain (Measured A6000-Line)	No significant impacts
Tahmoor LW22 to LW25	Longwalls have mined beneath 19 km of underground cables and 2.5 km of aerial cables	1200 mm Subsidence 6 mm/m Tilt 1.5 mm Tensile Strain 2.0 mm (typ.) and up to 5.0 mm/m Comp. Strain (Extensive street monitoring)	No significant impacts to underground cables. Some pole tilts and cable catenaries adjusted. Some consumer cables were re-tensioned as a precautionary measure
West Cliff LW29 to LW33	Longwalls have mined beneath 13 km of underground cables	950 mm Subsidence 1 mm/m Tensile Strain 5.5 mm/m Comp. Strain (Measured B-Line)	No significant impacts

It can be seen from the above table, that there were no reported impacts on the direct buried copper telecommunications cables in the above examples. It is also understood, that there have been no significant impacts on direct buried copper telecommunications cables elsewhere in the NSW Coalfields, where the depths of cover were greater than 400 metres, such as is the case above the proposed longwalls.

It can also be seen from the above table, that there have been only minor impacts on aerial copper telecommunications cables in the above examples. Some remedial measures were required, which included adjustments to cable catenaries, pole tilts and consumer cables which connect between the poles and houses. The incidence of these impacts, however, was very low.

Based on this experience, it is unlikely that the extraction of the proposed longwalls would result in any significant impacts on the direct buried or aerial copper telecommunications cables within the Study Area. Any minor impacts on these cables would be expected to be relatively infrequent and easily repaired.

6.5.6. Impact Assessments for the Telephone Exchange Building

The Quorrobolong Telephone Exchange is located 285 metres south of the finishing (south-eastern) end of Longwall A18, at its closest point to the proposed longwalls. At this distance, the exchange is predicted to experience approximately 20 mm of subsidence. While it is possible that the exchange could experience subsidence slightly greater than 20 mm, as the result of far-field vertical movements, it would not be expected to experience any significant tilts, curvatures and strains.

It is unlikely, therefore, that the exchange would experience any significant impacts resulting from the extraction of the proposed longwalls.

6.5.7. Impact Assessments for Telecommunications Infrastructure Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the range of potential strains along the optical fibre cable were increased by factors of up to 1.6 times, the strains would still be in the range of those experienced at collieries shown in Table 6.11, where non-conventional ground movements occurred. In these cases, longwalls were successfully mined beneath optical fibre cables where the measured strains were up to 5.5 mm/m, with the implementation of suitable management strategies.

If the range of potential strains along the direct buried copper cables were increased by factors of up to 1.6 times, the strains would still be in the range of those experienced at collieries shown in Table 6.12, where non-conventional ground movements occurred. As shown in this table, longwalls have been successfully mined beneath copper telecommunications cables where the measured strains were up to 5.5 mm/m, with the implementation of suitable management strategies.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the aerial cables, it is possible that some poles would require additional support, including the installation of guy wires, and that some cable catenaries would need to be adjusted. As shown Table 6.12, longwalls have been successfully mined beneath aerial copper telecommunications cables in the NSW Coalfields where the measured tilts were up to 6 mm/m and only on minor impacts have been observed.

6.5.8. Recommendations for Telecommunications Infrastructure

It is recommended that the optical fibre cable is monitored during the extraction of the proposed longwalls using optical fibre sensing techniques, such as OTDR monitoring. Mitigation measures can be undertaken, such as excavating and exposing the cable, if strain concentrations are detected during the mining period. With the required mitigation measures in place, it is expected that the optical fibre cable could be maintained in serviceable conditions throughout the mining period.

It is recommended that the aerial copper telecommunications cables are periodically visually monitored as each longwall is mined directly beneath them, so that any impacts can be identified and rectified accordingly. With these management strategies in place, it is unlikely that there would be any significant long term impacts on the telecommunications cables.

It is also recommended that management strategies are developed, in consultation with Telstra, to ensure that the optical fibre cable and copper telecommunications cables are maintained in serviceable conditions throughout the mining period.

6.6. Survey Control Marks

The locations of the survey control marks within and immediately adjacent to the Study Area are shown in Drawing No. MSEC484-16. The locations and details of the survey control marks were obtained from the *Land and Property Management Authority* using the *SCIMS Online* website (SCIMS, 2011).

There are three survey control marks which are located above the proposed longwalls, which could experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4.

The survey control marks located outside and in the vicinity of the Study Area are also expected to experience small amounts of subsidence and small far-field horizontal movements. It is possible that other survey control marks outside the immediate area could also be affected by far-field horizontal movements, up to 3 kilometres outside the Study Area. Far-field horizontal movements and the methods used to predict such movements are described further in Section 4.7.

It will be necessary on the completion of the longwalls, when the ground has stabilised, to re-establish any survey control marks that are required for future use. Consultation between the Austar and the Department of Lands will be required to ensure that these survey control marks are reinstated at the appropriate time, as required.

7.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE FARM LAND AND FARM FACILITIES

The following sections provide the descriptions, predictions and impact assessments for the farm land and farm facilities within the Study Area.

7.1. Agricultural Utilisation

The land within the Study Area, south of Big Hill Road and Nash Lane, has predominately been cleared for agricultural use. There are a number of vineyards and other planted areas on the rural properties within the Study Area which are shown in Drawings Nos. MSEC484-11 to MSEC484-15.

7.2. Rural Building Structures

The descriptions, predictions and impact assessments for these structures are provided in the following sections.

7.2.1. Descriptions of the Rural Building Structures

There are 71 rural building structures (Structure Type R) which have been identified within the Study Area, which include farm sheds, garages and other non-residential structures. The rural building structures are generally of lightweight construction.

The locations of the rural building structures are shown in Drawings Nos. MSEC484-11 to MSEC484-15 and details are provided in Table D.02 in Appendix D. The locations, sizes, and details of the rural building structures were determined from an aerial photograph of the area and from site investigations.

7.2.2. Predictions for the Rural Building Structures

Predictions of conventional subsidence, tilt and curvature have been made at the centroid and at the vertices of each rural building structure, as well as at eight equally spaced points placed radially 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.

A summary of the maximum predicted values of conventional subsidence, tilt and curvature for each rural building structure within the Study Area, resulting from the extraction of the proposed longwalls, is provided in Table D.02 in Appendix D.

If the longwalls were to be shifted or reoriented within the Extent of the Longwall Mining Area, the individual rural building structures would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the rural building structures across the Study Area would not be expected to change significantly.

The distributions of the maximum predicted conventional subsidence, tilt and curvature for the rural building structures within the Study Area, resulting from the extraction of the proposed longwalls, are illustrated in Fig. 7.1 and Fig. 7.2.

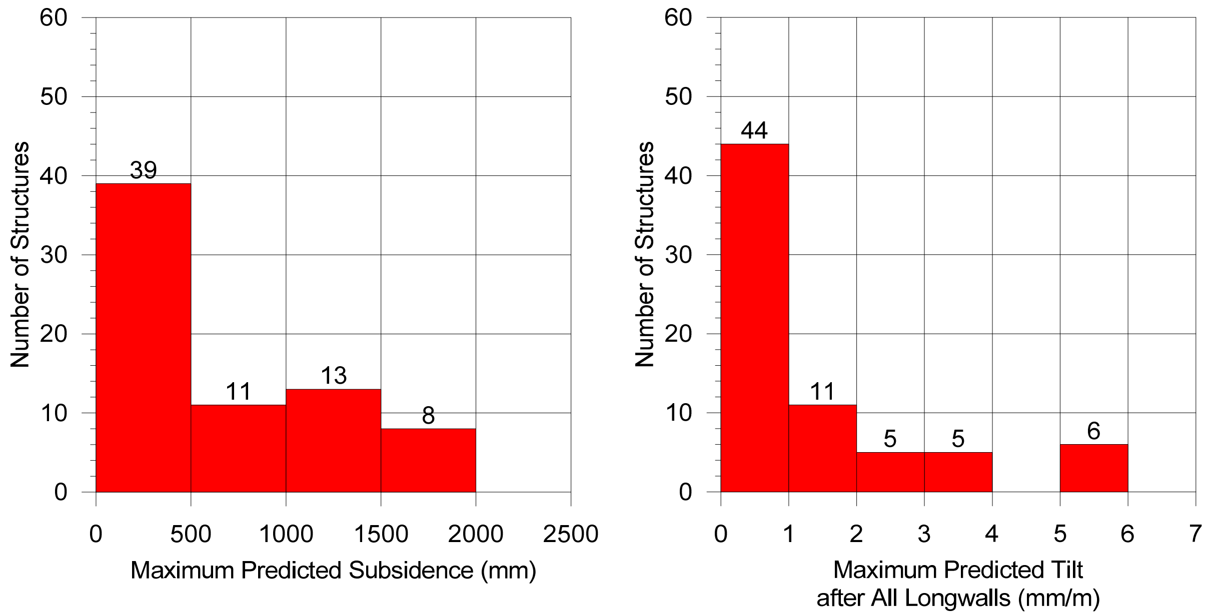

Fig. 7.1 Maximum Predicted Conventional Subsidence and Tilt for the Rural Building Structures within the Study Area Resulting from the Extraction of the Proposed Longwalls

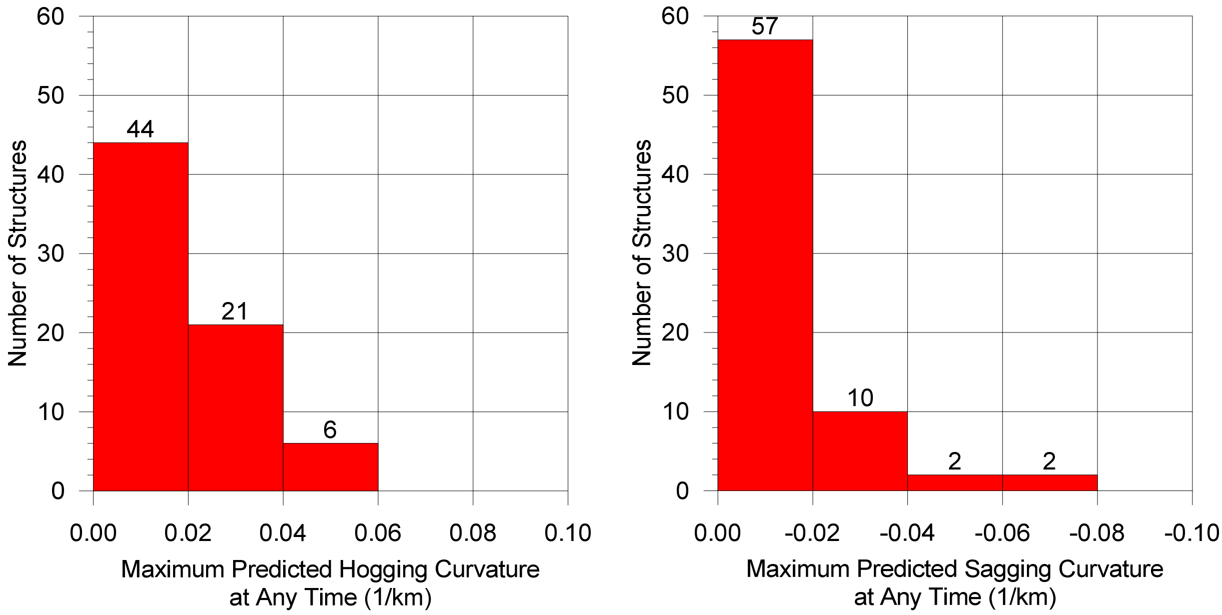

Fig. 7.2 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Rural Structures Resulting from the Extraction of the Proposed Longwalls

The rural building structures are at discrete locations and, therefore, the most relevant distributions of strain are the distributions of maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains in survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1. The results for survey bays above goaf are illustrated in Fig. 4.2 and the results for survey bays above solid coal are illustrated in Fig. 4.3.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, anomalous ground movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements

7.2.3. Comparison of Predictions for the Rural Building Structures with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the rural building structures with those provided in the Part 3A Application is provided in Table 7.1.

Table 7.1 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Rural Building Structures Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Hogging Curvature in Any Direction (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature in Any Direction (km^{-1})
Rural Building Structures	Previous Layout (Report No. MSEC309)	1825	6.0	0.07	0.08
	Modified Layout (Report No. MSEC484)	1675	6.0	0.05	0.08

It can be seen from the above table, that the maximum predicted mine subsidence movements at the rural building structures, based on the Modified Layout, are similar to or slightly less than those predicted based on the Previous Layout.

The predicted movements for each individual rural building structure slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each structure relative to the proposed longwalls. Further discussions on the potential impacts on the rural building structures resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

7.2.4. Impact Assessments for the Rural Building Structures

The maximum predicted tilts for the rural building structures, resulting from the extraction of the proposed longwalls, is 6 mm/m (i.e. 0.6 %), which represents a change in grade of 1 in 165. It has been found from previous longwall mining experience, that tilts of the magnitudes predicted within the Study Area generally do not result in any significant impacts on rural building structures. Some minor serviceability impacts could occur at the higher levels of predicted tilt, including door swings and issues with roof and pavement drainage, all of which can be repaired using normal building maintenance techniques.

The maximum predicted ground curvatures for the rural building structures, resulting from the extraction of the proposed longwalls, are 0.05 km^{-1} hogging and 0.08 km^{-1} sagging, which represent minimum radii of curvature of 20 kilometres and 13 kilometres, respectively. The range of predicted curvatures for the rural building structures is similar to those typically experienced in the Southern Coalfield.

The observed levels of impact on the rural building structures in the Southern Coalfield, therefore, should provide a reasonable guide to the overall levels of impact on the rural building structures within the Study Area. Longwalls in the Southern Coalfield have been successfully mined directly beneath rural building structures in the past, where the magnitudes of the predicted mine subsidence movements were similar to those predicted within the Study Area. A summary of some of these cases is provided in Table 7.2.

Table 7.2 Examples of Previous Experience of Mining Beneath Rural Building Structures in the Southern Coalfield

Colliery and LWs	Rural Building Structures	Maximum Predicted Movements at the Structures	Observed Impacts
Appin LW301 and LW302	4	770 mm Subsidence 6 mm/m Tilt 0.7 mm/m Tensile Strain 1.6 mm/m Comp. Strain	No reported impacts
Appin LW401 to LW409	75	1200 mm Subsidence 5 mm/m Tilt 1.2 mm/m Tensile Strain 2.2 mm/m Comp. Strain	No reported impacts
Appin LW701 and LW702	12	1300 mm Subsidence 5 mm/m Tilt 1.6 mm/m Tensile Strain 2.0 mm/m Comp. Strain	No reported impacts
Tahmoor LW22 to LW25	79	850 mm Subsidence 5 mm/m Tilt 0.8 mm/m Tensile Strain 1.7 mm/m Comp. Strain	Impacts reported at three rural building structures
West Cliff LW29 to LW33	184	1200 mm Subsidence 6 mm/m Tilt 1.4 mm/m Tensile Strain 1.8 mm/m Comp. Strain	Impacts to four large chicken sheds due to non-conventional movements.

There is extensive experience of mining directly beneath rural building structures in the Southern Coalfield which indicates that the incidence of impacts on these structures is very low. This is not surprising as rural building structures are generally small in size and being of light-weight construction they are less susceptible to impact than houses which are typically more rigid. In all cases, the rural building structures remained in safe and serviceable conditions.

It is expected, therefore, that all the rural building structures within the Study Area would remain safe and serviceable during the mining period, provided that they are in sound existing condition. The risk of impact is clearly greater if the structures are in poor condition, though the chances of there being a public safety risk remains very low. A number of rural building structures, which were in poor condition prior to mining, have been directly mined beneath and these structures have not experienced impacts during mining.

Any impacts on the rural building structures that occur as a result of the extraction of the proposed longwalls could be repaired using well established building techniques. With these remedial measures available, it is unlikely that there would be any significant long term impacts on rural building structures resulting from the extraction of the proposed longwalls.

7.2.5. Impact Assessments for the Rural Building Structures Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the rural building structures, it is likely that these structures would experience minor serviceability impacts, including door swings and issues with roof gutter and pavement drainage. It would still be unlikely that the stabilities of these rural building structures would be affected at this magnitude of tilt.

If the maximum upperbound curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the rural building structures, it is possible that some structures could experience slight or moderate impacts. It would still be expected, however, that all rural building structures would remain in a safe condition throughout the mining period and that any impacts could be repaired using well established building techniques.

7.2.6. Recommendations for the Rural Building Structures

The assessed impacts on the rural building structures within the Study Area, resulting from the extraction of the proposed longwalls, could be managed by the implementation of suitable management strategies.

It is recommended that the rural building structures located above the proposed longwalls should be inspected, prior to being mined beneath, to assess the existing conditions and to determine whether any preventive measures may be required. It is also recommended that the rural building structures are periodically visually monitored during the extraction of the proposed longwalls. With these management strategies in place, it is unlikely that there would be any significant long term impacts on the rural building structures.

7.3. Tanks

The descriptions, predictions and impact assessments for the tanks are provided in the following sections.

7.3.1. Descriptions of the Tanks

There are 39 water tanks (Structure Type T) which have been identified within the Study Area. The locations of the tanks are shown in Drawings Nos. MSEC484-11 to MSEC484-15 and details are provided in Table D.04 in Appendix D. The locations and sizes of the tanks were determined from an aerial photograph of the area. There are also a number of smaller rainwater and fuel storage tanks associated with the residences on each rural property which are not shown in the drawings.

7.3.2. Predictions for the Tanks

Predictions of conventional subsidence, tilt and curvature have been made at the centroid and at points located around the perimeter of each tank, as well as at points located at a distance of 20 metres from the perimeter of each tank.

A summary of the maximum predicted values of conventional subsidence, tilt and curvature for each tank within the Study Area, resulting from the extraction of the proposed longwalls, is provided in Table D.04 in Appendix D.

If the longwalls were to be shifted or reoriented within the Extent of the Longwall Mining Area, the individual tanks would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the tanks across the Study Area would not be expected to change significantly.

The distributions of the maximum predicted conventional subsidence, tilt and curvature for the tanks within the Study Area, resulting from the extraction of the proposed longwalls, are illustrated in Fig. 7.3 and Fig. 7.4.

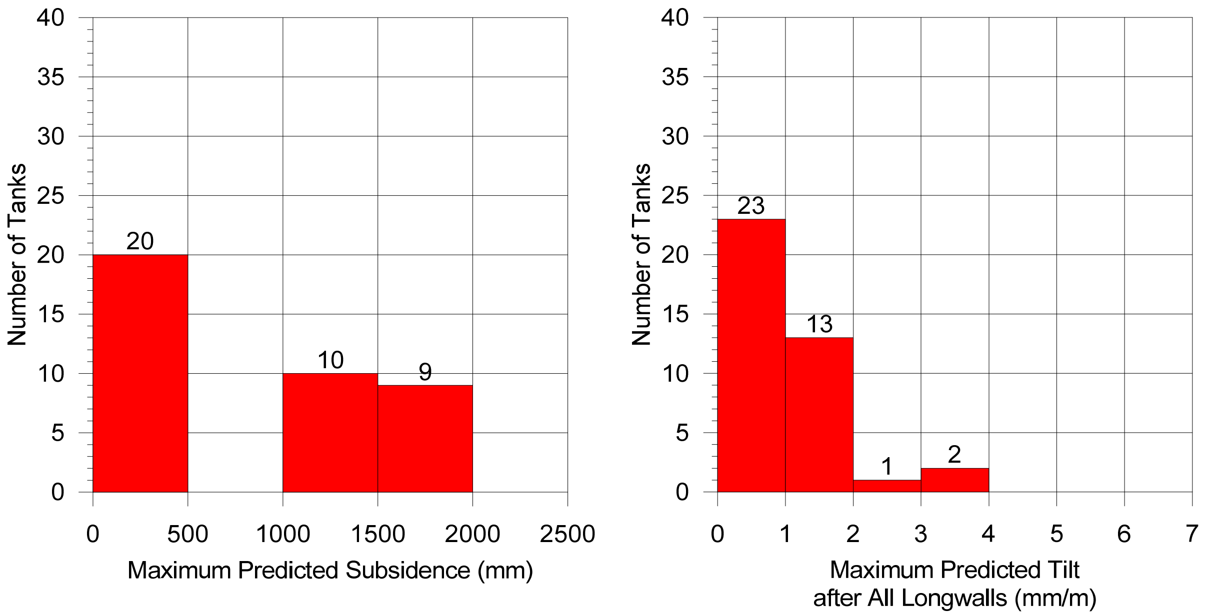

Fig. 7.3 Maximum Predicted Conventional Subsidence and Tilt for the Tanks within the Study Area Resulting from the Extraction of the Proposed Longwalls

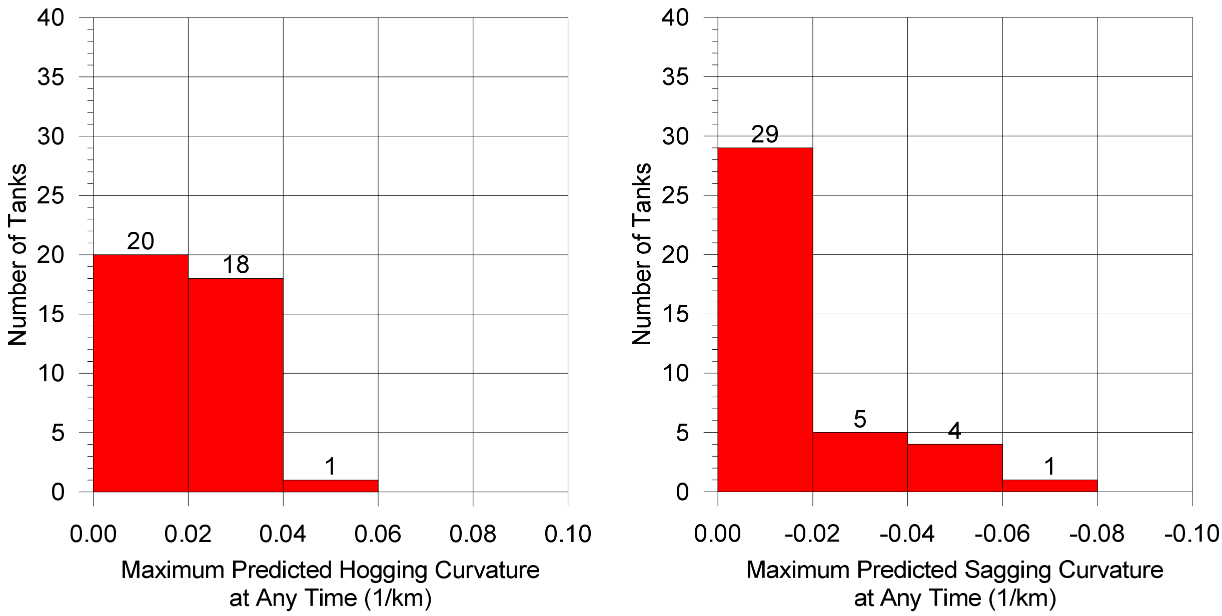

Fig. 7.4 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Tanks Resulting from the Extraction of the Proposed Longwalls

The tanks are at discrete locations and, therefore, the most relevant distributions of strain are the distributions of maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains in survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1. The results for survey bays above goaf are illustrated in Fig. 4.2 and the results for survey bays above solid coal are illustrated in Fig. 4.3.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

7.3.3. Comparison of Predictions for the Tanks with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the tanks with those provided in the Part 3A Application is provided in Table 7.3.

Table 7.3 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Tanks Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Tanks	Previous Layout (Report No. MSEC309)	1850	5.0	0.06	0.10
	Modified Layout (Report No. MSEC484)	1650	3.5	0.04	0.08

It can be seen from the above table, that the maximum predicted mine subsidence movements at the tanks, based on the Modified Layout, are similar to but slightly less than those predicted based on the Previous Layout.

The predicted movements for each individual tank slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each feature relative to the proposed longwalls. Further discussions on the potential impacts on the tanks resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

7.3.4. Impact Assessments for the Tanks

Tilt can potentially affect the serviceability of tanks by altering the water levels in the tanks, which can in turn affect the minimum level of water which can be released from the outlets. The maximum predicted conventional tilt for the tanks within the Study Area is 3.5 mm/m (i.e. 0.4 %), which represents a change in grade of 1 in 285. The predicted changes in grade are small and are unlikely, therefore, to result in any significant impacts on the serviceability of the tanks.

The tanks structures are typically constructed above ground level and, therefore, are unlikely to experience the curvatures and ground strains resulting from the extraction of the proposed longwalls. It is possible, that any buried water pipelines associated with the tanks within the Study Area could be impacted by the ground 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 significant impacts on the pipelines associated with the tanks.

7.3.5. Impact Assessments for the Tanks Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the tanks, the incidence of serviceability impacts on the tanks would still expected to be small, since the maximum changes in grade are in the order of 1 %. Any such impacts would be expected to be easily remediated by relevelling the tanks

If the maximum upperbound curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the tanks, the incidence of impacts on the tank structures would not be expected to change significantly, as they are not expected to directly experience these ground movements.

The incidence of impacts on the buried pipelines would, however, be expected to increase accordingly. Any impacts would still be expected to be of a minor nature which could be easily repaired. With these remedial measures in place, it would be unlikely that there would be any significant long term impacts on the pipelines associated with the tanks.

7.3.6. Recommendations for the Tanks

The assessed impacts on the tanks and associated infrastructure resulting from the extraction of the proposed longwalls are not significant. It is recommended that the tanks are visually monitored during the mining period.

7.4. Gas and Fuel Storages

There are domestic gas and fuel storages on the rural properties across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4.

The storage tanks are generally elevated above ground level and, therefore, are not susceptible to mine subsidence movements. It is possible, however, that any buried gas pipelines associated with the storage tanks within the Study Area could be impacted by the ground strains, if they are anchored by the storage tanks, or by other structures in the ground. Any impacts would be expected to be of a minor nature, including minor gas leaks, which could be easily repaired. It is unlikely that there would be any significant impacts on the pipelines associated with the gas and fuel storage tanks.

7.5. Farm Fences

There are a number of fences within the Study 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 Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4. If the longwalls were to be shifted or reoriented within the Extent of the Longwall Mining Area, the maximum predicted subsidence parameters would be expected to be similar to those provided in Chapter 4.

The maximum predicted conventional tilt within the Study Area is 6.5 mm/m (i.e. 0.7 %), which represents a change in grade of 1 in 155.

The fences are linear features and, therefore, the most relevant distribution of strain is the distribution of maximum strains measured along whole monitoring lines above previous longwall mining. The analysis of strains along whole monitoring lines during the mining of previous longwalls at the colliery is discussed in Section 4.5.2 and the results are illustrated in Fig. 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

It is possible that some of the wire fences within the Study Area would be impacted as a result of the extraction of the proposed longwalls. Any impacts on the wire fences are likely to be of a minor nature and relatively easy to remediate by re-tensioning the fencing wire, straightening the fence posts, and if necessary, replacing some sections of fencing.

Colorbond and timber paling fences are more rigid than wire fences and, therefore, are more susceptible to impacts resulting from mine subsidence movements. It is possible that these types of fences could be impacted as the result of the extraction of the proposed longwalls. Any impacts on Colorbond or timber paling fences are expected to be of a minor nature and relatively easy to remediate or, where necessary, to replace.

7.6. Farm Dams

The descriptions, predictions and impact assessments for these features are provided in the following sections.

7.6.1. Descriptions of the Farm Dams

There are 126 farm dams (Structure Type D) which have been identified within the Study Area. The locations of the farm dams are shown in Drawings Nos. MSEC484-11 to MSEC484-15 and details are provided in Table D.03 in Appendix D. The locations and sizes of the farm dams were determined from an aerial photograph of the area.

The dams are typically 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. The distributions of the longest lengths and surface areas of the farm dams within the Study Area are shown in Fig. 7.5.

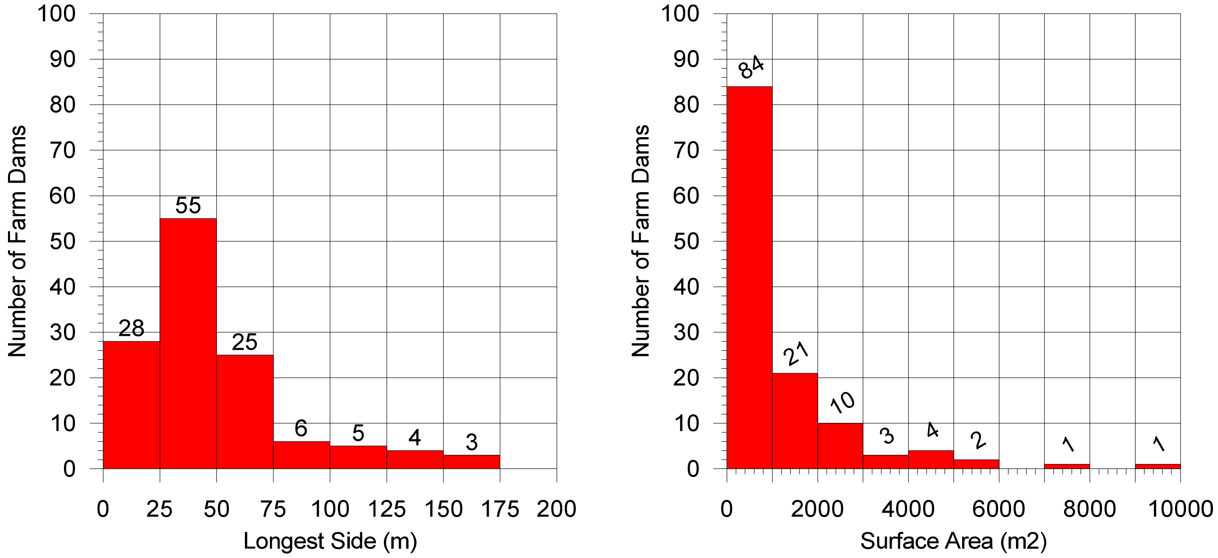

Fig. 7.5 Distributions of Longest Lengths and Surface Areas of the Farm Dams

7.6.2. Predictions for the Farm Dams

Predictions of conventional subsidence, tilt and curvature have been made at the centroid and around the perimeters of each farm dam. A summary of the maximum predicted values of conventional subsidence, tilt and curvature for each farm dam within the Study Area, resulting from the extraction of the proposed longwalls, is provided in Table D.03 in Appendix D.

If the longwalls were to be shifted or reoriented within the Extent of the Longwall Mining Area, the individual farm dams would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the farm dams across the Study Area would not be expected to change significantly.

The distributions of the maximum predicted conventional subsidence, tilt and curvature for the farm dams within the Study Area, resulting from the extraction of the proposed longwalls, are illustrated in Fig. 7.6, Fig. 7.7 and Fig. 7.8.

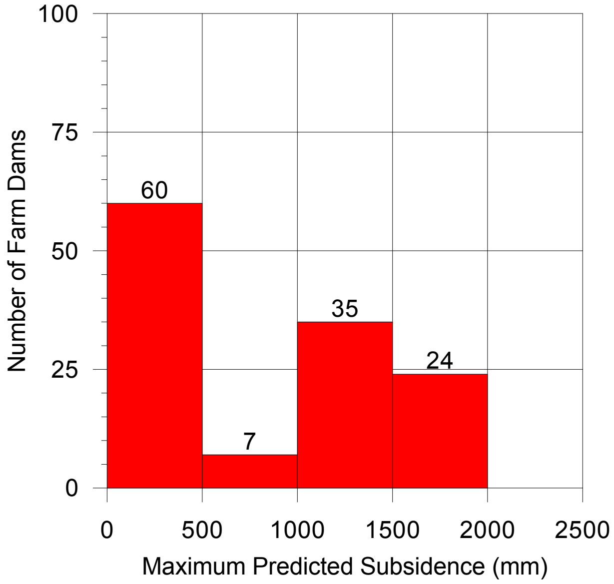

Fig. 7.6 Maximum Predicted Conventional Subsidence for the Farm Dams within the Study Area Resulting from the Extraction of the Proposed Longwalls

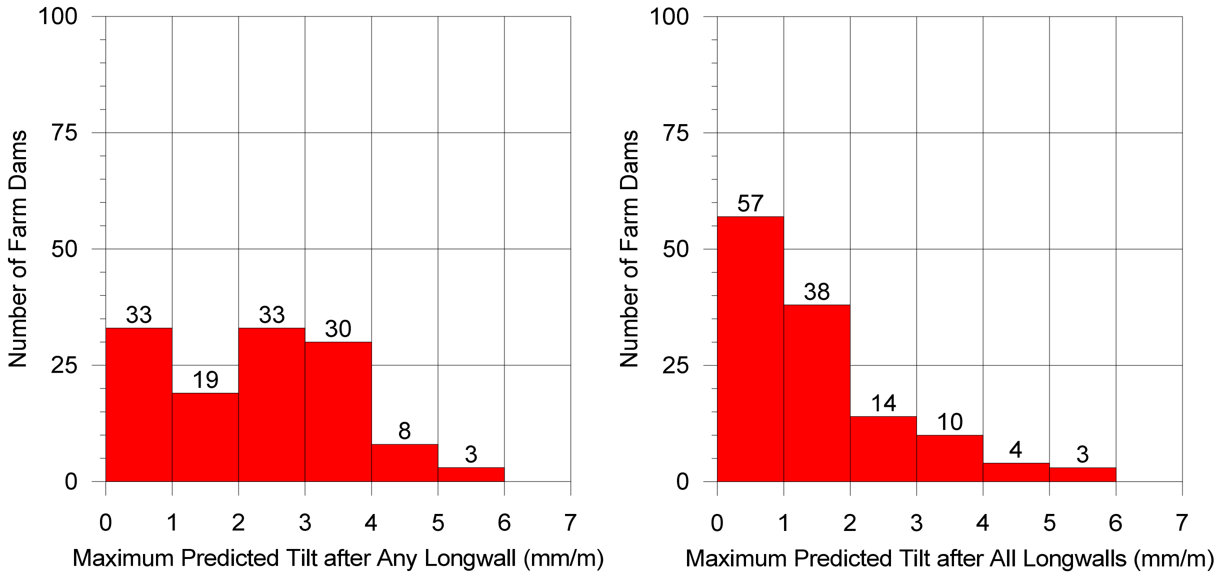

Fig. 7.7 Maximum Predicted Conventional Tilt after the Extraction of Any Longwall (Left) and after the Extraction of All Longwalls (Right) for the Farm Dams within the Study Area

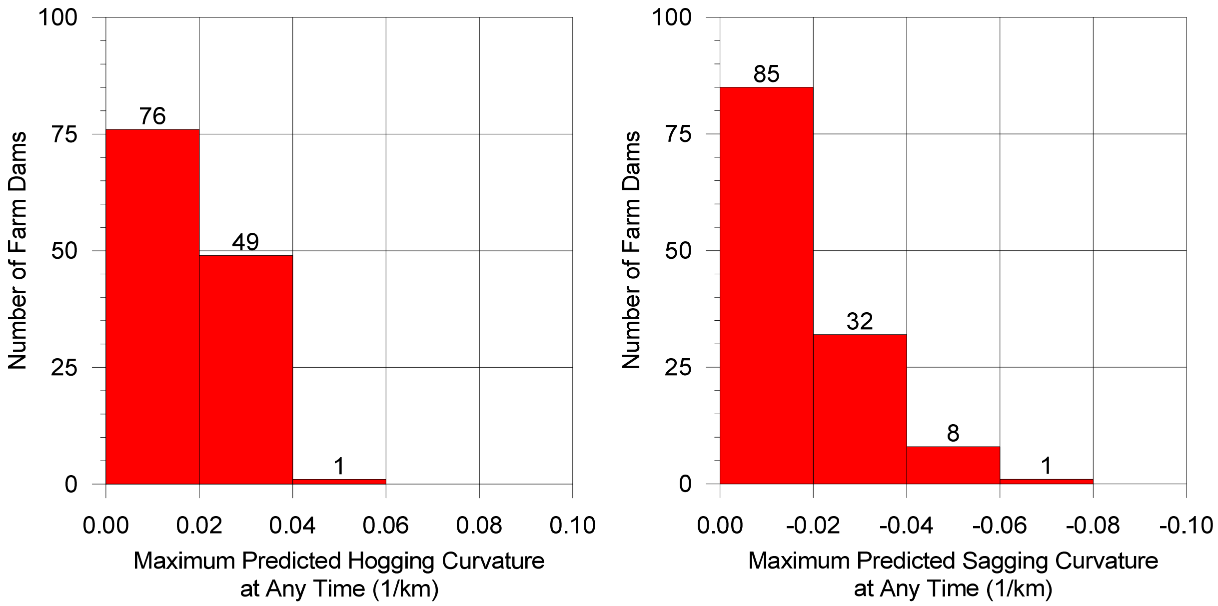

Fig. 7.8 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Farm Dams Resulting from the Extraction of the Proposed Longwalls

The dams have typically been constructed within the 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 it is expected, therefore, that the predicted valley related upsidence and closure movements at the dam walls would be much less than the predicted conventional subsidence movements and would not be significant.

The farm dams are at discrete locations and, therefore, the most relevant distributions of strain are the distributions of maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains in survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1. The results for survey bays above goaf are illustrated in Fig. 4.2 and the results for survey bays above solid coal are illustrated in Fig. 4.3.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, valley related upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements. The strains resulting from valley related movements are discussed separately in the following sections.

7.6.3. Comparison of Predictions for the Farm Dams with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the farm dams with those provided in the Part 3A Application is provided in Table 7.4.

Table 7.4 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Farm Dams Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Farm Dams	Previous Layout (Report No. MSEC309)	1900	6.0	0.05	0.12
	Modified Layout (Report No. MSEC484)	1750	6.0	0.05	0.07

It can be seen from the above table, that the maximum predicted mine subsidence movements at the farm dams, based on the Modified Layout, are similar to but slightly less than those predicted based on the Previous Layout.

The predicted movements for each individual farm dam slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each feature relative to the proposed longwalls. Further discussions on the potential impacts on the farm dams resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

7.6.4. Impact Assessments for the Farm Dams

The maximum predicted tilt for the farm dams within the Study Area, resulting from the extraction of the proposed longwalls, is 6 mm/m (i.e. 0.6 %), which represents a change in grade of 1 in 165. 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, by causing them to overflow, or can affect the stability of the dam walls by increasing the pressure on them.

The predicted changes in freeboard at the farm dams within the Study Area were determined by taking the difference between the maximum predicted subsidence and the minimum predicted subsidence anywhere around the perimeter of each farm dam. The predicted maximum changes in freeboard at the farm dams within the Study Area, after the completion of the proposed longwalls, are provided in Table D.03 in Appendix D and are illustrated in Fig. 7.9.

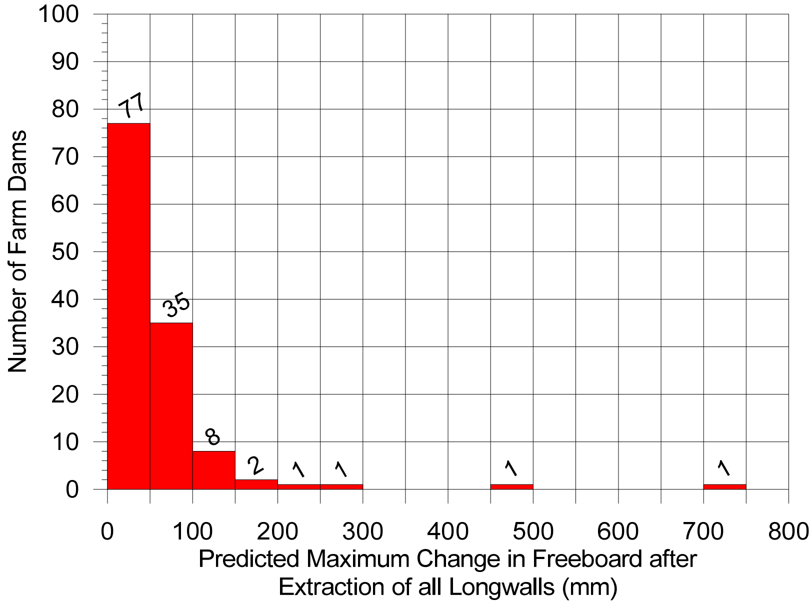

Fig. 7.9 Predicted Changes in Freeboards for the Farm Dams within the Study Area

The maximum predicted change in freeboard is 700 mm at a Dam A35d01, which is located near the commencing (north-eastern) end of Longwall A11. The predicted maximum changes in freeboard at the remaining farm dams within the Study Area are all less than 500 mm and are unlikely, therefore, to have a significant impact on the storage capacities or the stability of the dam walls.

The maximum predicted ground curvatures for farm dams, resulting from the extraction of the proposed longwalls, are 0.05 km^{-1} hogging and 0.07 km^{-1} sagging, which represent minimum radii of curvature of 20 kilometres and 14 kilometres, respectively. The range of predicted curvatures for the farm dams is similar to those typically experienced in the Southern Coalfield.

The observed levels of impact on the farm dams in the Southern Coalfield, therefore, should provide a reasonable guide to the likely levels of impact on the farm dams within the Study Area. Longwalls in the Southern Coalfield have been successfully mined directly beneath farm dams in the past, where the magnitudes of the predicted mine subsidence movements were similar to those predicted within the Study Area. A summary of some of these cases is provided in Table 7.5.

Table 7.5 Examples of Previous Experience of Mining Beneath Farm Dams in the Southern Coalfield

Colliery and LWs	Number of Farm Dams Directly Mined Beneath	Predicted Maximum Movements at Dams	Observed Impacts
Appin LW301 and LW302	3	750 mm Subsidence 6 mm/m Tilt 0.7 mm/m Tensile Strain 1.8 mm/m Comp. Strain	No reported impacts
Appin LW401 to LW409	49	1200 mm Subsidence 5 mm/m Tilt 1.2 mm/m Tensile Strain 2.2 mm/m Comp. Strain	No reported impacts
Appin LW701 and LW702	11	1100 mm Subsidence 4 mm/m Tilt 0.6 mm/m Tensile Strain 1.4 mm/m Comp. Strain	One farm dam reported to drain
Tahmoor LW22 to LW25	16	850 mm Subsidence 5 mm/m Tilt 1.0 mm/m Tensile Strain 1.7 mm/m Comp. Strain	No reported impacts
West Cliff LW29 to LW33	42	1100 mm Subsidence 6 mm/m Tilt 1.2 mm/m Tensile Strain 2.0 mm/m Comp. Strain	No reported impacts

It can be seen from the above table, that the incidence of adverse impacts on farm dams in the Southern Coalfield is very low. The farm dam reported to drain during the extraction of Appin Longwall 702 was of poor, shallow construction and seepage was observed at the base of the dam wall prior to mining. While no impacts were observed on the dam wall itself, the dam was observed to drain following mining of Appin Longwall 702.

It is expected, therefore, that the incidence of impacts on the farm dams within the Study Area, resulting from the extraction of the proposed longwalls, will be extremely low. If cracking or leakage of water were to occur in the farm dam walls, it is expected that this could be easily identified and repaired as required. It is not expected that any significant loss of water will occur from the farm dams, and any loss that did occur would flow into the tributary in which the dam was formed.

7.6.5. Impact Assessments for the Farm Dams Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the farm dams, the predicted maximum change in freeboard would be around 1 metre. These levels of movement could reduce the capacities of some farm dams below acceptable levels and, in these cases, it may be necessary to restore the capacities at the completion of mining

If the maximum upperbound curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the farm dams, the likelihood and extent of surface cracking would increase. Any surface cracking would still be expected to be of a minor nature and could be easily repaired. With any necessary remedial measures implemented, it is unlikely that any significant long term impact on the farm dams would result from the extraction of the proposed longwalls.

7.6.6. Recommendations for the Farm Dams

The assessed impacts on the farm dams, resulting from the extraction of the proposed longwalls, can be managed by the implementation of suitable management strategies. It is recommended that all water retaining structures be periodically visually monitored during the extraction of the proposed longwalls, to ensure that they remain in a safe and serviceable condition. With these management strategies in place, it is unlikely that there would be any significant long term impacts on the farm dams.

7.7. Groundwater Bores

The locations of the groundwater bores in the vicinity of the proposed longwalls are shown in Drawing No. MSEC484-16. The locations and details of the registered groundwater bores were obtained from the Department of Natural Resources using the *Natural Resource Atlas* website (NRAtlas, 2011).

The groundwater bores are located at a minimum distance of 280 metres from the proposed longwalls. It is possible that the groundwater bores could experience some impacts as a result of mining the longwalls. Impacts could include temporary lowering of the piezometric surface, blockage of the bore due to differential horizontal displacements at different horizons within the strata and changes to groundwater quality.

Such impacts on the groundwater bores can be readily managed, by repairing or replacing the bores at the completion of mining. If required, temporary alternative supplies of water could be provided by the colliery during the mining period.

8.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR AREAS OF ARCHEOLOGICAL AND HERITAGE SIGNIFICANCE

The descriptions, predictions and impact assessments for the archaeological and heritage sites within the Study Area are provided in the following sections.

8.1. Archaeological Sites

The descriptions, predictions and impact assessments for the archaeological sites within the Study Area are provided in the following sections.

8.1.1. Descriptions of the Archaeological Sites

There are no lands within the Study Area declared as an Aboriginal Place under the *National Parks and Wildlife Act 1974*. There are, however, a number of archaeological sites which have been identified within the Study Area, including a number of artefact scatters, isolated finds and potential archaeological deposits, which are located across the Study Area, as well as one grinding groove site, which is located 140 metres north of the proposed Longwall A7, and one scarred tree, which is located above the finishing (south-western) end of Longwall A10. The locations of the archaeological sites within the Study Area are shown in Drawing No. MSEC484-17 and details are provided in the report by Umwelt (2011b).

8.1.2. Predictions for the Archaeological Sites

The artefact scatters and isolated finds are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4. If the longwalls were to be shifted or reoriented within the Extent of the Longwall Mining Area, the maximum predicted subsidence parameters would be expected to be similar to those provided in Chapter 4.

The grinding groove site is located north of the proposed Longwall A7 and the scarred tree is located above the finishing (south-western) end of Longwall A10. A summary of the maximum predicted conventional subsidence parameters at the grinding groove site and the scarred tree, at any time during or after the extraction of each of the proposed longwalls, is provided in Table 8.1. The predicted parameters are the maxima within 20 metres of the sites.

Table 8.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature at the Grinding Groove Site and Scarred Tree Resulting from the Extraction of the Proposed Longwalls

Location	Longwall	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Grinding Groove Site	After LWA19	200	1.5	0.01	< 0.01
Scarred Tree	After LWA19	900	6.0	0.03	0.02

The predicted tilts provided in the above table are the maxima after the completion of each or all of the proposed longwalls. The predicted curvatures provided in the above table are the maxima at any time during or after the extraction of each of the proposed longwalls.

The grinding groove site is located near the base of a small watercourse and could, therefore, experience valley related upsidence and closure movements resulting from the extraction of the proposed longwalls. A summary of the maximum predicted upsidence and closure movements at the grinding groove site, after the extraction of each of the proposed longwalls, is provided in Table 8.2.

Table 8.2 Maximum Predicted Total Upsidence and Closure at the Grinding Groove Site Resulting from the Extraction of the Proposed Longwalls

Location	Longwall	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Grinding Groove Site	After LWA19	25	25

The archaeological sites are at discrete locations and, therefore, the most relevant distributions of strain are the distributions of maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains in survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1. The results for survey bays above goaf are illustrated in Fig. 4.2 and the results for survey bays above solid coal are illustrated in Fig. 4.3.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, valley related upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements. The strains resulting from valley related movements are discussed separately in the following sections

8.1.3. Comparison of Predictions for the Archaeological Sites with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the archaeological sites with those provided in the Part 3A Application is provided in Table 8.3

Table 8.3 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Archaeological Sites Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Hogging Curvature in Any Direction (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature in Any Direction (km^{-1})
Artefact Scatters and Isolated Finds	Previous Layout (Report No. MSEC309)	1925	6.7	0.06	0.12
	Modified Layout (Report No. MSEC484)	1800	6.5	0.05	0.09
Grinding Groove Site	Previous Layout (Report No. MSEC309)	1450	3.5	0.03	0.13
	Modified Layout (Report No. MSEC484)	200	1.5	0.01	< 0.01

It can be seen from the above table, that the maximum predicted mine subsidence movements at the grinding groove site, based on the Modified Layout, are much less than those predicted based on the Previous Layout. In consequence, the assessed level of impact for the grinding groove site reduces as a result of the proposed longwall modifications

The maximum predicted mine subsidence movements at the artefact scatters and isolated finds, based on the Modified Layout, are similar to but slightly less than those predicted based on the Previous Layout. The predicted movements for each individual site slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each feature relative to the proposed longwalls.

Further discussions on the potential impacts on the archaeological sites resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

8.1.4. Impact Assessments for the Archaeological Sites

The sites comprising the artefact scatters, isolated finds and potential archaeological deposits can potentially be affected by cracking in the surface soils as a result of mine subsidence movements. It is unlikely, however, that the artefacts themselves would be impacted by surface cracking.

Surface cracking in soils as the result of conventional subsidence movements is not commonly seen at depths of cover greater than 400 metres, such as at Austar, and any cracking that has been observed has generally been isolated and of a minor nature. It would be expected, therefore, that any surface cracking that occurs in the vicinity of the artefact scatters, isolated finds and potential archaeological deposits would be of a minor nature, due to the relatively small magnitudes of predicted ground curvatures and strains and due to the relatively high depths of cover.

Minor surface tensile cracking is generally limited to the top few metres of the surface soils and tends to seal naturally. If any significant cracking in the soil were to occur and were to be left untreated, however, erosion channels could potentially develop. It is recommended that Austar seek the required approvals from the appropriate authorities, prior to the remediation of any surface cracking in the locations of the artefact scatters, isolated finds and potential archaeological deposits.

Further discussions on the artefact scatters, isolated finds and potential archaeological deposits and the potential impacts resulting from the extraction of the proposed longwalls on these sites are provided in the report by Umwelt (2011b).

The maximum predicted conventional hogging and sagging curvatures at the grinding groove site are 0.01 km^{-1} and less than 0.01 km^{-1}, respectively, which equate to minimum radii of curvature of 100 kilometres and greater than 100 kilometres, respectively. The range of potential strains at the grinding groove site is expected to be similar to the range of strains measured above solid coal for the previously extracted longwalls at the colliery, which are illustrated in Fig. 4.3.

Elevated compressive strains could also occur at the grinding groove site due to valley related upsidence and closure movements. The maximum predicted upsidence and closure movements at the grinding groove site, resulting from the extraction of the proposed longwalls, are both 25 mm.

The maximum predicted curvatures, and the range of potential strains could be of sufficient magnitude to result in fracturing of the bedrock. Experience in the NSW Coalfields indicates that fracturing of bedrock at depths of cover greater than 400 metres, such as is the case within the Study Area, generally occurs in isolated locations and the likelihood that fracturing would be coincident with the grinding groove site is considered to be relatively low.

Preventive measures could be implemented at the grinding groove site, where required, including slotting of the bedrock around the site to isolate it from the ground curvatures and strains. It is possible, however, that the preventive measures could result in greater impacts on the site than those which would have occurred as a result of mine subsidence movements.

Scarred Trees can potentially be impacted by large ground deformations, however, this type of impact has only been observed for mining at very shallow depths of cover, say less than 100 metres. Based on the experience of previous longwall mining in the NSW Coalfields, it has been observed that trees are not impacted by mine subsidence movements at depths of cover greater than 400 metres, such as is the case within the Study Area. It is unlikely, therefore, that the scarred tree would be impacted as the result of the extraction of the proposed longwalls.

Further discussions are provided in the report by Umwelt (2011b)

8.1.5. Impact Assessments for the Archaeological Sites Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the archaeological sites, it is unlikely to result in any significant impacts, as the potential for surface cracking at these sites is not dependant on tilt, but rather on the ground curvatures and strains.

If the maximum upperbound curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the archaeological sites, the potential for surface cracking would increase. It would still be unlikely that the artefacts scatters or isolated finds themselves would be impacted by surface cracking. It is also unlikely that the grinding groove site would experience curvatures of these magnitudes, as this site is located 140 metres north of the proposed longwalls.

8.1.6. Recommendations for the Archaeological Sites

It is recommended that a condition survey of the archaeological sites be carried out prior to mining and a monitoring programme put in place to record the effects of mine subsidence on these sites. Further discussions and recommendations are provided in the report by Umwelt (2011b).

8.2. Historical Sites

The descriptions, predictions and impact assessments for the historical sites within the Study Area are provided in the following sections.

8.2.1. Descriptions for the Historical Sites

There are 11 historical sites which have been identified within the Study Area, the locations of which are shown in Drawing No. MSEC484-17 and details of which are provided in Table 8.4.

Table 8.4 Historical Sites within the Study Area

Item	Site Type	Description
1	Bridge	Timber bridge BR-QR01 (Refer to Section 6.2)
2	Quarry 1	Former quarry site
3	Quarry 2	Former quarry site
4	Ford	Scattered materials utilised in the construction of the ford
5	Culvert 1	Single concrete culvert beneath Quorrobolong Road
6	Culvert 2	Single concrete culvert beneath Quorrobolong Road
7	Culvert 3	Single concrete culvert beneath Quorrobolong Road
9	Fencing 1	Single timber post
10	Fencing 2	Single timber post
14	House Site	Potential former house site comprising brick rubble
16	Homestead Site 1	Structure Ref. A44a

A number of other historical sites have been identified outside, but in the vicinity of the Study Area, including an artefact scatter (Item 8), a cut tree (Item 11), a tree stump (Item 12) and a Homestead Site (Item 17). The locations of these sites are also shown in Drawing No. MSEC484-17.

Further descriptions of the historical sites within and adjacent to the Study Area are provided in the report by Umwelt (2011c).

8.2.2. Predictions for the Historical Sites

A summary of the maximum predicted conventional subsidence parameters for the historical sites within the Study Area, at any time during or after the extraction of each of the proposed longwalls, is provided in Table 8.5. The predicted parameters are the maxima within 20 metres of the site.

Table 8.5 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Historical Sites Resulting from the Extraction of the Proposed Longwalls

Location	Site Type	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
1	Bridge	25	< 0.5	< 0.01	< 0.01
2	Quarry 1	50	0.5	< 0.01	< 0.01
3	Quarry 2	50	0.5	< 0.01	< 0.01
4	Ford	1450	1.0	0.02	0.03
5	Culvert 1	300	2.5	0.02	< 0.01
6	Culvert 2	350	3.0	0.02	< 0.01
7	Culvert 3	350	3.0	0.01	< 0.01

Location	Site Type	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
9	Fencing 1	1550	0.5	0.03	0.04
10	Fencing 2	25	< 0.5	< 0.01	< 0.01
14	House site	1550	1.5	0.02	0.02
16	Homestead site 1	25	< 0.5	< 0.01	< 0.01

The predicted tilts provided in the above table are the maxima after the completion of each or all of the proposed longwalls. The predicted curvatures provided in the above table are the maxima at any time during or after the extraction of each of the proposed longwalls.

The historical sites are at discrete locations and, therefore, the most relevant distributions of strain are the distributions of maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains in survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1. The results for survey bays above goaf are illustrated in Fig. 4.2 and the results for survey bays above solid coal are illustrated in Fig. 4.3.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, valley related upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements

8.2.3. Comparison of Predictions for the Historical Sites with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the historical sites with those provided in the Part 3A Application is provided in Table 8.6.

Table 8.6 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Historical Sites Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Hogging Curvature in Any Direction (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature in Any Direction (km^{-1})
Historical Sites	Previous Layout (Report No. MSEC309)	1850	5.5	0.04	0.06
	Modified Layout (Report No. MSEC484)	1550	3.0	0.03	0.04

It can be seen from the above table, that the maximum predicted mine subsidence movements at the historical sites, based on the Modified Layout, are similar to but slightly less than those predicted based on the Previous Layout.

The predicted movements for each individual site slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each feature relative to the proposed longwalls. Further discussions on the potential impacts on the historical sites resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

8.2.4. Impact Assessments for the Historical Sites

The impact assessments for the historical sites are provided below. Further discussions on the historical sites and the potential impacts resulting from the extraction of the proposed longwalls are provided in the report by Umwelt (2011c).

Item 1 – Bridge Site

The *Bridge Site* (Ref. BR-QR01) is located 330 metres west of the finishing (south-western) end of Longwall A12, at its closest point to the proposed longwalls. The impact assessments for this bridge are provided in Section 6.2.

Item 2 and 3 – Quarry Sites

The *Quarry Sites 1 and 2* are located around 200 metres west of the finishing (south-western) end of the proposed Longwall A8, at their closest points to the proposed longwalls. At this distance, the quarry sites are predicted to experience approximately 50 mm of subsidence. While it is possible that these sites could experience subsidence slightly greater than 50 mm, as the result of far-field vertical movements, they would not be expected to experience any significant tilts and curvatures.

It is unlikely, therefore, that the quarry sites would experience any significant impacts resulting from the extraction of the proposed longwalls.

Items 4 – Ford Site

The *Ford Site* comprises remnants of a ford crossing, including bricks, stone, lumps of pebble cement and timber planks. The site is located above the proposed Longwall A15, towards the finishing (south-western) end of the longwall.

The site could potentially be affected by cracking in the surface soils as a result of mine subsidence movements. It is unlikely, however, that the remnants themselves would be impacted by surface cracking.

Surface cracking in soils as the result of conventional subsidence movements is not commonly seen at depths of cover greater than 400 metres, such as at Austar, and any cracking that has been observed has generally been isolated and of a minor nature. It is recommended that Austar seek the required approvals from the appropriate authorities, prior to carrying out remedial works in the location of the potential house site.

Items 5 to 7 – Culverts 1 to 3

The *Historical Culverts 1 to 3* are located above solid coal, adjacent to the finishing (south-western) ends of the proposed Longwalls A7 and A8.

The maximum predicted conventional tilt at the historical culverts is 3.0 mm/m (i.e. 0.3 %), which represents a change in grade of 1 in 330. The maximum predicted tilt is small and is unlikely, therefore, to result in any significant impacts on the serviceability of the historical culverts.

The maximum predicted conventional hogging and sagging curvatures at the historical culverts are 0.02 km^{-1} and less than 0.01 km^{-1}, respectively, which equate to minimum radii of curvatures of 50 kilometres and greater than 100 kilometres, respectively. The predicted curvatures and range of potential strains could result in some cracking in the historical culverts. As the magnitudes of these movements are small, any impacts would be expected to be minor and readily repaired.

Items 9 & 10 – Fencing Sites 1 and 2

The *Fencing Sites 1 and 2* each comprise a single timber post. The maximum predicted final tilt at the fencing sites is 0.5 mm/m (i.e. < 0.1 %), which represents a change in grade of 1 in 2000. The maximum predicted tilting of the fence posts is very small and is not expected, therefore, to be noticeable to the human eye. The fence posts are not expected to be impacted by the predicted curvatures or the range of potential ground strains, as the differential movements over the widths of the posts will be negligible.

Item 14 – Potential House Site

The *Potential House Site* is located above the proposed Longwall A14, towards the middle of this longwall. The site comprises brick rubble and no standing structures or foundations have been identified on the site. The site could potentially be affected by cracking in the surface soils as a result of mine subsidence movements. It is unlikely, however, that the brick rubble itself would be impacted by the mine subsidence movements.

Surface cracking in soils as the result of conventional subsidence movements is not commonly seen at depths of cover greater than 400 metres, such as at Austar Coal Mine, and any cracking that has been observed has generally been isolated and of a minor nature. It is recommended that Austar seek the required approvals from the appropriate authorities, prior to carrying out remedial measures in the location of the potential house site.

Items 16 – Homestead Site 1

The *Homestead Sites 1* (Structure Ref. A44a) is located at a distance of 250 metres north-east of the commencing (north-eastern) end of Longwall A9, at its closest point to the proposed longwalls. At this distance, the homestead is predicted to experience approximately 25 mm of subsidence. While it is possible that the homestead could experience subsidence slightly greater than 25 mm, as the result of far-field vertical movements, it would not be expected to experience any significant tilts and curvatures.

It is unlikely, therefore, that the homestead would experience any significant impacts resulting from the extraction of the proposed longwalls.

8.2.5. Impact Assessments for the Historical Sites Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the *Ford Site*, *Fencing Site 1*, or the *Potential House Site*, it would unlikely result in any significant impacts, as these sites comprise isolated artefacts. It is unlikely that the upperbound conventional tilt would occur at the remaining sites, as these sites are located outside the extents of the proposed longwalls.

If the maximum upperbound curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the *Ford Site*, *Fencing Site 1*, or the *Potential House Site*, the potential for surface cracking would increase. It would still be unlikely to result in any significant impacts, as these sites comprise isolated artefacts. It is unlikely that the upperbound conventional curvatures would occur at the remaining sites, as these sites are located outside the extents of the proposed longwalls.

8.2.6. Recommendations for the Historical Sites

It is recommended that a condition survey of the historical sites be carried out and that a monitoring programme be established to record the effects of mine subsidence on these sites. Further discussions and recommendations are provided in the report by Umwelt (2011c).

9.1. Houses

9.1.1. Descriptions of the Houses

There are 27 houses which have been identified within the Study Area, of which 25 are single-storey houses with lengths less than 30 metres (Type H1), and two are single-storey houses with lengths greater than 30 metres (Type H2). There are no double-storey houses identified within the Study Area.

The locations of the houses are shown in Drawings Nos. MSEC484-11 to MSEC484-15 and details are provided in Table D.01 in Appendix D. The locations and sizes of the houses were determined from an aerial photograph of the area. The types of construction of the houses were determined, where possible, from kerb side inspections.

The distribution of the maximum plan dimensions of the houses within the Study Area is provided in Fig. 9.1. The distributions of the wall and footing constructions of the houses within the Study Area are provided in Fig. 9.2. The distribution of the natural surface slopes at the houses within the Study Area is provided in Fig. 9.3.

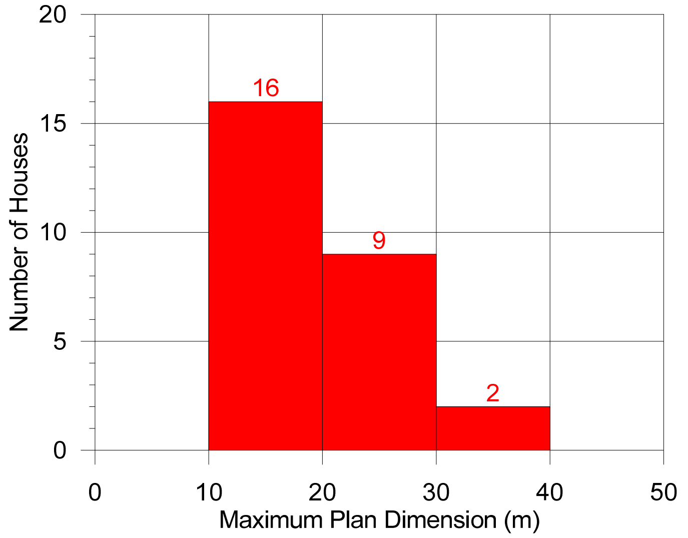

Fig. 9.1 Distribution of the Maximum Plan Dimension of Houses within the Study Area

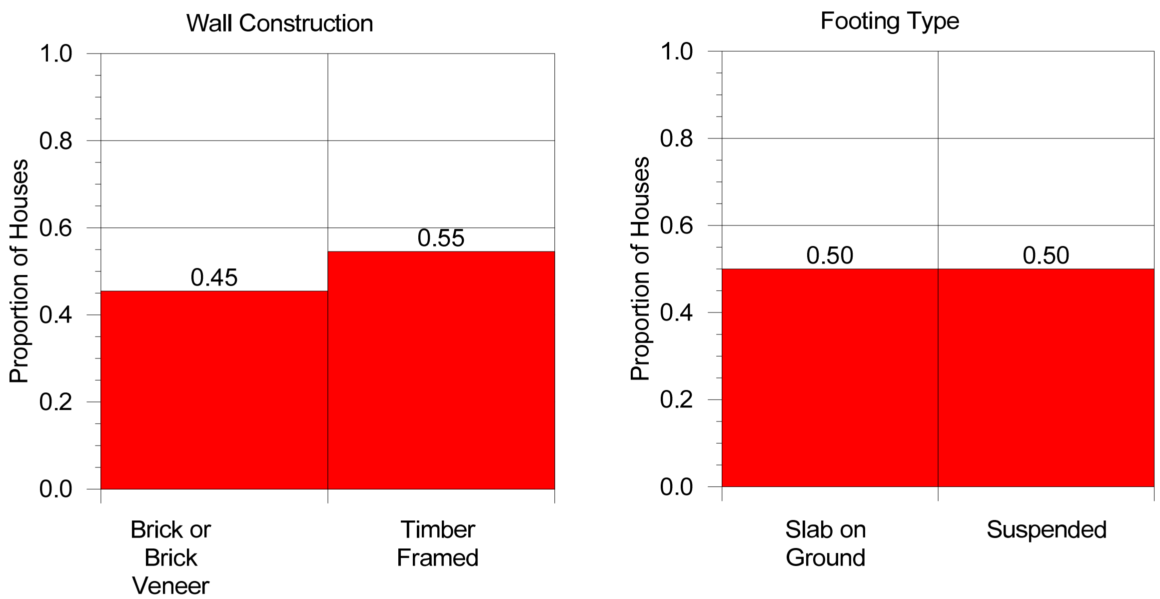

Fig. 9.2 Distributions of Wall and Footing Construction for Houses within the Study Area

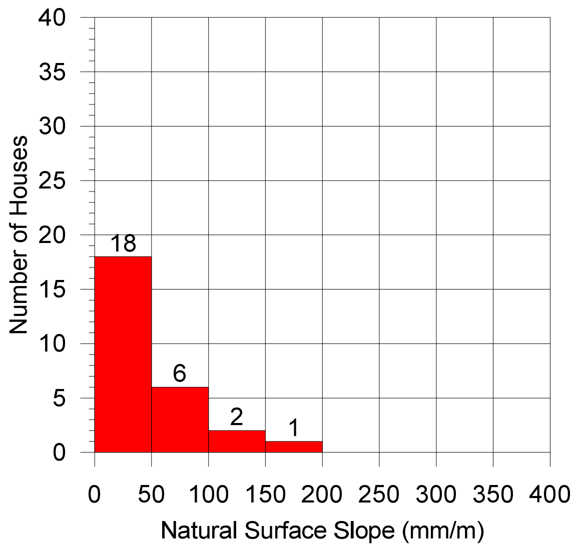

Fig. 9.3 Distribution of the Natural Surface Slope at the Houses within the Study Area

9.1.2. Predictions for the Houses

Predictions of conventional subsidence, tilt and curvature have been made at the centroid and at the vertices of each house, as well as at eight equally spaced points placed radially 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.

A summary of the maximum predicted values of conventional subsidence, tilt and curvature for each house within the Study Area, resulting from the extraction of the proposed longwalls, is provided in Table D.01 in Appendix D.

If the longwalls were to be shifted or reoriented within the Extent of the Longwall Mining Area, the individual houses would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the houses across the Study Area would not be expected to change significantly.

The distribution of the predicted conventional subsidence parameters for the houses within the Study Area are illustrated in Fig. 9.4, Fig. 9.5 and Fig. 9.6 below.

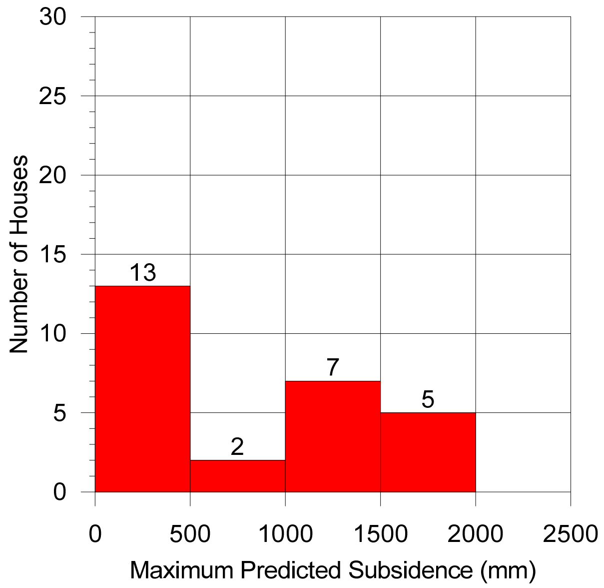

Fig. 9.4 Maximum Predicted Conventional Subsidence for the Houses within the Study Area Resulting from the Extraction of the Proposed Longwalls

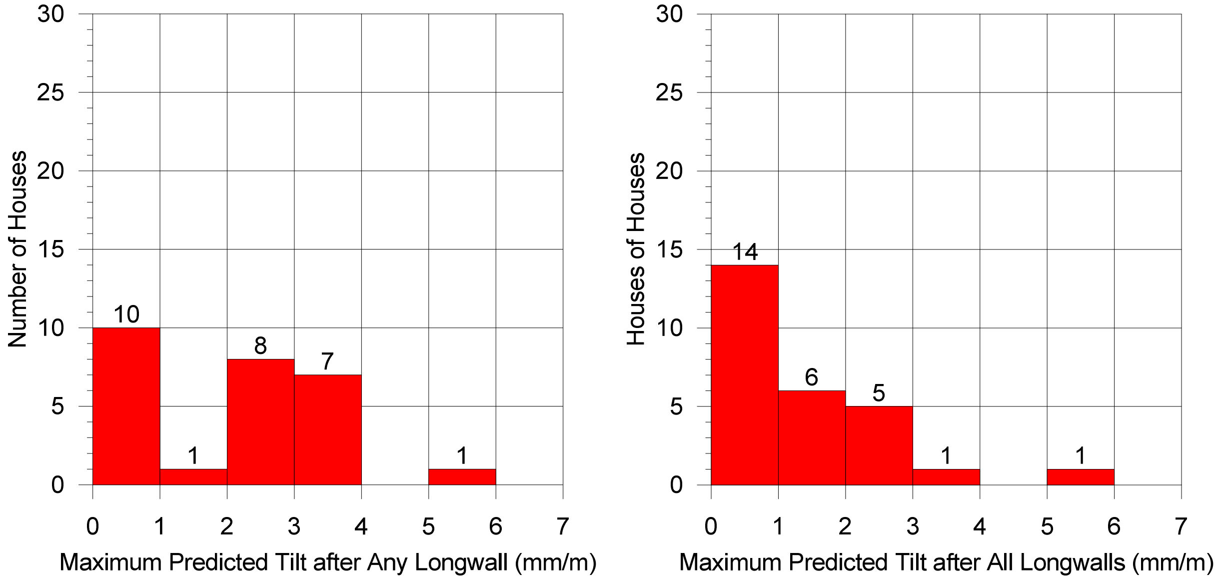

Fig. 9.5 Maximum Predicted Conventional Tilt after the Extraction of Any Longwall (Left) and after the Extraction of All Longwalls (Right) for the Houses within the Study Area

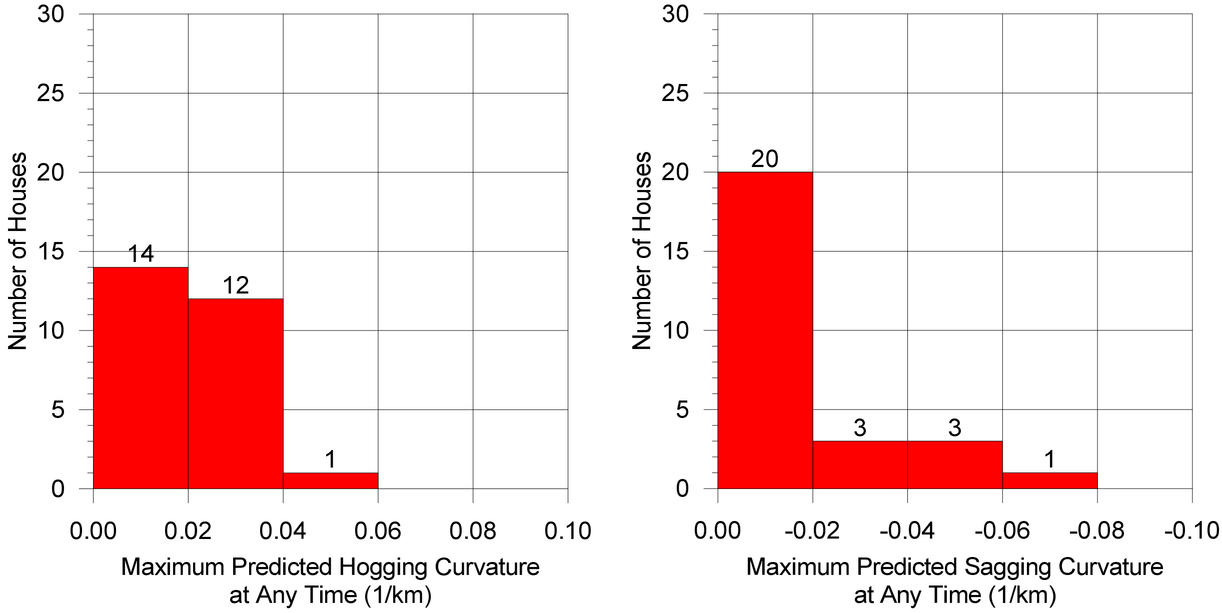

Fig. 9.6 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Houses Resulting from the Extraction of the Proposed Longwalls

The houses are at discrete locations and, therefore, the most relevant distributions of strain are the distributions of maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains in survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1. The results for survey bays above goaf are illustrated in Fig. 4.2 and the results for survey bays above solid coal are illustrated in Fig. 4.3.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

9.1.3. Comparison of Predictions for the Houses with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the houses with those provided in the Part 3A Application is provided in Table 9.1.

Table 9.1 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Houses Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Hogging Curvature in Any Direction (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature in Any Direction (km^{-1})
Houses	Previous Layout (Report No. MSEC309)	1875	5.5	0.06	0.08
	Modified Layout (Report No. MSEC484)	1675	5.5	0.04	0.08

It can be seen from the above table, that the maximum predicted mine subsidence movements at the houses, based on the Modified Layout, are similar to or slightly less than those predicted based on the Previous Layout.

The predicted movements for each individual house slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each structure relative to the proposed longwalls. Further discussions on the potential impacts on the houses resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

9.1.4. Impact Assessments for the Houses

The following sections provide the impact assessments for the houses within the Study Area.

Potential Impacts Resulting from Vertical Subsidence

Vertical subsidence does not directly affect the stability or serviceability of houses. The potential impacts on houses are affected by differential subsidence, which includes tilt, curvature and ground strain, and the impact assessments based on these parameters are described in the following sections.

Vertical subsidence in this case, however, could affect the heights of the houses above the flood level. The potential impacts on the houses resulting from the changes in flood level from the proposed mining is assessed as part of the flood study, which is described in the report by Umwelt (2011a).

Potential Impacts Resulting from Tilt

It has been found from past longwall mining experience that tilts of less than 7 mm/m generally do not result in any significant impacts on houses. Some minor serviceability impacts can occur at these levels of tilt, including door swings and issues with roof gutter and wet area drainage, all of which can be remediated using normal building maintenance techniques. Tilts greater than 7 mm/m can result in greater serviceability impacts which may require more substantial remediation measures, including the relevelling of wet areas or, in some cases, the relevelling of the building structure.

The maximum predicted tilt for the houses, resulting from the extraction of the proposed longwalls, is 5.5 mm/m (i.e. 0.6 %), which represents a change in grade of 1 in 180. It is expected, therefore, that only minor serviceability impacts would occur at the houses within the Study Area, as the result of tilt, which could be remediated using normal building techniques. It is expected that the houses within the Study Area will remain in safe conditions as the result of the mining induced tilts.

Potential Impacts Resulting from Curvature and Strain

The methods for predicting and assessing impacts on building structures have developed over time as knowledge and experience has grown. MSEC has provided predictions and impact assessments for the houses within the Study Area using the latest methods available at the time.

Background to the Method of Impact Assessment for Houses

Building structures have been directly mined beneath at a number of collieries throughout the NSW Coalfields. The experience gained has provided substantial information that has been used to continually develop the methods of impact assessment for houses. The assessments provided in this report are based on the latest research, which is summarised in Appendix C. The discussions and the method of assessment provided in this report are based on the experience of mining at depths of cover generally greater than 400 metres, such as is the case within the Study Area.

The most extensive data has come from the extraction of Tahmoor Longwalls 22 to 25, where more than 1000 residential and significant civil structures have experienced mine subsidence movements. The impacts to houses at Tahmoor Colliery were last analysed in detail following the completion of Longwall 24A. A summary of the observed frequency of impacts for all structures located within the 26½ degree angle of draw line from the extents of mining at that time is provided in Table 9.2.

Table 9.2 Observed Frequency of Impacts for Building Structures Resulting from the Extraction of Tahmoor Longwalls 22 to 24A

Group	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
All buildings (total of 1099)	967 (88.0 %)	92 (8.4 %)	37 (3.4 %)	3 (0.3 %)
Buildings directly above goaf (total of 669)	546 (81.6 %)	84 (12.6 %)	36 (5.4 %)	3 (0.4 %)
Buildings directly above solid coal (total of 430)	421 (97.9 %)	8 (1.9 %)	1 (0.2 %)	0 (0.0 %)

The repair categories R0 to R5 are described in Table C.4 in Appendix C.

The distributions of the maximum predicted conventional hogging and sagging curvatures for the houses, resulting from the extraction of Tahmoor Longwalls 22 to 24A, are provided in Fig. 9.7. It can be seen from this figure, that the houses were predicted to have experienced conventional hogging curvatures of up to 0.10 km^{-1} and conventional sagging curvatures of up to 0.15 km^{-1}.

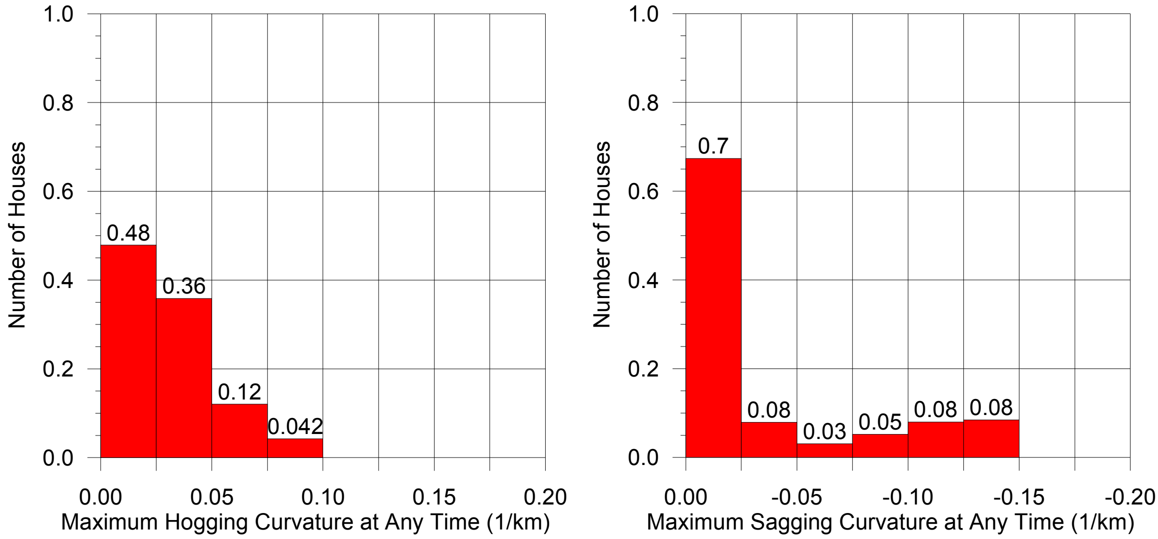

Fig. 9.7 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Houses Located Above Tahmoor Longwalls 22 to 24A

Extensive ground monitoring was undertaken during the extraction of Tahmoor Longwalls 22 to 24A. The distributions of the measured strains for survey bays above goaf is provided in Fig. 9.8.

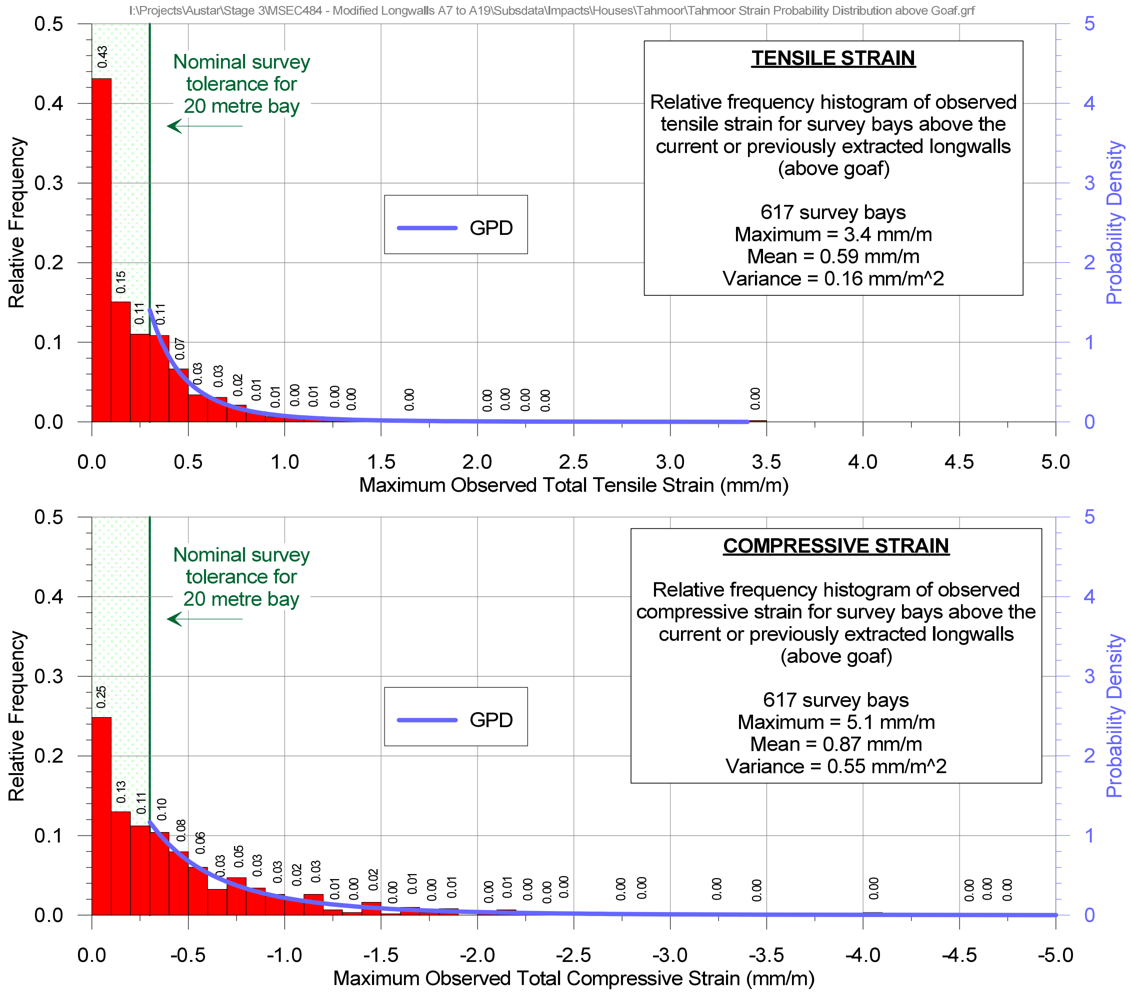

Fig. 9.8 Distributions of the Measured Maximum Tensile and Compressive Strains at Any Time during the Extraction of Tahmoor Colliery Longwalls 22 to 24A for Bays Located Above Goaf

The experience at Tahmoor Colliery indicates that the majority of observed impacts relate to minor effects that are relatively simple to repair, such as sticky doors or windows and cracks to plasterboard linings. In about 5 % of cases, however, substantial or more extensive repairs were required. In less than 1 % of cases, the houses experienced severe impacts, where the Mine Subsidence Board, in consultation with the owners, elected to rebuild the structure as the cost of repair exceeded the cost of replacement.

In all these cases, the residents were not exposed to any immediate and sudden safety hazards as the result of impacts that occurred due to mine subsidence movements. Emphasis is placed on the words “immediate and sudden” as, in rare cases, some structures have experienced severe impacts, but these impacts did not present an immediate risk to public safety as they developed gradually with ample time to relocate residents.

As part of ACARP Research Project C12015, a detailed analysis was undertaken to identify the trends that linked the frequency and severity of impacts with ground strain, ground curvature, type of construction and structure size. A method for assessment was developed for houses, using the primary parameters of ground curvature and type of construction, and further details of this method are provided in Appendix C. The method of assessment developed as part of the ACARP research project has been used to assess the potential impacts on the houses within the Study Area which is provided below.

Impact Assessment for Houses within the Study Area

The maximum predicted conventional hogging and sagging curvatures for the houses within the Study Area, resulting from the extraction of the proposed longwalls, are 0.04 km^{-1} and 0.08 km^{-1}, respectively, which equate to minimum radii of curvature of 25 kilometres and 13 kilometres, respectively. The range of predicted curvatures at these houses, therefore, is less than those predicted to have occurred for the houses above Tahmoor Colliery Longwalls 22 to 24A, which is illustrated in Fig. 9.7. It can also be seen from Fig. 4.2, that the range of potential strains above the proposed longwalls is similar to that measured above Tahmoor Colliery Longwalls 22 to 24A, which is illustrated in Fig. 9.8.

As the predicted curvatures and the range of potential strains for the houses within the Study Area are similar to or less than those experienced at Tahmoor Colliery, the observed levels of impact on the houses at Tahmoor Colliery should provide a reasonable, if not, conservative guide to the overall levels of impact on the houses within the Study Area.

The probability of impacts for each house within the Study Area has been assessed using the method developed as part of ACARP Research Project C12015, which is described in Appendix C. This method uses the primary parameters of ground curvature and type of construction. A summary of the predicted movements and the assessed impacts for each house within the Study Area is provided in Table D.01 in Appendix D. The distribution of the assessed impacts for the houses within the Study Area is provided in Table 9.3.

Table 9.3 Assessed Impacts for the Houses within the Study Area

Group	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
All houses (total of 27)	24 (89 %)	2 (7 %)	1 (4 %)	≈ 0 or 1 (< 0.5 %)

Trend analyses following the mining of Tahmoor Longwalls 22 to 24A indicate that the chance of impact is higher for the following houses:-

- Houses predicted to experience higher strains and curvatures,
- Houses with masonry walls,
- Masonry walled houses that are constructed on strip footings,
- Larger houses, and
- Houses with variable foundations, such as those with extensions added.

The primary risk associated with mining beneath houses is public safety. Residents have not been exposed to immediate and sudden safety hazards as a result of impacts that occur due to mine subsidence movements in the NSW Coalfields, where the depths of cover were greater than 400 metres, such as is the case above the proposed longwalls. This includes the recent experience at Tahmoor Colliery, which has affected more than 1000 houses, and the experiences at Teralba, West Cliff and West Wallsend Collieries, which have affected around 500 houses.

Emphasis is placed on the words “immediate and sudden” as in rare cases, some structures have experienced severe impacts, but the impacts did not present an immediate risk to public safety as they developed gradually with ample time to relocate residents.

All houses within the Study Area are expected to remain safe, serviceable and repairable throughout the mining period, provided that they are in sound structural condition prior to mining.

Potential Impacts Resulting from Downslope Movements

Longwall mining can result in downslope movements, where the natural surface grades are high, which can result in increased potential for impacts on houses. The natural surface slopes at each house are provided in Table D.01 in Appendix D and are illustrated in Fig. 9.3.

It can be seen from this table and figure, that the natural surface slopes in the locations of the houses are less than 200 mm/m (i.e. 20 %), which represents a natural grade of 1 in 5. The maximum natural surface slope at the houses identified within the Study Area is 150 mm/m (i.e. 15 %), which represents a natural grade of 1 in 7.

As described in Section 5.3.1, that natural slopes of less than 1 in 3 would not normally be considered steep. In many cases, natural slopes much greater than 1 in 3 would be considered stable. It is unlikely, therefore, that there would be any significant increase in the potential for impacts on the houses within the Study Area resulting from downslope movements.

The method of assessment for houses developed as part of ACARP Research Project C12015 included the experience of mining beneath houses having similar ranges of natural surface slopes. The range of natural surface slopes within the Study Area is unlikely, therefore, to affect the probabilities of impact for the houses obtained using this method.

9.1.5. Impact Assessments for the Houses Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the houses, it is likely that these structures would experience serviceability impacts, including door swings and issues with roof gutter and pavement drainage. It is also possible that, is some cases, that the houses would need to be relevelled. It would still be unlikely that stabilities of these houses would be affected at this magnitude of tilt.

If the maximum upperbound curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the houses, the curvatures would be similar to the maximum curvatures which have been predicted to have occurred for the houses above Tahmoor Colliery Longwalls 22 to 24A, which is illustrated in Fig. 9.7. Based on the experience at Tahmoor Colliery, it would still be expected, that the houses would remain in safe conditions throughout the mining period and that any impacts resulting from the mine subsidence movements could be remediated using well established building techniques.

9.1.6. Recommendations for the Houses

It is recommended that management strategies are developed as part of the Extraction Plans, to manage the potential for impacts to the residential and non-residential structures. The management strategies would include the following where access is provided to the property:-

- Identification of structures and their forms of construction prior to mining,
- Identification by a suitably qualified building inspector or structural engineer of any structures or structural elements that may be potentially unstable prior to mining,
- Consideration of implementing any mitigation measures, where necessary to address specific identified risks to public safety,
- Consideration of undertaking detailed monitoring of ground movements at or around structures, where necessary to address specific identified risks to public safety,
- Periodic inspections of structures that are considered to be at higher risk. These may include:-
    - Structures in close proximity to steep slopes where recommended by a geotechnical or subsidence engineer,
    - Structures identified as being potentially unstable where recommended by a structural or subsidence engineer, and
    - Pool fences.
- Co-ordination and communication with landowners and the Mine Subsidence Board during mining.

It is recommended that the houses are periodically visually monitored during the extraction of the proposed longwalls. With these strategies in place, it is expected that the houses would remain safe throughout the mining period.

9.2. Swimming Pools

9.2.1. Descriptions of the Swimming Pools

There are 8 privately owned swimming pools (Structure Type P) which have been identified within the Study Area, the locations of which are shown in Drawings Nos. MSEC484-11 to MSEC484-15 and for which details are provided in Table D.05 in Appendix D. The locations and sizes of the pools were determined from an aerial photograph of the area.

9.2.2. Predictions for the Swimming Pools

Predictions of conventional subsidence, tilt and curvature have been made at the centroid and at points located around the perimeter of each pool, as well as at points located at a distance of 20 metres from the perimeter of each pool.

A summary of the maximum predicted values of conventional subsidence, tilt and curvature for the pools within the Study Area, resulting from the extraction of the proposed longwalls, is provided in Table D.05 in Appendix D.

If the longwalls were to be shifted or reoriented within the Extent of the Longwall Mining Area, the individual pools would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the pools across the Study Area would not be expected to change significantly.

The distributions of the maximum predicted conventional subsidence, tilt and curvature for the pools within the Study Area, resulting from the extraction of the proposed longwalls, are illustrated in Fig. 9.9 and Fig. 9.10.

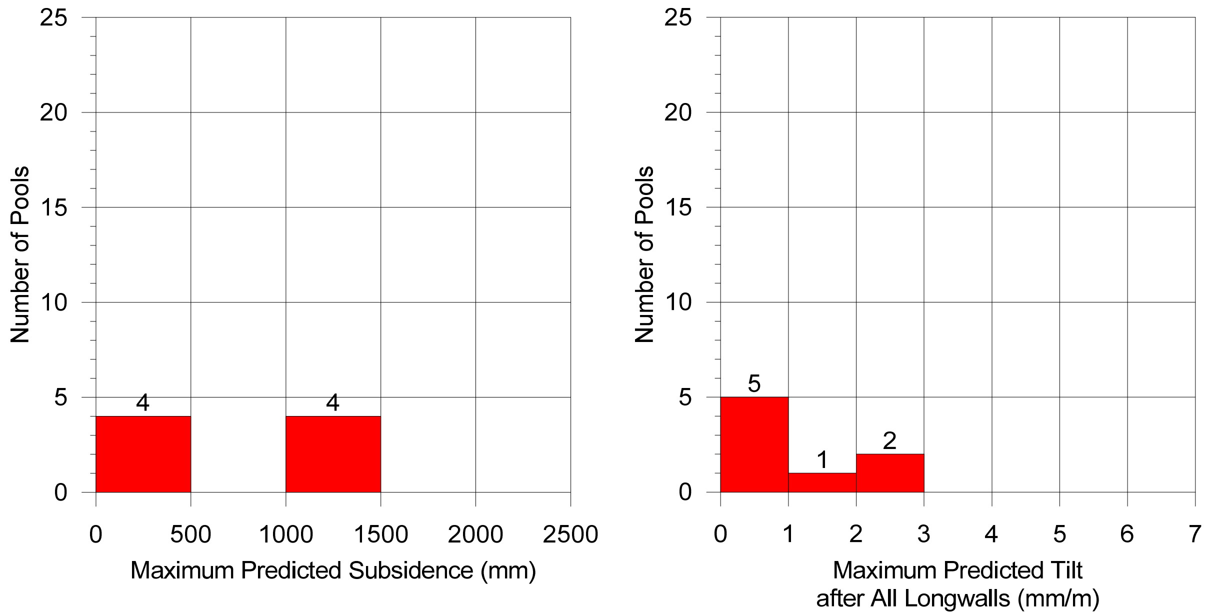

Fig. 9.9 Maximum Predicted Conventional Subsidence and Tilt for the Pools within the Study Area Resulting from the Extraction of the Proposed Longwalls

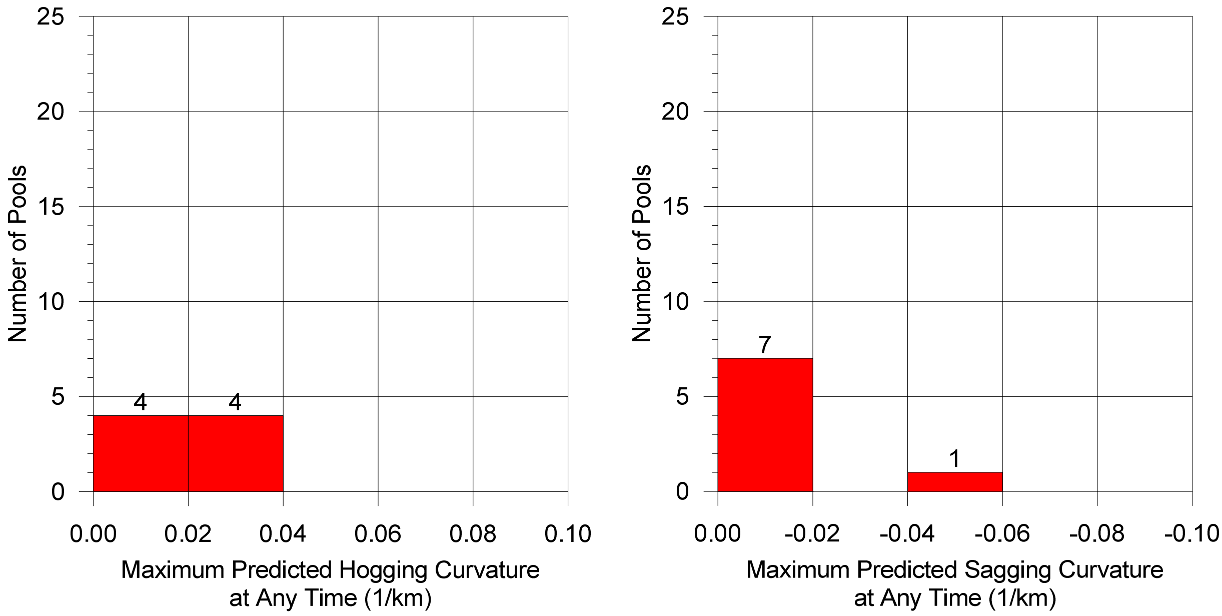

Fig. 9.10 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Pools Resulting from the Extraction of the Proposed Longwalls

The pools are at discrete locations and, therefore, the most relevant distributions of strain are the distributions of maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains in survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1. The results for survey bays above goaf are illustrated in Fig. 4.2 and the results for survey bays above solid coal are illustrated in Fig. 4.3.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

9.2.3. Comparison of Predictions for the Pools with those provided in the Part 3A Application

The comparison of the maximum predicted subsidence parameters for the pools with those provided in the Part 3A Application is provided in Table 9.4.

Table 9.4 Comparison of the Maximum Predicted Conventional Subsidence Parameters for the Pools Based on the Previous and Modified Layouts

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Hogging Curvature in Any Direction (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature in Any Direction (km^{-1})
Pools	Previous Layout (Report No. MSEC309)	1825	4.5	0.05	0.06
	Modified Layout (Report No. MSEC484)	1500	3.0	0.04	0.04

It can be seen from the above table, that the maximum predicted mine subsidence movements at the pools, based on the Modified Layout, are similar to or slightly less than those predicted based on the Previous Layout.

The predicted movements for each individual pool slightly increase or decrease, as a result of the proposed longwall modifications, depending on the locations of each structure relative to the proposed longwalls. Further discussions on the potential impacts on the pools resulting from the extraction of the proposed longwalls, based on the Modified Layout, are provided in the following sections.

9.2.4. Impact Assessments for the Swimming Pools

Mining-induced tilts are more noticeable in pools than other structures due to the presence of the water line and small gaps to the edge coping, particularly when the pool lining has been tiled. Skimmer boxes are also susceptible to being lifted above the water line due to mining induced tilt. The Australian Standard AS2783-1992 (Use of reinforced concrete for small swimming pools) requires that pools be constructed level ± 15 mm from one end to the other. This represents a tilt of approximately 3 mm/m for pools that are 10 metres in length. Australian Standard AS/NZS 1839:1994 (Swimming pools – Pre-moulded fibre-reinforced plastics – Installation) also requires that pools be constructed with a tilt of 3 mm/m or less.

It can be seen from Fig. 9.9, that all of the pools within the Study Area are predicted to experience tilts of 3 mm/m or less, at the completion of the proposed longwalls, which is similar to or less than the Australian Standard.

It can be seen from Fig. 9.10, that the pools within the Study Area are predicted to experience hogging curvatures of 0.04 km^{-1} or less and experience sagging curvatures of 0.06 km^{-1} or less. The range of predicted curvatures at these pools, therefore, is less than that predicted to have occurred for the houses and, hence, the pools above Tahmoor Colliery Longwalls 22 to 24A, which is illustrated in Fig. 9.7.

Observations during the mining of Tahmoor Colliery Longwalls 22 to 25 have shown that pools, particularly in-ground pools, are more susceptible to severe impacts than houses and other structures. Pools cannot be easily repaired and some of the impacted pools may need to be replaced in order to restore them to pre-mining condition or better.

As of May 2009, a total of 108 pools had experienced mine subsidence movements during the mining of Tahmoor Colliery Longwalls 22 to 25, of which 80 were located directly above the extracted longwalls. A total of 14 pools had impacts, all of which were located directly above the extracted longwalls. This represents an impact rate of approximately 18 %. A higher proportion of impacts has been observed for in-ground pools, particularly fibreglass pools. The majority of the impacts related to tilt or cracking, though in a small number of cases the impacts were limited to damage to skimmer boxes or the edge coping.

The maximum predicted subsidence parameters for the pools within the Study Area are less than the maxima predicted at Tahmoor Colliery. The incidence and levels of impacts on the pools in the Study Area, therefore, are expected to be less than those experienced at Tahmoor Colliery.

9.2.5. Impact Assessments for the Swimming Pools Based on Increased Predictions

If the maximum predicted conventional subsidence parameters were to be increased by a factor of 1.6 times, the maximum predicted parameters would be similar to the maximum upperbound parameters. It is unlikely that the maximum upperbound conventional subsidence parameters within the Study Area would be exceeded, as these parameters are based on achieving a maximum total subsidence of 65 % of effective extracted seam thickness, as discussed in Section 4.4, which would only be expected to occur for longwalls of critical or super-critical width.

If the maximum upperbound conventional tilt within the Study Area of 11 mm/m were to occur at the pools, the tilt would be greater than the Australian Standard. In this case, these pools may require remediation of the pool copings or, in some cases, complete replacement.

If the maximum upperbound curvatures within the Study Area of 0.09 km^{-1} hogging and 0.15 km^{-1} sagging were to occur at the pools, the curvatures would be of a similar order of magnitude to the maximum curvatures predicted to have occurred at Tahmoor Colliery. In this case, the potential impacts on the pools within the Study Area would be expected to be similar to those experienced at Tahmoor Colliery.

9.2.6. Recommendations for the Swimming Pools

While not strictly related to the pool structure, a number of pool gates have been impacted as the result of the previous extraction of longwalls beneath pools. While the gates can be easily repaired, the consequence of breaching pool fence integrity is considered to be severe. As a result, it is recommended that regular inspections of the integrity of pool fences during the active subsidence period be included in the development of any Management Plan for properties that have pools or are planning to construct a pool during the mining period.

9.3. On-Site Waste Water Systems

The residences on the rural properties within the Study Area have on-site waste water systems.

The on-site waste water systems are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4.

The on-site waste water systems are at discrete locations and, therefore, the most relevant distributions of strain are the distributions of maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains in survey bays during the mining of previous longwalls at the colliery is discussed in Section 4.5.1. The results for survey bays above goaf are illustrated in Fig. 4.2 and the results for survey bays above solid coal are illustrated in Fig. 4.3.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, among other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The maximum predicted change in grade for the on-site waste water systems within the Study Area are less than 1 %. It is unlikely, therefore, that the maximum predicted tilts would result in any significant impacts on the systems. The maximum predicted conventional tilts could, however, be of sufficient magnitude to affect the serviceability of the buried pipes between the houses and the on-site waste water systems, if the existing grades of these pipes are very small, say less than 1 %.

The on-site waste water system tanks are generally small, typically less than 3 metres in diameter, are constructed from reinforced concrete, and are usually bedded in sand and backfilled. It is unlikely, therefore, that the maximum predicted curvatures and ground strains would be fully transferred into the tank structures.

It is possible, however, that the buried pipelines associated with the on-site waste water tanks could be impacted by the ground 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 the implementation of these remedial measures, it would be unlikely that there would be any significant impacts on the pipelines associated with the on-site waste water systems.

9.4. Rigid External Pavements

Adverse impacts on rigid external pavements are often reported to the Mine Subsidence Board in the NSW Coalfields. This is because pavements are typically thin relative to their length and width. The design of external pavements is also not regulated by Council or the Mine Subsidence Board.

A study by MSEC of 120 properties at Tahmoor and Thirlmere indicated that 98 % of the properties with external concrete pavements demonstrated some form of cracking prior to mining. These cracks are sometimes difficult to distinguish from cracks caused by mine subsidence. It is therefore uncertain how many claims for damage can be genuinely attributed to mine subsidence impacts.

Residential concrete pavements are typically constructed with tooled joints which do not have the capacity to absorb compressive movements. It is possible that some of the smaller concrete footpaths or pavements within the Study Area, in the locations of the larger compressive ground strains, could buckle upwards if there are insufficient movement joints in the pavements. It is expected, however, that the buckling of footpaths and pavements would not be common, given the magnitudes of the predicted ground strains, and could be easily repaired.

9.5. Fences

The predictions and impact assessments for fences are provided in Section 7.3.

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

Glossary of Terms and Definitions

Some of the more common 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.
Closure	The reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides. It should be noted that the observed closure movement across a valley is the total movement resulting from various mechanisms, including conventional mining induced movements, valley closure movements, far-field effects, downhill movements and other possible strata mechanisms.
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, i.e. curvature is the second derivative of subsidence. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres (km-1)*, but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*. Curvature can be either **hogging** (i.e. convex) or **sagging** (i.e. concave).
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.
Face length	The width of the coalface measured across the longwall panel.
Far-field movements	The measured horizontal movements at pegs that are located beyond the longwall panel edges and over solid unmined coal areas. Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain.
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.
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, i.e. from rib to rib.

Shear deformations	The horizontal displacements that are measured across monitoring lines and these can be described by various parameters including; horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.
Strain	The change in the horizontal distance between two points divided by the original horizontal distance between the points, i.e. strain is the relative differential displacement of the ground along or across a subsidence monitoring line. Strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation. **Tensile Strains** are measured where the distance between two points or survey pegs increases and **Compressive Strains** where the distance between two points decreases. Whilst mining induced **strains** are measured **along** monitoring lines, ground **shearing** can occur both vertically, and horizontally **across** the directions of the monitoring lines.
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, but, 'subsidence of the ground' in some references can include both a vertical and horizontal movement component. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of *millimetres (mm)*. Sometimes the horizontal component of a peg's movement is not measured, but in these cases, the horizontal distances between a particular peg and the adjacent pegs are measured.
Super-critical area	An area of panel greater than the critical area.
Tilt	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 horizontal 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 %, or 1 in 1000.
Uplift	An increase in the level of a point relative to its original position.
Upsidence	Upsidence results from the dilation or buckling of near surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.

APPENDIX B. REFERENCES

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APPENDIX C. METHOD OF IMPACT ASSESSMENTS FOR HOUSES

APPENDIX C METHOD OF IMPACT ASSESSMENT FOR HOUSES

C.1. Introduction

The methods for predicting and assessing impacts on building structures have developed over time as knowledge and experience has grown. MSEC has provided predictions and impact assessments for the building structures within the Study Area using the latest methods available at this time.

Longwall mining has occurred directly beneath building structures at a number of collieries in the Coalfields of New South Wales. The most extensive data has come from extraction of Tahmoor Colliery Longwalls 22 to 24A, where more than 1000 residential and significant civil structures have experienced subsidence movements. The experiences gained during the mining of these longwalls, as well as longwalls at other collieries in the Southern, Hunter and Newcastle Coalfields, have provided substantial additional information that has been used to further develop the methods.

The information collected during the mining of Tahmoor Colliery Longwalls 22 to 24A has been reviewed in two parallel studies, one as part of a funded ACARP Research Project C12015, and the other at the request of Industry and Investment NSW (I&I).

The outcomes of these studies include:-

- Review of the performance of the previous method,
- Recommendations for improving the method of Impact Classification, and
- Recommendations for improving the method of Impact Assessment.

A summary is provided in the following sections.

C.2. Review of the Performance of the Previous Method

The most extensive data on house impacts has come from extraction of Tahmoor Colliery Longwalls 22 to 25 and a comparison between predicted and observed impacts is provided in Table C.1. The comparison is based on pre-mining predictions that were provided in SMP Applications for these longwalls and the observations of impacts using the previous method of impact classification. The comparison is based on information up to 30th November 2008. At this point in time, the length of extraction of Longwall 25 was 611 metres.

A total of 1037 houses and civil structures were affected by subsidence due to the mining of Tahmoor Colliery Longwalls 22 to 25 at this time. A total of 175 claims have been received by the Mine Subsidence Board (not including claims that have been refused) of which 14 claims do not relate to the main residence or civil structure.

Table C.1 Summary of Comparison between Observed and Predicted Impacts for each Structure

Strain Impact Category	Total No. of Observed Impacts for Structures predicted to be Strain Impact Category 0	Total No. of Observed Impacts for Structures predicted to be Strain Impact Category 1	Total No. of Observed Impacts for Structures predicted to be Strain Impact Category 2	Total
No impact	483	373	20	876
Cat 0	31	70	6	107
Cat 1	8	9	1	18
Cat 2	7	11	2	20
Cat 3	2	2	0	4
Cat 4	3	5	0	8
Cat 5	3	1	0	4
Total	537	471	29	1037
% claim	**10 %**	**21 %**	**31 %**	16 %
% Obs > Pred	**4 %**	**4 %**	**0 %**	-
% Obs <= Pred	**96 %**	**96 %**	**100 %**	-

Note: Predicted impacts due to conventional subsidence only, as described in the SMP Application.

Given that observed impacts are less than or equal to predicted impacts in 96 % of cases, it is considered that the previous methods are generally conservative even though non-conventional movements were not taken into account in the predictions and assessments. However, when compared on a house by house basis, the predictions have been substantially exceeded in a small proportion of cases.

The majority, if not all, of the houses that have experienced Category 3, 4 or 5 impacts are considered to have experienced substantial non-conventional subsidence movements. The consideration is based on nearby ground survey results, where upsidence bumps are observed in subsidence profiles and high localised strain is observed. The potential for impact from non-conventional movements were discussed generally and not included in the specific impact assessments for each structure.

The inability to specify the number or probability of impacts due to the potential for non-conventional movements is a shortcoming of the previous method. It is considered that there is significant room for improvement in this area and recommendations are provided later in this report.

The comparison shows a favourable observation that the overall proportion of claims increased for increasing predicted impact categories. This suggests that the main parameters currently used to make impact assessments (namely predicted conventional curvature and maximum plan dimension of each structure) are credible. Please note that we have stated predicted conventional curvature rather than strain, as predictions of strain were directly based on predictions of conventional curvature.

A significant over-prediction is observed at the low end of the spectrum of impacts (Category 0 and 1). A number of causes and/or possible causes for the deviations have been identified:

- Construction methods and standards may mitigate against small differential ground movements.
- The impacts may have occurred but the residents have not made a claim for the following reasons:-
    - All structures contain some existing, pre-mining defects. A pre-mining field investigation of 119 structures showed that it is very rare for all elements of a building to be free of cracks. Cracks up to 3 mm in width are commonly found in buildings. Cracks up to 1 mm in width are very common. There is a higher incidence of cracking in brittle forms of construction such as masonry walls and tiled surfaces.
    - In light of the above, additional very slight Category 0 and 1 impacts may not have been noticed by residents. A forensic investigation of all structures before or after mining may reveal that the number of actual impacts is greater than currently known.
    - Similarly, impacts have been noticed but some residents may consider them to be too trivial to make a claim. While difficult to prove statistically, it is considered that the frequency of claims from tenanted properties is less than the frequency of claims from owner-occupied properties.
- The impacts have been noticed but some residents are yet to make a claim at this stage. It has been observed that there is a noticeable time lag between the moment of impact and the moment of making a claim. More claims are therefore expected to be received in the future within areas that have already been directly mined beneath.
- The predictive method is deliberately conservative in a number of ways.
    - Predicted subsidence movements for each structure are based on the maximum predicted subsidence movements within 20 metres of the structure.
    - An additional 0.2 mm/m of strain was added.
    - Maximum strains were applied to the maximum plan dimension, regardless of the maximum predicted strain orientation.
    - The method of impact assessment does not provide for “nil impacts”. The minimum assessed level of impact is Category 0.
    - The impact data was based on double-storey full masonry structures in the UK.

Finally, it is considered that the previous method impact classification has masked the true nature and extent of impacts. It is recommended that an improved method of classification be adopted before embarking on any further analysis. This is discussed in the next chapter of this report.

C.3. Method of Impact Classification

C.3.1. Previous Method

The impacts to structures were previously classified in accordance with Table C1 of Australian Standard 2870-1996, but the Table has been extended by the addition of Category 5 and is reproduced below.

Table C.2 Classification of Damage with Reference to Strain

Impact Category	Description of typical damage 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

Note 1 of Table C1 states that *"Crack width is the main factor by which damage to walls is categorised. The width may be supplemented by other factors, including serviceability, in assessing category of damage".*

Impacts relating to tilt were classified according to matching impacts with the description in Table C.3, not the observed actual tilt. This is because many houses that have experience tilts greater than 5 mm/m have not made a claim to the MSB.

Table C.3 Classification of Damage with Reference to Tilt

Impact Category	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.

C.3.2. Need for Improvement to the Previous Method of Impact Classification

It is very difficult to design a method of impact classification that covers all possible scenarios and permutations. The application of any method is likely to find some instances that do not quite fit within the classification criteria.

Exposure to a large number of affected structures has allowed the mining industry to appreciate where improvements can be made to all aspects including the identification of areas for improvement in the previous method of impact classification.

A number of difficulties have been experienced with the previous method during the mining period. The difficulty centres on the use of crack width as the main classifying factor, as specified in Table C1 of Australian Standard 2870-1996.

A benefit of using crack width as the main factor is that it provides a clear objective measure by which to classify impact. However, experience has shown that crack width is a poor measure of the overall impact and extent of repair to a structure. The previous method of impact classification may be useful for assessing impact to newly built structures in a non-subsidence environment but further improvement and clarification is recommended before it can be effectively applied to houses impacted by mine subsidence.

The following aspects highlight areas where the previous classification system could be improved.-

- *Slippage on Damp Proof Course*

  Approximately 30 houses have experienced slippage along the damp proof course in Tahmoor. Slippage on some houses is relatively small (less than 10 mm) though substantial slippage has been observed in a number of cases, such as shown in Fig. C.1 below.

Fig. C.1 Example of slippage on damp proof course

Under the previous classification method, the "crack" width of the slippage may be very small (Category 1) but the distortion in the brickwork is substantial. Moreover, the extent of work required to repair the impact is substantial as it usually involves re-lining the whole external skin of the structure. Such impacts would be considered Category 4 based on extent of repair but only Category 1 or 2 based on maximum crack width.

There is no reference to slippage of damp proof course in the previous method of impact classification. However, if the extent of repair was used instead of using crack width as the main factor, the impact category would be properly classified as either Category 4 or Category 5.

It was recommended that slippage of damp proof courses be added to the previous impact classification table.

- *Cracks to brickwork*

  In some cases, cracks are observed in mortar only. For example, movement joints in some structures have been improperly filled with mortar instead of a flexible sealant, as shown in Fig. C.2. In these situations, the measured crack width may be significant but the impact is relatively simple to repair regardless of the crack width.

Fig. C.2 Example of crack in mortar only

In other cases, a small number of isolated bricks have been observed to crack or become loose. This is usually straightforward to repair. Under the previous impact classification method, a completely loose brick could be strictly classified as Category 5 as the crack width is infinitely large. This is clearly not the intention of the previous method but clarification is recommended to avoid confusion.

If a panel of brickwork is cracked, the method of repair is the same regardless of the width. While it is considered reasonable to classify large and severe cracks by its width, it is recommended that cracks less than 5 mm in width be treated the same rather than spread across Categories 0, 1 and 2.

If a brick lined structure contains many cracks of width less than 3 mm, the impact would be classified as no more than Category 2 under the previous method of impact classification. The extent of repair may be substantially more than a house that has experienced only one single 5 mm crack. However, it is recognised that it is very difficult to develop a simple method of classifying impacts based on multiple cracks in wall panels. How many cracks are needed to justify an increase in impact category?

- *Structures without masonry walls*

  Timber framed structures with lightweight external linings such weatherboard panels and fibro sheeting are not referenced in the previous classification table. If crack widths were strictly adopted to classify impacts, it may be possible to classify movement in external wall linings beyond Category 3 when in reality the repairs are usually minor.

  It was recommended that the impact classification table be extended to include structures with other types of external linings.

- *Minor impacts such as door swings*

  Experience has shown that one of the earliest signs of impact is the report of a sticking door. In some instances, the only observed impact is one or two sticking doors. It takes less than half an hour to repair a sticking door and impact is considered negligible.

  Such an impact would be rightly classified as Category 0 based on the previous method of impact classification as there is no observed crack. However, the previous classification table suggests that sticking doors and windows occur when Category 2 crack widths develop. It was recommended that the impact classification table be amended in this respect.

C.3.3. Broad Recommendations for Improvement of Previous Method of Impact Classification

It was recommended that crack width no longer be used as the main factor for classifying impacts. This does not mean that the use of crack width should be abandoned altogether. Crack width remains a good indicator of the severity of impacts and should be used to assist classification, particularly for impacts that are moderate or greater.

By focussing on crack width, the previous impact classification table appears to be classifying impacts from a structural stability perspective. It was recommended that a revised impact classification table be more closely aligned with all aspects of a building, including its finishes and services. Residents who are affected by impacts are concerned as much about impacts to internal linings, finishes and services as they are about cracks to their external walls and a revised impact classification method should reflect this.

With crack width no longer used as the main factor, it was recommended that the wording of the descriptions of impact in the classification table be extended to cover impacts to more elements of buildings. In keeping with the previous method of assessment, the level of impact should distinguish between cosmetic, serviceability and stability related impacts:-

- Low impact levels should relate to cosmetic impacts that do affect the structural integrity of the building and are relatively straight-forward to repair,
- Mid-level impact categories should relate to impacts to serviceability and minor structural issues, and
- High level impacts should be reserved for structural stability issues and impacts requiring extensive repairs.

C.3.4. Revised Method of Impact Classification

The following revised method of impact classification has been developed.

Table C.4 Revised Classification based on the Extent of Repairs

Repair Category	Extent of Repairs
Nil	No repairs required
R0 **Adjustment**	One or more of the following, where the damage does not require the removal or replacement of any external or internal claddings or linings:- - **Door** or **window** jams or swings, or - Movement of **cornices**, or - Movement at external or internal **expansion joints**.
R1 **Very Minor Repair**	One or more of the following, where the damage can be repaired by filling, patching or painting without the removal or replacement of any external or internal brickwork, claddings or linings:- - Cracks in **brick mortar** only, or isolated cracked, broken, or loose **bricks** in the external façade, or - Cracks or movement < 5 mm in width in any external or internal wall **claddings**, **linings**, or **finish**, or - Isolated cracked, loose, or drummy floor or wall **tiles**, or - Minor repairs to any **services** or **gutters**.
R2 **Minor Repair**	One or more of the following, where the damage affects a small proportion of external or internal claddings or linings, but does not affect the integrity of external brickwork or structural elements:- - Continuous cracking in **bricks** < 5 mm in width in one or more locations in the total external façade, or - Slippage along the **damp proof course** of 2 to 5 mm anywhere in the total external façade, or - Cracks or movement ≥ 5 mm in width in any external or internal wall **claddings**, **linings**, **finish**, or - Several cracked, loose or drummy floor or wall **tiles**, or - Replacement of any **services**.
R3 **Substantial Repair**	One or more of the following, where the damage requires the removal or replacement of a large proportion of external brickwork, or affects the stability of isolated structural elements:- - Continuous cracking in **bricks** of 5 to 15 mm in width in one or more locations in the total external façade, or - Slippage along the **damp proof course** of 5 to 15 mm anywhere in the total external façade, or - Loss of bearing to isolated walls, piers, columns, or other load-bearing elements, or - Loss of stability of isolated structural elements.
R4 **Extensive Repair**	One or more of the following, where the damage requires the removal or replacement of a large proportion of external brickwork, or the replacement or repair of several structural elements:- - Continuous cracking in **bricks** > 15 mm in width in one or more locations in the total external façade, or - Slippage along the damp proof course of 15 mm or greater anywhere in the total external façade, or - Relevelling of building, or - Loss of stability of several structural elements.
R5 **Re-build**	Extensive damage to house where the MSB and the owner have agreed to rebuild as the cost of repair is greater than the cost of replacement.

As discussed at the start of this chapter, it is very difficult to design a method of impact classification that covers all possible scenarios and permutations. While the method has been floated among some members of the mining industry, it is recommended that this table be reviewed broadly.

The recommended method has attempted to follow the current Australian Standard in terms of the number of impact categories and crack widths for Categories 3 and 4. The method is based on the extent of repairs required to repair the physical damage that has occurred, and does not include additional work that is occasionally required because replacement finishes cannot match existing damaged ones. It is therefore likely that the actual cost of repairs will vary greatly between houses depending on the nature of the existing level and type of finishes used.

The impacts experienced at Tahmoor Colliery have been classified in accordance with the revised method of classification with good results. The method allowed clearer trends to be found when undertaking statistical analyses.

A comparison between the previous and revised methods is shown in Fig. C.3.

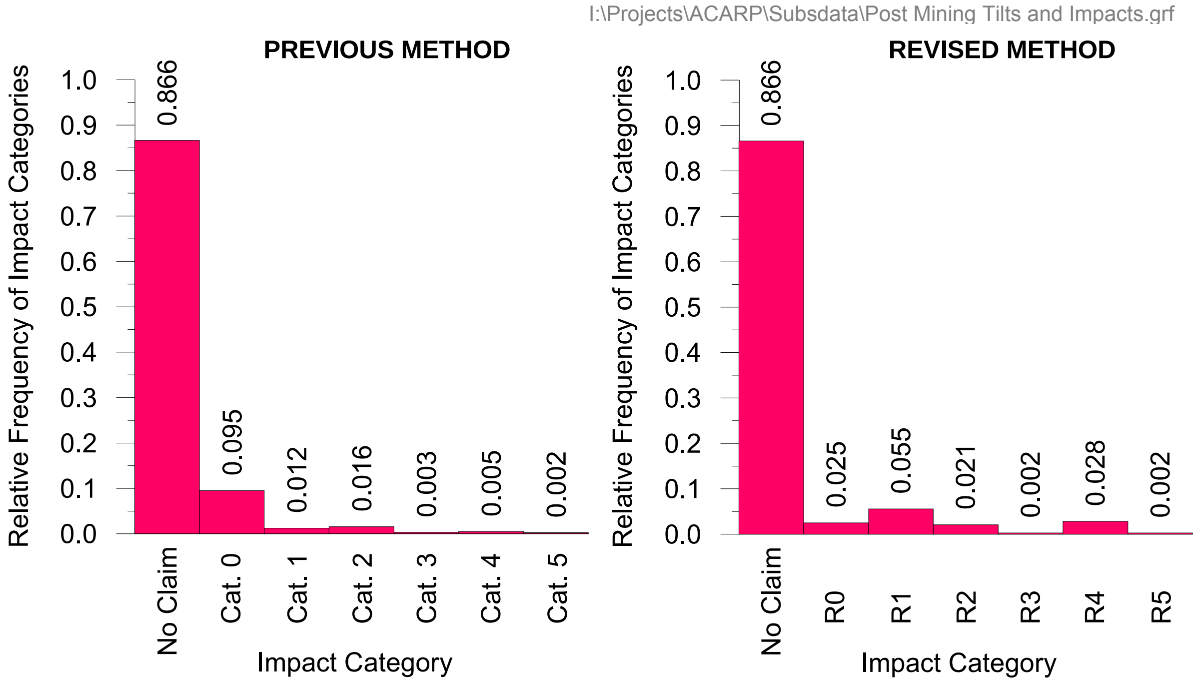


Fig. C.3 Comparison between Previous and Revised Methods of Impact Classification

It can be seen that there was an increased proportion in the higher impact categories using the revised method. This is brought about mainly by the recorded slippage on damp proof courses, which are classified as either Category 3 or Category 4 when they were previously classified as Category 1 or 2.

There was also a noticeable reduction in proportion of Category 0 impacts and noticeable increase in proportion of Category 1 impacts using the revised method. This is because the revised method reserves Category 0 impacts for impacts that did not result in cracking any linings, while the previous method allows hairline cracking to occur.

The consistent low proportion of Category 3 impacts under both the previous and current methods raises questions as to whether this category should be merged with Category 4.

C.4. Method of Impact Assessment

C.4.1. Need for Improvement of the Previous Method

The previous method of impact assessment provided specific quantitative predictions based on predicted conventional subsidence movements and general qualitative statements concerning the potential for impacts due to non-conventional movements. These non-conventional movements are additional to the predicted conventional movements.

This message was quite complex and created the potential for confusion and misunderstanding among members of the community who may easily focus on numbers and letters in a table that deal specifically with their house and misunderstand the message contained in the accompanying words of caution about the low level of reliability concerning predictions of conventional strain and potential for non-conventional movements.

This was unfortunately a necessary shortcoming of the previous method at the time as there was very little statistical information available to quantify the potential for impacts due to non-conventional movement. However, a great deal of statistical information is now available following the mining of Tahmoor Colliery Longwalls 22 to 24A and the method and message to the community can be improved.

While additional statistical information is now available, there remains limited knowledge at this point in time to accurately predict the locations of non-conventional movement. Substantial gains are still to be made in this area.

In the meantime, therefore, a probabilistic method of impact assessment has been developed. The method combines the potential for impacts from both conventional and non-conventional subsidence movement.

C.4.2. Factors that Could be Used to Develop a Probabilistic Method of Prediction

Trend analyses have highlighted a number of factors that could be used to develop a probabilistic method. The trends examined were:-

- *Ground tilt*

  This was found to be an ineffective parameter at Tahmoor Colliery as ground tilts have been relatively benign and a low number of claims have been made in relation to tilt.

- *Ground strain*

  There appears to be a clear link between ground strain and impacts, particularly compressive strain. The difficulty with adopting ground strain as a predictive factor lies in the ability to accurately predict ground strain at a point.

  Another challenge with using strain to develop a probabilistic method is that there is limited information that links maximum observed strains with observed impacts at a structure. Horizontal strain is a two-dimensional parameter and it has been measured along survey lines that are oriented in one direction only.

  The above issues are less problematic for curvature and the statistical analysis on the relationship between strain and curvature shows that the observed frequency of high strains increased with increasing observed curvature.

- *Ground curvature*

  Curvature appears to be the most effective subsidence parameter to develop a probabilistic method. The trend analysis showed that the frequency of impacts increased with increasing observed curvature.

  It should be noted that we are referring to conventional curvature and not curvatures that have developed as a result of non-conventional subsidence behaviour. This is because conventional curvature can be readily predicted with reasonable correlation with observations. It is also a relatively straight-forward exercise to estimate the observed smoothed or “conventional” curvature provided some ground monitoring is undertaken across and along extracted longwalls.

  Non-conventional curvature cannot be predicted prior to mining and is accounted for by using a probabilistic method of impact assessment.

  It has also been shown that the observed frequency of high strains increased with increasing observed curvature.

- *Position of structure relative to longwall*

  A clear trend was understandably found that structures located directly above goaf were substantially more likely to experience impact. The calculated probabilities may be applicable for mining conditions that are similar to those experienced at Tahmoor Colliery but will be less applicable for other mining conditions. An effective probabilistic method should create a link between the magnitude of differential subsidence movements and impact.

- *Construction type*

  Two trends have been observed. Not surprisingly, structures constructed with lightweight flexible external linings are able to accommodate a far greater range of subsidence movements than brittle inflexible linings such as masonry. The analyses merely quantified what was already well known. The second observation was that houses constructed with strip footings were noticeably more likely to experience impacts than houses constructed with a ground slab, particularly in relation to higher levels of impact. This is because houses with strip footings are more susceptible to slippage along the damp proof course.

- *Structure size*

  Trend analysis showed that larger structures attract a higher likelihood of impact. This is understandable as the chance of impacts increases with increasing footprint area. However, it is noted that the probability of severe impacts was not substantially greater for larger structures even though this would be expected if considering probabilities theoretically rather than empirically. It may be worthwhile including structure size as a factor in the development of a probabilistic method, though it is considered that it is a third order effect behind subsidence movements and construction type.

- *Structure age*

  The trend analysis for structure age did not reveal any noticeable trends.

- *Extensions, variable foundations and building joints*

  There is a clear trend of a higher frequency of impacts for structures that include extensions, variable foundations and building joints. The increased frequency appears to be related mainly to lower impact categories.

- *Urban or rural setting*

  While trends were observed, it is considered that they can be explained by other factors. However, consideration can be made to provide a more conservative estimate of probabilities in rural areas if structure size has not been taken into account.

C.4.3. Revised Method of Impact Assessment

A revised method of impact assessment has been developed. The method is probabilistic and currently includes conventional ground curvature and construction type as input factors.

Because of the relatively low number of buildings that suffered damage, the trends in the data were difficult to determine within small ranges of curvature. A decision was therefore taken to analyse the data in a limited number of curvature ranges, so that where possible a reasonable sample size would be available in each range. The ranges of curvature chosen were 5 to 15 kilometres, 15 to 50 kilometres and greater than 50 kilometres.

Because the incidence of damage for different construction types showed strong trends and because the sample size was reasonable for each type of structure, the data were analysed to determine the effect of radius of curvature on the incidence of damage for each of the three structure types and for each of the three curvature ranges.

The following probabilities are proposed in Table C.5.

Table C.5 Probabilities of Impact based on Curvature and Construction Type based on the Revised Method of Impact Classification

R (km)	Repair Category			
	No Repair or R0	R1 or R2	R3 or R4	R5
Brick or brick-veneer houses with Slab on Ground				
> 50	90 ~ 95 %	3 ~ 10 %	1 %	< 0.1 %
15 to 50	80 ~ 85 %	12 ~ 17 %	2 ~ 5 %	< 0.5 %
5 to 15	70 ~ 75 %	17 ~ 22 %	5 ~ 8 %	< 0.5 %
Brick or brick-veneer houses with Strip Footing				
> 50	90 ~ 95 %	3 ~ 10 %	1 %	< 0.1 %
15 to 50	80 ~ 85 %	7 ~ 12 %	2 ~ 7 %	< 0.5 %
5 to 15	70 ~ 75 %	15 ~ 20 %	7 ~ 12 %	< 0.5 %
Timber-framed houses with flexible external linings of any foundation type				
> 50	90 ~ 95 %	3 ~ 10 %	1 %	< 0.1 %
15 to 50	85 ~ 90 %	7 ~ 13 %	1 ~ 3 %	< 0.5 %
5 to 15	80 ~ 85 %	10 ~ 15 %	3 ~ 5 %	< 0.5 %

The results have been expressed as a range of values rather than a single number, recognising that the data had considerable scatter within each curvature range. While structure size and building extensions have not been included in the predictive tables, it is recommended to adopt percentages at the higher end of the range for larger structures or those with building extensions.

The percentages stated in each table are the percentages of building structures of that type that would be likely to be damaged to the level indicated within each curvature range. The levels of damage in the tables are indicated with reference to the repair categories described in the damage classification given in Table C.4.

To place these values in context, Table C.6 shows the actual percentages recorded at Tahmoor Colliery for all buildings within the sample.

Table C.6 Observed Frequency of Impacts observed for all buildings at Tahmoor Colliery

R (km)	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
> 50	94%	4%	1%	0%
15 to 50	86%	9%	4%	0.7%
5 to 15	76%	17%	7%	0%

It can be seen that the proposed probabilities for the higher impact categories have been increased compared to those observed to date. These have been deliberately increased, because it has been noticed that some of the claims for damage have been submitted well after the event and it is possible that the numbers damaged in this category could be increased as further claims are received and investigated. These numbers are particularly sensitive to change because the sample size is very small. In light of the above, it is recommended that the probabilities be revisited in the future as mining progresses.

The ranges provided in Table C.5 have been converted into a set of probability curves to remove artificial discontinuities that are formed by dividing curvatures into three categories. These are shown in Fig. C.4. The probability curves are applicable for all houses and civil structures.

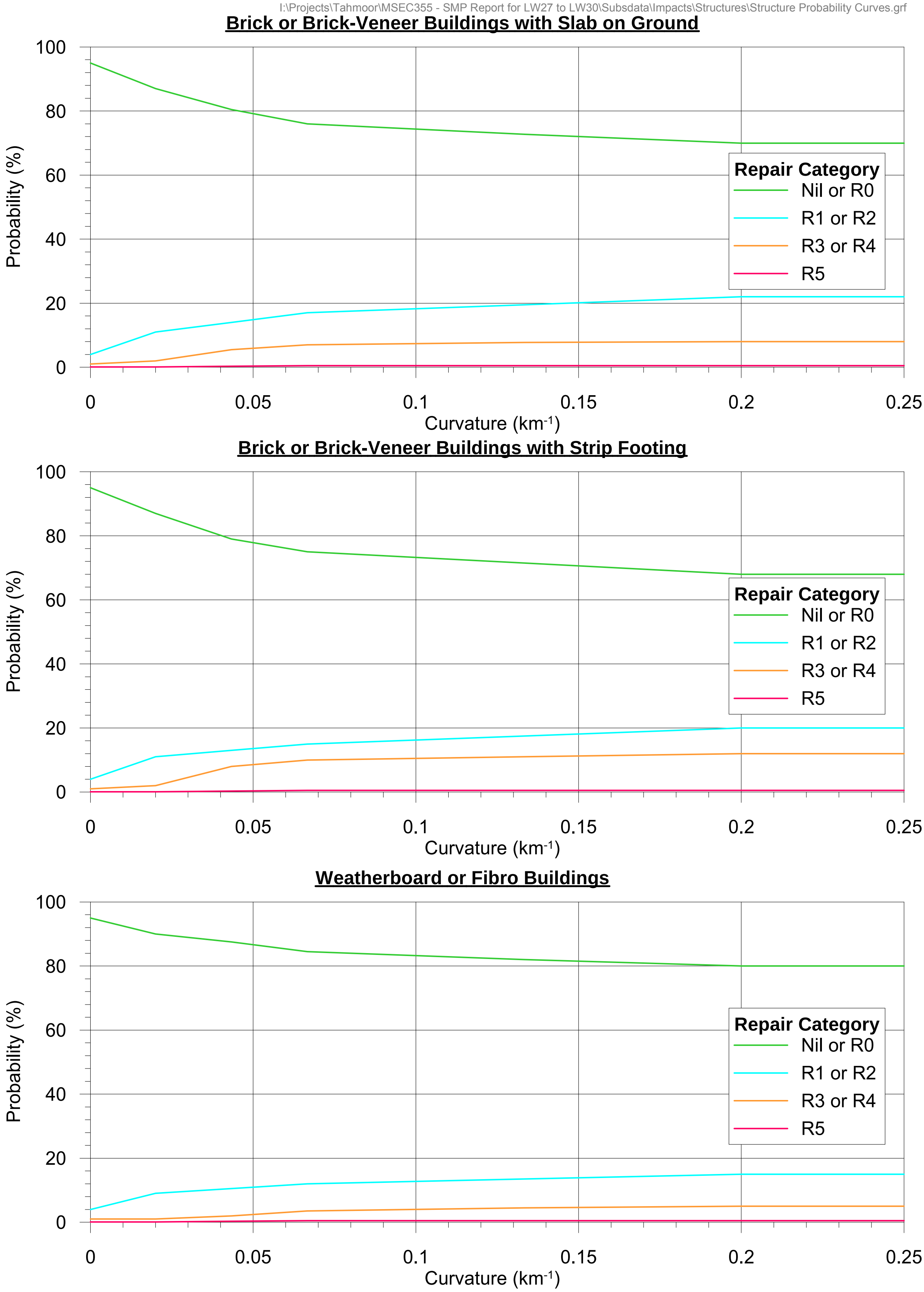


Fig. C.4 Probability Curves for Impacts to Buildings

APPENDIX D. TABLES

Table D.01 - Houses within the Study Area
Maximum Predicted Conventional Subsidence Parameters and Impact Assessments

House No.	MGA Easting	MGA Northing	Natural Ground Slope (mm/m)	Wall Type	Footing Type	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after Any Longwall (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Predicted Probabulity of Nil or Category R0 Impact (%)	Predicted Probabulity of Category R1 or R2 Impact (%)	Predicted Probabulity of Category R3 or R4 Impact (%)	Predicted Probabulity of Category R5 Impact (%)
A12a	347474	6357848	50	Timber Frame	Suspended Timber	24	Single	875	5.4	0.04	< 0.01	87	11	2	< 0.3
A13a	347823	6357987	50	Brick-Veneer	Slab On Ground	33	Single	1500	2.7	0.04	0.02	82	13	5	< 0.3
A14a	348074	6358041	< 50	Brick-Veneer	Slab On Ground	21	Single	1525	3.9	0.02	0.02	86	11	3	< 0.1
A16a	347318	6357709	< 50	-	-	18	Single	175	1.5	0.01	< 0.01	90	8	2	< 0.1
A17a	347721	6357468	< 50	Timber Frame	Suspended Timber	22	Single	1425	3.7	0.02	0.05	87	11	2	< 0.3
A18a	347988	6357529	< 50	-	-	18	Single	1525	2.7	0.03	0.04	82	12	6	< 0.2
A19a	347242	6357038	< 50	Brick-Veneer	Slab On Ground	16	Single	30	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
A20a	347338	6356771	< 50	-	-	20	Single	30	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
A23a	348241	6356012	< 50	-	-	23	Single	30	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
A24a	348118	6356042	< 50	-	-	20	Single	30	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
A25a	348471	6356349	< 50	-	-	24	Single	375	2.0	0.01	< 0.01	89	9	2	< 0.1
A25b	348424	6356386	< 50	-	-	21	Single	425	2.6	0.02	< 0.01	85	11	3	< 0.1
A26a	348178	6356677	< 50	-	-	13	Single	1350	4.0	0.03	0.05	79	13	8	< 0.3
A27a	348335	6356906	< 50	-	-	22	Single	1500	3.0	0.02	0.02	86	11	3	< 0.1
A28a	348725	6355881	< 50	-	-	15	Single	< 20	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
A29a	349194	6356711	< 50	-	-	20	Single	1525	3.2	0.02	0.02	85	11	3	< 0.1
A31a	347896	6358532	100	Timber Frame	Suspended Timber	11	Single	1675	3.7	0.02	0.08	84	12	4	< 0.5
A32a	348634	6358091	100	Timber Frame	Suspended Timber	12	Single	1425	2.7	0.02	0.02	90	9	1	< 0.1
A33a	349484	6357714	< 50	Brick-Veneer	Slab On Ground	18	Single	1600	3.6	0.03	0.05	80	14	6	< 0.3
A34a	348990	6358342	100	Brick-Veneer	-	20	Single	1375	2.4	0.03	0.02	85	11	3	< 0.1
A44a	348853	6359343	150	-	-	21	Single	30	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
A47a	349446	6355698	< 50	Timber Frame	Slab On Ground	17	Single	< 20	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
A51a	347299	6357089	< 50	-	-	16	Single	60	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
A53a	347302	6357202	50	-	-	31	Single	80	0.6	< 0.01	< 0.01	93	6	1	< 0.1
A65a	350308	6356662	< 50	-	-	22	Single	850	2.2	0.01	0.01	89	9	2	< 0.1
A66a	350331	6358374	150	-	-	17	Single	20	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
A98a	348590	6358440	50	Timber Frame	Suspended Timber	20	Single	1450	2.6	0.03	0.02	89	10	2	< 0.2
							Maximums:	**1675**	**5.4**	**0.04**	**0.08**				

Table D.02 - Rural Building Structures within the Study Area
Maximum Predicted Conventional Subsidence Parameters

Ref.	MGA Easting	MGA Northing	Longest Side (m)	Type	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after Any Longwall (mm/m)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
A12b	347473	6357887	14	Garage	925	5.5	5.5	0.04	0.02
A12c	347460	6357879	13	Shed	850	5.5	5.5	0.05	0.02
A12d	347458	6357851	4	Shed	750	5.5	5.5	0.04	< 0.01
A12e	347335	6357934	7	Shed	375	3.0	3.0	0.03	< 0.01
A12f	347355	6357999	123	Shed	800	6.0	6.0	0.05	0.01
A12g	347361	6358028	122	Shed	900	6.0	6.0	0.05	0.02
A12h	347360	6358060	90	Shed	850	5.5	5.5	0.05	0.02
A12i	347335	6357939	7	Shed	375	3.5	3.5	0.04	< 0.01
A13b	347810	6358042	18	Shed	1525	2.5	1.0	0.02	0.02
A13c	347829	6358008	4	Shed	1475	2.5	0.5	0.03	0.02
A14b	348059	6358048	11	Shed	1500	4.0	1.0	0.02	0.02
A14c	348031	6358057	15	Shed	1500	3.5	1.0	0.02	0.02
A14d	347911	6358055	14	Shed	1475	2.5	0.5	0.03	0.02
A16b	347329	6357679	8	Shed	175	1.5	1.5	0.01	< 0.01
A16c	347349	6357683	9	Shed	225	2.0	2.0	0.01	< 0.01
A16d	347319	6357644	9	Shed	150	1.5	1.5	0.01	< 0.01
A17b	347783	6357456	11	Shed	1500	3.5	2.0	0.03	0.04
A17c	347799	6357462	12	Shed	1500	3.5	1.5	0.03	0.04
A19b	347257	6357046	6	Shed	40	< 0.5	< 0.5	< 0.01	< 0.01
A19c	347263	6357025	3	Shed	40	< 0.5	< 0.5	< 0.01	< 0.01
A19d	347272	6357040	5	Shed	40	< 0.5	< 0.5	< 0.01	< 0.01
A19e	347271	6357028	4	Shed	40	< 0.5	< 0.5	< 0.01	< 0.01
A19f	347315	6357021	4	Shed	50	< 0.5	< 0.5	< 0.01	< 0.01
A19g	347317	6357029	4	Shed	50	< 0.5	< 0.5	< 0.01	< 0.01
A19h	347383	6356962	14	Shed	70	0.5	0.5	< 0.01	< 0.01
A20b	347365	6356773	14	Shed	30	< 0.5	< 0.5	< 0.01	< 0.01
A20c	347356	6356756	13	Shed	30	< 0.5	< 0.5	< 0.01	< 0.01
A20d	347332	6356817	7	Shed	30	< 0.5	< 0.5	< 0.01	< 0.01
A20e	347356	6356883	24	Shed	50	< 0.5	< 0.5	< 0.01	< 0.01
A23b	348221	6356043	19	Shed	40	< 0.5	< 0.5	< 0.01	< 0.01
A24b	348143	6356024	9	Shed	20	< 0.5	< 0.5	< 0.01	< 0.01
A26b	348170	6356733	18	Shed	1400	4.0	1.5	0.01	0.03
A26c	348127	6356760	20	Shed	1350	3.5	2.0	0.02	0.02
A28b	348758	6355903	19	Garage	20	< 0.5	< 0.5	< 0.01	< 0.01
A28c	348775	6355929	7	Shed	20	< 0.5	< 0.5	< 0.01	< 0.01
A29b	349238	6356747	10	Shed	1575	3.0	1.0	0.03	0.01
A29c	348900	6355864	6	Shed	20	< 0.5	< 0.5	< 0.01	< 0.01
A29d	348826	6355960	6	Shed	30	< 0.5	< 0.5	< 0.01	< 0.01
A29e	348783	6355870	4	Shed	< 20	< 0.5	< 0.5	< 0.01	< 0.01
A31b	347922	6358547	9	Shed	1675	3.5	2.5	0.02	0.08
A31c	347931	6358555	4	Shed	1675	3.5	2.5	0.02	0.08
A32b	348641	6358140	18	Shed	1425	2.5	0.5	0.02	0.02
A32c	348615	6358144	25	Shed	1450	2.5	1.0	0.02	0.02
A32d	348182	6357612	8	Shed	1525	2.5	1.0	0.02	0.02
A32e	348700	6358088	18	Shed	1450	3.5	1.0	0.02	0.02
A33b	349563	6357680	12	Shed	1600	2.0	0.5	0.02	0.02
A34b	349001	6358366	10	Garage	1375	2.5	1.0	0.02	0.02
A34c	349051	6358380	30	Shed	1350	2.5	1.0	0.02	0.02
A34d	348950	6358346	4	Shed	1375	2.5	1.0	0.02	0.02
A35a	348808	6358847	5	Shed	1300	2.5	2.0	0.03	0.01
A35b	348847	6358994	5	Shed	775	3.5	3.5	0.02	0.04
A44b	348817	6359365	10	Shed	20	< 0.5	< 0.5	< 0.01	< 0.01
A44c	348814	6359344	21	Shed	30	< 0.5	< 0.5	< 0.01	< 0.01
A47b	349460	6355680	11	Shed	< 20	< 0.5	< 0.5	< 0.01	< 0.01
A47c	349483	6355680	11	Shed	< 20	< 0.5	< 0.5	< 0.01	< 0.01
A47d	349436	6355683	5	Shed	< 20	< 0.5	< 0.5	< 0.01	< 0.01
A47e	349494	6355688	7	Shed	< 20	< 0.5	< 0.5	< 0.01	< 0.01
A47f	349457	6355704	3	Shed	< 20	< 0.5	< 0.5	< 0.01	< 0.01
A51b	347300	6357076	10	Shed	50	< 0.5	< 0.5	< 0.01	< 0.01
A51c	347304	6357108	8	Shed	60	< 0.5	< 0.5	< 0.01	< 0.01
A51d	347313	6357060	5	Shed	60	< 0.5	< 0.5	< 0.01	< 0.01
A53b	347283	6357183	10	Shed	60	< 0.5	< 0.5	< 0.01	< 0.01
A53c	347284	6357169	8	Shed	60	< 0.5	< 0.5	< 0.01	< 0.01
A65b	350333	6356656	13	Shed	800	2.5	2.5	0.01	0.01
A65c	350435	6356674	18	Shed	725	3.0	3.0	0.01	0.02
A65d	350432	6356649	19	Shed	700	3.0	3.0	0.01	0.02
A65e	350475	6356641	13	Shed	600	3.5	3.5	0.01	0.02
A66b	350327	6358362	17	Garage	30	< 0.5	< 0.5	< 0.01	< 0.01
A66c	350338	6358358	4	Shed	20	< 0.5	< 0.5	< 0.01	< 0.01
A66d	350367	6358342	4	Shed	20	< 0.5	< 0.5	< 0.01	< 0.01
A66e	350377	6358339	5	Shed	20	< 0.5	< 0.5	< 0.01	< 0.01
				Maximums:	**1675**	**6.0**	**6.0**	**0.05**	**0.08**

Table D.03 - Farm Dams within Study Area
Maximum Predicted Conventional Subsidence Parameters

Ref.	MGA Easting	MGA Northing	Length (m)	Surface Area (m2)	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after Any Longwall (mm/m)	Maximum Predicted Final Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Maximum Predicted Change in Freeboard after All Longwalls (mm)
A09d05	347115	6357669	22	210	30	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A09d06	347115	6357607	32	684	30	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A09d07	347111	6357539	16	191	20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A12d01	347275	6358079	38	1027	325	3.0	3.0	0.04	< 0.01	75
A12d02	347429	6357948	52	1552	825	5.9	5.9	0.05	0.02	275
A12d03	347263	6357942	37	721	200	1.6	1.6	0.02	< 0.01	< 50
A12d04	347366	6357825	30	628	325	2.6	2.6	0.03	< 0.01	75
A12d05	347257	6358172	18	171	325	3.3	3.3	0.04	< 0.01	< 50
A12d06	347370	6358181	14	114	825	5.4	5.4	0.02	0.03	75
A13d01	347760	6357952	24	311	1475	2.6	0.6	0.04	0.02	< 50
A13d02	347688	6357830	35	612	1500	3.2	2.6	0.01	0.04	75
A13d03	347798	6357725	27	481	1475	2.5	1.1	0.02	0.02	< 50
A13d04	347881	6358230	37	661	1550	4.0	1.1	0.02	0.03	< 50
A14d01	348029	6358184	65	2433	1500	2.4	1.0	0.02	0.02	50
A14d02	348132	6358118	98	4020	1500	3.7	1.0	0.03	0.02	50
A14d03	348091	6358144	28	485	1450	2.5	< 0.5	0.04	0.02	< 50
A14d04	348045	6357925	24	344	1550	3.3	1.0	0.03	0.04	< 50
A16d01	347335	6357586	87	1743	200	1.7	1.7	0.01	< 0.01	75
A16d02	347406	6357666	19	156	300	2.6	2.6	0.02	< 0.01	< 50
A16d03	347456	6357602	20	195	425	3.4	3.4	0.03	< 0.01	75
A16d04	347309	6357341	45	582	80	0.7	0.7	< 0.01	< 0.01	< 50
A17d01	347755	6357373	36	740	1375	2.5	2.5	0.01	0.02	75
A17d02	347605	6357611	135	5392	1300	5.0	5.0	0.02	0.02	475
A17d03	347756	6357621	72	1827	1425	2.6	1.7	0.03	0.02	100
A19d01	347259	6356951	27	512	30	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A19d02	347461	6356967	45	699	100	0.8	0.8	< 0.01	< 0.01	< 50
A19d03	347410	6357033	53	273	90	0.6	0.6	< 0.01	< 0.01	< 50
A20d02	347395	6356881	30	569	60	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A20d03	347655	6356813	94	2712	225	1.6	1.6	0.02	< 0.01	50
A20d04	347789	6356748	18	228	350	3.2	3.2	0.04	< 0.01	< 50
A21d03	347850	6356165	63	1258	30	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A21d04	347675	6356402	32	669	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A21d05	347862	6356358	85	3561	125	0.8	0.8	< 0.01	< 0.01	< 50
A21d06	347971	6356465	29	425	325	3.2	3.2	0.03	< 0.01	75
A23d01	348271	6355934	30	481	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A25d01	348340	6356277	62	1643	250	1.5	1.5	0.01	< 0.01	75
A25d02	348567	6356099	26	291	60	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A25d03	348392	6356576	38	655	1075	3.3	3.0	0.02	0.03	75
A25d04	348548	6356147	30	313	90	0.7	0.7	< 0.01	< 0.01	< 50
A26d01	348109	6356635	23	163	1175	3.5	3.0	0.02	0.04	50
A26d02	348069	6356507	14	73	700	4.4	4.4	0.01	0.02	< 50
A26d03	348007	6356090	43	573	30	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A27d01	348159	6357528	29	412	1475	2.4	< 0.5	0.02	0.01	< 50
A27d02	348471	6357028	66	1036	1550	2.5	0.7	0.02	0.01	< 50
A27d03	348209	6357012	22	216	1600	3.5	0.8	0.03	0.05	< 50
A27d04	348215	6357042	17	139	1600	3.9	< 0.5	0.02	0.02	< 50
A28d01	348679	6356004	124	3609	40	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A28d02	348616	6356373	39	860	550	3.4	3.4	0.01	0.01	125
A28d03	348756	6356815	135	4241	1500	3.9	1.3	0.02	0.02	50
A28d04	348597	6356999	56	1093	1575	3.7	1.2	0.02	0.02	< 50
A28d05	348900	6357284	46	997	1575	2.4	0.7	0.02	0.01	< 50
A28d06	349259	6357182	45	307	1625	2.5	0.8	0.02	0.02	< 50
A29d01	349062	6356092	120	1938	150	1.2	1.2	< 0.01	< 0.01	75
A29d02	348965	6356165	59	1219	200	1.4	1.4	< 0.01	< 0.01	< 50
A29d03	349022	6356166	36	395	200	1.6	1.6	0.01	< 0.01	< 50
A29d04	349072	6356169	20	223	225	1.9	1.9	0.01	< 0.01	< 50
A29d05	348969	6356387	46	956	725	4.2	4.2	0.03	< 0.01	175
A29d06	349008	6356560	25	421	1275	3.6	2.0	0.02	0.02	< 50
A29d07	348903	6356731	62	2103	1550	4.2	2.0	0.03	0.05	75
A29d08	348969	6356929	51	1318	1575	2.8	0.8	0.03	0.01	< 50
A29d09	349265	6357089	66	2160	1650	3.0	1.5	0.03	0.02	< 50
A29d10	348932	6356243	23	85	275	1.6	1.6	< 0.01	< 0.01	< 50
A29d11	349062	6355942	60	864	40	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A30d01	349204	6356135	36	823	225	1.6	1.6	0.01	< 0.01	50
A30d02	349457	6356088	131	4370	275	2.4	2.4	0.01	< 0.01	150
A30d03	349357	6356625	33	494	1650	3.7	2.5	0.03	0.06	75
A30d04	349445	6356682	38	698	1750	4.1	1.8	0.03	0.06	< 50
A30d05	349344	6356744	64	1891	1675	4.2	1.4	0.03	0.03	75
A30d07	349834	6356799	74	479	1225	2.5	1.5	0.03	0.02	75
A30d08	349872	6356700	82	1736	1150	3.0	0.7	0.02	0.02	75
A30d09	349326	6357174	20	295	1600	2.5	0.6	0.02	0.01	< 50
A30d10	349457	6355775	26	161	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A30d11	349142	6355968	17	107	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A31d01	347987	6358406	30	323	1450	2.7	< 0.5	0.04	0.01	< 50
A31d02	347881	6358512	17	186	1650	3.7	2.3	0.02	0.05	< 50
A31d03	348254	6358631	53	1319	1550	2.8	1.4	0.03	0.02	50
A32d01	348464	6358082	128	4412	1500	3.1	1.0	0.03	0.04	75

Table D.03 - Farm Dams within Study Area
Maximum Predicted Conventional Subsidence Parameters

Ref.	MGA Easting	MGA Northing	Length (m)	Surface Area (m2)	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after Any Longwall (mm/m)	Maximum Predicted Final Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Maximum Predicted Change in Freeboard after All Longwalls (mm)
A32d02	348570	6357634	63	2121	1500	3.9	1.0	0.02	0.02	50
A32d03	348811	6357707	166	7325	1525	3.8	1.1	0.03	0.04	50
A33d01	349164	6357928	114	3877	1475	3.6	1.2	0.02	0.02	75
A33d02	348986	6357700	36	840	1475	2.2	0.7	0.02	0.01	< 50
A34d01	348902	6358210	65	1514	1400	3.0	0.9	0.02	0.02	< 50
A34d02	348543	6358512	30	506	1525	3.0	1.4	0.03	0.02	< 50
A34d03	349008	6358403	32	378	1375	2.2	0.9	0.03	0.02	< 50
A35d01	349291	6358686	151	5354	1175	4.7	4.7	0.02	0.02	700
A35d02	348406	6358777	44	841	1600	3.6	2.1	0.03	0.02	50
A35d03	348835	6358912	30	543	1075	2.4	2.4	0.02	0.02	150
A35d04	348519	6359122	31	390	1050	4.0	4.0	0.02	0.07	150
A35d05	349357	6358919	27	439	150	1.4	1.4	< 0.01	< 0.01	< 50
A35d06	348885	6359120	17	177	175	1.7	1.7	0.01	< 0.01	< 50
A36d01	349306	6358386	164	9674	1375	3.2	1.3	0.02	0.03	100
A36d02	349483	6358629	47	817	825	4.4	4.4	0.02	0.03	225
A36d03	349466	6359006	40	888	40	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A37d01	349816	6357460	35	547	1400	3.0	1.9	0.02	0.01	75
A37d02	349697	6357786	27	406	1575	2.2	0.9	0.02	0.02	< 50
A37d03	349491	6357975	55	1179	1450	2.2	0.6	0.02	0.01	< 50
A37d04	349639	6358041	104	2869	1400	2.2	0.7	0.02	0.02	50
A37d05	349820	6357948	36	776	1425	3.5	1.5	0.02	0.03	50
A37d06	349785	6358130	35	752	1225	2.5	2.1	0.01	0.02	50
A37d07	349911	6357919	20	278	1300	2.1	1.1	0.02	0.02	< 50
A44d01	348941	6359295	20	268	20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A44d02	348840	6359192	66	2175	125	1.3	1.3	< 0.01	< 0.01	75
A44d03	348708	6359197	25	431	200	1.5	1.5	0.01	< 0.01	< 50
A44d04	349310	6359098	30	445	30	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A44d05	349440	6359077	23	319	20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A44d06	348791	6359205	7	39	100	1.0	1.0	< 0.01	< 0.01	< 50
A44d07	348796	6359264	14	93	60	0.6	0.6	< 0.01	< 0.01	< 50
A52d02	346961	6358236	21	240	30	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A63d01	350457	6356126	57	1148	20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A63d02	350318	6356259	49	1041	100	0.7	0.7	< 0.01	< 0.01	< 50
A63d03	350214	6356303	27	495	175	1.1	1.1	0.01	< 0.01	< 50
A64d03	350908	6356343	103	2775	20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A64d04	350895	6356512	31	622	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A64d05	350840	6356785	23	374	275	2.3	2.3	0.02	< 0.01	< 50
A65d01	350413	6356828	71	1799	1025	2.6	2.2	0.02	0.04	150
A65d02	350409	6356982	86	2264	1050	2.6	0.8	0.02	0.03	50
A65d03	350002	6356915	34	851	1100	1.7	0.9	0.02	0.02	< 50
A70d02	347082	6357819	30	483	40	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A71d01	350063	6357369	40	758	1075	2.8	< 0.5	0.02	0.03	< 50
A71d02	350591	6357620	62	1691	750	3.5	3.5	0.02	0.01	150
A71d03	349976	6357896	38	584	1200	1.7	1.0	0.01	0.02	75
A72d01	350822	6357888	27	438	60	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A72d02	350900	6357857	23	327	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
A73d02	350998	6357010	52	1175	150	1.1	1.1	< 0.01	< 0.01	< 50
A74d01	350902	6357306	71	2651	300	2.3	2.3	0.02	< 0.01	125
A77d01	351216	6357053	34	768	30	< 0.5	< 0.5	< 0.01	< 0.01	< 50
				Maximums:	**1750**	**6.0**	**6.0**	**0.05**	**0.07**	**700**

Table D.04 - Tanks within the Study Area
Maximum Predicted Conventional Subsidence Parameters

Ref.	MGA Easting	MGA Northing	Longest Side (m)	Type	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
A12t01	347301	6358030	3	Tank	350	3.2	0.04	< 0.01
A12t02	347306	6358029	3	Tank	350	3.4	0.04	< 0.01
A13t01	347806	6358000	7	Tank	1500	0.7	0.03	0.02
A14t01	348116	6358041	8	Tank	1500	1.0	0.02	0.02
A16t01	347305	6357715	3	Tank	150	1.3	0.01	< 0.01
A16t02	347305	6357710	3	Tank	150	1.3	0.01	< 0.01
A16t03	347337	6357672	3	Tank	200	1.6	0.01	< 0.01
A17t01	347778	6357458	3	Tank	1500	1.8	0.03	0.04
A17t02	347778	6357455	3	Tank	1500	1.8	0.03	0.04
A17t03	347809	6357461	4	Tank	1500	1.3	0.03	0.04
A18t01	347998	6357536	4	Tank	1550	0.9	0.03	0.03
A21t01	347733	6356237	4	Tank	25	< 0.5	< 0.01	< 0.01
A21t02	347741	6356236	4	Tank	25	< 0.5	< 0.01	< 0.01
A23t01	348220	6356056	4	Tank	50	< 0.5	< 0.01	< 0.01
A24t01	348144	6356041	8	Tank	25	< 0.5	< 0.01	< 0.01
A25t01	348452	6356345	8	Tank	350	1.8	0.01	< 0.01
A26t01	348124	6356771	2	Tank	1350	1.6	0.02	0.02
A28t01	348715	6355897	3	Tank	< 20	< 0.5	< 0.01	< 0.01
A28t02	348714	6355892	4	Tank	< 20	< 0.5	< 0.01	< 0.01
A31t01	347927	6358552	3	Tank	1650	2.3	0.02	0.08
A32t01	348432	6358096	4	Tank	1500	1.0	0.03	0.02
A32t02	348746	6357707	4	Tank	1500	1.1	0.02	0.02
A33t01	349492	6357746	3	Tank	1600	1.4	0.02	0.02
A33t02	349496	6357748	3	Tank	1600	1.4	0.02	0.02
A33t03	349563	6357671	3	Tank	1600	< 0.5	0.02	0.02
A33t04	349567	6357672	3	Tank	1600	< 0.5	0.02	0.02
A33t05	349466	6357684	3	Tank	1600	0.7	0.03	0.04
A33t06	349359	6357923	3	Tank	1450	0.6	0.02	0.01
A33t07	349364	6357924	3	Tank	1450	0.6	0.02	0.01
A34t01	348961	6358327	5	Tank	1350	0.8	0.03	0.02
A34t02	349034	6358375	3	Tank	1350	0.8	0.02	0.02
A44t01	348842	6359335	2	Tank	25	< 0.5	< 0.01	< 0.01
A47t01	349438	6355693	4	Tank	< 20	< 0.5	< 0.01	< 0.01
A47t02	349497	6355681	2	Tank	< 20	< 0.5	< 0.01	< 0.01
A53t01	347299	6357176	4	Tank	75	0.5	< 0.01	< 0.01
A53t02	347296	6357181	4	Tank	75	0.5	< 0.01	< 0.01
A53t03	347295	6357177	2	Tank	75	< 0.5	< 0.01	< 0.01
A66t01	350340	6358365	2	Tank	25	< 0.5	< 0.01	< 0.01
A73t01	350970	6357013	4	Tank	150	1.3	< 0.01	< 0.01
				Maximums:	**1650**	**3.4**	**0.04**	**0.08**

Table D.05 - Pools within the Study Area
Maximum Predicted Conventional Subsidence Parameters

Pool No.	MGA Easting	MGA Northing	Longest Side (m)	Type	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
A28p01	348728	6355900	9	Pool	1500	0.5	0.04	0.01
A51p01	347311	6357090	6	Pool	1450	3.0	0.02	0.04
A17p01	347738	6357446	7	Pool	25	< 0.5	< 0.01	< 0.01
A13p01	347833	6357998	7	Pool	350	2.0	0.02	< 0.01
A34p01	348990	6358361	11	Pool	< 20	< 0.5	< 0.01	< 0.01
A32p01	348630	6358071	12	Pool	1450	1.0	0.02	0.02
A25p01	348458	6356364	11	Pool	1350	1.0	0.02	0.02
A23p01	348243	6356026	10	Pool	50	< 0.5	< 0.01	< 0.01
				Maximums:	**1500**	**3.0**	**0.04**	**0.04**

APPENDIX E. FIGURES

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line A Resulting from the Extraction of Longwalls A7 to A19

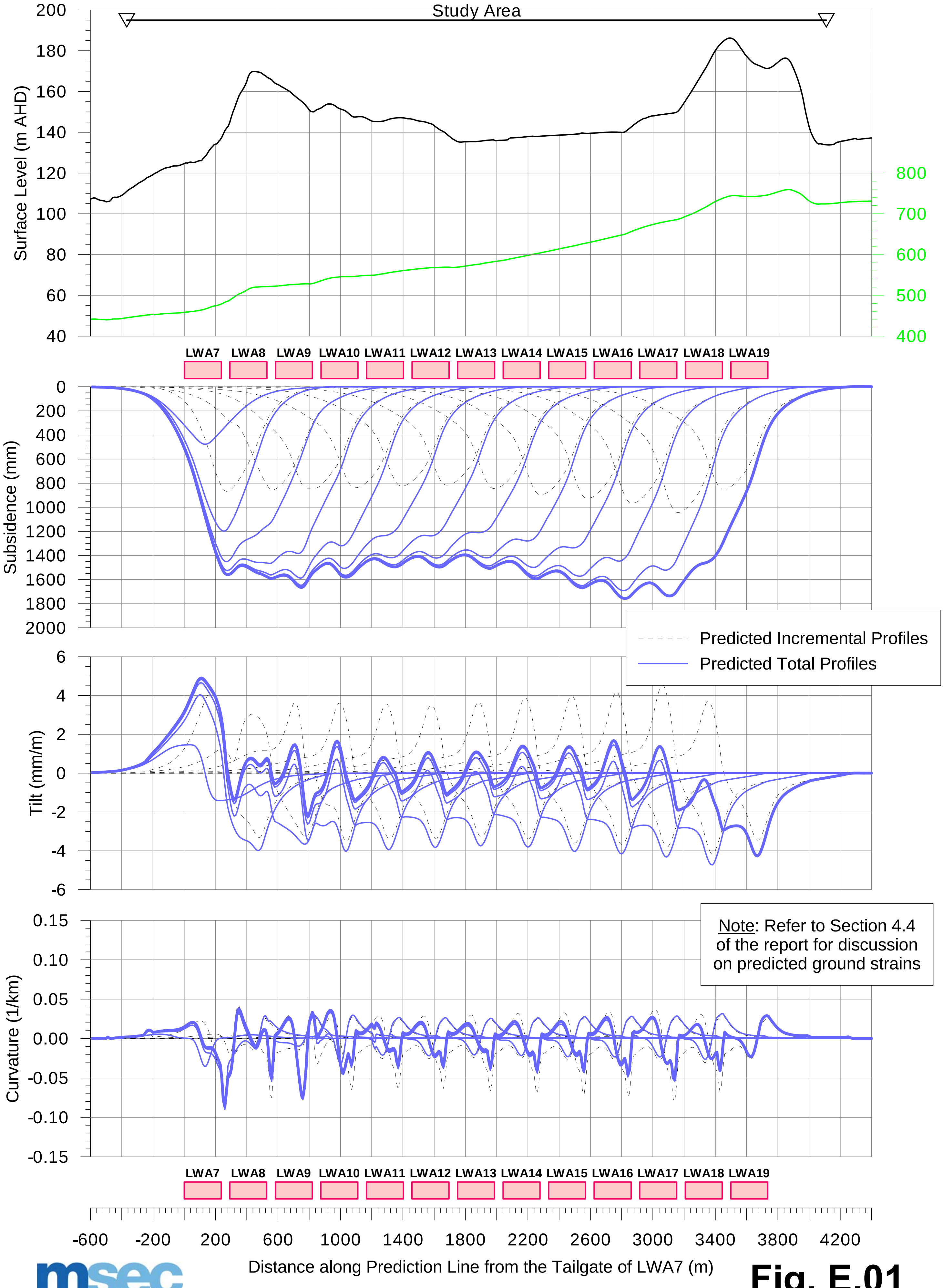
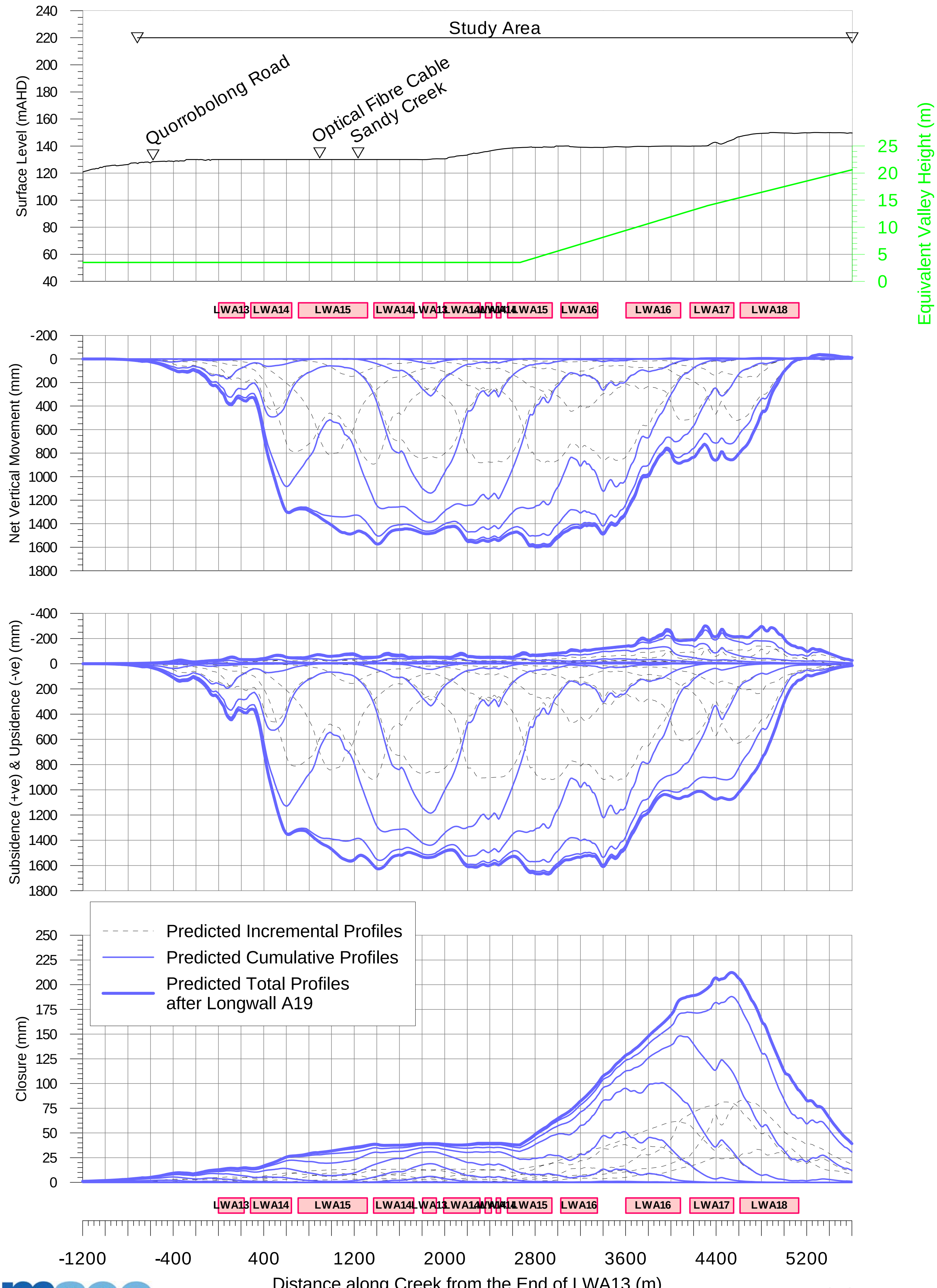


Fig. E.01

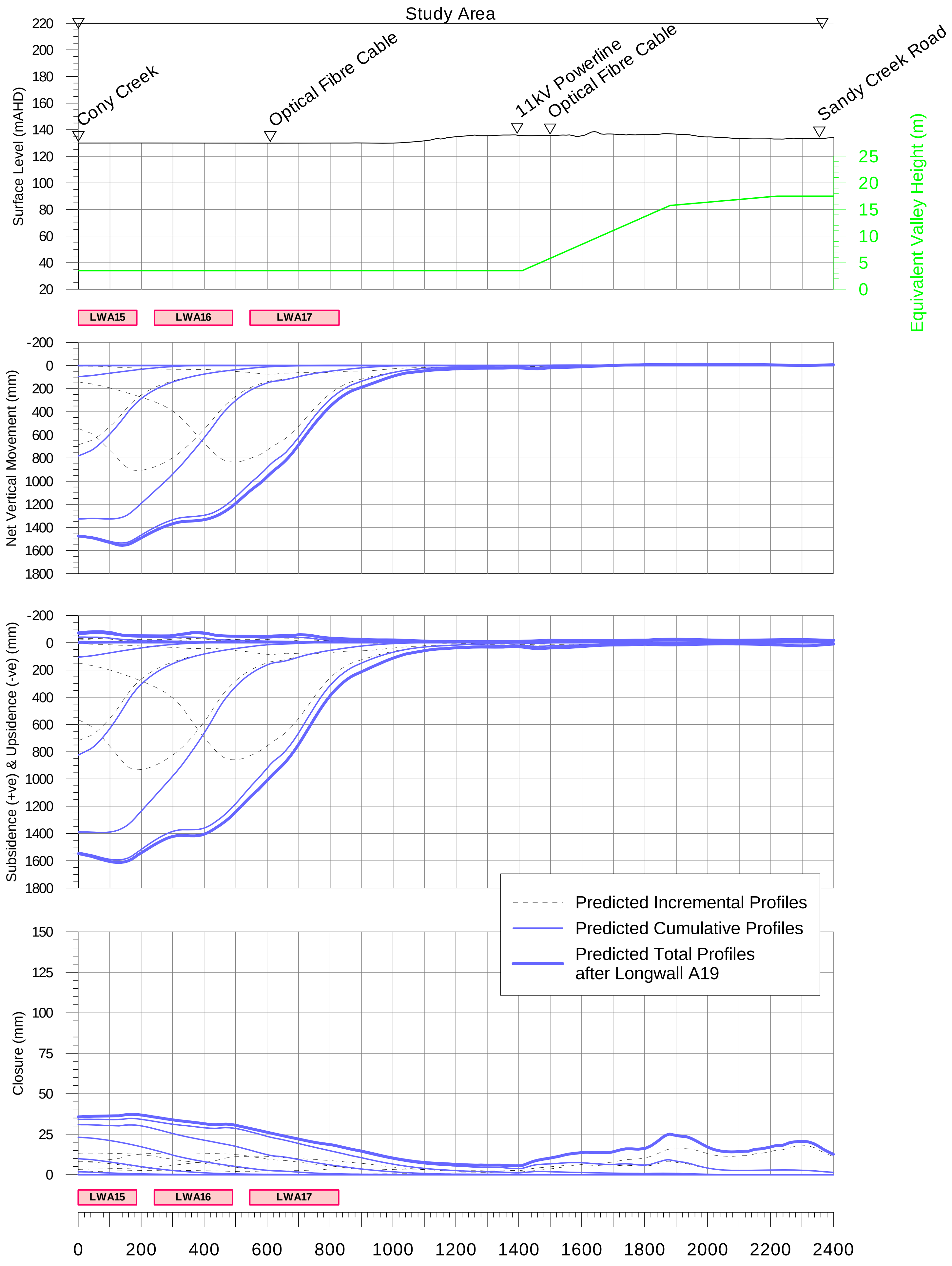
Predicted Profiles of Subsidence, Upsidence and Closure along Cony Creek Resulting from the Extraction of Longwalls A7 to A19



msec

Fig. E.02

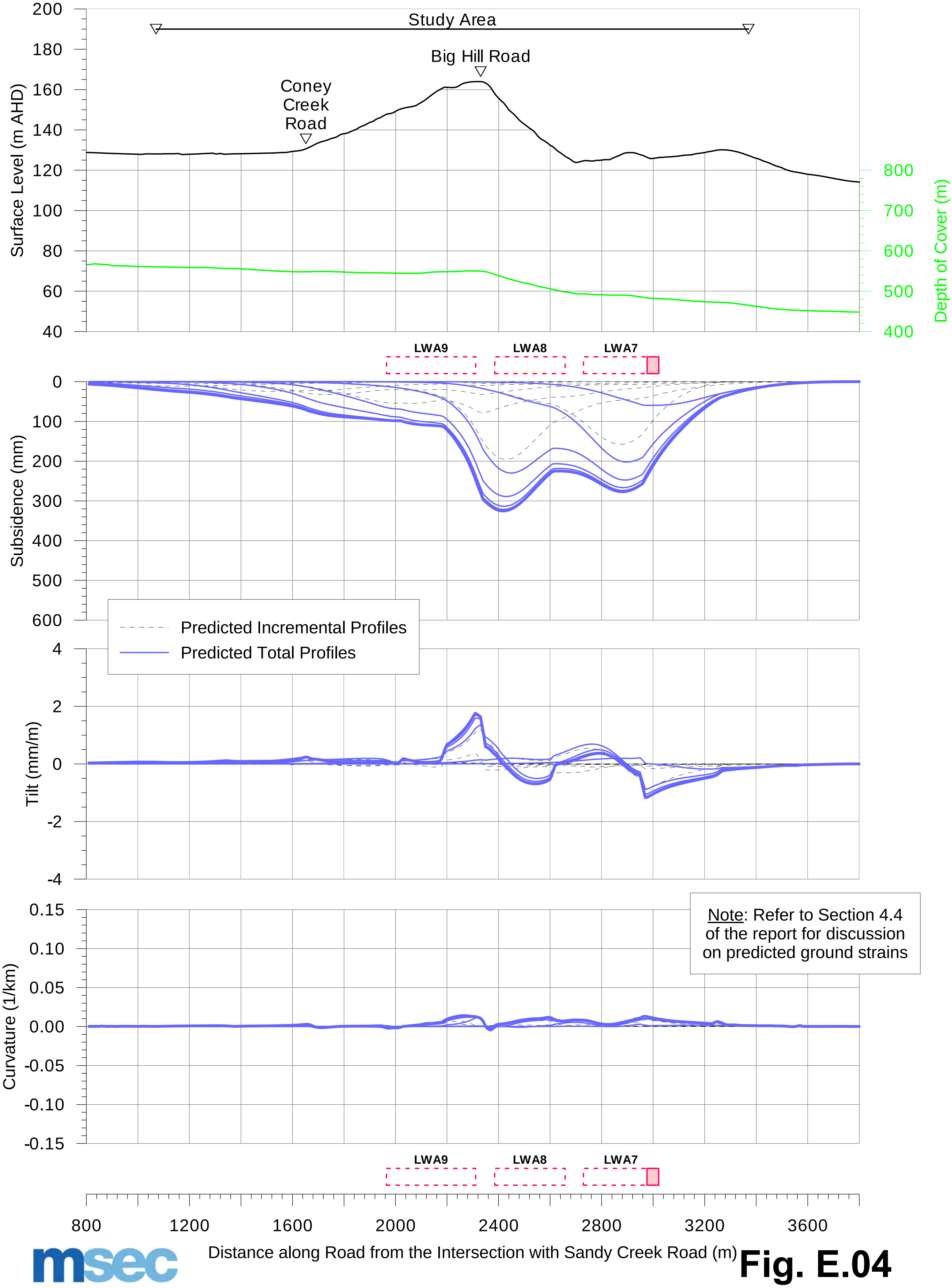
Predicted Profiles of Subsidence, Upsidence and Closure along Sandy Creek Resulting from the Extraction of Longwalls A7 to A19



msec

Fig. E.03

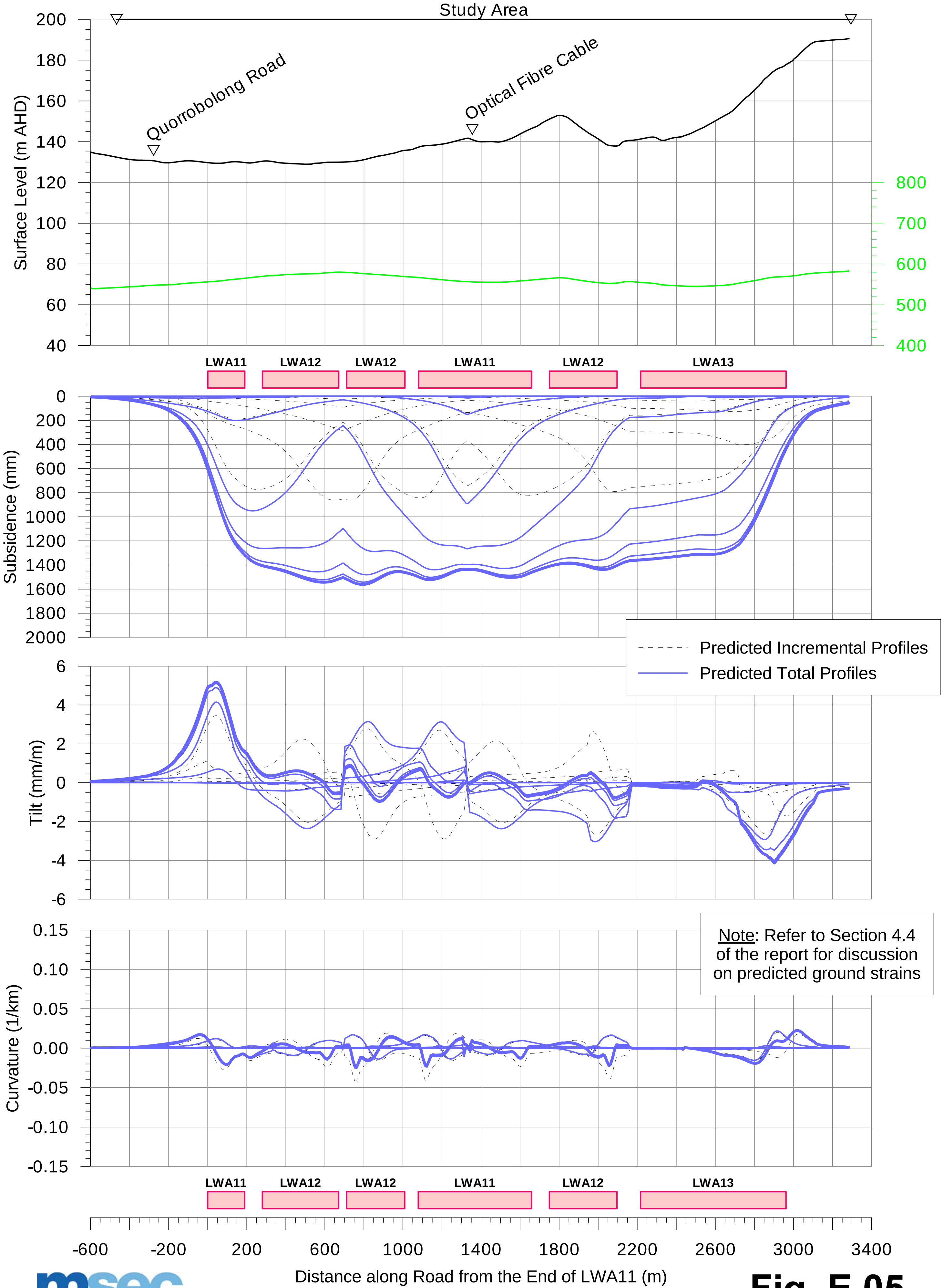
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Quorrobolong Road Resulting from the Extraction of Longwalls A7 to A19



msec

Fig. E.04

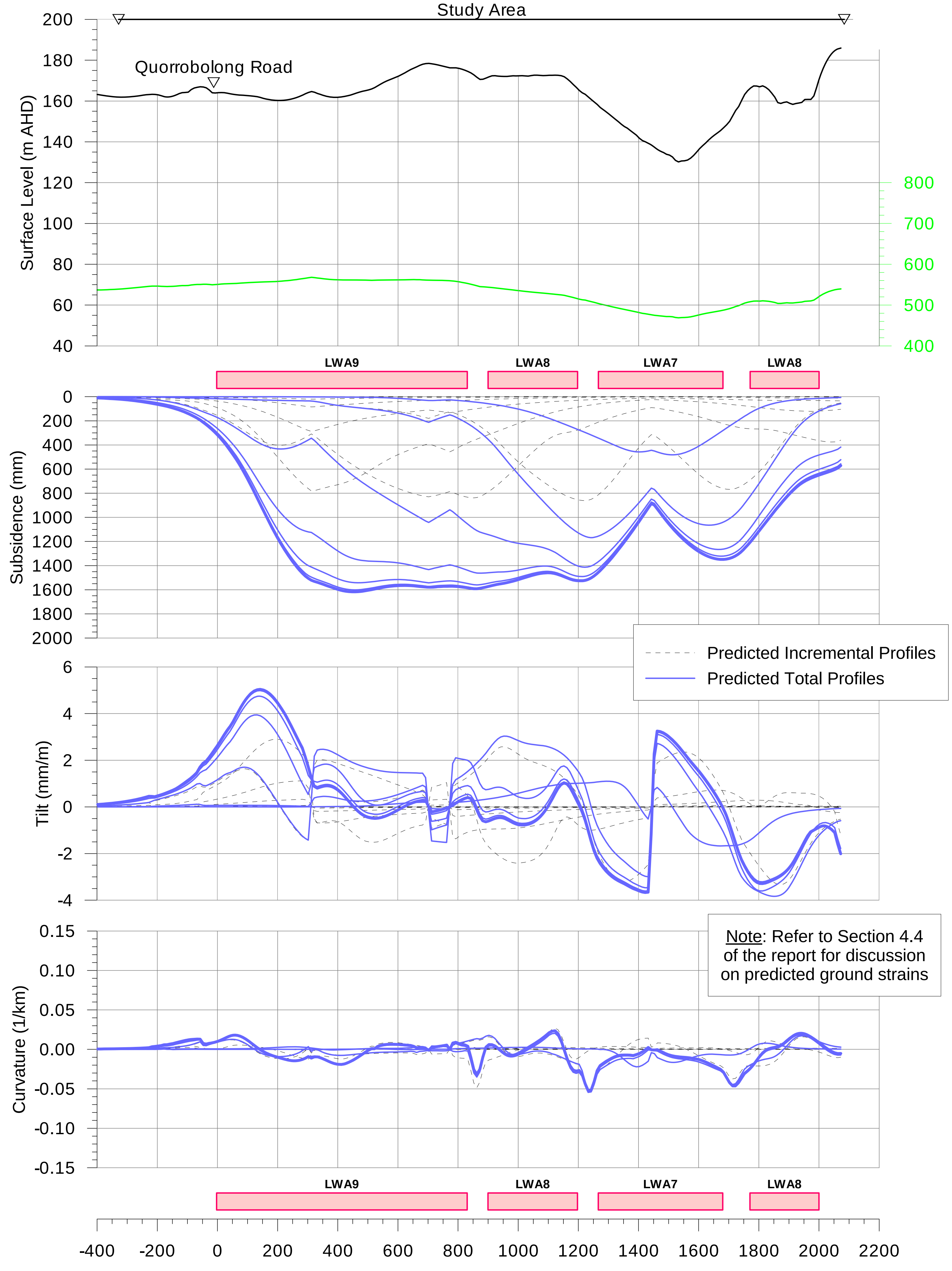
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Coney Creek Lane Resulting from the Extraction of Longwalls A7 to A19



msec

Fig. E.05

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Big Hill Road Resulting from the Extraction of Longwalls A7 to A19



msec

Fig. E.06

Predicted Profiles of Systematic Subsidence, Tilt and Curvature along the Optical Fibre Cable Resulting from the Extraction of Longwalls A7 to A19

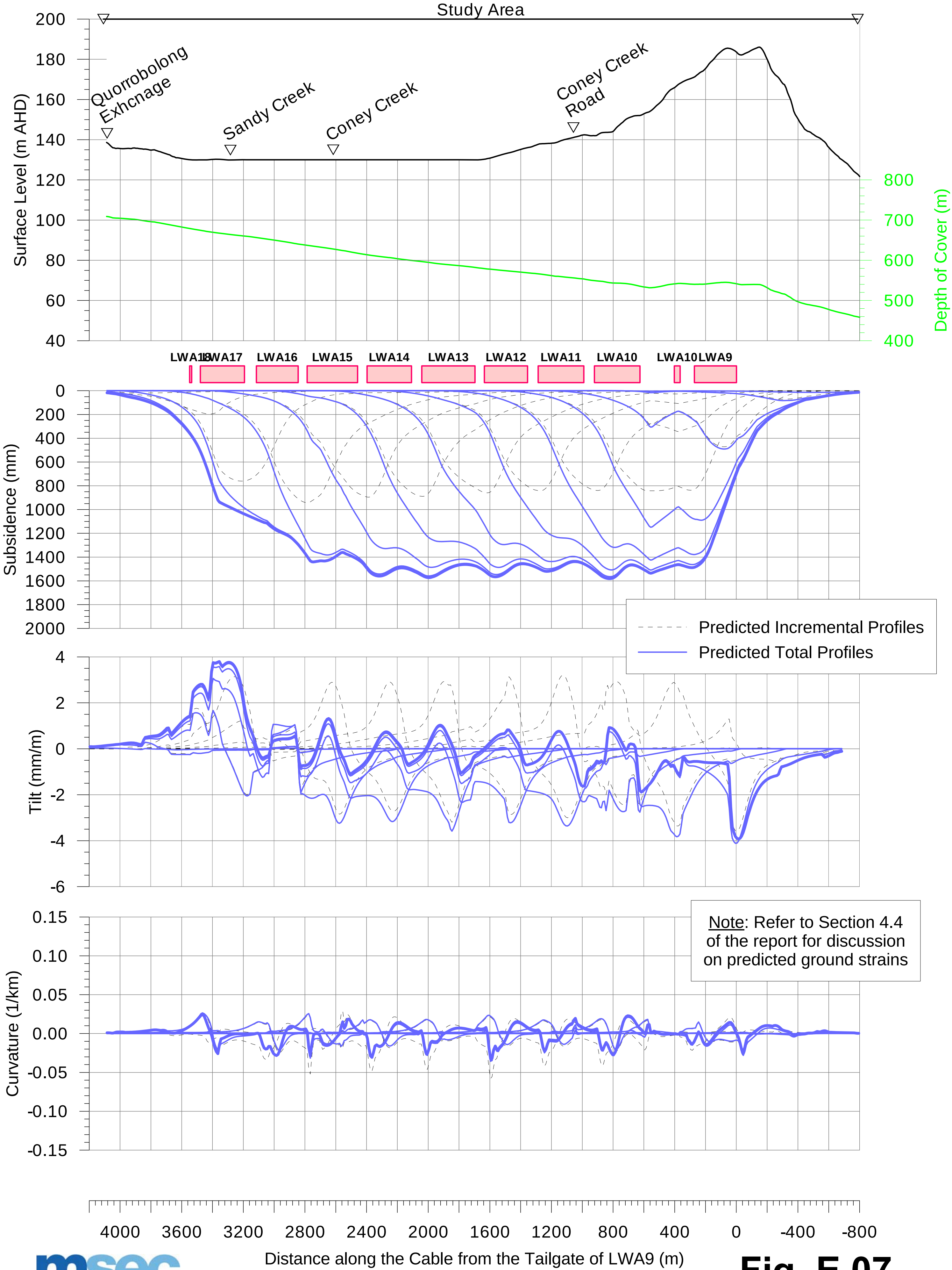


Fig. E.07

APPENDIX F. COMPARISONS BETWEEN OBSERVED AND BACK-PREDICTED SUBSIDENCE PROFILES FOR THE PREVIOUSLY EXTRACTED LONGWALLS AT THE COLLIERY

Comparison of Predicted and Observed Profiles along Sandy Creek Road Monitoring Line - LW2 to LW4

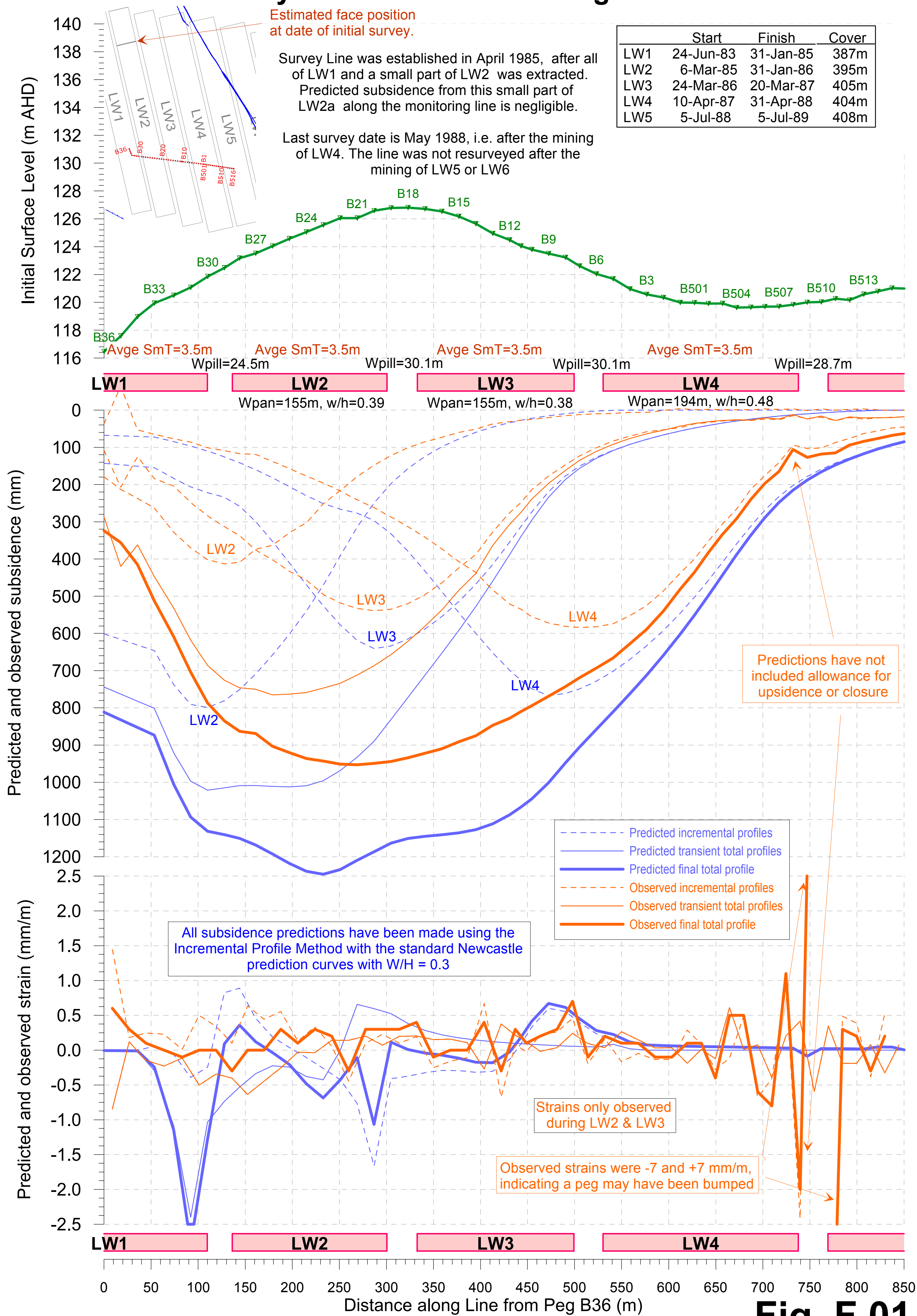
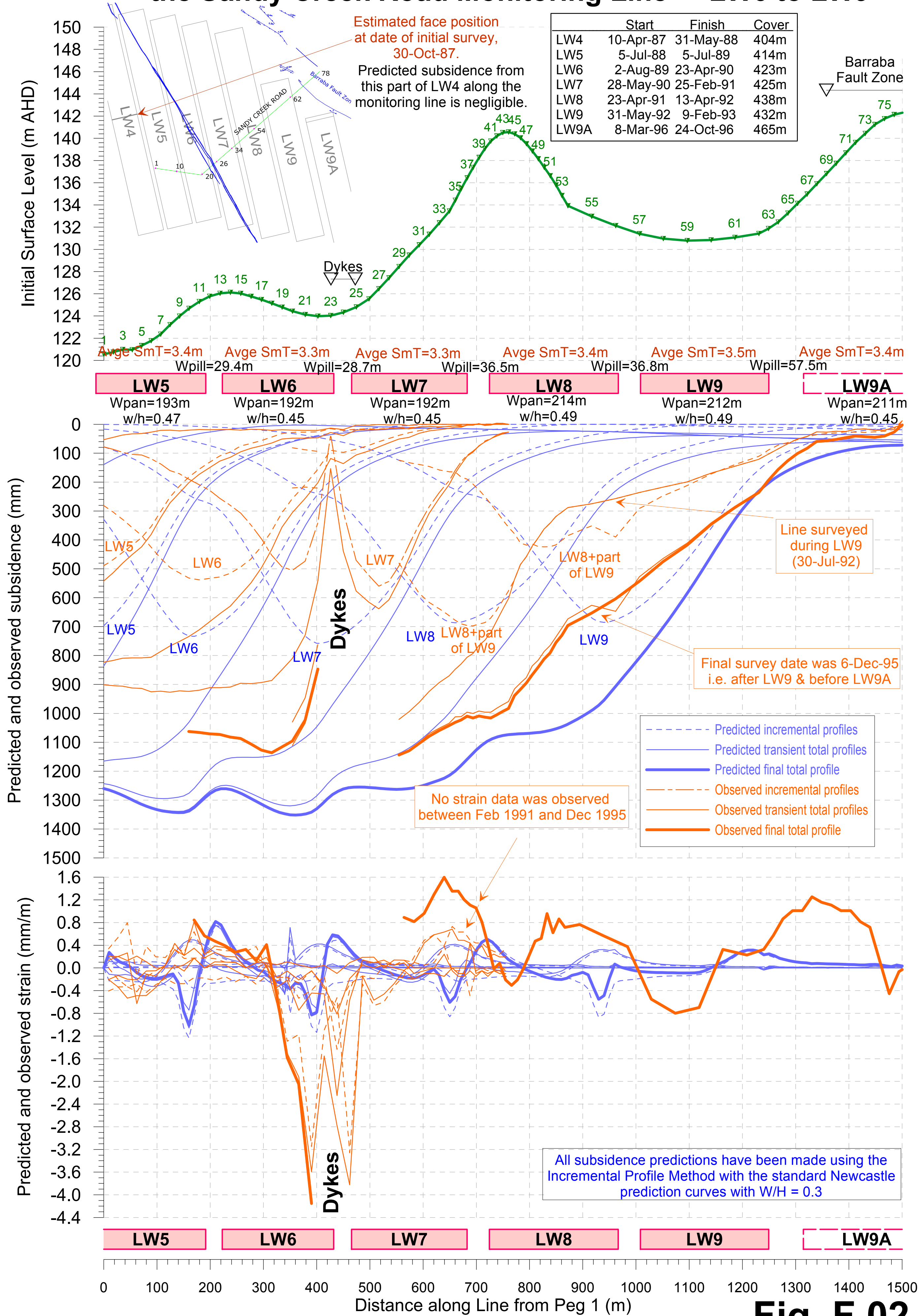


Fig. F.01

Comparison of Predicted and Observed Profiles along the Sandy Creek Road Monitoring Line - LW6 to LW9



	Start	Finish	Cover
LW4	10-Apr-87	31-May-88	404m
LW5	5-Jul-88	5-Jul-89	414m
LW6	2-Aug-89	23-Apr-90	423m
LW7	28-May-90	25-Feb-91	425m
LW8	23-Apr-91	13-Apr-92	438m
LW9	31-May-92	9-Feb-93	432m
LW9A	8-Mar-96	24-Oct-96	465m

Fig. F.02

Comparison of Predicted and Observed Profiles along the Dry Creek Road Monitoring Line

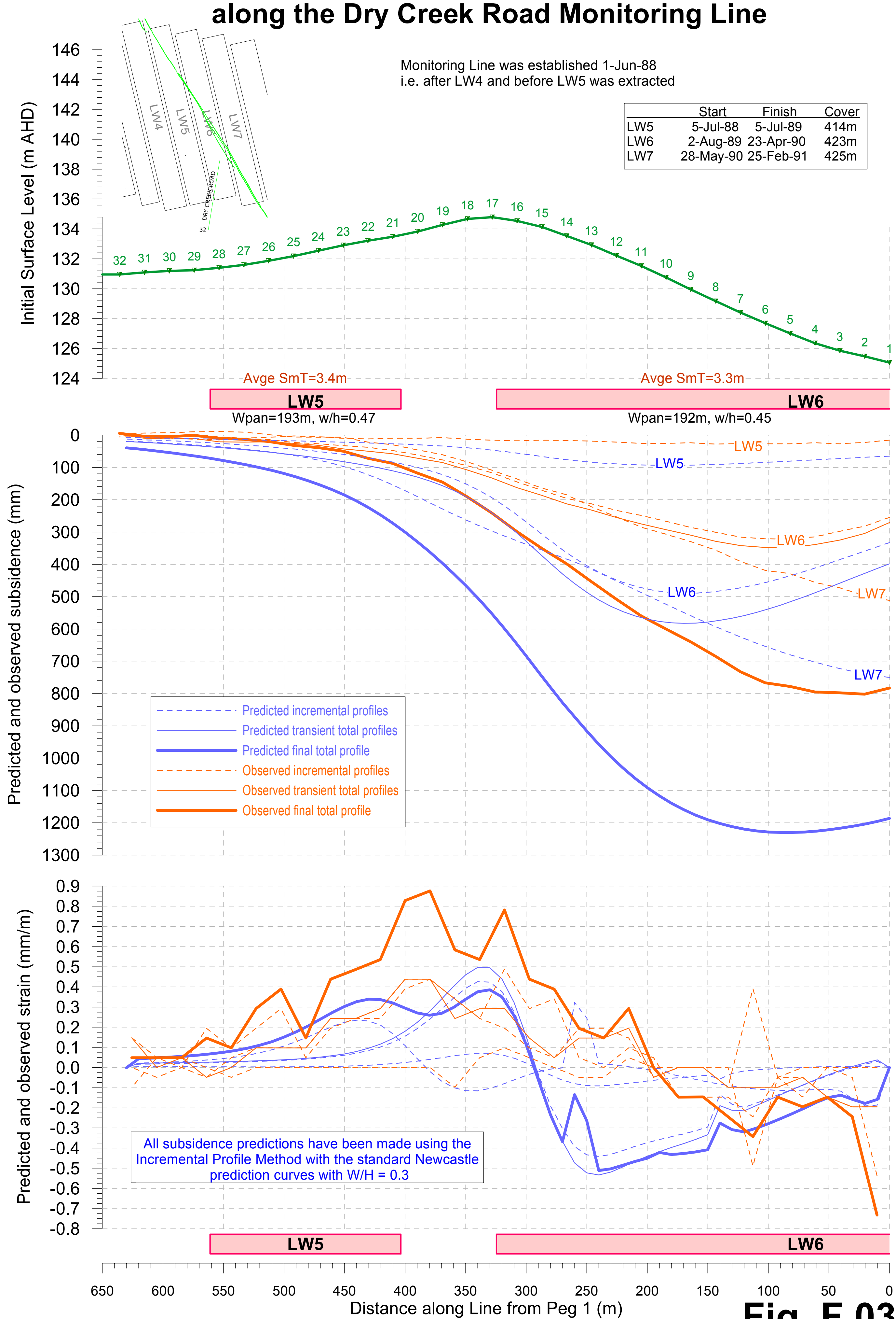


Fig. F.03

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Comparison of Predicted and Observed Profiles along Monitoring Line LW9A

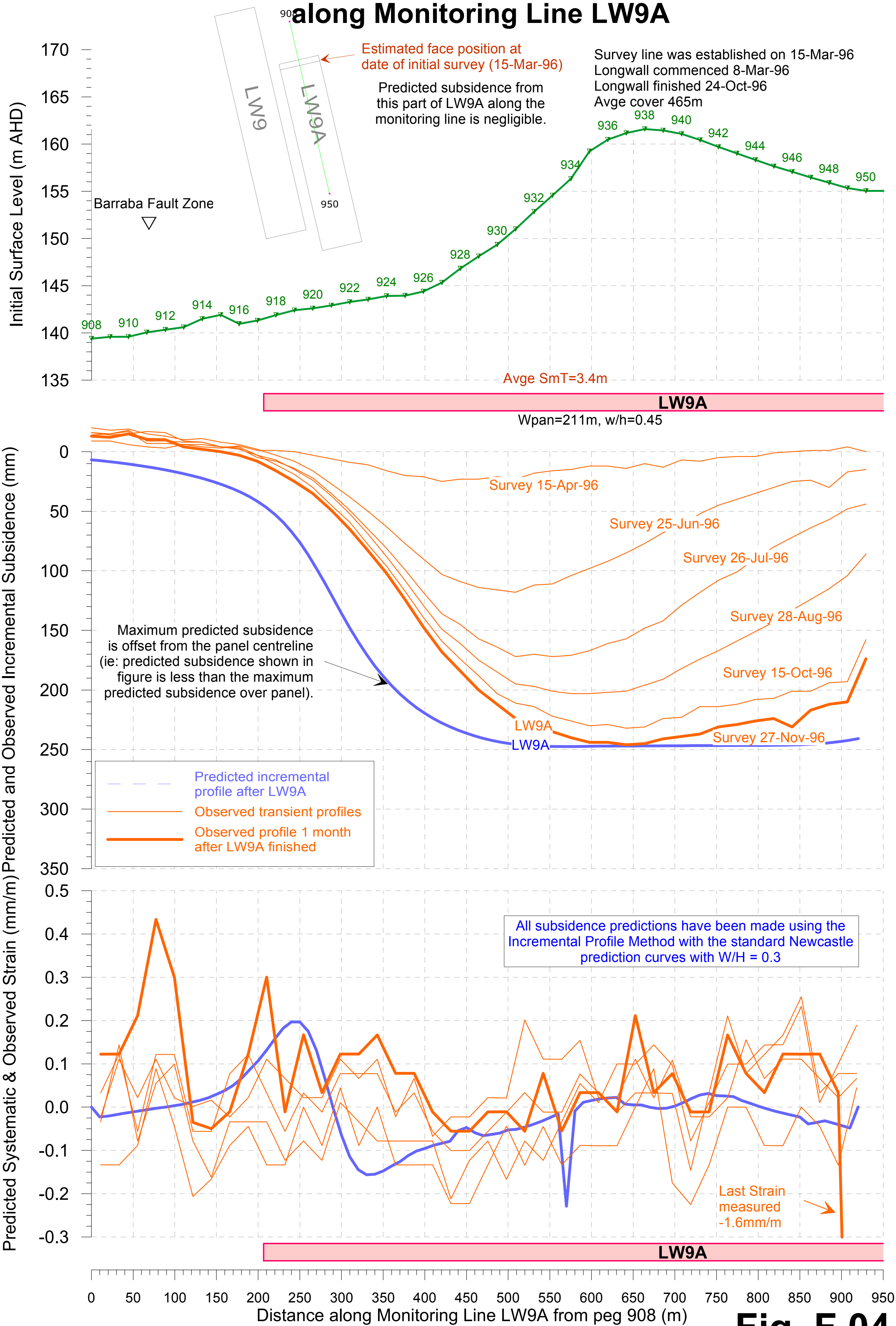

Fig. F.04

Comparison of Predicted and Observed Profiles across Monitoring Line LW10-12A

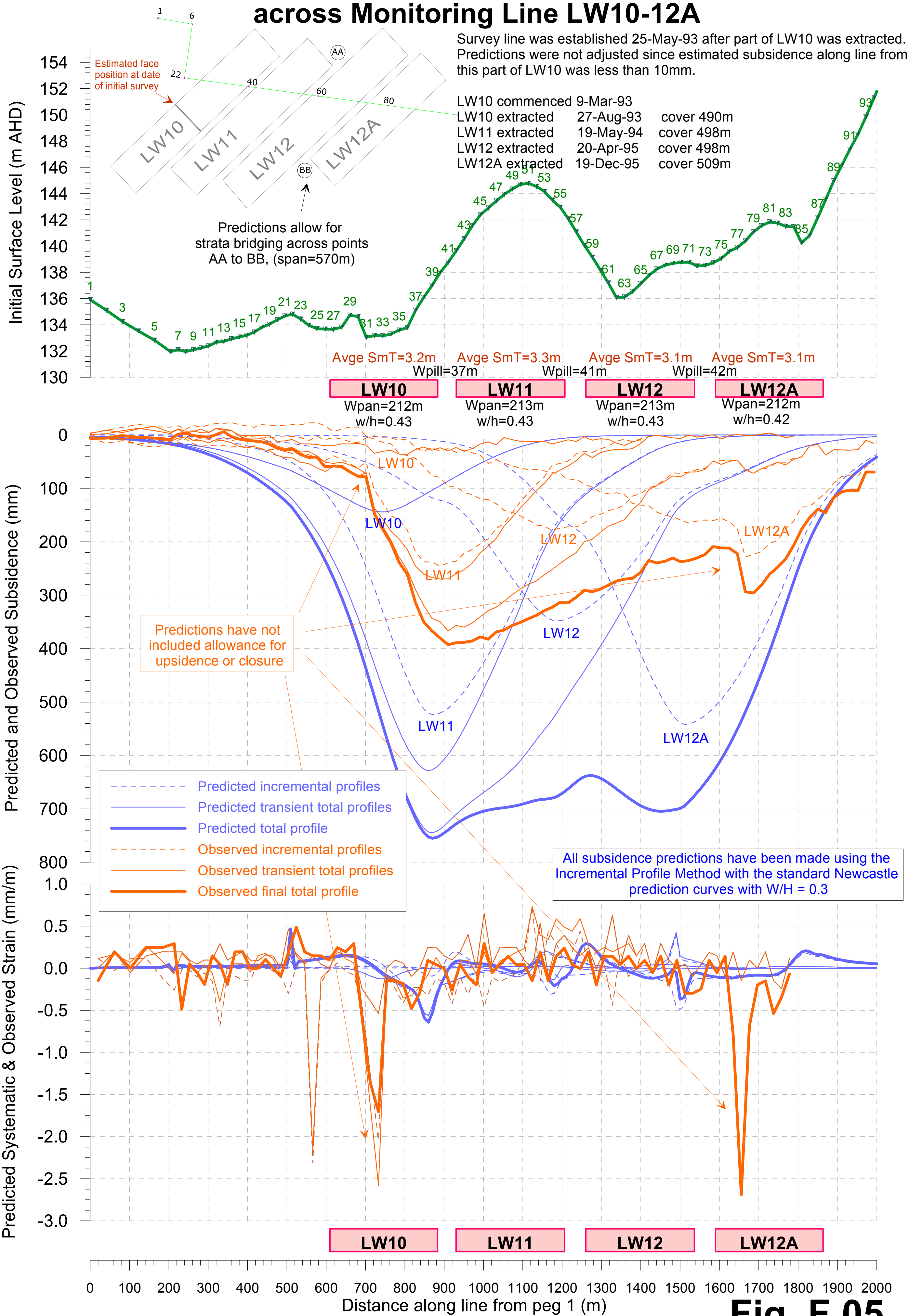

Fig. F.05

Comparison of Predicted and Observed Profiles along Monitoring Line LWSL1

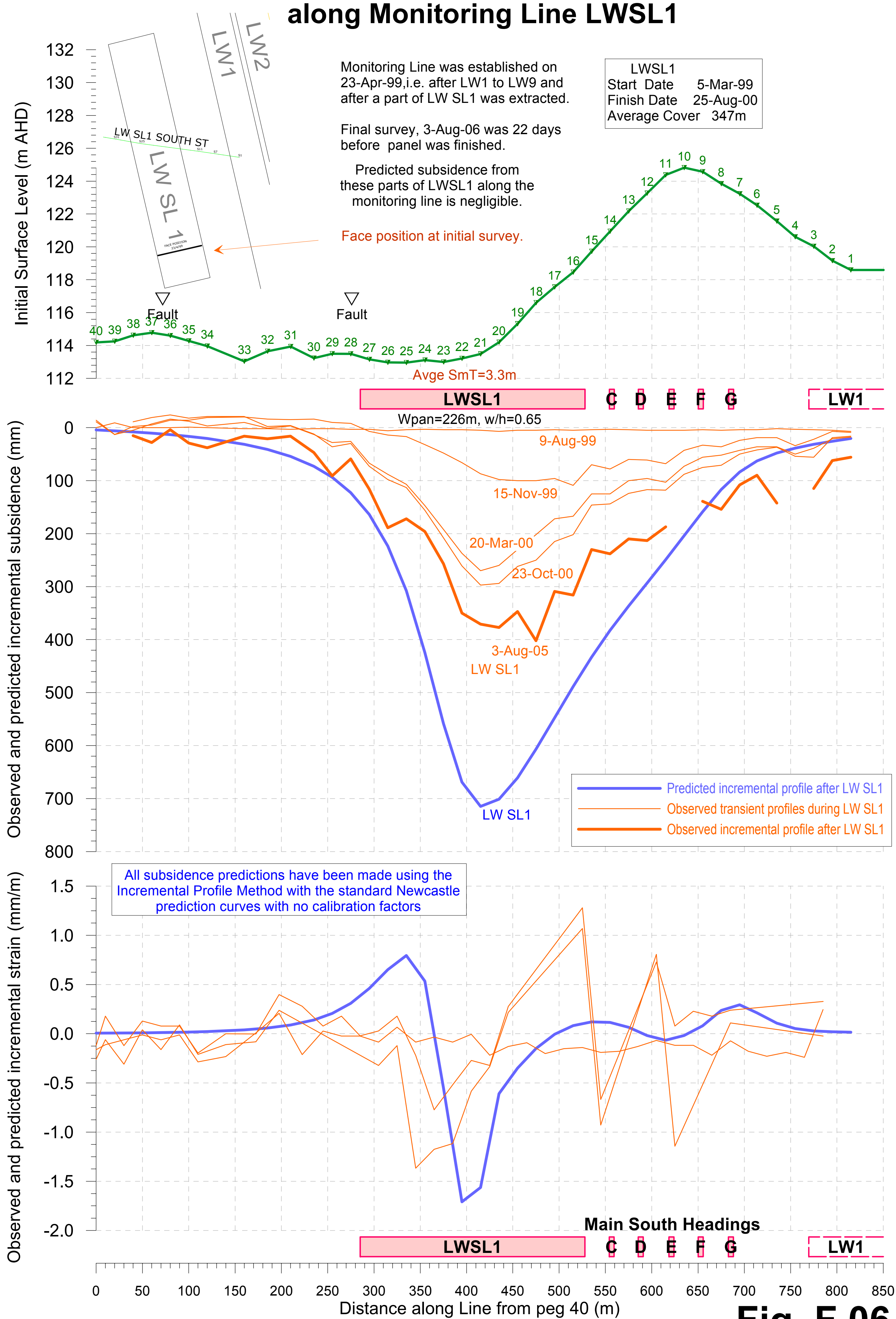

Fig. F.06

Comparison of Predicted and Observed Profiles along Monitoring Line LW13-Line2

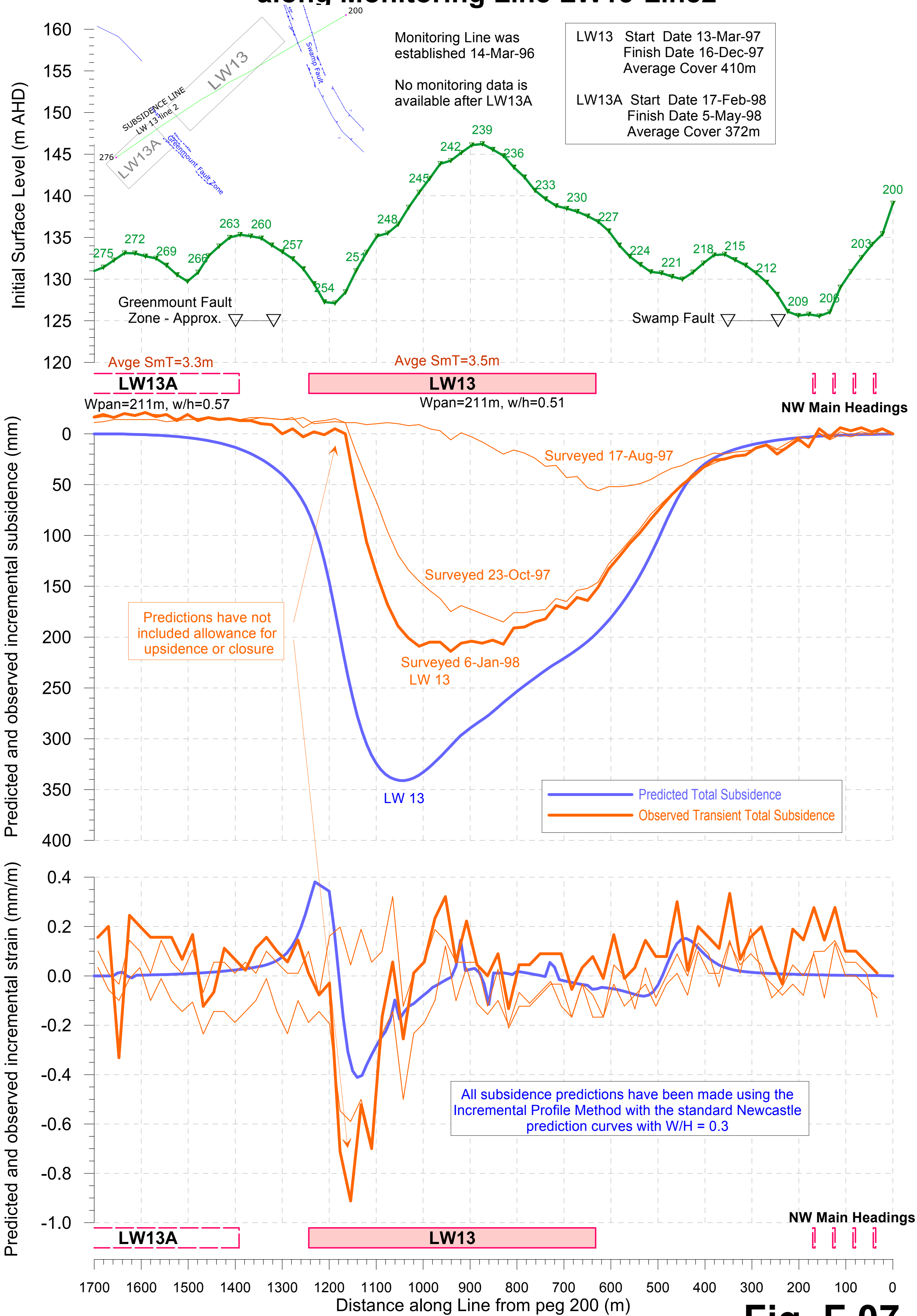

Fig. F.07

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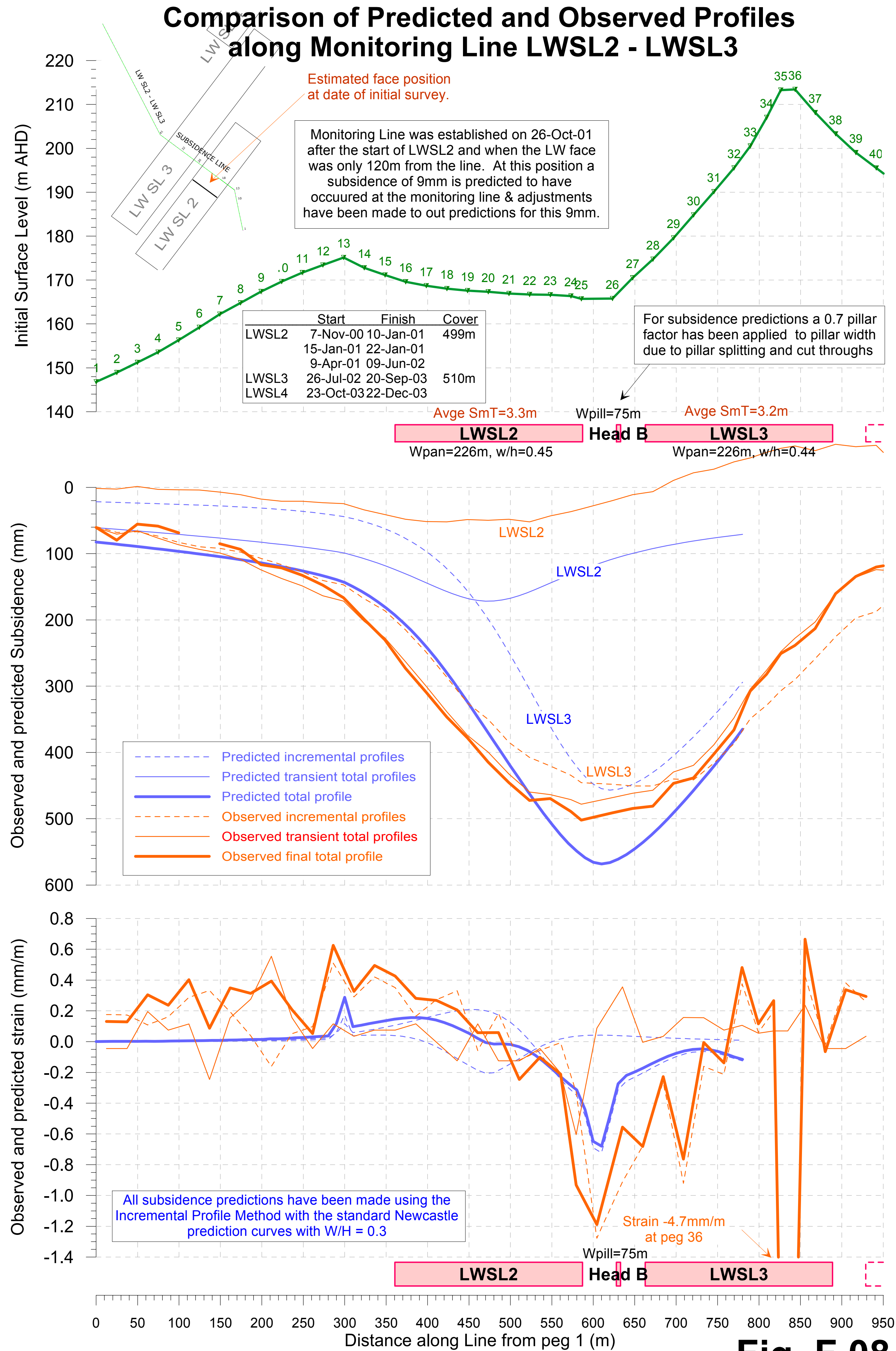

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Fig. F.08

Comparison of Back-Predicted and Observed Profiles Maximum Incremental Subsidence

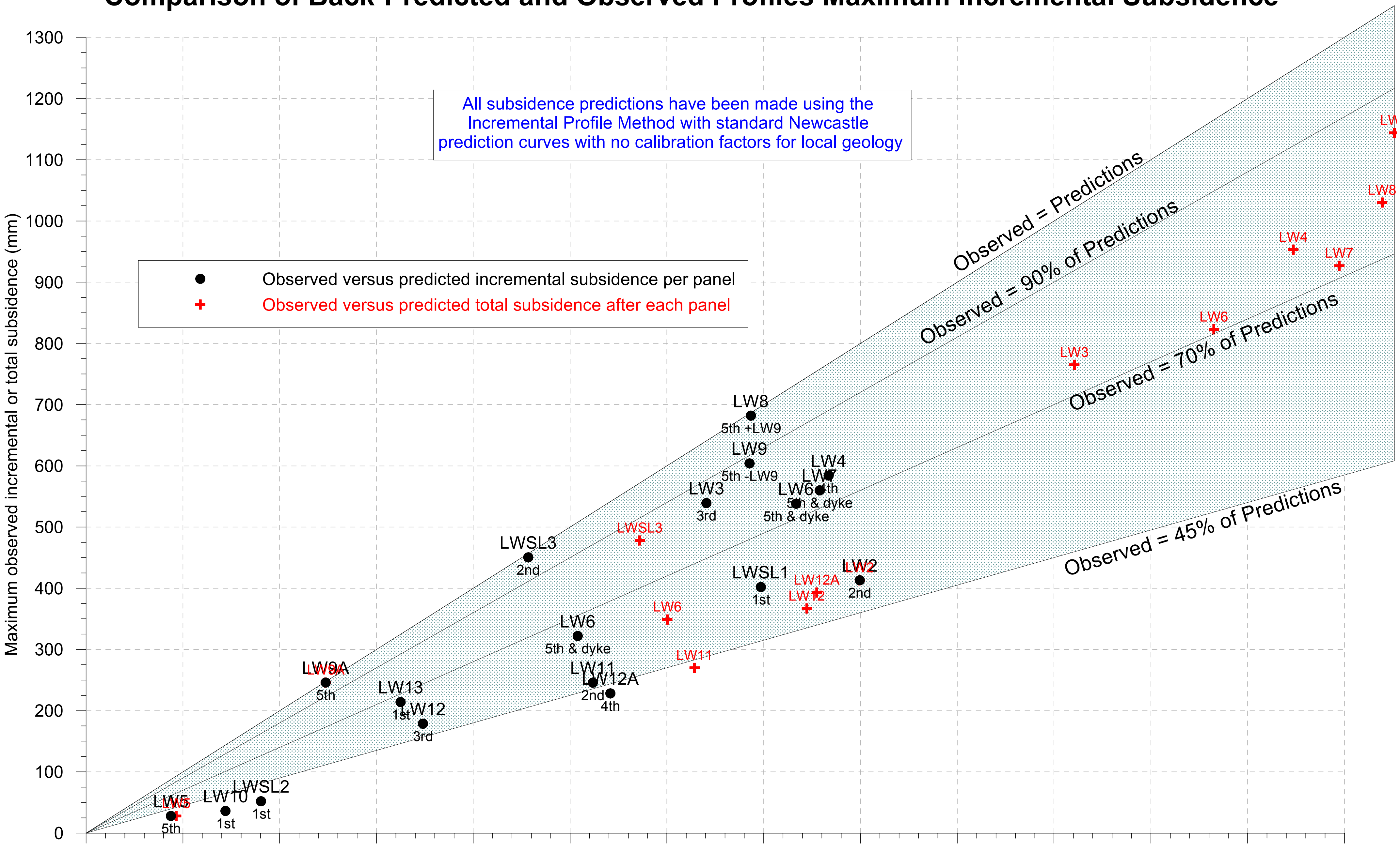

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Fig. F.09

Observed and MSEC Predicted Subsidence, Tilt and Strain Resulting from Longwalls A1 and A2 along Monitoring Line 1A

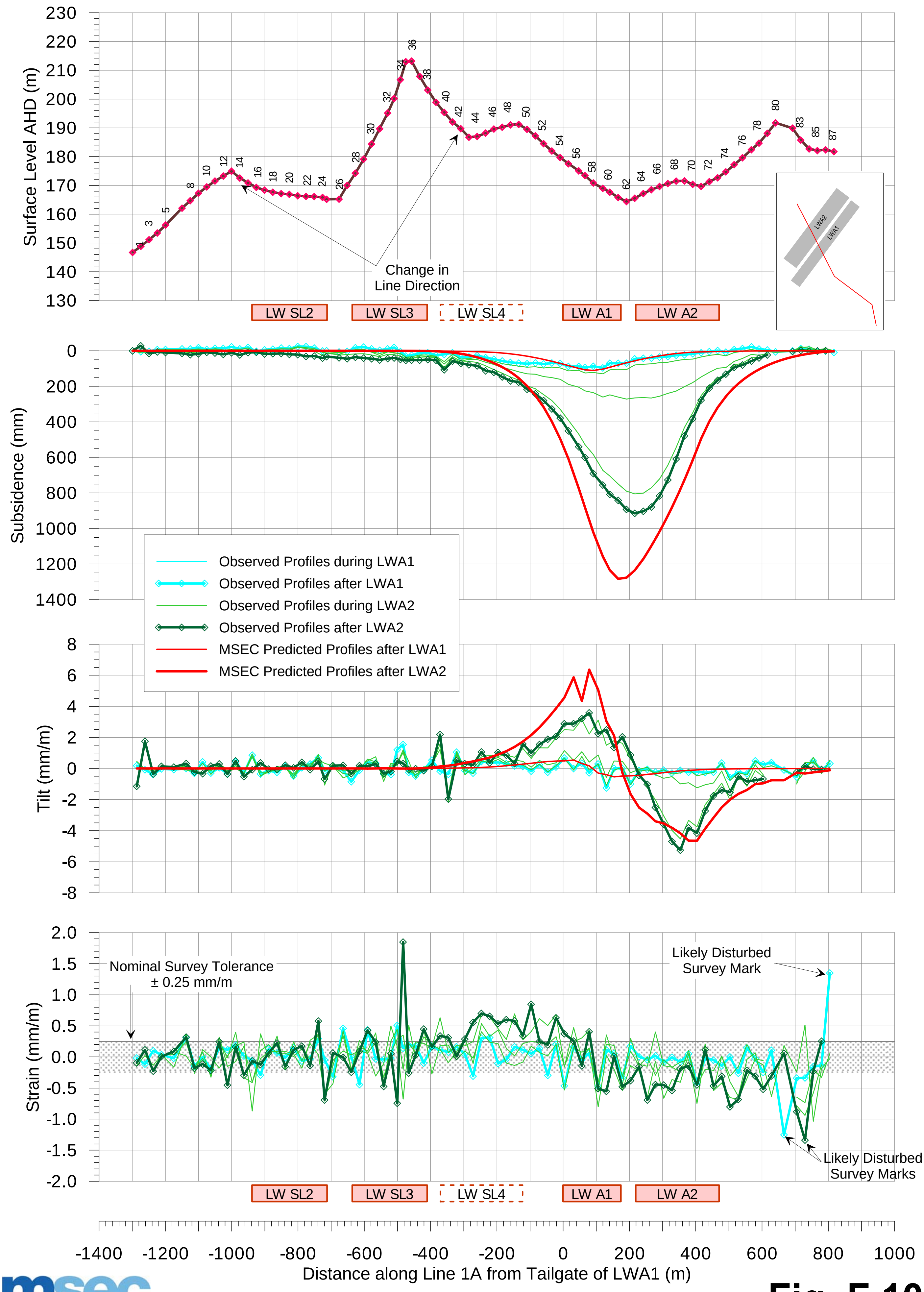
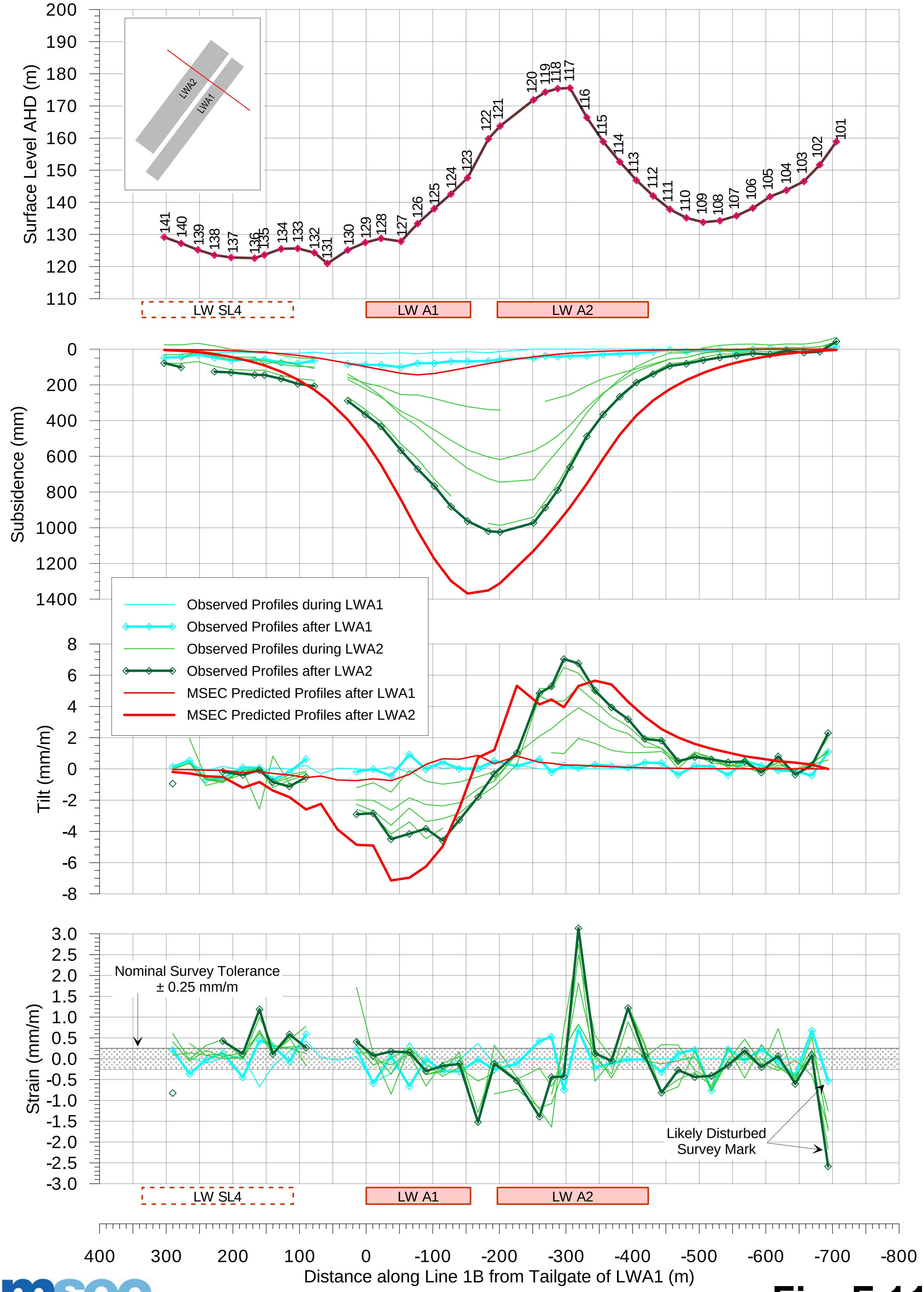


Fig. F.10

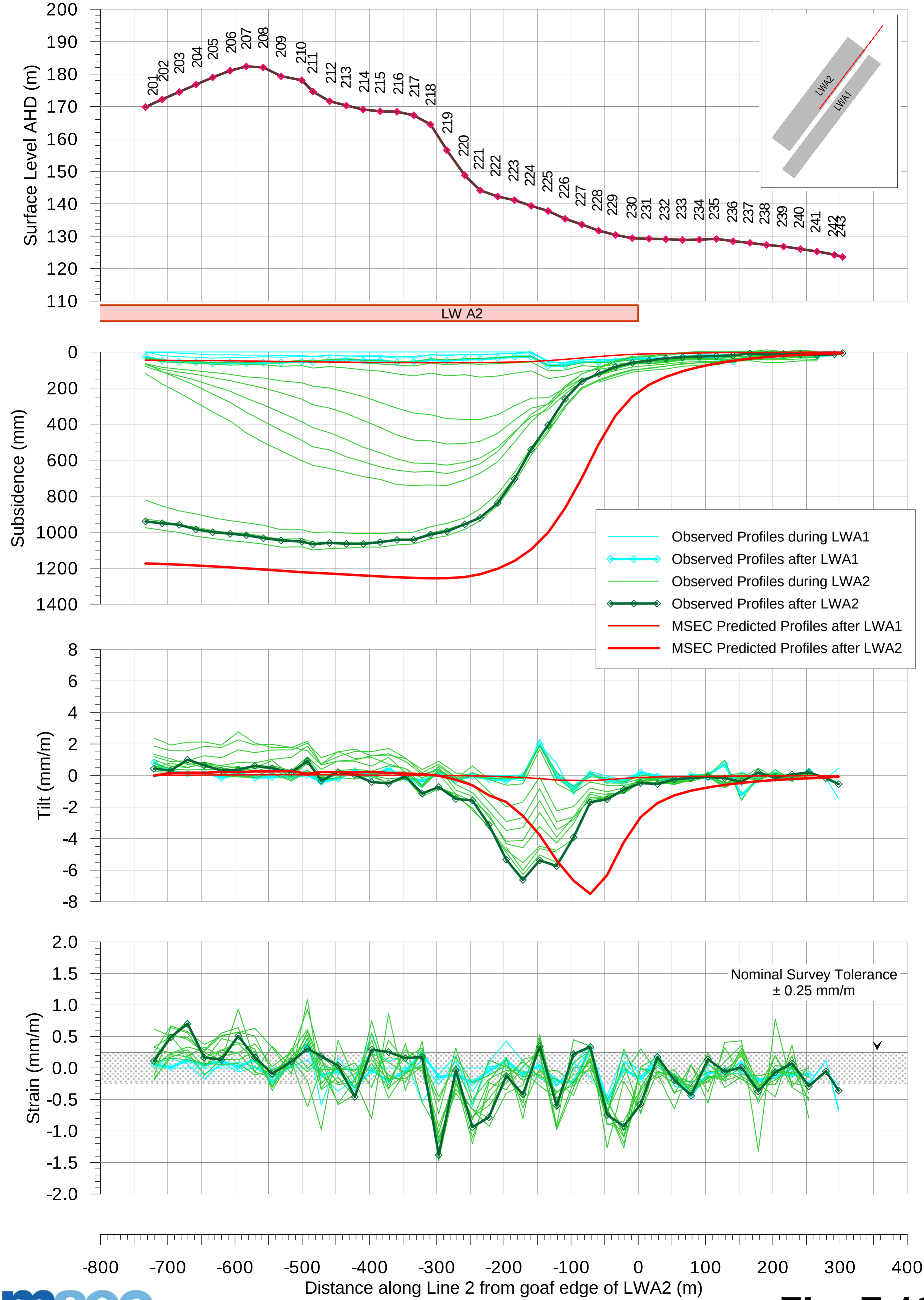
Observed and MSEC Predicted Subsidence, Tilt and Strain Resulting from Longwalls A1 and A2 along Monitoring Line 1B



msec

Fig. F.11

Observed and MSEC Predicted Subsidence, Tilt and Strain Resulting from Longwalls A1 and A2 along Monitoring Line 2

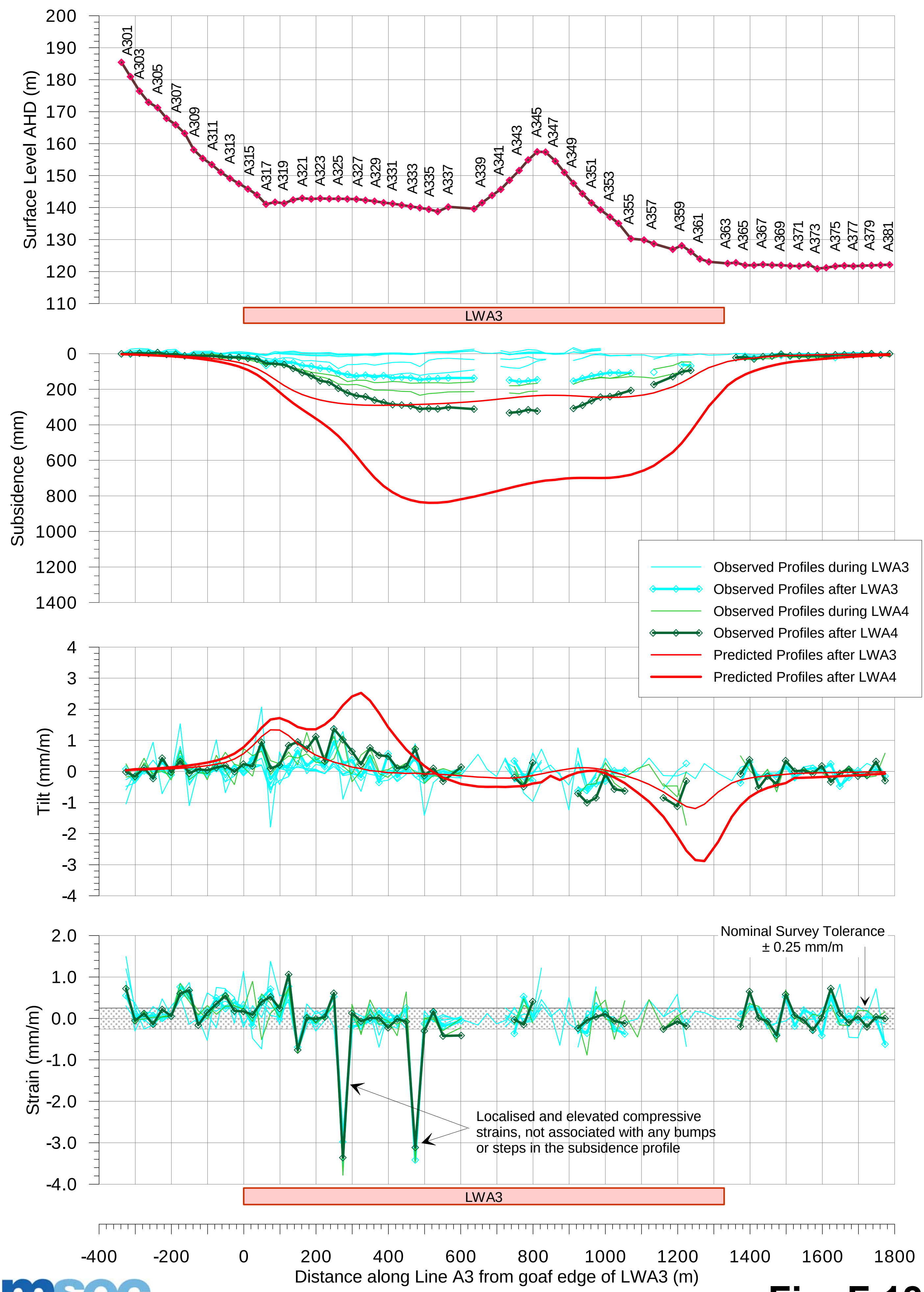


msec

Fig. F.12

I:\Projects\Austar\Stage 3\MSEC484 - Modified Longwalls A7 to A19\Subsdata\SurveyData\Fig. F.13 - A3-Line.grf.....13-May-11

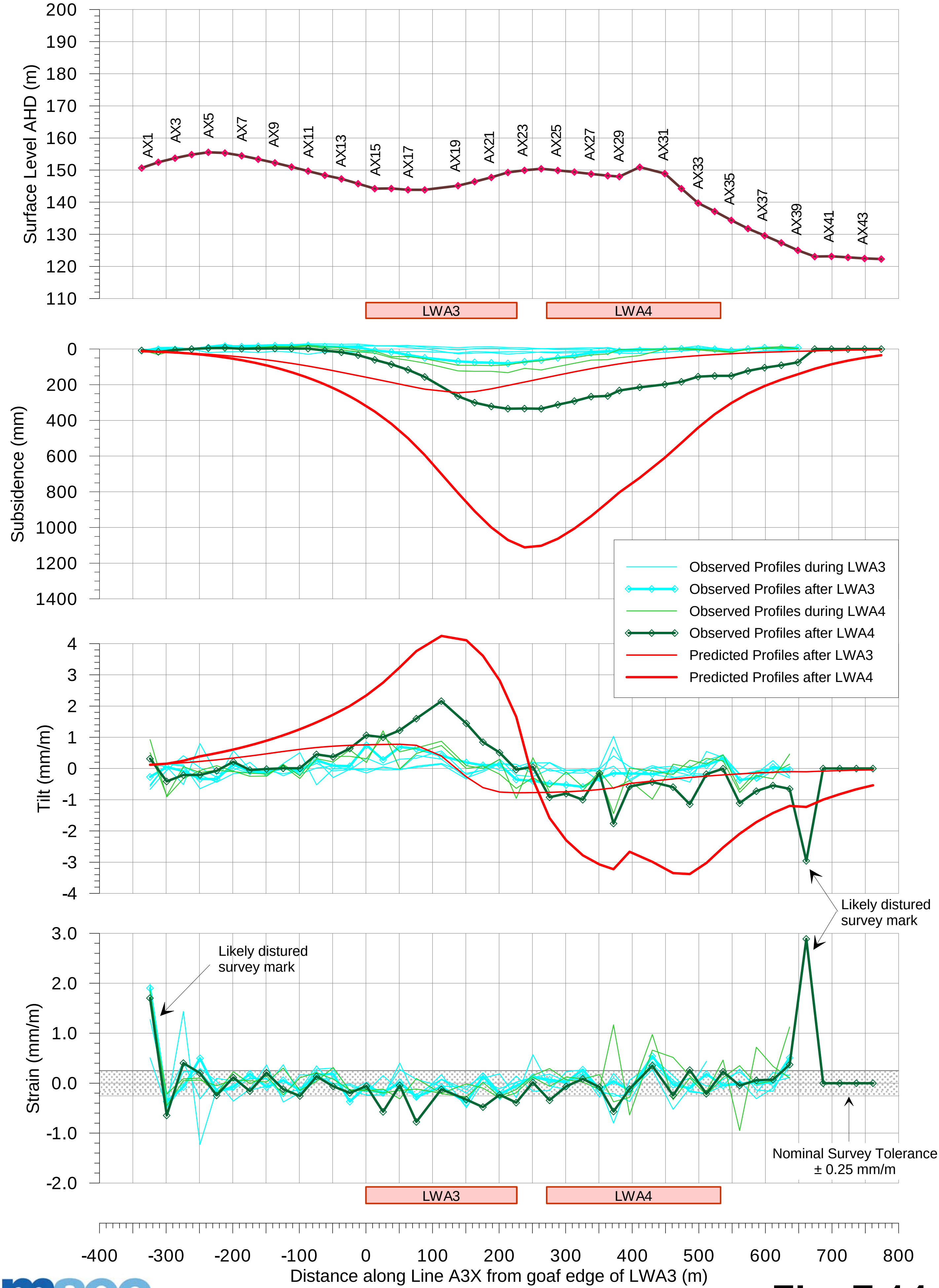
Observed and Predicted Subsidence, Tilt and Strain Resulting from Longwall A3 along Monitoring Line A3



msec

Fig. F.13

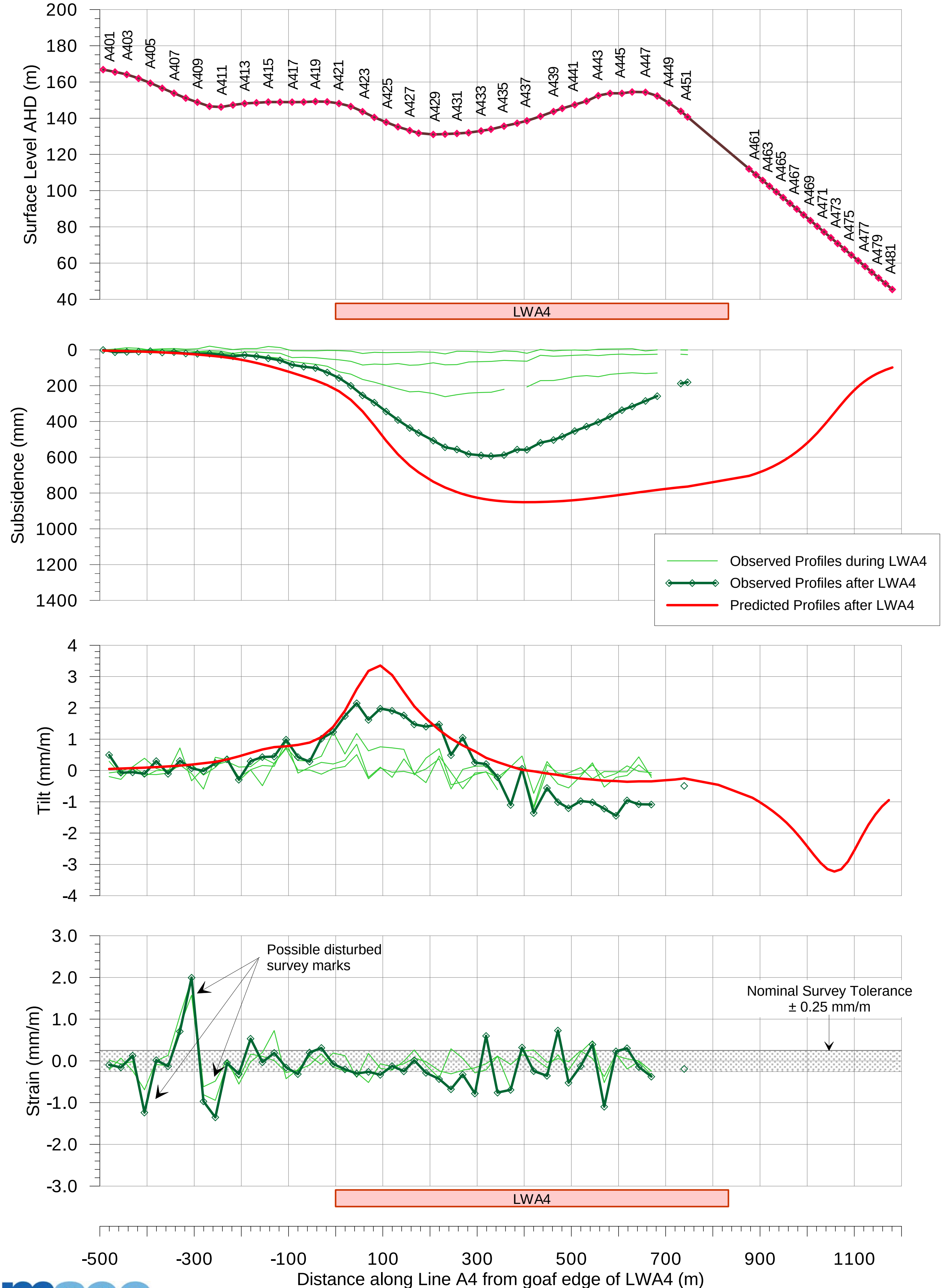
Observed and Predicted Subsidence, Tilt and Strain Resulting from Longwall A3 along Monitoring Line A3X



msec

Fig. F.14

Observed and Predicted Subsidence, Tilt and Strain Resulting from Longwall A4 along Monitoring Line A4



msec

Fig. F.15