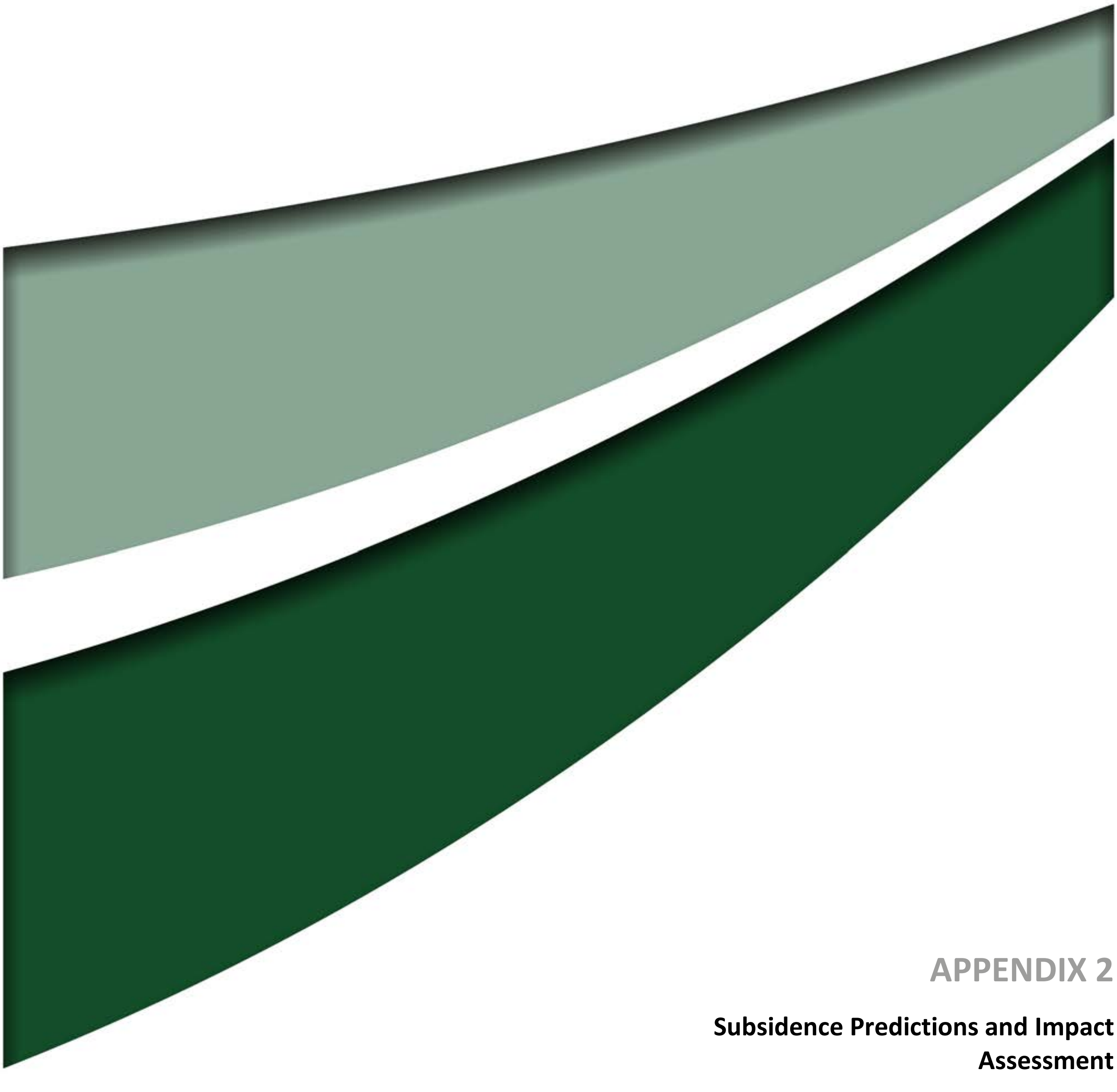

APPENDIX 2

Subsidence Predictions and Impact Assessment

REPORT: SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

Austar Coal Mine:

Longwalls B4 to B7

Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Modification Application for Longwalls B4 to B7 at the Austar Coal Mine

DOCUMENT REGISTER

Revision	Description	Author	Checker	Date
01	Draft Issue	JB	-	9th Feb 17
02	Draft Issue	JB	PD	4th Apr 17
A	Final Issue	JB	PD	10th Apr 17

Report produced to: Support the Modification Application for Longwalls B4 to B7 to be issued to the Department of Planning and Environment.

Associated reports:

MSEC275 (Revision C) – The Prediction of Subsidence Parameters and the Assessment of Mine Subsidence Impacts on Natural Features and Surface Infrastructure Resulting from the Extraction of Proposed Austar Longwalls A3 to A5 in Support of a SMP Application (February 2007).

MSEC417 (Revision C) – The Prediction of Subsidence Parameters and the Assessment of Mine Subsidence Impacts on Natural Features and Surface Infrastructure Resulting from the Extraction of the Proposed Longwall A5A in Stage 2 at the Austar Coal Mine (July 2010).

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).

MSEC484 (Revision A) – 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 (May 2011).

MSEC769 (Revision A) – Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Environmental Assessment for a Section 75W Modification Application for the Inclusion of the Proposed Longwalls B1 to B3 at the Austar Coal Mine (October 2015).

MSEC833 (Revision A) – Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan for Longwalls B1 to B3 at the Austar Coal Mine (April 2016).

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)

EXECUTIVE SUMMARY

Austar Coal Mine Pty Limited (Austar) has completed the extraction of Longwalls A1 and A2 in Stage 1, Longwalls A3 to A5A in Stage 2 and Longwalls A7 and A8 in Stage 3 of the Austar Coal Mine (the Mine) using Longwall Top Coal Caving (LTCC) mining techniques. Austar has approval to extract Longwalls B1 to B3 in the Bellbird South mining Area and, to date, has completed the extraction of Longwall B2 using conventional longwall mining techniques.

Austar is seeking approval to modify the existing Development Consent (DA 29/95) under Section 75W of the EP&A Act, to facilitate the extraction of four additional longwalls in the Bellbird South mining area, referred to as Longwalls B4 to B7 (LWB4 to LWB7), using conventional longwall mining techniques. The proposed longwalls are located immediately to the north-west of the approved Longwalls B1 to B3 and is a continuation of that series. The locations of the existing and the proposed longwalls in the Greta Seam are shown in Drawing No. MSEC869-01.

The predicted conventional subsidence parameters for the proposed longwalls have been obtained using the Incremental Profile Method. The subsidence model has been calibrated and reviewed using the available ground monitoring data above the previously extracted longwalls at the Mine. The maximum predicted mine subsidence movements due to the extraction of the proposed Longwalls B4 to B7 are: 1,350 mm vertical subsidence; 5.5 mm/m tilt (i.e. 0.55 %, or 1 in 180); 0.05 km^{-1} hogging curvature (20 km minimum radius) and 0.06 km^{-1} sagging curvature (17 km minimum radius).

The Study Area has been defined, as a minimum, as the surface area enclosed by a 26.5° angle of draw line from the extents of the proposed Longwalls B4 to B7 and by the predicted additional 20 mm subsidence contour resulting from the extraction of these proposed longwalls. Other features that could be subjected to far-field or valley related movements and could be sensitive to such movements have also been assessed in this report.

A number of natural and built features have been identified within or in the vicinity of the Study Area including: Quorrobolong Creek and ephemeral drainage lines; Sandy Creek Road and Barraba Lane; box culverts and circular culverts; 11 kV powerlines; copper telecommunications cables; rural structures; farm dams; archaeological sites; survey control marks; and houses.

The surface deformations due to the extraction of Longwalls B4 to B7 are expected to be of a minor nature, with crack widths typically less than 10 to 25 mm. No significant or visible surface cracking has been observed above the previously extracted Longwalls A3 to A8 in Stages 2 and 3 and Longwall B2 in the Bellbird South mining area. The built features have been assessed to experience only slight or minor impacts and they are expected to remain in safe and serviceable conditions throughout the mining period.

The assessments provided in this report indicate that the levels of impact on the natural and built features 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 features 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.

Built Features Management Plans have previously been developed for the approved Longwalls B1 to B3. It is recommended that these management plans are reviewed and updated, as required, to incorporate the proposed Longwalls B4 to B7. 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

1.0 INTRODUCTION 1
1.1. Background 1
1.2. Mining geometry 2
1.3. Surface and seam levels 3
1.4. Geological details 3
2.0 IDENTIFICATION OF SURFACE FEATURES 6
2.1. Definition of the Study Area 6
2.2. Natural features and items of surface infrastructure within the Study Area 6
3.0 OVERVIEW OF MINE SUBSIDENCE AND THE METHOD USED TO PREDICT THE MINE SUBSIDENCE PARAMETERS FOR THE LONGWALLS 9
3.1. Introduction 9
3.2. Overview of conventional subsidence parameters 9
3.3. Far-field movements 10
3.4. Overview of non-conventional subsidence movements 10
  3.4.1. Non-conventional subsidence movements due to changes in geological conditions 10
  3.4.2. Non-conventional subsidence movements due to steep topography 11
  3.4.3. Valley related movements 11
3.5. The Incremental Profile Method 12
3.6. Calibration and review of the Incremental Profile Method at Austar Coal Mine 13
4.0 MAXIMUM PREDICTED SUBSIDENCE PARAMETERS FOR THE LONGWALLS 20
4.1. Introduction 20
4.2. Maximum predicted conventional subsidence, tilt and curvature 20
4.3. Comparisons of the maximum predicted subsidence parameters 21
4.4. Predicted strains 22
  4.4.1. Analysis of strains measured in survey bays 23
  4.4.2. Analysis of strains measured along whole monitoring lines 25
4.5. Predicted conventional horizontal movements 25
4.6. Predicted far-field horizontal movements 26
4.7. General discussion on mining induced ground deformations 27
4.8. Estimated height of the fractured zone 29
5.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE NATURAL FEATURES 31
5.1. Natural Features 31
5.2. Streams 31
  5.2.1. Descriptions of the streams 31
  5.2.2. Predictions for the streams 32
  5.2.3. Impact assessments for the streams 34
  5.2.4. Recommendations for the streams 35
5.3. Aquifers and known groundwater resources 35
5.4. Steep slopes 35
5.5. Land prone to flooding and inundation 35
5.6. Swamps, wetlands and water related ecosystems 36

5.7. Natural vegetation 36

6.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE BUILT FEATURES 37

6.1. Public roads 37
- 6.1.1. Descriptions of the roads 37
- 6.1.2. Predictions for the roads 37
- 6.1.3. Impact Assessments for the roads 38
- 6.1.4. Recommendations for the Roads 39

6.2. Road bridges 39

6.3. Road drainage culverts 39
- 6.3.1. Descriptions of the road drainage culverts 39
- 6.3.2. Predictions for the road drainage culverts 40
- 6.3.3. Impact assessments for the road drainage culverts 40
- 6.3.4. Recommendations for the Road Drainage Culverts 41

6.4. Electrical infrastructure 41
- 6.4.1. Descriptions of the electrical infrastructure 41
- 6.4.2. Predictions for the electrical infrastructure 41
- 6.4.3. Impact assessments for the electrical infrastructure 42
- 6.4.4. Recommendations for the Electrical Infrastructure 42

6.5. Telecommunications infrastructure 43
- 6.5.1. Description of the telecommunications infrastructure 43
- 6.5.2. Predictions for the telecommunications infrastructure 43
- 6.5.3. Impact assessments for the telecommunications infrastructure 44
- 6.5.4. Recommendations for Telecommunications Infrastructure 44

6.6. Agricultural utilisation 44

6.7. Rural structures 45
- 6.7.1. Descriptions of the rural structures 45
- 6.7.2. Predictions for the rural structures 45
- 6.7.3. Impact assessments for the rural structures 45
- 6.7.4. Recommendations for the rural structures 46

6.8. Gas and fuel storages 46

6.9. Farm fences 47

6.10. Farm dams 47
- 6.10.1. Descriptions of the farm dams 47
- 6.10.2. Predictions for the farm dams 47
- 6.10.3. Impact assessments for the farm dams 48
- 6.10.4. Recommendations for the farm dams 49

6.11. Groundwater bores 49

6.12. Archaeological sites 50

6.13. Survey control marks 50

6.14. Houses 51
- 6.14.1. Descriptions of the houses 51
- 6.14.2. Predictions for the houses 51
- 6.14.3. Impact assessments for the houses 52

6.14.4. Recommendations for the houses 52

6.15. Pools 53

6.16. On-site waste water systems 53

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS 54

APPENDIX B. REFERENCES 57

APPENDIX C. FIGURES 59

APPENDIX D. TABLES 60

APPENDIX E. DRAWINGS 61

LIST OF TABLES, FIGURES AND DRAWINGS

Tables

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

Table No.	*Description*	*Page*
Table 1.1	Geometry of the proposed Longwalls B4 to B7	2
Table 1.2	Stratigraphy of the Newcastle Coalfield (after Ives et al, 1999, Moelle & Dean-Jones, 1995, Lohe & Dean-Jones, 1995, Sloan & Allan, 1995)	4
Table 2.1	Natural and built features	8
Table 4.1	Maximum predicted incremental conventional vertical subsidence, tilt and curvature due to the extraction of each of the longwalls	20
Table 4.2	Maximum predicted total conventional vertical subsidence, tilt and curvature after the extraction of each of the proposed longwalls	20
Table 4.3	Comparison of the maximum predicted total conventional subsidence parameters within the Bellbird South mining area	21
Table 4.4	Comparison of the maximum predicted total conventional subsidence parameters with the existing and approved longwalls in Stages 2 and 3 at the Mine	21
Table 4.5	Mine geometry for previously extracted longwalls at the Austar Coal Mine	22
Table 4.6	Predicted strains directly above Longwalls B4 to B7 (i.e. above goaf)	24
Table 4.7	Predicted strains outside Longwalls B4 to B7 (i.e. above solid coal)	25
Table 5.1	Maximum predicted total vertical subsidence, tilt and curvature for Quorrobolong Creek	33
Table 5.2	Maximum predicted total vertical subsidence, tilt and curvature for Drainage Line 1	33
Table 6.1	Maximum predicted total vertical subsidence, tilt and curvature for Sandy Creek Road	38
Table 6.2	Maximum predicted total vertical subsidence, tilt and curvature for the drainage culverts	40
Table 6.3	Maximum predicted total vertical subsidence and tilt for the 11 kV powerlines	42
Table 6.4	Maximum predicted total vertical subsidence, tilt and curvature for the copper telecommunications cables	43
Table 6.5	Maximum predicted total vertical subsidence, tilt and curvature for the rural structures	45
Table 6.6	Maximum predicted total vertical subsidence, tilt and curvature for the farm dams	48
Table 6.7	Registered groundwater bores within the Study Area	49
Table 6.8	Maximum predicted total vertical subsidence, tilt and curvature for the archaeological sites located within the Study Area	50
Table 6.9	Descriptions of the houses	51
Table 6.10	Maximum predicted total vertical subsidence, tilt and curvature for the houses	51
Table D.01	Maximum predicted subsidence parameters for the rural structures within the Study Area	App. D
Table D.02	Maximum predicted subsidence parameters for the farm dams within the Study Area	App. D
Table D.03	Maximum predicted subsidence parameters for the houses within the Study Area	App. D

Figures

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

Figure No.	*Description*	*Page*
Fig. 1.1	Aerial photograph showing the proposed Longwalls B4 to B7	2
Fig. 1.2	Surface and seam levels along Cross-section 1	3
Fig. 1.3	Surface lithology within the Study Area Geological Series Sheet Quorrobolong 9132-2-S (DMR, 1988)	5
Fig. 2.1	The proposed Longwalls B4 to B7 and the Study Area overlaid on CMA Map No. Quorrobolong 9132-2-S	7
Fig. 3.1	Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)	11

Fig. 3.2 Observed and predicted profiles of subsidence, tilt and strain along Line 1B above Longwalls A1 and A2 in Stage 1 14
Fig. 3.3 Observed and predicted profiles of subsidence, tilt and strain along Line A3X above Longwalls A3 to A5A in Stage 2 15
Fig. 3.4 Observed and predicted profiles of subsidence, tilt and strain along Line XL3 above Longwalls A7 and A8 in Stage 3 16
Fig. 3.5 Observed and predicted profiles of subsidence, tilt and strain along the Crossline above Longwall B2 in the Bellbird South Mining Area 17
Fig. 3.6 Observed and predicted profiles of subsidence, tilt and strain along Line B2 above Longwall B2 in the Bellbird South Mining Area 18
Fig. 4.1 Distributions of the measured maximum tensile and compressive strains during the extraction of previous longwalls for survey bays located above goaf 23
Fig. 4.2 Distributions of the measured maximum tensile and compressive strains during the extraction of previous longwalls for survey bays located above solid coal 24
Fig. 4.3 Distributions of measured maximum tensile and compressive strains along the monitoring lines during the extraction of previous longwalls 25
Fig. 4.4 Observed incremental far-field horizontal movements 26
Fig. 4.5 Example of surface tensile cracking in the natural ground surface (observed in the Southern Coalfield at a similar depth of cover as in the Study Area) 28
Fig. 4.6 Example of surface compression buckling observed in road pavement (observed in the southern coalfield at a similar depth of cover as the Study Area) 28
Fig. 4.7 Zones in the overburden according to Forster (1995) 29
Fig. 4.8 Zones in the overburden according to Peng and Chiang (1984) 29
Fig. 5.1 Quorrobolong Creek 32
Fig. 5.2 Typical drainage lines within the Study Area 32
Fig. 5.3 Natural and predicted post-mining levels and grades along Quorrobolong Creek 34
Fig. 5.4 Natural and predicted post-mining levels and grades along Drainage Line 1 34
Fig. 6.1 Sandy Creek Road (left side) and Barraba Lane (right side) 37
Fig. 6.2 Box culverts SCR-C1 (left side) and SCR-C2 (Right) 39
Fig. 6.3 Box culvert SCR-C3 (left side) and concrete culvert SCR-C4 (right side) 39
Fig. 6.4 11 kV Powerlines 41

Fig. C.01 Predicted profiles of conventional subsidence, tilt and curvature along Prediction Line 1 resulting from the extraction of Longwalls B1 to B7 App. C
Fig. C.02 Predicted profiles of conventional subsidence, tilt and curvature along Quorrobolong Creek resulting from the extraction of Longwalls B1 to B7 App. C
Fig. C.02 Predicted profiles of conventional subsidence, tilt and curvature along Drainage Line 1 resulting from the extraction of Longwalls B1 to B7 App. C
Fig. C.04 Predicted profiles of conventional subsidence, tilt and curvature along Sandy Creek Road resulting from the extraction of Longwalls B1 to B7 App. C
Fig. C.05 Predicted profiles of conventional subsidence, tilt along and tilt across the 11 kV Powerline Branch 1 resulting from the extraction of Longwalls B1 to B7 App. C
Fig. C.06 Predicted profiles of conventional subsidence, tilt along and tilt across the 11 kV Powerline Branch 2 resulting from the extraction of Longwalls B1 to B7 App. C

Drawings

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

Drawing No.	*Description*	*Revision*
MSEC869-01	Overall layout and monitoring	A
MSEC869-02	Layout of Longwalls B1 to B7	A
MSEC869-03	Surface level contours	A
MSEC869-04	Seam floor contours	A
MSEC869-05	Seam thickness contours	A
MSEC869-06	Depth of cover contours	A
MSEC869-07	Natural features	A
MSEC869-08	Surface infrastructure	A
MSEC869-09	Built features	A
MSEC869-10	Predicted additional subsidence contours due to LWB4 to LWB7	A
MSEC869-11	Predicted total subsidence contours due to LWB1 to LWB7	A
MSEC869-12	Predicted total subsidence contours due to LWB1 to LWB7 and existing longwalls	A

1.1. Background

Austar Coal Mine Pty Limited (Austar, the Mine) is located in the Newcastle Coalfield, approximately 10 km south-west of the township of Cessnock. The Mine has completed the extraction of Longwalls A1 and A2 in Stage 1, Longwalls A3 to A5A in Stage 2 and Longwalls A7 and A8 in Stage 3 using longwall top coal caving mining techniques. Austar has approval to extract the future Longwalls A9 to A19 in Stage 3 at the Mine.

Austar has approval for the extraction of Longwalls B1 to B3 (LWB1 to LWB3) using conventional longwall mining techniques within the Bellbird South mining area. These longwalls are located to the south of the previously extracted longwalls in Stage 2 at the Mine and to the east of the existing Longwalls 1 to 9A at the Ellalong Colliery. At the time of this report, the Mine had completed the extraction of Longwall B2 and is in the process of extracting Longwall B3.

Mine Subsidence Engineering Consultants (MSEC) was previously commissioned by Austar to prepare subsidence predictions and impact assessments for Longwalls B1 to B3. Report Nos. MSEC769 (Rev. A) and MSEC833 (Rev. A) which supported the Modification Application and the Extraction Plan for these longwalls.

Austar is seeking approval to modify the existing Development Consent (DA 29/95) under Section 75W of the EP&A Act, to facilitate the extraction of four additional longwalls in the Bellbird South mining area, referred to as Longwalls B4 to B7 (LWB4 to LWB7). The proposed longwalls are located on the north-western side of the approved Longwalls B1 to B3 and are a continuation of this longwall series. The locations of the approved and the proposed longwalls at the Mine are shown in Drawing No. MSEC869-01.

MSEC has now been commissioned by Austar to provide:

- subsidence predictions for Longwalls B4 to B7, including the cumulative movements due to the previously extracted and approved adjacent longwalls;
- subsidence predictions for each of the natural and built features in the mining area;
- impact assessments, in conjunction with other specialist consultants, for each of these natural and built features; and
- recommended management strategies and monitoring for Longwalls B4 to B7.

This report has been prepared to support the Modification Application for Longwalls B4 to B7 which will be submitted to the Department of Planning and Environment (DP&E). In some cases, this report will refer to other sources of information on specific natural and built features. This report, therefore, should be read in conjunction with the other relevant documents associated with this application.

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 area.

Chapter 2 defines the Study Area and provides a summary of the natural and built features within this area.

Chapter 3 provides an overview of longwall mining, mine subsidence parameters and the methods that have been used to predict the mine subsidence for the longwalls.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of Longwalls B4 to B7, including the cumulative movements due to the adjacent longwalls. The predicted parameters have also been compared with those based on the approved Longwalls B1 to B3.

Chapters 5 and 6 provide the predictions and impact assessments for each of the natural and built features within the mining area. The recommended management strategies and monitoring for these features are also provided in this chapter.

The proposed Longwalls B4 to B7 and the Study Area, as defined in Section 2.1, have been overlaid on an orthophoto of the area, and is shown in Fig. 1.1. The major natural and built features in the vicinity of the proposed longwalls can be seen in this figure.

Fig. 1.1 Aerial photograph showing the proposed Longwalls B4 to B7

1.2. Mining geometry

The layout of existing, approved and proposed longwalls in the Greta Seam is shown in Drawings Nos. MSEC869-01 and MSEC869-02. A summary of the dimensions of the proposed Longwalls B4 to B7 is provided in Table 1.1.

Table 1.1 Geometry of the proposed Longwalls B4 to B7

Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
LWB4	1,125	237	45
LWB5	1,105	237	50
LWB6	1,065	237	45
LWB7	725	237	45

The widths of the longwall extraction faces (i.e. excluding the first workings) are 226 m providing overall void widths (i.e. including the first workings) of 237 m. The lengths of extraction (i.e. excluding the installation headings) are approximately 9 m less than the overall void lengths provided in the above table. The longwalls will be extracted from the south-west towards the north-east (i.e. towards the main headings).

1.3. Surface and seam levels

The natural surface and the Greta Seam are illustrated along Cross-section 1 in Fig. 1.2, which has been taken transverse to the longwalls near their mid-lengths (looking north-east). The location of this cross-section is shown in Drawing Nos. MSEC869-03 to MSEC869-05, in Appendix E.

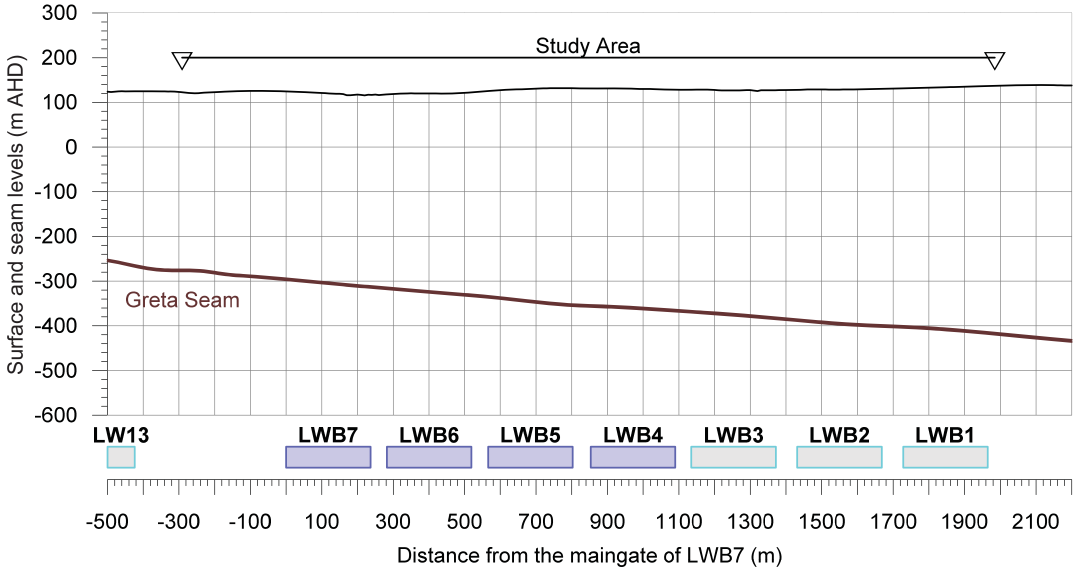

Fig. 1.2 Surface and seam levels along Cross-section 1

The surface level contours are shown in Drawing No. MSEC869-03. There are three small ridgelines located above the western, eastern and northern parts of the mining area. These ridgelines are separated by Quorrobolong Creek in the northern part of the mining area and by an unnamed drainage line in the southern part of the mining area.

The surface levels directly above the proposed longwalls vary from a high point of 160 m above Australian Height Datum (mAHD) above the commencing (i.e. south-western) end of Longwall B4, to a low point of approximately 115 mAHD along Quorrobolong Creek.

The seam floor contours, seam thickness contours and depth of cover contours for the Greta Seam are shown in Drawings Nos. MSEC869-04, MSEC869-05 and MSEC869-06, respectively. The contours are based on the latest information provided by the Mine.

The depth of cover to the Greta Seam directly above the proposed longwalls varies between a minimum of 400 m above the commencing (i.e. south-western) end of Longwall B7 and a maximum of 505 m above the finishing (i.e. north-eastern) end of Longwall B4. The seam floor within the proposed mining area dips from the west to the east, having an average gradient of around 8 %, or 1 in 12.

The thickness of the Greta Seam within the mining area varies between 3.7 and 4.8 m. It is proposed that a constant thickness of 3.4 m will be extracted using conventional longwall mining techniques.

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.

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
	Branxton		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			

Longwalls B4 to B7 will 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 m thick. The uppermost layer in the Greta Coal Measures is the Pelton Seam, which is less than 0.5 m 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 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 Department of Mineral Resources (DMR, 1988), now known as the Department of Industry – Division of Resources and Energy. It can be seen from this figure, that the surface lithology within the mining area comprises predominately of areas derived from the Branxton Formation (Pmb and Pmbf) and Quaternary alluvium (Qa).

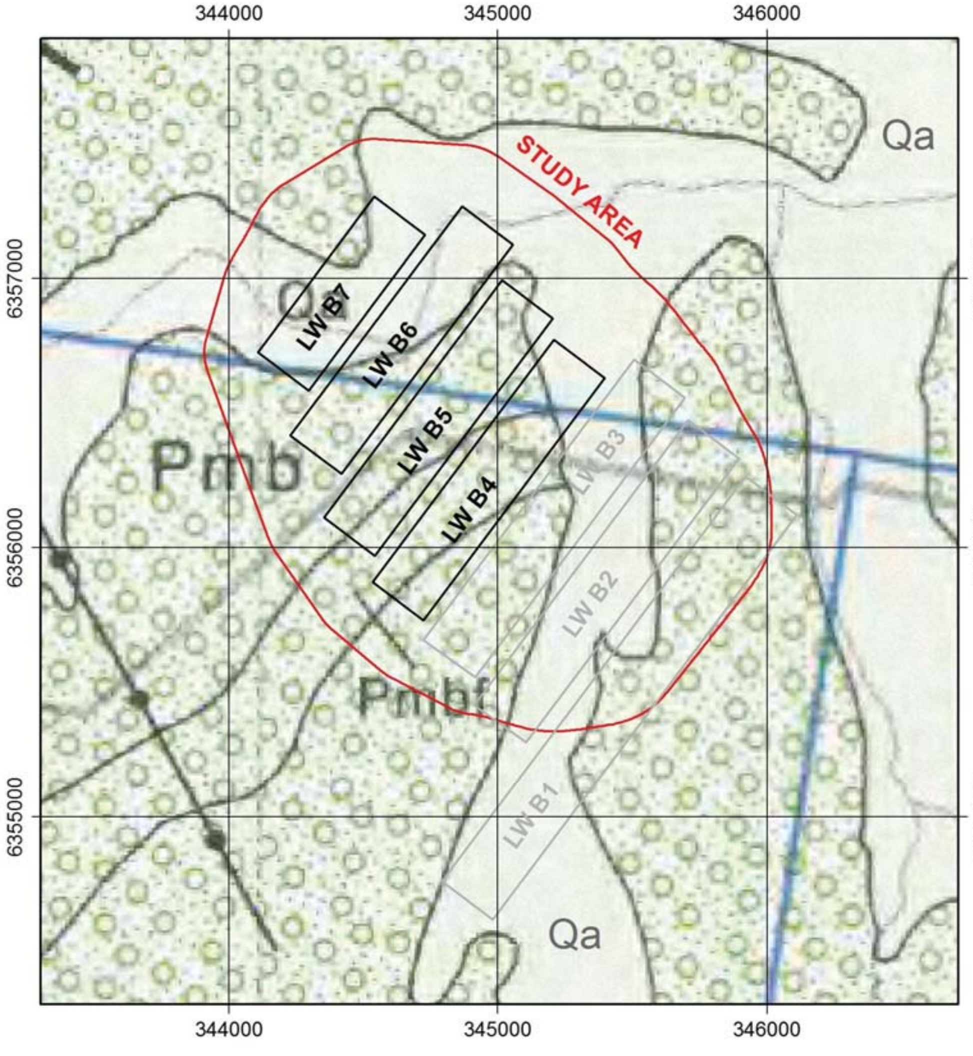

Fig. 1.3 Surface lithology within the Study Area
Geological Series Sheet Quorrobolong 9132-2-S (DMR, 1988)

The major geological zones identified at seam level are shown in Drawings Nos. MSEC869-04 and MSEC869-05. The *Swamp Fault Zone* has been identified near the finishing (i.e. north-eastern) ends of the proposed longwalls. The *Barraba Fault Zone* has also been identified adjacent to the commencing (i.e. south-western) ends of the longwalls. The nature and extents of these faulting zones will be better defined as further geological data is gathered during the development of the first workings and, if necessary, the extents of mining will be reviewed based on this information.

2.1. Definition of the Study Area

The *Study Area* is defined as the surface area that is likely to be affected by the mining of Longwalls B4 to B7 in the Greta Seam at the Mine. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:

- The 26.5° angle of draw line from the extents of Longwalls B4 to B7; and
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour resulting from the extraction of Longwalls B4 to B7.

The depth of cover contours are shown in Drawing No. MSEC869-06. The depth of cover varies between 400 and 505 m directly above the proposed Longwalls B4 to B7. The 26.5° angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 200 and 253 m around the extents of the longwall voids.

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 3.5 and 3.6. The angle of draw to the predicted total 20 mm subsidence contour has been calibrated to 30° adjacent to the longitudinal edges of the mining area (i.e. the maingate of the last longwall and tailgate of the first longwall in the series), in order to match those observed over the previously extracted longwalls at the Mine.

The predicted total 20 mm subsidence contour, therefore, is generally located outside the 26.5° angle of draw line adjacent to the longitudinal edges of the longwalls, and is generally located inside the 26.5° angle of draw line adjacent to the commencing and finishing ends of the longwalls. A line has therefore been drawn defining the Study Area, based upon the 26.5° angle of draw line and the predicted total 20 mm subsidence contour, whichever is furthest from the longwalls, and is shown in Drawings Nos. MSEC869-01 and MSEC869-02.

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.

2.2. 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 longwalls and the Study Area have been overlaid on an extract of this CMA Map and are shown in Fig. 2.1.

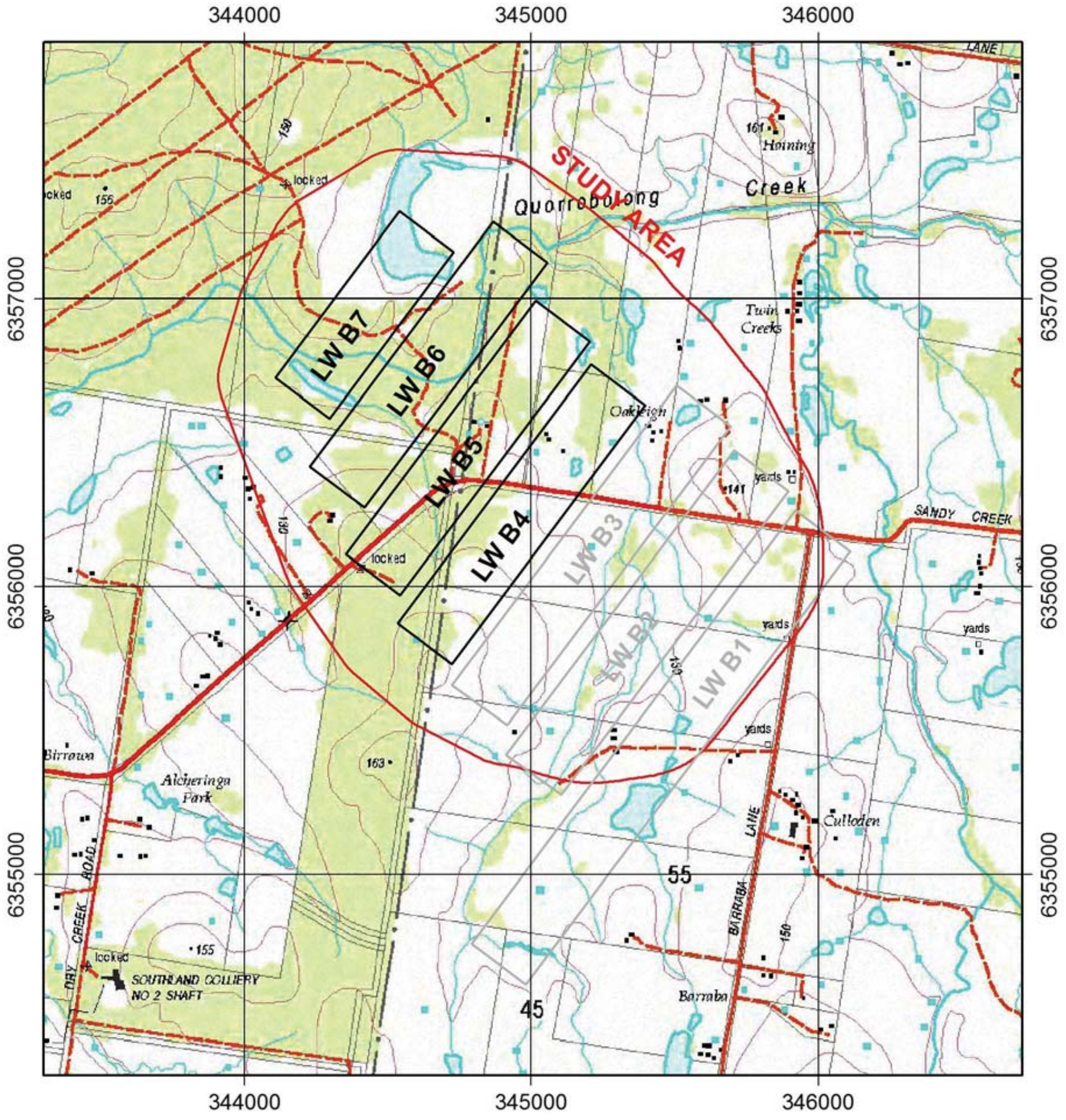

Fig. 2.1 The proposed Longwalls B4 to B7 and the Study Area overlaid on CMA Map No. Quorrobolong 9132-2-S

A summary of the natural and built features within the Study Area is provided in Table 2.1. The locations of these features are shown in Drawings Nos. MSEC869-07 to MSEC869-09. The descriptions of these features are provided in Chapters 5 and 6, as indicated by the Section number in Table 2.1.

Table 2.1 Natural and built features

Item	Within Study Area	Section number reference
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	×	
Rivers or Creeks	✓	5.2
Aquifers or Known Groundwater Resources	✓	5.3
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	×	
Steep Slopes	✓	5.4
Escarpments	×	
Land Prone to Flooding or Inundation	✓	5.5
Swamps, Wetlands or Water Related Ecosystems	✓	5.6
Threatened or Protected Species	✓	5.7
National Parks	×	
State Forests	×	
State Conservation Areas	×	
Natural Vegetation	✓	5.7
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	×	
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	✓	6.6
Farm Buildings or Sheds	✓	6.7
Tanks	✓	6.7
Gas or Fuel Storages	✓	6.8
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	✓	6.9
Farm Dams	✓	6.10
Wells or Bores	✓	6.11
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	✓	6.12
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.13
RESIDENTIAL ESTABLISHMENTS		
Houses	✓	6.14
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	✓	6.15 & 6.16
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

3.0 OVERVIEW OF MINE SUBSIDENCE AND THE METHOD USED TO PREDICT THE MINE SUBSIDENCE PARAMETERS FOR THE LONGWALLS

3.1. Introduction

This chapter provides an overview of the mine subsidence parameters and the methods that have been used to predict the mine subsidence movements resulting from the extraction of the longwalls. Further details on methods of mine subsidence prediction 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*.

3.2. 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 1,000.
- **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.

3.3. 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 4.6.

3.4. 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 m, 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 m, 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 greater 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.

3.4.1. 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 4.4 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.

3.4.2. 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 5.3.

3.4.3. 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. 3.1. The potential for these natural movements are influenced by the geomorphology of the valley.

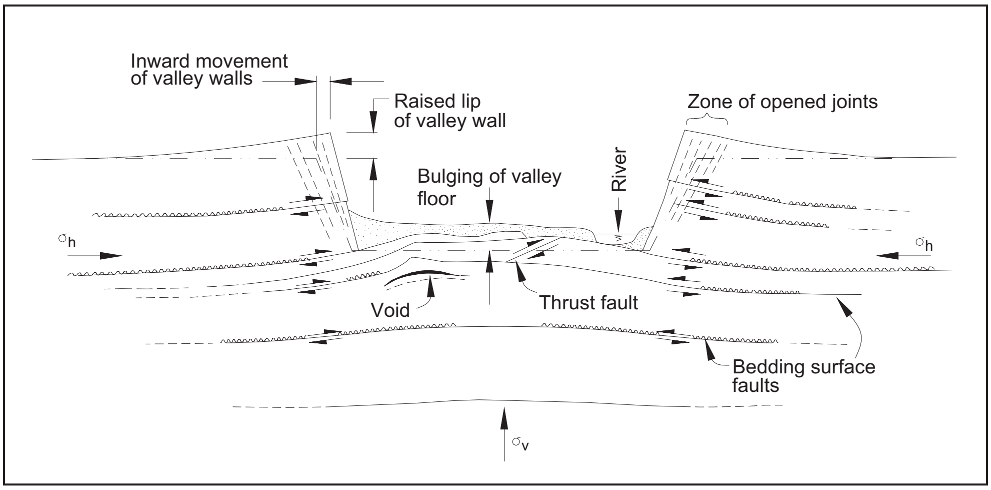

Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

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 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

3.5. The Incremental Profile Method

The Incremental Profile Method (IPM) was initially developed by Waddington Kay and Associates, now known as MSEC, as part of a study, in 1994 to assess the impacts of subsidence on particular surface infrastructure over a proposed series of longwall panels at Appin Colliery. The method evolved following detailed analyses of subsidence monitoring data from the Southern Coalfield, which was then extended to include detailed subsidence monitoring data from the Newcastle, Hunter and Western Coalfields.

The review of the detailed ground monitoring data from the New South Wales (NSW) Coalfields showed that whilst the final subsidence profiles measured over a series of longwalls were irregular, the observed incremental subsidence profiles due to the extraction of individual longwalls were consistent in both magnitude and shape and varied according to local geology, depth of cover, panel width, seam thickness, the extent of adjacent previous mining, the pillar width and stability of the chain pillar and a time-related subsidence component.

MSEC developed a series of subsidence prediction curves for the Newcastle and Hunter Coalfields, in 1996 to 1998, after receiving extensive subsidence monitoring data from Centennial Coal for the Cooranbong Life Extension Project (Waddington and Kay, 1998). The subsidence monitoring data from many collieries in the Newcastle and Hunter Coalfields were reviewed and, it was found, that the incremental subsidence profiles resulting from the extraction of individual longwalls were consistent in shape and magnitude where the mining geometries and overburden geologies were similar.

Since this time, extensive monitoring data has been gathered from the Southern, Newcastle, Hunter and Western Coalfields of NSW and from the Bowen Basin in Queensland, including: Angus Place, Appin, Awaba, Baal Bone, Bellambi, Beltana, Blakefield South, Bulga, Bulli, Burwood, Carborough Downs, Chain Valley, Clarence, Coalcliff, Cook, Cooranbong, Cordeaux, Corrimal, Cumnock, Dartbrook, Delta, Dendrobium, Donaldson, Eastern Main, Ellalong, Elouera, Fernbrook, Glennies Creek, Grasstree, Gretley, Invincible, John Darling, Kemira, Kestrel, Lambton, Liddell, Mandalong, Metropolitan, Moranbah North, Mt. Kembla, Munmorah, Nardell, Newpac, Newstan, Newvale, Newvale 2, NRE Wongawilli, Oaky Creek, Ravensworth, South Bulga, South Bulli, Springvale, Stockton Borehole, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, United, West Cliff, West Wallsend, and Wyee.

Based on the extensive empirical data, MSEC has developed standard subsidence prediction curves for the Southern, Newcastle, Hunter and Western Coalfields. The prediction curves can then be further refined, for the local geology and local conditions, based on the available monitoring data from the area. Discussions on the calibration and review of the IPM at the Mine are provided in Section 3.6.

The prediction of subsidence is a three stage process where, first, the magnitude of each increment is calculated, then, the shape of each incremental profile is determined and, finally, the total subsidence profile is derived by adding the incremental profiles from each longwall in the series. In this way, subsidence predictions can be made anywhere above or outside the extracted longwalls, based on the local surface and seam information.

For longwalls in the Newcastle and Hunter Coalfields, the maximum predicted incremental subsidence is initially determined, using the IPM subsidence prediction curves for a single isolated panel, based on the longwall void width (W) and the depth of cover (H). The incremental subsidence is then increased, using the IPM subsidence prediction curves for multiple panels, based on the longwall series, panel width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H). In this way, the influence of the panel width (W), depth of cover (H), as well as panel width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H) are each taken into account.

The shapes of the incremental subsidence profiles are then determined using the large empirical database of observed incremental subsidence profiles from the Newcastle and Hunter Coalfields. The profile shapes are derived from the normalised subsidence profiles for monitoring lines where the mining geometry and overburden geology are similar to that for the longwalls. The profile shapes can be further refined, based on local monitoring data, which is discussed further in Section 3.6.

Finally, the total subsidence profiles resulting from the series of longwalls are derived by adding the predicted incremental profiles from each of the longwalls. Comparisons of the predicted total subsidence profiles, obtained using the Incremental Profile Method, with observed profiles indicates that the method provides reasonable, if not, slightly conservative predictions where the mining geometry and overburden geology are within the range of the empirical database. The method can also be further tailored to local conditions where observed monitoring data is available close to the mining area.

3.6. Calibration and review of the Incremental Profile Method at Austar Coal Mine

The IPM was originally calibrated for the local conditions at the Mine during the preparation of the Subsidence Management Plan Application for Longwalls A3 to A5 in Stage 2, which was discussed in Section 3.4.1 of Report No. MSEC275.

The calibration was based on the available ground monitoring data at that time, which included: eight monitoring lines above Longwalls SL1 to SL4 and Longwalls 1 to 13A at Ellalong Colliery; and three monitoring lines above Longwalls A1 and A2 in Stage 1 of the Mine.

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 standard IPM was not modified for the presence of any thick massive strata units, which can reduce the sag subsidence directly above the extracted longwalls.

It was found that the values of maximum observed incremental subsidence for the previously extracted longwalls along each of the monitoring lines were less than the values of maximum back-predicted incremental subsidence obtained using the standard 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.

The reason that the observed subsidence profiles were wider 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. 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° adjacent to the longitudinal edges of the mining area, to match those observed over the previously extracted longwalls at the colliery.

Subsequent to the calibration undertaken as part of Report No. MSEC275, Austar has extracted Longwalls A3 to A5A in Stage 2, Longwalls A7 and A8 in Stage 3 and Longwall B2 in the Bellbird South mining area. The mine subsidence movements have been monitored along four monitoring lines in above Longwalls A3 to A5A, four monitoring lines above Longwalls A7 and A8 and three monitoring lines above Longwall B2. The comparisons between the observed and predicted movements have been provided in the End of Panel subsidence review reports for each of these longwalls.

The comparisons between the observed and predicted subsidence, tilt and strain have been provided for: Line 1B above Longwalls A1 and A2 in Fig. 3.2; Line A3X above Longwalls A3 to A5A in Fig. 3.3; Line XL3 above Longwalls A7 and A8 in Fig. 3.4; the Crossline above Longwall B2 in Fig. 3.5; and Line B2 above Longwall B2 in Fig. 3.6.

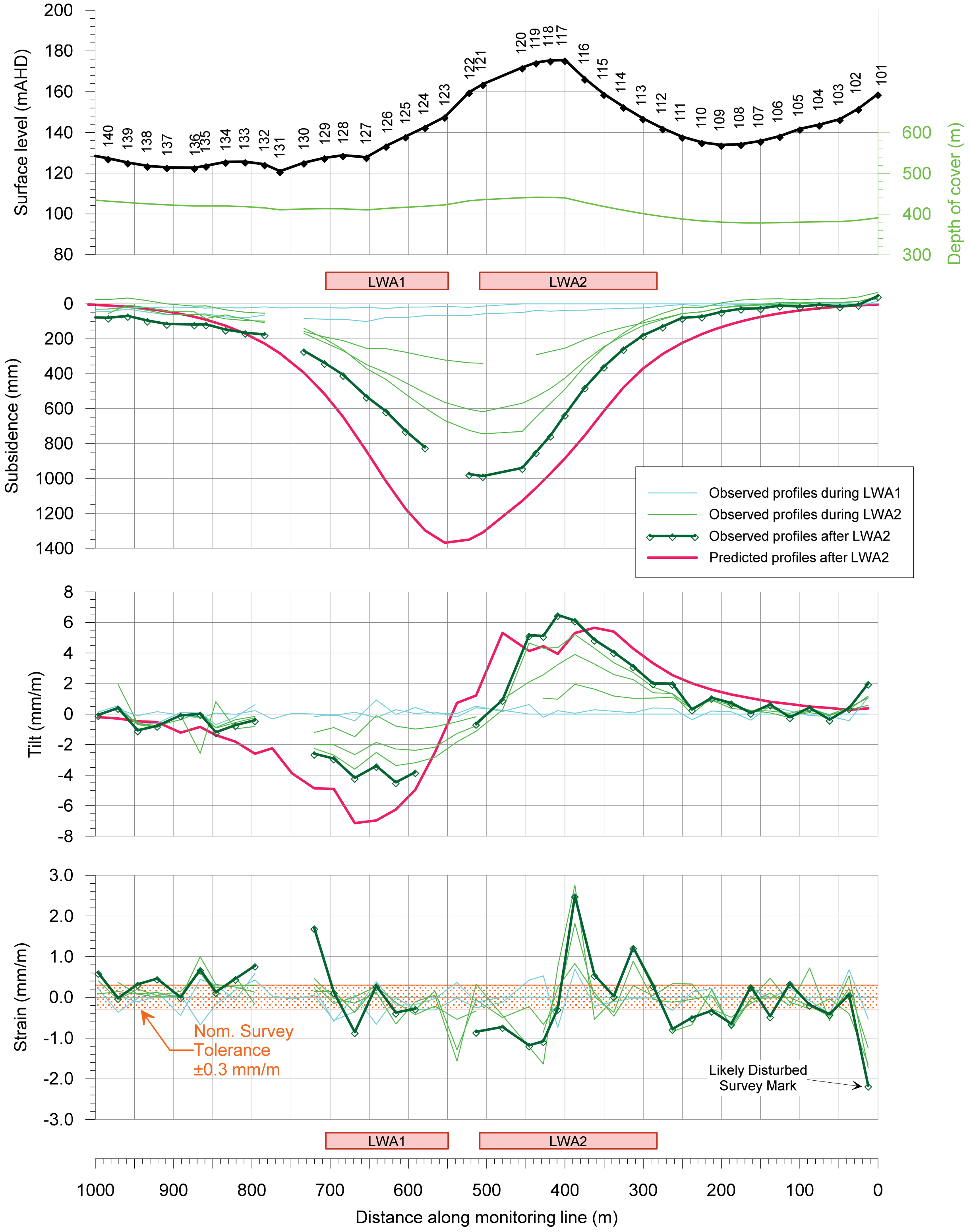

Fig. 3.2 Observed and predicted profiles of subsidence, tilt and strain along Line 1B above Longwalls A1 and A2 in Stage 1

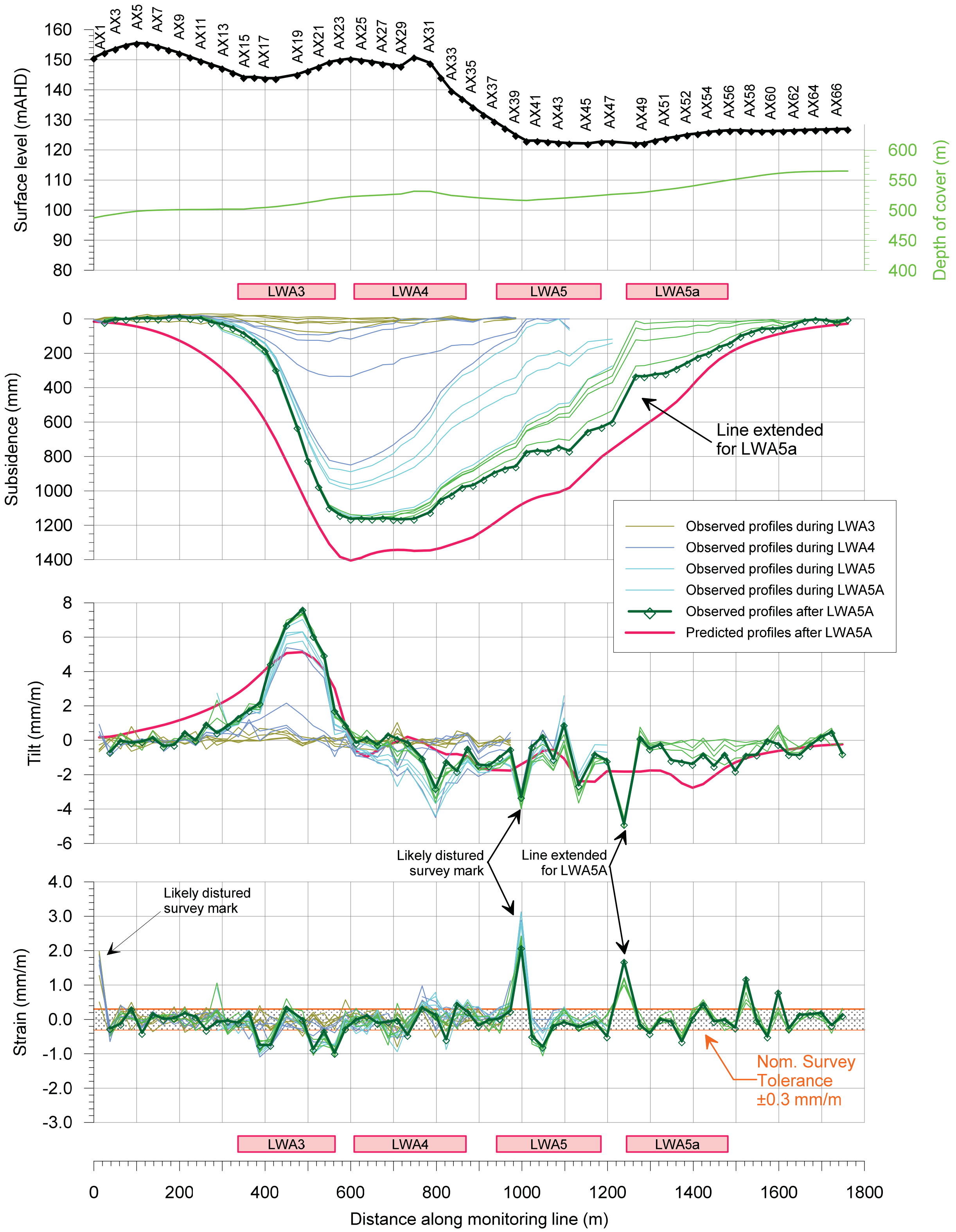

Fig. 3.3 **Observed and predicted profiles of subsidence, tilt and strain along Line A3X above Longwalls A3 to A5A in Stage 2**

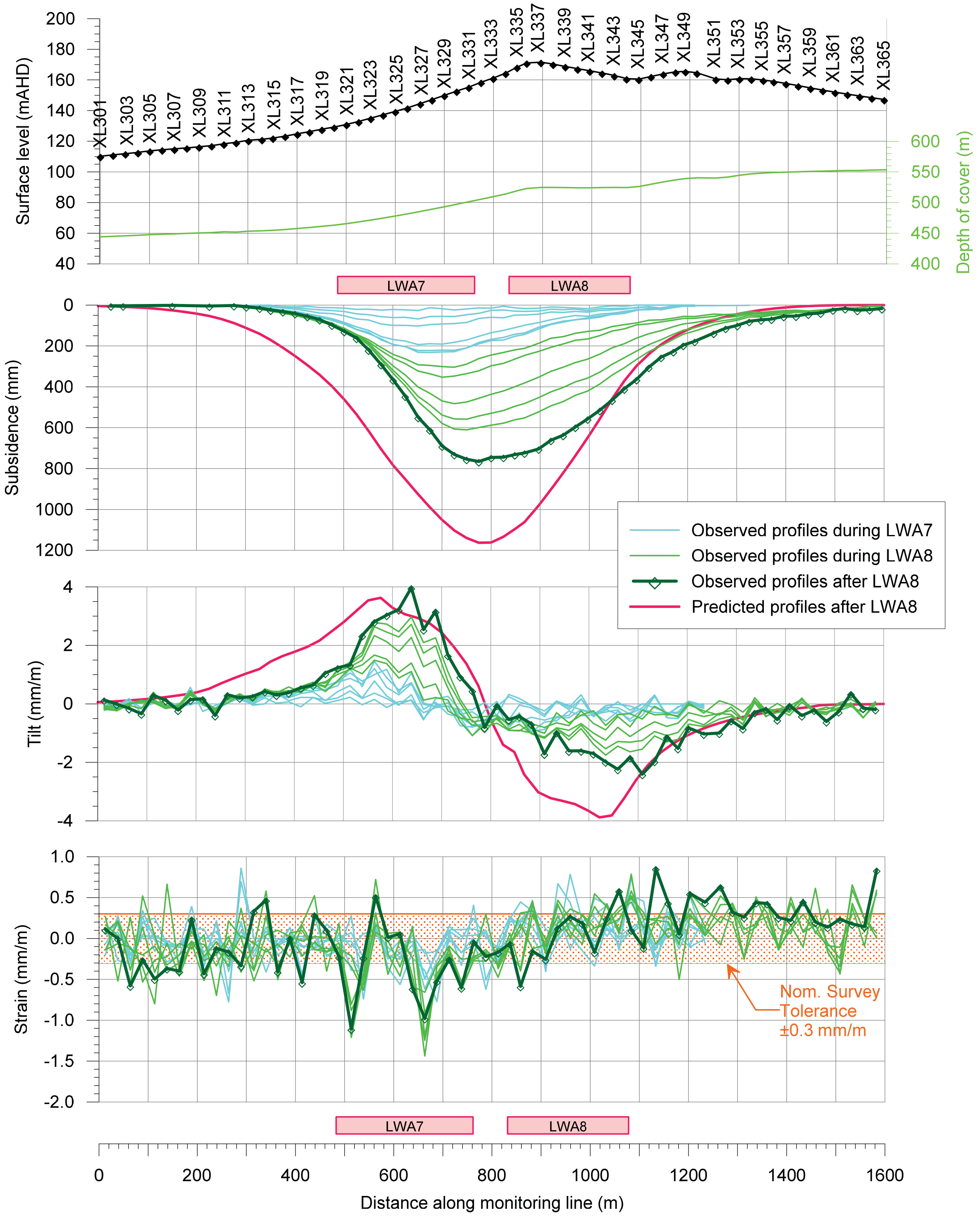

Fig. 3.4 **Observed and predicted profiles of subsidence, tilt and strain along Line XL3 above Longwalls A7 and A8 in Stage 3**

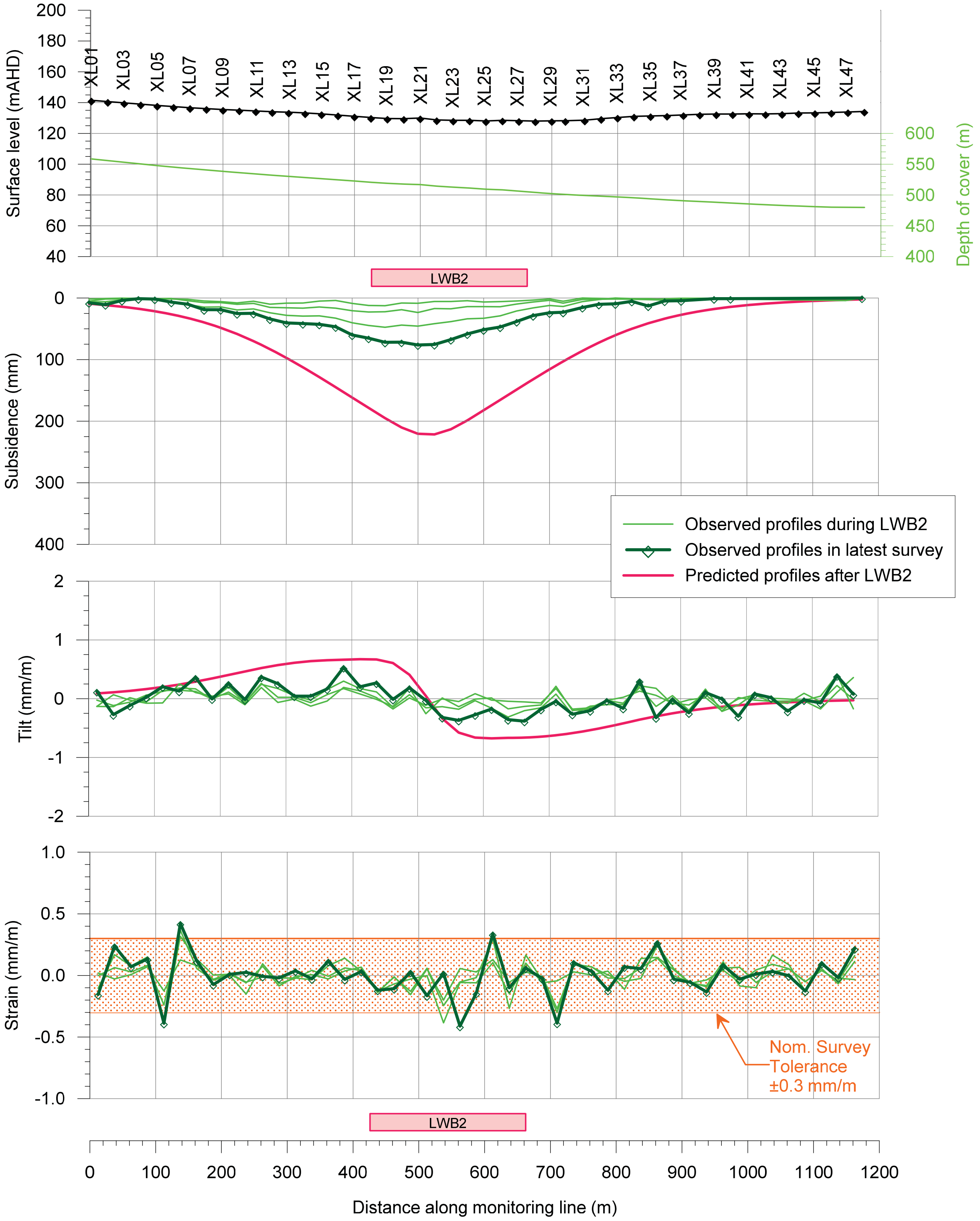

Fig. 3.5 **Observed and predicted profiles of subsidence, tilt and strain along the Crossline above Longwall B2 in the Bellbird South Mining Area**

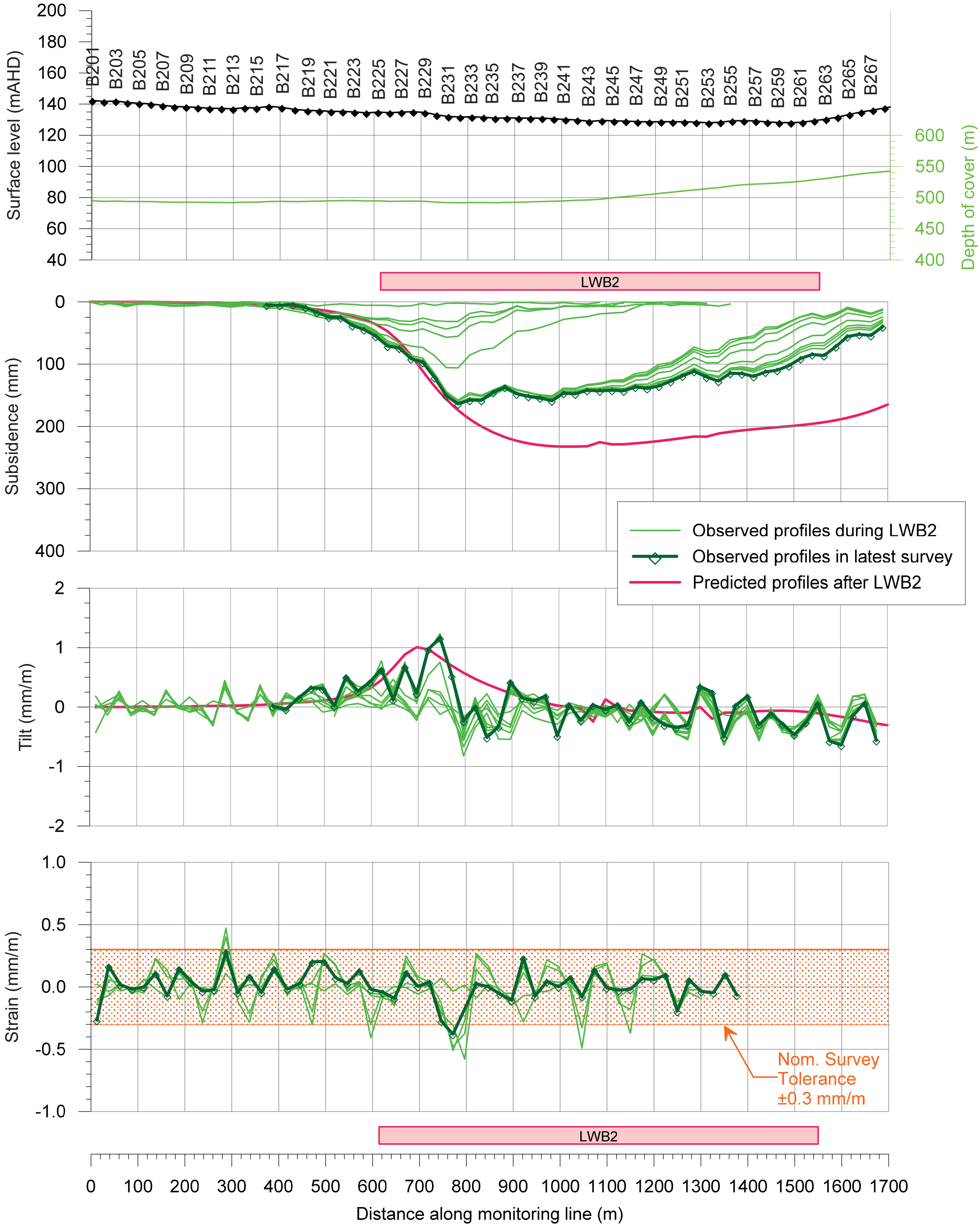

Fig. 3.6 **Observed and predicted profiles of subsidence, tilt and strain along Line B2 above Longwall B2 in the Bellbird South Mining Area**

It can be seen from Fig. 3.2 to Fig. 3.6, that the maximum observed vertical subsidence along these monitoring lines are less than the maxima predicted using the calibrated Incremental Profile Method. The percentages of the maximum observed to maximum predicted vertical subsidence are 75 % for Line 1B, 83 % for Line A3X, 66 % for Line XL3, 34 % for the Crossline and 70 % for Line B2. The IPM has provided conservative predictions of vertical subsidence as no subsidence reduction factor has been applied due to the presence of the massive Branxton Formation within the overburden.

The observed vertical subsidence slightly exceeds the predicted vertical subsidence outside the extents of the extracted longwalls adjacent to the tailgate of Longwall A1 (see Fig. 3.2), adjacent to the maingate of Longwall A8 (see Fig. 3.4) and adjacent to the commencing end of Longwall B2 (see Fig. 3.6). This low level vertical subsidence, however, is not associated with any significant observed tilts, curvatures or strains and impacts are not anticipated outside the extents of the extracted longwalls.

The shapes of the observed vertical subsidence profiles reasonably match the predicted profiles. The maximum observed tilts are generally less than the maxima predicted. However, the maximum observed tilt along Line A3X (see Fig. 3.3) of 7.6 mm/m is greater than the maximum predicted of 5.1 mm/m. It has been considered that the higher observed tilt is associated with the reduced subsidence above solid coal which may be the result of stronger strata cantilevering and reducing the subsidence over the tailgate of Longwall A3.

The maximum observed tilt along Line B2 (see Fig. 3.6) of 1.2 mm/m is slightly greater than the maximum predicted of 1.0 mm/m. This exceedance is very small and is within the order of accuracy of the prediction method and the survey tolerance. Localised and elevated tilts have also observed in other locations along the monitoring lines, which exceeded the predictions, however, it is likely that many of these have occurred as the result of disturbed survey marks, as they occurred outside of the extents of the longwalls.

The observed strains are typically less than those expected based on conventional ground movements, which are 1 mm/m tensile and 2 mm/m compressive. A localised tensile strain of 3.1 mm/m has occurred along Line 1B (see Fig. 3.2) which is considered to have been influenced by top of hill effects. Localised tensile strains between 1 mm/m and 2 mm/m have also occurred along Line A3X (see Fig. 3.3), which are likely the result of disturbed survey marks.

It is considered that the calibrated IPM has provided reasonable, if not, conservative predictions for the monitoring lines above the longwalls extracted in Stages 1 to 3 and in the Bellbird South mining area. It has not been considered necessary to undertake any further refinement of the subsidence prediction model based on the available results. It is expected that the calibrated IPM would provide reasonable, if not, slightly conservative predictions for the Longwalls B4 to B7.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of Longwalls B4 to B7. The predicted subsidence parameters and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

The predicted subsidence, tilt and curvature have been obtained using the Incremental Profile Method, which has been calibrated and reviewed based on the local mining conditions, as described in Sections 3.5 and 3.6. The predicted strains have been determined by analysing the strains measured at the Mine.

The maximum predicted subsidence parameters and the predicted subsidence contours provided in this report describe and 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 and 6.

4.2. Maximum predicted conventional subsidence, tilt and curvature

The predicted additional conventional subsidence contours, due to the extraction of the proposed Longwalls B4 to B7 only, are shown in Drawing No. MSEC869-10. These contours represent the additional movements after the completion of Longwall B3, but include the influence of the previous extracted Longwalls B1 to B3.

The predicted total conventional subsidence contours, due to the extraction of Longwalls B1 to B7, are shown in Drawing No. MSEC869-11. The predicted total subsidence contours including the adjacent existing and approved longwalls at Ellalong and Austar Mines are shown in Drawing No. MSEC869-12.

A summary of the maximum predicted values of incremental conventional vertical subsidence, tilt and curvature due to the extraction of each of the proposed longwalls is provided in Table 4.1. The incremental values are the additional movements due to each proposed longwall.

Table 4.1 Maximum predicted incremental conventional vertical subsidence, tilt and curvature due to the extraction of each of the longwalls

Longwall	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
LWB4	675	3.5	0.03	0.06
LWB5	625	3.5	0.03	0.05
LWB6	700	3.5	0.04	0.05
LWB7	725	4.0	0.05	0.06

A summary of the maximum predicted values of total conventional vertical subsidence, tilt and curvature after the extraction of each of the proposed longwalls is provided in Table 4.2. The total values are the maximum accumulated movements within the Study Area including the predicted movements due to the approved Longwalls B1 to B3.

Table 4.2 Maximum predicted total conventional vertical subsidence, tilt and curvature after the extraction of each of the proposed longwalls

Longwalls	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
LWB4	1,200	5.0	0.03	0.06
LWB5	1,250	5.5	0.04	0.06
LWB6	1,350	5.5	0.04	0.06
LWB7	1,350	5.5	0.05	0.06

The maximum predicted total vertical subsidence within Study Area is 1,350 mm, which represents 40 % of the proposed extraction height of 3.4 m. The maximum predicted subsidence occurs directly above the approved Longwall B3.

The maximum predicted total conventional tilt is 5.5 mm/m (i.e. 0.55 % or 1 in 180), which occurs adjacent to the maingate of Longwall B7. The maximum predicted total conventional curvatures are 0.05 km^{-1} hogging and 0.06 km^{-1} sagging, which represent minimum radii of curvatures of 20 km and 17 km, respectively.

The predicted conventional subsidence parameters vary across the Study Area as the result of, amongst other factors, variations in the depths of cover, seam thickness and overburden geology. To illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along Prediction Line 1, the location of which is shown in Drawing Nos. MSEC869-10 to MSEC869-12.

The predicted profiles of conventional vertical subsidence, tilt and curvature along Prediction Line 1, resulting from the extraction of Longwalls B1 to B7, are shown in Fig. C.01, in Appendix C. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines. The predicted total profiles after the completion of the approved Longwalls B1 to B3 are shown as cyan lines.

4.3. Comparisons of the maximum predicted subsidence parameters

The comparison of the maximum predicted subsidence parameters for the proposed Longwalls B4 to B7 with the maximum predicted for the approved Longwalls B1 to B3 is provided in Table 4.3. The total values are the maximum accumulated movements within the Study Area including the predicted movements due to the approved Longwalls B1 to B3.

Table 4.3 Comparison of the maximum predicted total conventional subsidence parameters within the Bellbird South mining area

Layout	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
LWB1 to LWB3	925	3.5	0.03	0.05
LWB1 to LWB7	1,350	5.5	0.05	0.06

The maximum predicted subsidence parameters after the extraction of the proposed Longwalls B4 to B7 are greater than the maximum predicted due to the approved Longwalls B1 to B3. The predicted parameters increase due to the accumulation of the movements from the four additional longwalls in the series.

The comparison of the maximum predicted subsidence parameters in the Bellbird South mining area with the maximum predicted in Stages 2 and 3 at the Mine is provided in Table 4.4. The total values are the maximum accumulated movements due to the extraction of each series of longwalls.

Table 4.4 Comparison of the maximum predicted total conventional subsidence parameters with the existing and approved longwalls in Stages 2 and 3 at the Mine

Layout	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
LWA3 to LWA5a (Stage 2 existing)	1,500	6.0	0.05	0.12
LWA8 to LWA19 (Stage 3 approved)	1,800	6.5	0.05	0.09
LWB1 to LWB7 (Bellbird South)	1,350	5.5	0.05	0.06

The maximum predicted subsidence parameters in the Bellbird South mining area are less than the maximum predicted due to the completed Longwalls A3 to A5a in Stage 2 and the approved Longwalls A7 to A19 in Stage 3 at the Mine. The predicted parameters for Stages 2 and 3 are greater, as these are based on longwall top coal caving mining techniques, whereas the longwalls in the Bellbird South mining area are extracted using conventional mining techniques.

4.4. 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 pre-existing natural 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, 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 conventional tensile and compressive strains. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones.

In the Newcastle Coalfield a factor of 10 is generally used to predict the conventional strains from curvatures. It has been found, however, that a factor of 15 provides a better prediction of the conventional strains at Austar Coal Mine based on reviews of the available ground monitoring data. The maximum predicted conventional strains for Longwalls B4 to B7, adopting a factor of 15, are 1 mm/m tensile and compressive.

At a point, however, there can be considerable variation from the linear relationship, resulting from non-conventional movements or from the normal scatters which are observed in strain profiles. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strain for low magnitudes of curvature. In this report, therefore, we have provided a statistical approach to account for the variability, instead of just providing a single predicted conventional strain.

The range of potential strains for the longwalls has been determined using monitoring data from the previously extracted longwalls at the Mine. Longwalls A1 and A2 in Stage 1, Longwalls A3 to A5A in Stage 2 and Longwalls A7 and A8 in Stage 3 were extracted using LTCC mining techniques. Longwall B2 in the Bellbird South mining area was extracted using conventional longwall mining techniques.

A summary of the overall void widths, depths of cover, width-to-depth ratios and seam thicknesses for these previously extracted longwalls is provided in Table 4.5.

Table 4.5 Mine geometry for previously extracted longwalls at the Austar Coal Mine

Stage	Longwall	Void width (m)	Depth of cover (m)	Width-to-depth ratio	Extraction thickness* (m)
Stage 1	LWA1	157	395 ~ 470	0.33 ~ 0.40	5.9 ~ 6.3
	LWA2	227	385 ~ 450	0.50 ~ 0.59	6.0 ~ 6.3
Stage 2	LWA3	227	485 ~ 535	0.42 ~ 0.47	4.7 ~ 6.2
	LWA4	237	500 ~ 535	0.44 ~ 0.47	4.7 ~ 6.1
	LWA5	237	510 ~ 535	0.44 ~ 0.46	5.0 ~ 6.0
	LWA5A	237	530 ~ 555	0.43 ~ 0.45	5.1 ~ 5.6
Stage 3	LWA7	237	455 ~ 520	0.46 ~ 0.52	5.6 ~ 6.0
	LWA8	237	490 ~ 555	0.43 ~ 0.48	3.4 ~ 6.0
Bellbird South	LWB2	237	485 ~ 545	0.43 ~ 0.49	3.4

Note: * denotes that the effective extraction thickness for Stages 1 to 3 (i.e. LTCC mining techniques) has been taken as 3 m bottom coal plus 85 % recovery of the top coal (i.e. remaining seam thickness).

The width-to-depth ratios for the previously extracted longwalls at the Mine typically vary between 0.4 and 0.5, with the ratios varying between 0.33 and 0.59 for the longwalls in Stage 1. The width-to-depth ratios for Longwalls B4 to B7 vary between 0.47 and 0.59 and, therefore, are within the range of those for the previously extracted longwalls.

The effective extraction thickness for the previously extracted longwalls in Stages 1 to 3 (i.e. longwall top coal caving mining techniques) varied between 3.4 and 6.3 m. A constant extraction thickness of 3.4 m was adopted for Longwall B2 in the Bellbird South mining area. It is proposed that Longwalls B4 to B7 will also extract a constant thickness of 3.4 m using conventional longwall mining techniques.

The range of strains measured during the extraction of the previous longwalls in Stages 1 to 3 and in the Bellbird South mining area should provide a good, if not, conservative indication of the range of potential strains for the proposed Longwalls B4 to B7. The mine subsidence movements were measured along 13 monitoring lines during the extraction of the previous longwalls at the Mine, which were: Line 1A, Line 1B and Line 2 in Stage 1; Line A3, Line A3X, Line A4 and Line A5A in Stage 2; Line XL3, Line A7, Line A8 and Quorrobolong Road in Stage 3; and the B2-Line and the BSX-Line in the Bellbird South mining area.

In order to improve the strain analysis, the monitoring lines above the previously extracted Longwalls SL1 to SL4 and Longwalls 1 to 13A at the adjacent Ellalong Colliery were also included. These longwalls were extracted using conventional longwall mining techniques, where the width-to-depth ratios typically varied between 0.4 and 0.5 and the seam thickness typically varied between 3.0 m and 3.5 m, which are similar to the ranges for the proposed Longwalls B4 to B7.

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.

4.4.1. 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 monitoring lines have been analysed to extract the maximum tensile and compressive strains that have been measured at any time during mining, for survey bays that were located directly above the goaf or the chain pillars that are located between the extracted longwalls. A number of probability distribution functions were fitted to the empirical data and, it was found, that a *Generalised Pareto Distribution* (GPD) provided good fits to the raw strain data.

The histogram of the maximum observed tensile and compressive strains measured in survey bays located above goaf is provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

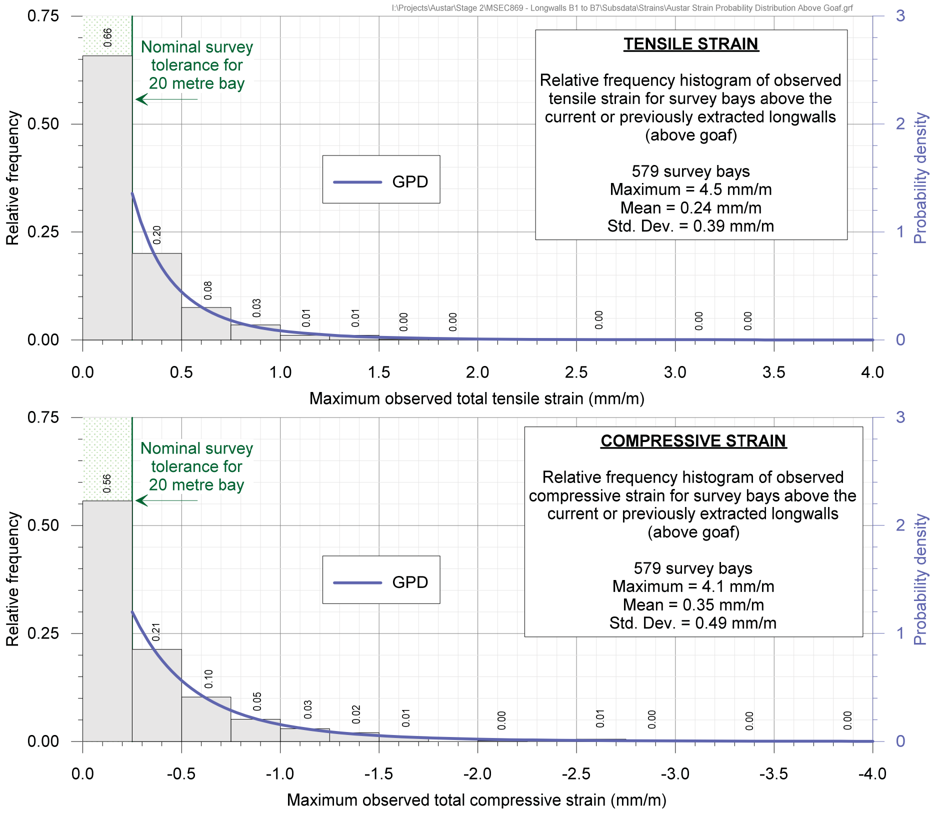

Fig. 4.1 **Distributions of the measured maximum tensile and compressive strains during the extraction of previous longwalls for survey bays located above goaf**

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). A summary of the predicted strains directly above Longwalls B4 to B7 (i.e. above goaf) is provided in Table 4.6.

Table 4.6 Predicted strains directly above Longwalls B4 to B7 (i.e. above goaf)

Location	Confidence level	Predicted tensile strain (mm/m)	Predicted compressive strain (mm/m)
Above goaf	95 %	0.9	1.2
	99 %	1.7	2.2

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

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

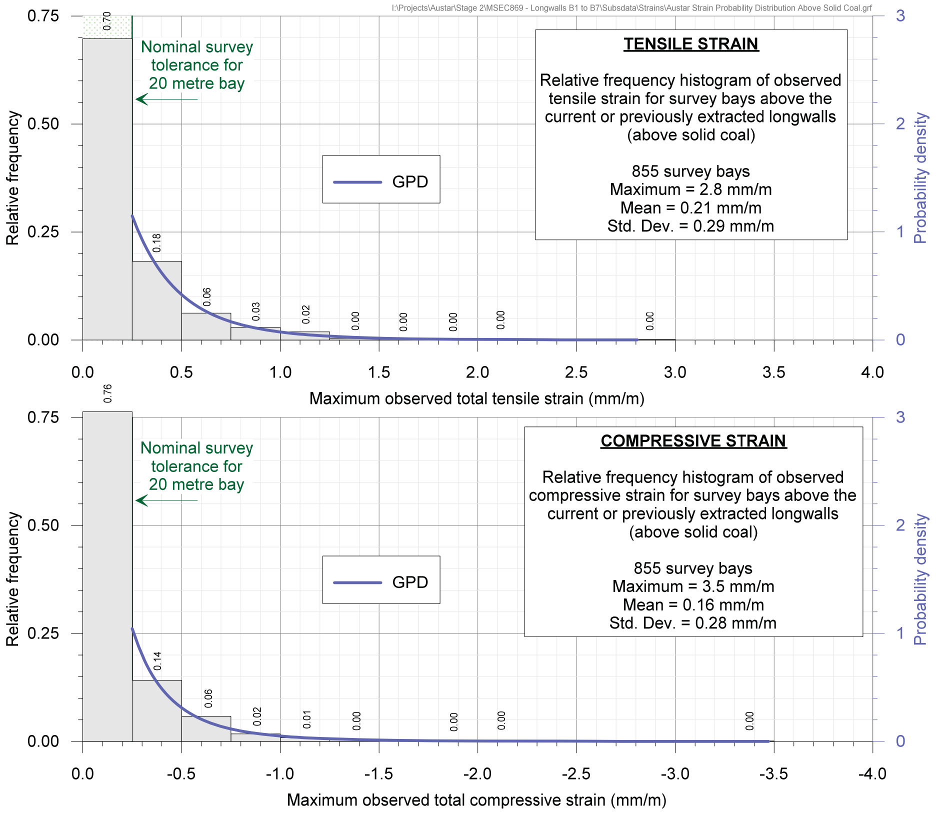

Fig. 4.2 **Distributions of the measured maximum tensile and compressive strains during the extraction of previous longwalls for survey bays located above solid coal**

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). A summary of the predicted strains outside but within 250 m of Longwalls B4 to B7 (i.e. above solid coal) is provided in Table 4.7.

Table 4.7 Predicted strains outside Longwalls B4 to B7 (i.e. above solid coal)

Location	Confidence level	Predicted tensile strain (mm/m)	Predicted compressive strain (mm/m)
Above solid coal	95 %	0.8	0.7
	99 %	1.3	1.3

4.4.2. 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 is provided in Fig. 4.3.

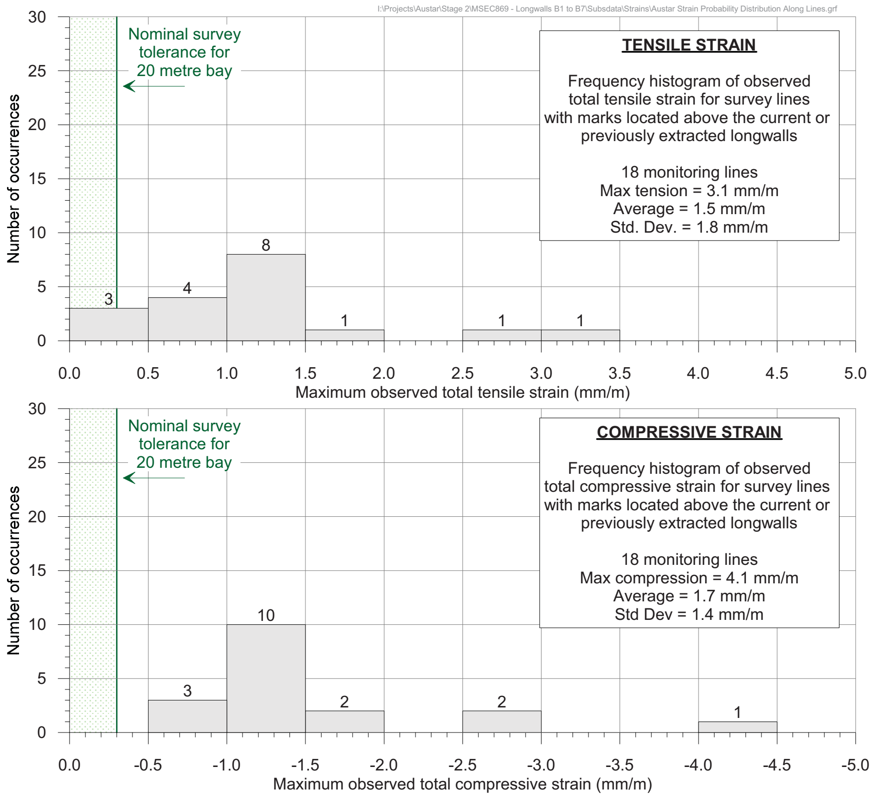

Fig. 4.3 **Distributions of measured maximum tensile and compressive strains along the monitoring lines during the extraction of previous longwalls**

It can be seen from Fig. 4.3, that 16 of the 18 monitoring lines (i.e. 89 % of the total) have recorded maximum total tensile strains of 2 mm/m or less. It can also be seen, that 15 of the 18 monitoring lines (i.e. 83 % of the total) also have recorded maximum compressive strains of 2 mm/m or less. The maximum observed strains along the monitoring lines, excluding the survey bays which appear to have been disturbed, were 3.1 mm/m tensile and 4.1 mm/m compressive.

4.5. Predicted conventional horizontal movements

The predicted conventional horizontal movements above Longwalls B4 to B7 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 the conventional 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 Mine, as described in Sections 3.5 and 3.6, 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 Longwalls B4 to B7, is 5.5 mm/m, which occurs adjacent to the maingate of Longwall B7. This area will experience the greatest predicted conventional horizontal movement towards the centre of the overall goaf area resulting from the extraction of the longwalls. The maximum predicted conventional horizontal movement is, therefore, approximately 85 mm, i.e. 5.5 mm/m multiplied by a factor of 15.

Conventional horizontal movements do not directly impact on natural and built features, 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 and built features are addressed in the impact assessments provided in Chapters 5 and 6.

4.6. Predicted far-field horizontal movements

In addition to the vertical subsidence movements that have been predicted above and adjacent to Longwalls B4 to B7, it is also likely that far-field horizontal movements will be experienced during the extraction of these longwalls.

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data from the NSW Coalfields, but predominately from the Southern Coalfield. 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 a single longwall, are provided in Fig. 4.4. The confidence levels, based on fitted *Generalised Pareto Distributions* (GPDs), have also been shown in this figure to illustrate the spread of the data.

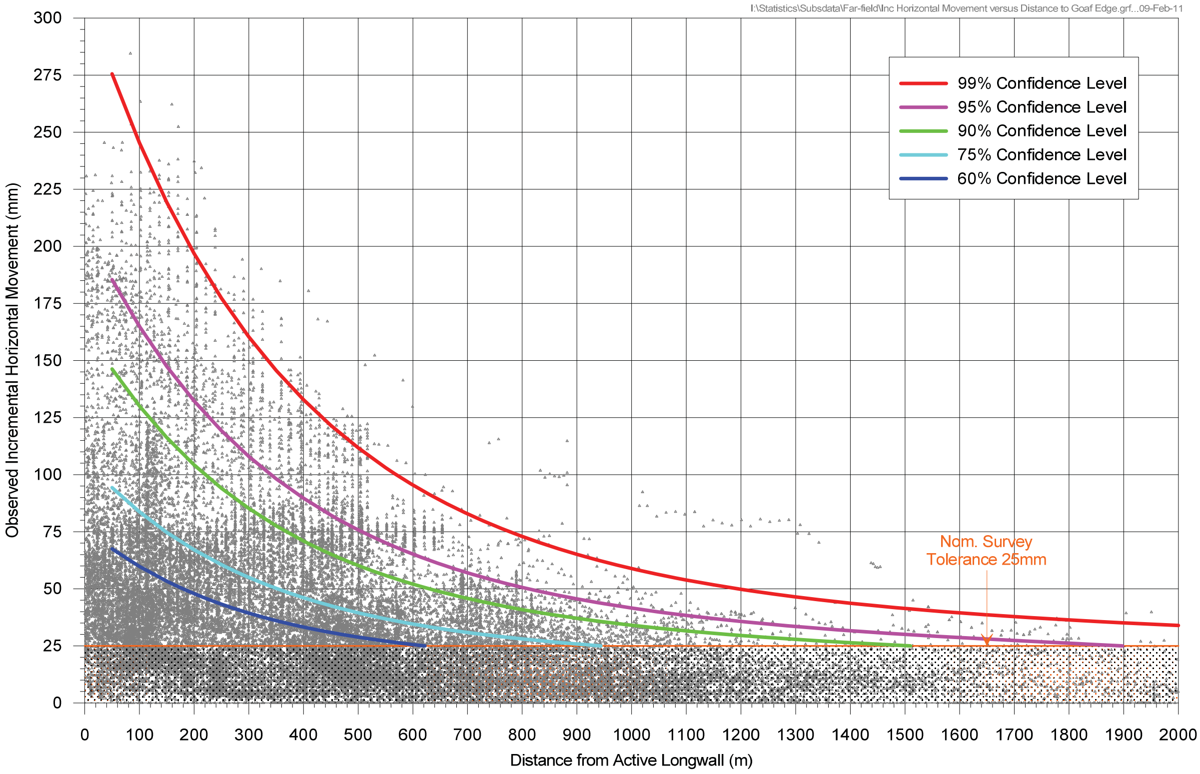

Fig. 4.4 Observed incremental far-field horizontal movements

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 have 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 Longwalls B4 to B7 are very small and could only be detected by ground 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 the order of survey tolerance (i.e. less than 0.3 mm/m).

The potential impacts of far-field horizontal movements on the natural and built features within the vicinity of the proposed longwalls are not expected to be significant. It is not considered necessary, therefore, that monitoring be established to measure the far-field horizontal movements resulting from these longwalls.

4.7. 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 m, 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 5.2. Cracking can also occur at the tops of steep slopes as the result of downslope movements, which is discussed in Section 5.4.

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.

There has been no significant or visible surface cracking above the previously extracted Longwalls A3 to A8 in Stages 2 and 3 and Longwall B2 in the Bellbird South mining area. The surface cracking, if any, resulting from the extraction of Longwalls B4 to B7 is expected to be of a minor nature, having widths generally less than 10 to 25 mm. It is expected that the surface cracking could be 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 from elsewhere in the NSW Coalfields are provided in the photographs in Fig. 4.5 and Fig. 4.6, respectively. These ground deformations were observed in the Southern Coalfield, where the depths of cover were similar to those within 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.

Fig. 4.5 Example of surface tensile cracking in the natural ground surface (observed in the Southern Coalfield at a similar depth of cover as in the Study Area)

Fig. 4.6 Example of surface compression buckling observed in road pavement (observed in the southern coalfield at a similar depth of cover as the Study Area)

4.8. Estimated height of the fractured zone

The extraction of longwalls results in deformation throughout the overburden strata. The terminology used by different authors to describe the strata deformation zones above extracted longwalls varies considerably and caution should be taken when comparing the recommendations from differing authors. Forster (1995) noted that most studies have recognised four separate zones, as shown in Fig. 4.7, with some variations in the definitions of each zone.

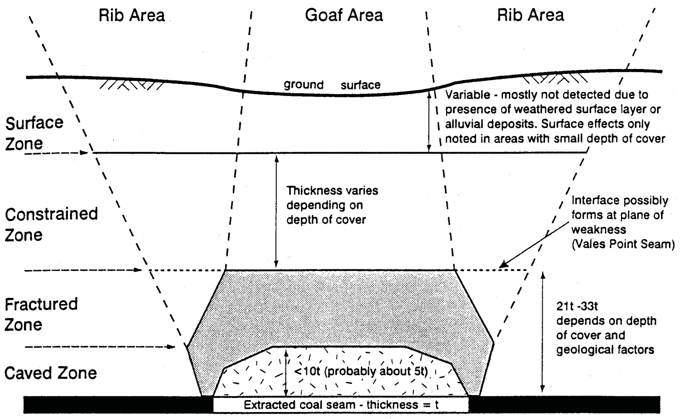

Fig. 4.7 **Zones in the overburden according to Forster (1995)**

Peng and Chiang (1984) recognised only three zones as reproduced in Fig. 4.8.

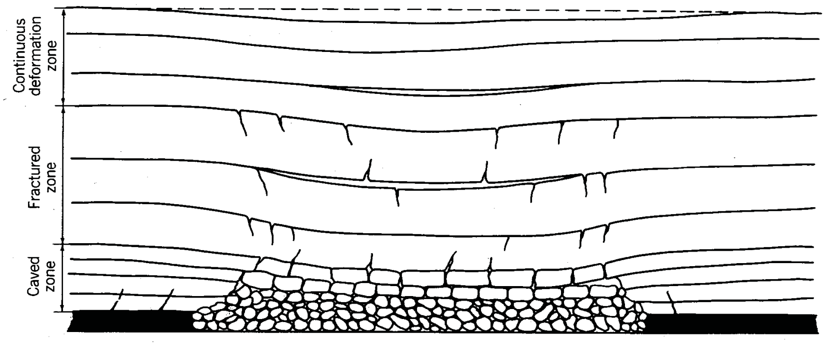

Fig. 4.8 **Zones in the overburden according to Peng and Chiang (1984)**

McNally et al (1996) also recognised three zones, which they referred to as the caved zone, the fractured zone and the elastic zone. Kratzsch (1983) identified four zones, but named them the immediate roof, the main roof, the intermediate zone and the surface zone.

For the purpose of these discussions, the following zones, as described by Singh and Kendorski (1981) and proposed by Forster (1995), as shown in Fig. 4.7, have been adopted:

- *Caved* or *Collapsed Zone* comprises loose blocks of rock detached from the roof and occupying the cavity formed by mining. This zone can contain large voids. It should be noted, that some authors note primary and secondary caving zones.
- *Disturbed* or *Fractured Zone* comprises in situ material lying immediately above the caved zone which have sagged downwards and consequently suffered significant bending, fracturing, joint opening and bed separation. It should be noted, that some authors include the secondary caving zone in this zone.
- *Constrained* or *Aquiclude Zone* comprises confined rock strata above the disturbed zone which have sagged slightly but, because they are constrained, have absorbed most of the strain energy without suffering significant fracturing or alteration to the original physical properties. Some bed separation or slippage can be present as well as some discontinuous vertical cracks, usually on the underside of thick strong beds, but not of a degree or nature which would result in connective cracking or significant increases in vertical permeability. Some increases in horizontal permeability can be found. Weak or soft beds in this zone may suffer plastic deformation.
- *Surface Zone* comprises unconfined strata at the ground surface in which mining induced tensile and compressive strains may result in the formation of surface cracking or ground heaving.

Just as the terminology differs between authors, the means of determining the extents of each of these zones also varies. Some of the difficulties in establishing the heights of the various zones of disturbance above extracted longwalls stem from the imprecise definitions of the fractured and constrained zones, the differing zone names, and the use of different testing methods and differing interpretations of monitoring data, such as extensometer readings.

Some authors interpret the collapsed and fractured zones to be the zone from which groundwater or water in boreholes would flow freely into the mine and, hence, look for the existence of aquiclude or aquitard layers above this height to confirm whether surface water would or would not be lost into the mine.

The heights of the collapsed and fractured zones above extracted longwalls are affected by a number of factors, which include the:

- widths of extraction;
- heights of extraction;
- depths of cover;
- types of previous workings, if any, above the current extractions;
- interburden thicknesses to previous workings;
- presence of pre-existing natural joints within each strata layer;
- thickness, geology, geomechanical properties and permeability of each strata layer;
- angle of break of each strata layer;
- spanning capacity of each strata layer, particularly those layers immediately above the collapsed and fractured zones;
- bulking ratios of each strata layer within the collapsed zone; and the
- presence of aquiclude or aquitard zones.

Some authors have suggested simple equations to estimate the heights of the collapsed and fractured zones based solely on the extracted seam height, others have suggested equations based solely on the widths of extraction, whilst others have suggested equations based on the width-to-depth ratios of the extractions. As this is a complex issue comprising the above factors, MSEC understand that no simple geometrical equation can properly estimate the heights of the collapsed and fractured zones and a more thorough analysis is required, which should include other properties, such as geology and permeability, of the overburden strata.

At the Austar Coal Mine, the massive sandstones in the Branxton Formation are capable of spanning the extracted voids with minimal sag subsidence, with the observed subsidence governed, to a large extent, by pillar compression. The combination of low width-to-depth ratios of the extracted longwalls and the properties of the overburden at the Mine limit the heights of vertical fracturing above the seam.

Two extensometers were installed above Longwalls A1 and A2 in Stage 1 at the Mine. The measured heights of vertical fracturing above the seam in these locations were: 86 m for Extensometer AQD1074 after Longwall A1; and 150 m for Extensometer AQD1085 after Longwall A2.

The height of the discontinuous fracturing (i.e. the Discontinuous Fracture Zone, or Zone B) can extend 1 to 1.5 times the longwall void width above the extracted seam. The overall void widths of the longwalls are 237 m and, therefore, the height of the discontinuous fracturing could extend 235 to 355 m above the seam.

The depth of cover above Longwalls B4 to B7 varies between 400 and 505 m. It is expected, therefore, that a constrained zone would develop in the upper section of the overburden, due to the high depths of cover, where vertical fracturing is generally discontinuous and unlikely, therefore, to result in significantly increased vertical hydraulic conductivity.

Further discussions on the effects of mining on the overburden and groundwater are provided by the specialist groundwater consultant in the report by Dundon Consulting (2017). Further details on sub-surface strata movements are provided in the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

The following sections provide the descriptions, predictions and impact assessments for the natural features within the Study Area, as identified in Chapter 2. The impact assessments are based on the predicted movements due to the extraction of the proposed Longwalls B4 to B7, as well as the predicted movements due to the previously extracted longwalls at Ellalong Colliery and Austar Coal Mine (i.e. cumulative movements due to the existing and proposed longwalls).

All significant natural features located outside the Study Area, which may be subjected to valley related or far-field horizontal movements due to the proposed Longwalls B4 to B7 and may be sensitive to these movements, have also been included as part of these assessments.

5.1. Natural Features

As listed in Table 2.1, the following natural features were not identified within the Study Area nor in the immediate surrounds:

- drinking water catchment areas or declared special areas;
- known springs or groundwater seeps;
- seas or lakes;
- shorelines;
- natural dams;
- cliffs or pagodas;
- escarpments;
- lands declared as critical habitat under the *Threatened Species Conservation Act 1995*;
- National Parks or State Forests;
- State Recreation Areas or State Conservation Areas;
- areas of significant geological interest; and
- other significant natural features.

The following sections provide the descriptions, predictions and impact assessments for the natural features which have been identified within or in the vicinity of the Study Area.

5.2. Streams

The locations of the streams within the Study Area are shown in Drawing No. MSEC869-07. The descriptions, predictions and impact assessments for these streams are provided in the following sections.

5.2.1. Descriptions of the streams

Quorrobolong Creek crosses directly above the proposed Longwalls B6 and B7. The total length of the creek located above these longwalls is approximately 1.3 km. Quorrobolong Creek has been previously directly mined beneath by Longwalls SL1 and 1 to 5 at Ellalong Colliery and by Longwalls A3 to A5A at the Austar Coal Mine, with a total length of approximately 4 km located directly above these previously extracted longwalls.

Quorrobolong Creek flows in a westerly direction to where it drains to Ellalong Lagoon, which is located more than 5 km from the proposed longwalls. The creek is ephemeral, but localised areas of natural ponding occur along its alignment. The natural grade of the section of creek within the Study Area varies between approximately 1 mm/m and 3 mm/m, with an average grade of approximately 2 mm/m.

The creek is incised into the natural surface soils, with the heights of the banks ranging between 3 and 5 m. The bed of the creek comprises Quaternary alluvium. There are debris accumulations along some sections of the creek, including tree branches, other vegetation and loose rocks.

Photographs of Quorrobolong Creek within the Study Area are provided in Fig. 5.1.

Fig. 5.1 Quorrobolong Creek

There are also ephemeral drainage lines within the Study Area that have formed on and between the small ridgelines. The locations of these drainage lines are shown in Drawing No. MSEC869-07. The largest ephemeral drainage line within the Study Area has been referred to as Drainage Line 1, in this report, as shown in Drawing No. MSEC869-07.

The drainage lines within the Study Area all drain to Quorrobolong Creek. The upper reaches of the drainage lines have formed in the Branxton Formation and have steep natural gradients, but with localised areas of ponding and stepping in some locations. The lower reaches of the drainage lines have shallow incisions into the natural surface soils that are comprised of Quaternary alluvium.

Photographs of the typical drainage lines within the Study Area are provided in Fig. 5.2.

Fig. 5.2 Typical drainage lines within the Study Area

5.2.2. Predictions for the streams

The predicted profiles of conventional subsidence, tilt and curvature along the alignment of Quorrobolong Creek are shown in Fig. C.02, in Appendix C. The predicted total profiles along the creek, after the extraction of each of the proposed longwalls, are shown as blue lines. The predicted profiles after the completion of the existing and approved longwalls are shown as the cyan lines.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for Quorrobolong Creek is provided in Table 5.1. The predictions are the maxima within the Study Area, i.e. do not include the sections of creek located above the previously extracted longwalls at Ellalong Colliery and Austar Coal Mine, but include the predicted movements resulting from these previous longwalls.

Table 5.1 Maximum predicted total vertical subsidence, tilt and curvature for Quorrobolong Creek

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Quorrobolong Creek	After LWB1 to LWB3	60	0.5	0.01	< 0.01
	After LWB4	60	0.5	0.01	< 0.01
	After LWB5	90	0.5	0.01	< 0.01
	After LWB6	650	3.0	0.02	0.02
	After LWB7	1,100	5.0	0.04	0.04

The tilts provided in the above table are the maxima predicted along the alignment of Quorrobolong Creek after the completion of each of the longwalls. The curvatures are the maxima predicted in any direction at any time during or after the extraction of each of the longwalls.

The predicted profiles of conventional subsidence, tilt and curvature along the alignment of Drainage Line 1 are shown in Fig. C.03, in Appendix C. The predicted total profiles along the drainage line, after the extraction of each of the proposed longwalls, are shown as blue lines. The predicted profiles after the completion of the existing and approved longwalls are shown as the cyan lines.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for Drainage Line 1 is provided in Table 5.2. The predictions are the maxima within the Study Area, but also include the predicted movements resulting from the adjacent previously extracted longwalls.

Table 5.2 Maximum predicted total vertical subsidence, tilt and curvature for Drainage Line 1

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Drainage Line 1	After LWB1 to LWB3	925	2.5	0.02	0.05
	After LWB4	1,150	3.0	0.02	0.06
	After LWB5	1,250	3.5	0.04	0.06
	After LWB6	1,350	3.5	0.04	0.06
	After LWB7	1,350	3.5	0.04	0.06

The streams are linear features and, therefore, the most relevant distributions of strain are the maximum strains measured along whole monitoring lines. The analysis of strain along whole monitoring lines during the extraction of the previous longwalls at the Mine is discussed in Section 4.4.2.

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 remaining drainage lines are located across the Study Area and, therefore, could experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence parameters within the Study Area is provided in Chapter 4.

Quorrobolong Creek and the drainage lines located within the Study Area have shallow incisions into the natural surface soils. It is unlikely, therefore, that these streams would experience any significant valley related movements resulting from the extraction of the proposed longwalls.

5.2.3. Impact assessments for the streams

The extraction of the proposed longwalls could potentially affect the surface water flows along the streams that are located directly above them. It is possible that locally increased ponding could occur if the mining induced tilts oppose and are greater than the natural gradients that exist before mining. The natural surface levels and grades and the predicted post mining surface levels and grades along Quorrobolong Creek and the Drainage Line 1 are illustrated in Fig. 5.3 and Fig. 5.4, respectively.

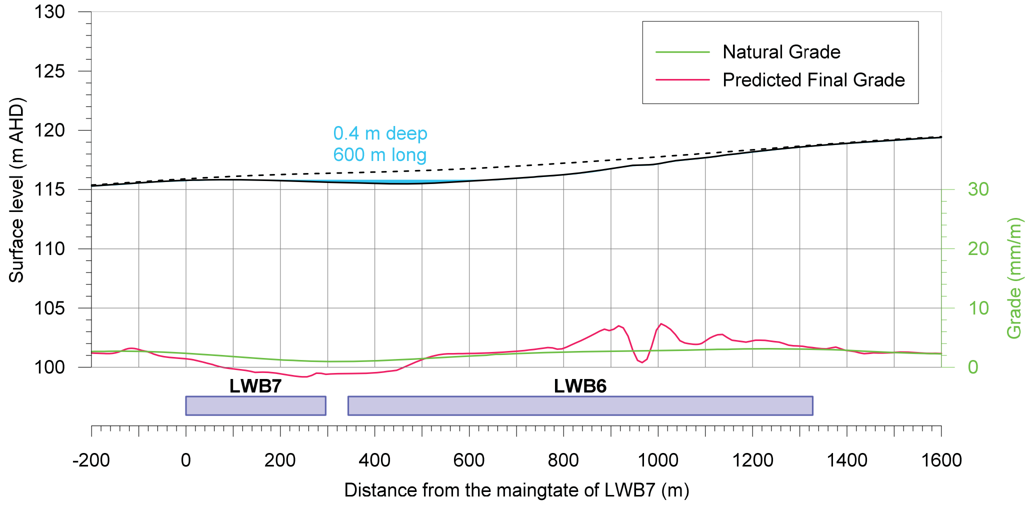

Fig. 5.3 Natural and predicted post-mining levels and grades along Quorrobolong Creek

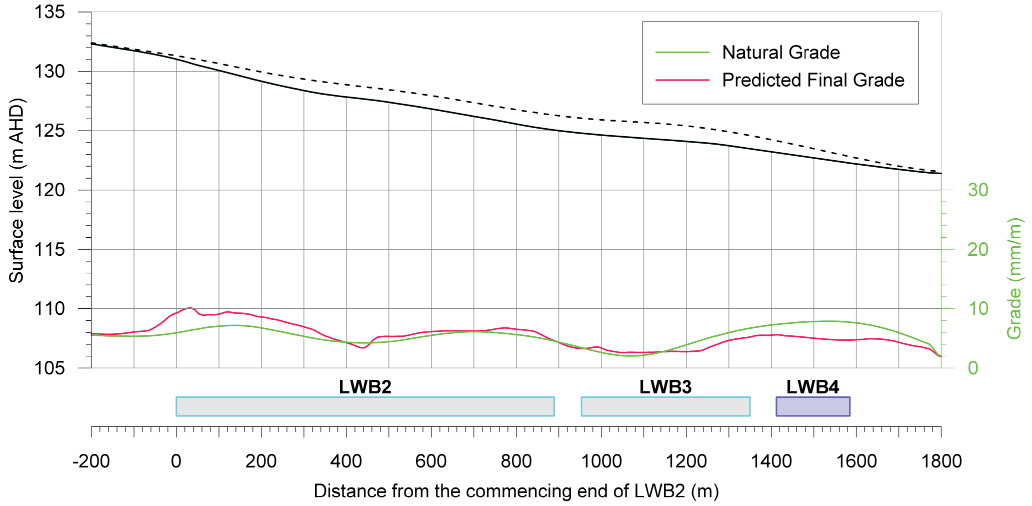

Fig. 5.4 Natural and predicted post-mining levels and grades along Drainage Line 1

Quorrobolong Creek has an average natural grade of approximately 2 mm/m within the Study Area. There is a predicted reversal in the creek grade above the chain pillar between the proposed Longwalls B6 and B7. It is possible, therefore, that there could be an increased potential for ponding to develop in this location. The mining-induced ponding is predicted to be up to 0.4 m deep and 600 m long along the alignment of the creek.

Drainage Line 1 has an average natural grade of approximately 6 mm/m within the Study Area. The post-mining grades along the drainage line are similar to the natural grades. There are no areas identified along Drainage Line 1 with the increased potential for ponding as a result of the proposed longwalls.

The other drainage lines within the Study Area have formed on the small ridgelines and have average natural grades greater than 10 mm/m. It is unlikely that increased ponding would develop along these other drainage lines as a result of the proposed longwalls.

A detailed flood model of the streams has been developed by Umwelt, using the predicted subsidence movements resulting from the extraction of the proposed longwalls, which have been provided by MSEC. The increased likelihoods of ponding and flooding along the streams have been assessed in the flood study and are provided in the report by Umwelt (2017b).

The maximum predicted curvature for Quorrobolong Creek is 0.04 km^{-1} both hogging and sagging, which represents a minimum radius of curvature of 25 km. The maximum predicted curvatures for the drainage lines within the Study Area are 0.05 km^{-1} hogging and 0.06 km^{-1} sagging, which represent minimum radii of curvature of 20 km and 17 km, respectively. The streams could also experience the full range of predicted ground strains which is discussed in Section 4.4.2.

It is likely that compressive buckling and dilation of the uppermost bedrock would occur beneath the natural surface soil beds along the streams that are located directly above the proposed longwalls. 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.

The Cessnock Sandstone forms the upper section of the overburden, which is relatively homogeneous and contains thick beds. A constrained zone is expected to develop in the upper section of the overburden, due to the high depths of cover, as described in Section 4.8. The vertical fracturing within the constrained zone is discontinuous and tortuous and, therefore, is unlikely to result in a significant increase in the vertical hydraulic conductivity.

The previous longwalls in Stages 2 and 3 at the Mine have been extracted beneath approximately 2.4 km of streams and no significant surface cracking or loss of surface water flows have been observed. It is considered unlikely, therefore, that there would be a net loss of water from the streams within the Study Area resulting from the extraction of the proposed longwalls.

The surface cracking above the proposed longwalls would tend to be naturally filled with the natural surface soils during subsequent flow events, especially during times of heavy rainfall. If the surface cracks were found not to fill naturally, remedial measures may be required at the completion of mining. Where necessary, the larger surface cracks in the stream beds could be remediated by infilling with the natural surface soils or other suitable materials, or by locally regrading and recompacting the surface.

Further discussion on the potential impacts on the changes in surface water flows are provided in the reports by Umwelt (2017a and 2017b).

5.2.4. Recommendations for the streams

It is recommended that the beds of the streams are periodically visually monitored during the extraction of the proposed longwalls, and that the major 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 streams resulting from the extraction of the proposed longwalls

5.3. Aquifers and known groundwater resources

The groundwater resources within the Study Area occur in the shallow alluvial aquifers associated with Quorrobolong Creek, the upper parts of the Branxton Formation and within the deeper Newcastle Coal Measures. Further descriptions of the aquifers within the Study Area are provided in the report by Dundon Consulting (2017).

5.4. Steep slopes

The definition of a steep slope provided in the NSW Department of Planning and Environment Standard and Model Conditions for Underground Mining (DP&E, 2012) is: *"An area of land having a gradient between 1 in 3 (33% or 18.3º) and 2 in 1 (200% or 63.4º)"*. The locations of any steep slopes were identified from the 1 m surface level contours, which were generated from the Light Detection and Ranging (LiDAR) survey of the area.

There are no broad areas that have been identified within the Study Area comprising steep slopes. That is, the natural grades within the Study Area are typically less than 1 in 3. The surface grades are locally greater than 1 in 3, in some isolated locations, such as along the banks of Quorrobolong Creek and the drainage lines. These areas could experience mining inducing cracking, as a result of the proposed longwalls, which is discussed in Section 5.2.

5.5. Land prone to flooding and inundation

The natural gradients along the alignments of Quorrobolong Creek and the lower reaches of the drainage lines are relatively flat and could be prone to flooding and inundation. A detailed flood study of the area has been undertaken and is described in the report by Umwelt (2017b).

5.6. Swamps, wetlands and water related ecosystems

There are no swamps or wetlands identified within the Study Area. There are water related ecosystems associated with the streams which are described in the report by Umwelt (2017c).

5.7. Natural vegetation

The land in the south-eastern part of the Study Area has been predominately cleared for agricultural and light residential uses. The land directly above the proposed longwalls contains large areas of native bushland, as shown in Fig. 1.1, predominately on the Crown and Austar-owned land. Threatened species and ecological communities have been identified within the Study Area and are described by the specialist ecology consultant (Umwelt, 2017c).

The potential for impacts on the natural vegetation are dependent on the surface cracking, changes in surface water and changes in groundwater. It is unlikely that significant surface cracking would occur as a result of the proposed longwalls, as none has been observed at Austar Coal Mine to date. Also, as described in Section 5.2, the streams within the Study Area are ephemeral and it is unlikely that the mining induced tilts would have a significant impact on the surface water flows. Further discussions on the potential impacts on the surface water are provided by Umwelt (2017b).

The following sections provide the descriptions, predictions and impact assessments for the built features which have been identified within or in the vicinity of the Study Area, as identified in Chapter 2. The impact assessments are based on the predicted movements due to the extraction of Longwalls B1 to B7, as well as the predicted movements due to the previously extracted longwalls at Ellalong Colliery and Austar Coal Mine (i.e. cumulative movements due to the existing and proposed longwalls).

6.1. Public roads

The locations of public roads within the Study Area are shown in Drawing No. MSEC869-08. 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

Sandy Creek Road crosses directly above the proposed Longwalls B4 and B5 as well as above the approved Longwalls B1 to B3. The total length of this road located directly above the Bellbird South mining area is approximately 1.8 km, of which approximately 0.9 km is located directly above the proposed longwalls. Sandy Creek Road has also been previously directly mined beneath by Longwalls 1 to 9 at Ellalong Colliery, to the west of the Study Area, with a total length of approximately 2 km located directly above these previously extracted longwalls.

Sandy Creek Road provides access between the township of Ellalong, which is located to the west of the Study Area, and Freemans Drive and Lake Road, which are located east of the Study Area. The section of road within the Study Area has a single carriageway with a bitumen seal and grass verges (i.e. no kerb and guttering), however, there are concrete v-channels adjacent to the road on the hill to the west of Barraba Lane. There is a small cutting above the south-western end of the proposed Longwall B5, which is less than 3 m in height. Drainage culverts are located where the road crosses the drainage lines, which are discussed in Section 6.3.

Barraba Lane is located in the south-eastern corner of the Study Area. The lane is located at a distance of 0.7 km east of Longwall B4, at its closest point to the proposed longwalls. Barraba Lane is an unsealed road that provides access to private properties located to the south of Sandy Creek Road.

Photographs of Sandy Creek Road (left side) and Barraba Lane (right side) are provided in Fig. 6.1.

Fig. 6.1 Sandy Creek Road (left side) and Barraba Lane (right side)

The roads are owned and maintained by the Cessnock City Council.

6.1.2. Predictions for the roads

The predicted profiles of conventional subsidence, tilt and curvature along the alignment of Sandy Creek Road are shown in Fig. C.04, in Appendix C. The predicted total profiles along the road, after the extraction of each of the proposed longwalls, are shown as blue lines. The predicted profiles after the completion of the existing and approved longwalls are shown as the cyan lines.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for Sandy Creek Road is provided in Table 6.1. The predictions are the maxima within the Study Area, i.e. do not include the sections of road located above the previously extracted longwalls at Ellalong Colliery and Austar Coal Mine, but include the predicted movements resulting from these previous longwalls.

Table 6.1 Maximum predicted total vertical subsidence, tilt and curvature for Sandy Creek Road

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Sandy Creek Road	After LWB1 to LWB3	850	2.5	0.02	0.05
	After LWB4	1,100	3.0	0.02	0.06
	After LWB5	1,250	3.5	0.03	0.06
	After LWB6	1,350	4.0	0.03	0.06
	After LWB7	1,350	4.0	0.03	0.06

The tilts provided in the above table are the maxima predicted along the alignment of Sandy Creek Road after the completion of each of the longwalls. The curvatures are the maxima predicted in any direction at any time during or after the extraction of each of the longwalls.

The roads are linear features and, therefore, the most relevant distributions of strain are the maximum strains measured along whole monitoring lines. The analysis of strain along whole monitoring lines during the extraction of the previous longwalls at the Mine is discussed in Section 4.4.2.

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 predicted additional vertical subsidence along Barraba Lane due to the extraction of the proposed Longwalls B4 to B7 is 30 mm. Whilst the lane could experience low levels of additional vertical subsidence due to the proposed longwalls, it is not expected to experience measurable tilts, curvatures or strains.

6.1.3. Impact Assessments for the roads

The maximum predicted conventional tilt for Sandy Creek Road is 4.0 mm/m (i.e. 0.4 %), which represents a change in grade of 1 in 250. The predicted tilts are less than 1 % and are unlikely, therefore, to result in adverse impacts on the serviceability or surface water drainage of this road. If additional ponding or adverse changes in surface water drainage were to occur as a result of the proposed longwalls, the road could be repaired using normal road maintenance techniques.

The maximum predicted conventional curvatures for Sandy Creek Road are 0.03 km^{-1} hogging and 0.06 km^{-1} sagging, which represent minimum radii of curvatures of 33 km and 17 km, respectively. The maximum predicted ground curvatures and the range of potential strains for this road are similar to or less than those predicted where: Longwalls A3 and A4 were extracted directly beneath Nash Lane (unsealed); and where Longwalls A7 and A8 were extracted beneath Quorrobolong Road (bitumen seal), Big Hill Road (unsealed) and a number of unsealed fire trails.

The previously extracted longwalls in Stages 2 and 3 at the Mine have extracted beneath approximately 1 km of public roads, which were maintained in safe and serviceable conditions at all times. Only isolated and minor impacts to the road surfaces have been observed, which were remediated using normal road maintenance techniques.

The predicted mine subsidence movements for Sandy Creek Road are also less than those typically experienced in the Southern Coalfield. The most extensive experience comes from Tahmoor Colliery, where Longwalls 22 to 27 have been extracted directly beneath approximately 24.5 km of local roads. A total of 46 impacts have been observed, to date, which equates to an average of one impact for every 533 m of pavement. The impacts were minor and did not present a public safety risk.

The predicted additional vertical subsidence along Barraba Lane due to the extraction of the proposed Longwalls B4 to B7 is 30 mm. It is unlikely, therefore, that this lane would experience adverse impacts as a result of the proposed longwalls.

It is expected that any impacts on the public 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.

6.1.4. Recommendations for the Roads

Management strategies have previously been developed for the public roads in the Bellbird South mining area for the approved Longwalls B1 to B3. It is recommended that the existing management strategies for the roads be reviewed in consultation with Cessnock City Council and, where required, are revised to include the effects of the proposed longwalls.

6.2. Road bridges

There are no road bridges within the Study Area. The *Quorrobolong Creek Forbes Bridge* (Ref. SCR-B1) is located outside the Study Area at a distance of approximately 0.9 km east of the proposed Longwall B4. The bridge is predicted to experience less than 20 mm vertical subsidence resulting from the extraction of Longwalls B4 to B7. Whilst the bridge could experience very low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains. It is not anticipated that adverse impacts would occur to the bridge due to the extraction of Longwalls B4 to B7.

6.3. Road drainage culverts

The locations of the road drainage culverts within the Study Area are shown in Drawing No. MSEC869-08. The descriptions, predictions and impact assessments for the culverts within the Study Area are provided in the following sections.

6.3.1. Descriptions of the road drainage culverts

There are three concrete box culverts (Refs. SCR-C1 to SCR-C3) that are located directly above the approved Longwall B3. These double box culverts have overall widths of 5 m and heights between 0.6 and 1.2 m. There is also a double 600 mm diameter concrete culvert (Ref. SCR-C4) located above the maingate of the approved Longwall B3 and a single 1.5 m diameter concrete culvert (Ref. SCR-C5) located above the proposed Longwall B5. Photographs of these culverts are provided in Fig. 6.2 and Fig. 6.3.

Fig. 6.2 Box culverts SCR-C1 (left side) and SCR-C2 (Right)

Fig. 6.3 Box culvert SCR-C3 (left side) and concrete culvert SCR-C4 (right side)

Dual 300 mm diameter circular concrete culverts are also located on Barraba Lane (Ref. BL-C1), near the intersection with Sandy Creek Road, which are directly above the approved Longwall B1. There are also other concrete drainage culverts within the Study Area beneath the driveways to the properties along Sandy Creek Road and Barraba Lane.

6.3.2. Predictions for the road drainage culverts

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the drainage culverts SCR-C1 to SCR-C5, after the completion of the approved and proposed longwalls, is provided in Table 6.2. The predictions are the maximum values within 20 m of the mapped locations of the culverts.

Table 6.2 Maximum predicted total vertical subsidence, tilt and curvature for the drainage culverts

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
SCR-C1	After LWB1 to LWB3	600	2.5	0.01	0.01
	After LWB1 to LWB7	1350	1.5	0.02	0.04
SCR-C2	After LWB1 to LWB3	500	3.0	< 0.01	< 0.01
	After LWB1 to LWB7	1350	1.5	0.02	0.06
SCR-C3	After LWB1 to LWB3	350	3.0	0.02	< 0.01
	After LWB1 to LWB7	1300	1.5	0.02	0.02
SCR-C4	After LWB1 to LWB3	150	1.5	0.01	< 0.01
	After LWB1 to LWB7	1200	1.0	0.03	0.02
SCR-C5	After LWB1 to LWB3	< 20	< 0.5	< 0.01	< 0.01
	After LWB1 to LWB7	900	2.5	0.02	0.03

The maximum predicted subsidence parameters for the dual circular culverts BL-C1 are: 150 mm vertical subsidence, 2.0 mm/m tilt, 0.02 km^{-1} hogging curvature and less than 0.01 km^{-1} sagging curvature. The other culverts located outside the extents of the longwalls could also experience vertical subsidence up to around 100 mm.

The culverts are point features and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays. The analysis of strain measured in individual survey bays during the extraction of the previous longwalls at the Mine is discussed in Section 4.4.1.

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.

6.3.3. Impact assessments for the road drainage culverts

The predicted curvatures and strains could be of sufficient magnitudes to result in cracking in the box culverts or the circular culverts that are located directly above the approved and proposed longwalls. It is unlikely, however, that these movements would adversely impact on the stability or structural integrity of these culverts. The potential impacts on the drainage culverts could be managed by visual inspection and, if required, any affected sections of the culvert repaired or replaced.

Previous experience of mining beneath culverts in the NSW Coalfields, at similar depths of cover, indicates that the incidence of impacts is very low. Impacts have generally been limited to cracking in the concrete headwalls which can be more readily remediated. In some cases, however, cracking in the culvert pipes occurred which required the culverts to be replaced.

6.3.4. Recommendations for the Road Drainage Culverts

Management strategies have previously been developed for the public roads, including the drainage culverts, in the Bellbird South mining area for the approved Longwalls B1 to B3. It is recommended that the existing management strategies for the roads and culverts be reviewed in consultation with Cessnock City Council and, where required, are revised to include the effects of the proposed longwalls.

6.4. Electrical infrastructure

The locations of the electrical infrastructure within the Study Area are shown in Drawing No. MSEC869-08. 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 comprise above ground 11 kV powerlines supported by timber poles. There are also low voltage powerlines that supply power to the rural properties within the Study Area. The total length of the powerlines located directly above the Bellbird South mining area is approximately 4.3 km, of which 2.4 km is located directly above the proposed longwalls.

Photographs of the 11 kV powerlines within the Study Area are provided in Fig. 6.4.

Fig. 6.4 11 kV Powerlines

The powerlines are owned and maintained by Ausgrid.

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, however, may 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 the tilts and by changes in the catenary profiles of the cables.

The predicted profiles of conventional subsidence, tilt along and tilt across the alignments of the 11 kV Powerline Branch 1 (adjacent to Sandy Creek Road) and 11 kV Powerline Branch 2 (north of Sandy Creek Road) are shown in Figs. C.05 and C.06, respectively, in Appendix C. The predicted total profiles along the powerlines, after the extraction of each of the proposed longwalls, are shown as blue lines. The predicted profiles after the completion of the existing and approved longwalls are shown as the cyan lines.

A summary of the maximum predicted values of total vertical subsidence and tilt for the powerlines is provided in Table 6.3. The predictions are the maxima within the Study Area, i.e. do not include the sections of the powerlines located above the previously extracted longwalls at Ellalong Colliery and Austar Coal Mine, but include the predicted movements resulting from these adjacent previous longwalls. The values provided in this table are also the maxima anywhere along the powerlines, i.e. not just at the pole locations.

Table 6.3 Maximum predicted total vertical subsidence and tilt for the 11 kV powerlines

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along the alignment (mm/m)	Maximum predicted total tilt across the alignment (mm/m)
11 kV Powerline Branch 1	After LWB1 to LWB3	875	2.5	1.5
	After LWB4	1,150	3.0	1.5
	After LWB5	1,250	3.0	1.5
	After LWB6	1,350	3.0	1.5
	After LWB7	1,350	4.0	3.0
11 kV Powerline Branch 2	After LWB1 to LWB3	175	1.5	< 0.5
	After LWB4	175	1.5	< 0.5
	After LWB5	450	1.5	3.0
	After LWB6	1,000	4.0	2.0
	After LWB7	1,200	4.0	1.5

The maximum predicted tilt in any direction at the powerpole locations is 4.0 mm/m (i.e. 0.4 %, or 1 in 250). The maximum predicted horizontal movement at the tops of the powerpoles, based on a pole height of 15 m, is 120 mm.

6.4.3. Impact assessments for the electrical infrastructure

A rule of thumb used by some electrical engineers is that the tops of the poles may displace up to 2 pole diameters horizontally before remediation works are considered necessary. Based on pole heights of 15 m and pole diameters of 250 mm, the maximum tolerable tilt at the pole locations is in the order of 33 mm/m. It is unlikely, therefore, that the powerlines within the Study Area would experience adverse impacts as a result of the proposed longwalls, even if the predictions were exceeded by a factor of 2 times.

Longwalls at the Mine and elsewhere in the NSW Coalfields have successfully been mined directly beneath powerlines in the past, where the magnitudes of the predicted mine subsidence movements were similar to or greater than those predicted within the Study Area. This includes approximately 4 km of powerlines located above Longwalls 1 to 12A at Ellalong Colliery and approximately 4.5 km of powerlines located above the Longwalls A3 to A5A and Longwalls A7 and A8 at the Austar Coal Mine and no adverse impacts have been reported.

Whilst adverse 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 very minor and easily repaired.

6.4.4. Recommendations for the Electrical Infrastructure

Management strategies have previously been developed for the 11 kV and consumer powerlines in the Bellbird South mining area for the approved Longwalls B1 to B3. It is recommended that the existing management strategies for the powerlines be reviewed in consultation with Ausgrid and, where required, are revised to include the effects of the proposed longwalls.

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. With the implementation of the necessary management strategies, it is expected that the powerlines can be maintained in safe and serviceable conditions at all times.

6.5. Telecommunications infrastructure

The locations of the telecommunications infrastructure within the Study Area are shown in Drawing No. MSEC869-08. 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 underground copper cables with some aerial connections to the houses. The cables generally follow the alignments of Sandy Creek Road and Barraba Lane and service the rural properties within the Study Area. The total length of the copper telecommunications cables located directly above the Bellbird South mining area is approximately 3.3 km, of which 1.0 km is located directly above the proposed longwalls. There are no optical fibre cables located within the Study Area.

6.5.2. Predictions for the telecommunications infrastructure

The copper telecommunications cables within the Study Area generally follow the alignments of the public roads. The predicted profiles of subsidence, tilt and curvature for these copper cables, therefore, are similar to those predicted along Sandy Creek Road which are shown in Fig. C.03, in Appendix C.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the copper telecommunications cable, after the completion of each of the longwalls, is provided in, is provided in Table 6.4.

Table 6.4 Maximum predicted total vertical subsidence, tilt and curvature for the copper telecommunications cables

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Copper telecommunications cables	After LWB1 to LWB3	850	3.5	0.02	0.05
	After LWB4	1,100	4.5	0.03	0.06
	After LWB5	1,250	5.0	0.03	0.06
	After LWB6	1,350	5.0	0.03	0.06
	After LWB7	1,350	5.0	0.03	0.06

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

The cables are linear features and, therefore, the most relevant distributions of strain are the maximum strains measured along whole monitoring lines. The analysis of strain along whole monitoring lines during the extraction of the previous longwalls at the Mine is discussed in Section 4.4.2.

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.

6.5.3. Impact assessments for the telecommunications infrastructure

The direct buried copper telecommunications cables are not directly affected by vertical subsidence or tilt. The maximum predicted curvatures for the cables are 0.03 km^{-1} hogging and 0.06 km^{-1} sagging, which represent minimum radii of curvatures of 33 km and 17 km, respectively. The copper cables are reasonably flexible and, therefore, are also unlikely to experience adverse impacts based on the magnitudes of the predicted conventional curvatures.

The direct buried copper cables, however, could be affected by the ground strains resulting from the extraction of the proposed longwalls. The copper cables are more likely to be impacted by the tensile strains rather than the 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.

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 at the Mine and elsewhere in the New South Wales Coalfields have successfully been mined directly beneath buried and aerial copper telecommunications cables in the past, where the magnitudes of the predicted mine subsidence movements were similar to or greater than those predicted within the Study Area. This includes approximately 0.8 km of cables located above Longwalls 1 to 12A at Ellalong Colliery and approximately 1.2 km of cables located above the Longwalls A3 to A5A and Longwalls A7 and A8 at the Austar Coal Mine and no adverse impacts have been reported.

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 m, such as is the case above the proposed longwalls. In some cases, there have been some minor impacts on aerial copper telecommunications cables, such as the 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 these impacts, however, was very low.

Based on this experience, it is unlikely that the extraction of the proposed longwalls would result in any adverse 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.

6.5.4. Recommendations for Telecommunications Infrastructure

Management strategies have previously been developed for the copper telecommunications cables in the Bellbird South mining area for the approved Longwalls B1 to B3. It is recommended that the existing management strategies for the cables be reviewed in consultation with Telstra and, where required, are revised to include the effects of the proposed longwalls.

With the implementation of the necessary management strategies, it is expected that the copper telecommunications cables can be maintained in safe and serviceable conditions at all times.

6.6. Agricultural utilisation

The land in the south-eastern part of the Study Area has been predominately cleared for agricultural and light residential uses. The land directly above the proposed longwalls contains large areas of native bushland, as can be seen in Fig. 1.1, but also includes built features associated with agricultural and residential use. The descriptions, predictions and impact assessments for the built features on these rural properties are provided in the following sections.

The potential for impacts on the land use within the Study Area can occur from the mining-induced surface cracking, changes in surface water drainage and changes in ground water. It is unlikely that significant surface cracking would occur as a result of the proposed longwalls, as none has been observed at Austar Coal Mine to date. Also, as described in Section 5.2, the streams within the Study Area are ephemeral and it is unlikely that the mining induced tilts would have a significant impact on the surface water flows. Further discussions on the potential impacts on the surface water drainage are provided by Umwelt (2017b).

6.7. Rural structures

6.7.1. Descriptions of the rural structures

The rural structures (Structure Type R) are shown in Drawing No. MSEC869-09. The locations, sizes and details of the rural structures were determined from the aerial photograph of the area and from kerb side inspections.

There are 48 rural structures that have been identified within the Study Area, of which 20 are located directly above the proposed Longwalls B4 to B7 and 14 are located directly above the approved Longwalls B1 to B3. The rural structures within the Study Area are generally of lightweight construction and include farm sheds, garages, tanks and other non-residential structures.

6.7.2. Predictions for the rural 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 m. In the case of a rectangular shaped structure, predictions have been made at a minimum of 45 points within and around the structure.

The predicted total conventional subsidence, tilts and curvatures for the rural structures within the Study Area are provided in Table D.01, in Appendix D. A summary of the maximum predicted subsidence parameters for the rural structures on each of the properties within the Study Area is provided in Table 6.5. The values include the predicted movements resulting from the previous extraction of the adjacent longwalls at Ellalong Colliery and Austar Coal Mine (i.e. cumulative movements).

Table 6.5 Maximum predicted total vertical subsidence, tilt and curvature for the rural structures

Property	Number of rural structures	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
A01	2	200	1.5	0.02	< 0.01
A02	9	825	5.0	0.03	0.02
A06	3	225	2.0	0.02	< 0.01
A08	6	825	4.0	0.03	0.02
B03	7	950	2.5	0.01	0.04
C01	4	1,200	1.0	0.02	0.02
C02	10	1,200	1.0	0.03	0.03
C03	2	30	< 0.5	< 0.01	< 0.01
C05	5	100	1.0	< 0.01	< 0.01

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

The rural structures are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays. The analysis of strain in survey bays during the extraction of the previous longwalls at the Mine is discussed in Section 4.4.1.

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.

6.7.3. Impact assessments for the rural structures

There are 20 rural structures that are located directly above the proposed Longwalls B4 to B7 and 14 structures located directly above the approved Longwalls B1 to B3. The maximum predicted movements for these structures are 1,200 mm vertical subsidence, 5.0 mm/m tilt, 0.03 km^{-1} hogging curvature and 0.04 km^{-1} sagging curvature.

The remaining 14 rural structures within the Study Area are located outside the extents of the proposed and approved longwalls. The maximum predicted movements for these structures are 225 mm vertical subsidence, 2.0 mm/m tilt, 0.02 km^{-1} hogging curvature and less than 0.01 km^{-1} sagging curvature.

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 structures. Some very minor serviceability impacts could occur at the rural structures located directly above the proposed longwalls, including door swings and minor issues with roof and pavement drainage, all of which can be repaired using normal building maintenance techniques.

The maximum predicted curvatures for the rural structures within the Study Area are similar to the maxima predicted for these types of structures that were located above the previously extracted longwalls at the Mine. There were 18 rural structures located directly above Longwalls A3 to A5A in Stage 2 and Longwalls A7 and A8 in Stage 3 and there were no reported mining related impacts.

There is also extensive experience of mining directly beneath rural structures in the Southern Coalfield, where the maximum predicted subsidence parameters are similar to or greater than the maxima predicted for the proposed longwalls. This incidence of impacts on these types of structures is very low, with adverse impacts generally reported for the larger industrial type sheds. This is not unexpected, as rural structures are generally small in size and of light-weight construction, they are less susceptible to impact than houses that are typically more rigid. In all cases, the rural structures remained in safe and serviceable conditions.

It is expected, therefore, that all the rural 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 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 structures, which were in poor condition prior to mining, have been directly mined beneath and these structures have not experienced impacts during mining.

The impacts on the rural 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 structures resulting from the extraction of the proposed longwalls.

6.7.4. Recommendations for the rural structures

Built Features Management Plans have previously been developed for properties located above and adjacent to the approved Longwalls B1 to B3. It is recommended that similar management plans are developed for the additional properties within the Study Area.

It is recommended that the rural 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 structures located directly above the proposed longwalls are periodically visually monitored during active subsidence. With these management strategies in place, it is unlikely that there would be any significant long term impacts on the rural structures.

6.8. Gas and fuel storages

There are domestic gas and fuel storages on the rural properties within the Study Area and, therefore, 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 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.

6.9. Farm fences

There are a number of fences within the Study Area that 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.

The fences are linear features and, therefore, the most relevant distributions of strain are the maximum strains measured along whole monitoring lines. The analysis of strain along whole monitoring lines during the extraction of the previous longwalls at the Mine is discussed in Section 4.4.2.

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.

6.10. Farm dams

6.10.1. Descriptions of the farm dams

The farm dams (Structure Type D) are shown in Drawing No. MSEC869-09. The locations and sizes of the dams were determined from the aerial photograph of the area. There are 24 farm dams that have been identified within the Study Area, of which six are located directly above the proposed Longwalls B4 to B7 and 11 are located directly above the approved Longwalls B1 to B3.

The farm dams are typically of earthen construction and have been established by localised cut and fill operations along the natural drainage lines. The largest dam is Ref. C03d01, which is located on land owned by the Mine, above the finishing (i.e. north-eastern) end of the proposed Longwall B7. This dam has a surface area of 46,900 m^2 and a maximum dimension of 440 m. The remaining dams within the Study Area have surface areas ranging between 30 and 6,220 m^2 and maximum plan dimensions ranging between 8 and 160 m.

6.10.2. Predictions for the farm dams

The predicted total conventional subsidence, tilts and curvatures for the farm dams within the Study Area are provided in Table D.02, in Appendix D. A summary of the maximum predicted subsidence parameters for the farm dams on each of the properties within the Study Area is provided in Table 6.6. The values include the predicted movements resulting from the previous extraction of the adjacent longwalls at Ellalong Colliery and Austar Coal Mine (i.e. cumulative movements).

Table 6.6 Maximum predicted total vertical subsidence, tilt and curvature for the farm dams

Property	Number of farm dams	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
A01	1	300	3.0	0.02	< 0.01
A02	1	175	1.5	0.02	< 0.01
A04	1	375	3.5	0.04	< 0.01
A06	4	525	4.5	0.03	0.03
A07	1	675	4.5	0.04	< 0.01
A08	2	625	4.0	0.03	0.02
B01	3	1,300	2.5	0.02	0.06
B02	2	825	4.5	0.02	0.02
B03	3	700	4.0	0.02	0.02
C01	1	1,250	1.5	0.02	0.04
C03	2	625	4.5	0.04	0.03
C05	2	40	< 0.5	< 0.01	< 0.01
C06	1	60	< 0.5	0.01	< 0.01

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

The farm dams are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays. The analysis of strain in survey bays during the extraction of the previous longwalls at the Mine is discussed in Section 4.4.1.

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.

6.10.3. Impact assessments for the farm dams

The maximum predicted tilt for the farm dams within the Study Area 4.5 mm/m (i.e. 0.45 %), which represents a change in grade of 1 in 225. 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.

The predicted changes in freeboard at the farm dams within the Study Area have been 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.02, in Appendix D.

The maximum predicted change in freeboard is 500 mm at Dam C03d01, which is located on land owned by the Mine, above the finishing (i.e. north-eastern) end of the proposed Longwall B7. This dam has formed in a natural depression of the land and there is no dam wall. The freeboard reduces (i.e. the stored water level increases) along the southern edge of this dam. There is an overflow channel in this location that drains to Quorrobolong Creek. It may be necessary to increase the height of the overflow channel, if required, to maintain the storage capacity of this dam.

The predicted maximum changes in freeboard at the remaining farm dams within the Study Area are 300 mm or less. It is unlikely, therefore, that the changes in freeboard to have a significant impact on the storage capacities.

The largest farm dam within the Study Area is Dam C03d01, which is located on land owned by the Mine, above the finishing (i.e. north-eastern) end of the proposed Longwall B7. The maximum predicted subsidence parameters for this dam are 625 mm vertical subsidence, 4.5 mm/m tilt, 0.04 km^{-1} hogging curvature and 0.03 km^{-1} sagging curvature.

The maximum predicted curvatures for the remaining farm dams are 0.04 km^{-1} hogging and 0.06 km^{-1} sagging, which equate to minimum radii of curvatures of 25 km and 17 km, respectively. These dams could experience the full range of the predicted strains, which is discussed in Section 4.4.

The dam walls are constructed with cohesive materials which would be expected to tolerate tensile strains of up to 3 mm/m without adverse impact, because of their inherent elasticity. The maximum predicted curvatures for the farm dams within the Study Area are similar to the maxima predicted for the farm dams which were located above the previously extracted longwalls at the Mine. There were 14 farm dams located directly above Longwalls A3 to A5A in Stage 2 and Longwalls A7 and A8 in Stage 3 and there were no reported mining related impacts.

There is also extensive experience of mining directly beneath farm dams in the Southern Coalfield, where the maximum predicted subsidence parameters are similar to or greater than the maxima predicted for the proposed longwalls. This incidence of impacts on farm dams is very low, being less than 0.5 %.

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.

6.10.4. Recommendations for the farm dams

Built Features Management Plans have previously been developed for properties located above and adjacent to the approved Longwalls B1 to B3. It is recommended that similar management plans are developed for the additional properties within the Study Area.

It is recommended that all water retaining structures located directly above the proposed longwalls be periodically visually monitored during active subsidence. With the necessary management strategies in place, it is unlikely that there would be any significant long term impacts on the farm dams.

6.11. Groundwater bores

The locations of the groundwater bores near the proposed longwalls are shown in Drawing No. MSEC869-09. The locations and details of the registered groundwater bores were obtained from the *Natural Resource Atlas* website (NRAtlas, 2017).

There are three registered groundwater bores that have been identified within the Study Area, which are shown in Drawing No. MSEC869-09. A summary of these bores is provided in Table 6.7. There are two other bores (Refs. GW080973 and GW054676) that have been decommissioned and, therefore, have not been shown in the drawing nor included in the table.

Table 6.7 Registered groundwater bores within the Study Area

Reference	Location	Authorised use	Owner
GW201408	Above the finishing end of the proposed Longwall B5	Monitoring	Austar Mine (Ref. NER1010)
GW080974	Located outside and adjacent to the finishing end of the proposed Longwall B4	Monitoring	DPI - Water
GW080975	Located outside and adjacent to the finishing end of the proposed Longwall B4	Monitoring	DPI - Water

It is possible that the groundwater bores could experience some impacts as a result of mining the proposed 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 Mine during the mining period.

Further discussions on the potential impacts on the groundwater resources are provided in the report by Dundon Consulting (2017).

6.12. Archaeological sites

Archaeological sites have been identified within the Study Area than comprise artefact scatters and isolated finds (Umwelt, 2017d). The boundaries for the larger artefact scatter sites and the isolated finds are shown in Drawing No. MSEC869-09. The archaeological sites are generally located near Quorrobolong Creek and the associated tributaries.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the archaeological sites within the Study Area, after the completion of each of the longwalls, is provided in Table 6.8.

Table 6.8 Maximum predicted total vertical subsidence, tilt and curvature for the archaeological sites located within the Study Area

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Archaeological sites	After LWB1 to LWB3	125	1.5	0.03	< 0.01
	After LWB4	125	1.5	0.03	< 0.01
	After LWB5	400	3.0	0.03	0.01
	After LWB6	1025	3.5	0.03	0.04
	After LWB7	1225	4.5	0.04	0.04

The archaeological sites are predicted to experience mine subsidence movements up to 1225 mm vertical subsidence, 4.5 mm/m tilt (i.e. 0.45 %), 0.04 km^{-1} hogging and sagging curvatures (25 km minimum radius of curvature).

The archaeological sites are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays. The analysis of strain in survey bays during the extraction of the previous longwalls at the Mine is discussed in Section 4.4.1.

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 archaeological sites could potentially be affected by cracking of the surface soils as a result of the proposed mining. It is expected that only isolated and minor cracking of the surface soils would develop, due to the extraction of the proposed Longwalls B4 to B7, which is discussed in Section 4.7. It is unlikely, however, that the scattered artefacts themselves would be impacted by any surface cracking.

Archaeological sites are located above the previously extracted Longwalls A3 to A5A in Stage 2 and Longwalls A7 and A8 in Stage 3 at the Mine. There has been no significant or visible surface cracking above these previously extracted longwalls. There have also been no reported adverse mining related impacts on the artefact scatters and isolated finds.

Management strategies should be developed to remediate any surface cracking, if required, in the vicinity of the archaeological sites. Further assessments of the potential impacts on the archaeological sites are provided in a report by Umwelt (2017d).

6.13. Survey control marks

The locations of the survey control marks near the proposed longwalls are shown in Drawing No. MSEC869-09. The locations and details of the state survey control marks were obtained from the *Land and Property Management Authority* using the *Six Viewer* (2017).

There are four survey control marks identified within the Study Area, located along the alignment of Sandy Creek Road. These marks are located directly above the approved and proposed longwalls and, therefore, 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.

Additional survey control marks located further afield could be affected by far-field horizontal movements, up to 3 kilometres outside the extents of the proposed longwalls. Far-field horizontal movements and the methods used to predict such movements are described further in Section 4.6.

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

6.14. Houses

6.14.1. Descriptions of the houses

There are six houses (Structure Type H) that have been identified within the Study Area, of which three are located directly above the proposed Longwalls B4 to B7 and one is located directly above the approved Longwalls B1 to B3. The locations of these houses are shown in Drawing No. MSEC869-09 and details provided in Table 6.9. The sizes of the houses were determined from the aerial photograph of the area. The types of construction of the houses were determined, where possible, from kerb side inspections.

Table 6.9 Descriptions of the houses

Structure ref.	Maximum planar dimension (m)	Number of Storeys	Wall construction	Footing construction	Roof construction
A02d	20	Single	Timber Frame	Piers	Metal
A06a	16	Single	Timber Frame	Slab on Ground	Metal
A08h01	24	Single	Timber Frame	Piers	Metal
C02h01	16	Double	Timber Frame	Piers	Metal
C04h01	23	Single	Steel Frame	Slab on Ground	Metal
C05h01	13	Single	Timber Frame	Piers	Tiles

House Ref. A02d is located above the approved Longwall B3. House Ref. A08h01 is located directly above the maingate of the proposed Longwall B5, near the finishing end of this longwall. House Ref. C02h01 is located above the middle of the proposed Longwall B5. House C04h01 is located above the commencing (i.e. south-western) end of the proposed Longwall B6. The remaining two houses are located outside the extents of the approved and proposed longwalls, at distances between 50 and 100 m.

6.14.2. 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 m. In the case of a rectangular shaped structure, predictions have been made at a minimum of 45 points within and around the structure.

The predicted total conventional subsidence, tilts and curvatures for the houses within the Study Area are provided in Table D.03, in Appendix D. A summary of the maximum predicted subsidence parameters for each of the houses within the Study Area is provided in Table 6.10. The values include the predicted movements resulting from the previous extraction of the adjacent longwalls at Ellalong Colliery and Austar Coal Mine (i.e. cumulative movements).

Table 6.10 Maximum predicted total vertical subsidence, tilt and curvature for the houses

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted final total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Houses	A02d	725	5.0	0.03	< 0.01
	A06a	175	1.0	0.02	< 0.01
	A08h01	700	3.5	0.02	0.02
	C02h01	1200	1.0	0.03	0.03
	C04h01	450	3.5	0.03	0.02
	C05h01	90	1.0	< 0.01	< 0.01

The houses are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays. The analysis of strain in survey bays during the extraction of the previous longwalls at the Mine is discussed in Section 4.4.1.

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.

6.14.3. 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 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 (2017b).

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 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 is 5 mm/m (i.e. 0.5 %), which represents a change in grade of 1 in 200. 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

There are three houses that are located directly above the proposed Longwalls B4 to B7 (i.e. Refs. C02h01, C04h01 and A08h01) and one house located directly above the approved Longwalls B1 to B3 (Ref. A02d). The maximum predicted curvature for these houses are 0.03 km^{-1} both hogging and sagging, which represent a minimum radius of curvature of 33 km. These houses could also experience strains of 0.9 mm/m tensile and 1.2 mm/m compressive, based on the 95 % confidence level.

The remaining two houses (i.e. Refs. A06a and C05h01) are located outside the extents of the proposed and approved longwalls, at distances of 50 to 100 m. The maximum predicted curvatures for these houses are 0.02 km^{-1} hogging and less than 0.01 km^{-1} sagging, which represent minimum radii of curvature of 50 km and greater than 100 km, respectively. These houses are expected to experience strains typically less than 0.5 mm/m, based on the 95 % confidence level.

The maximum predicted curvatures and strains for the houses within the Study Area are similar to the maxima predicted for the houses located above the previously extracted longwalls in Stages 2 at the Mine. Longwalls A3 to A5a were extracted directly beneath seven houses and no substantial impacts were reported.

It is unlikely, therefore, that the houses within the Study Area would experience substantial impacts as a result of the proposed mining. It is possible that some houses could experience some minor impacts, such as cracking in the internal plasterboard linings or cornices and cracking in the external brickwork. It would be expected that any such impacts could be remediated using normal building maintenance techniques. All houses within the Study Area are expected to remain safe, serviceable and repairable throughout the mining period.

6.14.4. Recommendations for the houses

Built Features Management Plans have previously been developed for properties located above and adjacent to the approved Longwalls B1 to B3. It is recommended that similar management plans are developed for the additional properties within the Study Area. It is recommended that the houses are periodically visually monitored during the extraction of the proposed longwalls.

6.15. Pools

There is one privately owned swimming pool (Ref. C02p01) identified within the Study Area, which is located above the proposed Longwall B5. This pool is located near House Ref. C02h01, which is shown in Drawing No. MSEC869-09.

The predicted subsidence parameters for the swimming pool are included in in Table D.01, in Appendix D. The maximum predicted parameters are: 1,200 mm vertical subsidence; 1.0 mm/m tilt (i.e. 0.1 %, or 1 in 1000); 0.03 km^{-1} hogging and sagging curvatures (33 km minimum radius).

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.

The maximum predicted tilt of the pool within the Study Area is 1 mm/m and, therefore, is less than the Australian Standard. The mining-induced tilt is very small and may not be noticeable.

Observations during the mining of Tahmoor Colliery Longwalls 22 to 27 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 March 2014, a total of 155 pools have experienced mine subsidence movements during the mining of Tahmoor Colliery Longwalls 22 to 27, of which 142 were located directly above the extracted longwalls. A total of 32 pools have reported impacts, of which all except two pools were located directly above the extracted longwalls. This represents an impact rate of approximately 21 %. A higher proportion of impacts have 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 curvatures and strains for the pool Ref. C02p01 are similar orders of magnitude to, but, less than the maxima predicted at Tahmoor Colliery. The potential for impacts on this pool, therefore, is expected to be similar to or less than that experienced at Tahmoor Colliery. The potential for major adverse impacts on pool Ref. C02p01 has been assessed as unlikely (i.e. less than 25 %).

6.16. On-site waste water systems

The residences on the rural properties within the Study Area have on-site waste water systems. The systems are located near the houses and, therefore, are expected to experience similar mine subsidence movements as the houses which are provided in Table D.03, in Appendix D.

The on-site waste water systems are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays. The analysis of strain in survey bays during the extraction of the previous longwalls at the Mine is discussed in Section 4.4.1.

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, however, could 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 m 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.

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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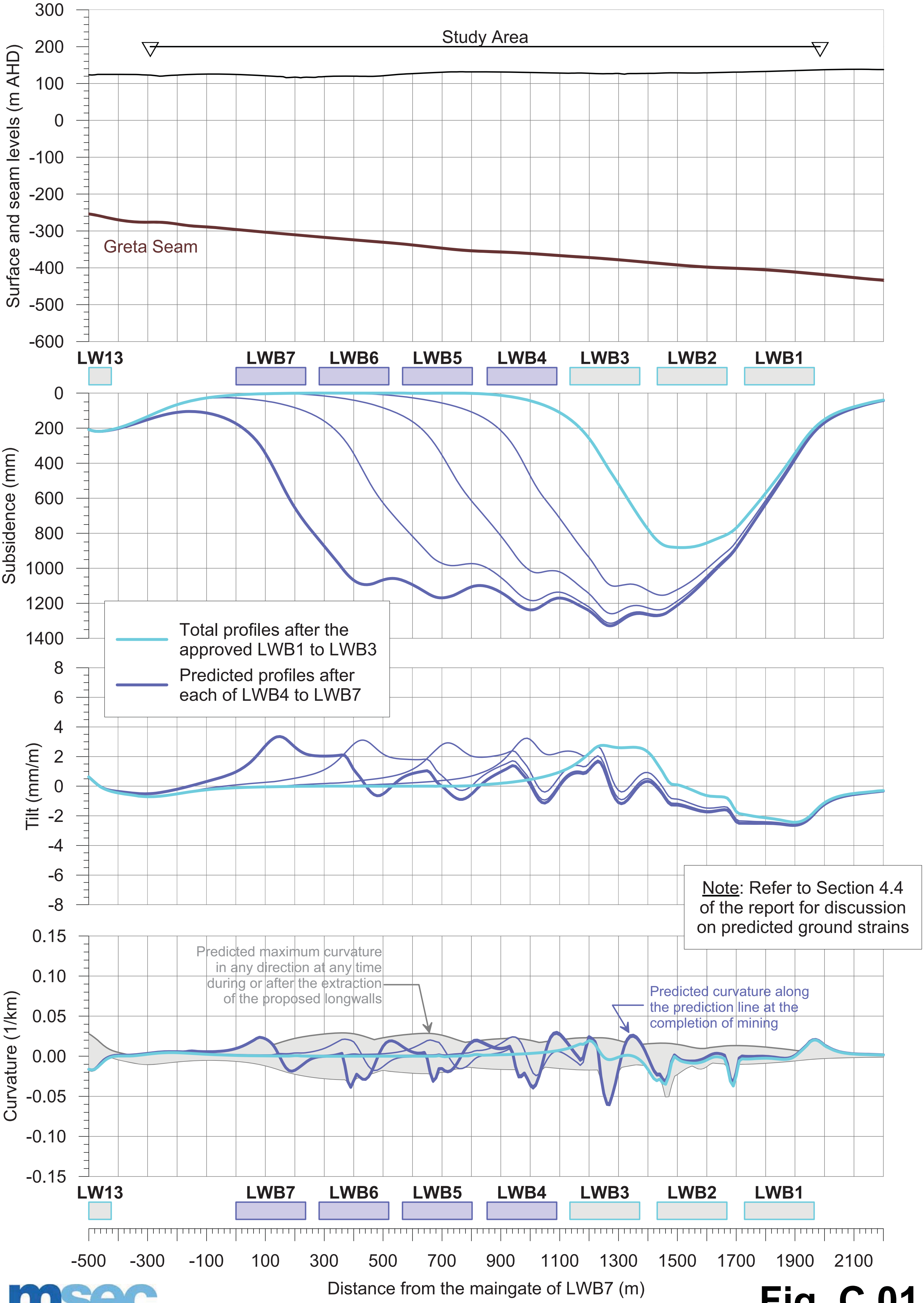
APPENDIX C.   FIGURES

I:\Projects\Austar\Stage 2\MSEC869 - Longwalls B4 to B7\Subsdata\Impacts\Prediction Lines\Fig. C.01 - Prediction Line 1.grf.....10-Apr-17

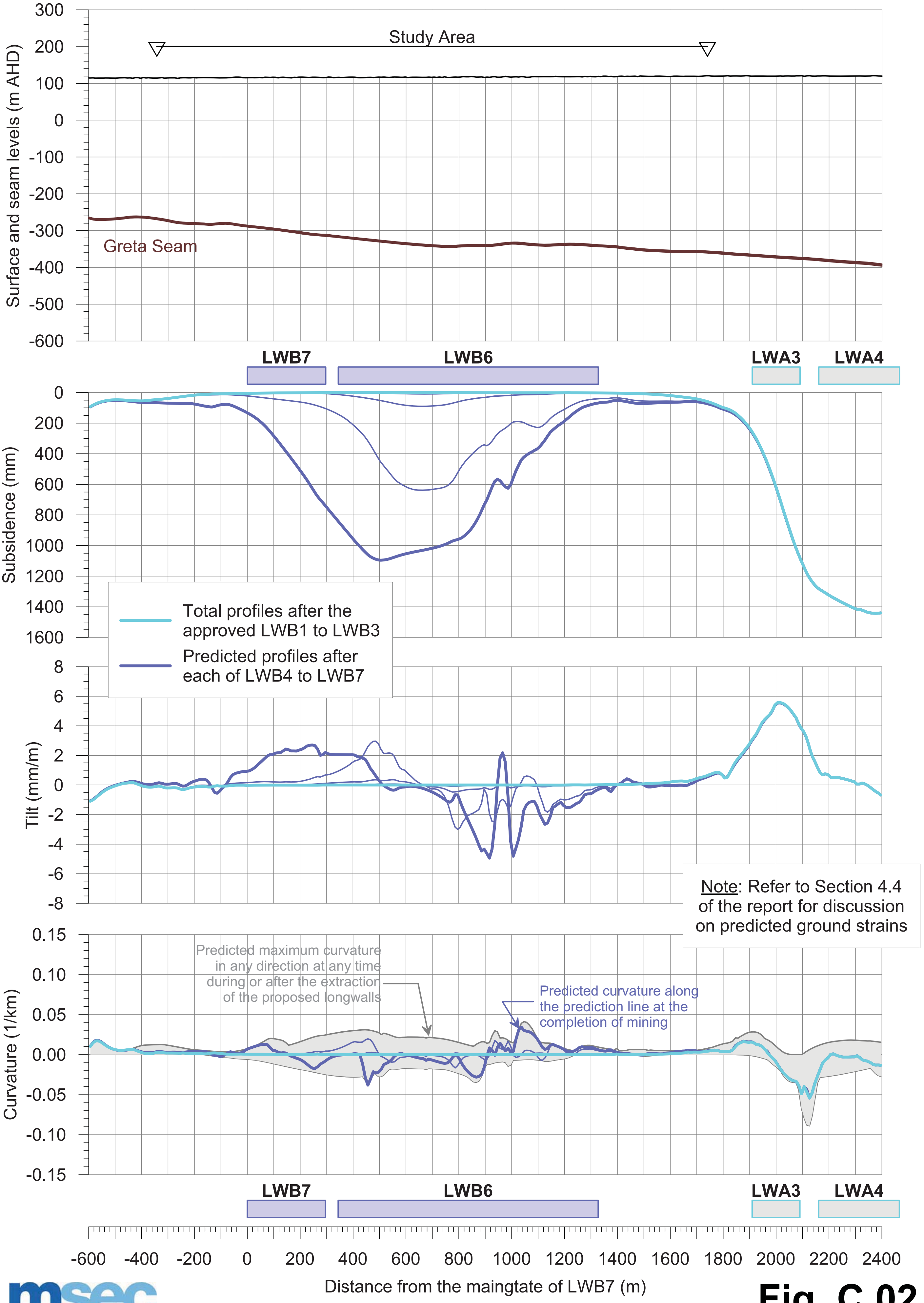
Predicted profiles of conventional subsidence, tilt and curvature along Prediction Line 1 resulting from the extraction of Longwalls B1 to B7



Note: Refer to Section 4.4 of the report for discussion on predicted ground strains

Fig. C.01

Predicted profiles of conventional subsidence, tilt and curvature along Quorrobolong Creek resulting from the extraction of Longwalls B1 to B7



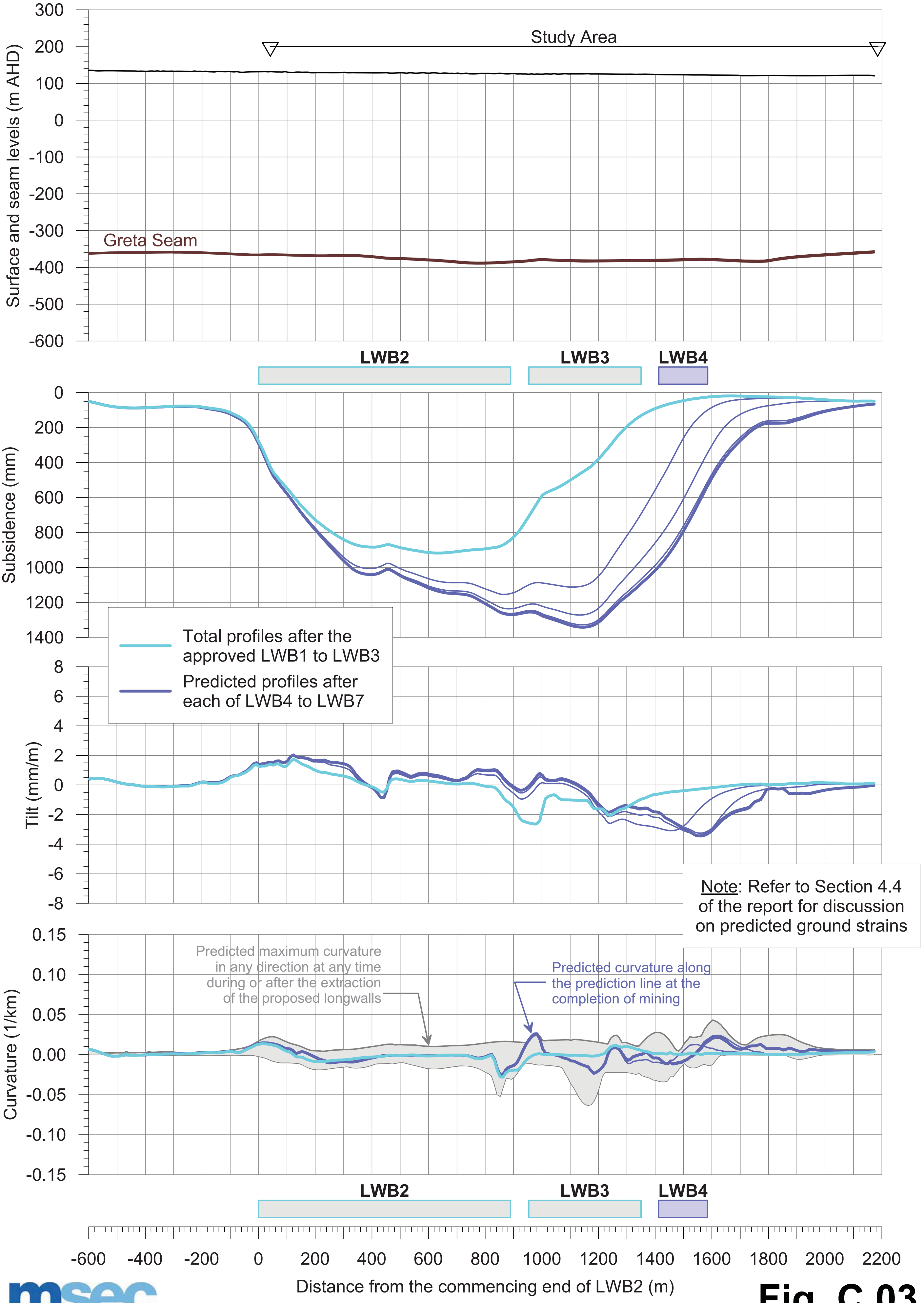
Note: Refer to Section 4.4 of the report for discussion on predicted ground strains

Predicted maximum curvature in any direction at any time during or after the extraction of the proposed longwalls

Predicted curvature along the prediction line at the completion of mining

Fig. C.02

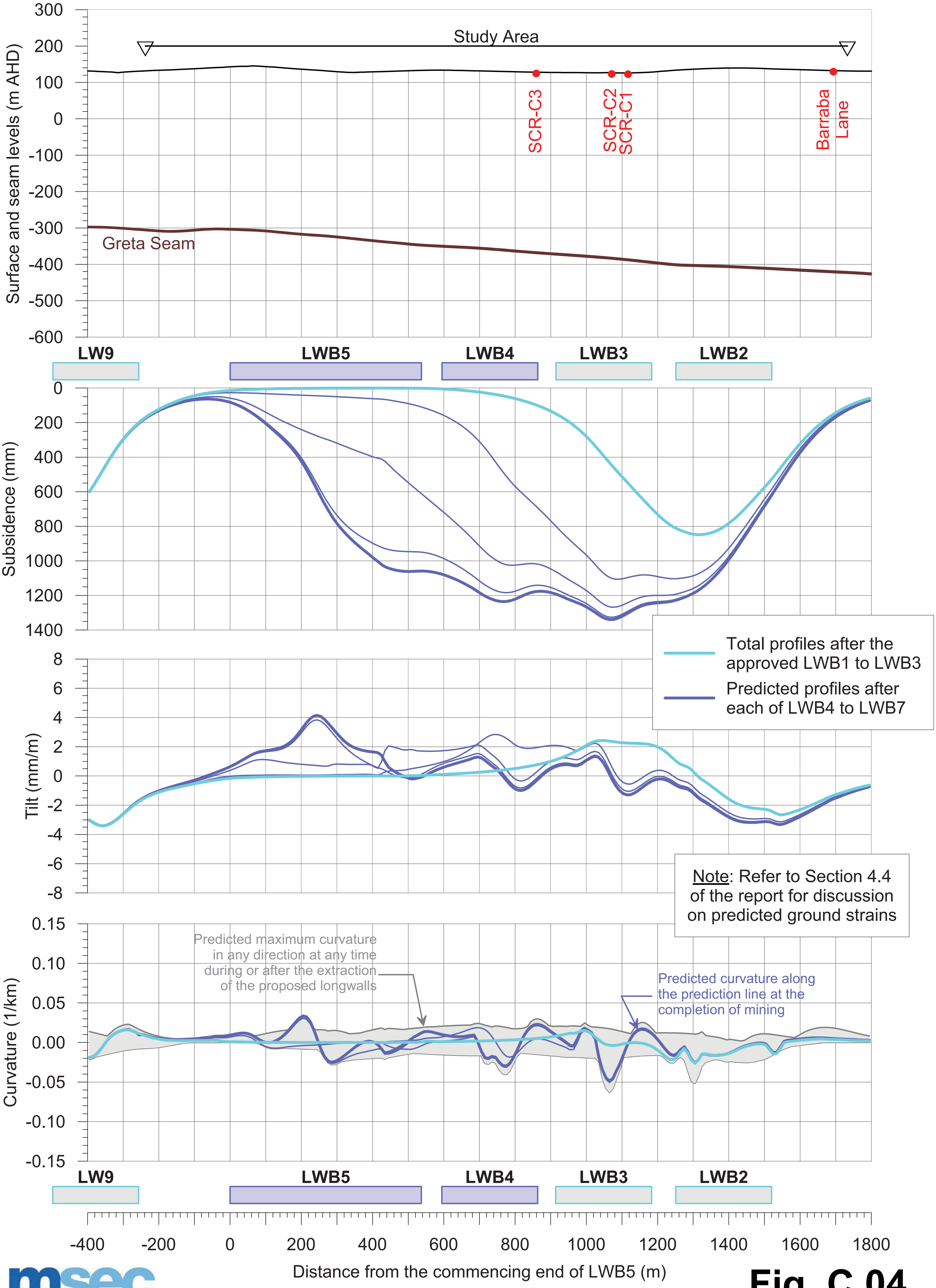
Predicted profiles of conventional subsidence, tilt and curvature along Drainage Line 1 resulting from the extraction of Longwalls B1 to B7



Note: Refer to Section 4.4 of the report for discussion on predicted ground strains

Fig. C.03

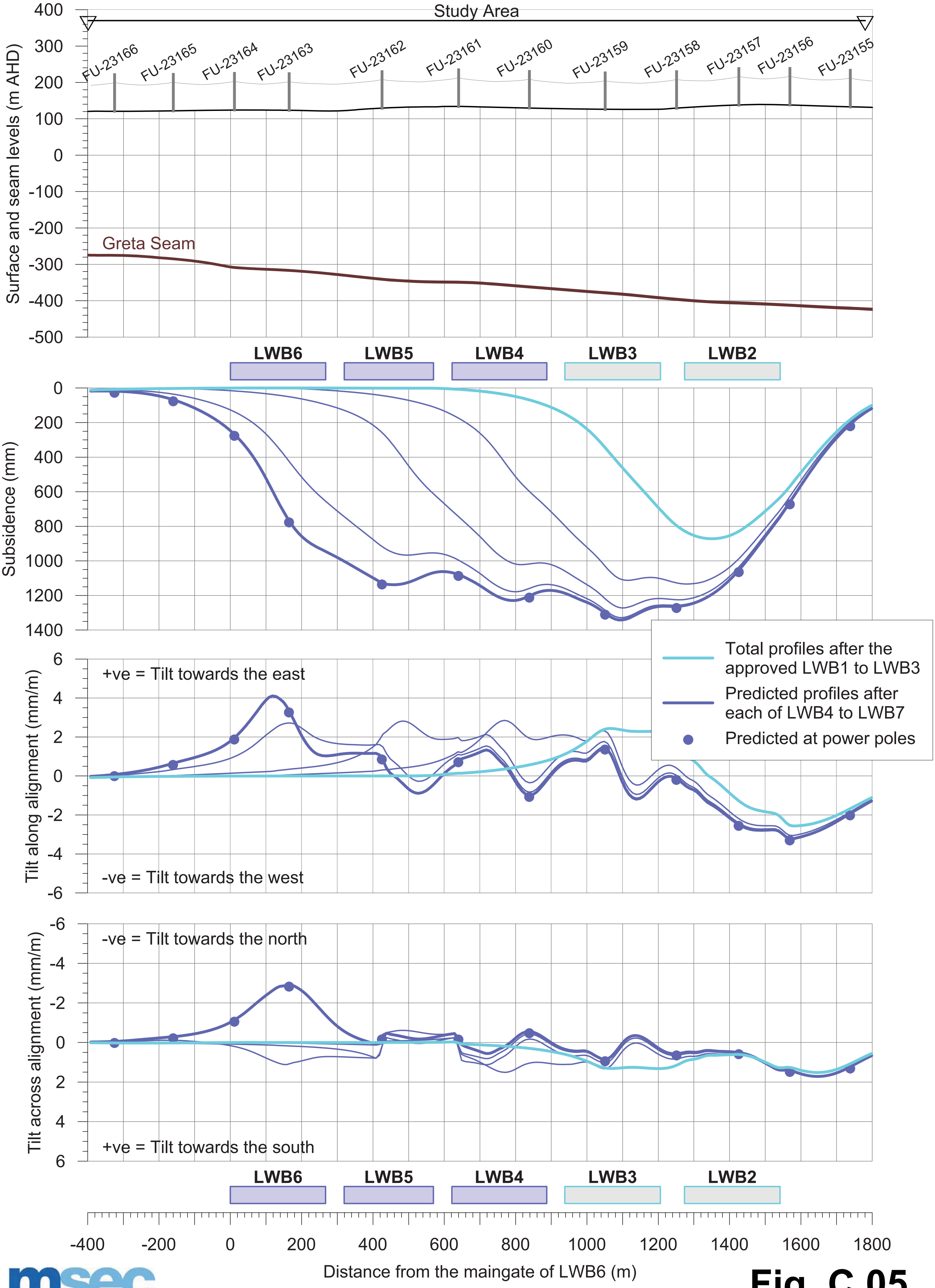
Predicted profiles of conventional subsidence, tilt and curvature along Sandy Creek Road resulting from the extraction of Longwalls B1 to B7



Note: Refer to Section 4.4 of the report for discussion on predicted ground strains

Fig. C.04

Predicted profiles of conventional subsidence, tilt along and tilt across the 11 kV Powerline Branch 1 resulting from the extraction of Longwalls B1 to B7

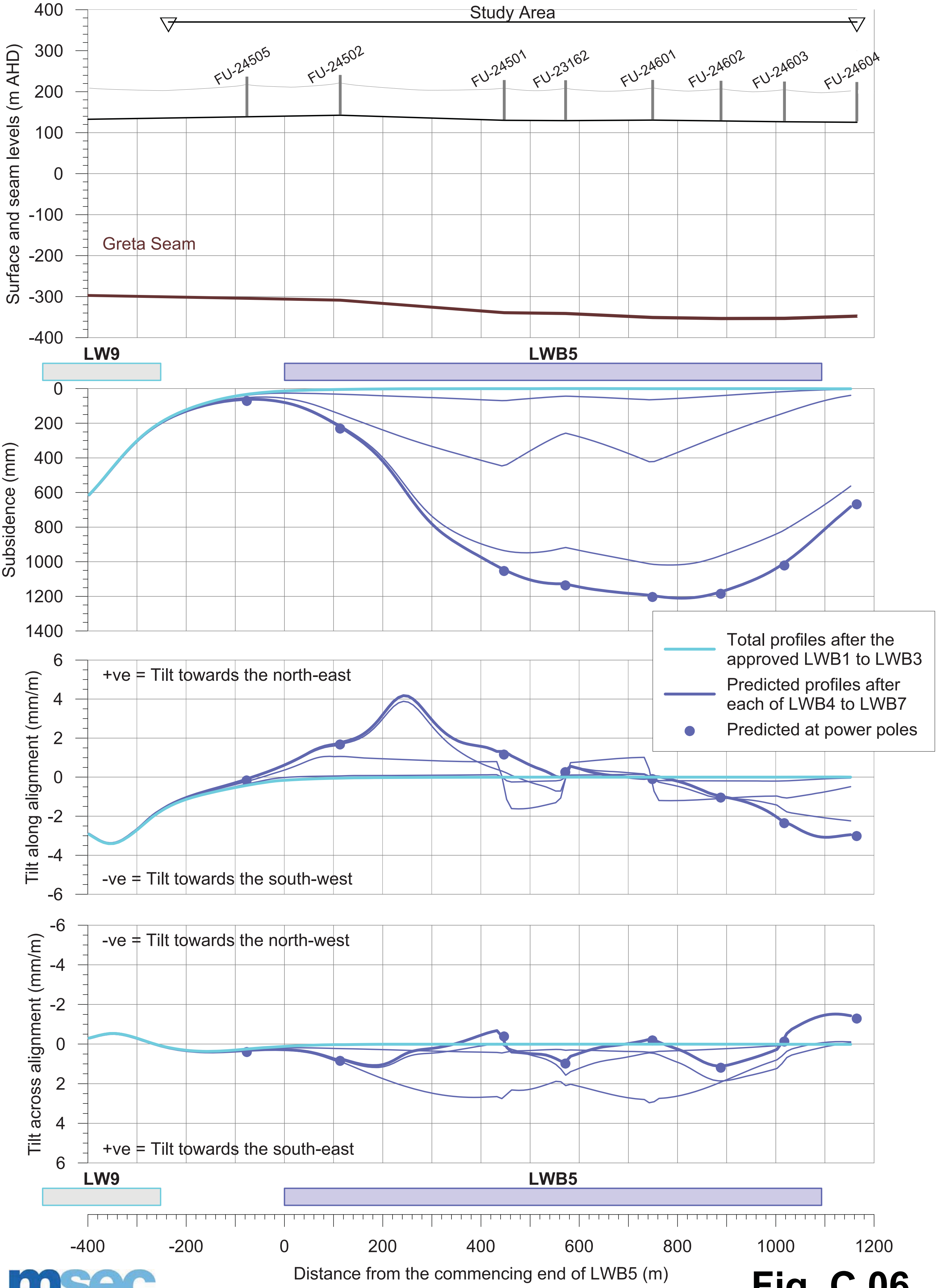


msec

Fig. C.05

I:\Projects\Austar\Stage 2\MSEC869 - Longwalls B4 to B7\Subsdata\Impacts\Electrical\Fig. C.06 - 11 kV Powerline Branch 2.grf.....10-Apr-17

Predicted Profiles of conventional subsidence, tilt along and tilt across the 11 kV Powerline Branch 2 resulting from the extraction of Longwalls B1 to B7



msec

Fig. C.06

APPENDIX D. TABLES

Table D.01 - Maximum predicted subsidence parameters for the rural structures within the Study Area

Property Reference	Structure Reference (refer to Drawing No. MSEC869-09)	Type	Predicted Total Subsidence after LWB1 to LWB3 (mm)	Predicted Total Subsidence after LWB4 (mm)	Predicted Total Subsidence after LWB5 (mm)	Predicted Total Subsidence after LWB6 (mm)	Predicted Total Subsidence after LWB7 (mm)	Predicted Total Tilt after LWB1 to LWB7 (mm/m)	Predicted Total Hogging Curvature after LWB1 to LWB7 (1/km)	Predicted Total Sagging Curvature after LWB1 to LWB7 (1/km)
A01	A01j	Shed	150	175	175	175	175	1.5	0.02	< 0.01
	A01k	Tank	150	175	175	200	200	1.5	0.02	< 0.01
A02	A02a	Shed	80	90	100	125	125	< 0.5	0.01	< 0.01
	A02b	Shed	70	80	100	125	150	0.5	0.01	< 0.01
	A02c	Shed	175	475	675	775	775	5.0	0.03	0.01
	A02e	Shed	150	425	625	725	750	5.0	0.03	< 0.01
	A02f	Shed	200	525	725	800	825	5.0	0.03	0.02
	A02g	Shed	90	275	475	600	625	4.5	0.03	< 0.01
	A02h	Tank	125	375	575	675	675	5.0	0.03	< 0.01
	A02i	Tank	125	400	600	675	700	5.0	0.03	< 0.01
	A02j	Tank	150	425	600	700	725	5.0	0.03	< 0.01
A06	A06b	Shed	100	150	175	200	200	1.5	0.02	< 0.01
	A06c	Shed	100	150	175	200	225	1.5	0.02	< 0.01
	A06d	Shed	100	150	175	225	225	2.0	0.02	< 0.01
A08	A08r01	Shed	< 20	< 20	30	525	650	4.0	0.03	0.02
	A08r02	Shed	< 20	< 20	40	550	725	4.0	0.03	0.02
	A08r03	Shed	< 20	< 20	50	600	750	4.0	0.02	0.02
	A08r04	Shed	< 20	< 20	70	675	825	3.5	0.02	0.02
	A08t01	Tank	< 20	< 20	50	625	750	3.5	0.02	0.02
	A08t02	Tank	< 20	< 20	70	675	825	3.5	0.02	0.02
B03	B03r07	Shed	750	775	800	800	800	2.5	0.01	0.02
	B03r08	Shed	800	875	900	900	900	2.5	0.01	0.04
	B03r09	Shed	825	925	950	950	950	2.5	0.01	0.04
	B03r10	Tank	800	875	875	875	875	2.5	0.01	0.04
	B03r11	Tank	750	825	825	825	825	2.5	0.01	0.02
	B03r12	Tank	775	850	850	850	850	2.5	0.01	0.04
	B03r13	Shed	800	875	900	900	900	2.5	0.01	0.04
C01	C01r01	Shed	< 20	250	875	1100	1200	1.0	0.02	0.02
	C01r02	Tank	< 20	225	875	1100	1200	1.0	0.02	0.02
	C01r03	Shed	< 20	150	725	1050	1150	1.0	0.02	0.02
	C01r04	Shed	< 20	200	825	1100	1150	1.0	0.02	0.02
C02	C02p01	Pool	< 20	50	325	975	1200	1.0	0.03	0.03
	C02r01	Garage	< 20	50	300	975	1200	1.0	0.03	0.03
	C02r02	Shed	< 20	50	300	950	1150	1.0	0.03	0.03
	C02r03	Shed	< 20	50	275	950	1150	1.0	0.03	0.03
	C02r04	Shed	< 20	40	250	925	1150	1.0	0.03	0.02
	C02r05	Shed	< 20	40	225	900	1150	1.0	0.03	0.02
	C02r06	Shed	< 20	50	350	975	1200	1.0	0.03	0.03
	C02r07	Gazebo	< 20	70	425	1000	1200	< 0.5	0.03	0.03
	C02t01	Tank	< 20	50	325	975	1200	1.0	0.03	0.03
	C02t02	Tank	< 20	50	350	975	1200	1.0	0.03	0.03
C03	C03r01	Shed	< 20	< 20	< 20	20	30	< 0.5	< 0.01	< 0.01
	C03r02	Shed	< 20	< 20	< 20	20	30	< 0.5	< 0.01	< 0.01
C05	C05r01	Shed	< 20	< 20	40	70	80	1.0	< 0.01	< 0.01
	C05r02	Awning	< 20	< 20	40	80	90	1.0	< 0.01	< 0.01
	C05t01	Tank	< 20	< 20	30	60	70	0.5	< 0.01	< 0.01
	C05t02	Tank	< 20	< 20	30	70	80	1.0	< 0.01	< 0.01
	C05t03	Tank	< 20	< 20	50	90	100	1.0	< 0.01	< 0.01
		Maximum	**825**	**925**	**950**	**1100**	**1200**	**5.0**	**0.03**	**0.04**

Table D.02 - Maximum predicted subsidence parameters for the farm dams within the Study Area

Property Reference	Dam Reference (refer to Drawing No. MSEC869-09)	Maximum Planar Dimension (m)	Surface Area (m2)	Predicted Total Subsidence after LWB1 to LWB3 (mm)	Predicted Total Subsidence after LWB4 (mm)	Predicted Total Subsidence after LWB5 (mm)	Predicted Total Subsidence after LWB6 (mm)	Predicted Total Subsidence after LWB7 (mm)	Predicted Total Tilt after LWB1 to LWB7 (mm/m)	Predicted Total Hogging Curvature after LWB1 to LWB7 (1/km)	Predicted Total Sagging Curvature after LWB1 to LWB7 (1/km)	Predicted Total Change in Freeboard (mm)
A01	A01d06	71	1467	250	275	300	300	300	3.0	0.02	< 0.01	50
A02	A02d01	133	6223	70	70	80	150	175	1.5	0.02	< 0.01	< 50
A04	A04d06	83	1806	375	375	375	375	375	3.5	0.04	< 0.01	150
A06	A06d01	81	2968	200	325	400	475	475	4.0	0.03	< 0.01	200
	A06d02	28	480	125	150	175	175	175	1.0	0.02	< 0.01	< 50
	A06d03	60	968	425	475	500	525	525	4.5	0.03	0.03	100
	A06d04	9	52	60	90	125	175	175	1.5	0.02	< 0.01	< 50
A07	A07d01	80	2464	< 20	30	300	625	675	4.5	0.04	< 0.01	200
A08	A08d01	76	2549	< 20	< 20	40	550	625	4.0	0.03	0.02	200
	A08d02	40	417	< 20	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01	< 50
B01	B01d01	40	956	800	900	925	950	950	2.5	0.01	0.04	100
	B01d02	47	879	425	1100	1250	1300	1300	1.5	0.02	0.06	< 50
	B01d03	35	1044	60	550	1000	1150	1200	1.5	0.02	0.04	< 50
B02	B02d01	63	1714	550	600	600	625	625	2.5	0.01	< 0.01	100
	B02d02	34	718	650	800	825	825	825	4.5	0.02	0.02	150
B03	B03d03	82	806	400	425	425	425	425	2.5	0.02	< 0.01	100
	B03d04	41	955	125	150	150	150	150	1.0	0.01	< 0.01	< 50
	B03d05	8	29	600	675	700	700	700	4.0	0.02	0.02	< 50
C01	C01d01	63	1695	80	625	1050	1200	1250	1.5	0.02	0.04	< 50
C03	C03d01	439	46886	70	70	70	150	625	4.5	0.04	0.03	500
	C03d02	159	3432	< 20	< 20	< 20	100	475	4.0	0.03	0.03	300
C05	C05d01	34	686	< 20	< 20	< 20	30	40	< 0.5	< 0.01	< 0.01	< 50
	C05d02	25	405	< 20	< 20	< 20	< 20	20	< 0.5	< 0.01	< 0.01	< 50
C06	C06d01	46	1006	50	50	50	60	60	< 0.5	0.01	< 0.01	< 50
			Maximum	**800**	**1100**	**1250**	**1300**	**1300**	**4.5**	**0.04**	**0.06**	**500**

Table D.03 - Maximum Predicted Subsidence Parameters for the Houses within the Study Area

Structure Reference (refer to Drawing No. MSEC869-09)	Predicted Total Subsidence after LWB1 to LWB3 (mm)	Predicted Total Subsidence after LWB4 (mm)	Predicted Total Subsidence after LWB5 (mm)	Predicted Total Subsidence after LWB6 (mm)	Predicted Total Subsidence after LWB7 (mm)	Predicted Total Tilt after LWB1 to LWB3 (mm/m)	Predicted Total Tilt after LWB4 (mm/m)	Predicted Total Tilt after LWB5 (mm/m)	Predicted Total Tilt after LWB6 (mm/m)	Predicted Total Tilt after LWB7 (mm/m)
A02d	200	475	625	725	725	2.0	4.0	5.0	5.0	5.0
A06a	100	150	150	175	175	< 0.5	0.5	1.0	1.0	1.0
A08h01	< 20	< 20	50	600	700	< 0.5	< 0.5	0.5	3.0	3.5
C02h01	< 20	60	375	1000	1200	< 0.5	< 0.5	3.0	2.0	1.0
C04h01	< 20	< 20	90	375	450	< 0.5	< 0.5	0.5	3.0	3.5
C05h01	< 20	< 20	40	80	90	< 0.5	< 0.5	< 0.5	1.0	1.0
Maximum	**200**	**475**	**625**	**1000**	**1200**	**2.0**	**4.0**	**5.0**	**5.0**	**5.0**

Table D.03 - Maximum Predicted Subsidence Parameters for the Houses within the Study Area

Structure Reference (refer to Drawing No. MSEC869-09)	Predicted Total Hogging Curvature after LWB1 to LWB3 (1/km)	Predicted Total Hogging Curvature after LWB4 (1/km)	Predicted Total Hogging Curvature after LWB5 (1/km)	Predicted Total Hogging Curvature after LWB6 (1/km)	Predicted Total Hogging Curvature after LWB7 (1/km)	Predicted Total Sagging Curvature after LWB1 to LWB3 (1/km)	Predicted Total Sagging Curvature after LWB4 (1/km)	Predicted Total Sagging Curvature after LWB5 (1/km)	Predicted Total Sagging Curvature after LWB6 (1/km)	Predicted Total Sagging Curvature after LWB7 (1/km)
A02d	0.02	0.03	0.03	0.03	0.03	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
A06a	< 0.01	0.01	0.01	0.02	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
A08h01	< 0.01	< 0.01	< 0.01	0.02	0.02	< 0.01	< 0.01	< 0.01	0.02	0.02
C02h01	< 0.01	< 0.01	0.02	0.03	0.03	< 0.01	< 0.01	< 0.01	0.03	0.03
C04h01	< 0.01	< 0.01	< 0.01	0.03	0.03	< 0.01	< 0.01	< 0.01	0.02	0.02
C05h01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Maximum	**0.02**	**0.03**	**0.03**	**0.03**	**0.03**	**< 0.01**	**< 0.01**	**< 0.01**	**0.03**	**0.03**

APPENDIX E. DRAWINGS

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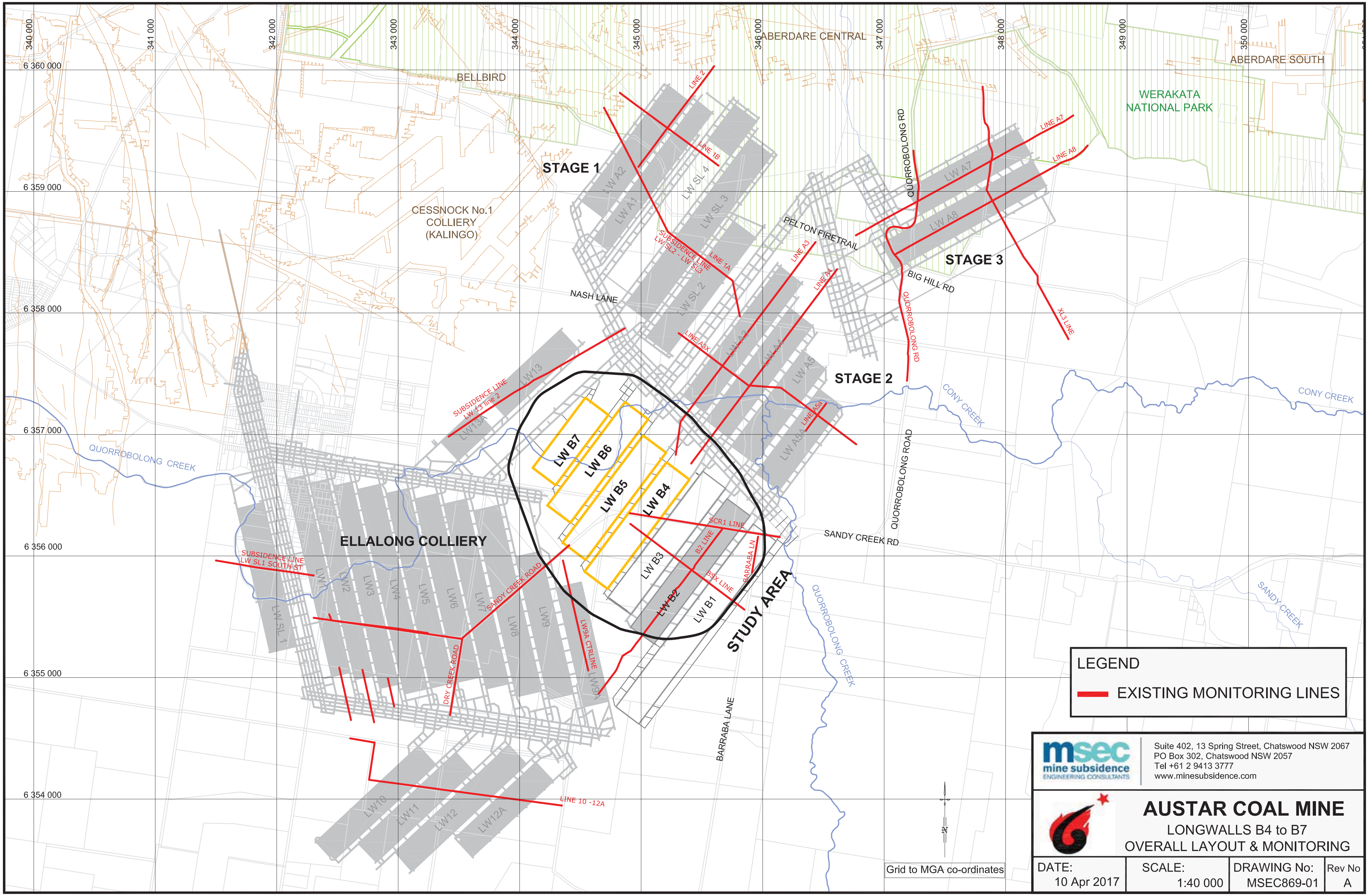

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AUSTAR COAL MINE
LONGWALLS B4 to B7
OVERALL LAYOUT & MONITORING

DATE:	SCALE:	DRAWING No:	Rev No
10 Apr 2017	1:40 000	MSEC869-01	A

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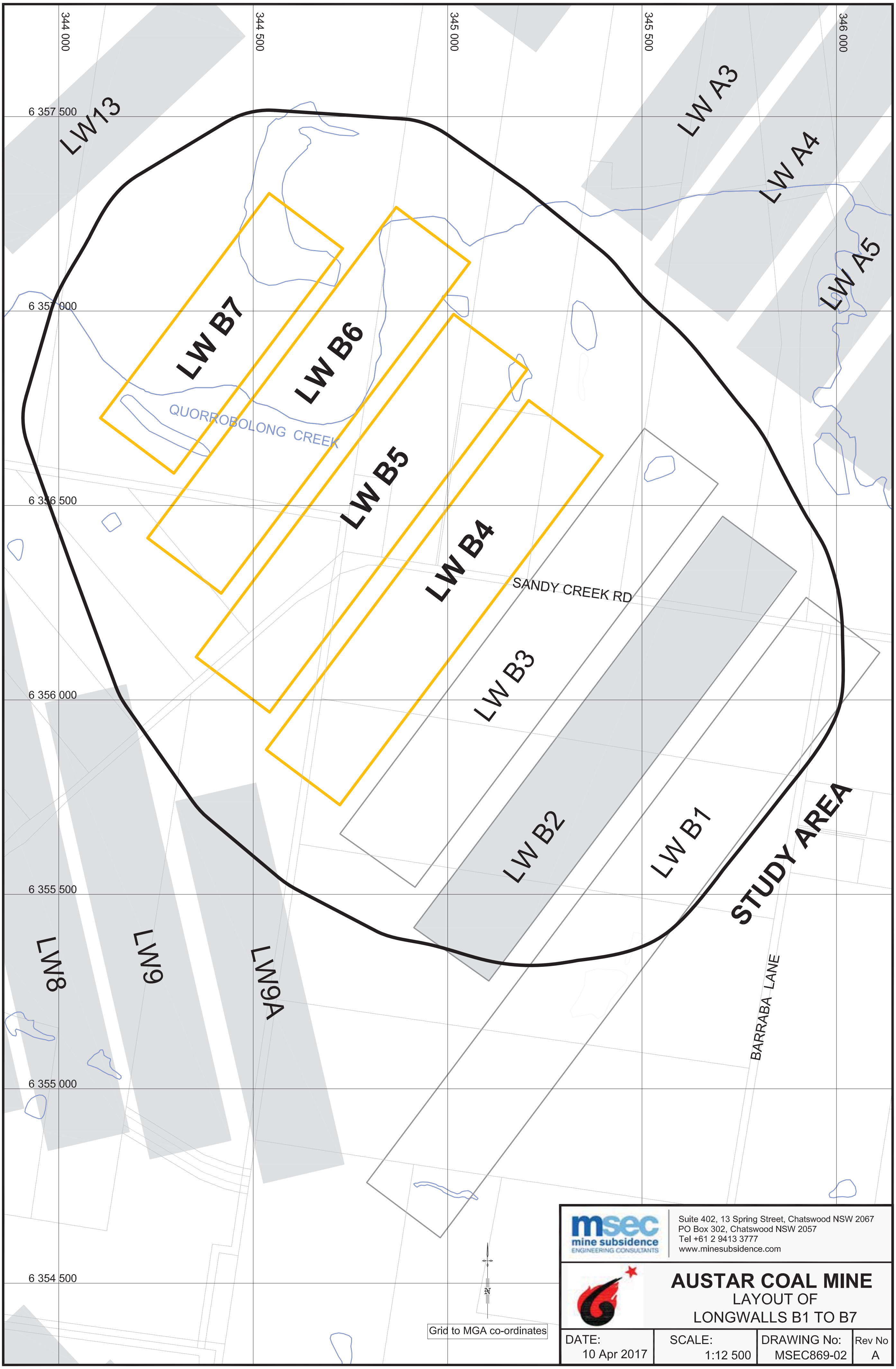

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AUSTAR COAL MINE
LAYOUT OF
LONGWALLS B1 TO B7

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10 Apr 2017	1:12 500	MSEC869-02	A

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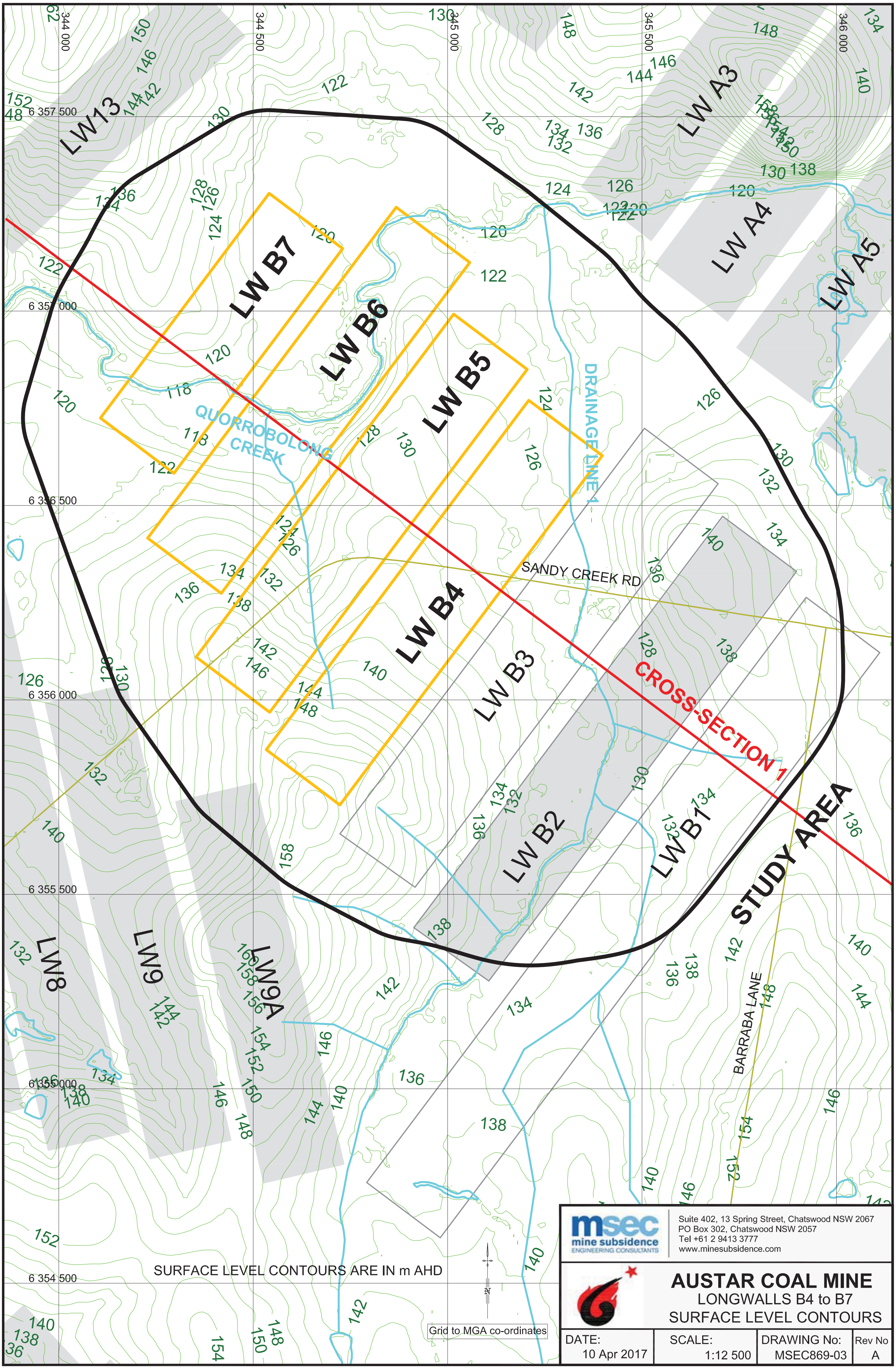

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AUSTAR COAL MINE
LONGWALLS B4 to B7
SURFACE LEVEL CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
10 Apr 2017	1:12 500	MSEC869-03	A

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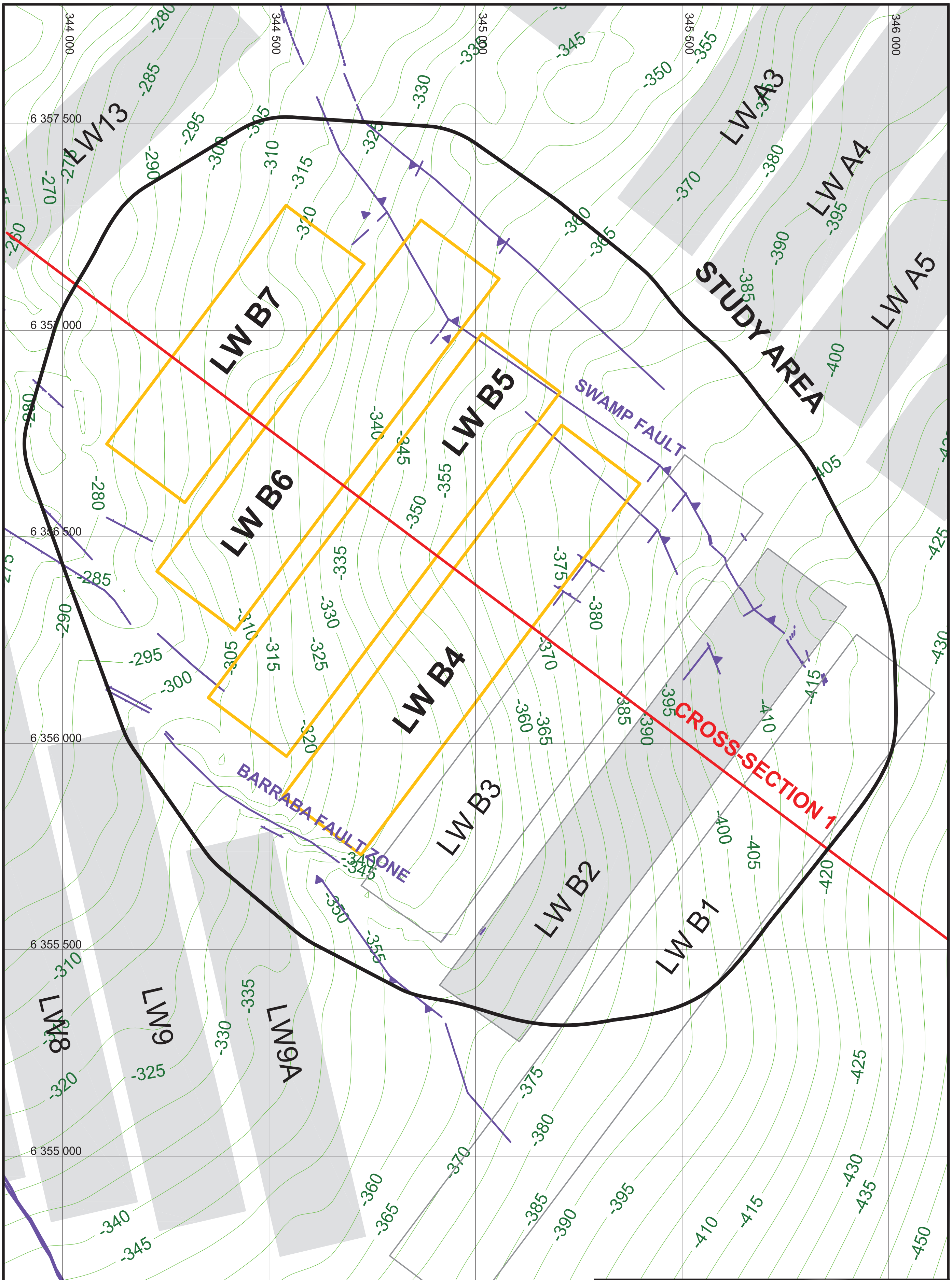

GRETA SEAM FLOOR CONTOURS ARE IN m AHD

Grid to MGA co-ordinates

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LONGWALLS B4 to B7
SEAM FLOOR CONTOURS

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10 Apr 2017	1:12 500	MSEC869-04	A

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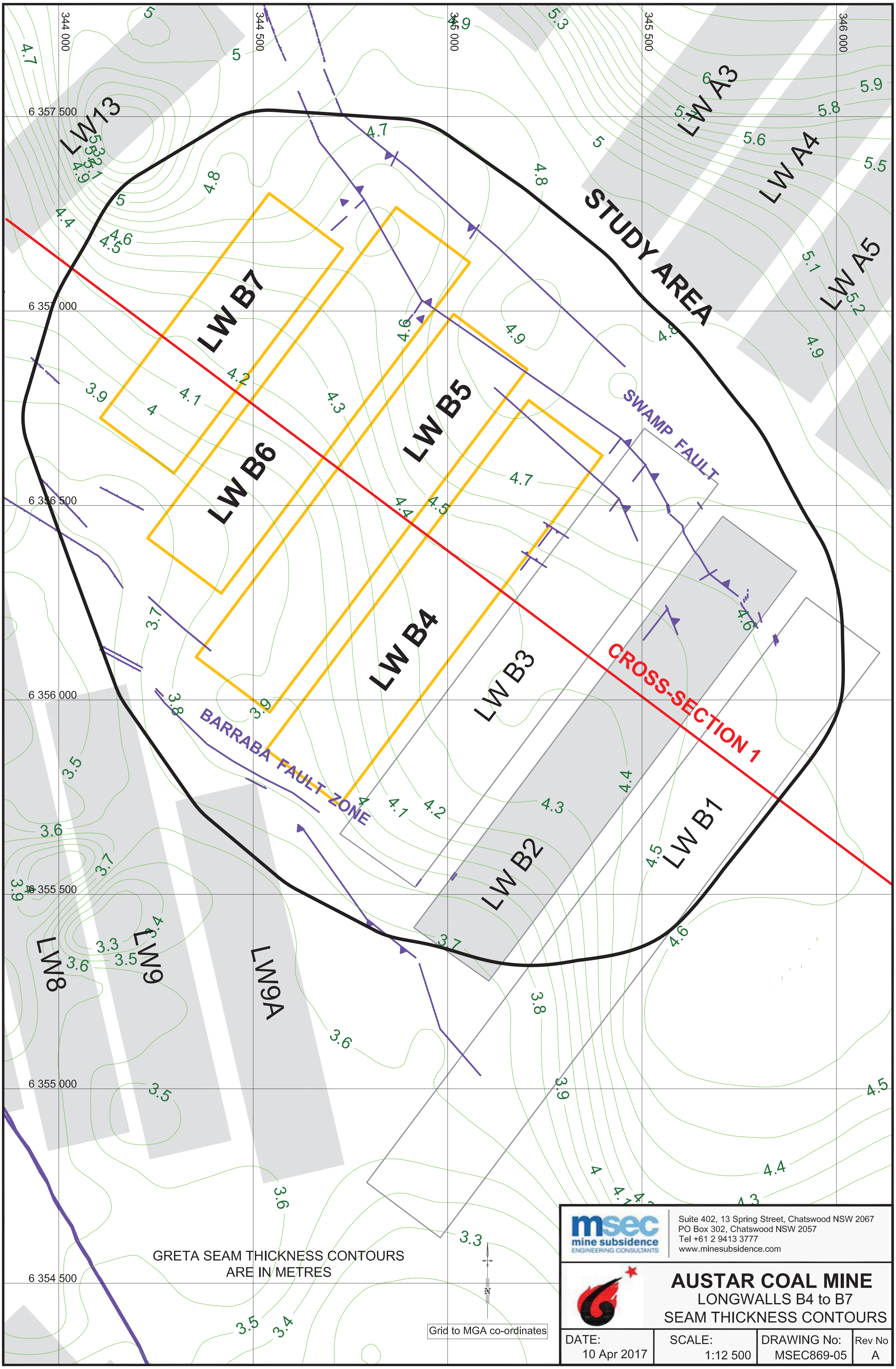

GRETA SEAM THICKNESS CONTOURS
ARE IN METRES

Grid to MGA co-ordinates

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AUSTAR COAL MINE
LONGWALLS B4 to B7
SEAM THICKNESS CONTOURS

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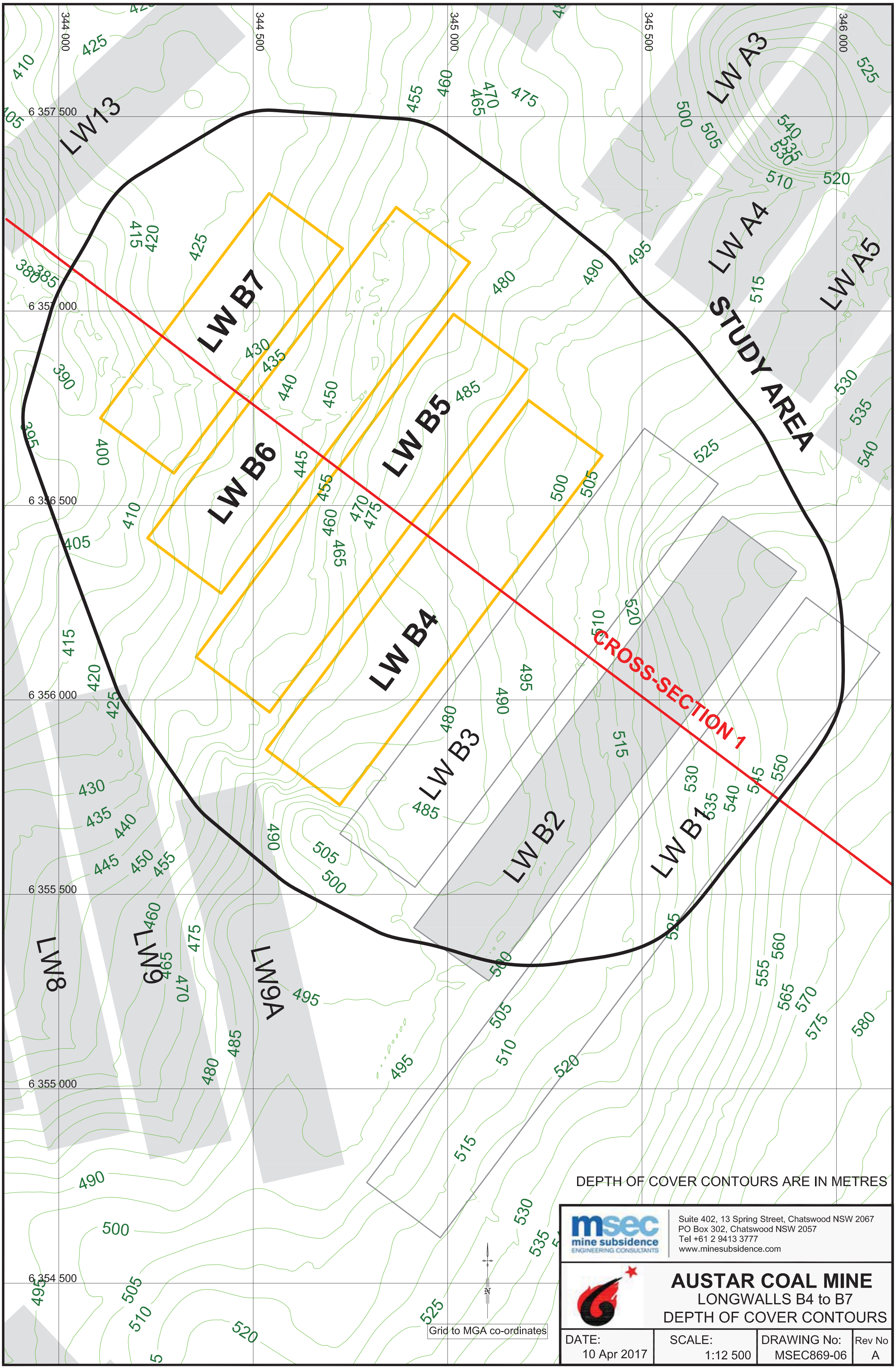

DEPTH OF COVER CONTOURS ARE IN METRES

Grid to MGA co-ordinates

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AUSTAR COAL MINE
LONGWALLS B4 to B7
DEPTH OF COVER CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
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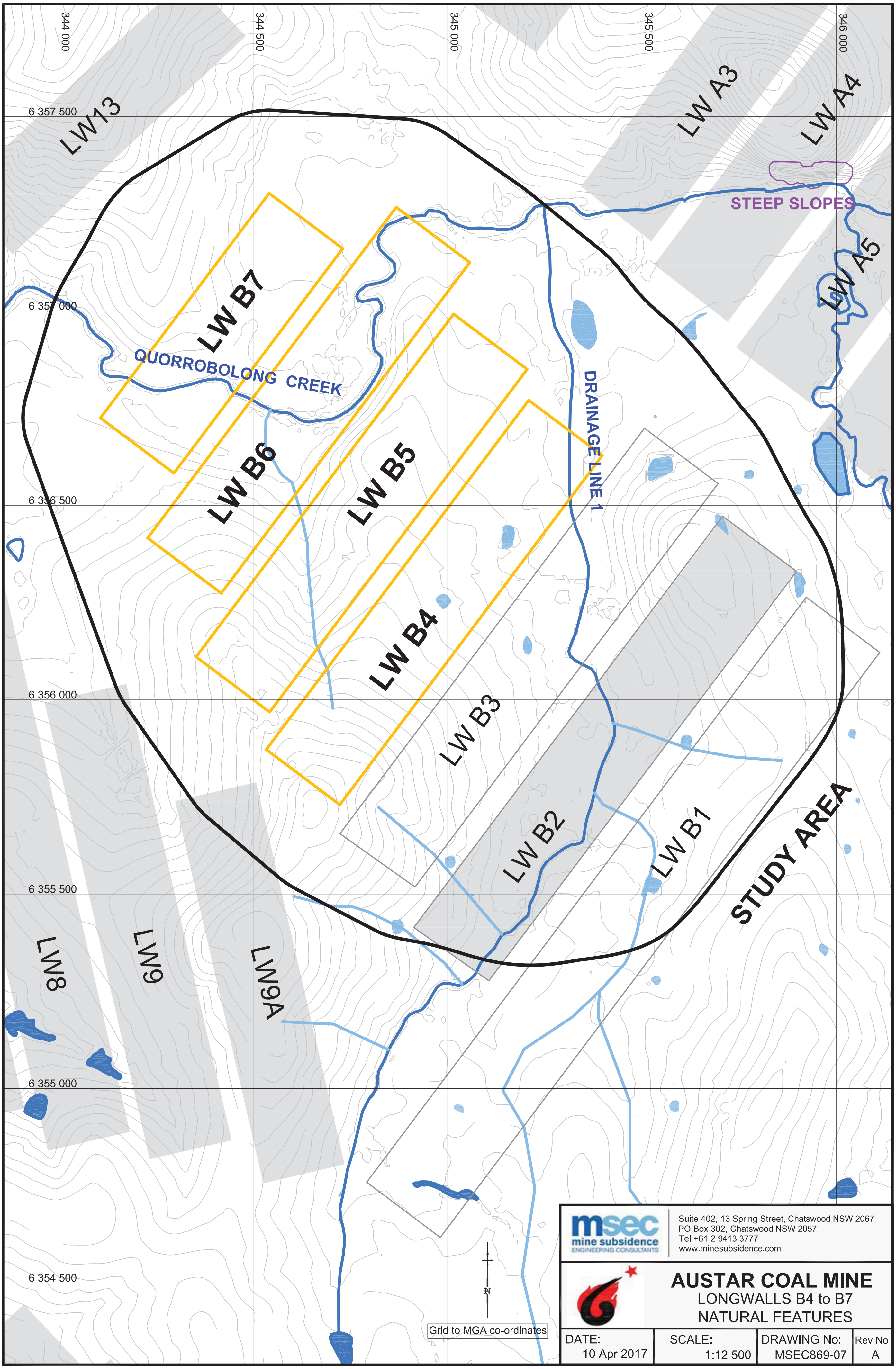

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LONGWALLS B4 to B7
NATURAL FEATURES

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10 Apr 2017	1:12 500	MSEC869-07	A

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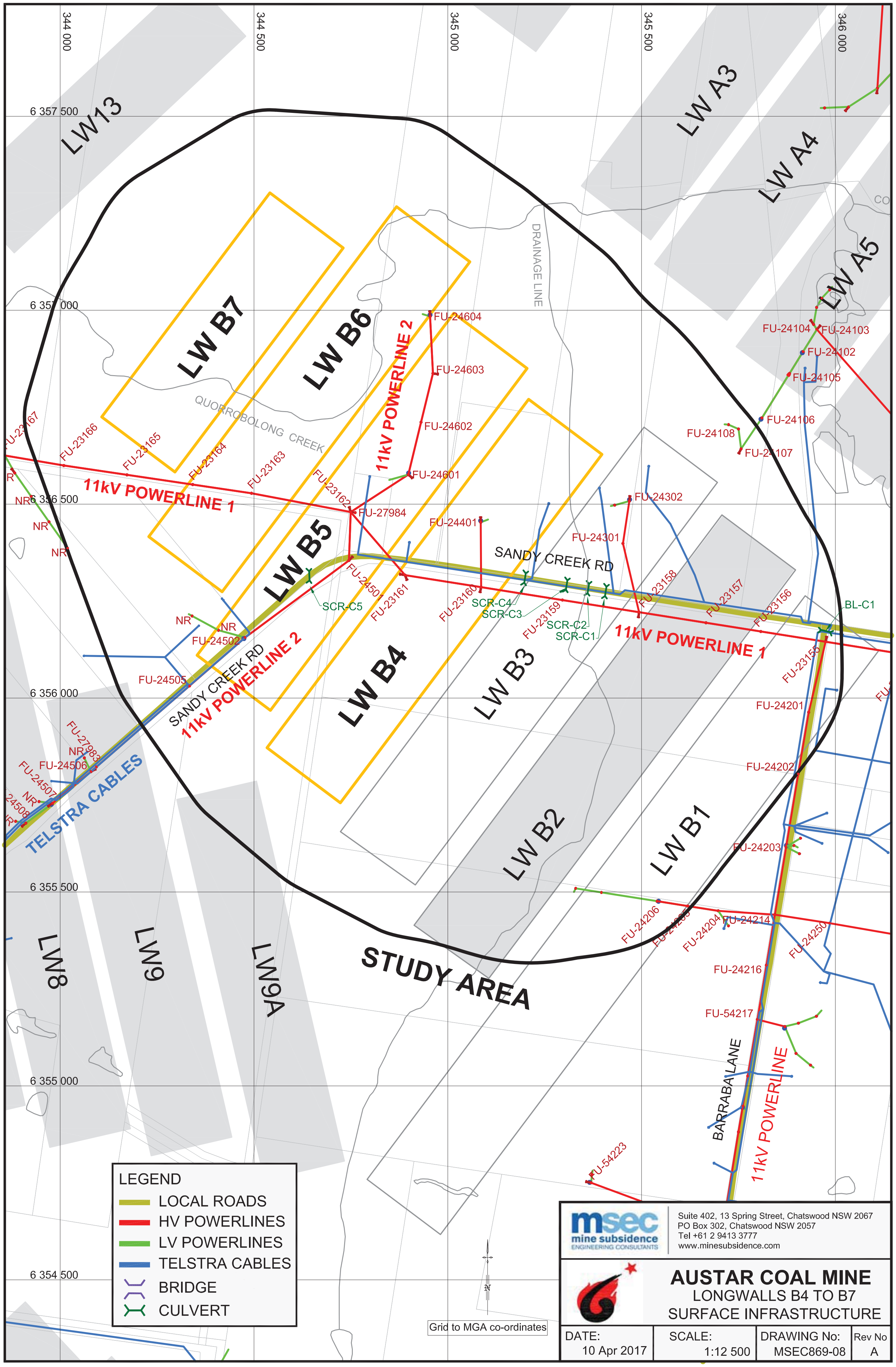

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AUSTAR COAL MINE
LONGWALLS B4 TO B7
SURFACE INFRASTRUCTURE

DATE:	SCALE:	DRAWING No:	Rev No
10 Apr 2017	1:12 500	MSEC869-08	A

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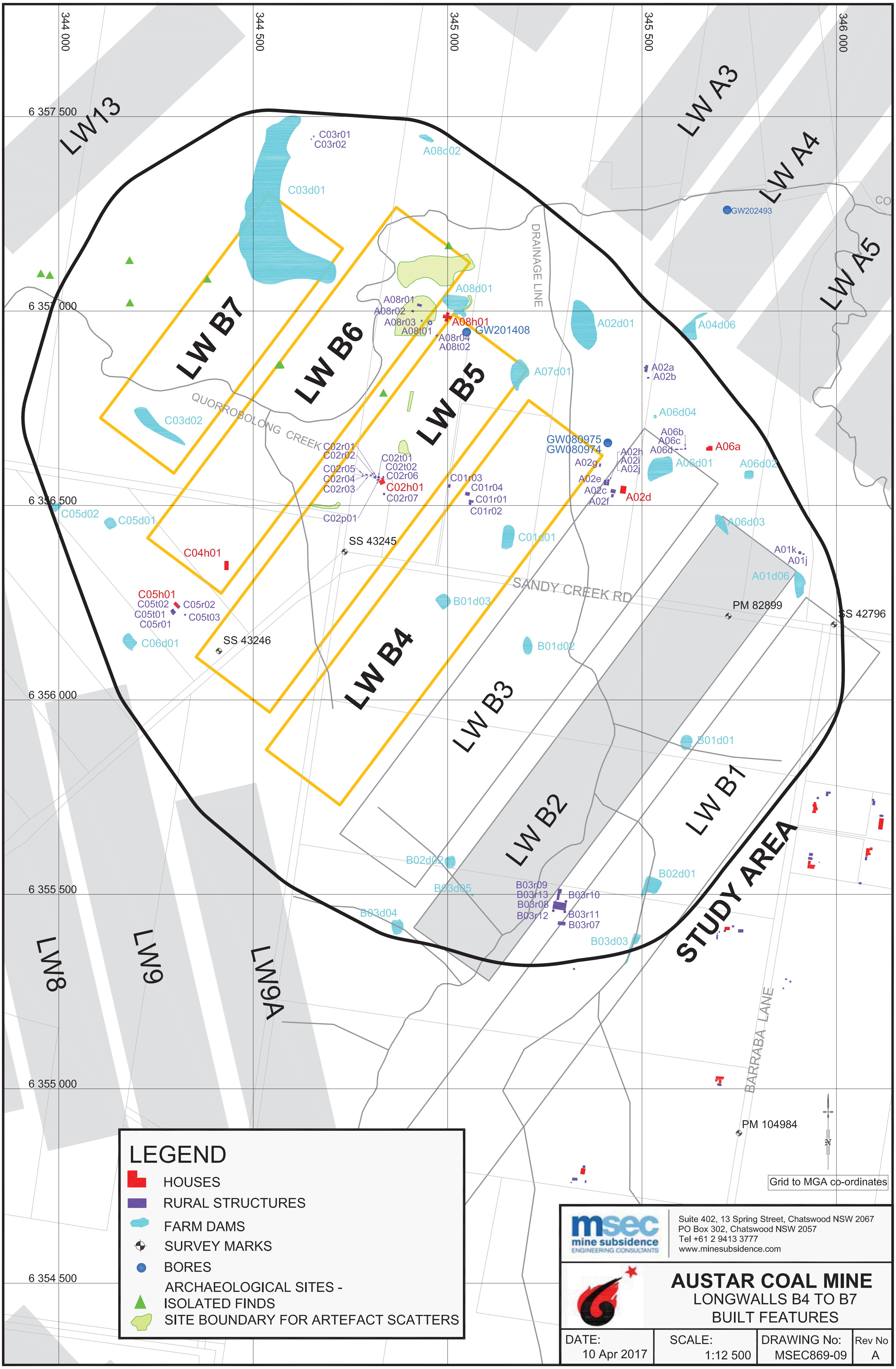

LEGEND

- 🟥 HOUSES
- ▬ RURAL STRUCTURES
- FARM DAMS
- ⊕ SURVEY MARKS
- ● BORES
- ▲ ARCHAEOLOGICAL SITES - ISOLATED FINDS
- SITE BOUNDARY FOR ARTEFACT SCATTERS

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LONGWALLS B4 TO B7
BUILT FEATURES

DATE:	SCALE:	DRAWING No:	Rev No
10 Apr 2017	1:12 500	MSEC869-09	A

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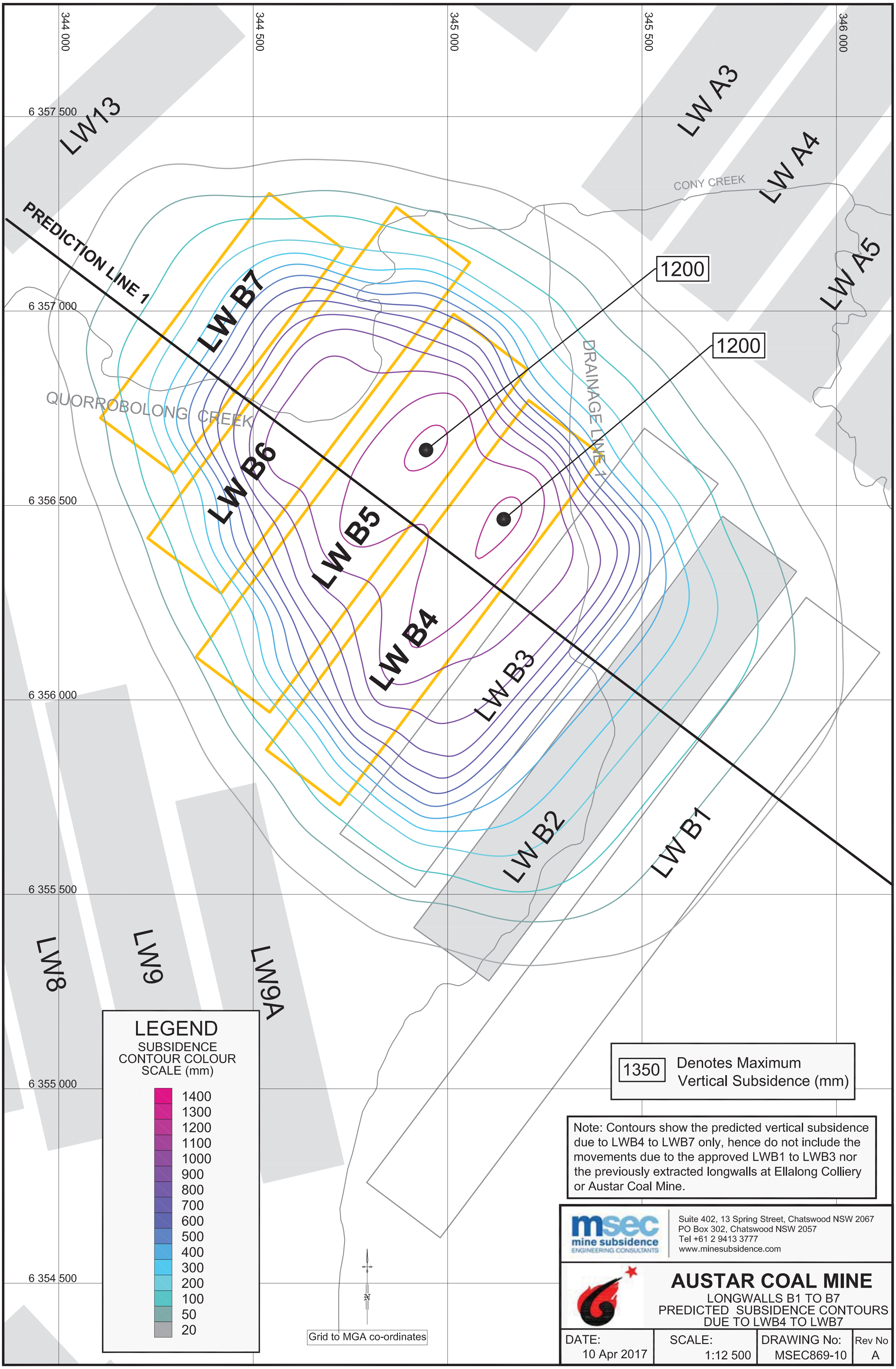

Note: Contours show the predicted vertical subsidence due to LWB4 to LWB7 only, hence do not include the movements due to the approved LWB1 to LWB3 nor the previously extracted longwalls at Ellalong Colliery or Austar Coal Mine.

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AUSTAR COAL MINE
LONGWALLS B1 TO B7
PREDICTED SUBSIDENCE CONTOURS
DUE TO LWB4 TO LWB7

DATE:	SCALE:	DRAWING No:	Rev No
10 Apr 2017	1:12 500	MSEC869-10	A

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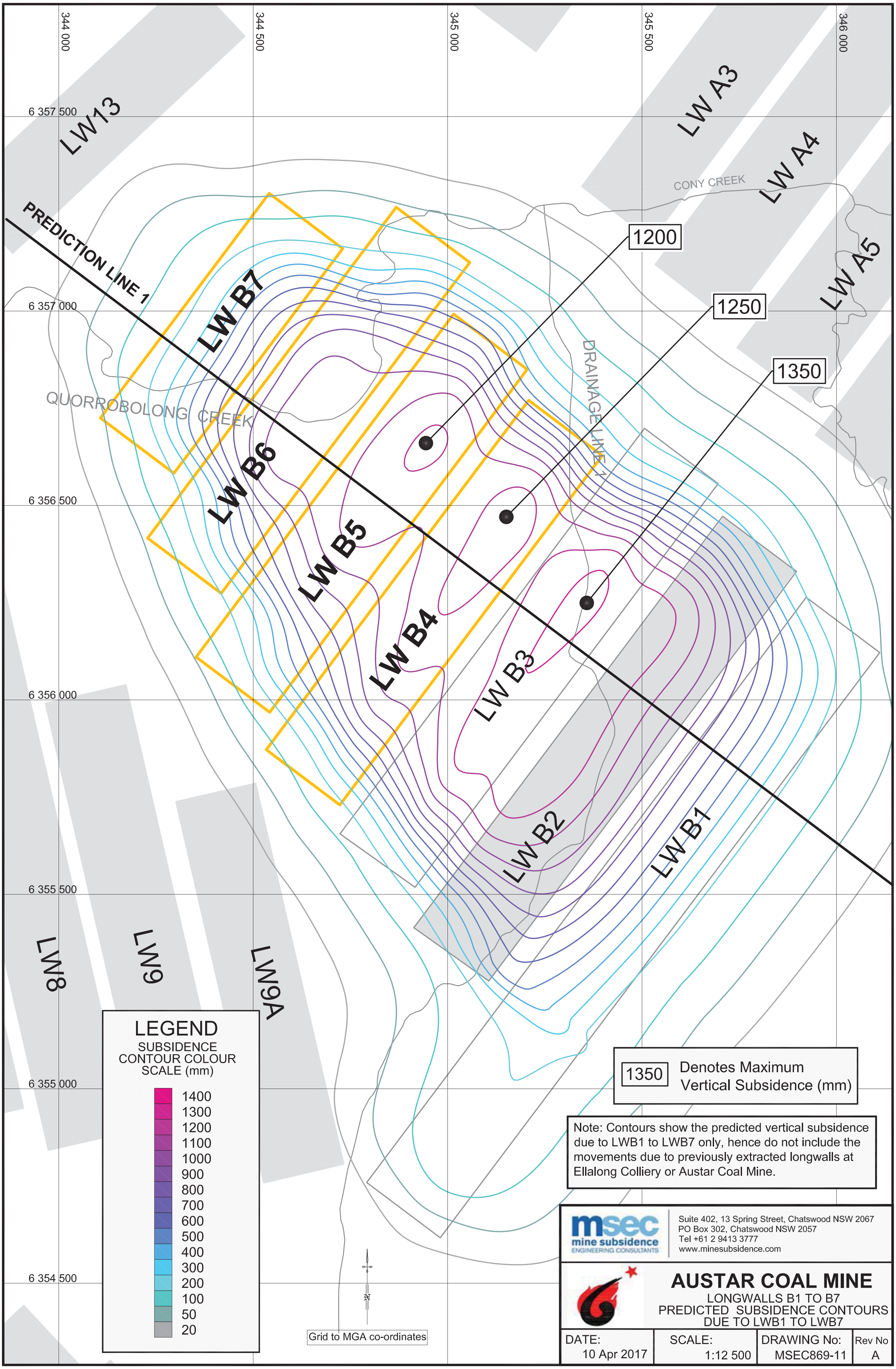

Note: Contours show the predicted vertical subsidence due to LWB1 to LWB7 only, hence do not include the movements due to previously extracted longwalls at Ellalong Colliery or Austar Coal Mine.

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LONGWALLS B1 TO B7
PREDICTED SUBSIDENCE CONTOURS
DUE TO LWB1 TO LWB7

DATE:	SCALE:	DRAWING No:	Rev No
10 Apr 2017	1:12 500	MSEC869-11	A

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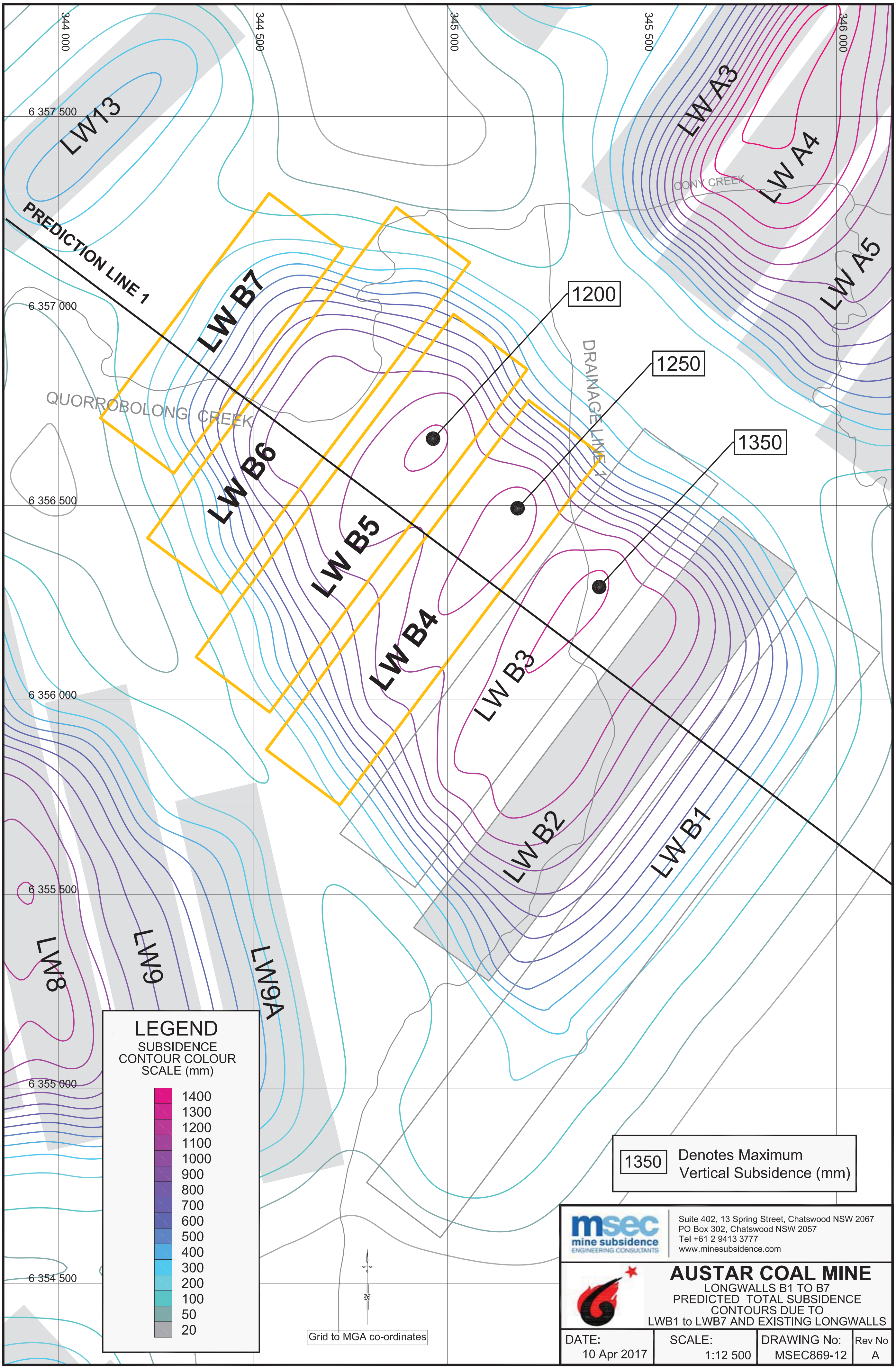

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AUSTAR COAL MINE
LONGWALLS B1 TO B7
PREDICTED TOTAL SUBSIDENCE
CONTOURS DUE TO
LWB1 to LWB7 AND EXISTING LONGWALLS

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10 Apr 2017	1:12 500	MSEC869-12	A