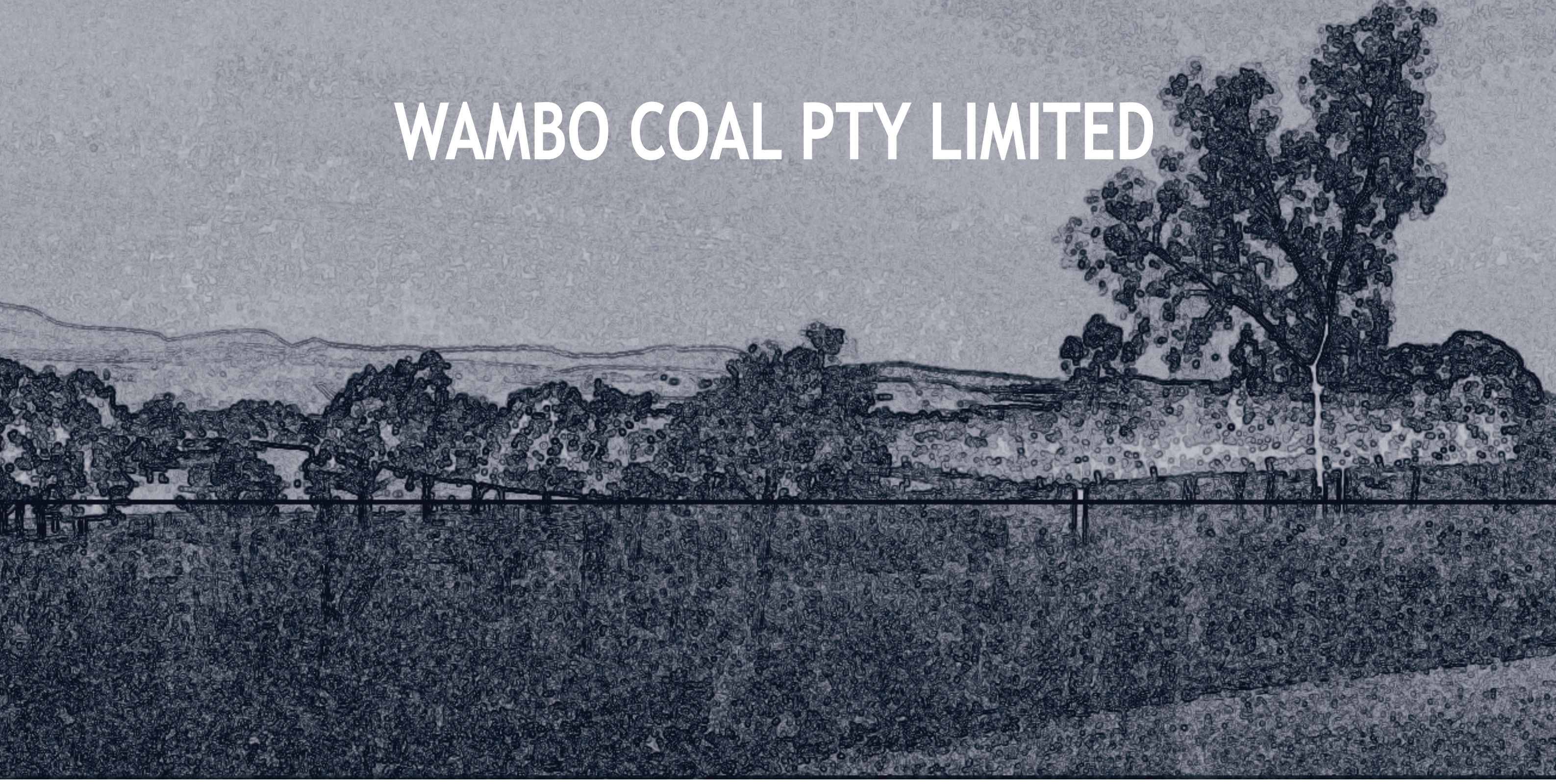
WAMBO COAL PTY LIMITED



SOUTH WAMBO UNDERGROUND MINE MODIFICATION

ENVIRONMENTAL ASSESSMENT

APPENDIX A

Subsidence Assessment

Peabody ENERGY

REPORT: SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

mine subsidence ENGINEERING CONSULTANTS

WAMBO COAL:

South Wambo Underground Mine Modification Subsidence Assessment

Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Modification Application for the Proposed Longwalls in the Woodlands Hill and Arrowfield Seams

DOCUMENT REGISTER

Revision	Description	Author	Checker	Date
01	Draft Issue	JB	-	11th Dec 15
02	Draft Issue	JB	-	22nd Dec 15
03	Draft Issue	JB	-	29th Jan 16
A	Final Issue	JB	PD	15th Mar 16
B	Final Issue	JB	PD	5th Apr 16

Report produced to:- Support the Modification Application for the South Wambo Underground Mine Modification.

Background reports available at *www.minesubsidence.com*[1]*:-*

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)

[1] Direct link: http://www.minesubsidence.com/index_files/page0004.htm

EXECUTIVE SUMMARY

Wambo Coal Pty Limited (WCPL) operates the Wambo Coal Mine, which is located in the Hunter Coalfield of New South Wales. The mine was approved under Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) in February 2004. The approved underground mining operations include the extraction of longwalls in the Whybrow, Wambo, Arrowfield and Bowfield Seams. The longwalls in the Wambo Seam at the North Wambo Underground Mine (NWUM) have been extracted beneath the overlying Homestead/Wollemi workings in the Whybrow Seam.

WCPL is seeking approval to modify the Development Consent (DA 305-7-2003) for the Wambo Coal Mine under Section 75W of the EP&A Act. The modification to the South Wambo Underground Mine would involve the re-alignment and extension/relation of the approved longwalls in Arrowfield Seam and the extraction of longwalls in the Woodlands Hill Seam rather than in the Bowfield Seam.

The longwalls in the Arrowfield Seam located to the east of Wollombi Brook are not proposed to be modified. WCPL also has approval to mine longwalls in the Bowfield Seam to the east of Wollombi Brook, however, these longwalls are no longer proposed to be mined based on the current mine plans.

Mine Subsidence Engineering Consultants (MSEC) has been commissioned by WCPL to:-

- provide subsidence predictions for the modified longwalls in the Woodlands Hill and Arrowfield Seams;
- compare the subsidence predictions with those previously provided for the approved layout comprising longwalls in the Arrowfield and Bowfield Seams;
- provide subsidence predictions for the natural and built features located above and in the vicinity of the proposed longwalls;
- compare the subsidence predictions for the natural and built features with those based on the approved layout; and to
- review and update the impact assessments, in conjunction with other specialist consultants, for each of these natural and built features, based on the modified layout.

This report has been prepared to support the Modification Application to be submitted to the Department of Planning and Environment.

The predicted subsidence for the proposed longwalls has been determined using the Incremental Profile Method, which has calibrated for multi-seam mining conditions using the available monitoring data from the NWUM and from elsewhere in the NSW Coalfields. This method has been used to predict the subsidence based on both the approved and modified layouts.

The maximum predicted additional subsidence, due to the extraction of the modified longwalls in the Woodlands Hill and Arrowfield Seams, is 4,050 mm, which represents around 68 % of the total extraction height of 6 metres in that location. The maximum predicted total subsidence, due to mining in the Wambo, Woodlands Hill and Arrowfield Seams, 6,250 mm, which represents around 78 % of the total extraction height of 8 metres in that location.

The maximum predicted total subsidence, based on the approved layout in the Wambo, Arrowfield and Bowfield Seams, is 9,000 mm. The maximum predicted total subsidence reduces as a result of the proposed modifications due to: the modified longwalls in the Woodlands Hill and Arrowfield Seams being *staggered* (i.e. offset); whereas the approved longwalls in the Arrowfield and Bowfield Seams were *stacked* (i.e. direct above/below). Also, the overall mining heights based on the modified layout are less than those based on the approved layout.

Whilst the maximum predicted vertical subsidence decreases as a result of the proposed modification, the surface area affected by mine subsidence increases.

A number of natural and built features have been identified within or in the vicinity of the proposed mining area, including: Wollombi Brook and associated alluvium; North Wambo, Wambo and Stony Creeks; the North Wambo Creek Diversion; cliffs and minor cliffs associated with the Wollemi Escarpment; steep slopes; unsealed roads, 66 and 11 kilovolt powerlines; telecommunications cables; water pipelines; fences; farm dams; the Wambo Open Cut; water storage dams; the mine administration buildings; archaeological sites; the Wambo Homestead Complex; and one house with associated rural structures (owned by WCPL).

The natural and built features located across the proposed mining area could experience greater or lesser ground movements as a result of the proposed modification, depending on their locations relative to the longwalls. The predicted subsidence parameters increase for the features including: Wambo and Stony Creeks; North Wambo Creek Diversion; steep slopes; 11 kV powerlines; and one grinding groove site.

The predicted subsidence parameters decrease for other surface features including: North Wambo Creek; unsealed roads; water pipelines; the 66 kV powerline; farm dams; and other archaeological sites.

The predicted subsidence parameters for the features located outside the extents of the proposed longwalls do not change significantly as a result of the proposed modification. These include Wollombi Brook; the cliffs associated with the Wollemi Escarpment; the National Park; and the Wambo Homestead Complex.

In the cases where the potential for impacts increase as a result of the proposed modification, the nature of these impacts and the management strategies do not significantly change. Management strategies have already been developed for many of the surface features for the previous extraction of the longwalls in the shallower Wambo Seam at the NWUM.

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 the appropriate management strategies. It should be noted, however, that more detailed assessments of some natural and built features have been undertaken by other specialist consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

The appropriate management strategies and monitoring for the natural and built features will be developed further during the Extraction Plan stage for the proposed longwalls.

Tables

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

Figures

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

Drawings

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

Drawing No.	*Description*	*Revision*
MSEC799-01	General Layout	B
MSEC799-02	Layout of Longwalls in the Woodlands Hill Seam	B
MSEC799-03	Layout of Longwalls in the Arrowfield Seam	B
MSEC799-04	Surface Level Contours	B
MSEC799-05	Woodlands Hill Seam Floor Contours	B
MSEC799-06	Woodlands Hill Seam Indicative Mining Height	B
MSEC799-07	Woodlands Hill Seam Depth of Cover Contours	B
MSEC799-08	Arrowfield Seam Floor Contours	B
MSEC799-09	Arrowfield Seam Indicative Mining Height	B
MSEC799-10	Arrowfield Seam Depth of Cover Contours	B
MSEC799-11	Geological Structures Identified at Seam Level	B
MSEC799-12	Whybrow Seam Depth of Cover Contours	B
MSEC799-13	Wambo Seam Depth of Cover Contours	B
MSEC799-14	Natural Features	B
MSEC799-15	Built Features	B
MSEC799-16	Predicted Additional Subsidence Contours due to the Woodlands Hill Seam Only	B
MSEC799-17	Predicted Additional Subsidence Contours due to the Woodlands Hill and Arrowfield Seams	B
MSEC799-18	Predicted Total Subsidence Contours due to the Wambo and Woodlands Hill Seams	B
MSEC799-19	Predicted Total Subsidence Contours due to the Wambo, Woodlands Hill and Arrowfield Seams	B
MSEC799-20	Predicted Total Subsidence Contours due to the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams	B

1.0 INTRODUCTION

1.1. Background

Wambo Coal Pty Limited (WCPL) operates the Wambo Coal Mine, which is located in the Hunter Coalfield of New South Wales (NSW). The mine was approved under Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) in February 2004. The approved underground mining operations include the extraction of longwalls in the Whybrow, Wambo, Arrowfield and Bowfield Seams. The approved operations in the Arrowfield and Bowfield Seams form part of the South Wambo Underground Mine (SWUM).

WCPL is seeking approval to modify the Development Consent (DA 305-7-2003) for Wambo Coal Mine under Section 75W of the EP&A Act. The Modification to the South Wambo Underground Mine would involve the realignment and extension/relocation of the approved longwalls in the Arrowfield Seam and the extraction of longwalls in the Woodlands Hill Seam rather than in the Bowfield Seam.

The proposed longwalls in the Woodlands Hill and Arrowfield Seams are shown in Drawings Nos. MSEC799-01 to MSEC799-03, in Appendix F.

The Modification would include mining beneath the existing Homestead/Wollemi workings in the Whybrow Seam and the completed longwalls in the Wambo Seam. The completed longwalls in the Wambo Seam at the North Wambo Underground Mine (NWUM), referred to as WMLW1 to WMLW10A in this report, were modified from the original approved layout as follows:

- In May 2005, the approved WMLW1 to WMLW8 were reorientated (*Wambo Seam Underground Modification Statement of Environmental Effects* [WCPL, 2005] [the 2005 SEE]);
- In July 2013, two additional longwalls (WMLW9 and WMLW10) contiguous with the existing North Wambo Underground Mine were approved (*North Wambo Underground Mine Modification Environmental Assessment* [WCPL, 2012]). Report No. MSEC495 (Rev. C) was issued in October 2012, which supported the Modification Application; and
- In April 2014, an additional longwall (WMLW10A) contiguous with the existing North Wambo Underground Mine was approved (*North Wambo Underground Mine Longwall 10A Modification Environmental Assessment* [WCPL, 2014]). Reports Nos. MSEC697 (Rev. B) and MSEC754 (Rev. A) were issued in August 2014 and April 2015 in support of the Modification Application.

The mining layout indicated in the Modification Application (WCPL, 2014) and in Reports Nos. MSEC697 (Rev. B) and MSEC754 (Rev. A), which included WMLW1 to WMLW10A in the Wambo Seam and the approved longwalls in the Arrowfield and Bowfield Seams, is referred to as the *Approved Layout* in this report.

The mining layout including the completed longwalls in the Wambo Seam and the proposed longwalls in the Woodlands Hill and Arrowfield Seams is referred to as the *Modified Layout* in this report.

The comparison between the *Approved Layout* (magenta outlines) and the *Modified Layout* (orange outlines) is provided in Fig. 1.1. It is noted, that there are approved longwalls in the Arrowfield Seam on the eastern side of Wollombi Brook (green outlines) which are not proposed to be modified. The existing United Collieries workings in the Arrowfield Seam are shown in blue in this figure.

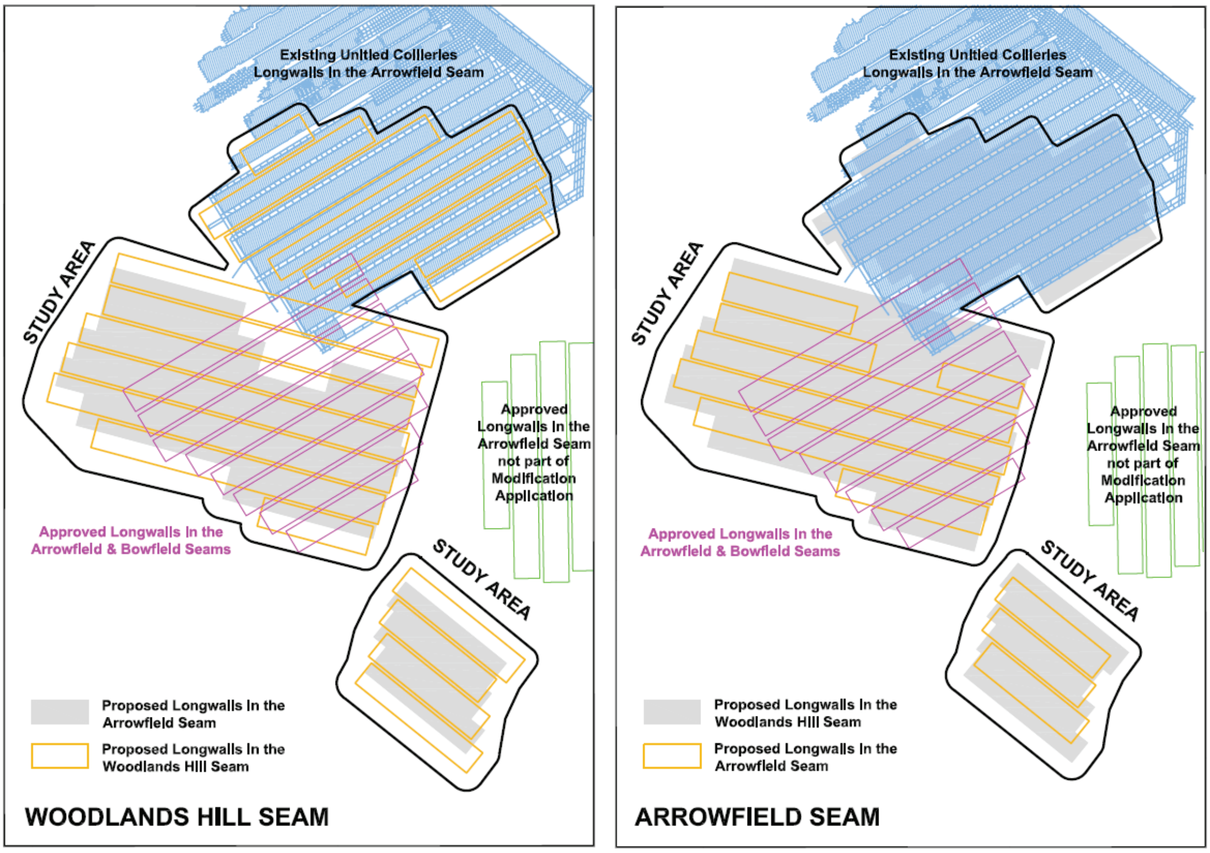


Fig. 1.1 Comparisons between the Approved and Modified Layouts

Mine Subsidence Engineering Consultants (MSEC) has been commissioned by WCPL to:-

- provide subsidence predictions for the proposed longwalls in the Woodlands Hill and Arrowfield Seams, based on the *Modified Layout*;
- compare the subsidence predictions, based on the *Modified Layout*, with those previously provided in the 2005 SEE, the *North Wambo Underground Mine Modification Environmental Assessment* (WCPL, 2012) and the *North Wambo Underground Mine Longwall 10A Modification Environmental Assessment* (WCPL, 2014), based on the *Approved Layout*;
- provide subsidence predictions for the natural and built features located above and in the vicinity of the proposed longwalls, based on the *Modified Layout*;
- compare the subsidence predictions for the natural and built features, based on the *Modified Layout*, with those previously provided based on the *Approved Layout* (WCPL, 2005, 2012 and 2014); and
- review and update the impact assessments, in conjunction with other specialist consultants, for each of these natural and built features, based on the *Modified Layout*.

This report has been prepared to support the Modification Application to be submitted to the Department of Planning and Environment.

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 the methods that have been used to predict the mine subsidence movements resulting from the extraction of the existing and proposed longwalls.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of the existing and proposed longwalls, based on the *Modified Layout*, and compares these with the parameters predicted based on the *Approved Layout*.

Chapters 5 and 6 provide the descriptions, predictions and impact assessments for each of the natural and built features which have been identified within the Study Area. Recommendations for each of these features are also provided, which have been based on the predictions and impact assessments.

The proposed longwalls in the Woodlands Hill and Arrowfield Seams and the Study Area, as defined in Section 2.1, have been overlaid on an orthophoto of the area, which is shown in Fig. 1.2.

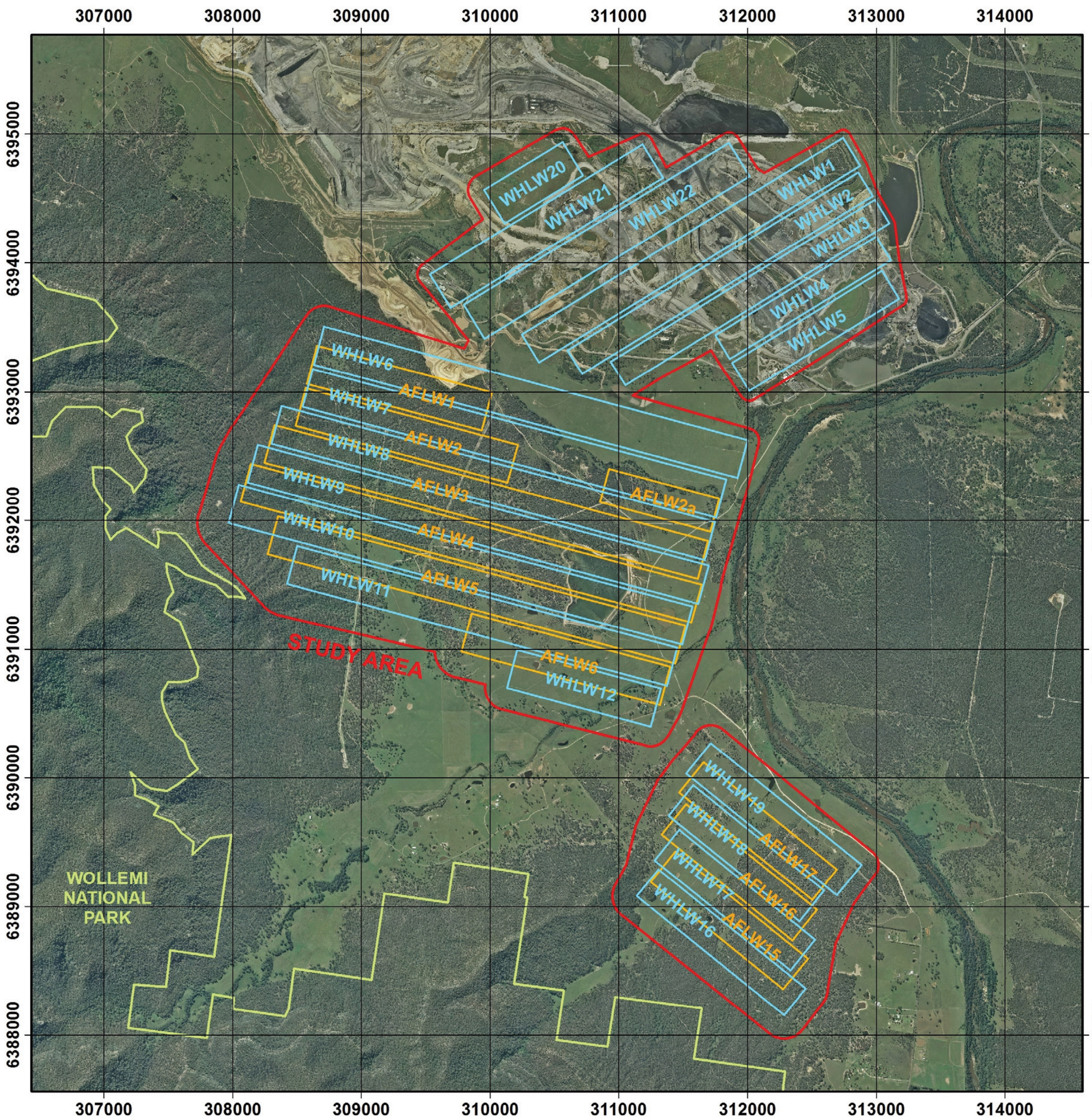


Fig. 1.2 Aerial Photograph Showing Locations of the Proposed Longwalls

1.2. Mining Geometry

The *Modified Layout* comprises 19 longwalls in the Woodlands Hill Seam (refer to Drawing No. MSEC799-02) and 10 longwalls in the Arrowfield Seam (refer to Drawing No. MSEC799-03). It is noted that the five approved longwalls in the Arrowfield Seam on the eastern side of Wollombi Brook are not proposed to be modified and, therefore, have not been re-assessed in this report.

Summaries of the dimensions for the longwalls are provided in Table 1.1 for the Woodlands Hill Seam and Table 1.2 for the Arrowfield Seam.

Table 1.1 Geometry of the Proposed Longwalls in the Woodlands Hill Seam

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
WHLW1	2,925	255	-
WHLW2	2,645	215	35
WHLW3	2,405	215	35
WHLW4	1,465	215	35
WHLW5	1,365	255	35
WHLW6	3,405	305	-
WHLW7	3,325	305	35
WHLW8	3,485	305	35
WHLW9	3,625	305	35
WHLW10	3,645	305	35
WHLW11	3,055	305	35
WHLW12	1,155	305	35
WHLW16	1,470	265	-
WHLW17	1,355	305	35
WHLW18	1,305	305	35
WHLW19	1,505	305	35
WHLW20	715	305	-
WHLW21	1,935	305	35
WHLW22	2,415	305	35

Table 1.2 Geometry of the Proposed Longwalls in the Arrowfield Seam

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
AFLW1	1,405	305	-
AFLW2	1,705	305	35
AFLW2A	885	265	35
AFLW3	3,485	305	35
AFLW4	3,625	305	35
AFLW5	3,275	305	35
AFLW6	1,595	305	35
AFLW15	1,325	305	-
AFLW16	1,305	305	35
AFLW17	1,330	305	35

The widths of the longwall extraction faces (i.e. excluding the first workings) are around 11 metres narrower than the overall void widths provided in the above tables. The lengths of extraction (i.e. excluding the installation heading) are around 7 metres shorter than the overall void lengths provided in these tables.

WCPL also has approval to extract a further five longwalls in each of the Arrowfield and Bowfield Seams on the eastern side of Wollombi Brook. The longwalls in the Arrowfield Seam are not proposed to be modified and, therefore, have not been re-assessed in this report. The longwalls in the Bowfield Seam are not proposed to be extracted based on the current mine plans. The approved longwalls in the Arrowfield Seam on the eastern side of Wollombi Brook have overall void widths of 260 metres, chain pillar widths of 40 metres and overall lengths varying between 1,515 metres and 2,480 metres.

1.3. Surface and Seam Levels

The surface levels and the levels for the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams are illustrated along Cross-sections 1 to 4 in Fig. 1.3 to Fig. 1.6, respectively. The locations of these cross-sections are shown in Drawings Nos. MSEC799-04, MSEC799-05 and MSEC799-08.

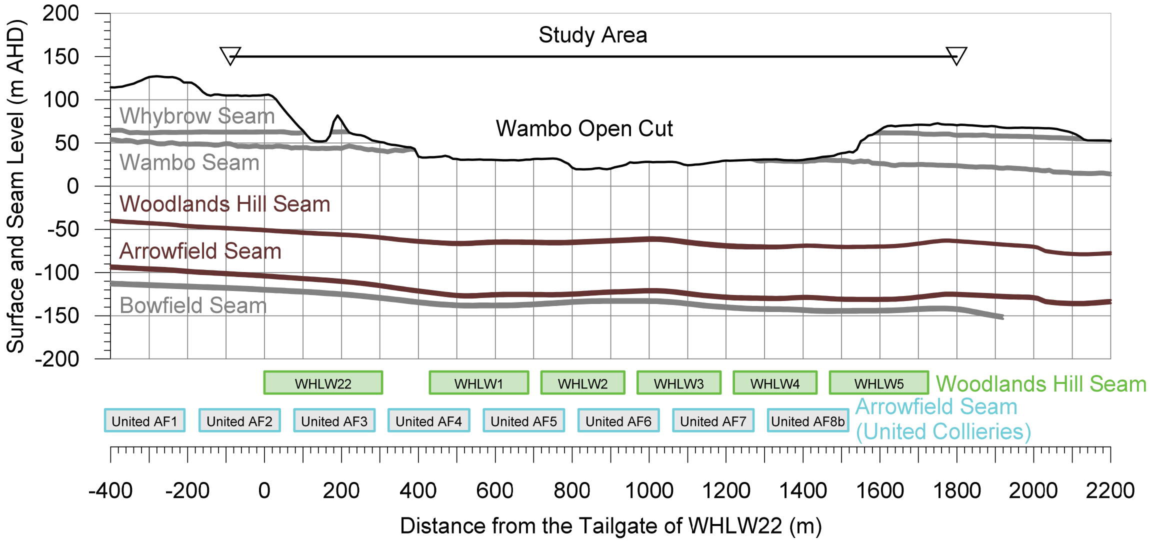


Fig. 1.3 Surface and Seam Levels along Cross-section 1

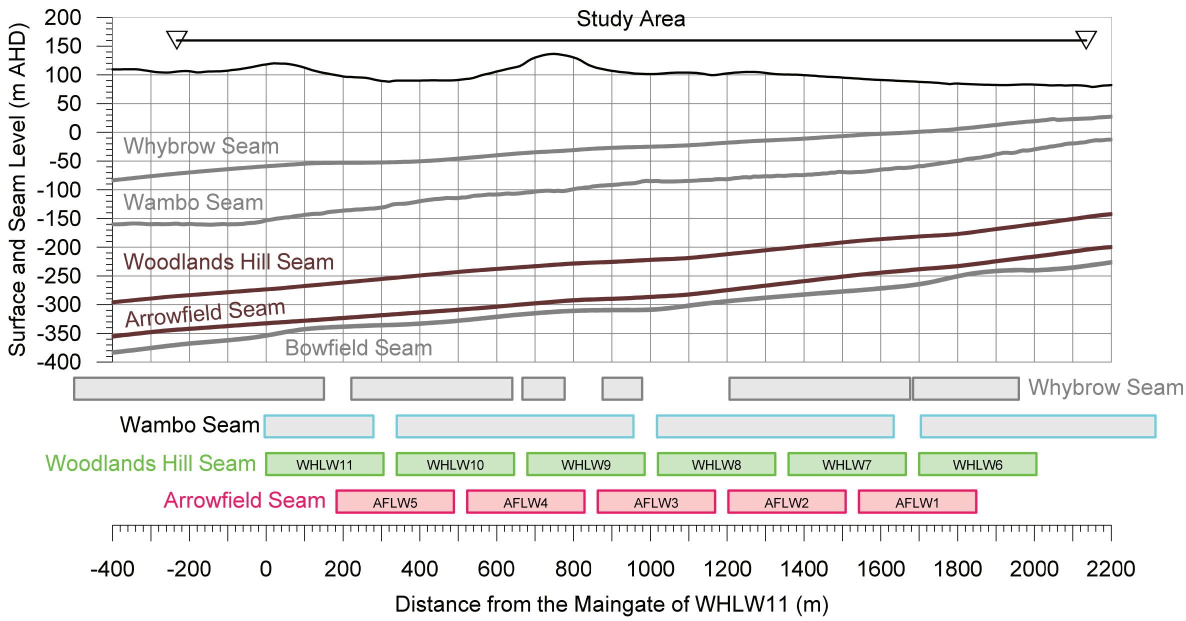


Fig. 1.4 Surface and Seam Levels along Cross-section 2

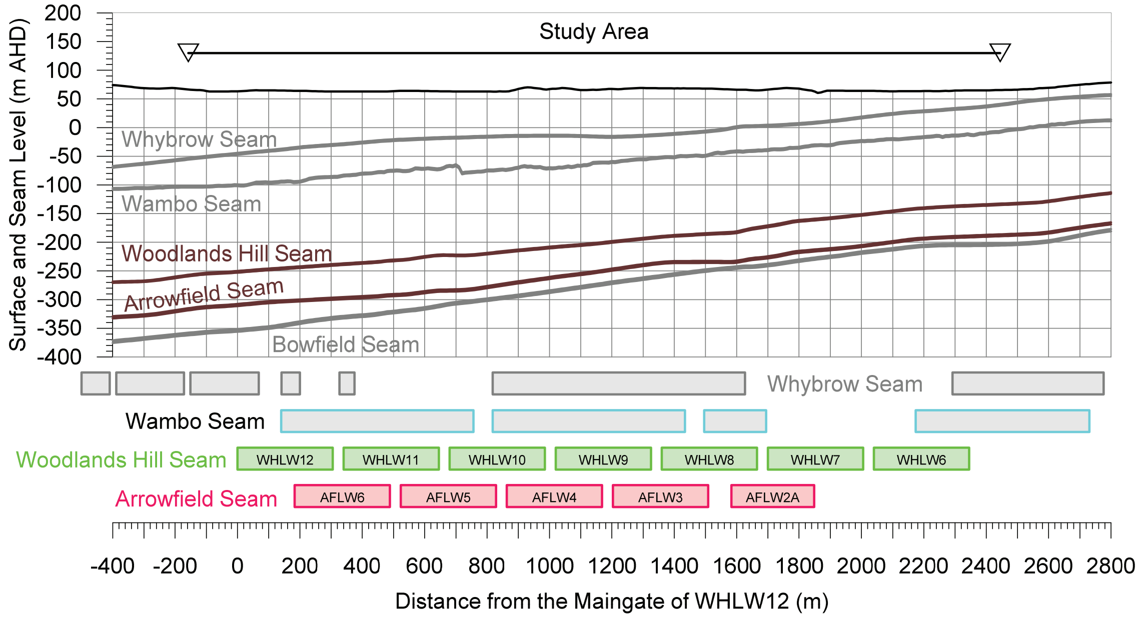


Fig. 1.5 Surface and Seam Levels along Cross-section 3

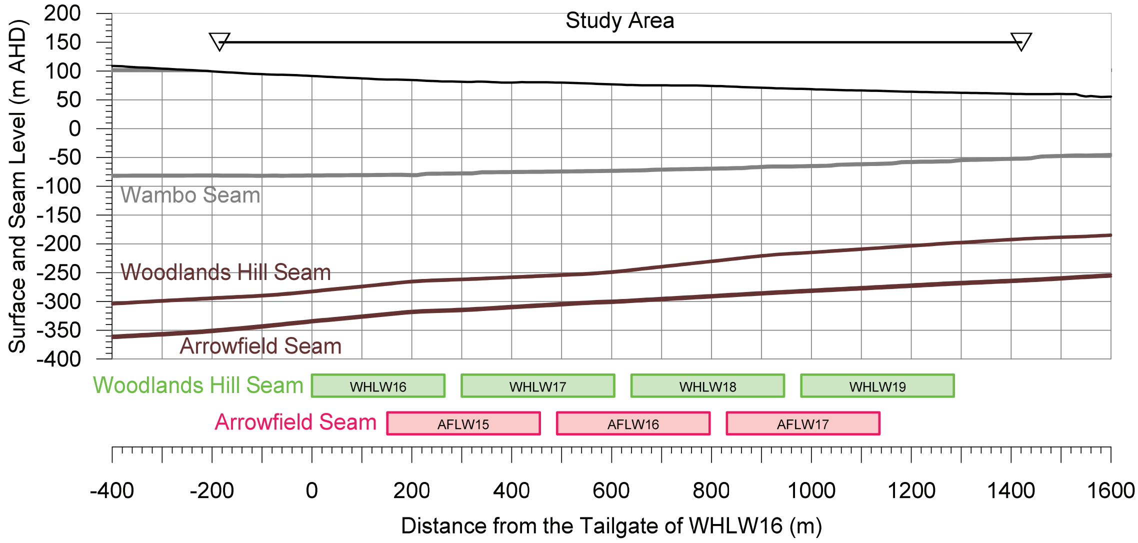


Fig. 1.6 Surface and Seam Levels along Cross-section 4

The surface level contours in the vicinity of the proposed longwalls are shown in Drawing No. MSEC799-04. The surface in the northern part of the proposed mining area (i.e. above WHLW1 to WHLW5 and WHLW20 to WHLW22) has been affected by the Wambo Open Cut.

The natural surface elsewhere above the proposed mining area generally falls from the west towards the east. The high point directly above the proposed longwalls is approximately 210 metres above Australian Height Datum (mAHD) on the steep slopes beneath the Wollemi Escarpment. The low point directly above the proposed longwalls is approximately 60 metres mAHD along the lower reaches of North Wambo and Wambo Creeks. The local low point (excluding the Wambo Open Cut) is approximately 55 metres along Wollombi Brook to the east of the proposed longwalls.

The natural surface gradients are highest in the western part of the mining area along the steep slopes beneath the Wollemi Escarpment. The gradients along these steep slopes typically range between 1 in 3 and 1 in 2 directly above the proposed longwalls. The natural surface is flatter in the eastern part of the mining area with gradients typically less than 1 in 20.

The seam floor contours, proposed mining heights and depths of cover contours for the Woodlands Hill Seam are shown in Drawings Nos. MSEC799-05, MSEC799-06 and MSEC799-07, respectively. The floor of the Woodlands Hill Seam falls from the north-east towards the south-west, having an average dip around 6 %, or 1 in 17.

The depths of cover above the Woodlands Hill Seam are shallowest in the north-eastern part of the proposed mining area, varying between 80 metres and 255 metres beneath the Wambo Open Cut. The depths of cover are the greatest in the south-western corner of the proposed mining area, varying up to 490 metres beneath the steep slopes at the base of the Wollemi Escarpment.

The Woodlands Hill Seam comprises a number of plies with mining targeting the B3 ply as well as the B1 and B4 plies in some areas. The proposed mining heights in the Woodlands Hill Seam vary between approximately 2.1 metres and 3.0 metres.

The seam floor contours, proposed mining heights and depths of cover contours for the Arrowfield Seam are shown in Drawings Nos. MSEC799-08, MSEC799-09 and MSEC799-10, respectively. The floor of the Arrowfield Seam also falls from the north-east towards the south-west, having an average dip around 5 %, or 1 in 20.

The depths of cover above the Arrowfield Seam vary from 270 metres, in the north-eastern corner, to a maximum of 560 metres in the western part of the proposed mining area. The interburden thickness between the Arrowfield and Woodlands Hill Seams varies between 40 metres and 80 metres.

The mining in the Arrowfield Seam will target the A to C plies. The proposed mining heights in this seam vary between approximately 2.9 metres and 4.1 metres.

The proposed longwalls will be extracted beneath the existing Homestead/Wollemi workings in the Whybrow Seam and the previously extracted NWUM longwalls in the Wambo Seam. The proposed WHLW1 to WHLW5 and WHLW20 to WHLW22 will also be extracted above the existing United Collieries longwalls in the Arrowfield Seam and beneath the Wambo Open Cut.

The depths of cover contours for the Whybrow and Wambo Seams are shown in Drawings Nos. MSEC799-12 and MSEC799-13. The depths of cover directly above the Homestead/Wollemi workings in the Whybrow Seam vary between 50 metres and 250 metres. The depths of cover above WMLW1 to WMLW10A in the Wambo Seam vary between 50 metres and 350 metres.

The interburden thicknesses between the Woodlands Hill and Wambo Seam varies between 110 metres and 150 metres above the proposed longwalls. The interburden thickness between the Wambo and Whybrow Seams varies between 55 metres and 95 metres.

1.4. Geological Details

The SWUM lies in the Hunter Coalfield, within the Northern Sydney Basin. A typical stratigraphic section of the Hunter Coalfield, reproduced from the Department of Mineral Resources (DMR) *Hunter Coalfield Regional 1:100 000 Geology Map*, is shown in Table 1.3 (DMR, 1993). It is noted that the DMR is now referred to as the Department of Industry, Skills and Regional Development (Department of Industry).

The Whybrow, Wambo, Woodlands Hill and Arrowfield Seams all lie within the Jerrys Plains Subgroup of the Wittingham Coal Measures. The rocks of the Wittingham Coal Measures mainly comprise frequently bedded sandstones and siltstones, but also include isolated thinner beds of conglomerate and tuff. The beds are generally less than 10 metres in thickness.

The Denman Formation marks the top of the Wittingham Coal Measures, which is overlain by the Newcastle Coal Measures. The Newcastle Coal Measures comprise the Watts Sandstone and the Apple Tree Flat, Horseshoe Creek, Doyles Creek and Glen Gallic Subgroups.

The available boreholes indicate that the overburden primarily consists of intermittent sandstone and siltstone layers, with intermediate conglomerate and tuffaceous layers. No subsidence reduction factors have been applied in the subsidence prediction model for any massive sandstone or conglomerate layers.

Table 1.3 Stratigraphy of the Hunter Coalfield (DMR, 1993)

Supergroup	Group	Subgroup	Formation	Seam
Singleton Supergroup	Narrabeen Group	Widden Brook Conglomerate		
	Newcastle Coal Measures	Glen Gallic Subgroup	Greigs Creek Coal	
			Redmanvale Creek Formation	
			Dights Creek Coal	
		Doyles Creek Subgroup	Waterfall Gully Formation	
			Pinegrove Formation	
		Horseshoe Creek Subgroup	Lucernia Coal	
			Strathmore Formation	
			Alcheringa Coal	
			Clifford Formation	
		Appletree Flat Subgroup	Charlton Formation	
			Abbey Green Coal	
		Watts Sandstone		
	Wittingham Coal Measures	Denman Formation		
		Jerrys Plains Subgroup	Mount Leonard Formation	**Whybrow Seam**
			Althorpe Formation	
			Malabar Formation	Redbank Creek Seam
				Wambo Seam
				Whynot Seam
				Blakefield Seam
			Mount Ogilvie Formation	Glen Munro Seam
				Woodlands Hill Seam
			Milbrodale Formation	
			Mount Thorley Formation	**Arrowfield Seam**
				Bowfield Seam
				Warkworth Seam
			Fairford Formation	
			Burnamwood Formation	Mount Arthur Seam
				Piercefield Seam
				Vaux Seam
				Broonie Seam
				Bayswater Seam
		Archerfield Sandstone		
		Vane Subgroup	Bulga Formation	
			Foybrook Formation	
			Saltwater Creek Formation	

The geological features that have been identified at seam level are shown in Drawing No. MSEC799-11.

A series of north-south trending faults and dykes have been identified within the Whybrow Seam above the eastern ends of WHLW6 to WHLW12 and AFLW2A to AFLW6. The faults have throws up to 1 metre and the dykes have widths up to 1 metre. An inferred north-east to south-west fault zone is also located further to the east above these proposed longwalls. The longwalls in the Wambo Seam were extracted directly beneath these fault zones and no significant irregular movements were observed.

There is a series of north-northeast (NNE) to south-southwest (SSW) trending faults located to the north-west of the proposed longwalls. The larger faults have throws ranging between 3 metres and 12 metres. These fault zones are also located adjacent to the previously extracted Homestead/Wollemi workings in the Whybrow Seam and the longwalls in the Wambo Seam.

No irregular ground movements were identified above WMLW1 along the XL1 and XL3-Lines. However, the observed subsidence exceeded that predicted above WMLW1 along the XL2 and SC1-Lines. It is possible that locally increased subsidence could develop above the commencing ends of the proposed WHLW6 to WHLW10 and AFLW1 to AFLW4. It is expected that any increased subsidence would be less than the maximum subsidence that occurs above the eastern part of the proposed mining area, where the depths of cover are shallower.

The largest structure in the area is the *Redmanvale Fault*, which has a throw greater than 20 metres. This fault is located more than 500 metres to the south-west of the proposed longwalls. At this distance, this fault is unlikely to have any significant effect on the subsidence movements.

The surface lithology in the area can be seen in Fig. 1.7, which shows the proposed longwalls and the 26.5 degree angle of draw line overlaid on the *Geological Map of Doyles Creek 9032*. The geological map was published by the DMR (1988), now known as the Department of Industry. It is noted that the surface in the north-eastern part of the Study Area has been affected by the Wambo Open Cut.

The surface lithology comprises the formations of the Narrabeen Group (Rn) along the steep slopes in the western part of the proposed mining area. The lithology transitions to the formations from the Newcastle Coal Measures (Psl) and the Jerrys Plains Subgroup of the Wittingham Coal Measures (Pswj) in the central part of the proposed mining area. Unconsolidated Quaternary sediments (Qa) are present along the major creeks and adjacent to Wollombi Brook in the eastern part of the proposed mining area.

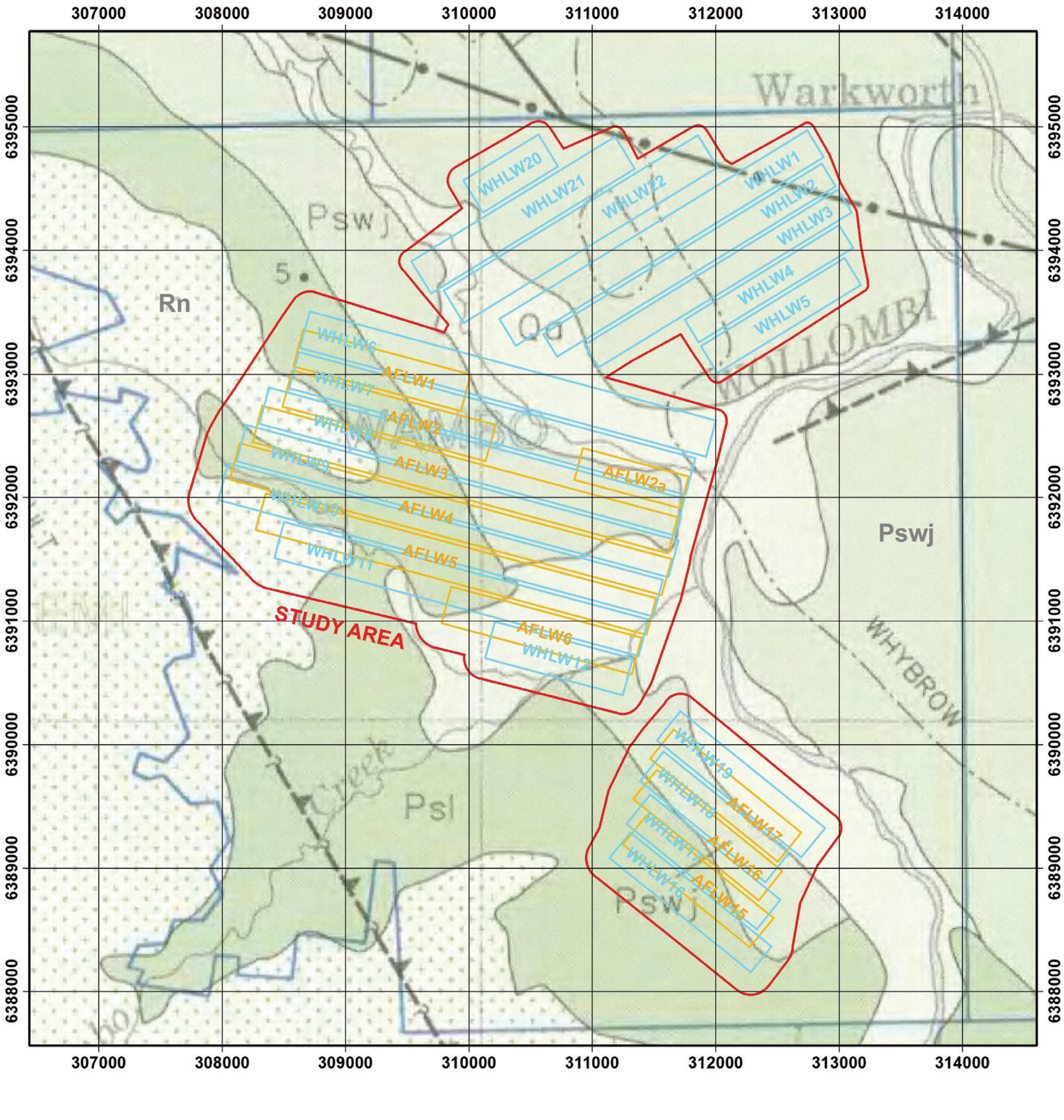


Fig. 1.7 Proposed Longwalls Overlaid on Geological Map Doyles Creek 9032

2.1. Definition of the Study Area

The Study Area is defined as the surface area that is likely to be affected by the extraction of the proposed longwalls in the Woodlands Hill and Arrowfield Seams, based on the *Modified Layout*. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:-

- The 26.5 degree angle of draw line from the extents of the proposed longwalls in the Woodlands Hill and Arrowfield Seam, based on the *Modified Layout*; and
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour resulting from the extraction of the proposed longwalls in the Woodlands Hill and Arrowfield Seams.

The depth of cover contours for the Woodlands Hill and Arrowfield Seams are shown in Drawings Nos. MSEC799-07 and MSEC799-10, respectively. It can be seen from these drawings that the depths of cover above the proposed longwalls vary between 80 metres and 490 metres for the Woodlands Hill Seam and between 270 metres and 560 metres for the Arrowfield Seam.

The 26.5 degree angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 40 metres and 280 metres around the limits of the proposed extraction areas.

The predicted limit of vertical subsidence has been taken as the predicted 20 mm subsidence contour due to the extraction of the proposed longwalls in the Woodlands Hill and Arrowfield Seams. The predicted subsidence has been determined using the calibrated Incremental Profile Method, which is described in Chapter 3. The predicted additional conventional subsidence contours due to the extraction of the proposed longwalls only are shown in Drawing No. MSEC799-17.

A line has therefore been drawn defining the Study Area, based upon the 26.5 degree angle of draw line and the predicted 20 mm subsidence contour, whichever is furthest from the proposed longwalls, and is shown in Drawings Nos. MSEC799-01 and MSEC799-02.

There are areas that lie outside the Study Area that are expected to experience either far-field movements, or valley related movements. The surface features which could be sensitive to such movements have been identified and have been included in the assessments provided in this report.

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

A number of the major natural and built features 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 Doyles Creek 9032-1N, Parnell 9032-1S and Singleton 9132-4N. The proposed longwalls and the Study Area have been overlaid on an extract of these CMA maps in Fig. 2.1. It is noted that the features in the north-eastern part of the Study Area have been affected by the Wambo Open Cut.

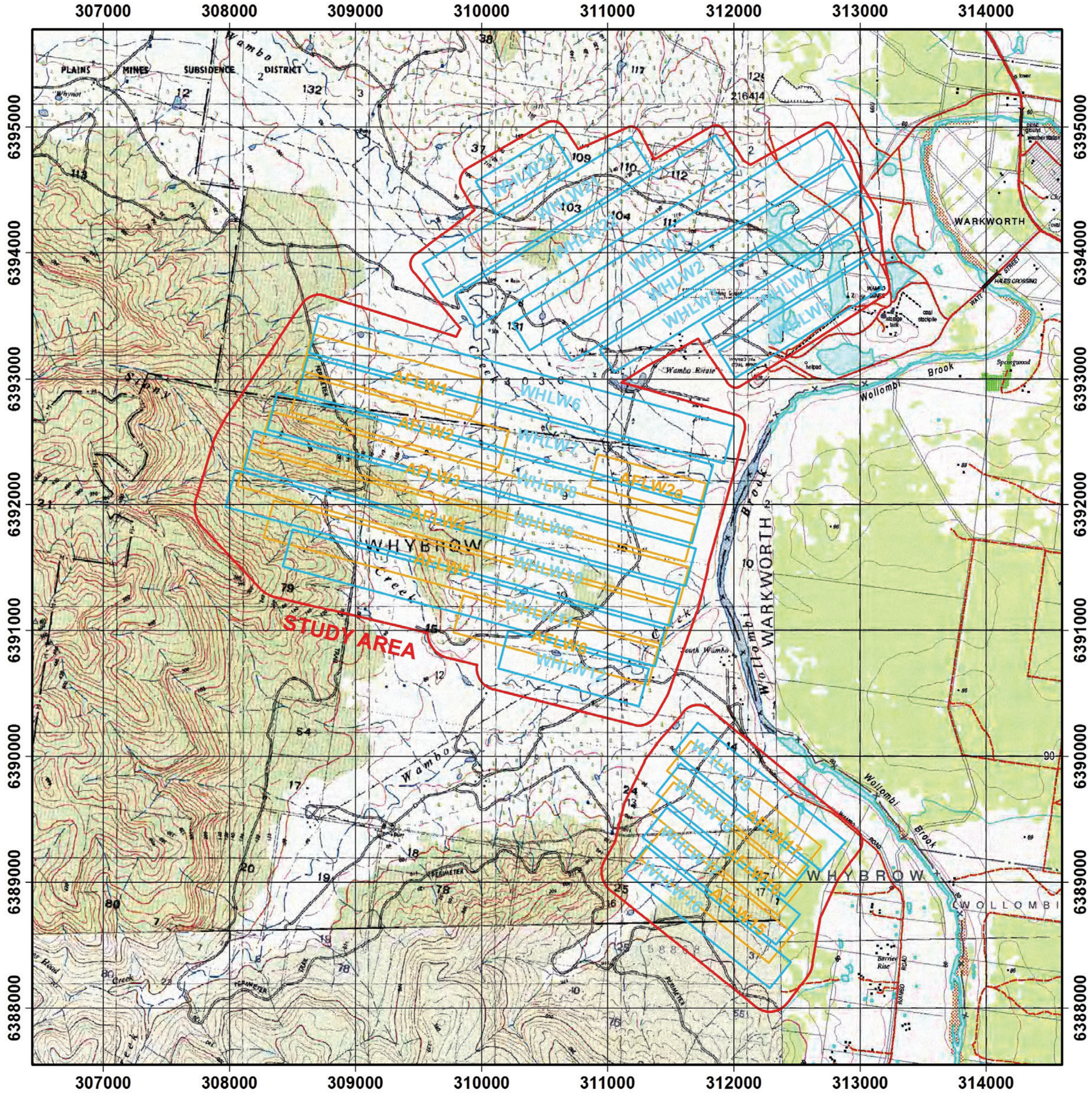


Fig. 2.1 Proposed Longwalls Overlaid on CMA Maps Nos. Doyles Creek 9032-1N, Parnell 9032-1S and Singleton 9132-4N

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. MSEC799-14 and MSEC799-15. The descriptions, predictions and impact assessments for each of the natural and built features are provided in Chapters 5 and 6.

Table 2.1 Natural and Built Features within the Study Area

Item	Within Study Area	Section Number
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	×	
Streams	✓	5.2 & 5.3
Aquifers or Known Groundwater Resources	✓	5.5
Springs or Groundwater Seeps	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.7
Steep Slopes	✓	5.8
Escarpments	✓	5.6
Land Prone to Flooding or Inundation	✓	5.9
Swamps or Wetlands	×	
Water Related Ecosystems	✓	5.10
Threatened or Protected Species	✓	5.11
Lands Defined as Critical Habitat	×	
National Parks	×	5.12
State Forests	×	
State Recreation or Conservation Areas	×	
Natural Vegetation	✓	5.13
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	×	
Roads (All Types)	✓	6.2
Bridges	×	
Tunnels	×	
Culverts	✓	6.2
Water, Gas or Sewerage Infrastructure	✓	6.3
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Plant	✓	6.4
Telecommunication Lines or Associated Plants	✓	6.5
Water Tanks, Water or Sewage Treatment Works	×	
Dams, Reservoirs or Associated Works	×	
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	×	
Shopping Centres	×	
Community Centres	×	
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

Item	Within Study Area	Section Number
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	✓	6.8
Farm Buildings or Sheds	✓	6.18
Tanks	×	
Gas or Fuel Storages	×	
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	✓	6.13
Mine Related Infrastructure Including Exploration Bores and Gas Wells	✓	6.14
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL SIGNIFICANCE	✓	6.15
AREAS OF HISTORICAL SIGNIFICANCE	✓	6.16
ITEMS OF ARCHITECTURAL SIGNIFICANCE	✓	6.16
PERMANENT SURVEY CONTROL MARKS	✓	6.17
RESIDENTIAL ESTABLISHMENTS		
Houses	✓	6.18
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	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

3.1. Introduction

This chapter provides an overview of the methods that have been used to predict the mine subsidence movements resulting from the extraction of the existing and proposed 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. 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 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 and Hunter 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 and Hunter Coalfields. The predictions 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 of the Incremental Profile Method for the South Wambo Underground Mine are provided in Section 3.3.

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 Hunter Coalfield. 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 proposed longwalls. The profile shapes can be further refined, based on local monitoring data, which is discussed further in Section 3.3.

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.

3.3. Calibration of the Incremental Profile Method

The proposed WHLW1 to WHLW6 and WHLW20 to WHLW22 in the Woodlands Hill Seam are located above the previously extracted United Collieries longwalls in the Arrowfield Seam. These longwalls are also located beneath the Wambo Open Cut.

The proposed WHLW6 to WH12 in the Woodlands Hill Seam are located beneath the previously extracted Homestead/Wollemi workings in the Whybrow Seam and the previously extracted WMLW1 to WMLW10A in the Wambo Seam. The AFLW1 to AFLW8 in the Arrowfield Seam are then proposed to be extracted beneath these longwalls and workings.

The proposed WHLW16 to WHLW19 in the Woodlands Hill Seam are generally located outside the extents of previous mining (i.e. single-seam mining conditions). The northern corner of the mining area, however, is partially located beneath the previously extracted Homestead/Wollemi workings in the Whybrow Seam. The AFLW15 to AFLW17 are then proposed to be extracted beneath WHLW16 to WHLW19.

The Incremental Profile Method has been calibrated to local conditions using ground monitoring data from the NWUM and from other nearby collieries. This has been achieved by comparing the observed mine subsidence movements along monitoring lines with those back-predicted using the standard Incremental Profile Method for the Hunter Coalfield.

WCPL provided MSEC with monitoring data along a number of monitoring lines above WMLW1 to WMLW10A in the Wambo Seam. These longwalls were extracted beneath the Homestead/Wollemi workings in the Whybrow Seam and above the United Collieries longwalls in the Arrowfield Seam (referred to as the Woodlands Hill Seam by United Collieries). The existing workings and the locations of the monitoring lines at the NWUM are shown in Fig. 3.1.

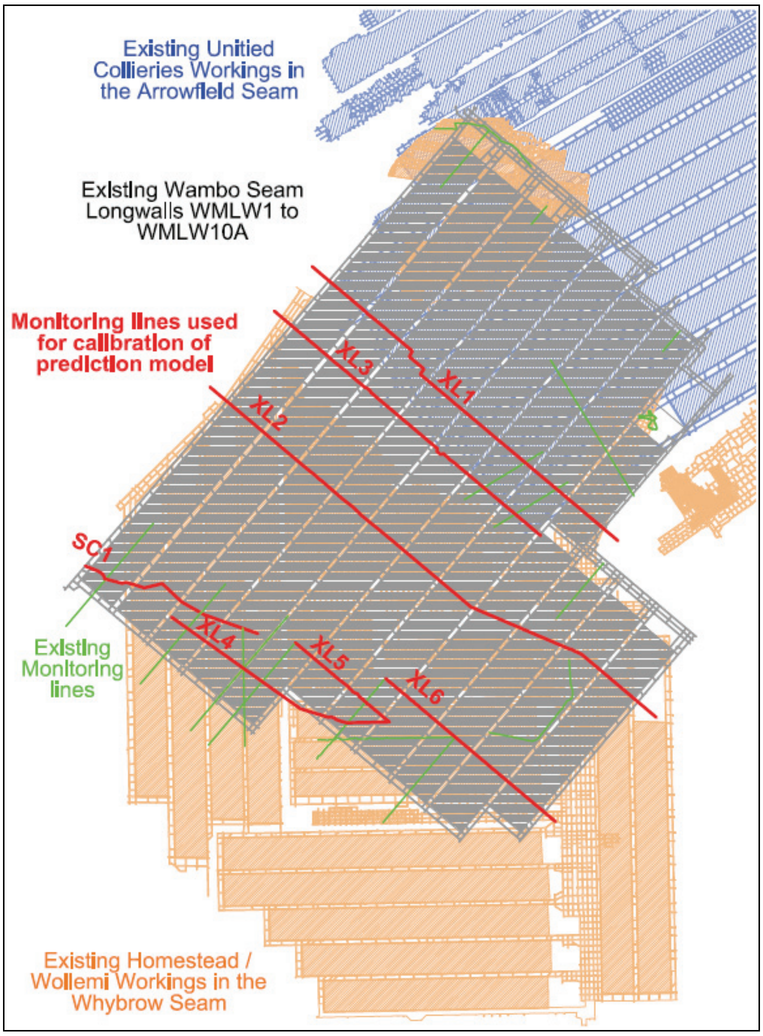


Fig. 3.1 Existing Workings and Monitoring Lines at the NWUM

The following sections describe the calibration of the Incremental Profile Method for single-seam and multi-seam conditions.

3.3.1. Calibration for Single-seam Mining Conditions

The proposed WHLW16 to WHLW19 are generally located outside the extents of the existing workings (i.e. single-seam mining conditions). The northern corner of this mining area, however, is partially located beneath the previously extracted Homestead/Wollemi workings in the Whybrow Seam.

The depths of cover above the proposed WHLW16 to WHLW19 vary between 260 metres and 380 metres and, therefore, the width-to-depth ratios vary between 0.7 and 1.2 (i.e. subcritical to critical in width). The maximum achievable subsidence in the Hunter Coalfield, for single-seam super-critical conditions, is generally 60 % to 65 % of the extracted thickness.

The standard Incremental Profile Method for the Hunter Coalfield has been used to predict the mine subsidence movements for the monitoring lines at the NWUM and at a number of other nearby collieries, including United, South Bulga, Beltana No. 1 Underground and Glennies Creek. Comparisons between the observed and predicted movements indicate that the standard prediction model generally provides reasonable, if not slightly conservative, predictions of the mine subsidence parameters for single-seam mining conditions.

For example, the comparisons between the observed and predicted profiles of subsidence, tilt and curvature for the XL3-Line at the NWUM, where there are no existing overlying workings (i.e. single-seam conditions), is shown in Fig. C.03, in Appendix C. The comparisons for monitoring lines at other nearby collieries in the Hunter Coalfield, where the width-to-depth ratios were around 0.7, 2.0 and 3.0 are also shown in C.08, C.09 and C.10, respectively, in Appendix C.

It can be seen from these figures, that the observed profiles of subsidence, tilt and curvature along these monitoring lines reasonably match those predicted using the standard Incremental Profile Method for the Hunter Coalfield. In some locations, there are small lateral shifts between the observed and predicted profiles, which could be the result of surface dip, seam dip, or variations in the overburden geology.

The magnitudes of the maximum observed subsidence along the XL3-Line were similar to the maxima predicted using the standard Incremental Profile Method, and represent around 65 % of the extracted seam thicknesses. The magnitudes of the maximum observed subsidence along the other three monitoring lines from the Hunter Coalfield (i.e. Figs. C.08 to C.10) were less than the maxima predicted, and represent between 40 % and 50 % of the extracted seam thicknesses.

The magnitudes of the observed tilts and curvatures along the monitoring lines were also reasonably similar to those predicted using the standard Incremental Profile Method for the Hunter Coalfield. It can be seen, however, that the observed tilts and curvatures were less than those predicted, in some locations, whilst the observed tilts and curvatures exceeded those predicted in other locations. This demonstrates the difficulty in predicting tilts and curvatures at a point, especially at shallower depths of cover. It is important then to recognise that there is greater potential for variation between observed and predicted movements at a point, as the depth of cover decreases.

Based on these comparisons, it is considered that the standard Incremental Profile Method for the Hunter Coalfield provides reasonable predictions of subsidence, tilt and curvature in these cases, for single-seam mining conditions. It has not been considered necessary, therefore, to provide any specific calibration of the standard model for the proposed longwalls based on single-seam mining conditions.

3.3.2. Calibration for Multi-seam Mining Conditions

Monitoring data from multi-seam longwall mining in the coalfields of NSW and overseas show that the maximum subsidence, as proportions of the extracted seam heights, are greater than those for equivalent single-seam mining cases. The monitoring data from the multi-seam cases also show that the shapes of the subsidence profiles are affected by the locations and stabilities of the goafs and chain pillars in the previously extracted seam as the longwalls are extracted beneath the existing workings.

Review of the Multi-seam Monitoring Data due to Mining in the Wambo Seam at the NWUM

WCPL extracted WMLW1 to WMLW10A at the NWUM beneath the existing Homestead/Wollemi workings in the Whybrow Seam and partially above the existing United Collieries longwalls in the Arrowfield Seam (referred to as the Woodlands Hill Seam by United Collieries).

The Incremental Profile Method was initially calibrated for the local multi-seam conditions based on the monitoring data collected during WMLW1 to WMLW4, which was described in Section 3.3.2 of Report No. MSEC495. The calibration also considered the multi-seam monitoring data available from other collieries in the Hunter and Newcastle Coalfields, including Blakefield South, Newstan, Sigma, Liddell and Cumnock. The maximum predicted subsidence for the longwalls in the Wambo Seam was taken to be 100 % of the extracted seam thickness for multi-seam mining conditions. This was consistent with the maximum vertical subsidence determined using the equation that was proposed by Li et al (2007).

Further multi-seam monitoring data has been collected during the extraction of WMLW5 to WMLW10 in the Wambo Seam at the NWUM. The predictions obtained using the calibrated in Incremental Profile Method have been reviewed based on the latest monitoring data.

The locations of the existing workings and the monitoring lines at the NWUM are shown in Fig. 3.1. The main transverse lines were the XL1-Line, XL2-Line, XL4-Line, XL5-Line, XL6-Line and the SC1-Line. It is noted, that the XL3-Line was located between the existing workings in the Whybrow and Arrowfield Seams, i.e. single-seam mining conditions, and was discussed in the previous section.

A summary of the mining geometries and the maximum observed subsidence along the main transverse monitoring lines, due to the extraction of the longwalls in the Wambo Seam, is provided in Table 3.1. The XL1-Line was located where the longwalls in the Wambo Seam were extracted above the existing United Collieries longwalls in the Arrowfield Seam. The remaining monitoring lines were located where the longwalls in the Wambo Seam were extracted beneath the existing Homestead/Wollemi workings in the Whybrow Seam.

Table 3.1 Multi-seam Monitoring Data from the NWUM

Monitoring Line	Wambo Seam Longwall	Void Width (m)	Average Depth of Cover (m)	Average Mining Height (m)	Interburden Thickness (m)	Maximum Observed Incremental Subsidence (m)	Longwall Width-to-Depth Ratio	Incremental Subsidence / Mining Height
XL1-Line	WMLW2	260	80	2.3	45	1.6	3.3	0.69
	WMLW3	260	80	2.3	40	1.5	3.2	0.67
	WMLW4	260	85	2.3	40	1.9	3.1	0.82
	WMLW5	260	85	2.3	40	1.4	3.2	0.60
	WMLW6	260	90	2.3	45	1.5	2.8	0.65
	WMLW7	260	95	2.3	50	1.5	2.7	0.66
XL2-Line	WMLW1	260	165	2.2	65	2.5	1.6	1.16
	WMLW2	260	160	2.2	60	1.6	1.7	0.74
	WMLW3	260	155	2.2	55	2.0	1.7	0.92
	WMLW4	260	145	2.2	45	2.1	1.8	0.97
	WMLW5	260	140	2.2	45	1.8	1.9	0.84
	WMLW6	260	145	2.2	50	1.8	1.8	0.83
	WMLW7	260	155	2.2	60	1.6	1.7	0.71
	WMLW8A	260	155	2.2	60	1.5	1.7	0.69
	WMLW9	260	150	2.2	60	2.1	1.7	0.96
	WMLW10	260	145	2.2	65	1.6	1.8	0.72
XL4-Line	WMLW3	260	250	2.5	75	2.3	1.0	0.90
	WMLW4	260	235	2.5	80	2.1	1.1	0.85
	WMLW5	260	225	2.5	85	1.9	1.2	0.76
	WMLW7	260	240	2.5	75	1.7	1.1	0.68
XL5-Line	WMLW5	260	220	2.5	70	2.3	1.2	0.92
	WMLW6	260	240	2.5	65	2.3	1.1	0.91
	WMLW7	260	225	2.5	65	1.7	1.2	0.67
XL6-Line	WMLW7	260	210	2.2	65	1.7	1.2	0.79
	WMLW8	260	205	2.2	70	2.0	1.3	0.91
	WMLW19	260	200	2.3	80	1.9	1.3	0.82
	WMLW10	260	195	2.4	90	1.6	1.3	0.69
SC1-Line	WMLW2	260	255	2.5	80	2.2	1.0	0.87
	WMLW3	260	235	2.5	75	2.0	1.1	0.79
	WMLW4	260	220	2.5	75	2.4	1.2	0.97

It can be seen from the above table, that the observed incremental subsidence due to the extraction of the longwalls in the Wambo Seam represented between 0.60 and 1.16 times the mining height, with an average around 0.81 times the mining height. It is noted, that the XL1-Line was located near the ends of the United Collieries longwalls and, therefore, end effects could have reduced the multi-seam effects of these existing workings along this monitoring line.

It is considered, therefore, that adopting a maximum predicted subsidence of 100 % of the extracted seam thickness should generally provide conservative predictions for multi-seam conditions for the Wambo Seam. The observed subsidence can exceed the predictions, in some locations, due to locally increased subsidence due to the effects of the chain pillars in the overlying workings.

The shapes of the multi-seam subsidence profiles were calibrated using the available monitoring data at that time from the NWUM and from the Blakefield South Mine. The multi-seam monitoring data indicates that the shapes of multi-seam subsidence profiles depend on, amongst other factors, the depths of cover, interburden thickness, extraction heights and the relative locations between the longwalls within each seam.

In the cases where the chain pillars within the lower seam are located directly beneath the chain pillars or panel edges in the overlying seam, referred to as *stacked* conditions, the observed subsidence profiles are steeper and more localised above the longwalls when compared with those for similar single-seam conditions. In the cases where the chain pillars within the lower seam are offset from the chain pillars or panel edges in the overlying seam, referred to as *staggered* conditions, the subsidence profiles are flatter and extend further when compared with those for similar single-seam conditions.

The observed and the predicted profiles of subsidence, tilt and curvature for the XL1-Line, XL2-Line, XL4-Line, XL5-Line, XL6-Line and the SC1-Line are shown in Figs. C.01 to C.07, in Appendix C. It is noted, that the XL3-Line was for single-seam mining conditions and was discussed in the previous section.

It can be seen from these figures, that the observed profiles of subsidence along the monitoring lines reasonably matched those predicted using the calibrated Incremental Profile Method for multi-seam conditions. The maximum observed tilts and curvatures were in similar locations as the predicted maxima. Localised and elevated tilts and curvatures were observed in some locations, which exceeded the predictions, due to the multi-seam conditions.

The magnitudes of the maximum observed subsidence along the XL1-Line (refer to Fig. C.01) were less than the maxima predicted using the calibrated Incremental Profile Method, and represented between 67 % and 82 % of the extracted seam thicknesses. This monitoring line was located near the ends of the United Collieries longwalls and, therefore, end effects could have reduced the multi-seam influence of the existing workings along this monitoring line.

The maximum observed subsidence exceeded the maximum predicted subsidence above WMLW1 along the XL2-Line (refer to Fig. C.02). In this location, the monitoring line was close to the finishing end of the overlying LW10B in the Whybrow Seam and, therefore, mining in the Wambo Seam could have resulted in greater reactivation of the goaf which was partially supported by the longwall end, resulting in the locally higher subsidence. There is a series of faults located north-west of WMLW1 that could have also affected the vertical subsidence in this location.

The maximum observed subsidence also exceeded the maximum predicted subsidence above WMLW6 along the XL4-Line (refer to Fig. C.04). This monitoring line was located close to the end of the longwall and, therefore, the prediction was reduced due to the end effects. The observed subsidence for this longwall was less than the prediction when the end effects are excluded.

The maximum observed subsidence exceeded the maximum predicted subsidence above WMLW1 along the SC1-Line (refer to Fig. C.07). In this location, the monitoring line was near the commencing end of WMLW1 and, therefore, the predicted subsidence had been reduced due to end effects. Away from the longwall commencing end, the maximum predicted subsidence above WMLW1 was around 1,500 mm, for single-seam conditions, which is closer to the maximum observed subsidence of 1,727 mm in this location.

Elsewhere, the maximum observed vertical subsidence along the monitoring lines were typically within ±15 % to ±25 % of the maximum predicted vertical subsidence, which is generally considered acceptable for subsidence prediction methods.

The magnitudes of the observed tilts and curvatures along the monitoring lines were also reasonably similar to those predicted using the calibrated Incremental Profile Method for multi-seam conditions. It can be seen, however, that the observed tilts and curvatures were greater than those predicted, in some locations, due to the reactivation of the existing workings. It is important then to recognise that there is greater potential for variation between observed and predicted movements at a point for multi-seam conditions.

The observed tilts and curvatures exceeded those predicted where the longwall edges in the Wambo Seam were located directly beneath the panels edges in the Whybrow Seam, i.e. *stacked* conditions. These exceedances are localised, as the longwalls in the Wambo Seam are orientated obliquely to the panels in the overlying Whybrow Seam and, therefore, the *stacked* conditions only occur in discrete locations.

The observed tilts and curvatures also locally exceeded the predictions due to the less regular subsidence profile resulting from the multi-seam conditions. The magnitudes of these localised movements, however, were typically less than the maxima predicted anywhere above the extracted longwalls.

Based on these comparisons, it is considered that the calibrated Incremental Profile Method for multi-seam conditions provides reasonable predictions of subsidence, tilt and curvature in these available cases.

Multi-seam Calibration for the Future Longwalls in the Woodlands Hill and Arrowfield Seams

The extraction of the proposed longwalls on the Woodlands Hill Seam will reactivate the existing goafs above the Wambo Seam and, to a lesser extent, the Whybrow Seam. Similarly, the extraction of the proposed longwalls in the Arrowfield Seam will reactive the existing goafs above the Woodlands Hill Seam and, to lesser extents, the Wambo and Whybrow Seams.

The interburden thickness between the Woodlands Hill Seam and Wambo Seam varies between 110 metres and 150 metres, which is greater than the interburden thickness between the Wambo and Whybrow Seams, which varies between 55 metres and 95 metres. The multi-seam interaction due to the mining in the Woodlands Hill Seam, therefore, is expected to be less than that observed due to the extraction of the longwalls in the Wambo Seam.

The interburden thickness between the Arrowfield and Woodlands Hill Seams varies between 40 metres and 80 metres. Whilst the interburden thickness is similar to that between the Wambo and Whybrow Seams, the depth of cover to the Arrowfield Seam is greater than that to the Wambo Seam.

The calibration of the Incremental Profile Method for the Woodlands Hill and Arrowfield Seams, therefore, has been undertaken using the available multi-seam data from the NSW Coalfields. The empirical multi-seam data for these cases are illustrated in Fig. 3.2, below, which shows the maximum observed subsidence, as a proportion of the extracted seam thickness, versus the longwall width-to-depth ratio. The multi-seam cases from the NWUM are shown as the blue diamonds, and the multi-seam cases from elsewhere in the NSW Coalfields are shown as the green and red diamonds. Single-seam mining cases are also shown in this figure, for comparison, as the light grey diamonds.

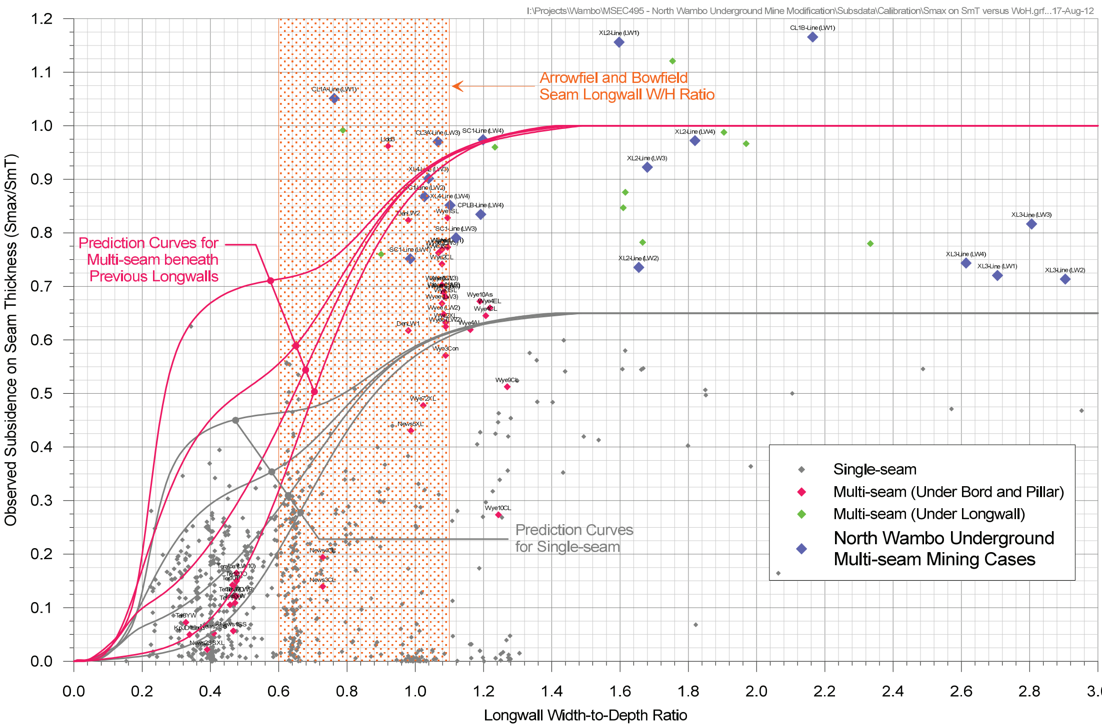


Fig. 3.2 Maximum Observed Subsidence versus Longwall Width-to-Depth Ratio for Historical Multi-seam Mining Cases

The typical prediction curves used for single-seam mining conditions are shown as the grey lines, in the above Fig. 3.2, for various mine geometries. These prediction curves have been scaled up, so as to achieve a maximum predicted incremental subsidence of 100 % of extracted seam thickness, which are shown as the red curves in this figure.

It can be seen, that these prediction curves provide reasonable estimates of the maximum subsidence for the multi-seam cases for longwalls beneath longwalls (i.e. green and blue diamonds). In some cases, the maximum observed subsidence exceeds the prediction curves, however, in many of these cases the maximum subsidence was localised and the subsidence elsewhere was below the prediction curves.

The multi-seam prediction curves provide subsidence around 55 % greater than those obtained using the standard single-seam prediction curves. In practice, the additional subsidence due to multi-seam mining conditions will be dependent on a number of factors, including the interburden thickness, the extraction heights in both seams, the conditions of the remnant pillars in the overlying seam.

It is considered, that the multi-seam prediction curves, illustrated in Fig. 3.2 as the red curves, should provide reasonable predictions of the maximum subsidence, as a proportion of the extraction height, for the proposed longwalls in the Woodlands Hill and Arrowfield Seams.

3.4. Reliability of the Predicted Conventional Subsidence Parameters

The Incremental Profile Method is based upon a large database of observed subsidence movements in the NSW Coalfields and has been found, in most cases, to give reasonable, if not, slightly conservative predictions of maximum subsidence, tilt and curvature. The predicted profiles obtained using this method also reflect the way in which each parameter varies over the mined area and indicate the movements that are likely to occur at any point on the surface.

In this case, the Incremental Profile Method was calibrated using local monitoring data from the NWUM, as well as from other nearby collieries in the Hunter Coalfield. The subsidence model was also calibrated using the available multi-seam monitoring data from the NWUM and from elsewhere in the NSW Coalfields.

The prediction of the conventional subsidence parameters at specific points is more difficult than the prediction of the maxima anywhere above extracted longwalls. Variations between predicted and observed parameters at a point can occur where there is a lateral shift between the predicted and observed subsidence profiles, which can result from seam dip or variations in topography. In these situations, the lateral shift can result in the observed parameters being greater than those predicted in some locations, whilst the observed parameters are less than those predicted in other locations.

Notwithstanding the above, the Incremental Profile Method provides site specific predictions for each natural and built feature and, hence, provides a more realistic assessment of the subsidence impacts than by applying the maximum predicted parameters at every point, which would be overly conservative and would yield an excessively overstated assessment of the potential subsidence impacts.

The prediction of strain at a point is even more difficult as there tends to be a large scatter in observed strain profiles. It has been found that measured strains can vary considerably from those predicted at a point, not only in magnitude, but also in sign, that is, the tensile strains have been observed where compressive strains were predicted, and vice versa. For this reason, the prediction of strain in this report has been based on a statistical approach, which is discussed in Section 4.4.

It is also likely that some localised irregularities will occur in the subsidence profiles due to near surface geological features and multi-seam mining conditions. The irregular movements are accompanied by elevated tilts, curvatures and strains, which often exceed the conventional predictions. In most cases, it is not possible to predict the locations or magnitudes of these irregular movements. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains, including both conventional and non-conventional anomalous strains, which is discussed in Section 4.4.

4.0 MAXIMUM PREDICTED SUBSIDENCE PARAMETERS FOR THE EXISTING AND PROPOSED LONGWALLS

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the existing longwalls in the Whybrow and Wambo Seams and the proposed longwalls in the Woodlands Hill and Arrowfield Seams. The predicted subsidence parameters and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

The predicted vertical subsidence, tilt and curvature have been obtained using the Incremental Profile Method, which has been calibrated for multi-seam conditions, as described in Section 3.3. The reliability of this prediction method is discussed in Section 3.4. The predicted strains have been determined by analysing the strains measured at the NWUM as a result of the previous mining in the Wambo Seam.

The predictions for the natural and built features are provided in Chapters 5 and 6.

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

4.2.1. Predictions for the Existing Workings in the Whybrow Seam

The existing Homestead/Wollemi workings were extracted in the Whybrow Seam. The void widths of the longwalls and total extraction panels varied between 55 metres and more than 400 metres. The depth of cover directly above these workings varied between 50 metres and 250 metres.

The existing workings in the Whybrow Seam were supercritical in width where the depths of cover were the shallowest (i.e. in the north-eastern part of the mining area) and subcritical where the depths of cover were the greatest (i.e. in the south-western part of the mining area).

The maximum subsidence that developed for supercritical conditions is expected to have been 60 % to 65 % of the working height, which is the maximum achievable for single-seam mining conditions in the Hunter Coalfield. The maximum predicted subsidence for the existing Homestead/Wollemi workings, therefore, is 1,800 mm to 2,000 mm based on a working height of 3.0 metres.

The SC1-Line was established prior to longwalls in the Whybrow Seam mining directly beneath it. One survey was carried out in September 2007, after Longwalls 10 to 13 had been extracted directly beneath this monitoring line. The longwall void widths were 210 metres and the depth of cover along this monitoring line varied between 140 metre and 200 metres and, therefore, the longwall width-to-depth ratios were 1.0 and 1.5.

The subsidence parameters measured along the SC1-Line should, therefore, provide a reasonable guide to the maximum movements which occurred as a result of mining in the Whybrow Seam. In the survey carried out in September 2007, the maximum observed subsidence directly above the longwalls varied between 1,500 mm to 1,750 mm and the subsidence observed directly above the chain pillars was around 200 mm. The maximum observed tilts varied between 20 mm/m and 30 mm/m. The observed strains were typically between 5 mm/m and 10 mm/m, with localised elevated strains around 20 mm/m.

The predicted subsidence parameters and the predicted subsidence contours provided in this report do not include the subsidence that occurred as a result of mining in the Whybrow Seam. That is, the conditions post mining in the Whybrow Seam have been taken as the baseline for the predictions and impact assessments provided in this report. Whilst the predicted subsidence parameters resulting from the mining in the Whybrow Seam have not been included, the effects of these existing workings on the subsidence resulting from mining in the Wambo, Woodlands Hill and Arrowfield Seams have been considered.

4.2.2. Predictions for the Existing Longwalls in the Wambo Seam

WCPL has completed the extraction of WMLW1 to WMLW10A in the Wambo Seam at the NWUM. The ground movements that resulted from the extraction of these longwalls were measured using a number of monitoring lines. The locations of these monitoring lines are shown in Fig. 3.1.

The observed profiles of subsidence, tilt and curvature along the main transverse monitoring lines are shown in Figs. C.01 to C.07, in Appendix C. The predicted profiles are also shown in these figures and the comparisons with the observed movements are provided in Section 3.3. The Incremental Profile Method was calibrated using the available ground monitoring data at the NWUM.

A summary of the maximum predicted values of additional conventional subsidence, tilt and curvature due to mining in the Wambo Seam only, is provided in Table 4.1. The values do not include the predicted movements resulting from the extraction of the previous workings in the Whybrow Seam, but include the multi-seam effects due to the presence of these existing workings.

Table 4.1 Maximum Predicted Additional Conventional Subsidence, Tilt and Curvature due to Mining in the Wambo Seam Only

Seams	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Wambo Seam	2,600	60	> 3.0	> 3.0

The maximum predicted additional subsidence due to mining of the Wambo Seam only is 2,600 mm, which represents 100 % of the seam thickness in this location. The maximum predicted subsidence occurs above the south-western end of WMLW10, where the seam thickness is the greatest.

The maximum observed subsidence along the main transverse monitoring lines, due to mining in the Wambo Seam only, was 2,600 mm which occurred along the XL2-Line above WMLW4. It is noted, that up to 3,540 mm subsidence was measured along the SC1-Line, however, this also included subsidence resulting from the extraction of the overlying workings in the Whybrow Seam.

The maximum predicted conventional tilt due to mining of the Wambo Seam only is 60 mm/m (i.e. 6 %, or 1 in 17). The maximum predicted conventional hogging and sagging curvatures are both greater than 3.0 km^{-1}, which represent a minimum radius of curvature less than 0.3 kilometres The maximum predicted tilt and curvatures occur at the north-eastern ends of the longwalls, where the depths of cover are the shallowest.

4.2.3. Predictions for the Approved Layout

The predicted conventional subsidence parameters due to mining in the Wambo, Arrowfield and Bowfield Seams, based on the *Approved Layout*, were originally provided in a report by Holt (2003) which supported the *Wambo Development Project Environmental Impact Statement* (WCPL 2003, the 2003 EIS), and then in a subsequent report by Holt (2005) which supported the 2005 SEE.

The maximum predicted subsidence resulting from the extraction of the longwalls in the Wambo Seam only, provided in the 2005 SEE, was 1,300 mm to 1,800 mm (Holt, 2005). The maximum predicted total subsidence due to mining in the Wambo, Arrowfield and Bowfield Seams, provided in the 2005 SEE, was 4,500 mm to 5,200 mm (Holt, 2005).

The original subsidence predictions provided in the 2003 EIS and the 2005 SEE used the methods outlined in the DMR Newcastle Guidelines (Holla, 1987). It was stated in the subsidence report by Holt (2003) that the method is:-

> "*based on real subsidence monitoring of single seam workings*", and that
>
> "*the massive nature of sandstone interburden between seams suggests that a 60% of mined-height factor be used for maximum subsidence prediction for the proposed longwall operations*".

It was also stated in the subsidence report by Holt (2005) that:-

> "*Experience with other multi-seam operations also suggests that the 60% of mined height for maximum subsidence prediction is appropriate where seams are widely separated. Where seams are more closely spaced the figure increases to 65% of mined height*".

Since the 2005 SEE, more detailed multi-seam monitoring data has been gathered from the NSW Coalfields, including at the NWUM, which indicates that the subsidence which develops from multi-seam mining is greater than 60 % of the mining height, as described in Section 3.3.2.

The maximum predicted tilts and strains due to mining in the Wambo, Arrowfield and Bowfield Seams were also provided in the 2003 EIS and the 2005 SEE. It was described in the subsidence report by Holt (2003) that:-

> "*Surface strains have been calculated using the empirical formulae provided in the Newcastle Subsidence Guideline. The empirical formula for tilt that is provided in the Newcastle Guideline is known to predict strains much lower than that measured for shallow workings. In the absence of more detailed prediction methods the Newcastle Guideline formulae have been adopted*",
>
> "*The values quoted are for single seam workings*", and
>
> "*Multi-seam workings would change the amount of surface strain because of likely re-working of previously subsided ground. The amounts cannot be accurately predicted by the methods set down in the Newcastle Coalfield Guideline because it is restricted to single seam workings*".

It was stated in the 2005 SEE, however, that the standard empirical formulae were modified based on the observed tilts and strains resulting from the extraction of United Collieries Panels 1 and 2. It was described in the subsidence report by Holt (2005) that:-

> "*Surface strains have been calculated using site specific empirical formulae of the same form developed for the published subsidence guidelines. The predictions are based on actual strain and tilt measurements and are not derived from smoothed subsidence data, so represent realistic maximum predicted values*".

It appears from the above extracts, that the predicted tilts and strains provided in the 2005 SEE were obtained using modified empirical formulae based on the DMR Newcastle Guidelines (Holla, 1987). Whilst these empirical formulae have been improved, based on the limited available multi-seam data, they are essentially based on higher depth of cover single-seam workings and, hence, are less reliable.

Based on this, it is difficult to compare the predicted tilts and strains provided in the 2005 SEE with those predicted based on the *Modified Layout*, as the Incremental Profile Method has been calibrated for multi-seam conditions using the more detailed local monitoring data.

Subsequently, WCPL sought approval for the extraction of three additional longwalls in the Wambo Seam, being WMLW9, WMLW10 and WMLW10A, which was addressed in the *North Wambo Underground Mine Modification Environmental Assessment* (WCPL, 2012) and the *North Wambo Underground Mine Longwall 10A Modification Environmental Assessment* (WCPL, 2014). Reports Nos. MSEC495 (Rev. C), MSEC697 (Rev. B) and MSEC754 (Rev. A) were issued in support of these applications.

The predicted subsidence contours and parameters provided in Reports Nos. MSEC495 (Rev. C), MSEC697 (Rev. B) and MSEC754 (Rev. A) included the now completed longwalls in the Wambo Seam and the currently approved longwalls in the Arrowfield and Bowfield Seams. The predictions provided in these reports were obtained using the calibrated Incremental Profile Method.

The predicted subsidence contours and parameters provided in this report for the *Approved Layout*, therefore, have also been determined using the calibrated Incremental Profile Method, which is described in Section 3.3.

Existing and Approved Longwalls Located West of Wollombi Brook

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature due to mining in the Wambo, Arrowfield and Bowfield Seams, based on the *Approved Layout*, is provided in Table 4.2. The values are the maxima within the Study Area obtained using the calibrated Incremental Profile Method, as described in Section 3.3.

Table 4.2 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature due to Mining in the Wambo, Arrowfield and Bowfield Seams Based on Approved Layout

Seams	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Wambo and Arrowfield Seam	5,250	65	> 3.0	> 3.0
Wambo, Arrowfield and Bowfield Seams	9,000	90	> 3.0	> 3.0

The maximum predicted total subsidence due to mining in the Wambo, Arrowfield and Bowfield Seams, based on the *Approved Layout*, is 9,000 mm, which represents around 90 % of the total extraction height of 10 metres in this location. The maximum predicted total subsidence occurs directly above WMLW6, AFLW13 and BFLW13.

The maximum predicted total tilt is 90 mm/m (i.e. 9.0 %, or 1 in 11). The maximum predicted total hogging and sagging curvatures are both greater than 3.0 km^{-1}, which represents a minimum radius of curvature less than 0.3 kilometres. The maximum predicted total tilts and curvatures occur in the north-eastern part of the mining area, where the depths of cover are the shallowest.

Approved Longwalls in the Arrowfield and Bowfield Seams Located East of Wollombi Brook

WCPL currently has approval to mine five longwalls in the Arrowfield Seam and five longwalls in the Bowfield Seam east of Wollombi Brook. The longwalls in the Bowfield are no longer proposed to be mined based on the current mine plans. The approved five longwalls in the Arrowfield Seam on the eastern side of Wollombi Brook are not proposed to be modified and, therefore, have not been re-assessed in this report.

The predicted subsidence contours due to the extraction of the approved longwalls in the Arrowfield Seam east of Wollombi Brook have been included in Drawings Nos. MSEC799-17 and MSEC799-19. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature due to mining in the approved longwalls in the Arrowfield Seam east of Wollombi Brook is provided in Table 4.3. The values are the maxima obtained using the calibrated Incremental Profile Method, as described in Section 3.3.

Table 4.3 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature due to Mining in the Approved Longwalls in the Arrowfield Seam East of Wollombi Brook

Seams	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Arrowfield Seam (East of Wollombi Brook)	2,750	50	1.5	1.5

The maximum predicted total subsidence due to mining the approved longwalls in the Arrowfield Seam east of Wollombi Brook is 2,750 mm, which represents 65 % of the total extraction height of around 4 metres in this location. The approved longwalls are supercritical in width and, therefore, the predicted subsidence is the maximum achievable for single-seam mining conditions.

The maximum predicted total tilt is 50 mm/m (i.e. 5.0 %, or 1 in 20). The maximum predicted total hogging and sagging curvatures are 1.5 km^{-1}, which represents a minimum radius of curvature of 0.7 kilometres.

Predicted Subsidence Contours based on the Approved Layout

The predicted total subsidence contours for the Approved Layout are provided in: Fig. 4.1 based on mining in the Wambo, Arrowfield and Bowfield Seams; and Fig. 4.2 based on mining in the Whybrow, Wambo, Arrowfield and Bowfield Seams.

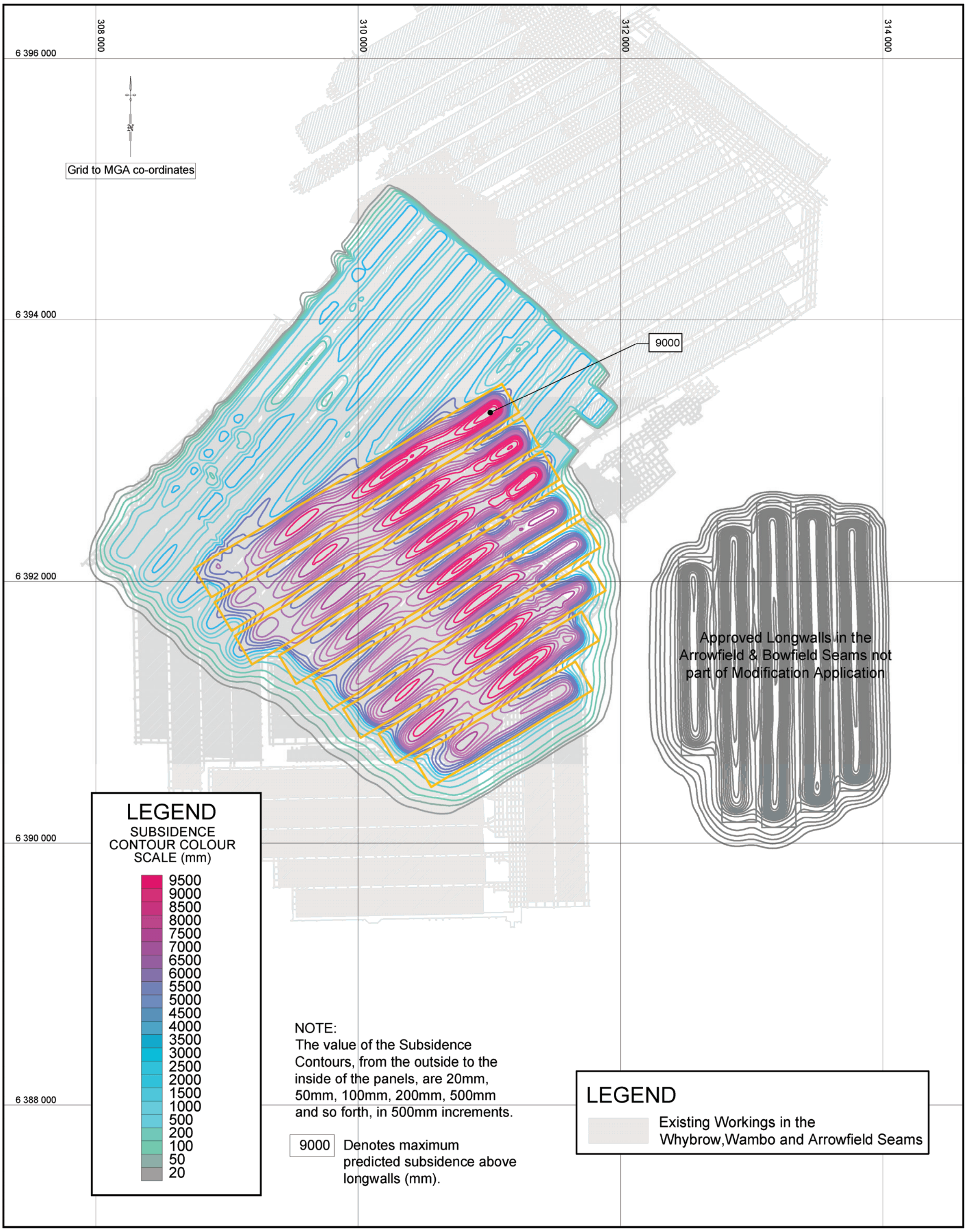


Fig. 4.1 Predicted Total Subsidence Contours Resulting from the Extraction of the Wambo, Arrowfield and Bowfield Seams Based on the Approved Layout

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\Fig 4.2 WY_WM_AF_BF (Apvd).dwg

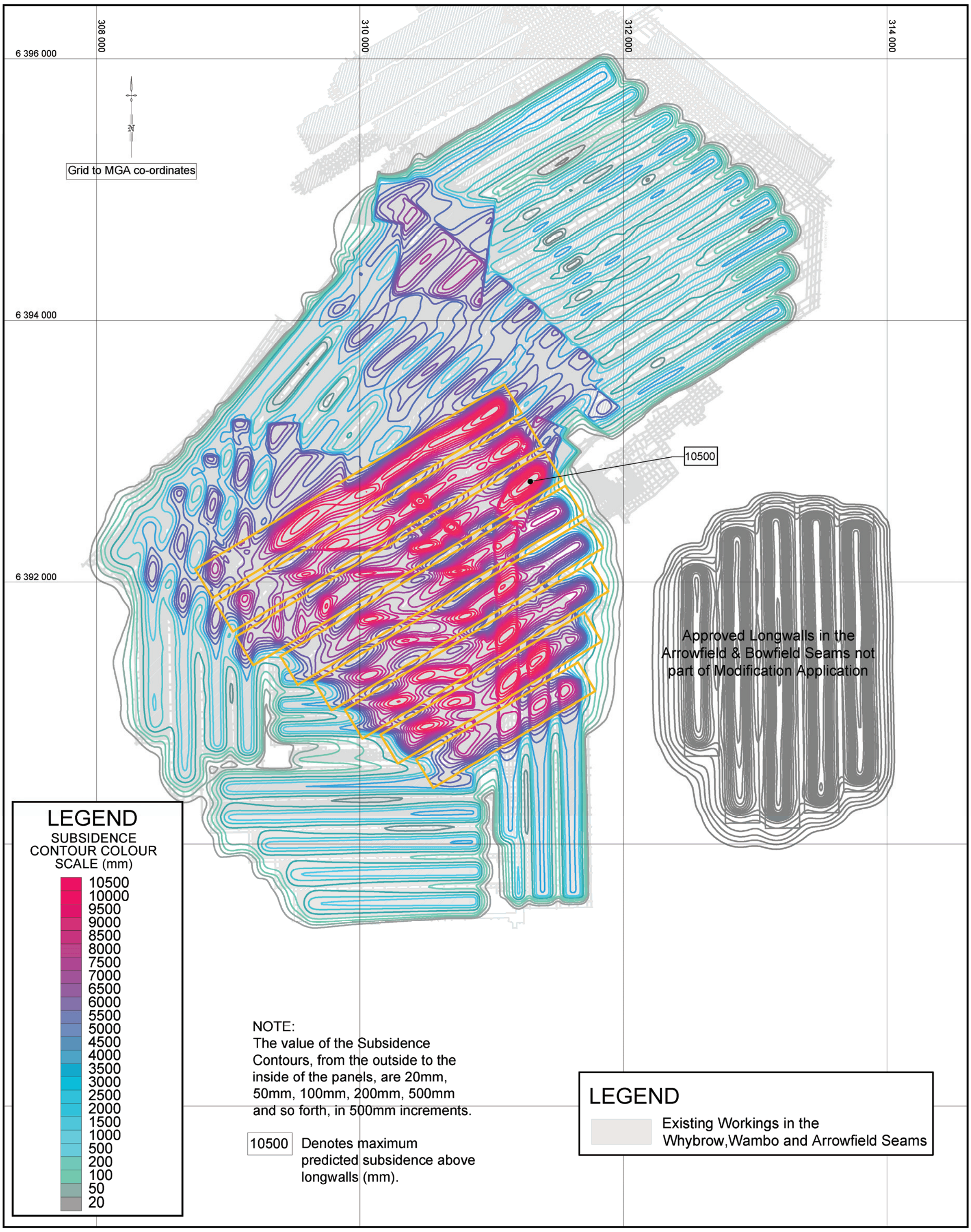


Fig. 4.2 Predicted Total Subsidence Contours Resulting from the Extraction of the Whybrow, Wambo, Arrowfield and Bowfield Seams Based on the Approved Layout

4.2.4. Predictions for the Modified Layout

The predicted additional conventional subsidence contours due to the extraction of the proposed longwalls in the Woodlands Hill Seam only are shown in Drawing No. MSEC799-16. The predicted additional conventional subsidence contours due to the extraction of the proposed longwalls in both the Woodlands Hill and Arrowfield Seams are shown in Drawing No. MSEC799-17. The contours include the multi-seam effects of the previously extracted Homestead/Wollemi workings in the Whybrow Seam and the longwalls in the Wambo Seam.

A summary of the maximum predicted values of additional conventional subsidence, tilt and curvature, due to the extraction of each of the proposed seams, is provided in Table 4.4. The values do not include the predicted movements resulting from the extraction of the previous workings in the Whybrow and Wambo Seams, but include the multi-seam effects due to the presence of these existing workings.

Table 4.4 Maximum Predicted Additional Conventional Subsidence, Tilt and Curvature due to Mining of the Proposed Longwalls in the Woodlands Hill and Arrowfield Seams

Seam	Maximum Predicted Additional Conventional Subsidence (mm)	Maximum Predicted Additional Conventional Tilt (mm/m)	Maximum Predicted Additional Conventional Hogging Curvature (km^{-1})	Maximum Predicted Additional Conventional Sagging Curvature (km^{-1})
Woodlands Hill Seam Only	3,200	50	1.5	1.5
Woodlands Hill and Arrowfield Seams	4,050	50	1.5	1.5

The maximum predicted additional subsidence due to mining of the Woodlands Hill and Arrowfield Seams is 4,050 mm, which represents around 68 % of the total extraction height of 6 metres in this location. It is noted, that the maximum predicted subsidence is less than 100 % of the total extraction height, due to the stagger between the longwalls in each of the seams and due to the higher depths of cover.

The maximum predicted additional tilt is 50 mm/m (i.e. 5 %, or 1 in 20). The maximum predicted additional hogging and sagging curvatures are both 1.5 km^{-1}, which represents a minimum radius of curvature of 0.7 kilometres.

The predicted total conventional subsidence contours due to mining in the Wambo, Woodlands Hill and Arrowfield Seams, based on the *Modified Layout*, are shown in Drawings Nos. MSEC799-18 and MSEC799-19. The contours include the effects of the previously extracted Homestead/Wollemi workings in the overlying Whybrow Seam and the existing United Collieries longwalls in the Arrowfield Seam.

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature due to mining in the Wambo, Woodlands Hill and Arrowfield Seams, based on the *Modified Layout*, is provided in Table 4.5. The values are the maxima within the Study Area obtained using the calibrated Incremental Profile Method, as described in Section 3.3.

Table 4.5 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams Based on Modified Layout

Seams	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Wambo and Woodlands Hill Seams	5,200	75	> 3.0	> 3.0
Wambo, Woodlands Hill and Arrowfield Seams	6,250	75	> 3.0	> 3.0

The maximum predicted total subsidence due to mining in the Wambo, Woodlands Hill and Arrowfield Seams, based on the *Modified Layout*, is 6,250 mm, which represents around 78 % of the total extraction height of 8 metres in this location. The maximum predicted total subsidence occurs above WMLW5, WHLW8 and the chain pillar between AFLW2 and AFLW3.

The maximum predicted total tilt is 75 mm/m (i.e. 7.5 %, or 1 in 13). The maximum predicted total hogging and sagging curvatures are both greater than 3.0 km^{-1}, which represents a minimum radius of curvature less than 0.3 kilometres. The maximum predicted total tilts and curvatures occur in the north-eastern part of the mining area, where the depths of cover are the shallowest.

The predicted total conventional subsidence contours due to mining in the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams, based on the *Modified Layout*, are shown in Drawing No. MSEC799-20. The contours include the predicted movements due to the previously extracted Homestead/Wollemi workings in the overlying Whybrow Seam and the existing United Collieries longwalls in the Arrowfield Seam.

The maximum predicted total subsidence due to mining in the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams, based on the *Modified Layout*, is 8,200 mm, which represents around 75 % of the total extraction height of approximately 11 metres in this location. The maximum predicted total subsidence occurs above AFLW4 and AFLW5.

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

The comparison of the maximum predicted total conventional subsidence parameters, based on the *Approved Layout* and the *Modified Layout*, is provided in Table 4.6. The values are the maxima due to mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams (i.e. not including the subsidence due to the previously extracted Homestead/Wollemi workings in the overlying Whybrow Seam and the existing United Collieries longwalls in the Arrowfield Seam).

Table 4.6 Comparison of Maximum Predicted Subsidence Parameters due to Mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	9,000	90	> 3.0	> 3.0
Modified Layout	6,250	75	> 3.0	> 3.0

It is noted, that the predictions for the *Approved Layout* are greater than that previously provided in the report by Holt (2005), which supported the 2005 SEE, as the Incremental Profile Method has been calibrated to the local monitoring data from the NWUM, whereas the original predictions had to rely on the prediction method outlined in the DMR Newcastle Guidelines (Holla, 1987). Also, more detailed multi-seam monitoring data from the NSW Coalfields has been gathered, since the 2005 SEE, which has allowed further calibration of the Incremental Profile Method, as described in Section 3.3.

It can be seen from Table 4.6, that the maximum predicted total vertical subsidence, based on the *Modified Layout*, of 6,250 mm, is less than the maxima predicted based on the *Approved Layout,* of 9,000 mm, which was obtained using the calibrated Incremental Profile Method. The predicted subsidence decreases as a result of the proposed modification for the following reasons:

- The proposed longwalls in the Woodlands Hill and Arrowfield Seams are *staggered* based on the *Modified Layout*, whereas the proposed longwalls in the Arrowfield and Bowfield Seams are *stacked* (i.e. directly above and below) based on the *Approved Layout*, i.e. the locations of the maxima for each seam are offset based on the *Modified* Layout and are coincident based on the *Approved Layout*; and
- The proposed mining heights for the *Modified Layout* are between approximately 2.1 metres and 3.0 metres in the Woodlands Hill Seam and approximately 2.9 metres and 4.1 metres in the Arrowfield Seam, whereas the proposed mining heights for the *Approved Layout* were between 3.2 metres and 4.2 metres for the Arrowfield Seam and between 3.0 metres and 4.5 metres for the Bowfield Seam, i.e. the proposed mining heights have decreased.

Whilst the depth of cover and interburden thickness for the topmost seam based on the *Modified Layout* (i.e. Woodlands Hill Seam) are less than those based on the *Approved Layout* (i.e. Arrowfield Seam), these have smaller effects than the offset of the longwalls and the reduced mining heights as described above. Also, the interburden thickness between the two seams based on the *Modified Layout* (i.e. Woodlands Hill and Arrowfield Seam) is greater than that based on the *Approved Layout* (i.e. Arrowfield and Bowfield Seam).

The maximum predicted total tilt, based on the *Modified Layout*, of 75 mm/m (i.e. 7.5 %, or 1 in 13), is less than the maxima predicted based on the *Approved Layout* using the calibrated Incremental Profile Method, of 90 mm/m (i.e. 9.0 %, or 1 in 11).

The maximum predicted total curvatures are greater than 3.0 km^{-1} (i.e. minimum radius of curvature less than 0.3 kilometres) based on both the *Modified Layout* and *Approved Layout*. Generally, the predicted curvatures reduce as a result of the proposed modification, but it is more difficult to directly compare the curvatures at these higher magnitudes, as they occur as localised and elevated values.

The predicted profiles of conventional subsidence, tilt and curvature along Prediction Lines 1 to 4, based on the *Approved Layout* and *Modified Layout*, are illustrated in Figs. E.01 to E.04, in Appendix E. The locations of these prediction lines are shown in Drawing No. MSEC799-16 to MSEC799-19. The predicted profiles have been based on those obtained using the calibrated Incremental Profile Method.

The predicted profiles resulting from the extraction of the existing longwalls in the Wambo Seam are shown as the solid cyan lines in these figures. The predicted profiles after the completion of the proposed longwalls in the Woodlands Hill and Arrowfield Seams, based on the *Modified Layout*, are shown as the solid green and red lines, respectively. The predicted profiles after the completion of the longwalls in the Arrowfield and Bowfield Seams, based on the *Approved Layout*, are shown as the dashed green and red lines, respectively, in Figs. E.02 and E.03.

It is noted, that the prediction lines are orientated perpendicular to the proposed longwalls in the Woodlands Hill and Arrowfield Seams, based on the *Modified Layout*, so as to show the greatest tilts and curvatures. The tilts and curvatures based on the *Approved Layout* appear smaller than those based on the *Modified Layout*, however, this is a consequence of the predictions lines being oblique to these longwalls, i.e. the tilts and curvatures are less than the maxima based on the *Approved Layout*.

Whilst the predicted vertical subsidence and tilt decrease as a result of the proposed modification, the surface area affected by mine subsidence increases. The surface area located directly above the proposed longwalls is: 860 hectares (ha) based on the *Approved Layout*; and 1,700 ha based on the *Modified Layout*. It is noted, that these surface areas include the approved longwalls that are located east of Wollombi Brook.

It is also noted, that the majority of the surface area located above the *Modified Layout* is either above the existing Homestead/Wollemi workings in the Whybrow Seam, above the existing United Collieries longwalls in the Arrowfield Seam, or affected by the Wambo Open Cut. The surface area that is located above the proposed longwalls that has not been previously affected by mining (underground or open cut) and has not been previously approved is around 185 ha.

The comparison of the maximum predicted total conventional subsidence parameters for the longwalls located east of Wollombi Brook is provided in Table 4.7. The *Approved Layout* comprises five longwalls in each of the Arrowfield and Bowfield Seams. The *Modified Layout* comprises only the longwalls within the Arrowfield Seam.

Table 4.7 Comparison of Maximum Predicted Subsidence Parameters for the Longwalls Located East of Wollombi Brook

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (Arrowfield and Bowfield Seams Located East of Wollombi Brook)	6,950	90	> 3.0	> 3.0
Modified Layout (Arrowfield Seam Located East of Wollombi Brook)	2,750	50	1.5	1.5

The maximum predicted total subsidence parameters for the longwalls located east of Wollombi Brook reduce as a result of the proposed modification. The maximum predicted total vertical subsidence, based on the *Modified Layout*, is around 40 % of the maxima predicted based on the *Approved Layout*.

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, the depth of bedrock and, in this case, multi-seam mining conditions. 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.

It has been found that, for single-seam mining conditions, applying a constant factor to the predicted maximum curvatures provides a reasonable prediction for the normal or conventional 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 Hunter Coalfield, it has been found that a factor of 10 provides a reasonable relationship between the predicted maximum curvatures and the predicted maximum conventional strains for single-seam conditions. 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.

It is not simple to provide a similar relationship between curvature and strain for multi-seam mining conditions, since there is very limited empirical data to establish this relationship. In addition to this, localised strains also develop in multi-seam mining conditions, as the result of remobilising the existing goaf and chain pillars in the overlying seam, which are not directly related to curvature.

The width-to-depth ratios for the proposed longwalls vary between: 0.7 and 2.8 (average of 1.2) for the Woodlands Hill Seam; and 0.6 and 1.0 (average of 0.8) for the Arrowfield Seam. The interburden thicknesses for these longwalls vary between: 110 metres and 150 metres above the Woodlands Hill Seam; and 40 metres and 80 metres above the Arrowfield Seam.

Extensive multi-seam monitoring data was collected during the extraction of WMLW1 to WMLW10A at the NWUM. The width-to-depth ratios for these longwalls varied between 1.0 and 3.3 (average of 1.7), which is greater than those for the proposed longwalls in the Arrowfield Seam and, to a lesser extent the Woodlands Hill Seam. The interburden thickness varied between 55 metres and 95 metres, which is similar to that for the Arrowfield Seam and less than that for the Woodlands Hill Seam.

The range of strains measured during the extraction of the longwalls in the Wambo Seam should, therefore, provide a reasonable, if not, slightly conservative indication of the range of potential strains for the proposed longwalls in the Woodlands Hill Seam where the depths of cover are the shallowest (i.e. north-eastern part of the mining area). The monitoring data should provide a conservative indication of the range of strains for the proposed longwalls in the Arrowfield Seam and for the Woodlands Hill Seam at the higher depths of cover.

The main transverse lines with multi-seam conditions at the NWUM were the XL1-Line, XL2-Line, XL4-Line, XL5-Line, XL6-Line and the SC1-Line. The locations of these monitoring lines are shown in Fig. 3.1.

The data used in the analysis of observed strains included those resulting from both conventional and non-conventional anomalous movements. The strains resulting from damaged or disturbed survey marks have been excluded.

4.4.1. Analysis of Strains 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 the extraction of the previous longwalls at the NWUM, for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls, which has been referred to as "*above goaf*".

The histograms of the maximum observed tensile and compressive strains measured for the survey bays located directly above goaf is provided in Fig. 4.3. The probability distribution functions, based on the fitted Generalised Pareto Distributions (GPDs), have also been shown in this figure.

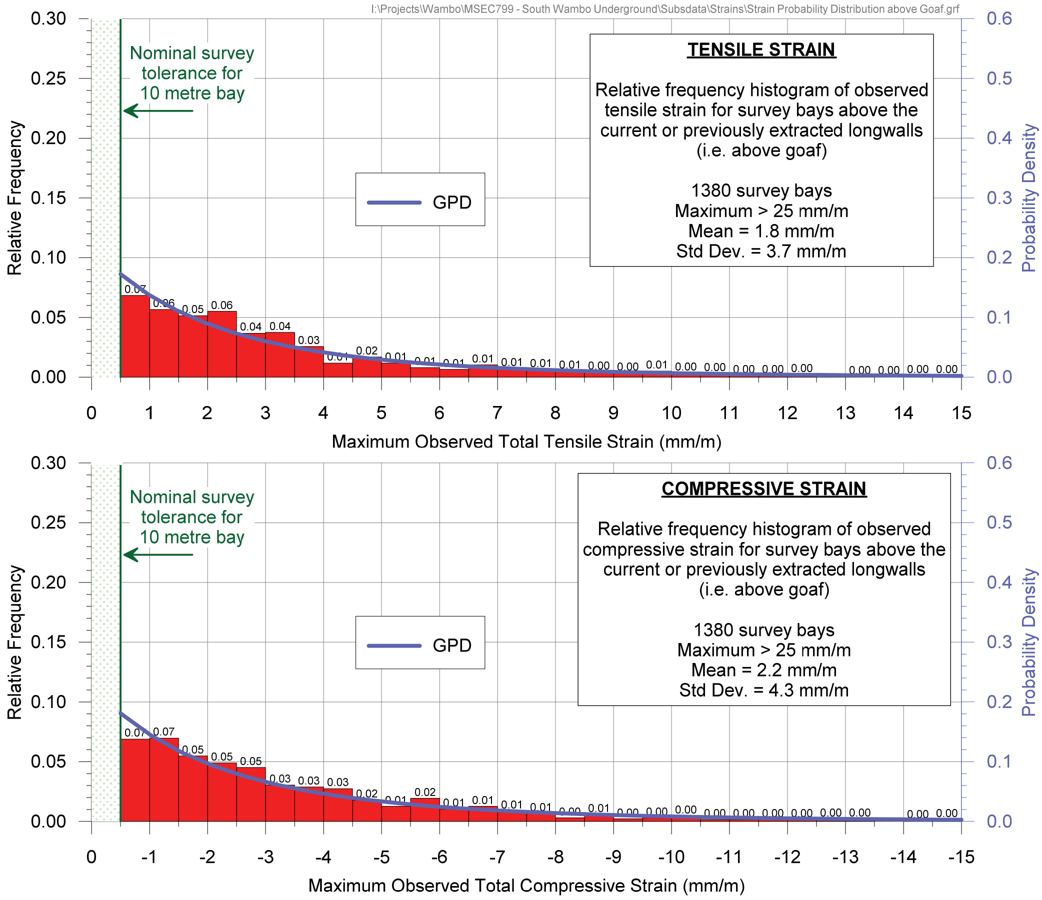


Fig. 4.3 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located Directly Above Goaf due to the Extraction of the Wambo Seam

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

The 95 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining were 8 mm/m tensile and 9 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining were 17 mm/m tensile and 19 mm/m compressive.

4.4.2. Analysis of Strains 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 total tensile and compressive strains measured anywhere along the monitoring lines, for the monitoring lines at the NWUM, is provided in Fig. 4.4.

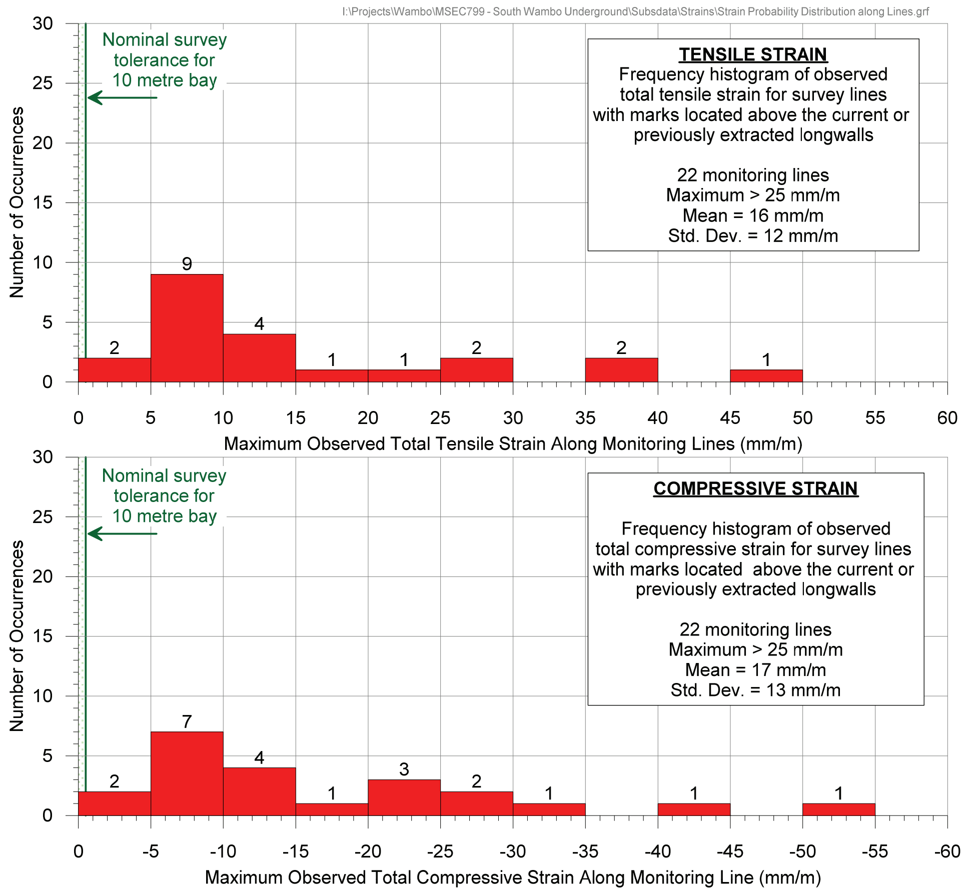


Fig. 4.4 Distributions of Measured Maximum Tensile and Compressive Strains along the Monitoring Lines due to the Extraction of the Wambo Seam

It can be seen from Fig. 4.4, that 11 of the 22 monitoring lines (i.e. 50 %) have recorded maximum total tensile strains of 10 mm/m, or less, and that 16 of the monitoring lines (i.e. 73 %) have recorded maximum total tensile strains of 20 mm/m, or less. It can also be seen, that 9 of the 22 monitoring lines (i.e. 41 %) have recorded maximum compressive strains of 10 mm/m, or less, and that 14 of the monitoring lines (i.e. 64 %) have recorded maximum compressive strains of 20 mm/m, or less.

4.5. Predicted Far-field Horizontal Movements

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

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data 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. 4.5. The confidence levels, based on fitted Generalised Pareto Distributions (GPDs), have also been shown in this figure to illustrate the spread of the data.

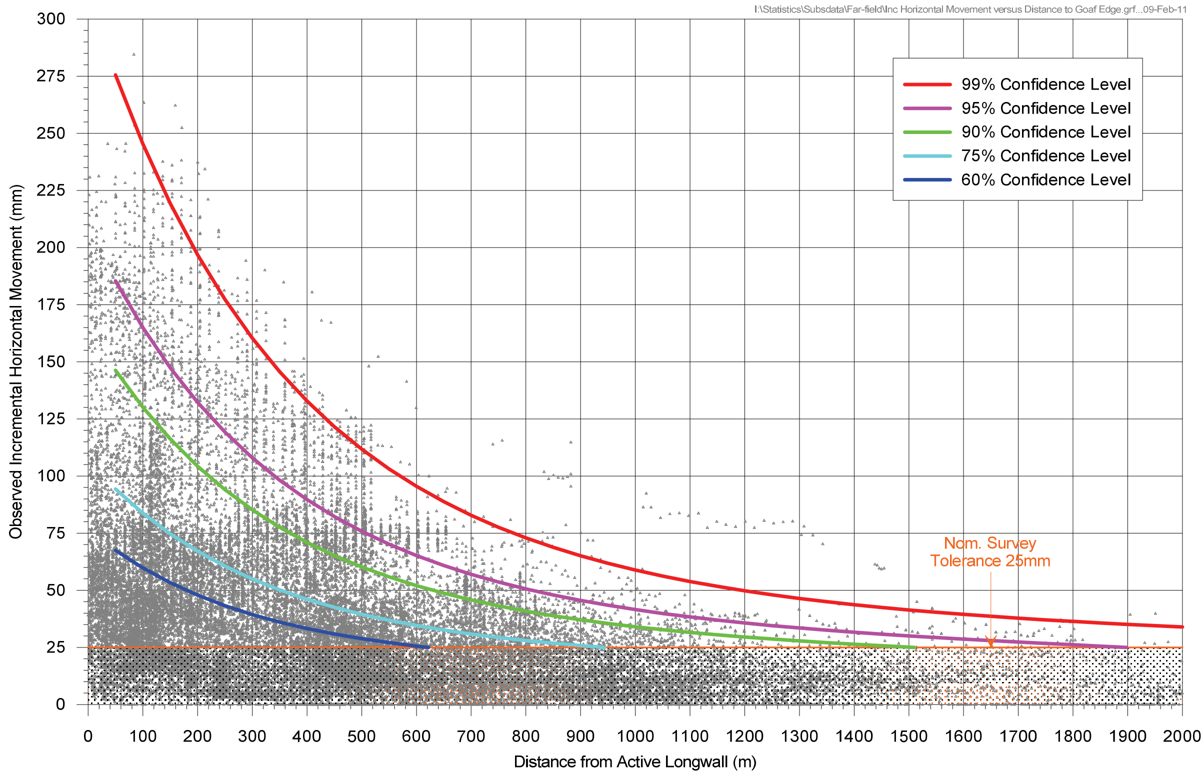


Fig. 4.5 Observed Incremental Far-Field Horizontal Movements

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 the proposed longwalls are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than 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 the proposed mining.

4.6. Non-Conventional Ground Movements

It is likely non-conventional ground movements will occur within the Study Area, due to near surface geological features and multi-seam mining conditions, which are discussed in Section B.5, in Appendix B. These non-conventional movements are often accompanied by elevated tilts, curvatures and strains which are likely to exceed the conventional predictions.

In most cases, it is not possible to predict the exact locations or magnitudes of the non-conventional movements due to near surface geological conditions, which are often referred to as 'anomalous' movements. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains, including both conventional and non-conventional strains, which is discussed in Section 4.4.

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 joints in the bedrock, the presence of near surface geological structures and multi-seam mining conditions.

Fractures and joints in bedrock occur naturally during the formation of the strata and from subsequent disturbance, tectonic movements, igneous intrusions, erosion and weathering processes. 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.

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

At shallower depths of cover, it is also likely that transient surface cracks will occur above and parallel to the moving extraction face, i.e. at right angles to the longitudinal edges of the longwall, as the subsidence trough develops. This cracking, however, tends to be transient, since the tensile phase of the travelling wave, which causes the cracks to open up, is generally followed by a compressive phase, which partially recloses them. It has been observed in the past, however, that surface cracks which occur during the tensile phase of the travelling wave do not fully close during the compressive phase, and tend to form compressive ridges at the surface.

The incidence of surface cracking is dependent on the location relative to the extracted longwall goaf edges, the depth of cover, the extracted seam thickness and the thickness and inherent plasticity of the soils that overlie the bedrock. The widths and frequencies of the cracks are also dependent upon the pre-existing jointing patterns in the bedrock. Large joint spacing can lead to concentrations of strain and possibly the development of fissures at rockhead, which are not necessarily coincident with the joints.

The range of the surface crack widths resulting from the extraction of the proposed longwalls is expected to be similar to that previously observed at the NWUM. Surface cracking above the previously extracted longwalls at the NWUM have been typically in the order of 25 mm to 50 mm, with surface cracks in some locations greater than 150 mm. Photographs of typical cracking at the NWUM are provided in Fig. 4.6.

Fig. 4.6 Photographs of Surface Cracking at the NWUM

The surface cracking observed at the NWUM is similar to that observed for multi-seam mining elsewhere in the NSW Coalfields, where the depths of cover, extraction heights and interburden thicknesses are similar. For example, the surface cracking observed during the extraction of BSLW1 to BSLW5 at the Blakefield South Mine beneath the previously extracted longwalls in the Whybrow Seam typically varied up to 50 mm, with a maximum observed crack width around 500 mm. Photographs of typical surface cracking observed above these longwalls are provided in Fig. 4.7.

Fig. 4.7 Photographs of Surface Cracking above BSLW1 at the Blakefield South Mine

The surface crack widths resulting from the extraction of the proposed longwalls, therefore, is expected to be typically in the order of 25 mm to 50 mm, with widths greater than 150 mm in some locations. These surface deformations can be remediated using methods similar to those developed for the previously extracted longwalls at the NWUM.

Further discussion on surface cracking is provided in the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

4.8. Estimated Height of the Fractured Zone

Longwall mining results in surface and sub-surface subsidence movements and it creates new fractures and opens up or widens pre-existing bedding planes and natural joints within the overburden. The location of and the impacts from these mining induced fractures within the overburden depend on both the mining geometry and the overburden geology.

A number of researchers have investigated and commented on the likely mechanics of mining induced strata deformations. A common approach to the study of these impacts has centred on classifying the overburden strata over mined panels into a number of zones with different deformation characteristics. The size and nature of these zones has been based on fracture observations, sub-surface borehole measurements or pore pressure and permeability monitoring. However, the terminology used by different authors to describe these strata deformation zones above extracted longwalls varies considerably and caution should be taken when comparing the recommendations from differing authors.

Singh and Kendorski (1981) proposed the following three zones that were called the: fracture zone; aquiclude zone; and zone of surface cracking. These zones are illustrated in Fig. 4.8.

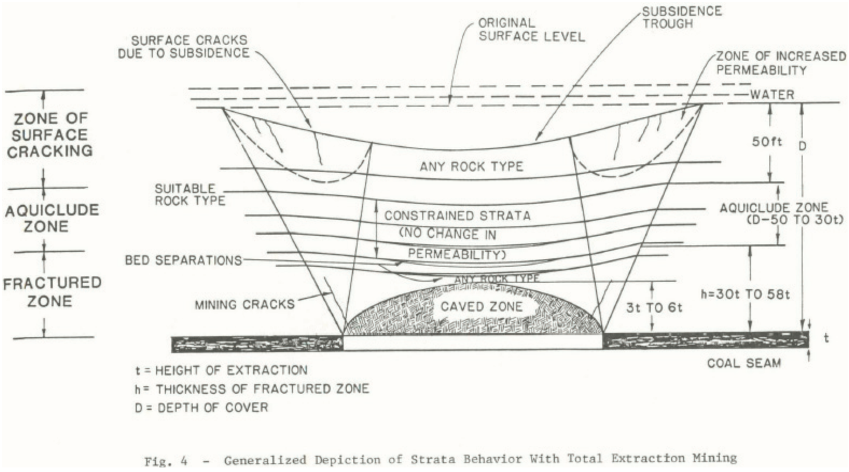


Fig. 4.8 Zones in the Overburden according to Singh and Kendorski (1981)

Kratzsch (1983) identified four zones, but named them the: immediate roof; main roof; intermediate zone; and surface zone. These zones are illustrated in Fig. 4.9.

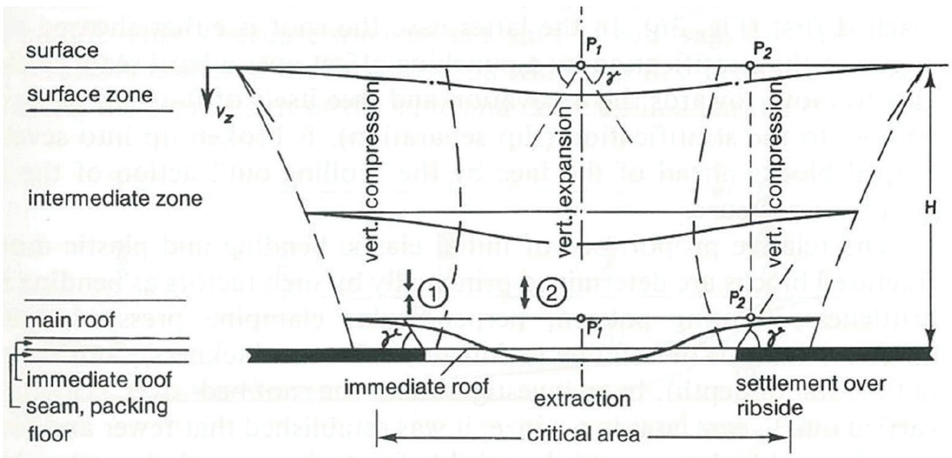


Fig. 4.9 Zones in the Overburden according to Kratzsch (1983)

Peng and Chiang (1984) recognised only three zones as reproduced in Fig. 4.10.

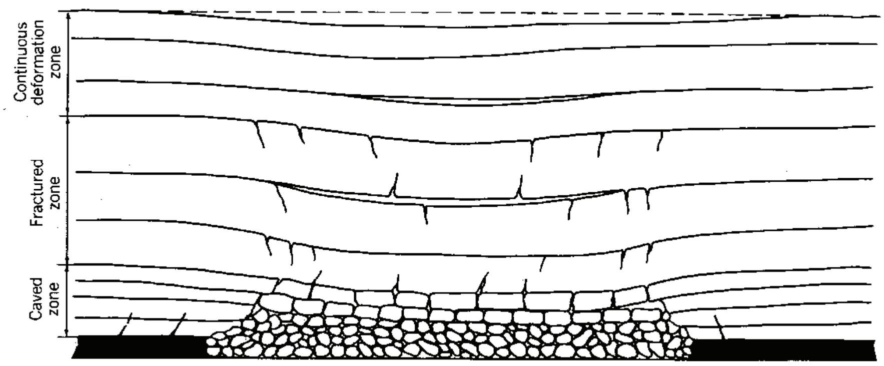


Fig. 4.10 Zones in the Overburden According to Peng and Chiang (1984)

Whittaker and Reddish (1989) used physical models built of sand, plaster and water mixes that were suitably scaled in strength and size to simulate the movement of the overburden, to illustrate the development of fracture propagation and to demonstrate the strata mechanisms. An example of the physical models is provided in Fig. 4.11.

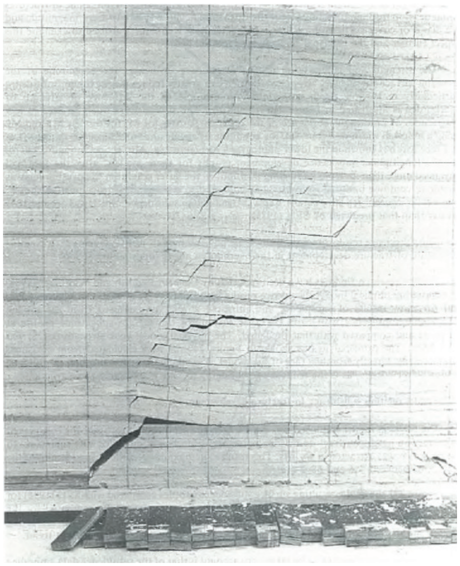


Fig. 4.11 Physical Modelling of the Overburden (Whittaker and Reddish, 1989)

Two fracturing zones were considered in these models: firstly the maximum height extended by those fractures which were judged to be vertically interconnected with the extraction horizon, referred to as *Zone A*; and secondly the extent of any appreciable fracturing even if they did not necessarily directly connect with the extraction horizon, referred to as *Zone B*.

Zone A fracture development was interpreted as being indicative of where free flow from an overlying aquifer would readily occur, whilst Zone B could be indicative of where there might be a risk of water inflow seeping horizontally from an overlying aquifer but not necessarily flowing downwards to the mine. The interpretation of these fracture development zones as a proportion of the depth of cover based on maximum tensile stresses in the overburden was presented in Fig. 4.12 (Whittaker and Reddish, 1989).

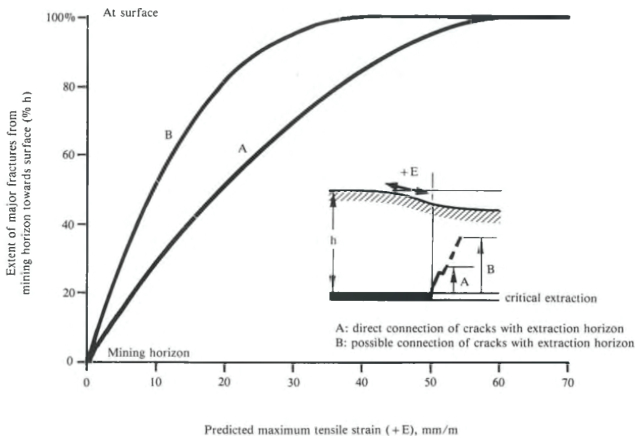


Fig. 4.12 Extent of Major Fractures from the Mining Horizon (Whittaker and Reddish, 1989)

Whittaker and Reddish (1989) also recognised that local geology and depth of mining play important roles, especially in influencing the magnitude and extent of fracture development. They stated that bands of low permeability, such as claystones, shales, siltstones, mudstones and tuffs within the overburden, can act as major factors in controlling water seeping from overlying horizons, even though stronger fractured beds may exist above and below such pliable and impervious bands. It was also noted that the existence of pliable mudstone beds within the strata sequence would tend to inhibit the magnitude and extent of fracture development above the ribside.

Forster and Enever (1992) undertook a major groundwater investigation over supercritical extraction areas in the Central Coast of NSW and concluded that that overburden could be sub divided into four separate zones, as shown in Fig. 4.13, with some variations in the definitions of each zone. Forster and Enever noted that while the height of the caved zone over these total extraction areas were related principally to the extracted seam height, seam depth and the nature of the roof lithology, the extent of the overlying disturbed zone was dependent on the strength and deformation properties of the strata and to a lesser extent on the seam thickness, depth of cover and width of the panel.

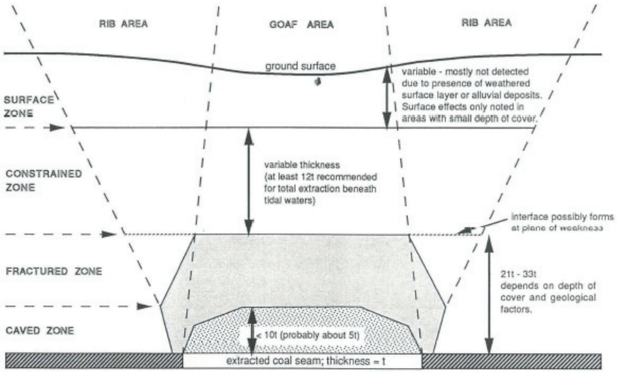


Fig. 4.13 Zones in the Overburden according to Forster and Enever (1992)

McNally et al (1996) recognised only three zones, which they referred to as the: caved zone; fractured zone; and elastic zone. These zones are illustrated in Fig. 4.14.

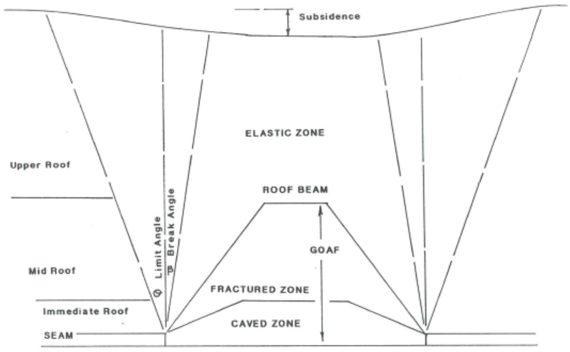


Fig. 4.14 Zones in the Overburden according to McNally et al. (1996)

Ditton, Frith and Hill (2003) reviewed the available borehole data in the Central Coast Region of the Newcastle Coalfield and derived formulas for the Height of Connected Fracturing (HoCF), referred to as Zone A, and the Height of (disconnected) Fracturing (HoF), referred to as Zone B. Ditton, Frith and Hill confirmed the definition that the HoCF refers to where the fracturing provides a direct hydraulic connection with the workings. The HoF refers to the height at which the horizontal permeability increases as a result of strata de-lamination and fracturing, however, a direct connection with the workings does not occur.

Ditton (2005) provided the following description of five zones, as illustrated in Fig. 4.15. It can be noted that Ditton has split the constrained zone, as described by Forster and Enever into the Dilated Zone (B) and the Confined Zone (C).

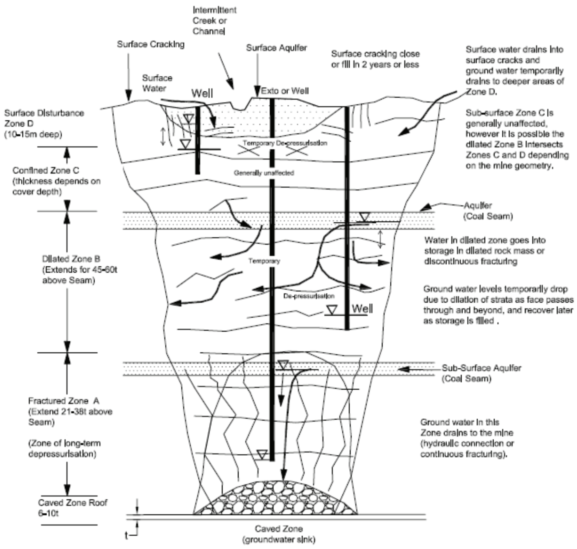


Fig. 4.15 Zones in the Overburden according to Ditton (2005)

Since then there have been several major government inquiries that have reviewed the effects of mining on surface and groundwater and the potential loss of water towards a mine. These inquiry reports have been based on the following sketch that was prepared by Mackie (DoP, 2008) to explain the nature of fracturing over a coal mine. This model has four zones as illustrated in Fig. 4.16.

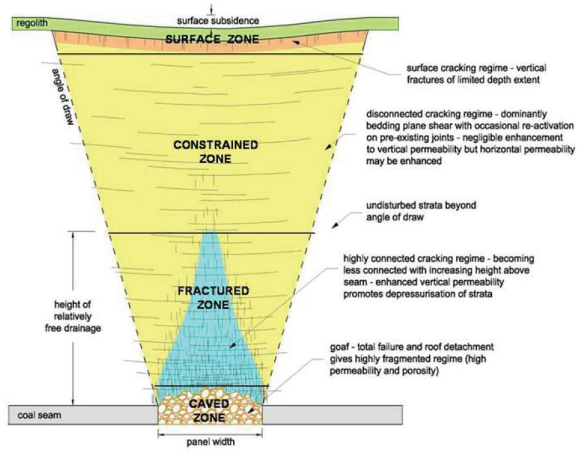


Figure 12: Conceptual Model of Caving and the Nature of Fracturing above a Mine Excavation

Fig. 4.16 Zones in the Overburden according to Mackie (DoP, 2008)

For the purpose of the discussions provided in this report, the following four zones have been adopted:-

- *Caved Zone* (or Zone AA) 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 describe primary and secondary caving zones.
- *Fractured Zone* comprises in-situ material that has undergone significant deformation and is supported by the material in the caved zone. This zone has sagged downwards and consequently suffered significant bending, fracturing, joint opening and bed separation. This zone is further divided into the *Continuous Fracture Zone* (or Zone A) and the *Discontinuous Fracture Zone* (or Zone B).
- *Elastic Deformation Zone* (or Zone C) comprises confined rock strata above the disturbed zone which have sagged slightly but, because they are constrained by the disturbed zone, 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 Cracking Zone* (or Zone D) 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 the various 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 clarity regarding whether the fractures were continuous, connected, discontinuous or not connected; the use of different extensometer borehole testing methods, the use of differing permeability or piezometer measuring methods and differing interpretations of monitoring data.

Some authors have suggested simple equations to estimate the heights of the collapsed and fractured zones based solely on the extracted seam height, whilst others have suggested equations based solely on the widths of extraction, and then others have suggested equations should have been based on the width-to-depth ratios of the extractions. Some authors interpret the influence of geology on the height of the Continuous Fracture Zone (A) based only on the subsidence reduction potential due to presence of massive strong strata layers. Whilst others believe that the presence of layers of low permeability, such as claystones, shales, siltstones, mudstones and tuffs within the overburden, was a more important influencing factor.

Simple geometrical and geotechnical equations can be developed to estimate the height of the Discontinuous Fracture Zone (B). It is more difficult to develop the relationships to estimate the height of the Continuous Fracture Zone (A), due to the influence of low permeability strata layers in the overburden. The height of the Continuous Fracture Zone (A) above extracted longwalls is affected by a number of factors including:-

- widths of extraction (W);
- heights of extraction (t);
- depths of cover (H);
- presence and proximity of previous workings, if any, adjacent to or above the current extractions;
- 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 within the overburden.

Two recent ACARP funded reports provide extensive discussions on modelling techniques to assess the heights of the various defined zones over mined panels, which are:

- CSIRO, Guo, Adhikary and Gaveva (2007), "*Hydrogeological Response to Longwall Mining*", ACARP Research Project No. C14033; and
- Gale (2008), "*Aquifer Inflow Prediction above Longwall Panels*", ACARP Research Project No. C13013.

The height of the Discontinuous Fracture Zone (B) can extend 1 to 1.5 times the longwall width above the extracted seam. The overall void widths of the proposed longwalls are typically 305 metres in the Woodlands Hill and Arrowfield Seams. However, the void widths of WHLW1 to WHLW5, WHLW16 and AFLW2A vary between 215 metres 265 metres.

The height of the Discontinuous Fracture Zone (B) could extend 300 metres to 450 metres above the proposed longwalls in the Woodlands Hill and Arrowfield Seams. The interburden thicknesses between the Woodlands Hill and Wambo Seam varies between 110 metres and 150 metres above the proposed longwalls. The interburden thickness between the Arrowfield and Woodlands Hill Seams varies between 40 metres and 80 metres.

It is expected, therefore, that the discontinuous fractured zone resulting from the extraction of the proposed longwalls would extend up to the existing workings in the Wambo and Whybrow Seams, re-activate the existing goaf, with the fracturing extending up to the surface where the depths of cover are the shallowest.

This does not necessarily imply that there will be hydraulic connectivity between the surface and the seam, as the vertical fractures can be discontinuous near to the surface where the depths of cover are higher. It is not expected that there would be a hydraulic connection between the surface and the proposed seams, as none was observed after the extraction of the longwalls at the Wambo Seam at the NWUM.

This includes the extraction of the Homestead/Wollemi workings in the Whybrow Seam directly beneath Stony Creek and the extraction of WMLW1 to WMLW8A in the Wambo Seam directly beneath both North Wambo and Stony Creeks. This was anticipated by Holt (2003), who stated that "*This depth of cover is not expected to cause connection from the surface to the workings as it has not caused connection to single seam workings in the WCPL lease area before*".

Further discussions on the heights of fracturing and specific geology and permeability of the overburden strata are provided in the report by *HydroSimulations* (2016). 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*.

5.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE NATURAL FEATURES

The following sections provide the descriptions, predictions and impact assessments for the natural features within the Study Area, as identified in Chapter 2. All significant natural features located outside the Study Area, which may be subjected to valley related or far-field horizontal movements and may be sensitive to these movements, have also been included as part of these assessments.

The impact assessments provided in this report include consideration of the: geological model that has been developed by WCPL; the database of geological structures identified during exploration and mining of other seams at the Wambo Coal Mine; and the local ground monitoring data from the NWUM and other nearby collieries in the Hunter Coalfield.

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;
- swamps or wetlands;
- lands declared as critical habitat under the *Threatened Species Conservation Act 1995*;
- State Recreation Areas or State Conservation Areas;
- State Forests;
- 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. Wollombi Brook

5.2.1. Description of Wollombi Brook

The location of *Wollombi Brook* is shown in Drawing No. MSEC799-14. Wollombi Brook is located outside the Study Area, but has been included in the assessments provided in this report. A summary of the minimum distances of Wollombi Brook from the proposed longwalls is provided in Table 5.1.

Table 5.1 Distances of Wollombi Brook from the Proposed Longwalls

Seam	Series	Minimum Distance and Closest Longwall
Woodlands Hill	WHLW1 to WHLW5	380 metres south-east of WHLW5
	WHLW6 to WHLW12	180 metres east of WHLW9
	WHLW16 to WHLW19	280 metres north-east of WHLW19
	WHLW20 to WHLW22	1.5 kilometres east of WHLW22
Arrowfield	AFLW1 to AFLW6	220 metres east of AFLW4
	AFLW15 to AFLW17	430 metres north-east of AFLW17

The proposed longwalls are located at a minimum distance of 180 metres from Wollombi Brook. A cross-section through the proposed WHLW9 and AFLW3 and Wollombi Brook is provided in Fig. 5.1. It can be seen from this figure, that the 26.5 degree angle of draw line is located outside the nearest bank and the 40 metre buffer for Wollombi Brook.

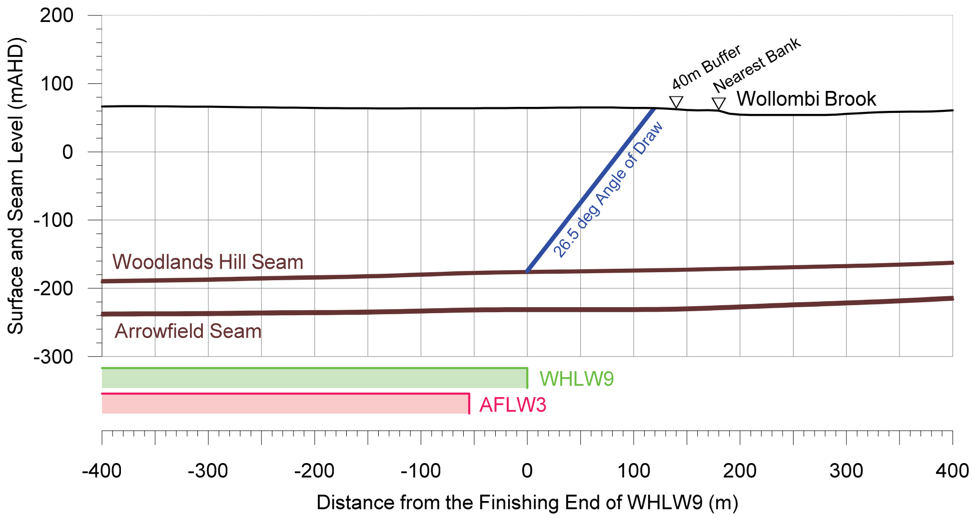


Fig. 5.1 Cross-section through Wollombi Brook and WHLW9 and AFLW3

The previously extracted WMLW10A is located at a minimum distance of 125 metres from Wollombi Brook. The United Collieries longwalls in the Arrowfield Seam were extracted also extracted up to 145 metres from Wollombi Brook.

Wollombi Brook is a perennial stream associated with a shallow aquifer. The bed of Wollombi Brook comprises alluvial deposits which are situated approximately 5 metres below the banks on each side of Wollombi Brook. The natural grade of Wollombi Brook, in the vicinity of the proposed longwalls, is less than 5 mm/m (i.e. less than 0.5 %), or a grade of less than 1 in 200.

The limit of the alluvium for Wollombi Brook is shown in Drawing No. MSEC799-14, which is based on the geophysical mapping undertaken by *Groundwater Imaging* (2012). The alluvium associated with Wollombi Brook is located immediately adjacent to the proposed WHLW6 to WHLW12 and AFLW1 to AFLW6. The alluvium is partially located above the proposed WHLW19 and AFLW17.

Photographs of Wollombi Brook are provided in Fig. 5.2, which were taken near the confluence with North Wambo Creek.

Fig. 5.2 Photographs of Wollombi Brook

5.2.2. Predictions for Wollombi Brook

A summary of the maximum predicted values of additional subsidence, tilt and curvature for Wollombi Brook, due to mining in the Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 5.2. The predictions include the multi-seam effects of the existing workings in the overlying Whybrow and Wambo Seams.

Table 5.2 Maximum Predicted Additional Subsidence, Tilt and Curvature for Wollombi Brook due to Mining in the Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seams	Maximum Predicted Additional Subsidence (mm)	Maximum Predicted Additional Tilt (mm/m)	Maximum Predicted Additional Hogging Curvature (km^{-1})	Maximum Predicted Additional Sagging Curvature (km^{-1})
Wollombi Brook	WH Seam Only	< 20	< 0.5	< 0.01	< 0.01
	WH and AF Seams	< 20	< 0.5	< 0.01	< 0.01

A summary of the maximum predicted values of accumulated subsidence, tilt and curvature for Wollombi Brook, after the completion of mining in the Wambo, Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 5.3. The predictions include the multi-seam effects of the existing workings in the overlying Whybrow Seam.

Table 5.3 Maximum Predicted Total Subsidence, Tilt and Curvature for Wollombi Brook after Mining in the Wambo, Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seam	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Wollombi Brook	WM Seam Only	< 20	< 0.5	< 0.01	< 0.01
	WM and WH Seams	< 20	< 0.5	< 0.01	< 0.01
	WM, WH and AF Seams	< 20	< 0.5	< 0.01	< 0.01

The section of Wollombi Brook in the vicinity of the proposed longwalls has a shallow incision into the alluvium. It is unlikely, therefore, that Wollombi Brook would experience any significant valley related movements resulting from the extraction of the proposed longwalls.

5.2.3. Comparisons of Predictions for Wollombi Brook

The comparison of the maximum predicted conventional subsidence parameters for Wollombi Brook, based on the *Approved Layout* and the *Modified Layout*, is provided in Table 5.4. The predicted parameters are the maxima due to mining in the Wambo, Arrowfield and Bowfield Seams for the *Approved Layout* and due to mining in the Wambo, Woodlands Hill and Arrowfield Seams for the *Modified Layout*.

Table 5.4 Comparison of the Maximum Predicted Subsidence Parameters for Wollombi Brook due to Mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams

Location	Layout	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Wollombi Brook	Approved	< 20	< 0.5	< 0.01	< 0.01
	Modified	< 20	< 0.5	< 0.01	< 0.01

The predicted total vertical subsidence for Wollombi Brook is less than 20 mm based on both the *Approved* and *Modified Layouts*. The maximum predicted subsidence parameters for Wollombi Brook, therefore, do not change as result of the proposed modification.

5.2.4. Impact Assessments for Wollombi Brook

The banks of Wollombi Brook are located at a distance of 180 metres east of WHLW9, at its closest point to the proposed longwalls. At this distance, Wollombi Brook is predicted to experience less than 20 mm of vertical subsidence. While it is possible that Wollombi Brook could experience very low levels of vertical subsidence, it would not be expected to experience any measurable tilts, curvatures or ground strains.

The alluvium associated with Wollombi Brook is located immediately adjacent to the proposed WHLW6 to WHLW12 and AFLW1 to AFLW6. In this location, the alluvium is predicted to experience up to around 100 mm vertical subsidence. Whilst the alluvium would experience low levels of vertical subsidence, it is not predicted to experience any significant tilts, curvatures or strains. The alluvium is partially located above the proposed WHLW19 and AFLW17. In this location, the alluvium is predicted to experience vertical subsidence up to around 2.2 metres.

The potential impacts of the proposed longwalls on the alluvium associated with Wollombi Brook is discussed by the specialist groundwater consultant in the report by *HydroSimulations* (2016).

It was stated, in the 2003 EIS, that the "*Mining of the longwall panels would be constrained by the subsidence exclusion zone limited to an angle of 26.5 degrees from the vertical to "Protected Land" (i.e. within 40 m of Wollombi Brook in accordance with the Rivers and Foreshore Improvement Act, 1948)*". The proposed longwalls are located outside this subsidence exclusion zone (i.e. the 40 metre buffer), as illustrated in Fig. 5.1. This cross-section taken where Wollombi Brook is located closest to the proposed longwalls.

It is unlikely, therefore, that Wollombi Brook would be adversely impacted as a result of the extraction of the proposed longwalls. Further discussions on the potential impacts on the alluvial aquifer associated with Wollombi Brook are provided in the report by *HydroSimulations* (2016).

5.2.5. Recommendations for Wollombi Brook

It is recommended that existing management strategies for Wollombi Brook are reviewed based on the *Modified Layout*, including the piezometers to measure the groundwater levels and the ground monitoring lines to measure the actual limit of vertical subsidence. The appropriate management strategies and monitoring for Wollombi Brook will be finalised during the Extraction Plan stage for the proposed longwalls.

5.3. North Wambo, Wambo and Stony Creeks

5.3.1. Description of the Creeks

North Wambo, Wambo and Stony Creeks are located within the Study Area. These creeks are shown in Drawing No. MSEC799-14. The discussions on the North Wambo Creek Diversion are provided in Section 5.4.

The natural section of North Wambo Creek (i.e. downstream of the creek diversion) commences above the tailgate of the proposed WHLW6. The creek flows generally in an easterly direction to where it joins Wollombi Brook to the east of the proposed mining area.

The natural section of the creek has been previously directly mined beneath by WMLW1 to WMLW8A in the Wambo Seam, with a total length of 3.3 kilometres located above these longwalls. North Wambo Creek is proposed to be directly mined beneath by WHLW6, WHLW7 and partially by AFLW2A. The total length of creek located directly above the proposed longwalls is 1.8 kilometres.

North Wambo Creek has a shallow incision into the natural surface soils which are derived from the Jerrys Plains Subgroup of the Wittingham Coal Measures and Quaternary Alluvium. The lower reaches have exposed bedrock and debris accumulation near the confluence with Wollombi Brook. The creek is ephemeral but there are some standing pools along the lower reaches.

Photographs of North Wambo Creek are provided in: Fig. 5.3 downstream of the creek diversion above the previously extracted WMLW4; and Fig. 5.4 along the lower reaches near the confluence with Wollombi Brook.

Fig. 5.3 Photographs of North Wambo Creek (Downstream of Creek Diversion)

Fig. 5.4 Photographs of North Wambo Creek (Lower Reaches)

Wambo Creek commences in the Wollemi National Park to the south-west of the existing and proposed mining areas. The creek flows generally in a north-easterly direction to where it joins Wollombi Brook east of the previously extracted WMLW10A.

The creek has been previously directly mined beneath by the Homestead/Wollemi workings in the Whybrow Seam, with a total length of 3.4 kilometres located directly above these workings. Wambo Creek is also proposed to be directly mined beneath by WHLW11, WHLW12 and AFLW6. The total length of creek located directly located above the proposed longwalls is 0.9 kilometres.

Wambo Creek has a shallow incision into the Quaternary Alluvium. The creek is ephemeral but there are some standing pools along the flatter sections. Photographs of Wambo Creek are provided in Fig. 5.5.

Fig. 5.5 Photographs of Wambo Creek

Stony Creek commences in the Wollemi National Park to the west of the existing and proposed mining areas. The creek flows generally in an easterly direction to where it joins North Wambo Creek south of the previously extracted WMLW10A.

The creek has been previously directly mined beneath by the Homestead/Wollemi workings in the Whybrow Seam and by WMLW1 to WMLW6 in the Wambo Seam. Stony Creek is also proposed to be directly mined beneath by WHLW10, WHLW11, AFLW4 and AFLW5. The total length of creek located directly above the proposed longwalls is 2.6 kilometres.

Stony Creek has a shallow incision into the natural surface soils which are derived from the Newcastle Coal Measures and Quaternary Alluvium. There are sections along the creek which have exposed bedrock and, in some locations, have formed into small cascades with isolated pools along the upper reaches. There are also significant debris accumulations which includes boulders and tree branches.

Photographs of Stony Creek are provided in: Fig. 5.6 along the upper reaches above the previously extracted WMLW1; and Fig. 5.7 along the lower reaches south of the previously extracted WMLW10A.

Fig. 5.6 Photographs of Stony Creek (Upper Reaches)

Fig. 5.7 Photographs of Stony Creek (Lower Reaches)

5.3.2. Predictions for the Creeks

The predicted profiles of conventional subsidence, tilt and curvature along North Wambo, Wambo and Stony Creeks, based on the *Approved Layout* and *Modified Layout*, are illustrated in Figs. E.05, E.06 and E.07, respectively, in Appendix E. The profiles are based on the extraction of the existing and proposed longwalls in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams, but also include the multi-seam effects of the existing workings in the overlying Whybrow Seam.

The predicted profiles due to the extraction of the existing longwalls in the Wambo Seam are shown as the solid cyan lines in these figures. The predicted profiles based on the *Approved Layout* are shown as: the dashed green lines after the completion of mining in the Arrowfield Seam; and dashed red lines after the completion of mining in the Bowfield Seam. The predicted profiles based on the *Modified Layout* are shown as: the solid green lines after the completion of mining in the Woodlands Hill Seam; and solid red lines after the completion of mining in the Arrowfield Seam.

A summary of the maximum predicted values of additional subsidence, tilt and curvature for the creeks, due to mining in the Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 5.5. The predictions include the multi-seam effects of the existing workings in the overlying Whybrow and Wambo Seams.

Table 5.5 Maximum Predicted Additional Subsidence, Tilt and Curvature for the Creeks due to Mining in the Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seams	Maximum Predicted Additional Subsidence (mm)	Maximum Predicted Additional Tilt (mm/m)	Maximum Predicted Additional Hogging Curvature (km^{-1})	Maximum Predicted Additional Sagging Curvature (km^{-1})
North Wambo Creek	WH Seam Only	2,200	25	0.35	0.50
	WH and AF Seams	2,550	25	0.35	0.45
Wambo Creek	WH Seam Only	2,250	16	0.35	0.50
	WH and AF Seams	3,100	20	0.50	0.40
Stony Creek	WH Seam Only	2,400	19	0.20	0.40
	WH and AF Seams	3,500	13	0.25	0.30

A summary of the maximum predicted values of accumulated subsidence, tilt and curvature for the creeks, after the completion of mining in the Wambo, Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 5.6. The predictions include the multi-seam effects of the existing workings in the overlying Whybrow Seam.

Table 5.6 Maximum Predicted Total Subsidence, Tilt and Curvature for the Creeks after Mining in the Wambo, Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seam	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
North Wambo Creek	WM Seam Only	2,300	60	> 3.0	2.3
	WM and WH Seams	4,050	65	> 3.0	2.4
	WM, WH and AF Seams	4,050	65	> 3.0	2.4
Wambo Creek	WM Seam Only	< 20	< 0.5	0.01	< 0.01
	WM and WH Seams	2,250	16	0.35	0.50
	WM, WH and AF Seams	3,100	20	0.50	0.40
Stony Creek	WM Seam Only	2,300	25	0.45	0.70
	WM and WH Seams	4,550	30	0.65	0.70
	WM, WH and AF Seams	5,600	30	0.65	0.70

The sections of the creeks located above the proposed longwalls have shallow incisions into the natural surface soils and, therefore, the predicted valley related movements are not significant when compared with the predicted conventional movements described above.

The creeks are located directly above the proposed longwalls and, therefore, could experience the full range of predicted strains. The analysis of strains measured at the NWUM is provided in Section 4.4. Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Section 4.4 includes those resulting from both conventional and non-conventional anomalous movements.

5.3.3. Comparisons of Predictions for the Creeks

The comparison of the maximum predicted conventional subsidence parameters for the creeks, based on the *Approved Layout* and the *Modified Layout*, is provided in Table 5.7. The predicted parameters are the maxima due to mining in the Wambo, Arrowfield and Bowfield Seams for the *Approved Layout* and due to mining in the Wambo, Woodlands Hill and Arrowfield Seams for the *Modified Layout*.

Table 5.7 Comparison of the Maximum Predicted Subsidence Parameters for the Creeks due to Mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams

Location	Layout	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
North Wambo Creek	Approved	8,150	100	> 3.0	> 3.0
	Modified	4,050	65	> 3.0	2.4
Wambo Creek	Approved	1,650	16	0.20	0.15
	Modified	3,100	20	0.50	0.40
Stony Creek	Approved	4,900	30	0.55	0.75
	Modified	5,600	30	0.65	0.70

The maximum predicted vertical subsidence and tilt for North Wambo Creek, based on the *Modified Layout*, are less than the maxima predicted based on the *Approved Layout*. These parameters reduce, since the proposed longwalls are *staggered* based on the *Modified Layout*, which results in less subsidence when compared with the *stacked* arrangement based on the *Approved Layout*. The maximum predicted curvatures for North Wambo Creek are similar, as these are largely governed by the previous extraction of the longwalls in the shallower Wambo Seam.

The maximum predicted subsidence parameters for Wambo and Stony Creek, based on the *Modified Layout*, are greater than the maxima predicted based on the *Approved Layout*. The predicted parameters increase, as these creeks were only partially located above the proposed longwalls based on the *Approved Layout*.

5.3.4. Impact Assessments for the Creeks

The impact assessments for North Wambo Creek, Wambo Creek and Stony Creek based on the *Modified Layout* are provided in the following sections. The impact assessments for the North Wambo Creek Diversion are provided in Section 5.4.

Potential for Increased Levels of Ponding, Flooding and Scouring

Mining can potentially result in increased levels of ponding in locations where the mining induced tilts oppose and are greater than the natural stream gradients that exist before mining. Mining can also potentially result in an increased likelihood of scouring of the stream beds in the locations where the mining induced tilts considerably increase the natural stream gradients that exist before mining.

The natural and the predicted post-mining surface levels and grades along North Wambo Creek, Wambo Creek and Stony Creek are illustrated in Fig. 5.8, Fig. 5.9 and Fig. 5.10, respectively. The final profiles are based on the *Modified Layout* due to mining in the Wambo, Arrowfield and Woodlands Hill Seams. The surface levels and grades have also been provided for an ‘Unnamed Creek’ in Fig. 5.11. The Unnamed Creek is located above the proposed WHLW16 to WHLW19 and AFLW15 to AFLW17 as shown in Drawing No. MSEC799-14.

It is noted, that these ponding areas can differ from the topographical depressions indicated in plan in Fig. 5.27, as they have been based on the predicted changes in surface levels along the original alignments of the creeks, i.e. they do not consider the natural grades across the alignments of the creeks. The extraction of the proposed longwalls will result in some changes in the creek alignments, due to the natural and mining induced cross-grades and, in consequence, the actual ponding areas are expected to be less than those illustrated below.

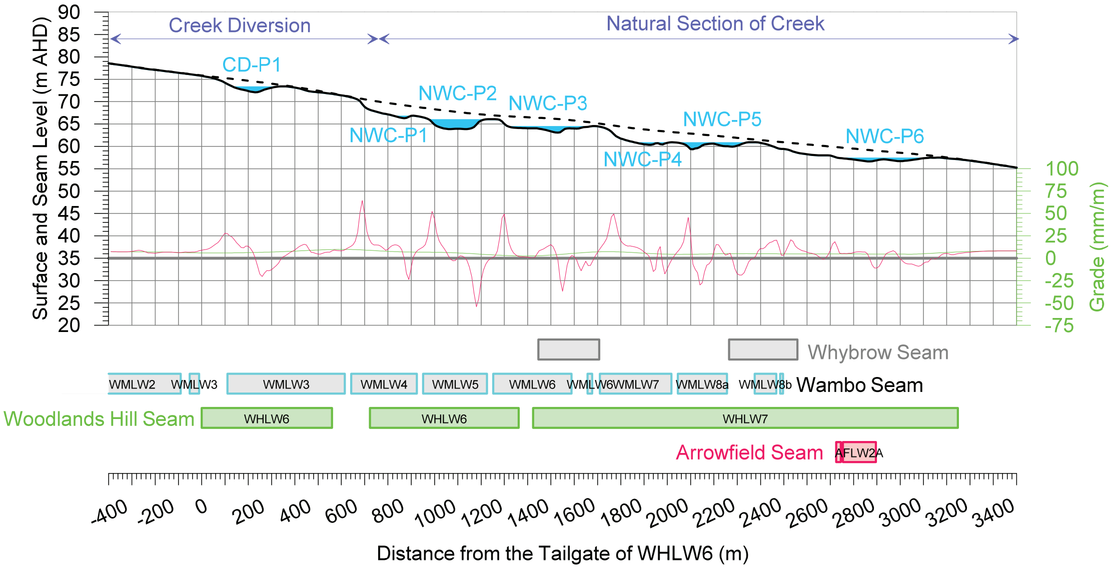


Fig. 5.8 Natural and Predicted Subsided Surface Levels and Grades along North Wambo Creek

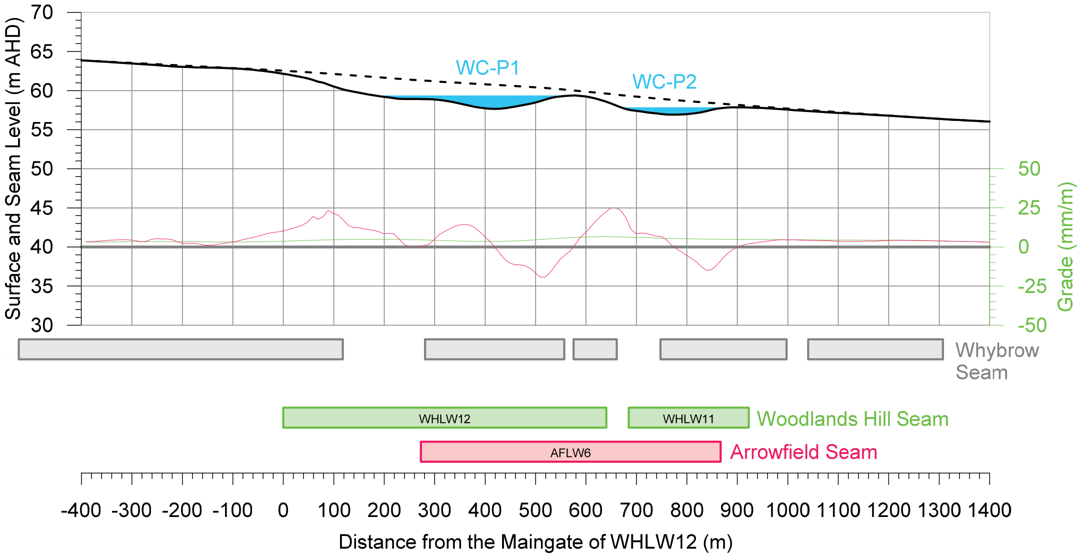


Fig. 5.9 Natural and Predicted Subsided Surface Levels and Grades along Wambo Creek

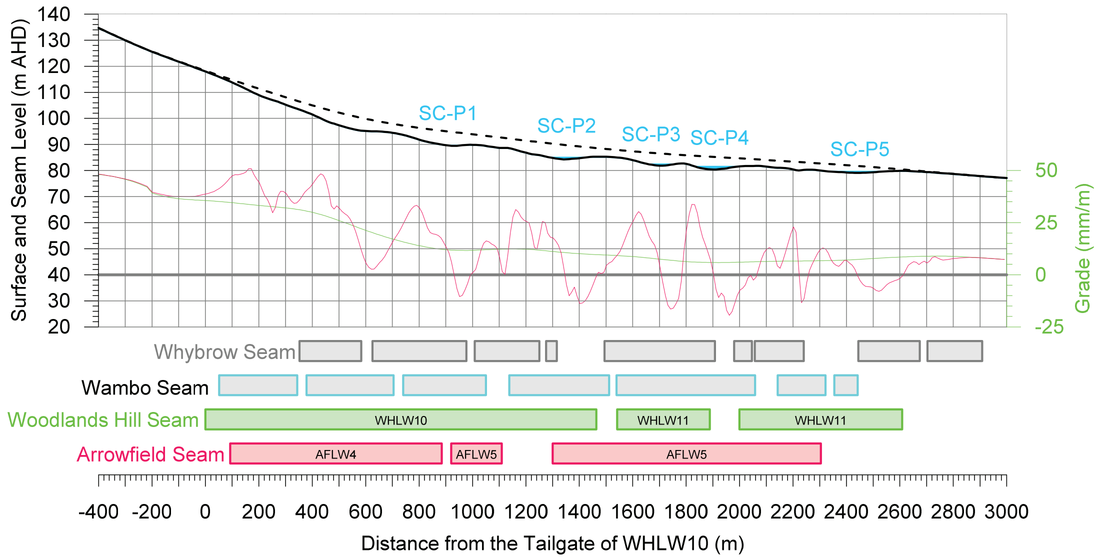


Fig. 5.10 Natural and Predicted Subsided Surface Levels and Grades along Stony Creek

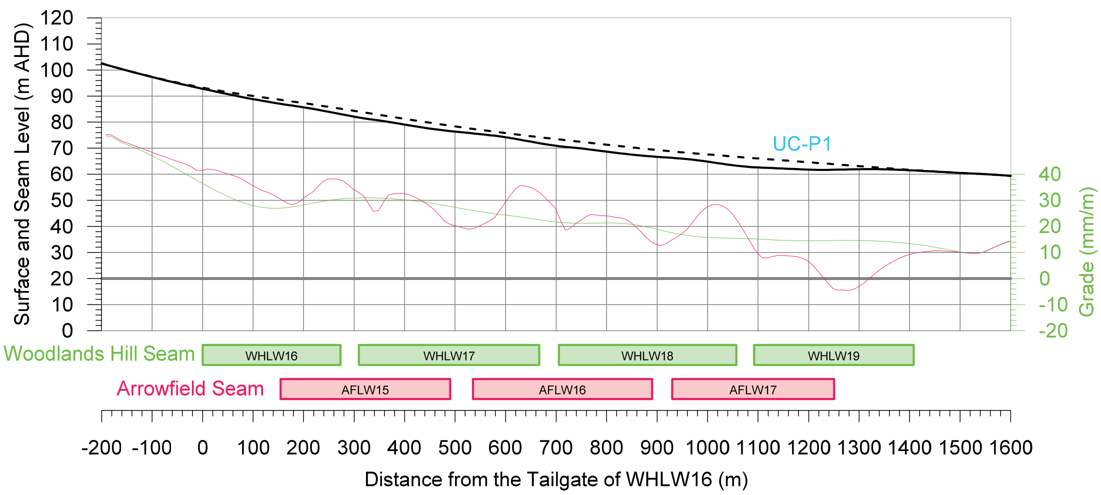


Fig. 5.11 Natural and Predicted Subsided Surface Levels and Grades along the Unnamed Creek

It can be seen from Fig. 5.8 to Fig. 5.10, that there are predicted reversals of grade along North Wambo, Wambo and Stony Creeks upstream of the chain pillars in both the Wambo and Woodlands Hill Seams. It is expected that ponding areas will develop along these creeks as shown in these figures. It is noted, that these predicted ponding areas are based on the previous extraction of the longwalls in the Wambo Seam plus the proposed extraction of the longwalls in the Woodlands Hill and Arrowfield Seams. A predicted reversal of grade also occurs along the Unnamed Creek at the downstream end of the proposed mining area.

A summary of the predicted maximum depths and lengths of the ponding areas along the creeks, based on the *Modified Layout*, is provided in Table 5.8. The extents of ponding have been provided after the completion of the Wambo Seam and after the completion of both the Woodlands Hill and Arrowfield Seams.

Table 5.8 Predicted Maximum Depths and Lengths of the Ponding Areas along the Creeks (Modified Layout)

Creek	Ponding Area	Predicted Extent due to Wambo Seam Only	Predicted Extent due to Wambo, Woodlands Hill and Arrowfield Seams
North Wambo Creek	NWC-P1	1.2 m deep x 225 m long	0.6 m deep x 100 m long
	NWC-P2	1.6 m deep x 250 m long	2.2 m deep x 275 m long
	NWC-P3	1.7 m deep x 300 m long	1.5 m deep x 375 m long
	NWC-P4	1.6 m deep x 250 m long	0.6 m deep x 150 m long
	NWC-P5	0.9 m deep x 75 m long	1.6 m deep x 350 m long
	NWC-P6	-	0.9 m deep x 450 m long
Wambo Creek	WC-P1	-	1.7 m deep x 400 m long
	WC-P2	-	1.0 m deep x 250 m long
Stony Creek	SC-P1	0.5 m deep x 125 m long	0.4 m deep x 100 m long
	SC-P2	0.5 m deep x 175 m long	1.0 m deep x 200 m long
	SC-P3	0.8 m deep x 150 m long	0.9 m deep x 150 m long
	SC-P4	1.2 m deep x 200 m long	1.4 m deep x 250 m long
	SC-P5	-	0.8 m deep x 300 m long
Unnamed Creek	UC-P1	-	0.3 m deep x 150 m long

There are six ponding areas predicted to develop along the natural section of North Wambo Creek, after the completion of the proposed longwalls, having maximum depths between 0.6 metres and 2.2 metres and overall lengths between 100 metres and 450 metres. The depths and lengths of ponding areas NWC-P1 and NWC-P4 and the depth of the ponding area NWC-P3, after the completion of the Woodlands Hill and Arrowfield Seams, are less than those predicted to have developed after the completion of the Wambo Seam. The reason for this is that the proposed longwalls are *staggered* with the existing overlying longwalls and, therefore, their extraction results in more uniform stream grades.

The predicted ponding along North Wambo Creek, based on the *Modified Layout*, is less than that predicted based on the *Approved Layout*. The reason for this is that the proposed longwalls are *staggered* based on the *Modified Layout*, which results in less subsidence when compared with the *stacked* arrangement based on the *Approved Layout*. There are six ponding areas predicted to develop along North Wambo Creek, based on the *Approved Layout*, having maximum depths between 0.8 metres and 6.0 metres and overall lengths between 200 metres and 450 metres.

There are two ponding areas predicted to develop along Wambo Creek, after the completion of the proposed longwalls, having maximum depths up to 1.7 metres and overall lengths up to 400 metres. There are no predicted ponding areas along this creek after the completion of the Wambo Seam, as this creek is located outside the extents of these previously extracted longwalls.

The predicted ponding along Wambo Creek, based on the *Modified Layout*, is greater than that predicted based on the *Approved Layout*. There are four ponding areas predicted to develop along Wambo Creek, based on the *Approved Layout*, having maximum depths between 0.2 metres and 0.7 metres and overall lengths between 125 metres and 250 metres.

There are five ponding areas predicted to develop along Stony Creek, after the completion of the proposed longwalls, having maximum depths between 0.4 metres and 1.4 metres and overall lengths between 100 metres and 300 metres. The predicted ponding along this creek, based on the *Modified Layout*, is similar to that predicted based on the *Approved Layout*. There are four ponding areas predicted to develop along Stony Creek, based on the *Approved Layout*, having maximum depths between 0.2 metres and 1.6 metres and overall lengths between 75 metres and 500 metres.

If adverse impacts were to develop as the result of increased ponding along the creeks, these could be remediated by locally regrading the beds, so as to re-establish the natural gradients. The creeks have shallow incisions in the natural surface soils and, therefore, it is expected that the mining induced ponding areas could be reduced by locally excavating the channels downstream of these areas. The larger ponding areas may require excavation into the topmost bedrock, depending on the thickness of the overlaying surface soils.

Potential for Cracking in the Creek Beds and Fracturing of Bedrock

It is expected that fracturing of the topmost bedrock would develop along the sections of creeks located directly above the proposed longwalls. The existing fractures along the section of North Wambo Creek located above the previously extracted longwalls within the Wambo Seam would also be reactivated.

North Wambo, Wambo and Stony Creeks have shallow incisions into the natural surface soils. Cracking in the beds of the creeks would be visible at the surface where the depths of the surface soils are shallow, or where the bedrock is exposed. The mining induced compression can also result in dilation and the development of bed separation in the topmost bedrock. The dilation is expected to develop predominately within the top 10 metres to 20 metres of the bedrock.

The creeks are ephemeral and, therefore, surface water flows only occur during and for short periods after rainfall events. In times of heavy rainfall, the majority of the runoff would flow over the natural surface soil beds and would not be diverted into the dilated strata below. In times of low flow and prior to remediation, however, surface water flows could be diverted into the dilated strata below the beds.

It would be expected, that the fracturing in the underlying bedrock would gradually be filled with the surface soils during subsequent flow events, especially during times of heavy rainfall. If the surface cracks were found not to fill naturally, some remedial measures may be required at the completion of mining. Where necessary, any significant surface cracks in the creek beds could be remediated by infilling with the surface soil or other suitable materials, or by locally regrading and recompacting the surface.

As described in Section 4.8, it is expected that the discontinuous fractured zone above the proposed longwalls would extend up to the existing workings in the overlying Whybrow and Wambo Seams. It is not expected, however, that there would be a direct hydraulic connection between the surface and proposed longwalls, as this has not been previously observed at the Wambo Coal Mine. This includes the extraction of the Homestead/Wollemi workings in the Whybrow Seam directly beneath Stony Creek and the extraction of WMLW1 to WMLW8A in the Wambo Seam directly beneath both North Wambo and Stony Creeks.

Similar experiences have been found elsewhere in the Hunter and Newcastle Coalfields indicating that mining induced fracturing and dilation do not have long term adverse impacts on ephemeral streams comprising natural soil beds. For example, the ephemeral drainage lines at South Bulga and the Beltana No. 1 Underground Mine were previously mined beneath by longwalls in the Whybrow Seam, where the depths of cover varied between 40 metres and 200 metres. Although surface cracking was observed across the mining area, there were no observable surface water flow diversions in the drainage lines, resulting from the extraction of these longwalls, after the remediation of the larger surface cracks had been completed.

It will be necessary to remediate some sections of the creeks after the extraction of the proposed longwalls directly beneath them. This would include regrading the beds and infilling the larger surface cracking. It is expected that there would be no long term adverse impacts on these creeks after the completion of the necessary surface remediation.

The predicted subsidence parameters for North Wambo Creek reduce as a result of the proposed modification. The potential impacts on this creek, based on the *Modified Layout*, are less than those assessed based on the *Approved Layout*. The predicted subsidence parameters for Wambo Creek, however, increase as a result of the proposed modification. The maximum predicted tilts, curvatures and strains for Stony Creek, based on the *Modified Layout*, are similar to those predicted based on the *Approved Layout*.

The nature of the potential impacts and the methods of remediation for the creeks are not expected to change significantly as a result of the proposed modification. Whilst more extensive remediation of Wambo Creek may be required, based on the *Modified Layout*, the remediation required for North Wambo Creek is anticipated to be less than that required based on the *Approved Layout*.

5.3.5. Recommendations for the Creeks

Management strategies have previously been developed for the sections of the creeks which have already been directly mined beneath at the NWUM. It is recommended that the existing management strategies for the creeks be reviewed and, where required, are revised to include the effects of the proposed longwalls.

5.4. The North Wambo Creek Diversion

5.4.1. Description of North Wambo Creek Diversion

The location of the North Wambo Creek Diversion is shown in Drawing No. MSEC799-14.

North Wambo Creek has been diverted around the active Bates South Open Cut Pit. The majority of the creek diversion is located upstream of the proposed longwalls. The downstream section of the diversion crosses above the proposed WHLW6, with a total length of 0.6 kilometres located above this longwall. The section of the North Wambo Creek Diversion located within the Study Area (i.e. Stage 3) was completed in 2013.

The North Wambo Creek Diversion is ephemeral. The creek diversion has been constructed within the natural surface soils and partly excavated into the uppermost bedrock. The heights of the banks typically ranging between 3 to 5 metres. Photographs of the creek diversion are provided in Fig. 5.12.

Fig. 5.12 Photographs of the North Wambo Creek Diversion

5.4.2. Predictions for North Wambo Creek Diversion

The predicted profiles of conventional subsidence, tilt and curvature along the natural section of North Wambo Creek and the Creek Diversion, based on the *Approved Layout* and *Modified Layout*, are illustrated in Fig. E.05, in Appendix E. It is noted, that Stage 3 of the North Wambo Creek Diversion was constructed after the extraction of the Whybrow and Wambo Seams in that location. The predicted profiles in the location of the creek diversion, therefore, are the additional movements due to the proposed longwalls only.

The predicted profiles based on the *Modified Layout* are shown as: the solid green lines after the completion of mining in the Woodlands Hill Seam; and solid red lines after the completion of mining in the Arrowfield Seam. These profiles include the multi-seam effects of the existing workings in the overlying Whybrow and Wambo Seams.

A summary of the maximum predicted values of additional subsidence, tilt and curvature for the North Wambo Creek Diversion, due to mining in each of the Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 5.9. The predictions include the multi-seam effects of the existing workings in the overlying Whybrow and Wambo Seams.

Table 5.9 Maximum Predicted Additional Subsidence, Tilt and Curvature for the Creek Diversion due to Mining in the Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seam	Maximum Predicted Additional Subsidence (mm)	Maximum Predicted Additional Tilt (mm/m)	Maximum Predicted Additional Hogging Curvature (km^{-1})	Maximum Predicted Additional Sagging Curvature (km^{-1})
North Wambo Creek Diversion	WH Seam Only	2,300	25	0.30	0.30
	WH and AF Seams	2,400	25	0.35	0.30

The North Wambo Creek Diversion has a shallow incision into the natural surface soils and excavated into the uppermost bedrock. The predicted valley related movements, therefore, are not significant when compared with the predicted conventional movements described above.

5.4.3. Comparisons of Predictions for the North Wambo Creek Diversion

The comparison of the maximum predicted conventional subsidence parameters for the North Wambo Creek Diversion, based on the *Approved Layout* and the *Modified Layout*, is provided in Table 5.10. The predicted parameters are the maxima due to mining in the Arrowfield and Bowfield Seams for the *Approved Layout* and due to mining in the Woodlands Hill and Arrowfield Seams for the *Modified Layout*.

Table 5.10 Comparison of the Maximum Predicted Subsidence Parameters for the Creek Diversion due to Mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams

Location	Layout	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
North Wambo Creek Diversion	Approved	20	< 0.5	< 0.01	< 0.01
	Modified	2,400	25	0.35	0.30

The North Wambo Creek Diversion was only predicted to experience low levels of vertical subsidence based on the *Approved Layout*. The reason for this is that the approved longwalls were located at a minimum distance of 200 metres from the creek diversion. The North Wambo Creek Diversion is located directly above the proposed WHLW6 based on the *Modified Layout*.

The maximum predicted subsidence parameters for the North Wambo Creek Diversion, therefore, increase as a result of the proposed modification. The following section provides the updated impact assessments based on these modified predictions.

5.4.4. Impact Assessments for the North Wambo Creek Diversion

The impact assessments for the North Wambo Creek Diversion, based on the *Modified Layout*, are provided below. The impact assessments for natural section of the creek are provided in Section 5.3.4.

The existing and the predicted post-mining surface levels and grades along North Wambo Creek, including the creek diversion, are illustrated in Fig. 5.8. The final profiles in the location of the creek diversion are due to mining in the Woodlands Hill and Arrowfield Seams (i.e. excluding the Whybrow and Wambo Seams) based on the *Modified Layout*.

It can be seen from this figure, that ponding is predicted to develop in one location along the creek diversion. A summary of the predicted maximum depth and length of the ponding area along North Wambo Creek Diversion, based on the *Modified Layout*, is provided in Table 5.11. The diversion was constructed after the completion of the longwalls in the Wambo Seam, in that location and, therefore, no ponding is predicted to have occurred at that time.

Table 5.11 Predicted Maximum Depths and Lengths of the Ponding Areas along the Creek Diversion (Modified Layout)

Creek	Ponding Area	Predicted Extent due to the Woodlands Hill and Arrowfield Seams
North Wambo Creek Diversion	CD-P1	1.3 m deep x 200 m long

If adverse impacts were to develop as the result of increased ponding along the creek diversion, these could be remediated by locally regrading the bed, so as to re-establish the gradients. The creek diversion has a shallow incision in the natural surface soils and excavated into the topmost bedrock. It is expected that the mining induced ponding areas could be reduced by locally excavating the channels downstream of the ponding area.

Fracturing and dilation of the topmost bedrock is expected to develop along the section of the creek diversion located directly above the proposed WMLW6. The creek diversion is ephemeral and, therefore, surface water flows only occur during and for short periods after rainfall events. In times of heavy rainfall, the majority of the runoff would flow over the soil or rock bed and would not be diverted into the dilated strata below. In times of low flow, however, surface water flows could be diverted into the dilated strata below the bed.

It would be expected, that the fracturing in the underlying bedrock would gradually be filled with the surface soils during subsequent flow events, especially during times of heavy rainfall. If the surface cracks were found not to fill naturally, some remedial measures may be required at the completion of mining. Where necessary, any significant surface cracks in the bed of the creek diversion could be remediated by infilling with the surface soil or other suitable materials, or by locally regrading and recompacting the surface.

5.4.5. Recommendations for the North Wambo Creek Diversion

It is recommended that remediation strategies are developed so that the larger surface cracking within the alignment of the North Wambo Creek Diversion can be remediated during active subsidence. Similar strategies have been developed for the section of the creek diversion located above the South Bates WYLW11 to WYLW13 in the Whybrow Seam.

5.5. Aquifers and Known Groundwater Resources

The descriptions, predictions and the assessment of potential impacts on the aquifers and groundwater resources within the Study Area are provided in the Groundwater Assessment report prepared by *HydroSimulations* (2016).

There are no *Ground Water Management Areas*, as defined by the Department of Environment, Climate Change and Water, within the Study Area. There are, however, registered groundwater bores in the vicinity of the Study Area, which as discussed in Section 6.11.

5.6. Escarpments

The Wollemi Escarpment is located to the south-west of the proposed mining area.

The Macquarie Dictionary defines an *escarpment* as *"a long, cliff-like ridge of rock, or the like, commonly formed by faulting or fracturing of the earth's crust*". The Collins Dictionary of Geology defines an *escarpment* as *"a high, more or less continuous, cliff or long steep slope situated between a lower more gently inclined surface and a higher surface*". It appears, from these examples, that some definitions of an escarpment include only the cliffs and rock formations, whilst other definitions also include the steep slopes.

In this report, the escarpment has been defined as the continuous sections of high level cliffline along the boundary of the Wollemi National Park. The lower levels of discontinuous cliffline, the isolated rock outcrops and the steep slopes have not been included as part of the escarpment.

The extent of the escarpment was determined from detailed site investigations by MSEC and WCPL, as well as from the orthophotograph and the surface level contours which were generated from the Light Detection and Ranging (LiDAR) survey of the area. The extents of the cliffs associated with the Wollemi Escarpment are shown in Drawing No. MSEC799-14. These cliffs are also shown in more detail in Fig. 5.13.

The impact assessments for the cliffs associated with the Wollemi Escarpment are included in Section 5.7. The impact assessments for the Wollemi National Park are provided in Section 5.12.

5.7. Cliffs

5.7.1. Descriptions of the Cliffs

The definitions of cliffs and minor cliffs provided in the NSW DP&E Standard and Model Conditions for Underground Mining (DP&E, 2012) are:

"Cliff	*Continuous rock face, including overhangs, having a minimum length of 20 metres, a minimum height of 10 metres and a minimum slope of 2 to 1 (>63.4º)*
Minor Cliff	*A continuous rock face, including overhangs, having a minimum length of 20 metres, heights between 5 metres and 10 metres and a minimum slope of 2 to 1 (>63.4º); or a rock face having a maximum length of 20 metres and a minimum height of 10 metres"*

The cliffs and minor cliffs were identified using the 1 metre surface level contours generated from the Light Detection and Ranging (LiDAR) survey and from detailed site investigations. The locations of the cliffs in the vicinity of the proposed longwalls are shown in Drawing No. MSEC799-14. The cliffs have also been shown in more detail in Fig. 5.13, below, along with the minor cliffs and the larger rock outcrops. The proposed longwalls in the Woodlands Hill and Arrowfield Seams are shown as the orange outlines and the existing longwalls in the Whybrow and Wambo Seams are shown as the grey outlines in this figure.

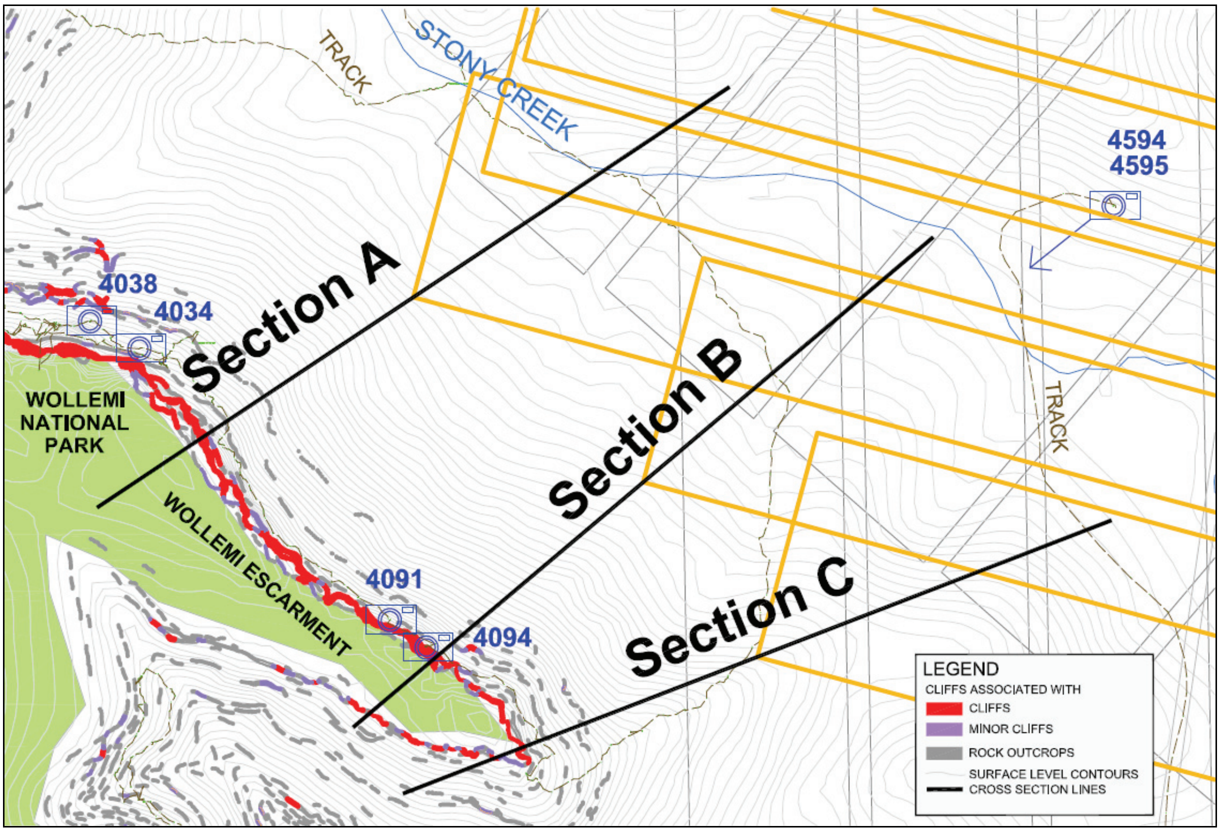


Fig. 5.13 Cliffs, Minor Cliffs and Rock Outcrops Adjacent to the Proposed Longwalls

The cliffs associated with the Wollemi Escarpment are located at minimum distances of 325 metres from WHLW10 and 310 metres from AFLW5 at their closest points to the proposed longwalls in each of these seams. This section of cliffline was also located at a minimum distance of 210 metres from the previously extracted Longwall 13 of the Homestead/Wollemi workings in the Whybrow Seam.

The section of the Wollemi Escarpment located closest to the proposed longwalls comprises a series of disjointed cliffs and minor cliffs having an overall length of around 1 kilometre. The cliffline comprises cliffs and minor cliffs on one to three levels having overall heights generally varying between 20 metres and 35 metres, reducing to between 10 metres to 20 metres along the south-eastern extent.

Photographs of the Wollemi Escarpment are provided in Fig. 5.14 to Fig. 5.16. The locations of these photographs are indicated in Fig. 5.13.

Fig. 5.14 Photographs of the Wollemi Escarpment (IMGP4594 and IMGP4595)

Fig. 5.15 Photograph of the Cliffs at the North-Western End of the Wollemi Escarpment (IMGP4034 and IMGP4038)

Fig. 5.16 Photograph of the Cliffs at South-Eastern End of the Wollemi Escarpment (IMGP4094 and IMGP4091)

Sections A to C (as shown in Fig. 5.13) have been taken through the Wollemi Escarpment and the proposed longwalls in Fig. 5.17 to Fig. 5.19, respectively. The locations of these sections are shown in Fig. 5.13. These sections have been taken where the proposed longwalls are closest to the cliffs.

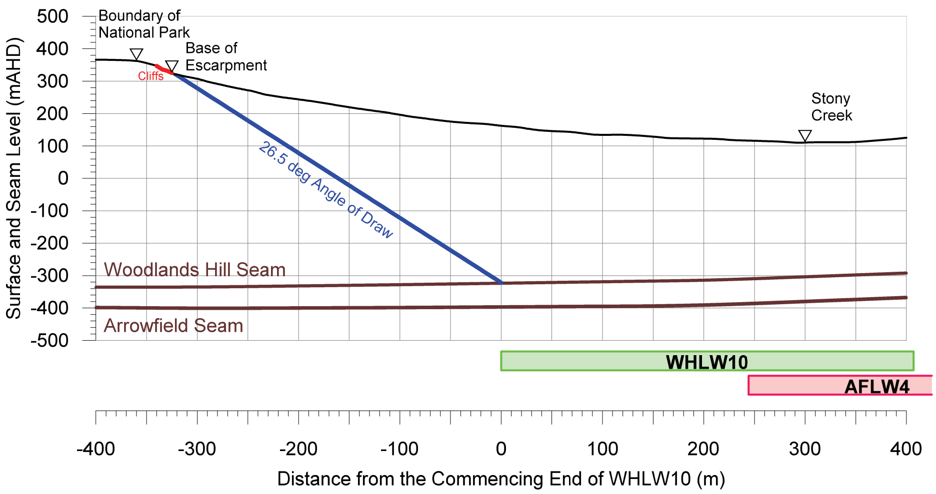


Fig. 5.17 Section A through the Wollemi Escarpment and WHLW10

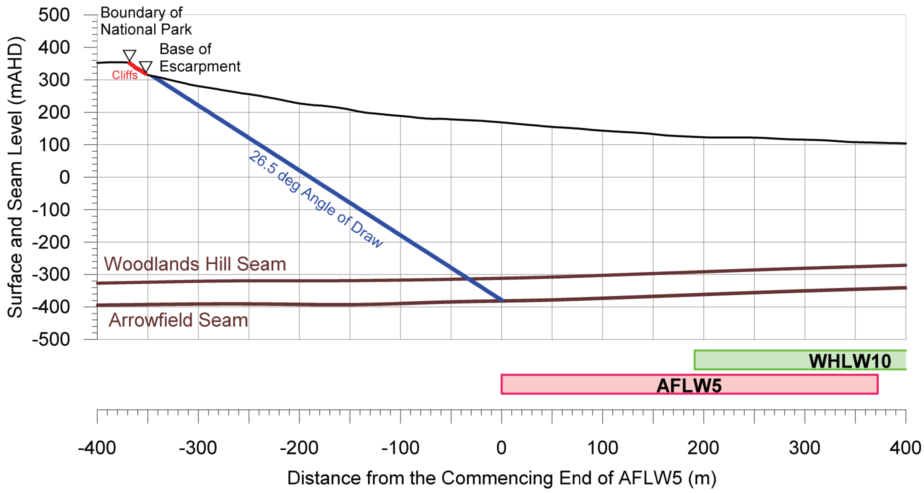


Fig. 5.18 Section B through the Wollemi Escarpment and AFLW5

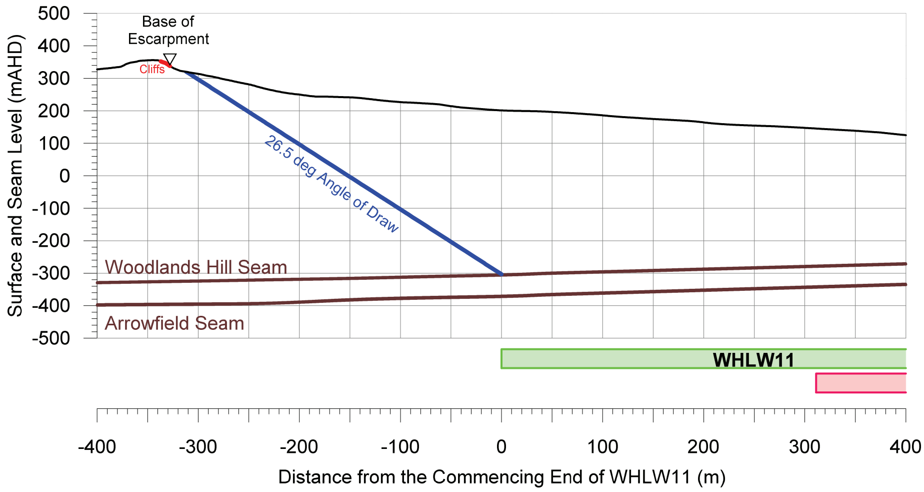


Fig. 5.19 Section C through the Wollemi Escarpment and WHLW11

The cliffs associated with the Wollemi Escarpment are located outside the 26.5 degree angle of draw lines from the proposed longwalls in the Woodlands Hill and Arrowfield Seams. The locations of the cliffs, the base of the Wollemi Escarpment and the angles of draw from the proposed longwalls are illustrated in Fig. 5.17 to Fig. 5.19.

It is noted that the Study Area differs from the 26.5 degree angles of draw lines in this location, as the Study Area is based on an angle of draw using the depth of cover above the longwall perimeters and, therefore, does not take into account the increasing depth of cover to the south-west of the longwalls. For this reason, all the cliffs associated with the Wollemi Escarpment, immediately to the south-west of the longwalls, have been included as part of the impact assessments provided in this report.

5.7.2. Predictions for the Cliffs

A summary of the maximum predicted values of additional subsidence, tilt and curvature for the cliffs associated with the Wollemi Escarpment, due to mining in each of the Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 5.12. The predictions include the multi-seam effects of the existing workings in the overlying Whybrow and Wambo Seams.

Table 5.12 Maximum Predicted Additional Subsidence, Tilt and Curvature for the Cliffs due to Mining in the Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seam	Maximum Predicted Additional Subsidence (mm)	Maximum Predicted Additional Tilt (mm/m)	Maximum Predicted Additional Hogging Curvature (km^{-1})	Maximum Predicted Additional Sagging Curvature (km^{-1})
Cliffs	WH Seam Only	< 20	< 0.5	< 0.01	< 0.01
	WH and AF Seams	< 20	< 0.5	< 0.01	< 0.01

The cliffs could also experience far-field horizontal movements as a result of mining the proposed longwalls. There is no available far-field horizontal movement data at the NWUM along the steep slopes beneath the Wollemi Escarpment. The predicted far-field horizontal movements, therefore, have been based on the observations at Dendrobium Mine, which has similar or shallower depths of cover and similar natural surface gradients.

Eight longwalls have been extracted in Areas 1, 2 and 3A at Dendrobium Mine. The depths of cover vary between 170 metres and 320 metres in Area 1, between 150 metres and 310 metres in Area 2 and between 275 metres and 385 metres in Area 3A. The longwalls were extracted in the Wongawilli Seam and had width-to-depth ratios typically ranging between 0.8 and 1.4. Escarpments were located directly above the longwalls in Areas 1 and 2 and the surface was highly undulating in Area 3A, with the natural gradients varying between 1 in 3 and 1 in 2 directly above the longwalls.

The observed 3D horizontal movements at Dendrobium Mine outside the extents of the longwalls (i.e. above solid coal only) are illustrated in Fig. 5.20.

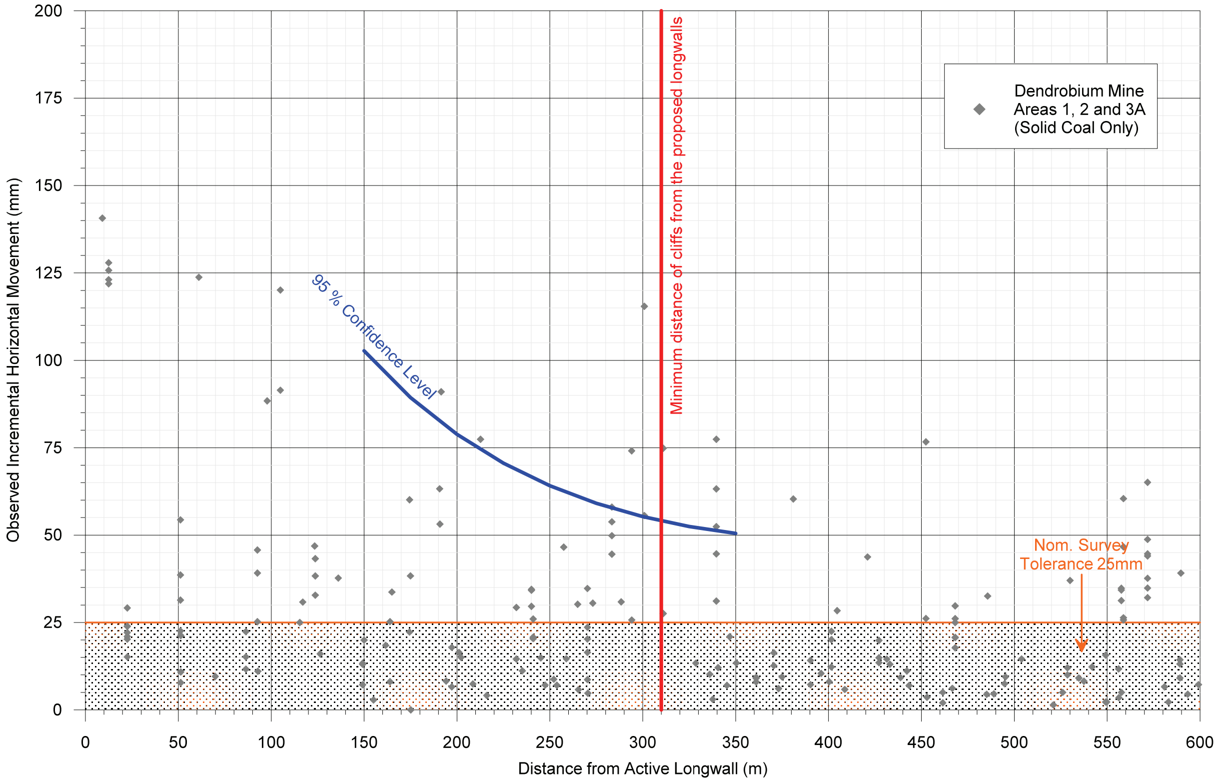


Fig. 5.20 Observed 3D Horizontal Movements in Areas 1, 2 and 3A at Dendrobium Mine

It can be seen from the above figure, that the survey marks located above solid coal at Dendrobium Mine experience incremental horizontal movements up to around 60 mm at a distance of 310 metres from the longwalls, based on the 95 % confidence level. These movements tend to be bodily movements, towards the extracted longwalls, which are accompanied by very low levels of strain, typically less than the order of survey tolerance.

5.7.3. Comparisons of Predictions for the Cliffs

The comparison of the maximum predicted conventional subsidence parameters for the cliffs associated with the Wollemi Escarpment, based on the *Approved Layout* and the *Modified Layout*, is provided in Table 5.13. The predicted parameters are the maxima due to mining in the Wambo, Arrowfield and Bowfield Seams for the *Approved Layout* and due to mining in the Wambo, Woodlands Hill and Arrowfield Seams for the *Modified Layout*.

Table 5.13 Comparison of the Maximum Predicted Subsidence Parameters for the Cliffs due to Mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams

Location	Layout	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Cliffs	Approved	< 20	< 0.5	< 0.01	< 0.01
	Modified	< 20	< 0.5	< 0.01	< 0.01

The cliffs associated with the Wollemi Escarpment are predicted to experience less than 20 mm vertical subsidence based on both the *Approved* and *Modified Layouts*.

5.7.4. Impact Assessments for the Cliffs

The maximum predicted vertical subsidence for the cliffs associated with the Wollemi Escarpment is less than 20 mm based on the *Modified Layout*. The cliffs are not predicted to experience any significant conventional tilts, curvatures or strains, even if the predicted vertical subsidence was exceeded by a factor of 2 times.

The cliffs could also experience low level far-field horizontal movements of up to around 60 mm. These movements are expected to be bodily movements towards the extracted longwalls and are not expected to be associated with any significant strains. It is unlikely, therefore, that the cliffs associated with the Wollemi Escarpment would be adversely impacted by the far-field horizontal movements, even if these predictions were exceeded by a factor of 2 times.

The existing Wollemi/Homestead workings in the Whybrow Seam were extracted adjacent to the section of the Wollemi Escarpment closest to the proposed longwalls. Longwall 13 was extracted at a distance of 210 metres east of the cliffs, at its closest point. The location of these previous workings and the escarpment are illustrated in Fig. 5.21.

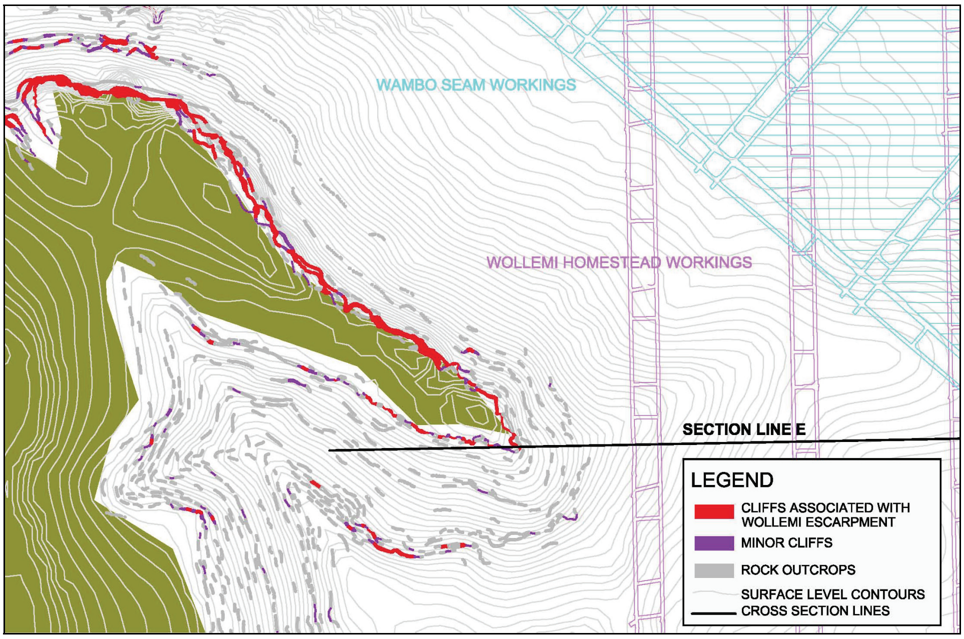


Fig. 5.21 Wollemi/Homestead Workings and the Wollemi Escarpment

There is no ground monitoring data available for the Wollemi/Homestead workings in the location where Longwall 13 is closest to the Wollemi Escarpment. Section E has been taken through the Wollemi/Homestead workings and the escarpment which is shown in Fig. 5.22.

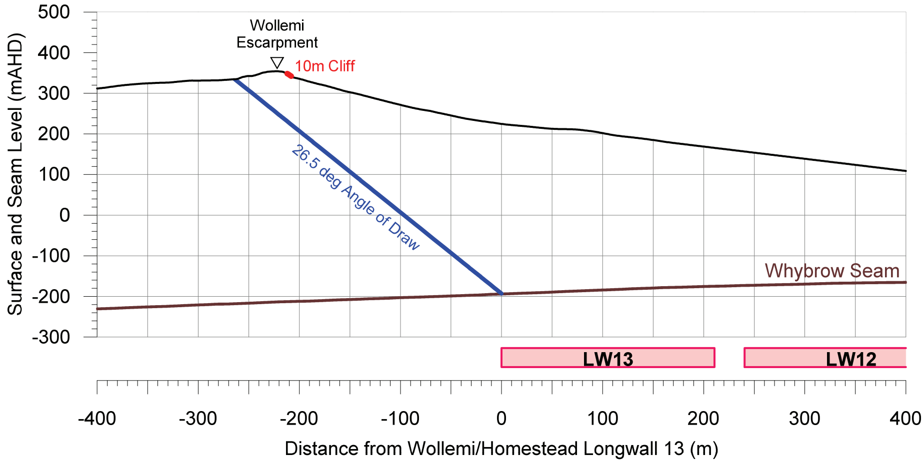


Fig. 5.22 Section E through the Wollemi Escarpment and the Wollemi/Homestead Workings

It can be seen from the above figure, that the Wollemi/Homestead workings were extracted to within a distance of 210 metres from the cliffs associated with the Wollemi Escarpment, which is equivalent to a 21 degree angle of draw as measured from the base of the escarpment. There were no reported impacts for the cliffs associated with the Wollemi Escarpment resulting from the extraction of the Wollemi/Homestead workings.

Similarly, it is not expected that there would be any adverse impacts on the cliffs associated with the Wollemi Escarpment resulting from the extraction of the proposed longwalls in the Woodlands Hill and Arrowfield Seams.

5.7.5. Recommendations for the Cliffs

It is recommended that monitoring is undertaken to measure the actual angle of draw to the limit of vertical subsidence using a longitudinal ground monitoring line at the commencing ends of the proposed WHLW10 and AFLW5, or other suitable monitoring methods. It is also recommended that the cliffs are periodically visually inspected during and after the completion of the longwalls.

5.8. Steep Slopes

5.8.1. Descriptions of the Steep Slopes

The definition of a steep slope provided in the NSW DP&E 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 metre surface level contours which were generated from the LiDAR survey of the area.

Natural steep slopes have been identified beneath the Wollemi Escarpment as shown in Drawing No. MSEC799-14. These steep slopes are located above the western ends of the proposed WHLW8 to WHLW11 in the Woodlands Hill Seam and the proposed AFLW2 to AFLW5 in the Arrowfield Seam. The previously extracted Longwalls 11 to 13 at the Wollemi/Homestead Mine in the Whybrow Seam were also extracted directly beneath these steep slopes.

The natural surface gradients of the steep slopes typically range between 1 in 3 and 1 in 2 directly above the proposed longwalls. The gradients increase up to 1 in 1 at the higher elevations beneath the escarpment, which are located outside the extents of the proposed longwalls.

The surface soils along the steep slopes are generally derived from the Narrabeen Group (Rn), as can be inferred from Fig. 1.7. The slopes are stabilised by the natural vegetation, which can be seen in Fig. 1.2.

There are also artificial steep slopes within the Wambo Open Cut, which are discussed separately in Section 6.13. The discussions provided below are for the natural steep slopes.

5.8.2. Predictions for the Steep Slopes

A summary of the maximum predicted values of additional subsidence, tilt and curvature for the steep slopes, due to mining in each of the Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 5.14. The predictions include the multi-seam effects of the existing workings in the overlying Whybrow and Wambo Seams.

Table 5.14 Maximum Predicted Additional Subsidence, Tilt and Curvature for the Steep Slopes due to Mining in the Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seam	Maximum Predicted Additional Subsidence (mm)	Maximum Predicted Additional Tilt (mm/m)	Maximum Predicted Additional Hogging Curvature (km^{-1})	Maximum Predicted Additional Sagging Curvature (km^{-1})
Steep Slopes	WH Seam Only	2,300	8	0.09	0.09
	WH and AF Seams	3,400	10	0.10	0.04

A summary of the maximum predicted values of accumulated subsidence, tilt and curvature for the steep slopes, after the completion of mining in the Wambo, Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 5.15. The predictions include the multi-seam effects of the existing workings in the overlying Whybrow Seam.

Table 5.15 Maximum Predicted Total Subsidence, Tilt and Curvature for the Steep Slopes after Mining in the Wambo, Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seam	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Steep Slopes	WM Seam Only	2,300	30	0.50	0.70
	WM and WH Seams	4,600	35	0.55	0.80
	WM, WH and AF Seams	5,700	40	0.60	0.75

The steep slopes are located directly above the proposed longwalls and, therefore, could experience the full range of predicted strains. The analysis of strains measured at the NWUM is provided in Section 4.4. Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Section 4.4 includes those resulting from both conventional and non-conventional anomalous movements.

5.8.3. Comparisons of Predictions for the Steep Slopes

The comparison of the maximum predicted conventional subsidence parameters for the steep slopes, based on the *Approved Layout* and the *Modified Layout*, is provided in Table 5.16. The predicted parameters are the maxima due to mining in the Wambo, Arrowfield and Bowfield Seams for the *Approved Layout* and due to mining in the Wambo, Woodlands Hill and Arrowfield Seams for the *Modified Layout*.

Table 5.16 Comparison of the Maximum Predicted Subsidence Parameters for the Steep Slopes due to Mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams

Location	Layout	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Steep Slopes	Approved	4,050	35	0.50	0.70
	Modified	5,700	40	0.60	0.75

It can be seen from the above table, that the maximum predicted vertical subsidence for the steep slopes increases as a result of the proposed modification. The maximum predicted tilt and curvatures, based on the *Modified Layout*, are similar to but slightly greater than the maxima predicted based on the *Approved Layout*.

5.8.4. Impact Assessments for the Steep Slopes

The maximum predicted tilt for the steep slopes based on the *Modified Layout* is 40 mm/m (i.e. 4 %, or 1 in 25). The predicted tilts for the steep slopes are small when compared to the natural surface grades, which are greater than 1 in 3. It is unlikely, therefore, that the mining induced tilts themselves would result in any adverse impact on the stability of these steep slopes.

The steep slopes are more likely to be impacted by curvature and ground strain, rather than tilt. The potential impacts would generally result from the horizontal movements in the downslope direction, resulting in tension cracks appearing at the tops of the steep slopes and compression ridges forming at the bottoms of the steep slopes.

The maximum predicted total tilts and curvatures for the steep slopes after the completion of the proposed longwalls in the Woodlands Hill and Arrowfield Seams are similar orders of magnitudes as those predicted due to the previous extraction of the Homestead/Wollemi workings in the shallower Whybrow Seam.

The surface cracking along the steep slopes resulting from the proposed mining could be similar to that previously observed at the NWUM. Photographs of surface cracking on the steep slopes due to previous Homestead/Wollemi workings in the Whybrow Seam are provided in Fig. 5.23.

Fig. 5.23 Photograph of Surface Cracking on Steep Slopes (IMGP4101 and IMGP4102)

The maximum predicted total curvatures for the steep slopes based on the *Modified Layout* are 0.60 km^{-1} hogging and 0.75 km^{-1} sagging, which represent minimum radii of curvature of 1.7 kilometres and 1.3 kilometres, respectively.

The maximum predicted total curvatures and strains for the steep slopes are similar orders of magnitude as those predicted to have occurred for Dendrobium Longwalls 1 and 2, which mined directly beneath a ridgeline with similar surface gradients. The observed surface cracking along the steep slopes from this case study, therefore, can also be used to provide an indication of the potential surface cracking along the steep slopes directly above the proposed longwalls.

Dendrobium Longwalls 1 and 2 mined directly beneath a ridgeline where steep slopes had natural surface gradients of up to 1 in 1 (i.e. 100 %, or an angle to the horizontal of 45°). The maximum predicted conventional curvatures resulting from the extraction of these longwalls were 0.35 km^{-1} hogging and 0.75 km^{-1} sagging.

A number of surface cracks were observed along the steep slopes located directly above Dendrobium Longwalls 1 and 2 which are shown in Fig. 5.24.

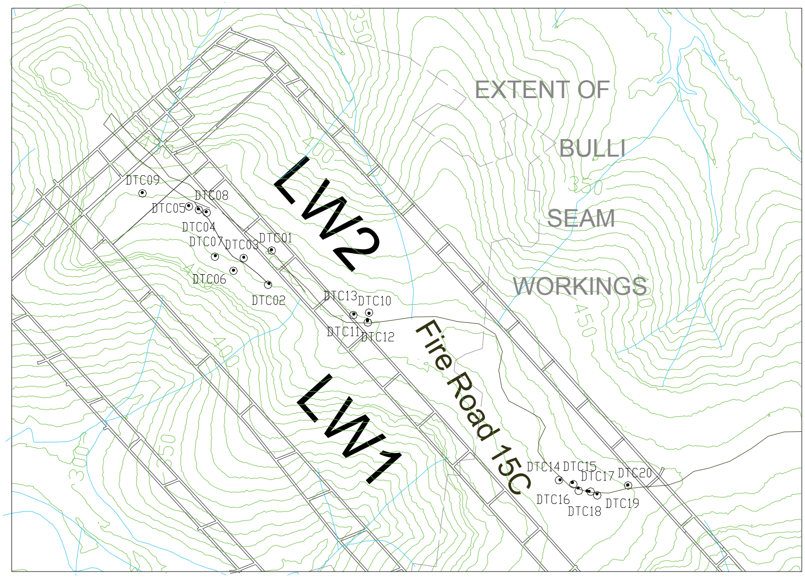


Fig. 5.24 Locations of Observed Surface Cracking above Dendrobium Longwalls 1 and 2

The largest surface cracks observed in Dendrobium Area 1 occurred along the top of the ridgeline, having widths of up to 400 mm, which were associated with down slope movement of the surface soils. Additional surface cracks, typically in the order of 100 mm to 150 mm in width, were also observed further down the ridgeline and the steep slopes.

Photographs of the surface cracking at Dendrobium Mine are provided in Fig. 5.25.

Fig. 5.25 Surface Tension Cracking due to Down Slope Movements at Dendrobium Mine

The steep slopes located above the proposed longwalls are heavily vegetated and natural erosion due to soil instability (i.e. natural down slope movements) was not readily apparent from the site investigations undertaken. If tension cracks were to develop, as the result of the extraction of the proposed longwalls, then soil erosion could occur if these cracks were left untreated.

Some remediation might be required after the extraction of the proposed longwalls, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the slopes in the longer term. Similarly, where cracking restricts the passage of vehicles along the tracks and fire trails that are required to be open for access, it is recommended that these cracks are treated in the same way.

5.8.5. Recommendations for the Steep Slopes

It is recommended that the steep slopes are periodically visually monitored during the mining period and until any necessary remedial measures are completed, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the slopes in the longer term.

5.9. Land Prone to Flooding or Inundation

The land within the Study Area adjacent to the creeks could be susceptible to inundation, during major rainfall events, as the result of the surface water flows originating the steep slopes to the west of the Study Area.

The predicted post-mining surface level contours after the completion of the existing longwalls and proposed longwalls are illustrated in Fig. 5.26 based on the *Approved Layout* and in Fig. 5.27 based on the *Modified Layout*. The existing farm dams are indicated by the blue hatching in these figures. The extents of the predicted topographical depressions after the completion of existing longwalls in the Wambo Seam are illustrated by the green hatching.

The extents of the predicted topographical depressions after the completion of mining in the Wambo, Arrowfield and Bowfield Seams, based on the *Approved Layout*, is illustrated by the purple hatching in Fig. 5.26. The extents of the predicted topographical depressions after the completion of mining in the Wambo, Woodlands Hill and Arrowfield Seams, based on the *Modified Layout*, is illustrated by the purple hatching in Fig. 5.27.

It can be seen from these figures, that topographical depressions were predicted to developed, after the completion the longwalls in the Wambo Seam (i.e. green hatching), on the northern side of North Wambo Creek and adjacent to South Wambo Dam, based on both the *Approved* and *Modified Layouts*. The maximum depths of these depressions are typically between 1 metre and 2 metres.

These topographical depressions are predicted to increase in size and additional topographical depressions are predicted to develop as a result of mining the proposed longwalls in the Woodlands Hill and Arrowfield Seams (i.e. the purple hatching). The largest topographic depression based on the *Modified Layout* is located south-east of South Wambo Dam, having a maximum depth of 4.5 metres. The remaining topographical depressions have depths typically between 1 metres and 2 metres.

The maximum depth of the topographical depression located adjacent to South Wambo Dam is 5.3 metres based on the *Approved Layout*. The depths and extents of the topographical depressions reduce as a result of the proposed modification, since the proposed longwalls are *staggered* based on the *Modified Layout*, which results in less subsidence when compared with the *stacked* arrangement based on the *Approved Layout*.

The difference between the green and purple hatching in Fig. 5.27 indicates the increased extents of the topographical depressions as a result of the proposed mining based on the *Modified Layout*. It is highlighted, however, that the potential for increased ponding is also dependent on a number of other factors, including rainfall, catchment sizes, surface water runoff, permeation and evaporation and, therefore, the actual extents and depths of ponding are expected to be smaller than the topographical depressions.

The potential for increased ponding within the Study Area, after the completion of the proposed longwalls, could affect the land use in area including access along some unsealed roads. It is also recommended that management strategies are developed as part of the Extraction Plan process for the proposed longwalls, so that access can be maintained along the unsealed roads.

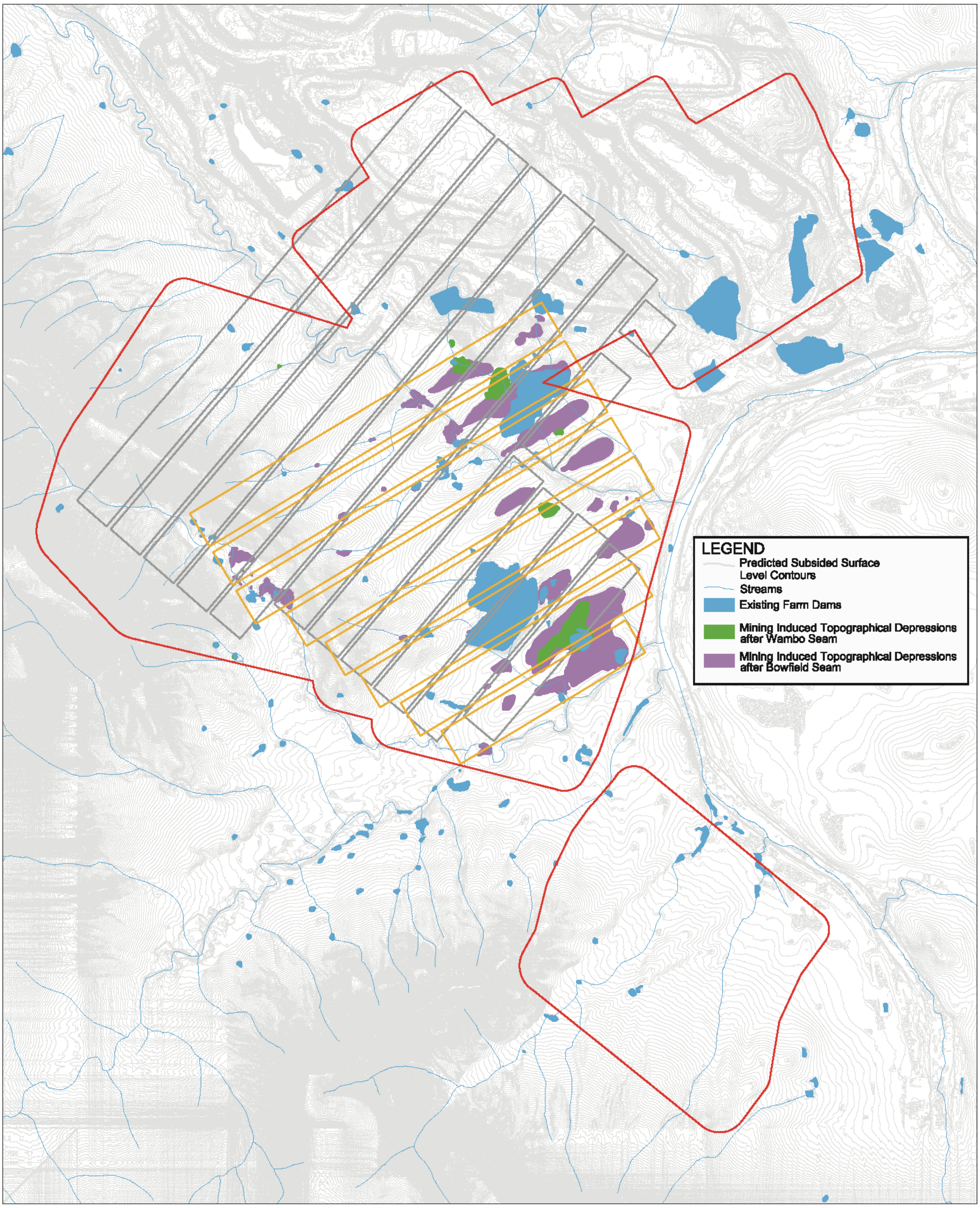


Fig. 5.26 Predicted Post Mining Surface Level Contours and Topographical Depressions based on the Approved Layout

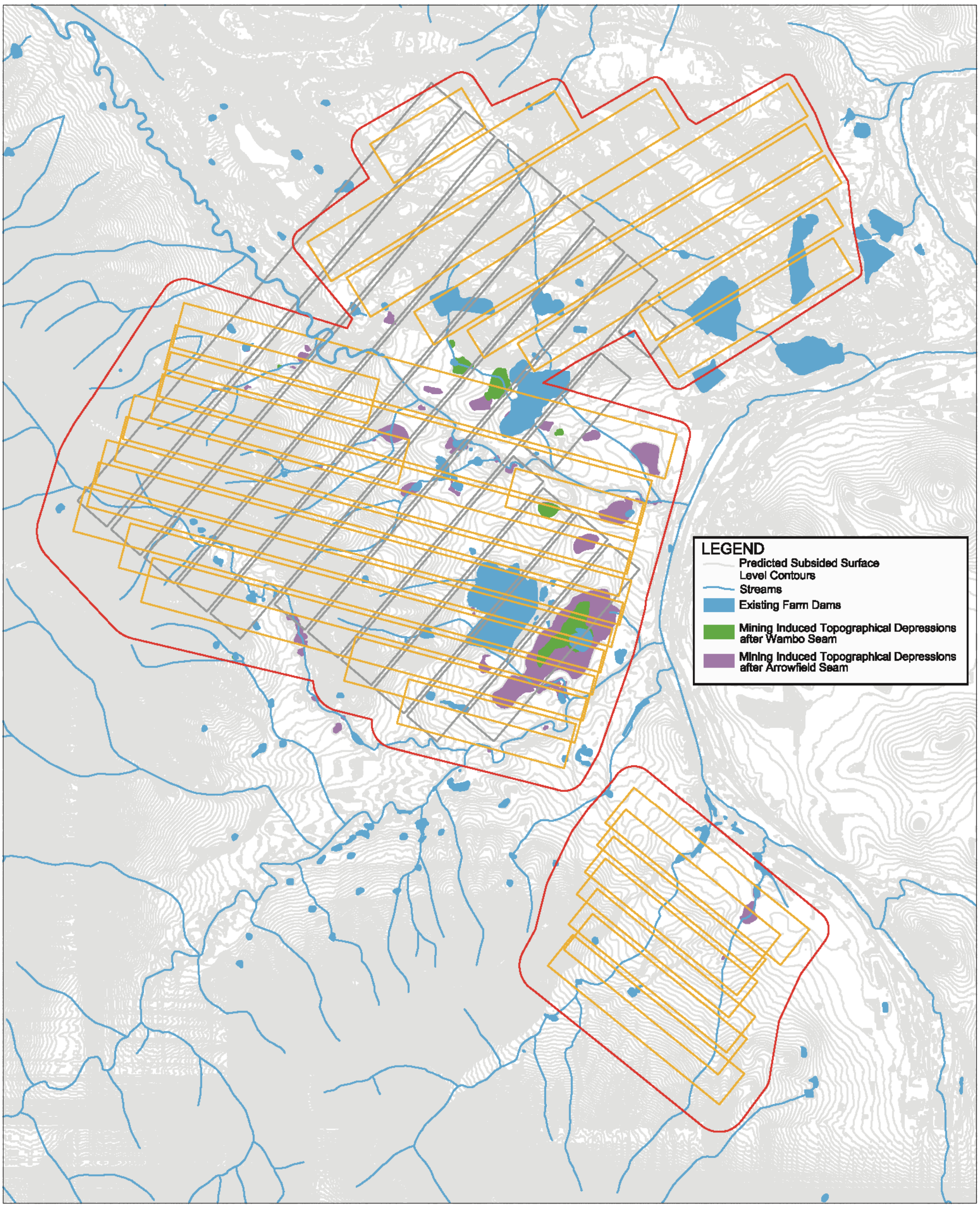


Fig. 5.27 Predicted Post Mining Surface Level Contours and Topographical Depressions based on the Modified Layout

Further discussions on the potential impacts on surface water drainage are provided by the specialised surface water consultant in the report by *Advisian* (2016).

5.10. Water Related Ecosystems

There are water related ecosystems associated with the drainage within the Study Area, which are described and assessed in the report prepared by *Eco Logical Australia* (2016).

5.11. Threatened or Protected Species

An investigation of the flora and fauna within the Study Area has been undertaken, which is described and assessed in the reports prepared by *FloraSearch* (2016) and *Eco Logical Australia* (2016).

5.12. National Parks or Wilderness Areas

The *Wollemi National Park* is located to the south-west and to the west of the proposed longwalls. The boundary of the National Park is located at minimum distances of 340 metres from the commencing end of WHLW11 and 310 metres from the commencing end of AFLW5, at its closest points to the proposed longwalls. The location of the National Park is shown in Drawing No. MSEC799-01.

The land within the National Park is predicted to experience less than 20 mm vertical subsidence resulting from the extraction of the proposed longwalls, based on both the *Approved* and *Modified Layouts*. The magnitude of the predicted vertical subsidence is similar to the natural movements that occur due to wetting and drying of the surface soils. These low level vertical movements are not expected to be associated with any measurable tilts, curvatures or strains.

The National Park could experience low level far-field horizontal movements. As described in Section 5.7, the Wollemi Escarpment (i.e. the cliffs on the boundary of the National Park) are predicted to experience horizontal movements of up to around 60 mm. These movements are expected to be bodily movements towards the extracted longwalls and are not expected to be associated with any significant tilts, curvatures or strains.

It is unlikely, therefore, that the National Park would be adversely impacted by the vertical or far-field horizontal movements, even if these predictions were exceeded by a factor of 2 times. The predictions and impact assessments for the Wollemi Escarpment (i.e. the cliffs along the boundary of the National Park) are provided in Section 5.7.

The drainage lines within the National Park are located at distances greater than 500 metres from the proposed longwalls. Whilst minor and isolated fracturing have been observed up to around 400 metres from longwall mining, these have occurred within very incised river valleys within the Southern Coalfield and had no adverse impacts on the streams. The drainage lines within the National Park are on top of the escarpment (i.e. small valley heights) and, therefore, it is unlikely that mining induced fracturing would occur at these distances from the proposed longwalls.

It is unlikely that there would be any adverse impacts to the Wollemi National Park, even if the predictions were exceeded by a factor of 2 times.

5.13. Natural Vegetation

The surface in the north-eastern part of the Study Area has been affected by the Wambo Open Cut. The vegetation has been partially cleared along the flat lying areas in the eastern part of the Study Area. There is natural vegetation along the steep slopes in the western part of the Study Area, which can be seen from the aerial photograph in Fig. 1.2. A detailed survey of the natural vegetation has been undertaken and is described and assessed in the report prepared by *FloraSearch* (2016).

6.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE BUILT FEATURES

The following sections provide the descriptions, predictions and impact assessments for the built features within the Study Area, as identified in Chapter 2. All significant built features located outside the Study Area, which may be subjected to valley related or far-field horizontal movements and may be sensitive to these movements, have also been included as part of these assessments.

The impact assessments provided in this report include consideration of the: geological model that has been developed by WCPL; the database of geological structures identified during exploration and mining of other seams at the Wambo Coal Mine; and the local ground monitoring data from the NWUM and other nearby collieries in the Hunter Coalfield.

6.1. Public Utilities

There are unsealed roads, drainage culverts, water pipelines, powerlines and telecommunications cables within the Study Area that are owned and maintained by WCPL. There are no other public utilities identified within the Study Area.

6.2. Unsealed Roads

6.2.1. Descriptions of the Unsealed Roads

There are unsealed roads within the Study Area used for the mining operations, the locations of which are shown in Drawing No. MSEC799-15. Whilst there are no public roads within the Study Area, the road above the proposed WHLW7 to WHLW11 and AFLW2 to AFLW6 is a right of way in favour of several private properties, the route of which may be varied on reasonable notice. A photograph of a typical road within the Study Area is provided in Fig. 6.1

Fig. 6.1 Photograph of an Unsealed Road

There are circular concrete drainage culverts within the Study Area where the unsealed roads cross the drainage lines.

6.2.2. Predictions for the Unsealed Roads

The unsealed roads are located across the Study Area and, therefore, could experience the full range of predicted subsidence movements. A summary of the maximum predicted mine subsidence parameters within the Study Area was provided in Chapter 4.

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

6.2.3. Comparisons of Predictions for the Unsealed Roads

The comparison of the maximum predicted conventional subsidence parameters for the unsealed roads within the Study Area, based on the *Approved Layout* and the *Modified Layout*, is provided in Table 6.1.

Table 6.1 Comparison of Maximum Predicted Subsidence Parameters for the Unsealed Roads due to Mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	9,000	90	> 3.0	> 3.0
Modified Layout	6,250	75	> 3.0	> 3.0

The maximum predicted vertical subsidence and tilt, based on the *Modified Layout*, are less than the maxima predicted based on the *Approved Layout*. The maximum predicted total curvatures are greater than 3.0 km^{-1} based on both the *Approved* and *Modified Layouts*. Generally, the predicted curvatures reduce as a result of the proposed modification, but it is more difficult to directly compare at these higher magnitudes, as they occur as localised and elevated values.

6.2.4. Impact Assessments for the Unsealed Roads

It is expected, at these magnitudes of predicted curvatures and strains, that cracking and heaving of the unsealed road surfaces would occur as each of the proposed longwalls mine beneath them. It is expected, however, that the unsealed roads could be maintained in safe and serviceable condition throughout the mining period using normal road maintenance techniques.

The drainage culverts could experience the full range of predicted subsidence movements. The predicted tilts could result in a reduction or, in some cases, a reversal of grade of the drainage culverts. In these cases, the culverts would need to be re-established to provide the minimum required grades. The predicted curvatures and ground strains could result in cracking of the concrete culverts. It may be necessary to repair, or in some cases, replace the affected culverts.

6.2.5. Recommendations for the Unsealed Roads

It is recommended that management strategies are developed for the unsealed roads, which could include the establishment of methods to remediate the unsealed road surfaces which are adversely impacted by mining, if required. The roads should also be visually monitored during active subsidence. The appropriate management strategies and monitoring for the roads will be developed during the Extraction Plan stage for the proposed longwalls.

6.3. Water Pipelines

6.3.1. Description of the Water Pipelines

There are a number of water pipelines located within the Study Area which supply water for mining activities. The polyethylene pipelines are shallow buried or resting on the natural ground. Photographs of the typical water pipelines within the Study Area are provided in Fig. 6.2.

Fig. 6.2 Photographs of the Water Pipelines

The pipelines are owned and maintained by WCPL.

6.3.2. Predictions for the Water Pipelines

The water pipelines are located across the Study Area and, therefore, could experience the full range of predicted subsidence movements. A summary of the maximum predicted mine subsidence parameters within the Study Area was provided in Chapter 4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst 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. Comparisons of Predictions for the Water Pipelines

The comparison of the maximum predicted conventional subsidence parameters for the water pipelines within the Study Area, based on the *Approved Layout* and the *Modified Layout*, is provided in Table 6.2.

Table 6.2 Comparison of Maximum Predicted Subsidence Parameters for the Water Pipelines due to Mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	9,000	90	> 3.0	> 3.0
Modified Layout	6,250	75	> 3.0	> 3.0

The maximum predicted vertical subsidence and tilt, based on the *Modified Layout*, are less than the maxima predicted based on the *Approved Layout*. The maximum predicted total curvatures are greater than 3.0 km^{-1} based on both the *Approved* and *Modified Layouts*. Generally, the predicted curvatures reduce, as a result of the proposed modification, but it is more difficult to directly compare at these higher magnitudes, as they occur as localised and elevated values.

6.3.4. Impact Assessments for the Water Pipelines

The water pipelines are pressure mains and are unlikely, therefore, to be affected to any great extent by changes in gradient due to vertical subsidence or tilt. The pipelines are shallow buried or resting on the natural ground and, therefore, it is unlikely that the localised curvatures or ground strains would be fully transferred into them.

Polyethylene pipelines are flexible and would be expected to tolerate the predicted curvatures and strains without adverse impact. It is possible, although unlikely, that minor impacts could occur, if they are anchored to the ground and the strains are fully transferred into the pipeline. Any impacts are expected to be of a minor nature which could be readily remediated.

Extensive experience of mining beneath polyethylene pipelines in the NSW Coalfields, where the mine subsidence movements were similar to those predicted for the proposed longwalls, indicates that incidences of impacts are low and generally of a minor nature.

6.3.5. Recommendations for the Water Pipelines

It is recommended that management strategies are developed for the water pipelines, which could include the establishment of methods to remediate the pipelines which are adversely impacted by mining, if required. The pipelines should also be visually monitored during active subsidence. The appropriate management strategies and monitoring for the pipelines will be developed during the Extraction Plan stage for the proposed longwalls.

6.4. Electrical Infrastructure

6.4.1. Description of the Electrical Infrastructure

The electrical infrastructure within the Study Area includes a 66 kilovolt (kV) powerline and a number of 11 kV powerlines. These powerlines comprise aerial copper cables supported by timber poles. The locations of the electrical infrastructure are shown in Drawing No. MSEC799-15.

The 66 kV powerline is located partially above the southern ends of the proposed WHLW1 to WHLW5 and WHLW22. This powerline is also located above the previously extracted WMLW1 to WMLW8 in the Wambo Seam and the previously extracted United Collieries longwalls in the Arrowfield Seam.

The 11 kV powerlines are located above the proposed longwalls in both the Woodlands Hill and Arrowfield Seams. These powerlines are also located above the previously extracted Homestead/Wollemi workings in the Whybrow Seam, the previously extracted longwalls in the Wambo Seam and the United Collieries workings in the Arrowfield Seam.

Photographs of the 11 kV powerlines within the Study Area are provided in Fig. 6.3.

Fig. 6.3 Photographs of the 11 kV Powerlines

The 11 kV powerline Branch 1 is owned by Ausgrid and the remaining powerlines are owned by WCPL.

6.4.2. Predictions for the Electrical Infrastructure

The predicted profiles of conventional subsidence and tilt for the 66 kV powerline and the 11 kV powerline Branches 1 to 3, based on the *Approved Layout* and *Modified Layout*, are illustrated in Figs. E.08 to E.11, in Appendix E. The profiles are based on the extraction of the existing and proposed longwalls in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams, but also include the multi-seam effects of the existing workings in the overlying Whybrow Seam or the existing United Collieries longwalls in the underlying Arrowfield Seam.

The predicted profiles due to the extraction of the existing longwalls in the Wambo Seam are shown as the solid cyan lines in these figures. The predicted profiles based on the *Approved Layout* are shown as: the dashed green lines after the completion of mining in the Arrowfield Seam; and dashed red lines after the completion of mining in the Bowfield Seam. The predicted profiles based on the *Modified Layout* are shown as: the solid green lines after the completion of mining in the Woodlands Hill Seam; and solid red lines after the completion of mining in the Arrowfield Seam.

A summary of the maximum predicted values of additional subsidence and tilt for the powerlines, due to mining in the Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 6.3. The predictions include the multi-seam effects of the existing workings in the overlying Whybrow and Wambo Seams.

Table 6.3 Maximum Predicted Additional Subsidence and Tilt for the Powerlines due to Mining in the Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seams	Maximum Predicted Additional Subsidence (mm)	Maximum Predicted Additional Tilt Along Alignment (mm/m)	Maximum Predicted Additional Tilt Across Alignment (mm/m)
66 kV Powerline	WH Seam Only	1,350	25	25
	WH and AF Seams	1,350	25	25
11 kV Powerline (Branch 1)	WH Seam Only	2,800	25	14
	WH and AF Seams	3,550	30	5
11 kV Powerline (Branch 2)	WH Seam Only	2,150	25	4
	WH and AF Seams	3,200	20	3
11 kV Powerline (Branch 3)	WH Seam Only	2,900	35	25
	WH and AF Seams	2,950	35	25

A summary of the maximum predicted values of accumulated subsidence and tilt for the powerlines, after the completion of mining in the Wambo, Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 6.4. The predictions include the multi-seam effects of the existing workings in the overlying Whybrow Seam.

Table 6.4 Maximum Predicted Total Subsidence and Tilt for the Powerlines after Mining in the Wambo, Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seam	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt Along Alignment (mm/m)	Maximum Predicted Total Tilt Across Alignment (mm/m)
66 kV Powerline	WM Seam Only	2,300	75	> 100
	WM and WH Seams	2,600	75	> 100
	WM, WH and AF Seams	2,600	75	> 100
11 kV Powerline (Branch 1)	WM Seam Only	2,300	25	65
	WM and WH Seams	4,900	40	65
	WM, WH and AF Seams	5,650	40	65
11 kV Powerline (Branch 2)	WM Seam Only	2,250	45	35
	WM and WH Seams	4,150	60	35
	WM, WH and AF Seams	5,400	50	35
11 kV Powerline (Branch 3)	WM Seam Only	2,400	75	> 100
	WM and WH Seams	3,800	60	> 100
	WM, WH and AF Seams	3,800	60	> 100

The cables are supported by timber poles above the ground and, therefore, they are not adversely impacted by ground strain.

6.4.3. Comparisons of Predictions for the Electrical Infrastructure

The comparison of the maximum predicted conventional subsidence parameters for the powerlines, based on the *Approved Layout* and the *Modified Layout*, is provided in Table 6.5. The predicted parameters are the maxima due to mining in the Wambo, Arrowfield and Bowfield Seams for the *Approved Layout* and due to mining in the Wambo, Woodlands Hill and Arrowfield Seams for the *Modified Layout*.

Table 6.5 Comparison of the Maximum Predicted Subsidence Parameters for the Powerlines due to Mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams

Location	Layout	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt Along Alignment (mm/m)	Maximum Predicted Total Tilt Across Alignment (mm/m)
66 kV Powerline	Approved	8,450	90	> 100
	Modified	2,600	75	> 100
11 kV Powerline (Branch 1)	Approved	6,550	25	65
	Modified	5,650	40	65
11 kV Powerline (Branch 2)	Approved	7,500	45	60
	Modified	5,400	50	35
11 kV Powerline (Branch 3)	Approved	2,400	75	> 100
	Modified	3,800	60	> 100

The maximum predicted vertical subsidence for the 66 kV powerline and the 11 kV powerline Branch 1 and, based on the *Modified Layout*, are less than the maxima predicted based on the *Approved Layout*. The maximum predicted vertical subsidence for the 11 kV powerline Branch 3 increases as a result of the proposed modification, as this powerline is located outside the extents of the proposed longwalls based on the *Approved Layout*.

The maximum predicted tilts for the powerlines, based on the *Modified Layout*, are similar orders of magnitude as the maxima predicted based on the *Approved Layout*. The reason for this is that the maximum predicted tilts are largely governed by the previous extraction of the longwalls in the shallower Wambo Seam.

The predicted tilts increase in some locations and decrease in other locations along the alignments of the powerlines as a result of the proposed modification. The following section provides the impact assessments for the powerlines based on the *Modified Layout*.

6.4.4. Impact Assessments for the Electrical Infrastructure

The maximum predicted total tilts for the powerlines, based on the *Modified Layout*, are greater than 100 mm/m (i.e. greater than 10 %, or 1 in 10) for the 66 kV powerline and the 11 kV powerline Branch 3; 65 mm/m (i.e. 6.5 %, or 1 in 15) for the 11 kV powerline Branch 1; and 60 mm/m (i.e. 6.0 %, or 1 in 17) for the 11 kV powerline Branch 2. The maximum predicted total tilts are largely governed by the previous extraction of the longwalls in the Wambo Seam.

The maximum predicted additional tilts for the powerlines, due to the mining of the Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, are 25 mm/m (i.e. 2.5 %, or 1 in 40) for the 66 kV powerline; 30 mm/m (i.e. 3.0 %, or 1 in 33) for the 11 kV powerline Branch 1; 25 mm/m (i.e. 2.5 %, or 1 in 40) for the 11 kV powerline Branch 2; and 35 mm/m (i.e. 3.5 %, or 1 in 30) for the 11 kV powerline Branch 3.

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 metres and pole diameters of 250 mm, the maximum tolerable tilt at the pole locations is in the order of 33 mm/m.

It is possible, therefore, that some preventive measures will be required for the powerlines prior to the proposed mining directly beneath them. It may be necessary that preventive measures are implemented, which could include the installation of cable rollers, guy wires or additional poles, or the adjustment of cable catenaries.

Extensive experience of mining beneath powerlines in the NSW Coalfields, where the mine subsidence movements were similar to those predicted for the proposed longwalls, indicates that incidences of impacts are manageable with the implementation of the necessary strategies.

6.4.5. Recommendations for the Electrical Infrastructure

It is recommended that management strategies are developed for the 66 kV and 11 kV powerlines, which could include visual pre-mining inspections, so that the appropriate preventive measures can be established. The powerlines should also be visually monitored during active subsidence, so that they can be maintained in safe and serviceable conditions at all times. The appropriate management strategies and monitoring for the powerlines will be developed during the Extraction Plan stage for the proposed longwalls.

6.5. Telecommunications Infrastructure

An aerial optical fibre cable follows the alignment of the 11 kV powerline Branch 3. This cable is owned and maintained by WCPL. This cable is predicted to experience mine subsidence movements similar to the powerline, which is summarised in Section 6.4.2. The optical fibre cable could be adversely impacted by the differential horizontal movements at the tops of the supporting poles. It will be necessary to develop management strategies for this cable, which could include cable rollers and adjustment the catenaries during active subsidence.

There are also direct buried optical fibre cable and copper cables along the main access road to the site administration buildings. These cables are also owned and maintained by WCPL. The direct buried cables are located outside the extents of the proposed longwalls. It is unlikely, therefore, that these cables would experience adverse impacts as a result of the proposed mining.

6.6. Public Amenities

As listed in Table 2.1, there were no public amenities identified within the Study Area.

6.7. Farm Land or Facilities

As listed in Table 2.1, the following farm land or facilities were not identified within the Study Area nor the immediate surrounds:-

- tanks, gas or fuel storages;
- poultry sheds or glass houses;
- hydroponic systems or irrigation systems; and
- other significant farm features.

The following sections describe the farm land and facilities which have been identified within and in the vicinity of the Study Area.

6.8. Agriculture Utilisation and Agriculture Improvements

The land in the eastern part of the Study Area has been partially cleared and is used for light grazing. There are also some farm features within the Study Area, which are described in the following sections.

6.9. Fences

The fences are located across the Study Area and, therefore, they are expected to 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.

Wire fences can be affected by tilting of the fence posts and by changes of tension in the fence wires due to strain as mining occurs. These types of 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 significant impacts.

It is likely, therefore, that some of the wire fences within the Study Area would be impacted as the result of the extraction of the longwalls in the Arrowfield and Woodlands Hill Seams. Any impacts on the wire fences could be remediated by re-tensioning the fencing wire, straightening the fence posts, and if necessary, replacing some sections of fencing.

The management of potential subsidence impacts on fences would be detailed in the relevant Extraction Plan for consideration and approval by the relevant authorities, and would be consistent with the requirements of the Wambo Development Consent.

6.10. Farm Dams

6.10.1. Descriptions of the Farm Dams

There are farm dams located with the Study Area on WCPL owned land. The locations of these farm dams are shown in Drawing No. MSEC799-15. The farm dams are typically of earthen construction and have been established by localised cut and fill operations within the natural drainage lines. There are also water storage dams used for mining activities which are discussed separately in Section 6.14.1.

6.10.2. Predictions for the Farm Dams

The farm dams are located across the Study Area and, therefore, could experience the full range of predicted subsidence movements. A summary of the maximum predicted mine subsidence parameters within the Study Area was provided in Chapter 4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst 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. Comparisons of Predictions for the Farm Dams

The comparison of the maximum predicted conventional subsidence parameters for the unsealed roads within the Study Area, based on the *Approved Layout* and the *Modified Layout*, is provided in Table 6.6.

Table 6.6 Comparison of Maximum Predicted Subsidence Parameters for the Farm Dams due to Mining in the Wambo, Woodlands Hill and Arrowfield / Bowfield Seams

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	9,000	90	> 3.0	> 3.0
Modified Layout	6,250	75	> 3.0	> 3.0

The maximum predicted vertical subsidence and tilt, based on the *Modified Layout*, are less than the maxima predicted based on the *Approved Layout*. The maximum predicted total curvatures are greater than 3.0 km^{-1} based on both the *Approved* and *Modified Layouts*. Generally, the predicted curvatures reduce, as a result of the proposed modification, but it is more difficult to directly compare at these higher magnitudes, as they occur as localised and elevated values.

6.10.4. Impact Assessments for the Farm Dams

Changes in freeboard could potentially reduce the storage capacity of some of the farm dams. If the storage capacity of any farm dams were adversely affected as a result of mining, these could be re-instated by raising the earthen walls of the affected dams.

It is expected, at the magnitudes of predicted curvatures and strains, that fracturing and buckling would occur in the uppermost bedrock beneath the natural surface soils. Surface cracking in the bases of the farm dams would be visible, especially where the depths of bedrock are relatively shallow. It may be necessary to remediate some of the farm dams, at the completion of mining, by excavating and re-establishing cohesive material in the beds of the farm dams to reduce permeability.

6.10.5. Recommendations for the Farm Dams

Management strategies have previously been developed for the farm dams which have already been directly mined beneath at the NWUM. It is recommended that the existing management strategies for the farm dams be reviewed and, where required, are revised to include the effects of the proposed longwalls.

6.11. Registered Groundwater Bores

The locations of the registered groundwater bores in the vicinity of the Study Area are shown in Drawing No. MSEC799-15. The locations and details of these were obtained from the Department of Natural Resources using the *Natural Resource Atlas* website (NRAtlas, 2015).

There were no registered groundwater bores identified within the Study Area. There were a number of bores identified in the vicinity of the Study Area, primarily to the north and east of the proposed longwalls, adjacent to Wollombi Brook. These groundwater bores are owned by WCPL and their intended use are for stock, irrigation, exploration, mining and monitoring. It appears from the information obtained from NRAtlas, that none of the bores in the immediate vicinity of the proposed longwalls are used for potable water.

It is likely that the groundwater bores will experience some impacts as the result of the proposed mining in the Woodlands Hill and Arrowfield Seams. Impacts may include temporary lowering of the piezometric surfaces, blockage of the bores 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.

Further discussions on the potential impacts on the groundwater are provided by the specialised groundwater consultant in the report by *HydroSimulations* (2016).

6.12. Industrial, Commercial or Business Establishments

As listed in Table 2.1, there were no industrial, commercial or business establishments identified within the Study Area, apart from WCPL and other mine related infrastructure.

6.13. Open Cut Mining Areas

The Wambo Open Cut is located in the north-eastern part of the Study Area. WHLW1 to WHLW5 and WHLW20 to WHLW22 are proposed to be extracted directly beneath the pit and emplacement areas. The longwalls in the Arrowfield and Bowfield Seams, based on the *Approved Layout*, were located to the south of the Wambo Open Cut. The United Collieries longwalls in the Arrowfield Seam have previously been extracted directly beneath the open cut mining area.

Emplacement areas are located within the Wambo Open Cut including the North East Tailings Dam. Further emplacement areas are proposed within the pit. A photograph of the Wambo Open Cut Pit and the highwall are provided in Fig. 6.4.

Fig. 6.4 Wambo Open Cut

The extraction of the proposed longwalls beneath the Wambo Open Cut could affect the stability of the highwalls. The mine subsidence could also result in additional settlement of spoil emplacement within the pit. WCPL will need to develop management strategies to maintain safe conditions in the Wambo Open Cut during and after the completion of the proposed mining. Management strategies have previously been developed for the extraction of the United Collieries longwalls in the Arrowfield Seam beneath the open cut mining area and for the NWUM beneath the emplacement areas and in the vicinity of the pit walls.

6.14. Mine Related Infrastructure

6.14.1. Water Storage Dams

The South Wambo Dam is located above the proposed WHLW9 to WHLW10 and AFLW4 and AFLW5. This dam was previously directly mined beneath by WMLW9 and WMLW10 in the Wambo Seam at the NWUM. This dam is owned by WCPL and supplies water for mining activities. The Eagle Nest Water Storage Dam is located outside the Study Area.

The location of the South Wambo Dam is shown in Drawing No. MSEC799-15. The dam has a planar area of around 270,000 m^2 and a maximum planar dimension of around 700 metres. The dam wall follows the southern and eastern perimeters of the dam and is up to around 5 metres high. The dam was dewatered prior to the extraction of the longwalls in the Wambo Seam directly beneath it.

Photographs of the South Wambo Dam are provided in Fig. 6.5.

Fig. 6.5 Photographs of the South Wambo Dam

The South Wambo Dam has been approved by the NSW Dams Safety Committee (now referred to as Dams Safety NSW).

It is expected that the extraction of the proposed longwalls beneath the South Wambo Dam would result in fracturing and buckling in the uppermost bedrock. Cracking in the base of the dam or in the dam wall could result in the loss of stored water from the dam.

The South Wambo Dam is owned by WCPL and, therefore, it will be necessary for WCPL to develop management strategies for the dam, which could include lowering the water level or completely draining the dam prior to directly mining beneath it. The stored water was removed from the dam during the previous extraction of the longwalls in the Wambo Seam directly beneath it. The management strategies would be developed based on a risk assessment as part of the Extraction Plan process in consultation with Dams Safety NSW and DRE.

6.14.2. Tailings Emplacements

The North-East Tailings Dam is located above the proposed longwalls WHLW1 to WHLW4 and WHLW22. The tailings dam covers an area of 26.1 hectares and has been decommissioned. The North-East Tailings Dam is a prescribed dam and has been approved by the NSW Dams Safety Committee (now referred to as Dams Safety NSW).

In addition, future tailings emplacement areas would be developed above the proposed longwalls WHLW1 to WHLW5 and WHLW21 to WHLW22 in the Homestead in pit area.

The tailings emplacements are operated by WCPL and, therefore, it will be necessary for WCPL to develop management strategies for the emplacement areas. The management strategies would be developed as part of the Extraction Plan process in consultation with Dams Safety NSW and DRE.

6.14.3. Administration Buildings

The WCPL administration buildings are located within the Study Area. The locations of these structures are shown in drawing no. MSEC799-15 and in more detail in Fig. 6.6.

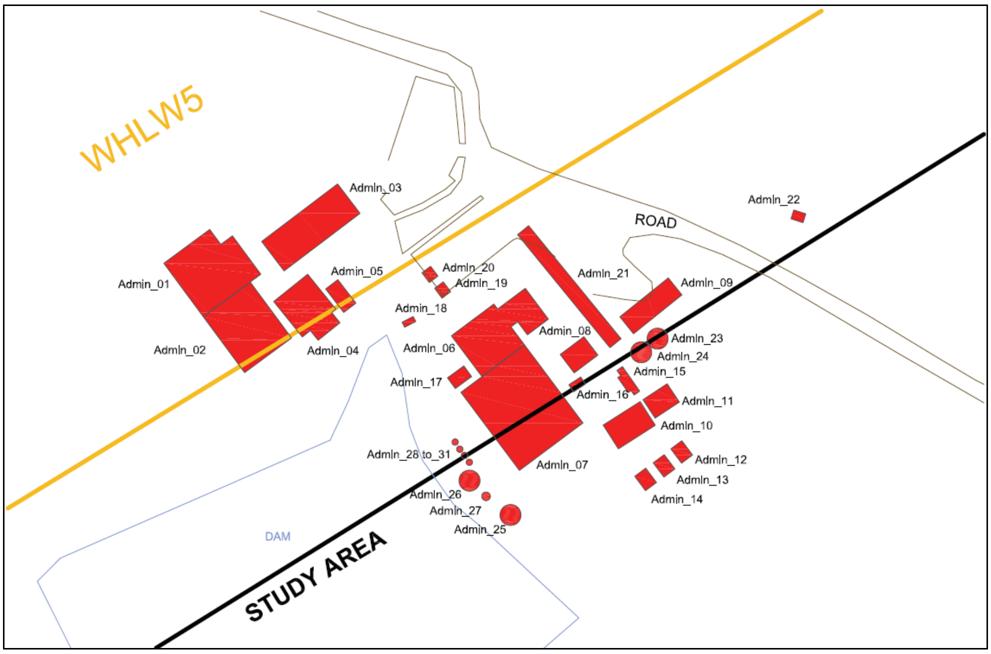


Fig. 6.6 Administration Building Structures

Some administration building structures are located directly above the proposed WHLW5. These structures comprise steel framed storage and machinery sheds. These structures are predicted to experience additional ground movements due to the extraction of WHLW5 up to: 1,100 mm vertical subsidence; 25 mm/m tilt (i.e. 2.5 %, or 1 in 40); 1.0 km^{-1} hogging curvature (i.e. 1 kilometre minimum radius); and 0.6 km^{-1} sagging curvature (i.e. 1.7 kilometre minimum radius).

The remaining structures are located outside the extents of the proposed longwalls. These structures include the office buildings, bath houses, storages sheds, tanks and other ancillary structures. These structures are predicted to experience additional ground movements due to the extraction of WHLW5 up to: 100 mm vertical subsidence; 5 mm/m tilt (i.e. 0.5 %, or 1 in 200); 0.2 km^{-1} hogging curvature (i.e. 5 kilometre minimum radius); and less than 0.01 km^{-1} sagging curvature (i.e. greater than 100 kilometre minimum radius).

It will be necessary to manage the potential impacts on these building structures during active subsidence. Preventive measures may be required for some of these structures to maintain them in safe conditions. Alternatively, some structures can be left unoccupied during active subsidence and then remediated prior to reoccupying them.

6.14.4. Services

The services associated with the mining activities include: unsealed roads (refer to Section 6.2; water supply pipelines (refer to Section 6.3); powerlines (refer to Section 6.4); and telecommunications cables (refer to Section 6.5).

6.14.5. Exploration Drillholes

There are exploration drillholes located across the Study Area. These drillholes could experience the full range of predicted subsidence movements, which were described in Chapter 4. It is likely, therefore, that fracturing and shearing would occur in the drillholes as the result of the proposed mining. It is recommended that the exploration drillholes are grouted and capped prior to being directly mined beneath.

6.15. Archaeological Sites

6.15.1. Descriptions of the Archaeological Sites

There are no lands within the Study Area declared as an Aboriginal Place under the *National Parks and Wildlife Act 1974*. Excluding the artefact scatters and isolated finds, there are six archaeological sites which have been identified within the Study Area, being Site Refs. 32, 117, 332, 334, 335 and 360. There are also a further six sites located in the vicinity of the Study Area, being Site Refs. 329, 330, 331, 377, 386 and 387.

The locations of the archaeological sites (excluding the artefact scatters and isolated finds) are shown in Drawing No. MSEC799-15. A summary of these archaeological sites is provided in Table 6.7.

Table 6.7 Identified Archaeological Sites

Site Reference	Description	Location
32	Possible Scarred Tree	Outside the proposed mining area, 140 metres east of WHLW8
117	Grinding Groove Site and Artefact Scatter	Directly above WHLW6
329	Grinding Groove Site	Outside the Study Area, 180 metres east of WHLW7
330	Grinding Surface	Outside the Study Area, 140 metres east of WHLW9
331	Grinding Surface	Outside the Study Area, 140 metres east of WHLW9
332	Grinding Surface	Outside the proposed mining area, 80 metres east of WHLW9
334	Earth Mound	Outside the proposed mining area, 100 metres east of WHLW8
335	Earth Mound with Artefacts	Outside the proposed mining area, 120 metres east of WHLW8
360	Scarred Tree	Directly above WHLW11 and AFLW6
377	Grinding Groove Site	Outside the Study Area, 160 metres east of WHLW9
386	Grinding Groove Site	Outside the Study Area, 340 metres west of AFLW4
387	Grinding Groove Site	Outside the Study Area, 500 metres west of WHLW9

There is also a *Bora Ground* (i.e. ceremonial site) located on the eastern side of Wollombi Brook based on previous records and anecdotal evidence. This site is located outside the Study Area at a distance of more than 400 metres from the proposed longwalls based on the *Modified Layout*.

Detailed descriptions of the archaeological sites are provided in the report by the specialised archaeological consultant *RPS* (2016).

6.15.2. Predictions for the Archaeological Sites

The artefact scatters and isolated finds are located across the proposed mining area and, therefore, could experience the full range of predicted subsidence movements. A summary of the maximum predicted mine subsidence parameters within the Study Area is provided in Chapter 4.

The predicted total conventional subsidence, tilts and curvatures for the remaining archaeological sites, based on the *Approved Layout* and the *Modified Layout*, are provided in Table D.01, in Appendix D. The predicted parameters are the maxima due to mining in the Wambo, Arrowfield and Bowfield Seams for the *Approved Layout* and due to mining in the Wambo, Woodlands Hill and Arrowfield Seams for the *Modified Layout*. These predictions include the multi-seam effects due to the presence of the overlying workings in the Whybrow Seam.

It is noted, that specific subsidence predictions for the archaeological sites were not provided in the subsidence report by Holt (2005) which supported the 2005 SEE. For this reason, the predicted subsidence parameters based on the *Approved Layout* have been determined using the calibrated Incremental Profile Method, as described in Section 3.3.

A summary of the maximum predicted values of additional subsidence, tilt and curvature for the archaeological sites, due to mining the Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 6.8. The predictions include the multi-seam effects due to the existing workings in the overlying Whybrow and Wambo Seams.

Table 6.8 Maximum Predicted Additional Subsidence, Tilt and Curvature for the Archaeological Sites due to Mining in the Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seams	Maximum Predicted Additional Subsidence (mm)	Maximum Predicted Additional Tilt (mm/m)	Maximum Predicted Additional Hogging Curvature (km^{-1})	Maximum Predicted Additional Sagging Curvature (km^{-1})
Grinding Groove Sites	WH Seam Only	1,900	2.5	0.2	0.1
	WH and AF Seams	1,900	2.5	0.2	0.1
Grinding Surface Sites	WH Seam Only	< 20	0.5	< 0.01	< 0.01
	WH and AF Seams	30	1	0.01	< 0.01
Scarred Trees	WH Seam Only	1,950	10	< 0.01	0.45
	WH and AF Seams	2,950	1	< 0.01	0.45
Earth Mounds	WH Seam Only	< 20	< 0.5	< 0.01	< 0.01
	WH and AF Seams	< 20	< 0.5	< 0.01	< 0.01

A summary of the maximum predicted values of accumulated subsidence, tilt and curvature for the archaeological sites, after the completion of mining in the Wambo, Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 6.9. The predictions include the multi-seam effects due to the existing workings in the overlying Whybrow Seam.

Table 6.9 Maximum Predicted Total Subsidence, Tilt and Curvature for the Archaeological Sites after Mining in the Wambo, Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Seam	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Grinding Groove Sites	WM Seam Only	1,950	35	< 0.01	2.2
	WM and WH Seams	3,900	30	0.2	2.3
	WM, WH and AF Seams	3,900	30	0.2	2.3
Grinding Surface Sites	WM Seam Only	< 20	< 0.5	< 0.01	< 0.01
	WM and WH Seams	< 20	0.5	< 0.01	< 0.01
	WM, WH and AF Seams	30	1	0.01	< 0.01

Location	Seam	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Scarred Trees	WM Seam Only	300	5	0.3	< 0.01
	WM and WH Seams	2,250	15	0.3	0.45
	WM, WH and AF Seams	3,250	6.5	0.3	0.45
Earth Mounds	WM Seam Only	< 20	< 0.5	< 0.01	< 0.01
	WM and WH Seams	< 20	< 0.5	< 0.01	< 0.01
	WM, WH and AF Seams	< 20	< 0.5	< 0.01	< 0.01

The archaeological sites located directly above the proposed longwalls could experience the full range of predicted strains. The analysis of strains measured at the NWUM is provided in Section 4.4. Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Section 4.4 includes those resulting from both conventional and non-conventional anomalous movements.

The archaeological sites located outside the extents of the proposed longwalls are predicted to experience strains generally less than 0.5 mm/m tensile and compressive. The creeks have shallow incisions into the surface soils and, therefore, the strains due to valley closure movements are not expected to be significant.

The Bora Ground is located more than 400 metres from the proposed longwalls based on the *Modified Layout*. At this distance, this site is not predicted to experience any measurable vertical subsidence, tilts, curvatures or strains as a result of mining these proposed longwalls.

6.15.3. Comparisons of Predictions for the Archaeological Sites

The comparisons of the maximum predicted total conventional subsidence parameters for the archaeological sites, based on the *Approved Layout* and the *Modified Layout*, are provided in Table 6.10 to Table 6.13. The predicted parameters are the maxima due to mining in the Wambo, Arrowfield and Bowfield Seams for the *Approved Layout* and due to mining in the Wambo, Woodlands Hill and Arrowfield Seams for the *Modified Layout*.

Table 6.10 Comparison of the Maximum Predicted Subsidence Parameters for the Grinding Groove Sites based on the Approved and Modified Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	2,050	30	0.1	2.2
Modified Layout	3,900	30	0.2	2.3

Table 6.11 Comparison of the Maximum Predicted Subsidence Parameters for the Grinding Surface Sites based on the Approved and Modified Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	1,650	35	0.45	0.2
Modified Layout	30	1	0.01	< 0.01

Table 6.12 Comparison of the Maximum Predicted Subsidence Parameters for the Scarred Trees based on the Approved and Modified Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	3,300	25	0.6	0.01
Modified Layout	3,250	6.5	0.3	0.45

Table 6.13 Comparison of the Maximum Predicted Subsidence Parameters for the Earth Mounds based on the Approved and Modified Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	675	16	0.25	0.15
Modified Layout	< 20	< 0.5	< 0.01	< 0.01

It can be seen from Table 6.10, that the maximum predicted vertical subsidence, hogging curvature and sagging curvature for the grinding groove sites increase as a result of the proposed modification. The reason for this is that Site Ref. 117 is located directly above the proposed WMLW6 based on the *Modified Layout* and is located outside the proposed longwalls based on the *Approved Layout*. The remaining grinding groove sites are located outside the extents of the proposed longwalls based on the *Modified Layout*.

It can be seen from Table 6.11, that the maximum predicted subsidence parameters for the grinding surface sites decrease as a result of the proposed modification. These sites are all located outside the extents of the proposed longwalls based on the *Modified Layout*.

It can be seen from Table 6.12, that the maximum predicted vertical subsidence, tilt and hogging curvature for the confirmed and possible scarred trees decrease as a result of the proposed modification. The maximum predicted sagging curvature increases for Site Ref. 360, as it is located directly above the proposed WHLW11 and AFLW6 based on the *Modified Layout*.

It can be seen from Table 6.13, that the maximum predicted subsidence parameters for the earth mounds decrease as a result of the proposed modification. These sites are located outside the extents of the proposed longwalls based on the *Modified Layout*.

The impact assessments for the archaeological sites have been reviewed in the following sections using on the predicted subsidence parameters based on the *Modified Layout*.

6.15.4. Impact Assessments for the Artefact Scatters and Isolated Finds

There are artefact scatters and isolated finds located above the proposed longwalls.

These sites can potentially be affected by cracking of the surface soils as a result of mine subsidence movements. It is unlikely, however, that the scattered artefacts or isolated finds themselves would be impacted by surface cracking. It is possible, however, that if remediation of the surface was required after mining, that these works could potentially impact these sites.

It is recommended that WCPL seek the required approvals from the appropriate authorities, in the event that remediation of the surface is required in the locations of the artefact scatters and isolated finds.

Further assessments of the potential impacts on the open sites are provided in the report by the specialised archaeological consultant *RPS* (2016).

6.15.5. Impact Assessments for the Grinding Groove and Grinding Surface Sites

There are five identified grinding groove sites (Refs. 117, 329, 377, 386 and 387) and three identified grinding surface sites (Refs. 330, 331 and 332).

Grinding groove Site Ref. 117 is located directly above the proposed WMLW6 and is predicted to experience additional curvatures of 0.2 km^{-1} hogging and 0.1 km^{-1} sagging due to the extraction of the proposed longwalls. This site is predicted to have already experienced 2.2 km^{-1} sagging curvature due to the previous extraction of WMLW4 directly beneath it.

It is likely that fracturing of the bedrock would develop in the vicinity of the grinding groove Site Ref. 117 as a result of the extraction of WHLW6 directly beneath it. It is difficult to assess the likelihood of impact at this site, as there are many factors which cannot be quantified, such as the in situ stress, inclusions and existing weaknesses with the bedrock.

The potential for adverse impacts on the grinding groove Site Ref. 117 is considered to be unlikely (i.e. less than 25 %) based on the *Modified Layout*. The potential for impact on this site due to the proposed mining is considered to be less than that when the site was directly mined beneath by WMLW4 due to lower predicted curvatures and strains.

The grinding groove Site Ref. 117 was located at a minimum distance of 90 metres from the longwalls in the Arrowfield and Bowfield Seams based on the *Approved Layout*, i.e. outside the extents of these longwalls. The potential for adverse impact at this site, therefore, has increased as a result of the proposed modification from rare (i.e. less than 5 %) to unlikely (i.e. less than 25 %).

The remaining grinding groove and grinding surface sites are located outside the extents of the proposed longwalls. Whilst the sites located closest to the proposed longwalls could experience low levels of vertical movement, they are not predicted to experience any significant tilts, curvatures or strains. It is unlikely that these sites would experience adverse impacts as a result of mining the proposed longwalls.

The grinding surface Sites Refs. 330, 331 and 332 were located above the longwalls in the Arrowfield and Bowfield Seams based on the *Approved Layout*. Also the grinding groove Site Ref. 377 was located at a distance of 60 metres from these longwalls. These four sites are now located outside the extents of the proposed longwalls, based on the *Modified Layout*, at distances varying between 80 metres and 160 metres from WHLW9. The potential for impacts for Sites Refs. 330, 331, 332 and 377, therefore, have decreased as a result of the proposed modification.

The grinding groove Site Ref. 329 is located at a similar distance from the proposed longwalls based on the *Approved* and *Modified Layouts*. Also the grinding groove Sites Refs. 386 and 387 are located well outside the proposed longwalls (i.e. more than 300 metres) based on both the *Approved* and *Modified Layouts*. The potential for impacts that these three sites do not change as a result of the proposed modification.

Further assessments of the potential impacts on the grinding groove and grinding surface sites are provided in the report by the specialised archaeological consultant *RPS* (2016).

6.15.6. Impact Assessments for the Scarred Trees

There are two identified scarred trees, being Site Refs. 32 (possible) and 360. Site Ref. 32 is located outside the extents of the proposed longwalls. Site Ref. 360 is located directly above the proposed WHLW11 and AFLW6, as well as above the previously extracted Homestead/Wollemi workings in the Whybrow Seam and above the chain pillar of WMLW8A and WMLW9 in the Wambo Seam.

Site Ref. 32 could experience low levels of vertical movement, but it is not predicted to experience any significant tilts, curvatures or strains. It is unlikely that this site would experience adverse impacts as a result of mining the proposed longwalls.

Site Ref. 360 is predicted to experience additional ground movements of 2,950 mm vertical subsidence, 1 mm/m tilt and 0.45 km^{-1} hogging curvature due to mining of the proposed longwalls.

It has been found, from past longwall mining experience, that the incidence of impacts on trees is extremely rare. Impacts on trees in the Hunter and Newcastle Coalfields have only been previously observed where the depths of cover were extremely shallow, in the order of 50 metres or less, or on very steeply sloping terrain, in the order of 1 in 1 or greater.

In the location of the scarred tree Site Ref. 360, the depths of cover are 125 metres to the existing workings in the Whybrow Seam, 210 metres to the existing longwalls in the Wambo Seam and 325 metres to the proposed longwalls in the Woodlands Hill Seam. The natural surface in this location is relatively flat, with the natural gradient being less than 1 in 3. It is unlikely, therefore, that the scarred tree would be adversely impacted as a result of the extraction of the proposed longwalls.

Surface cracking or ground heaving will develop as a result of the multi-seam mining, which is described in Section 4.7. The incidence of the larger surface deformations being coincident with the scarred tree at Site Ref. 360 is considered low. It is unlikely, therefore, that this scarred tree would experience adverse impacts as a result of the proposed mining.

Further assessments of the potential impacts on the scarred trees are provided in the report by the specialised archaeological consultant *RPS* (2016).

6.15.7. Impact Assessments for the Earth Mounds

There are two identified earth mounds, being Sites Refs. 334 and 335. Both these sites are located outside the extents of the proposed longwalls.

The earth mound sites could experience low levels of vertical movement, but they are not predicted to experience any significant tilts, curvatures or strains. It is unlikely that these sites would experience adverse impacts as a result of mining the proposed longwalls.

Further assessments of the potential impacts on the earth mound sites are provided in the report by the specialised archaeological consultant *RPS* (2016).

6.15.8. Impact Assessments for the Bora Ground

The Bora Ground is located more than 400 metres from the proposed longwalls based on the *Modified Layout*. At this distance, this site is not predicted to experience any measurable vertical subsidence, tilts, curvatures or strains. It is unlikely, therefore, that the Bora Ground would experience adverse impacts as a result of mining these proposed longwalls, even if the predictions were exceeded by a factor of 2 times.

6.16. Wambo Homestead Complex

6.16.1. Descriptions of the Wambo Homestead Complex

The Wambo Homestead Complex is located within the Study Area. The locations of the building structures (Refs. WH_01 to WH_09) are shown in Drawing No. MSEC799-15 and in Fig. 6.7. The State Heritage Register listing boundary, referred to as the Wambo Homestead Complex Curtilage (the Curtilage), has also been shown in the drawing and this figure.

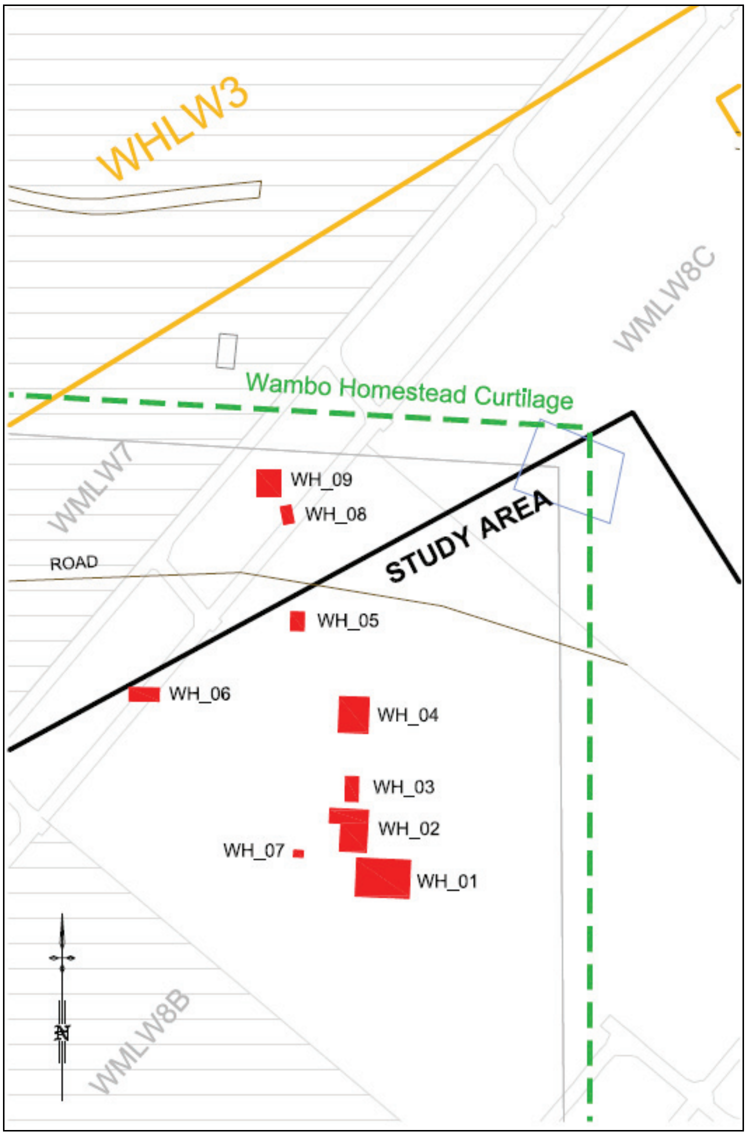


Fig. 6.7 Locations of the Building Structures on the Wambo Homestead Complex

The building structures on the homestead complex are all located outside the extents of the proposed longwalls. Structures WH_08 and WH_09 are located above a previously extracted United Collieries longwall in the Arrowfield Seam.

The proposed WHLW3 crosses the north-western corner of the Curtilage, as shown in Fig. 6.7. The proposed WHLW6, WHLW7 and AFLW2A also cross the southern part of the Curtilage. The previously extracted WMLW7 and WMLW8B in the Wambo Seam and the previously extracted Homestead/Wollemi workings in the Whybrow Seam are also partially located within the Curtilage.

The existing workings in the Whybrow Seam were grouted as part of the management strategies for WMLW7 and WMLW8. It was described in the Extraction Plan for these longwalls that:

> "*The grouting is being undertaken primarily as a mitigation measure to minimise the potential for flooding due to chimney failure and pot hole development resulting from failure of remnant pillars within the Homestead Mine workings. In addition, grouting of some of the previous Homestead Mine workings is a requirement of WCPL's approval to mine within the curtilage of the WHC* [Wambo Homestead Complex]."

The main homestead (Ref. WH_01) is located 200 metres south-east of WHLW3, at its closest point to the proposed longwalls. This structure is a single storey sandstone building with a timber framed roof. Photographs of the homestead are provided in Fig. 6.8.

Fig. 6.8 Homestead Building Structure

The other building structures include the Kitchen Wing (Ref. WH_02), Servants Wing (Ref. WH_03), Carriage House with Stables (Ref. WH_04), Slab Horse Boxes (Ref. WH_05), Stud Masters Cottage (Ref. WH06), Butchers Hut (Ref. HW_07) and Mounting Yard and Horse Boxes (Refs. WH_08 and WH_09). These buildings comprise a mixture of sandstone, brick and timber framed structures. Further details are provided in the Wambo Homestead Complex Mine Management Plan (Godden Mackay Logan, 2012) prepared for the NWUM.

6.16.2. Predictions for the Wambo Homestead Complex

A summary of the maximum predicted values of additional subsidence, tilt and curvature for the Wambo Homestead Complex building structures, due to mining the Woodlands Hill and Arrowfield Seams based on the *Modified Layout*, is provided in Table 6.14. The predictions include the multi-seam effects due to the existing workings in the overlying Whybrow and Wambo Seams.

Table 6.14 Maximum Predicted Additional Subsidence, Tilt and Curvature for the Homestead Complex Building Structures due to Mining in the Woodlands Hill and Arrowfield Seams (Modified Layout)

Location	Ref.	Maximum Predicted Additional Subsidence (mm)	Maximum Predicted Additional Tilt (mm/m)	Maximum Predicted Additional Hogging Curvature (km^{-1})	Maximum Predicted Additional Sagging Curvature (km^{-1})
Wambo Homestead Complex	WH_01	< 20	< 0.5	< 0.01	< 0.01
	WH_02	< 20	< 0.5	< 0.01	< 0.01
	WH_03	< 20	< 0.5	< 0.01	< 0.01
	WH_04	< 20	< 0.5	< 0.01	< 0.01
	WH_05	< 20	< 0.5	< 0.01	< 0.01
	WH_06	< 20	0.5	< 0.01	< 0.01
	WH_07	< 20	< 0.5	< 0.01	< 0.01
	WH_08	30	1	0.06	< 0.01
	WH_09	60	2	0.07	< 0.01

Structures Refs. WH01 to WH07 are located outside the extents of the proposed longwalls at distances between 100 metres and 200 metres. These structures are predicted to experience strains less than 0.5 mm/m tensile and compressive.

Structures Refs. WH_08 and WH_09 (Mounting Yard and Horse Boxes) are located at distances between 60 metres and 80 metres from the proposed WHLW3. These structures are also directly above a previously extracted United Collieries longwall in the Arrowfield Seam. The range of strains for these structures have been determined by analysing the measured strains at similar distances outside the previously extracted longwalls in the Wambo Seam. This should provide conservative predictions of strain due to mining in the Woodlands Hill Seam. The maximum predicted strains for WH_08 and WH_09 are 2 mm/m tensile and compressive based on the 95 % confidence level.

6.16.3. Comparisons of Predictions for the Wambo Homestead Complex

The comparisons of the maximum predicted additional conventional subsidence parameters for the Wambo Homestead Complex, based on the *Approved Layout* and the *Modified Layout*, are provided in Table 6.15. The predicted parameters are the maxima due to mining in the Arrowfield and Bowfield Seams for the *Approved Layout* and due to mining in the Woodlands Hill and Arrowfield Seams for the *Modified Layout*.

Table 6.15 Comparison of the Maximum Predicted Additional Subsidence Parameters for the Wambo Homestead Complex based on the Approved and Modified Layouts

Layout	Ref.	Maximum Predicted Additional Subsidence (mm)	Maximum Predicted Additional Tilt (mm/m)	Maximum Predicted Additional Hogging Curvature (km^{-1})	Maximum Predicted Additional Sagging Curvature (km^{-1})
Approved Layout	WH_01 to WH_09	< 20	< 0.5	< 0.01	< 0.01
Modified Layout	WH_01 to WH_07	< 20	< 0.5	< 0.01	< 0.01
	WH_08	30	1	0.06	< 0.01
	WH_09	60	2	0.07	< 0.01

The predicted additional subsidence parameters for Structures Refs. WH_01 to WH_07, based on the *Modified Layout*, are the same as the maxima predicted based on the *Approved Layout*. The predicted additional subsidence parameters for WH_08 and WH_09 increase as a result of the proposed modification. These structures are still predicted to experience only low levels of additional vertical subsidence.

The comparisons of the maximum predicted total conventional subsidence parameters for the Wambo Homestead Complex, based on the *Approved Layout* and the *Modified Layout*, are provided in Table 6.16. The predicted parameters are the maxima due to mining in the Wambo, Arrowfield and Bowfield Seams for the *Approved Layout* and due to mining in the Wambo, Woodlands Hill and Arrowfield Seams for the *Modified Layout*.

Table 6.16 Comparison of the Maximum Predicted Total Subsidence Parameters for the Wambo Homestead Complex based on the Approved and Modified Layouts

Layout	Ref.	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Approved Layout	WH_01 to WH_09	200	15	0.9	< 0.01
Modified Layout	WH_01 to WH_09	250	16	1.0	< 0.01

The maximum predicted total vertical subsidence, tilt and hogging curvature, based on the *Modified Layout*, are greater than the maxima predicted based on the *Approved Layout*. The predicted changes in tilt and curvature are 5 % to 10 % of the maxima. The predicted changes in the subsidence parameters for Structures Refs. WH_01 to WH_07 are less than 1 % of the maxima.

6.16.4. Impact Assessments for the Wambo Homestead Complex

The predicted subsidence parameters for Structures Refs. WH_01 to WH_07, based on the *Modified Layout*, are the same as those predicted based on the *Approved Layout*. The assessed impacts and the management strategies for these structures do not change as a result of the proposed modification.

The predicted additional vertical subsidence for Structures Refs. WH_08 and WH_09 are 30 mm and 60 mm, respectively. These structures are located above a United Collieries Longwall 7 in the Arrowfield Seam. It was estimated that these two building structures experienced vertical subsidence ranging between 50 and 200 mm resulting from the extraction of this longwall (DgS, 2012).

Structures Refs. WH_08 and WH_09 were also located immediately adjacent to the previously extracted WMLW7 in the Wambo Seam. The cumulative subsidence due to the previous mining in both the Wambo and Arrowfield Seams was predicted to be 300 mm to 490 mm for WH_08 and 215 mm to 519 mm for WH_09 (Table 20 from DgS, 2012).

It was assessed that Structures Refs. WH_08 and WH_09 have experienced 'Moderate' tilt impacts (i.e. greater than 7 mm/m) due the previous mining (Table 23 from DgS, 2012). It was then stated that "*the impacts to the WHC structures is not discernible between measured mine subsidence and the near-surface movements associated with clay reactivity to moisture content changes*" (DgS, 2012).

The predicted additional subsidence for Structures Refs. WH_08 and WH_09 due to the proposed mining are small when compared with the subsidence predicted to have already occurred due to the previous mining in the Wambo and Arrowfield Seams. These two structures are timber framed and are unlikely, therefore, to experience adverse impacts due to the low levels of additional subsidence of 30 mm to 60 mm.

6.16.5. Recommendations for the Wambo Homestead Complex

Monitoring and management strategies have been previously developed for the Wambo Homestead Complex for the previously extracted WMLW7 and WMLW8. It is recommended that these strategies are reviewed based on the predicted additional subsidence at WH_08 and WH_09.

It is recommended that a structural engineer inspect Structure Refs. WH_08 and WH_09 and, if required, preventive measured developed to minimise the potential for any adverse impacts. These measured would need to be developed in consultation with the Heritage consultant. The management strategies would be developed as part of the Extraction Plan for the proposed longwalls.

In accordance with Condition 57, Schedule 4 of the Development Consent (DA 305-7-2003), WCPL would submit an application under Section 60 of the *Heritage Act 1977* to the Heritage Council prior to the commencement of any development on land within the State Heritage Register listing boundary for the Wambo Homestead Complex.

6.17. State Survey Control Marks

The locations and details of the state survey control marks were obtained from the *Land and Property Management Authority* using the *Six Viewer* (2015). There were no state survey control marks identified within or in the immediate vicinity of the Study Area. There were state survey control marks identified further afield, outside the extents of Drawing No. MSEC799-15, which are located at distances greater than 1 kilometre from the proposed longwalls.

The survey control marks located in the area 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 4.5 and in Section B.4 in Appendix B.

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

6.18. Houses and Associated Structures

There is one house and associated rural building structures located within the Study Area. This property is owned by WCPL and has been tenanted. The locations of these structures are shown in Drawing No. MSEC799-15 and in Fig. 6.9.

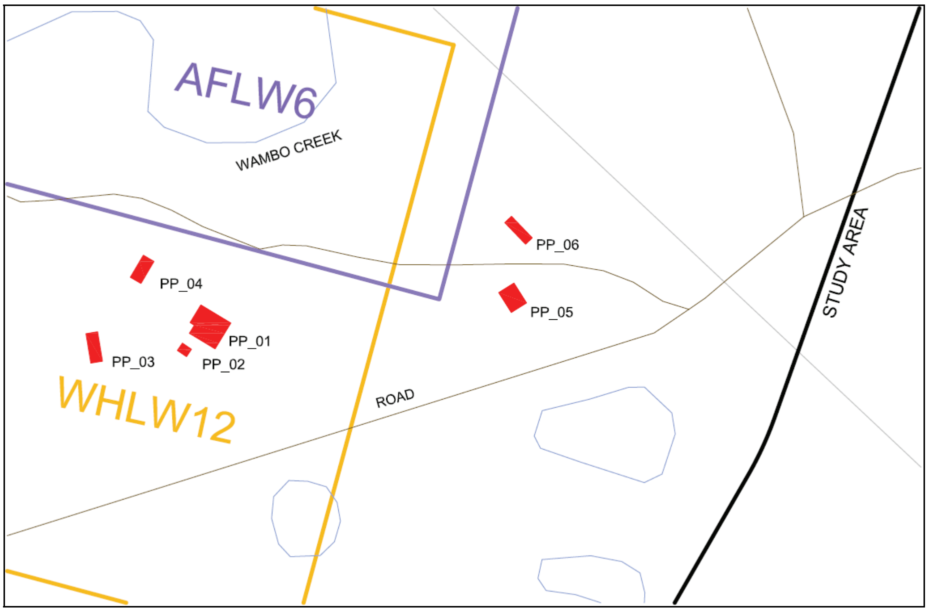


Fig. 6.9 Locations of the Building Structures on the WCPL Property

The house Ref. PP_01 is a single storey timber framed structure on piers with a metal roof. The rural building structures Refs. PP_02 to PP_06 are metal clad storage sheds.

The buildings structures are predicted to experience ground movements due to the proposed longwalls up to: 2,500 mm vertical subsidence; 25 mm/m tilt (i.e. 2.5 %, or 1 in 40); and 0.5 km^{-1} hogging and sagging curvature (i.e. 2 kilometres minimum radius of curvature).

The house and rural structures located above the proposed longwall could experience adverse impacts. It will be necessary to remediate these impacts prior to re-tenanting the property.

APPENDIX A. REFERENCES

References

DgS (2012). *Subsidence Data Review and Impact Assessment for Longwalls 7 and 8 at North Wambo Underground Mine, Warkworth*. DGS Report No. NWU-001/4, May 2012.

Ditton (2005). *Surface and Sub-Surface Investigation and Monitoring Plan for LWs 1 to 6 at the Proposed North Wambo Mine*. Wambo Coal Pty Ltd.

Ditton, Frith and Hill (2003). *Review of industry subsidence data in relation to the influence of overburden lithology on subsidence and an initial assessment of a sub-surface fracturing model for groundwater analysis*. ACARP Project C10023. Australian Coal Industry's Research Program.

DoP (2008). *Impacts of Potential Underground Coal Mining in the Wyong Local Government Area – Strategic Review*. The NSW Department of Planning, July 2008.

DMR (1998). *Geological Series Sheet 9032-I-N (Edition 1)*. Department of Mineral Resources, 1988.

DMR (1993). *Hunter Coalfield Regional Geology 1:100 000 Geology Map, 2nd Edition*. Geological Survey of New South Wales, Sydney. Department of Mineral Resources, 1993.

Eco Logical Australia (2016). *Wambo Coal Mine – South Wambo Underground Mine Modification Fauna Assessment*. Prepared for Wambo Coal Pty Limited.

FloraSearch (2016). *South Wambo Underground Mine Modification – Flora Assessment*. Prepared for Wambo Coal Pty Limited.

Forster and Enever (1992). *Study of the Hydrogeological Response of Overburden Strata to Underground Mining Central Coast - New South Wales*. NSW Office of Energy.

Gale (2008). *Aquifer Inflow Prediction above Longwall Panels*. Winton, G. SCT Operations. ACARP Research Project No. C13013, September 2008.

Godden Mackay Logan (2012). *Mine Management Plan – Underground Mining in the Vicinity of Wambo Homestead Complex.* Prepared for Wambo Coal Pty Limited.

Groundwater Imaging (2012). *A Transient Electromagnetic Investigation of the Extent of the Wollombi Brook Alluvium at the Wambo Coal Mine Site.* Groundwater Imaging Pty Ltd, July 2012.

Guo et al (2007). *Hydrogeological Response to Longwall Mining*. Guo, H., Adhikary, D.P., Gaveva, D. CSIRO Exploration and Mining. ACARP Research Project No. C14033, October 2007.

Holt (2003). *Wambo Development Project Subsidence Assessment*. G. E. Holt and Associates Pty Ltd. Document No. SUBREP-06, April 2003.

Holt (2005). *Review of Subsidence Assessment for Re-Orientation of Wambo Seam Longwall Panels for the Wambo Development Project*. G. E. Holt and Associates Pty Ltd. 18th January 2005.

HydroSimulations (2016). *South Wambo Underground Mine Modification Groundwater Assessment*. Prepared for Wambo Coal Pty Limited.

Kratzsch, H., (1983). *Mining Subsidence Engineering*, Published by Springer - Verlag Berlin Heidelberg New York.

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

McNally, et al (1996). *Geological Factors influencing Longwall-Induced Subsidence*. McNally, G.H., Willey, P.L. and Creech, M. Symposium on Geology in Longwall mining, 12-13 November 1996, Eds G.H. McNally and C.R. Ward, pp 257-267.

NRAtlas, (2015). *Natural Resource Atlas* website, viewed on the 22nd December 2015. The Department of Natural Resources. http://nratlas.nsw.gov.au/

Peng and Chiang (1984). *Longwall Mining*. Wiley, Peng S.S. & Chiang H.S. New York, pg 708.

RPS (2016). *South Wambo Underground Mine Modification Cultural Heritage Impact Assessment.* Prepared for Wambo Coal Pty Limited.

SEE (2005). *Wambo Development Project - Wambo Seam Underground Mine Modification – Statement of Environmental Effects*. Resource Strategies Pty Ltd. Project No. WAM-04-08. Document No. SEE-01-I. January 2005.

Singh and Kendorski (1981). *Strata Disturbance Prediction for Mining Beneath Surface Water and Waste Impoundments*. Singh, M., M., Kendorski, F., S. Proceedings of the 1st Annual Conference on Ground Control in Mining, Morgantown WV, July 1981.

Six Viewer (2015). Spatial Information Exchange, accessed on the 22nd December 2016. Land and Property Information. https://www.six.nsw.gov.au/wps/portal/

Waddington and Kay (2002). *Management Information Handbook on the Undermining of Cliffs, Gorges and River Systems*. ACARP Research Projects Nos. C8005 and C9067, September 2002.

Whittaker and Reddish (1989). *Subsidence – Occurrence, Prediction and Control.* Whittaker, B.N. and Reddish, D.J. Elsevier.

APPENDIX B. OVERVIEW OF LONGWALL MINING, DEVELOPMENT OF SUBSIDENCE AND MINE SUBSIDENCE PARAMETERS

APPENDIX B OVERVIEW OF LONGWALL MINING, DEVELOPMENT OF SUBSIDENCE AND MINE SUBSIDENCE PARAMETERS

B.1. Introduction

This appendix provides a brief overview of longwall mining, the development of mine subsidence and the parameters which are typically used to quantify mine subsidence movements. Further details are provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

B.2. Overview of Longwall Mining

WCPL has approval to extract longwalls in the Whybrow, Wambo, Arrowfield and Bowfield Seams at the Wambo Coal Mine. WCPL now proposes to extract a modified layout of longwalls in the Arrowfield and Woodlands Hill Seams, which is the subject of this modification application, and is referred to as South Wambo Underground Mine. A generic cross section through the immediate roof strata and along the length of a typical longwall, at the coal face, is shown in Fig. B. 1.

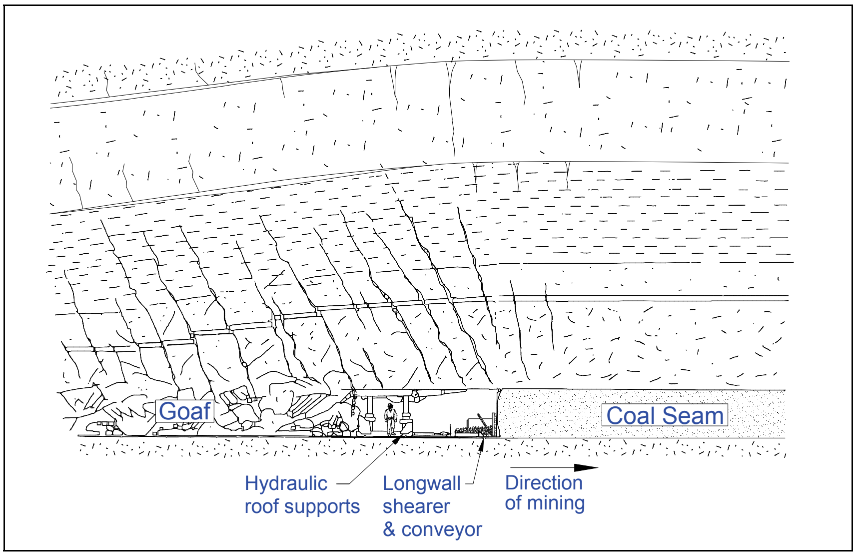


Fig. B. 1 Cross-section along the Length of a Typical Longwall at the Coal Face

The coal is removed by a shearer, which cuts the coal from the coal face on each pass as it traverses the width of the longwall. The roof at the coal face is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata, and provide a secure working space at the coal face. The coal is then transported by a face conveyor belt which is located behind and beneath the shearer. As the coal is removed from each section of the coal face, the hydraulic supports are stepped forward, and the coal face progresses (retreats) along the length of the longwall.

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

At the surface, the ground subsides vertically as well as moves horizontally towards the centre of the mined goaf area. The maximum subsidence at the surface varies, depending on a number of factors including longwall geometry, depth of cover, extracted seam thickness, overburden geology and previous workings. The maximum achievable subsidence in the Hunter Coalfield, for a critical width of extraction and single-seam mining conditions, is generally 60 % to 65 % of the extracted seam thickness.

The previously extracted longwalls in Wambo Seam are located beneath the existing Homestead/Wollemi workings in the overlying Whybrow Seam. The proposed longwalls in the Arrowfield and Woodlands Hill Seams are located beneath the workings in the Whybrow and Wambo Seams. The maximum achievable subsidence for multi-seam conditions is greater than that for single-seam conditions, as a result of the re-activation of the overlying goaf and pillars. Further discussions on multi-seam subsidence are provided in Section 3.3.2 of this report.

B.3. Overview of Conventional Subsidence Parameters

The normal ground movements resulting from the extraction of 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 distances between two points increase and **Compressive Strains** occur when the distances between two points decrease. 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 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), and vice versa.

The **additional** subsidence, tilts, curvatures and strains are those which result from the extraction of the proposed longwalls in each of the Arrowfield and Woodlands Hills Seams, including the affects due to the re-activation of the existing workings in the overlying Whybrow and Wambo Seams. The **total** subsidence, tilts, curvatures and strains are the accumulated parameters after the completion of the longwalls in either the Arrowfield, or Woodlands Hill Seams, including the affects due to the re-activation of the existing overlying workings. The **travelling** tilts, curvatures and strains are the transient movements as the longwall extraction face mines directly beneath a given point.

B.4. Far-field Movements

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

Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain. These movements generally do not result in impacts on natural or built features, 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 and strain

B.5. Overview of Non-Conventional Subsidence Movements

Conventional subsidence profiles are typically smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata spanning the extracted void and the compression of the pillars and the strata above the pillars. 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. Irregular subsidence movements are generally associated with:-

- shallow depths of cover;
- sudden or abrupt changes in geological conditions;
- steep topography; and
- valley related mechanisms.

Non-conventional movements due to abovementioned conditions are discussed in the following sections.

B.5.1 Non-Conventional Subsidence Movements due to Shallow Depth of Cover

Irregular ground movements are commonly observed in shallow mining situations, where the collapsed zone, which develops above the extracted longwalls, extends near to the surface. This type of irregularity is generally only seen where panel widths are supercritical and where the depths of cover are less than 100 metres, which occurs in some areas above the proposed longwalls in the Woodlands Hill Seam within the Wambo Open Cut Pit. These irregular movements appear as localised bumps and steps in the observed subsidence profiles, which are accompanied by elevated tilts, curvatures and ground strains.

The levels of irregular subsidence movement at varying depths of cover can be seen in the observed subsidence profiles over the previously extracted Whybrow Seam longwalls at South Bulga Colliery, which are shown in Fig. B. 2.

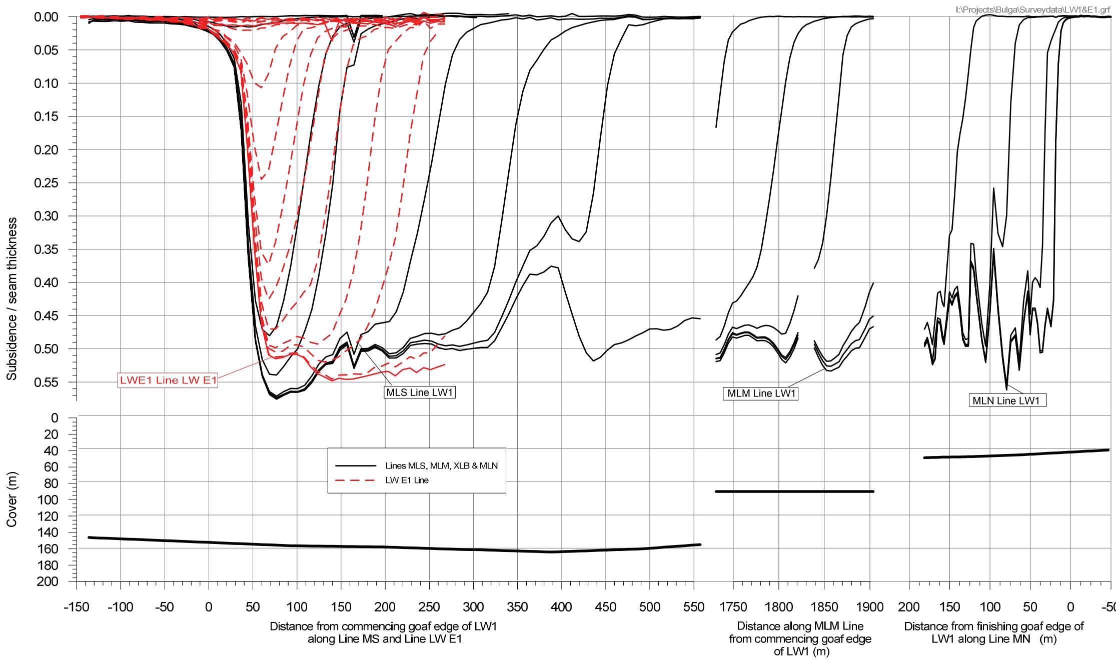


Fig. B. 2 Observed Subsidence Profiles at South Bulga Colliery

The observed subsidence profiles along the MLS and LWE1 monitoring lines above the southern ends of Whybrow Seam Longwalls 1 and E1, respectively, having average depths of cover of 160 metres, are shown in the left of this figure. The observed subsidence profile along the MLM monitoring line above the northern end of Longwall 1, having an average depth of cover of 90 metres, is shown near the middle of the figure. The observed subsidence profile along the MLN monitoring line above the northern end of Longwall 1, having an average depth of cover of 45 metres, is shown in the right of this figure.

The observed subsidence profiles are relatively smooth (i.e. normal or conventional) along the MLS and LWE1 monitoring lines, where the depths of cover are much greater than 100 metres. The observed subsidence profile is still relatively smooth along the MLM monitoring line, where the depth of cover is just less than 100 metres. The observed subsidence profile along the MLN line is very irregular (i.e. irregular or non-conventional), where the depth of cover is less than 50 metres.

B.5.2 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 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 and built features, which are provided in Chapters 5 and 6, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

B.5.3 Non-conventional Subsidence Movements due to Steep Topography

Non-conventional movements can also result the increased horizontal movements in the downslope direction 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 downslope movements include the development of tension cracks at the tops and sides of the steep slopes and compression ridges at the bottoms of the steep slopes.

Further discussions on the potential for downslope movements for the steep slopes within the Study Area are provided in Section 5.8.

B.5.4 Valley Related Movements

The watercourses within the Study Area may be subjected to valley related movements, which are commonly observed along stream alignments in the Southern Coalfield, but less commonly observed in the Hunter and Newcastle Coalfields. The reason why valley related movements are less commonly observed in the Northern Coalfields 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. B. 3. The potential for these natural movements are influenced by the geomorphology of the valley.

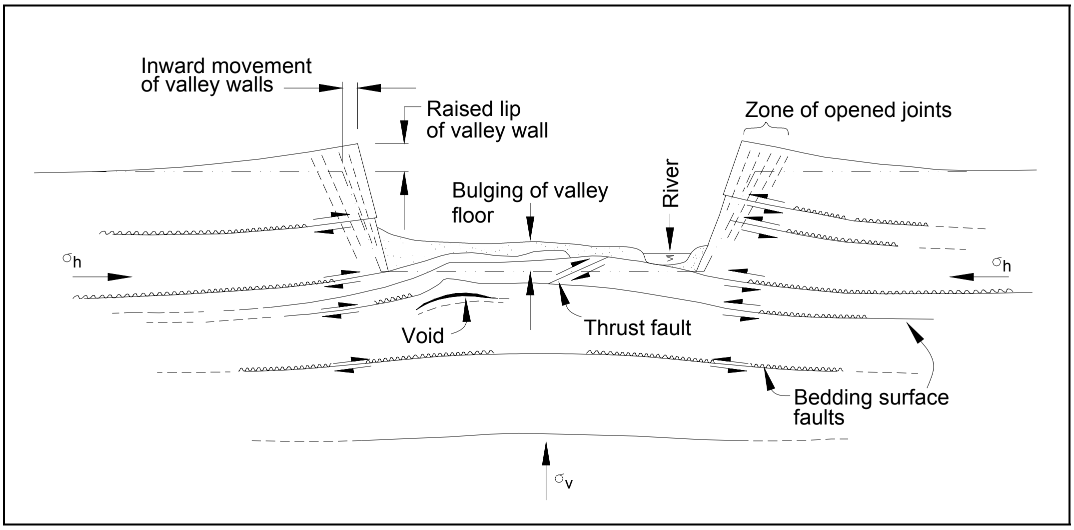


Fig. B. 3 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

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

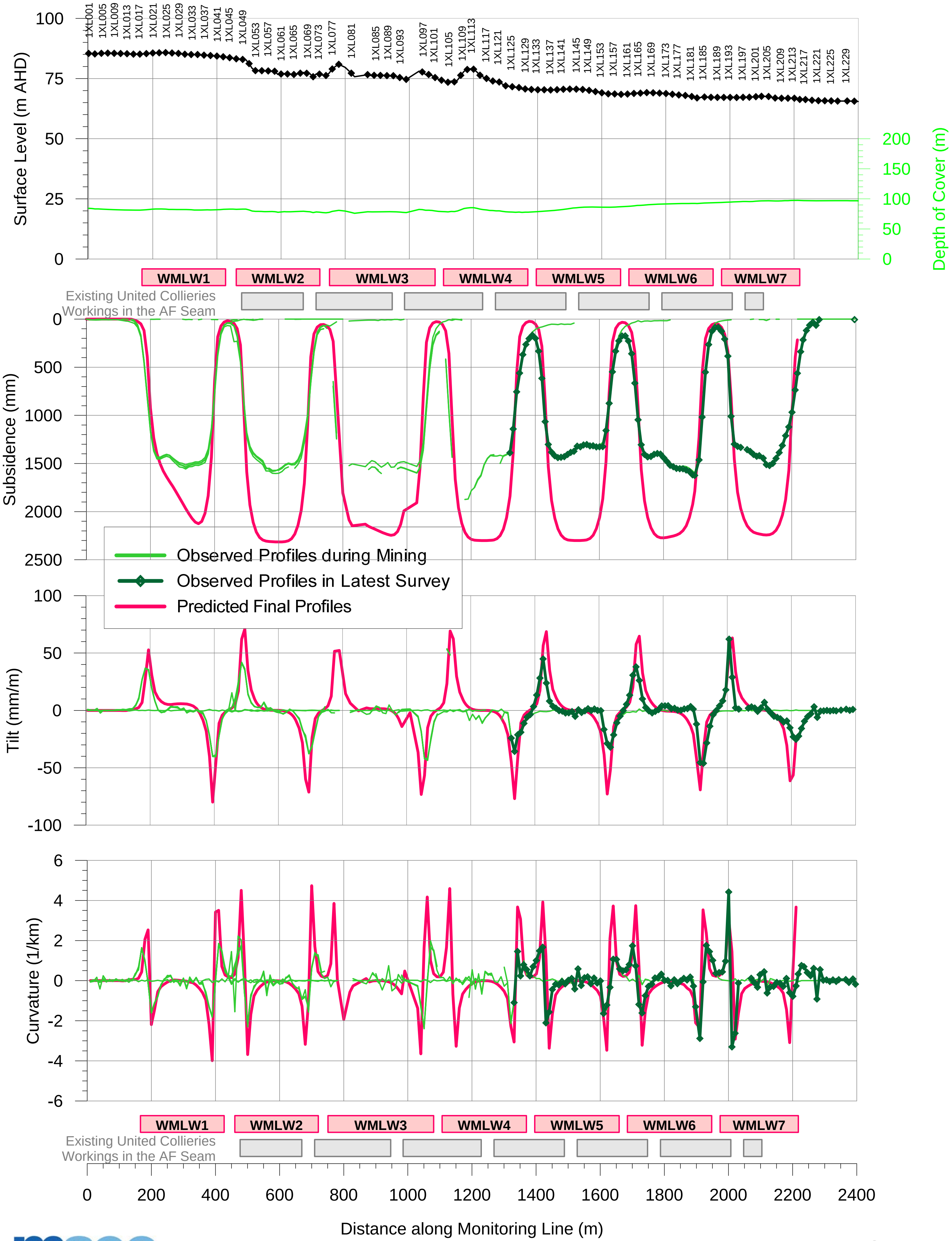
- **Upsidence** is the reduced subsidence, or the relative uplift within a valley which results from the dilation or buckling of near surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.
- **Closure** is the reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides.
- **Compressive Strains** occur within the bases of valleys as a result of valley closure and upsidence movements. **Tensile Strains** also occur in the sides and near the tops of the valleys as a result of valley closure movements. The magnitudes of these strains, which are typically expressed in the units of *millimetres per metre (mm/m)*, are calculated as the changes in horizontal distance over a standard bay length, divided by the original bay length.

The predicted valley related movements resulting from the extraction of the proposed longwalls were made using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002). Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

APPENDIX C. COMPARISONS BETWEEN OBSERVED AND PREDICTED PROFILES OF SUBSIDENCE, TILT AND CURVATURE

I:\Projects\Wambo\MSEC799 - South Wambo Underground\Subsdata\Calibration\Fig. C.01 - XL1-Line.grf.....15-Mar-16

Profiles of Observed and Back-Predicted Total Subsidence, Tilt and Curvature along the XL1-Line at the North Wambo Underground Mine

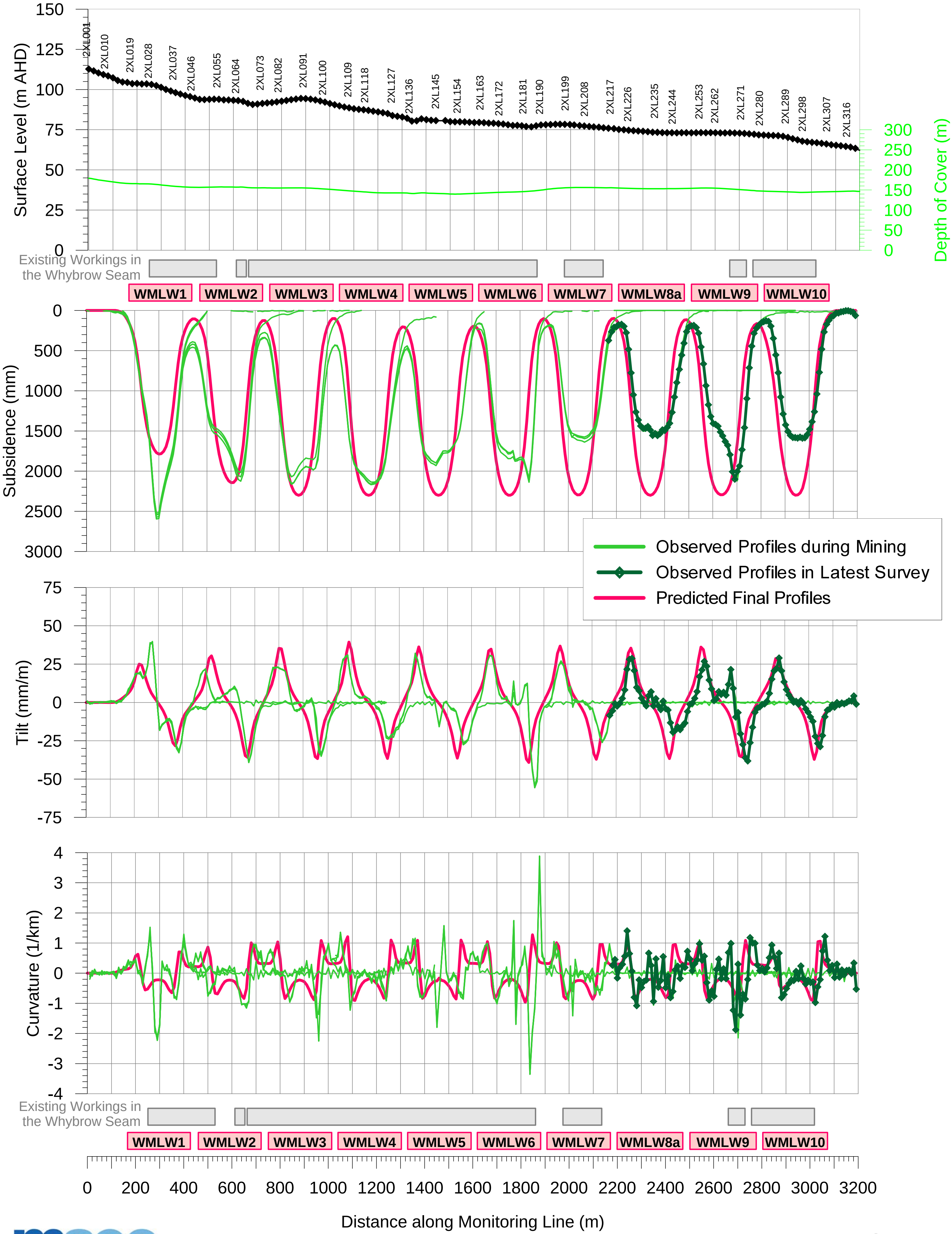


msec

Fig. C.01

I:\Projects\Wambo\MSEC799 - South Wambo Underground\Subsdata\Calibration\Fig. C.02 - XL2-Line.grf.....15-Mar-16

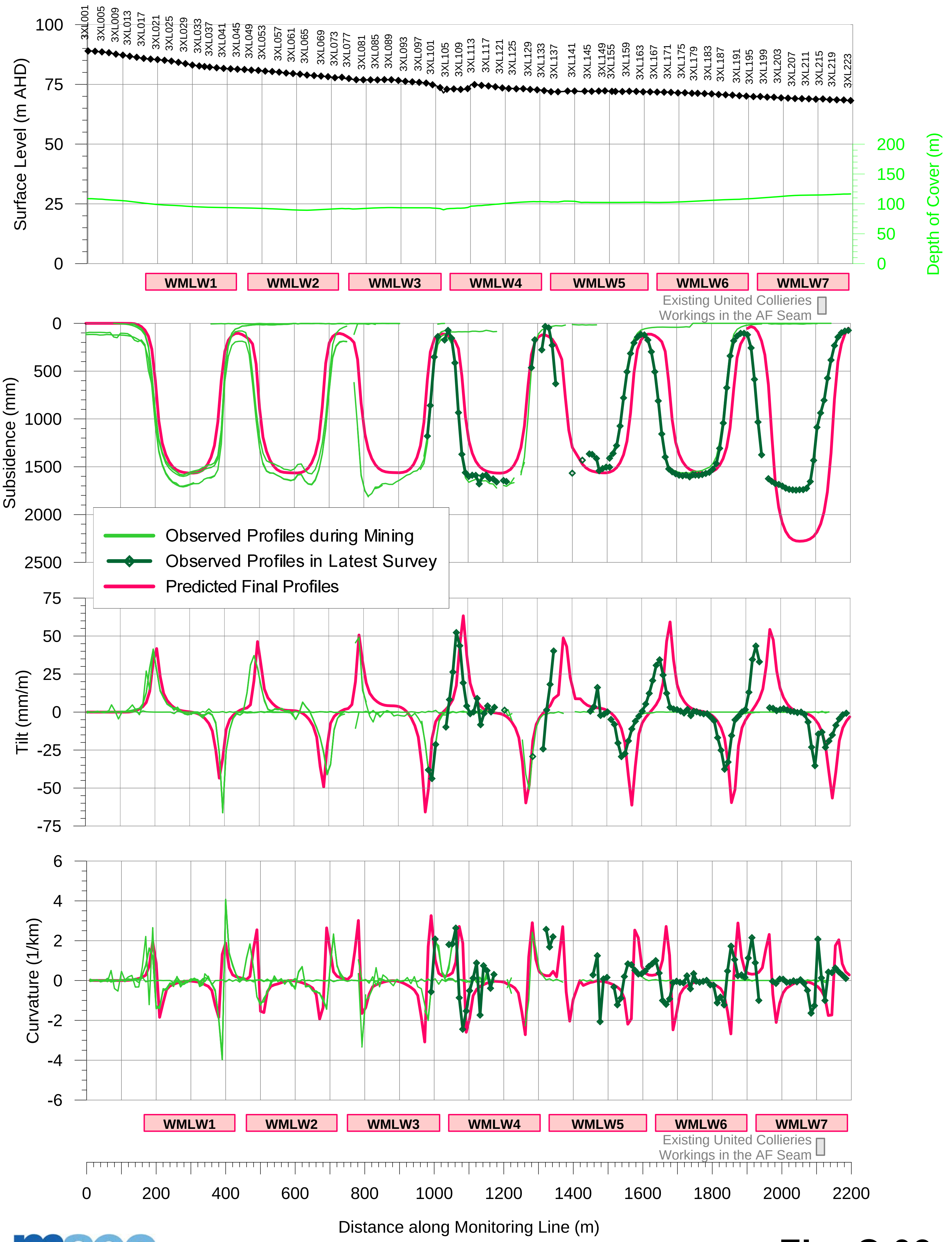
Profiles of Observed and Back-Predicted Total Subsidence, Tilt and Curvature along the XL2-Line at the North Wambo Underground Mine



msec

Fig. C.02

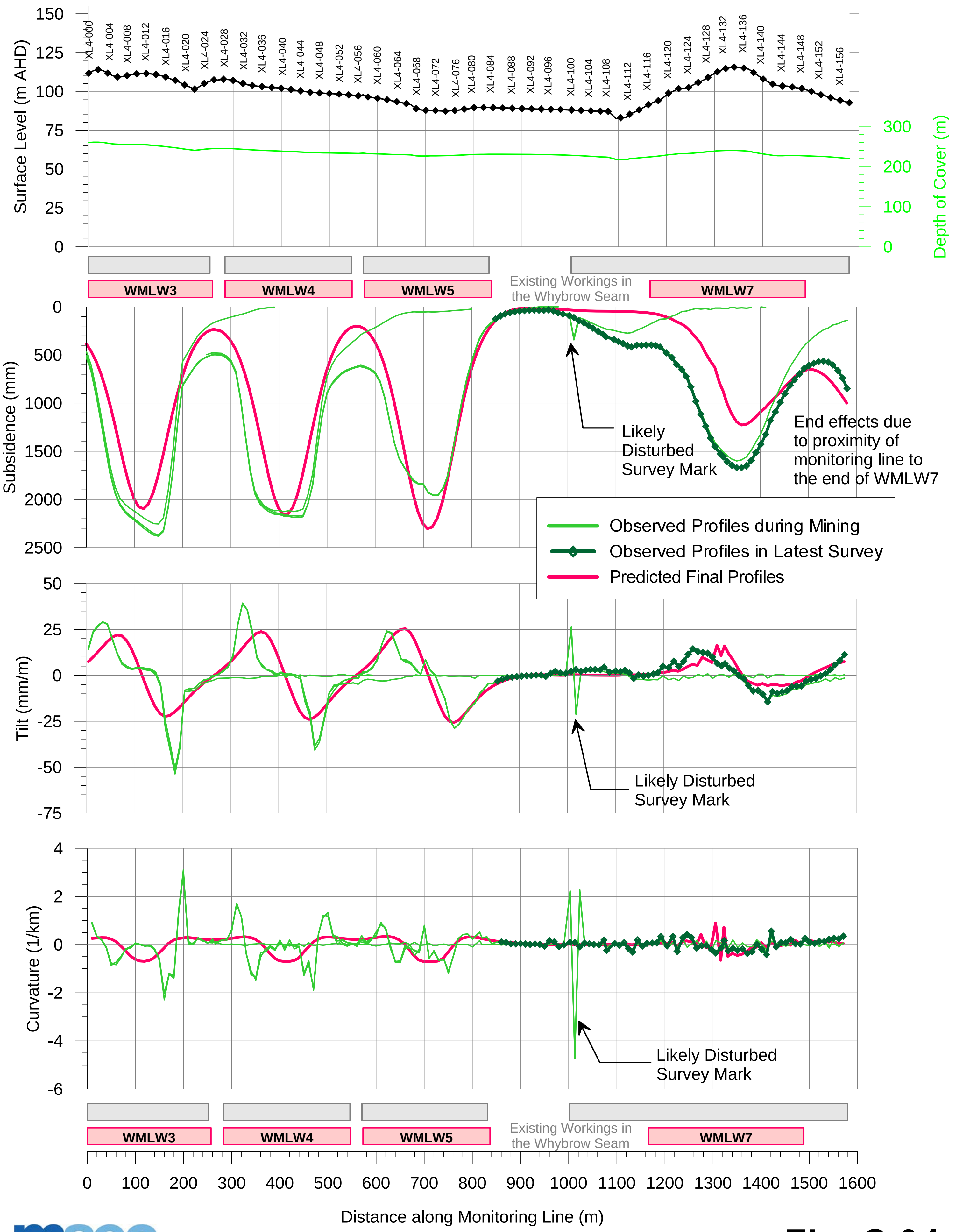
Profiles of Observed and Back-Predicted Total Subsidence, Tilt and Curvature along the XL3-Line at the North Wambo Underground Mine



msec

Fig. C.03

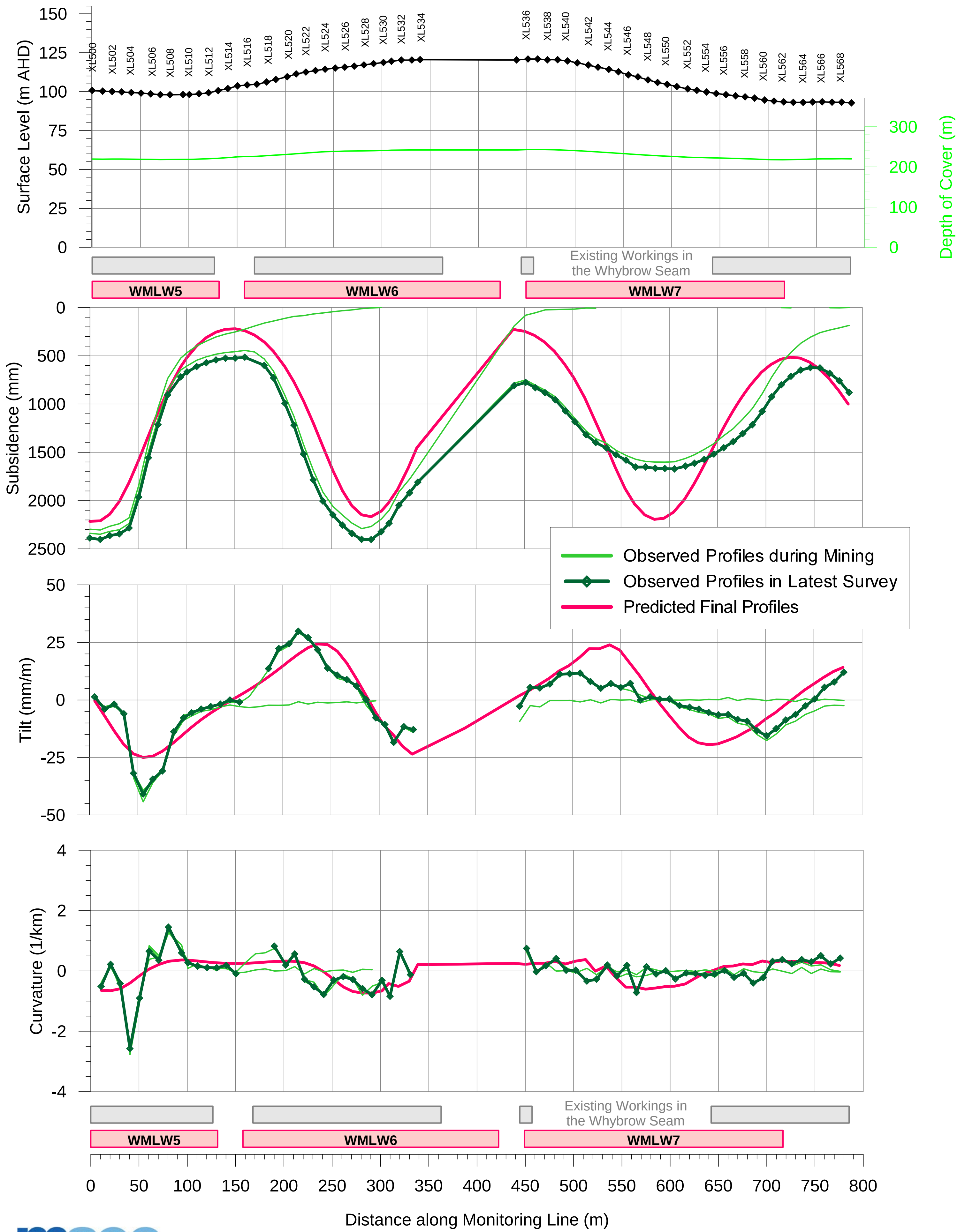
Profiles of Observed and Back-Predicted Total Subsidence, Tilt and Curvature along the XL4-Line at the North Wambo Underground Mine



msec

Fig. C.04

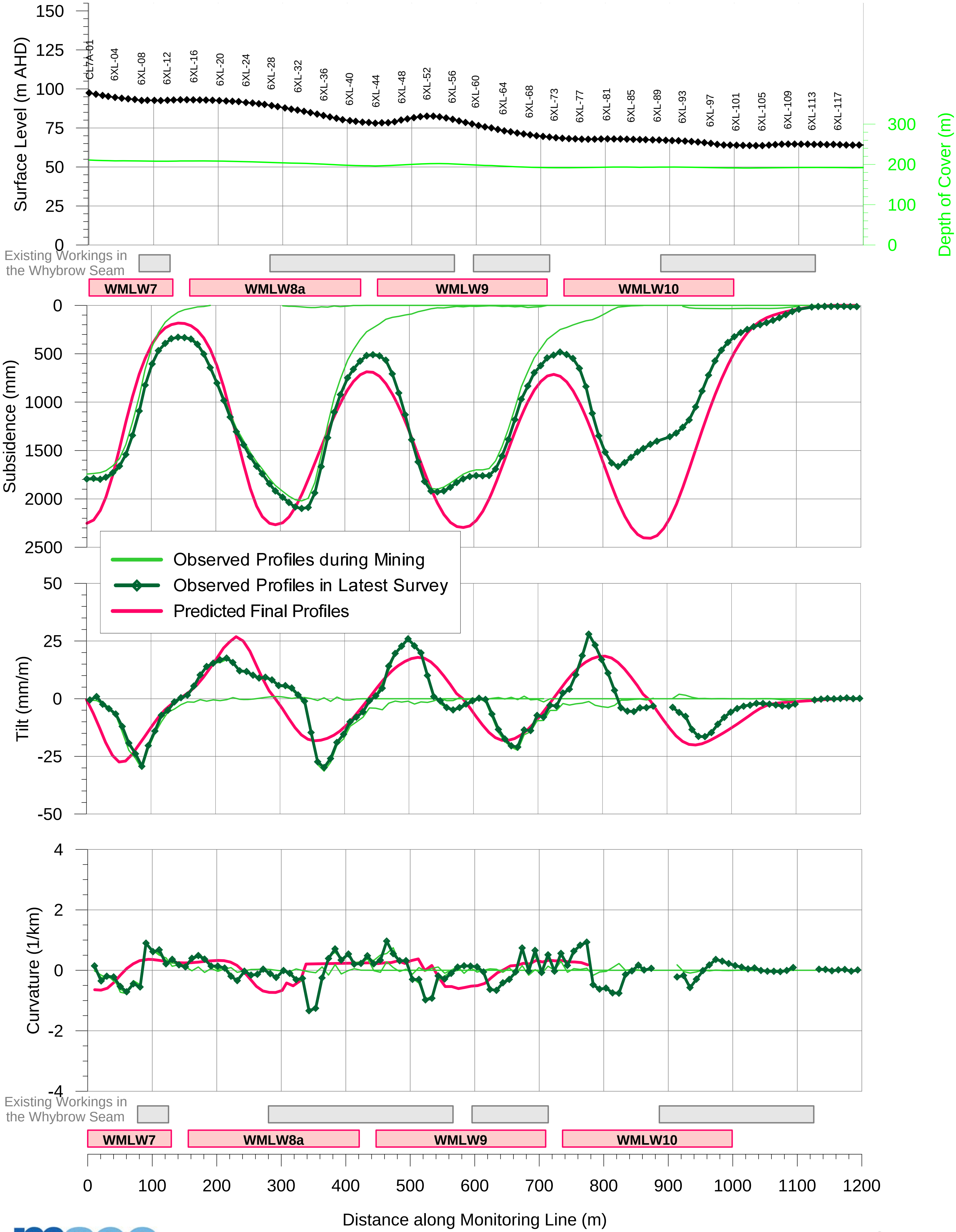
Profiles of Observed and Back-Predicted Total Subsidence, Tilt and Curvature along the XL5-Line at the North Wambo Underground Mine



msec

Fig. C.05

Profiles of Observed and Back-Predicted Total Subsidence, Tilt and Curvature along the XL6-Line at the North Wambo Underground Mine



msec

Fig. C.06

I:\Projects\Wambo\MSEC799 - South Wambo Underground\Subsdata\Calibration\Fig. C.07 - SC1-Line.grf.....15-Mar-16

Profiles of Observed and Back-Predicted Total Subsidence, Tilt and Curvature along the SC1-Line at the North Wambo Underground Mine

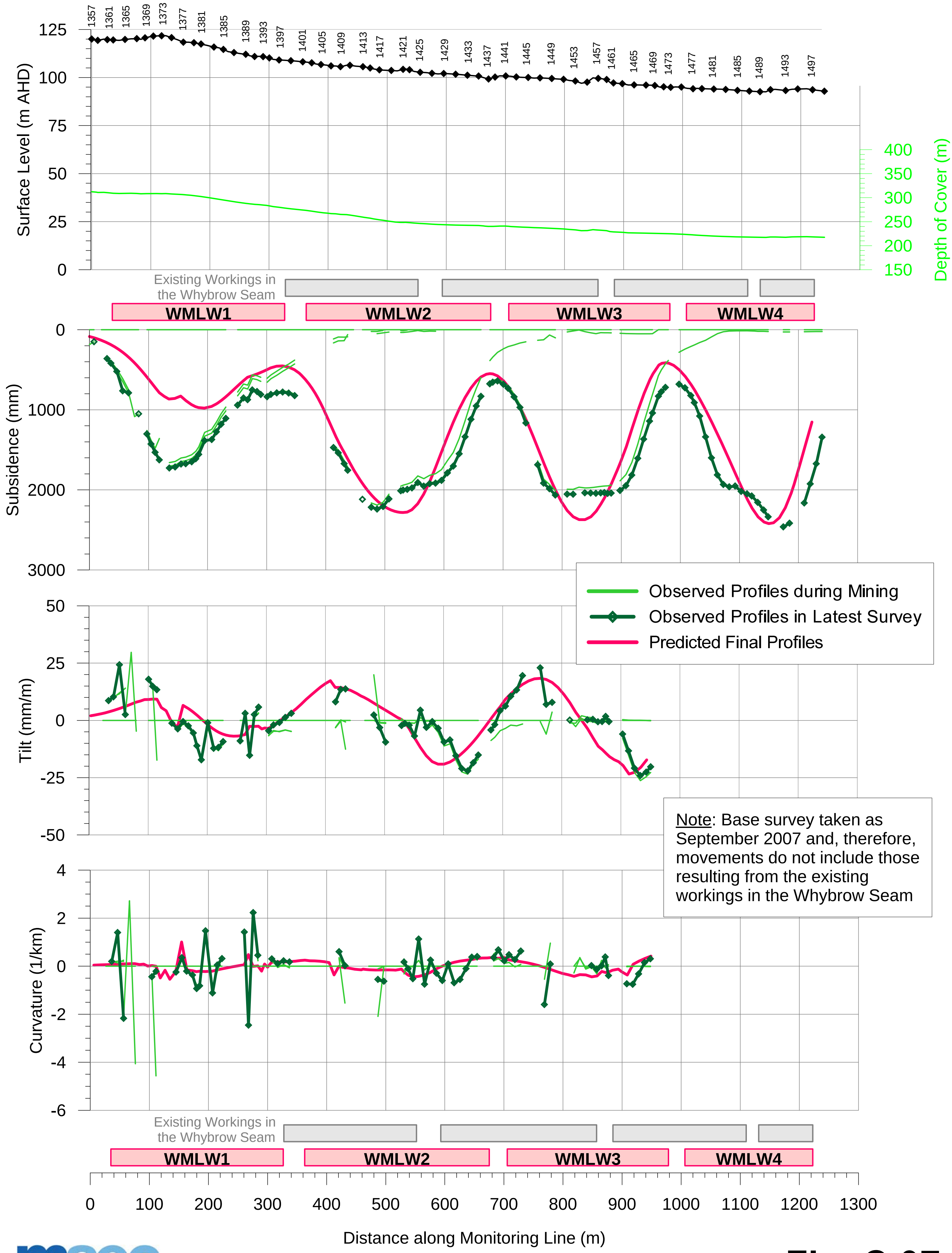
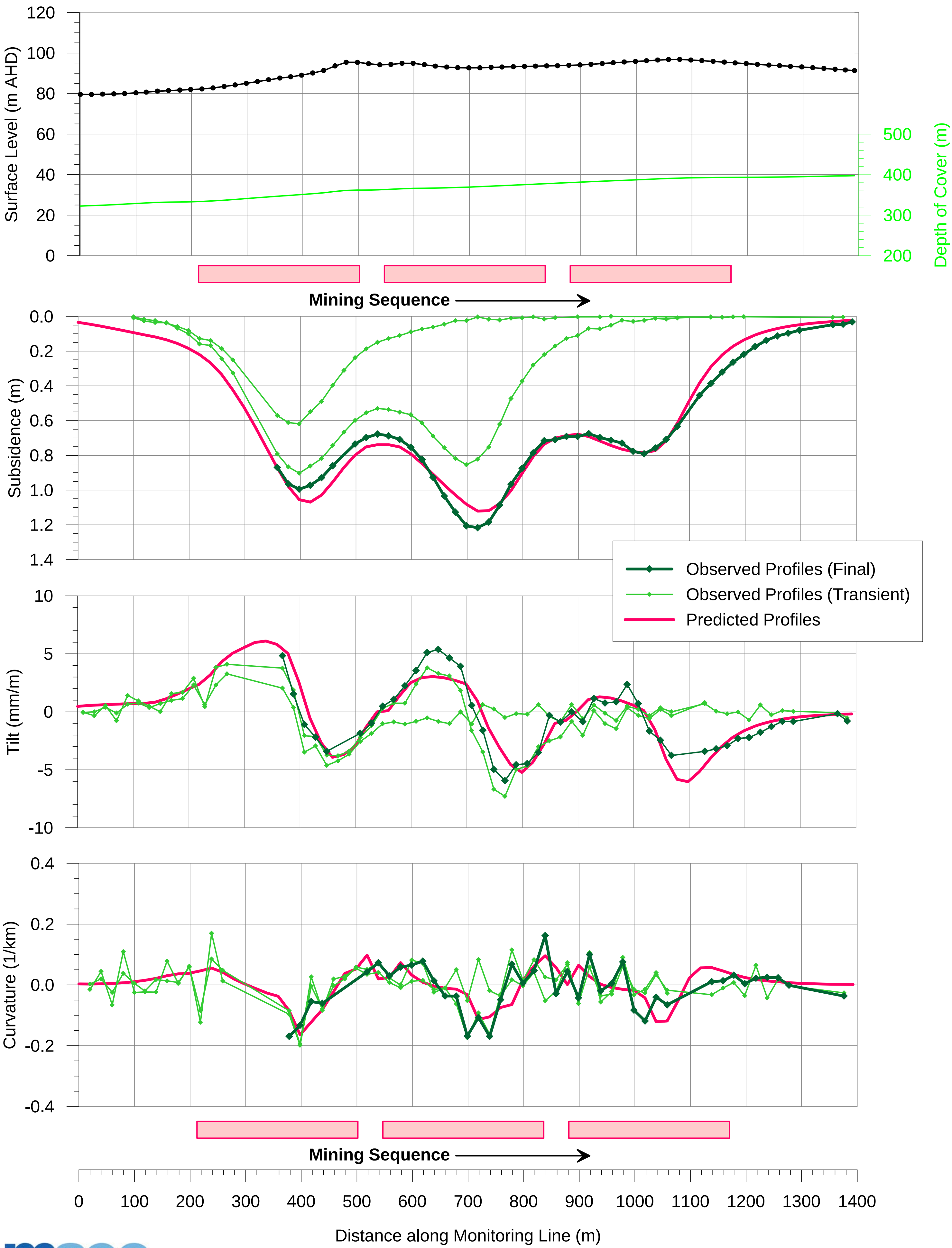


Fig. C.07

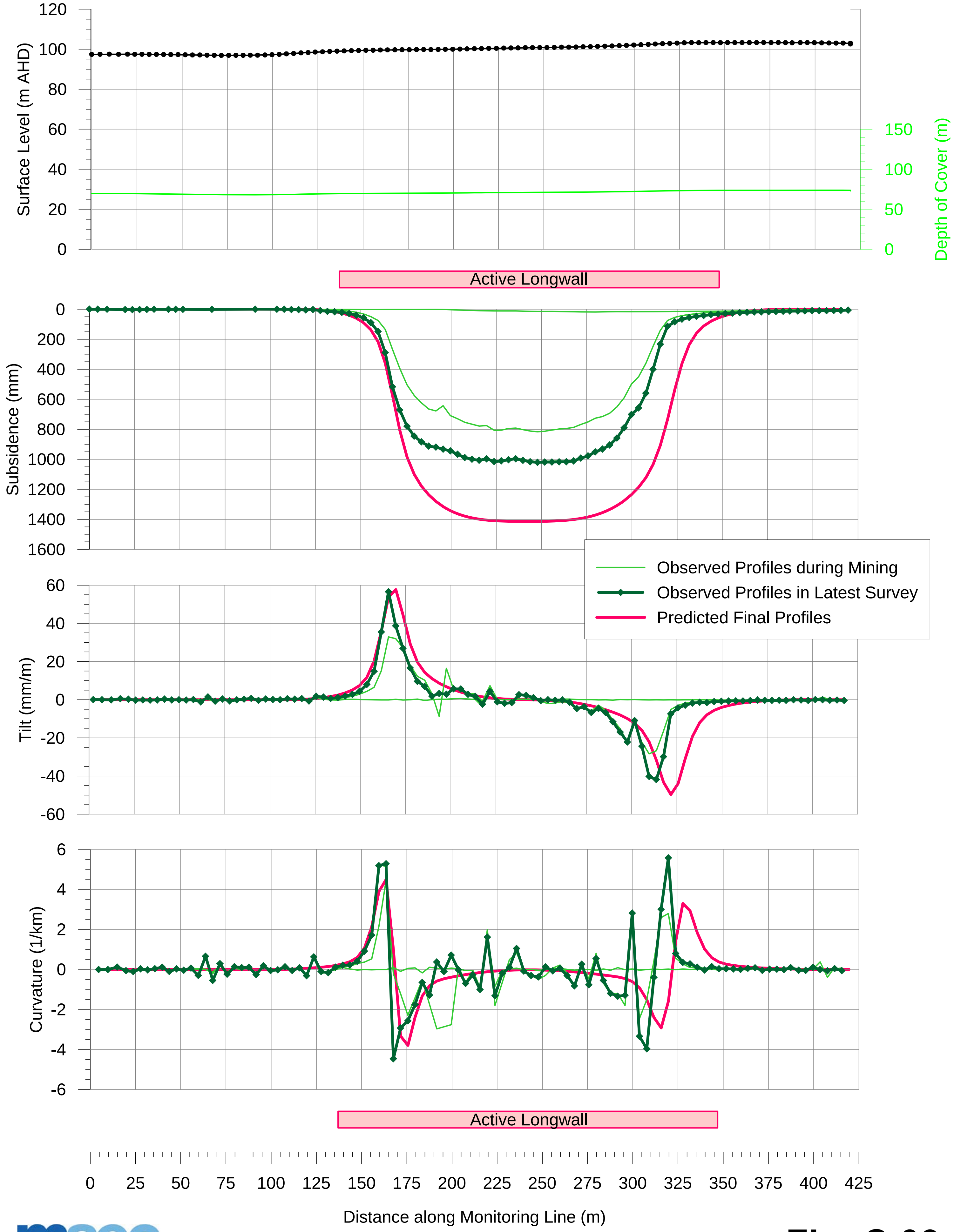
Profiles of Observed and Back Predicted Total Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with a W/H Ratio of 0.7



msec

Fig. C.08

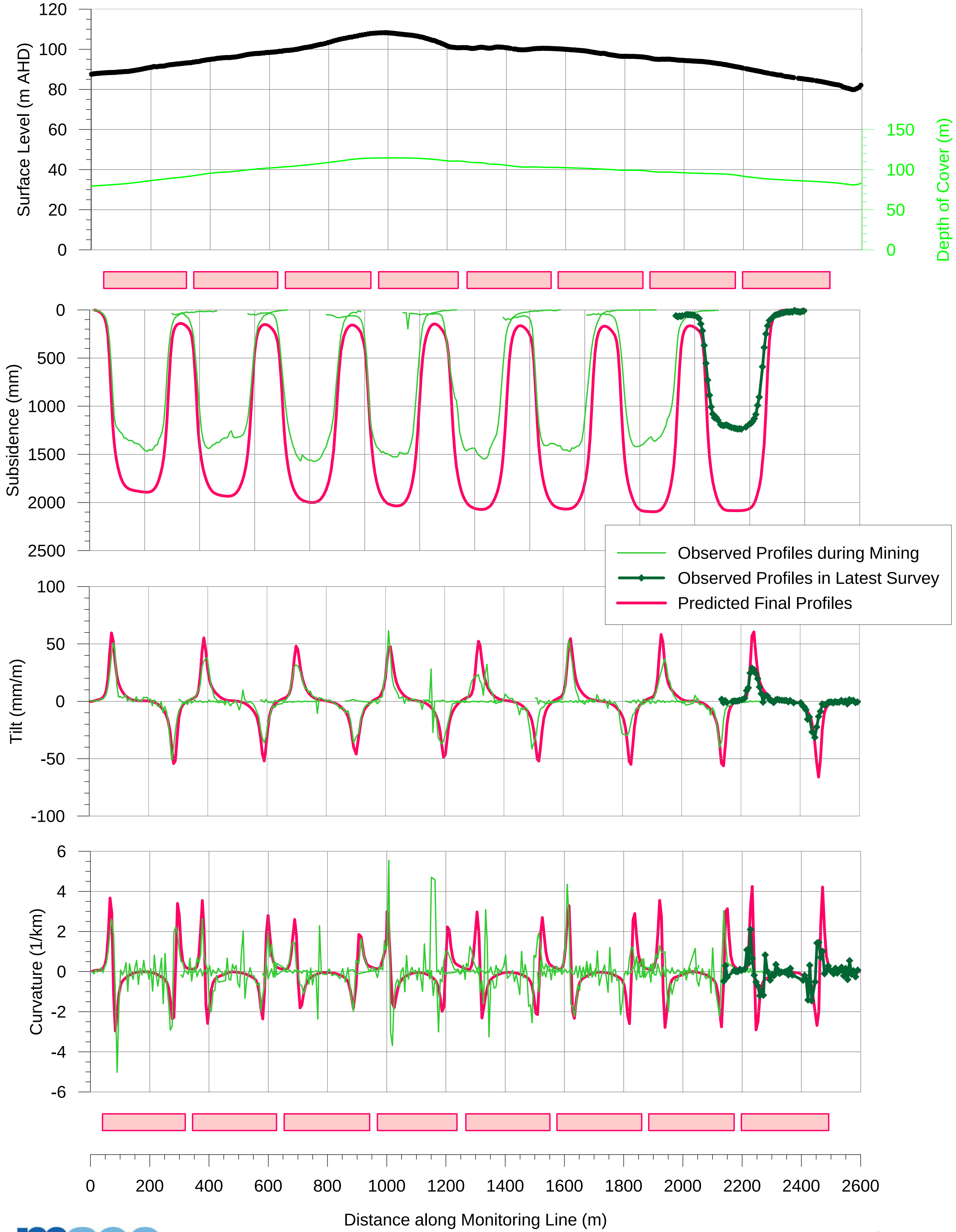
Profiles of Observed and Back Predicted Total Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with a W/H Ratio of 2.0



msec

Fig. C.09

Profiles of Observed and Back Predicted Total Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with a W/H Ratio of 3.0



msec

Fig. C.10

APPENDIX D. TABLES

Table D.01 - Maximum Predicted Subsidence Parameters for the Archaeological Sites

Site Name	Type	Predicted Additional Subsidence due to AF and BF Seams Based on the Approved Layout (mm)	Predicted Additional Subsidence due to WH and AF Seams Based on the Modified Layout (mm)	Predicted Total Subsidence due to the WM, AF and BF Seams Based on the Approved Layout (mm)	Predicted Total Subsidence due to the WM, WH and AF Seams Based on the Modified Layout (mm)	Incremental Change in Subsidence due to the Proposed Modification (mm)
32	Scarred Tree	275	< 20	275	< 20	-275
117	Grinding Grooves and Artefact Scatter	70	1,900	2,050	3,900	1,850
329	Grinding Groove Site	< 20	< 20	< 20	< 20	< 20
330	Grinding Surfaces	375	< 20	375	< 20	-375
331	Grinding Surfaces	400	< 20	400	< 20	-400
332	Grinding Surfaces	1,650	30	1,650	30	-1,620
334	Earth Mound with Artefacts	675	< 20	675	< 20	-675
335	Earth Mound with Artefacts	525	< 20	525	< 20	-525
360	Scarred Tree	3,000	2,950	3,300	3,250	-50
377	Grinding Groove Site	275	< 20	275	< 20	-275
386	Grinding Groove Site	< 20	< 20	< 20	< 20	< 20
387	Grinding Groove Site	< 20	< 20	< 20	< 20	< 20
	Maximum	**3,000**	**2,950**	**3,300**	**3,900**	**1,850**

Table D.01 - Maximum Predicted Subsidence Parameters for the Archaeological Sites

Site Name	Type	Predicted Additional Tilt due to AF and BF Seams Based on the Approved Layout (mm/m)	Predicted Additional Tilt due to WH and AF Seams Based on the Modified Layout (mm/m)	Predicted Total Tilt due to the WM, AF and BF Seams Based on the Approved Layout (mm/m)	Predicted Total Tilt due to the WM, WH and AF Seams Based on the Modified Layout (mm/m)	Incremental Change in Tilt due to the Proposed Modification (mm/m)
32	Scarred Tree	9	< 0.5	9	< 0.5	-9
117	Grinding Grooves and Artefact Scatter	< 0.5	< 0.5	30	30	< 0.5
329	Grinding Groove Site	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
330	Grinding Surfaces	7.5	< 0.5	7.5	< 0.5	-8
331	Grinding Surfaces	8.5	< 0.5	8.5	< 0.5	-9
332	Grinding Surfaces	35	1	35	1	-34
334	Earth Mound with Artefacts	16	< 0.5	16	< 0.5	-16
335	Earth Mound with Artefacts	14	< 0.5	14	< 0.5	-14
360	Scarred Tree	18	1	25	6.5	-19
377	Grinding Groove Site	7.5	< 0.5	7.5	< 0.5	-8
386	Grinding Groove Site	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
387	Grinding Groove Site	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
	Maximum	**35**	**1**	**35**	**30**	**-7.5**

Table D.01 - Maximum Predicted Subsidence Parameters for the Archaeological Sites

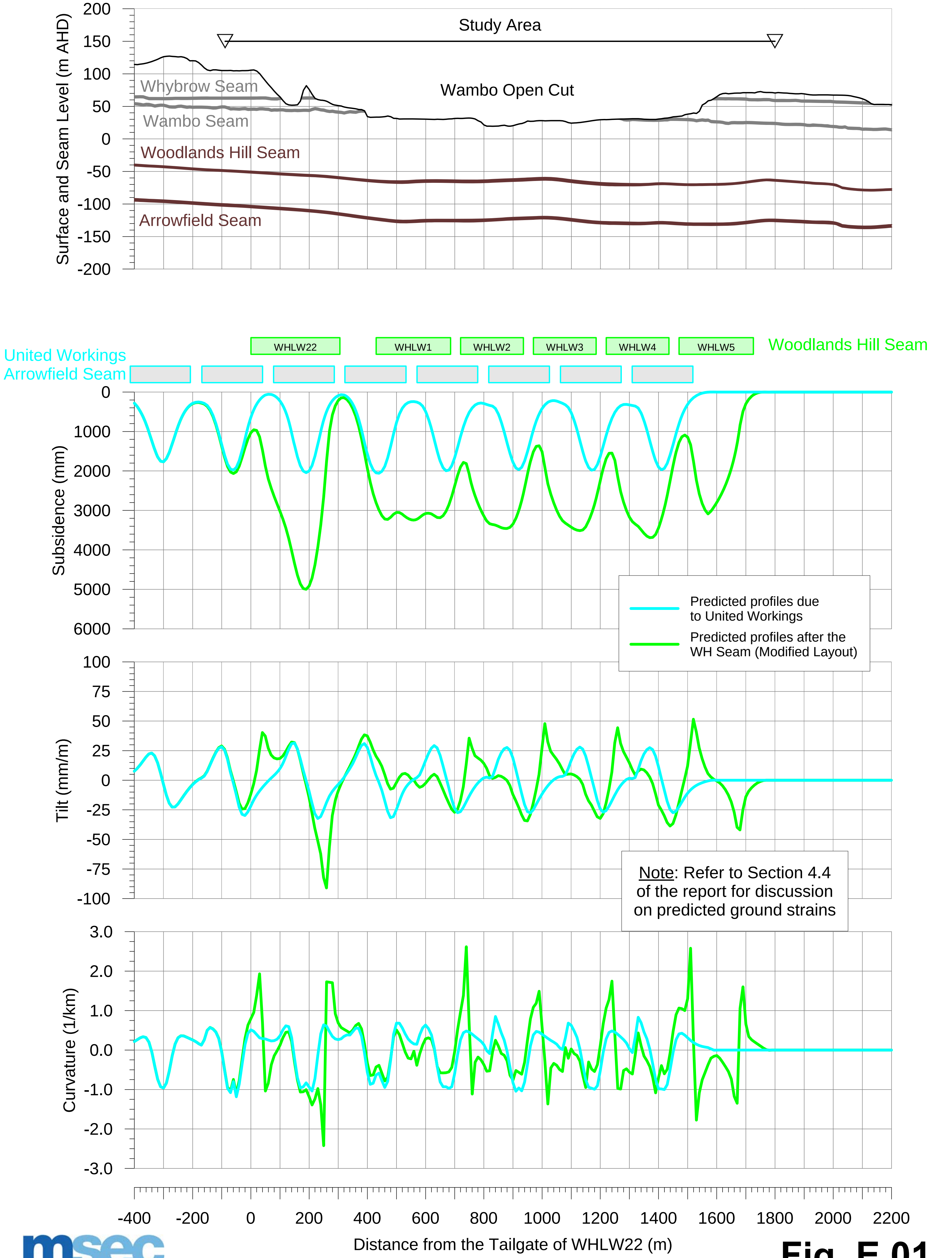
Site Name	Type	Predicted Additional Hogging Curvature due to AF and BF Seams Based on the Approved Layout (1/km)	Predicted Additional Hogging Curvature due to WH and AF Seams Based on the Modified Layout (1/km)	Predicted Total Hogging Curvature due to the WM, AF and BF Seams Based on the Approved Layout (1/km)	Predicted Total Hogging Curvature due to the WM, WH and AF Seams Based on the Modified Layout (1/km)	Incremental Change in Hogging Curvature due to the Proposed Modification (1/km)
32	Scarred Tree	0.20	< 0.01	0.20	< 0.01	-0.20
117	Grinding Grooves and Artefact Scatter	0.01	0.20	0.01	0.20	0.19
329	Grinding Groove Site	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
330	Grinding Surfaces	0.15	< 0.01	0.15	< 0.01	-0.15
331	Grinding Surfaces	0.20	< 0.01	0.20	< 0.01	-0.20
332	Grinding Surfaces	0.45	0.01	0.45	0.01	-0.44
334	Earth Mound with Artefacts	0.25	< 0.01	0.25	< 0.01	-0.25
335	Earth Mound with Artefacts	0.20	< 0.01	0.20	< 0.01	-0.20
360	Scarred Tree	0.30	< 0.01	0.60	0.30	-0.30
377	Grinding Groove Site	0.10	< 0.01	0.10	< 0.01	-0.10
386	Grinding Groove Site	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
387	Grinding Groove Site	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Maximum	**0.45**	**0.20**	**0.60**	**0.30**	**0.19**

Table D.01 - Maximum Predicted Subsidence Parameters for the Archaeological Sites

Site Name	Type	Predicted Additional Sagging Curvature due to AF and BF Seams Based on the Approved Layout (1/km)	Predicted Additional Sagging Curvature due to WH and AF Seams Based on the Modified Layout (1/km)	Predicted Total Sagging Curvature due to the WM, AF and BF Seams Based on the Approved Layout (1/km)	Predicted Total Sagging Curvature due to the WM, WH and AF Seams Based on the Modified Layout (1/km)	Incremental Change in Sagging Curvature due to the Proposed Modification (1/km)
32	Scarred Tree	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
117	Grinding Grooves and Artefact Scatter	< 0.01	0.10	2.20	2.30	0.10
329	Grinding Groove Site	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
330	Grinding Surfaces	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
331	Grinding Surfaces	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
332	Grinding Surfaces	0.20	< 0.01	0.20	< 0.01	-0.20
334	Earth Mound with Artefacts	0.15	< 0.01	0.15	< 0.01	-0.15
335	Earth Mound with Artefacts	0.09	< 0.01	0.09	< 0.01	-0.09
360	Scarred Tree	0.01	0.45	0.01	0.45	0.44
377	Grinding Groove Site	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
386	Grinding Groove Site	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
387	Grinding Groove Site	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Maximum	**0.20**	**0.45**	**2.20**	**2.30**	**0.44**

APPENDIX E. FIGURES

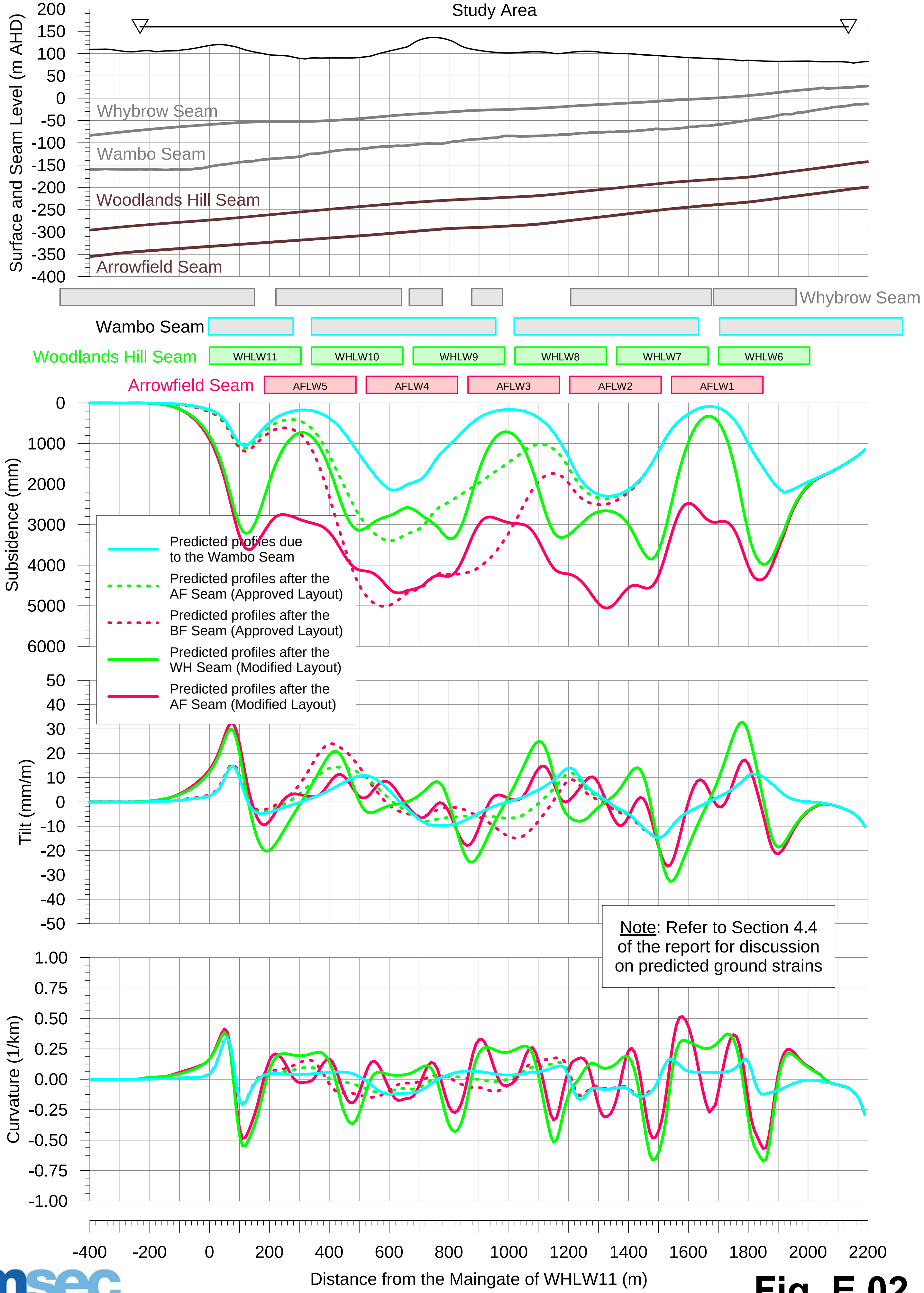
Predicted Profiles of Total Subsidence, Tilt and Curvature along Prediction Line 1 due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams



msec

Fig. E.01

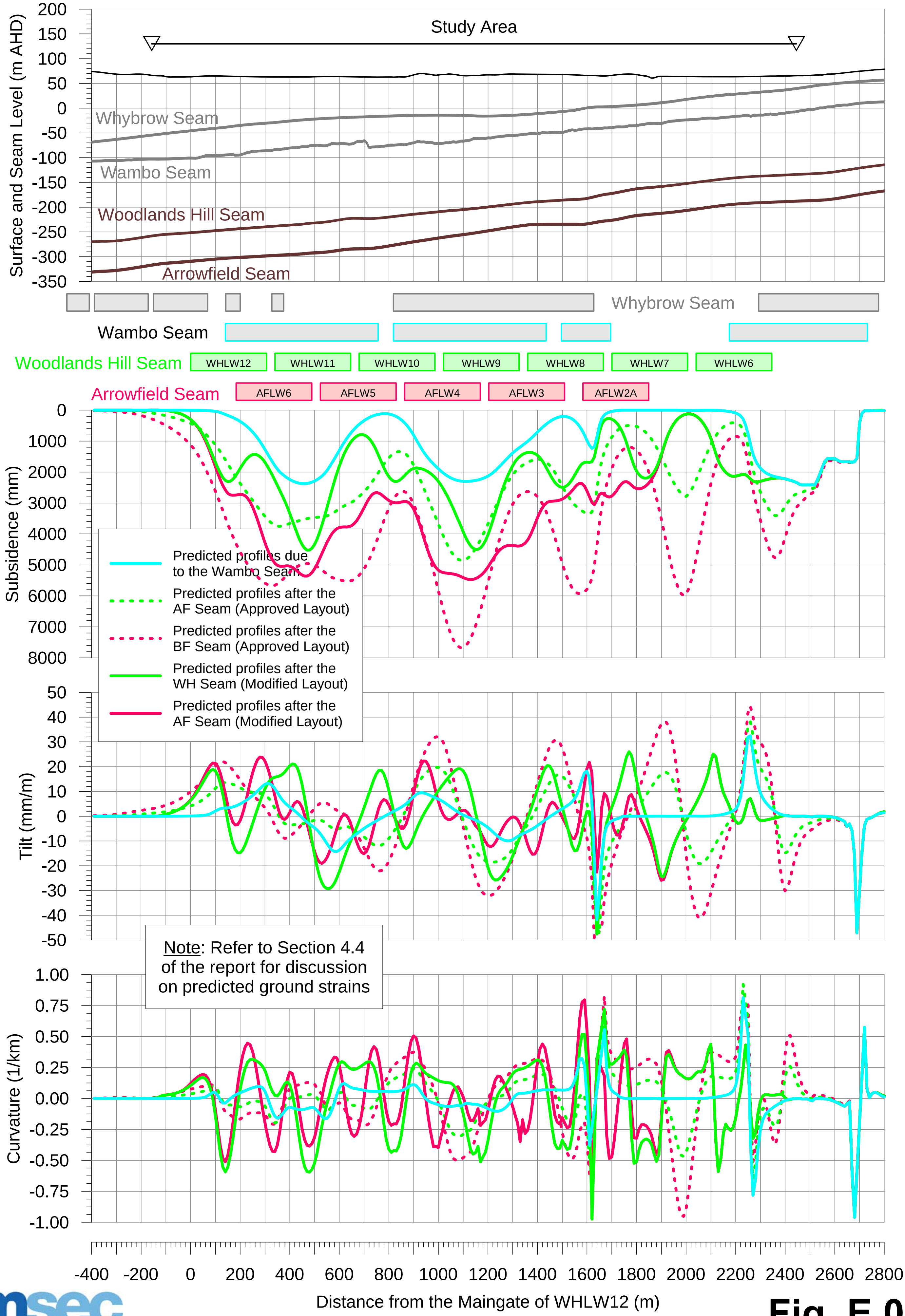
Predicted Profiles of Total Subsidence, Tilt and Curvature along Prediction Line 2 due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams



msec

Fig. E.02

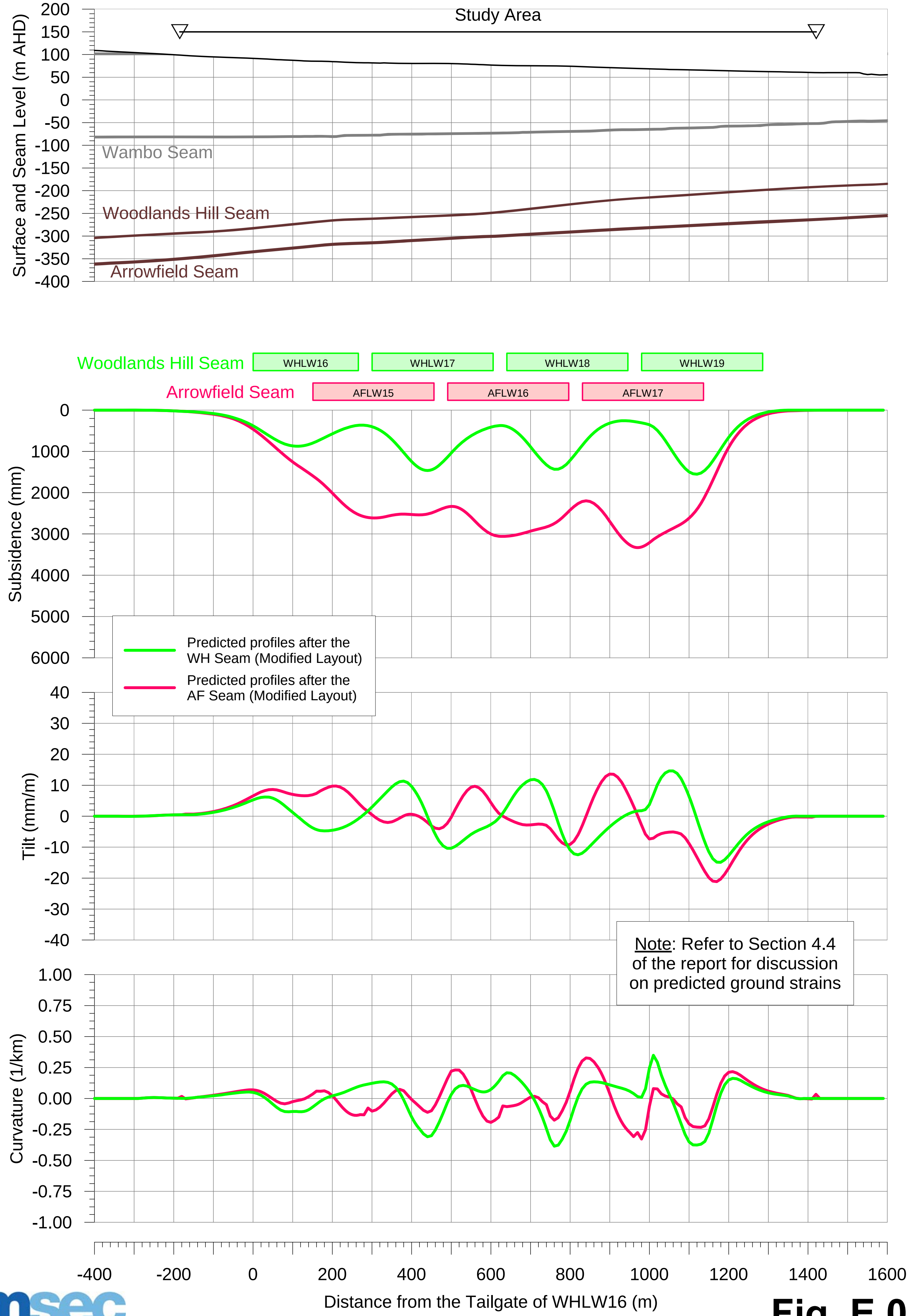
Predicted Profiles of Total Subsidence, Tilt and Curvature along Prediction Line 3 due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams



msec

Fig. E.03

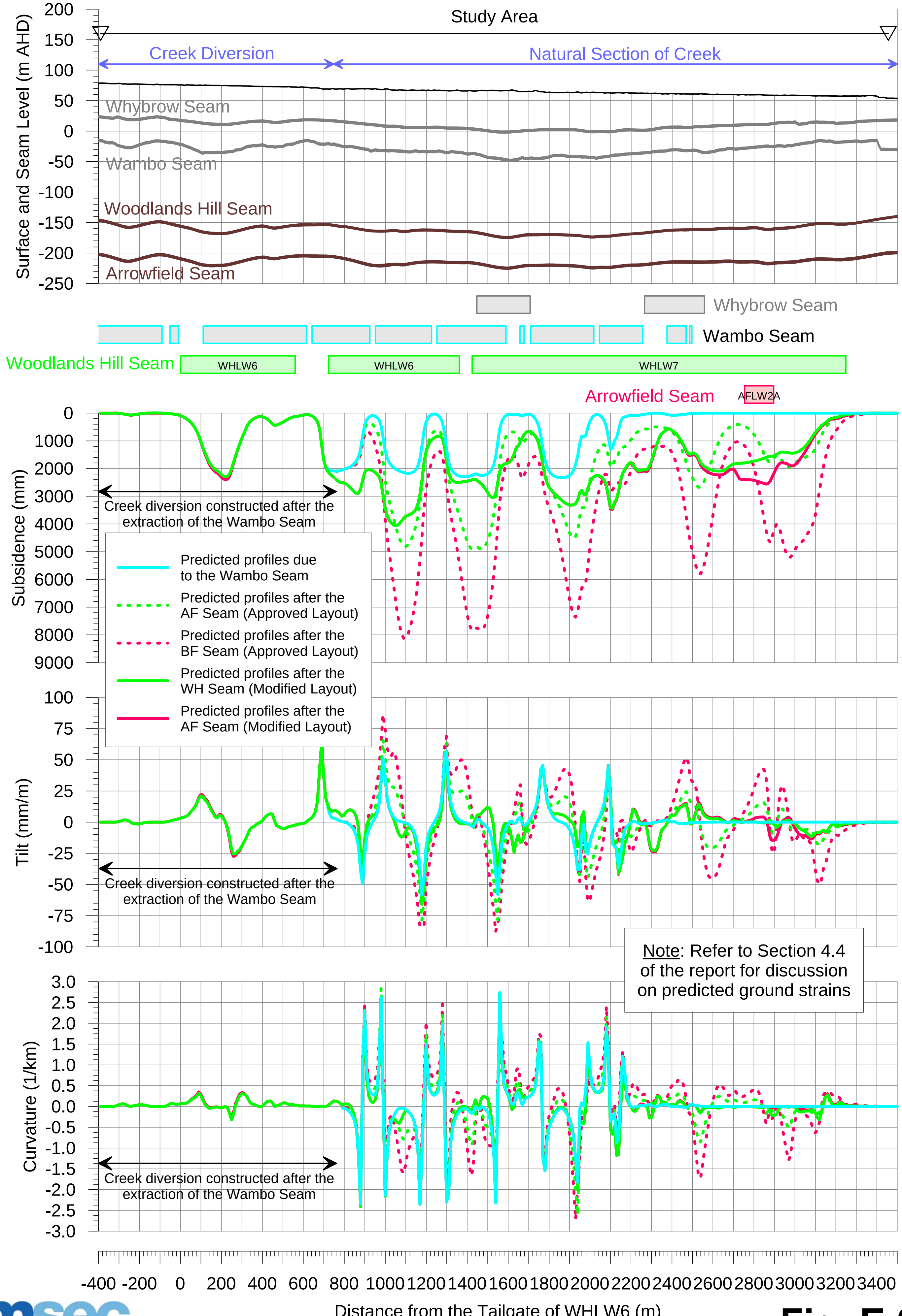
Predicted Profiles of Total Subsidence, Tilt and Curvature along Prediction Line 4 due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams



msec

Fig. E.04

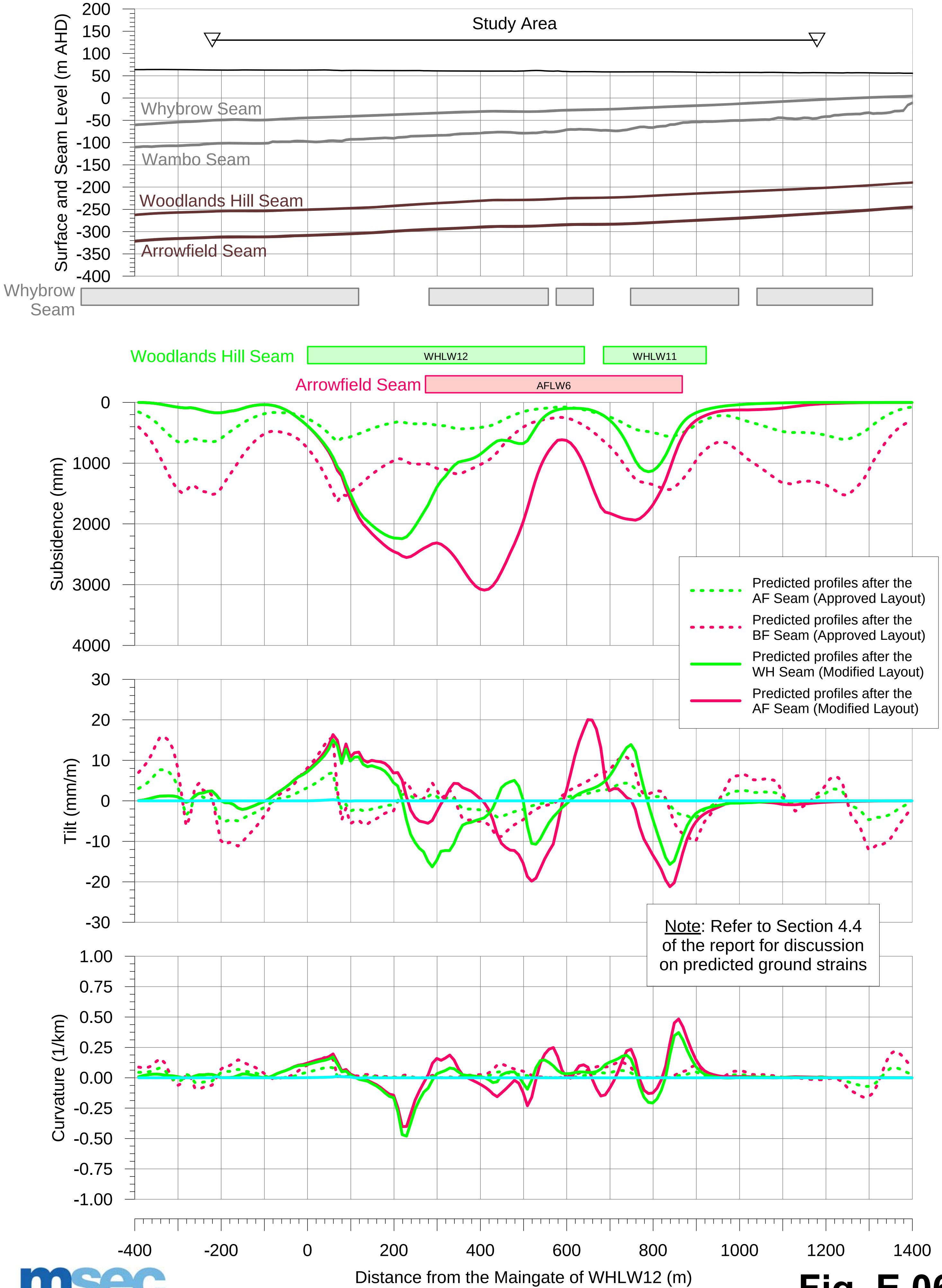
Predicted Profiles of Total Subsidence, Tilt and Curvature along North Wambo Creek due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams



msec

Fig. E.05

Predicted Profiles of Total Subsidence, Tilt and Curvature along Wambo Creek due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams

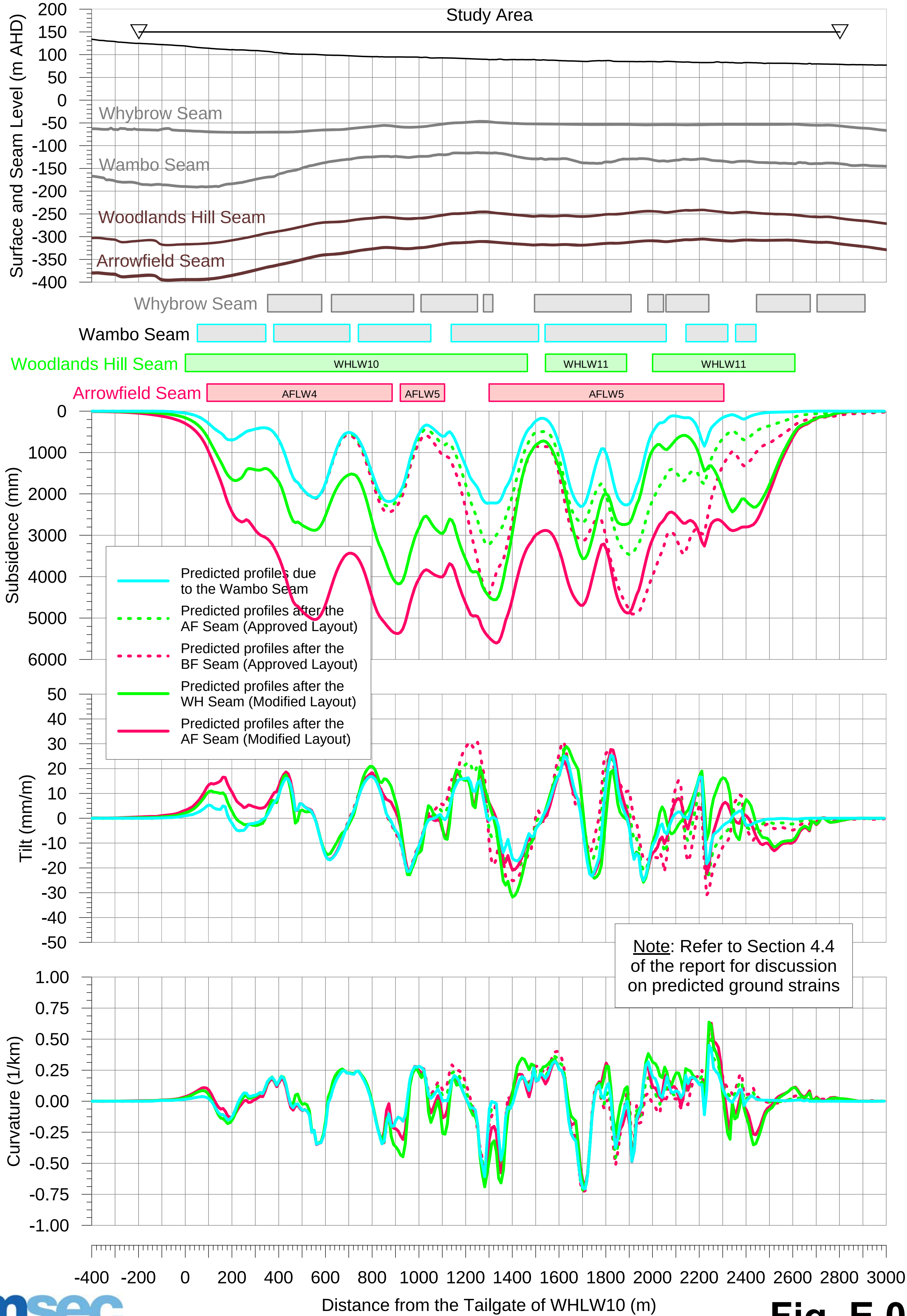


msec

Fig. E.06

I:\Projects\Wambo\MSEC799 - South Wambo Underground\Subsdata\Impacts\Creeks\Fig. E.07 - Stony Creek.grf.....05-Apr-16

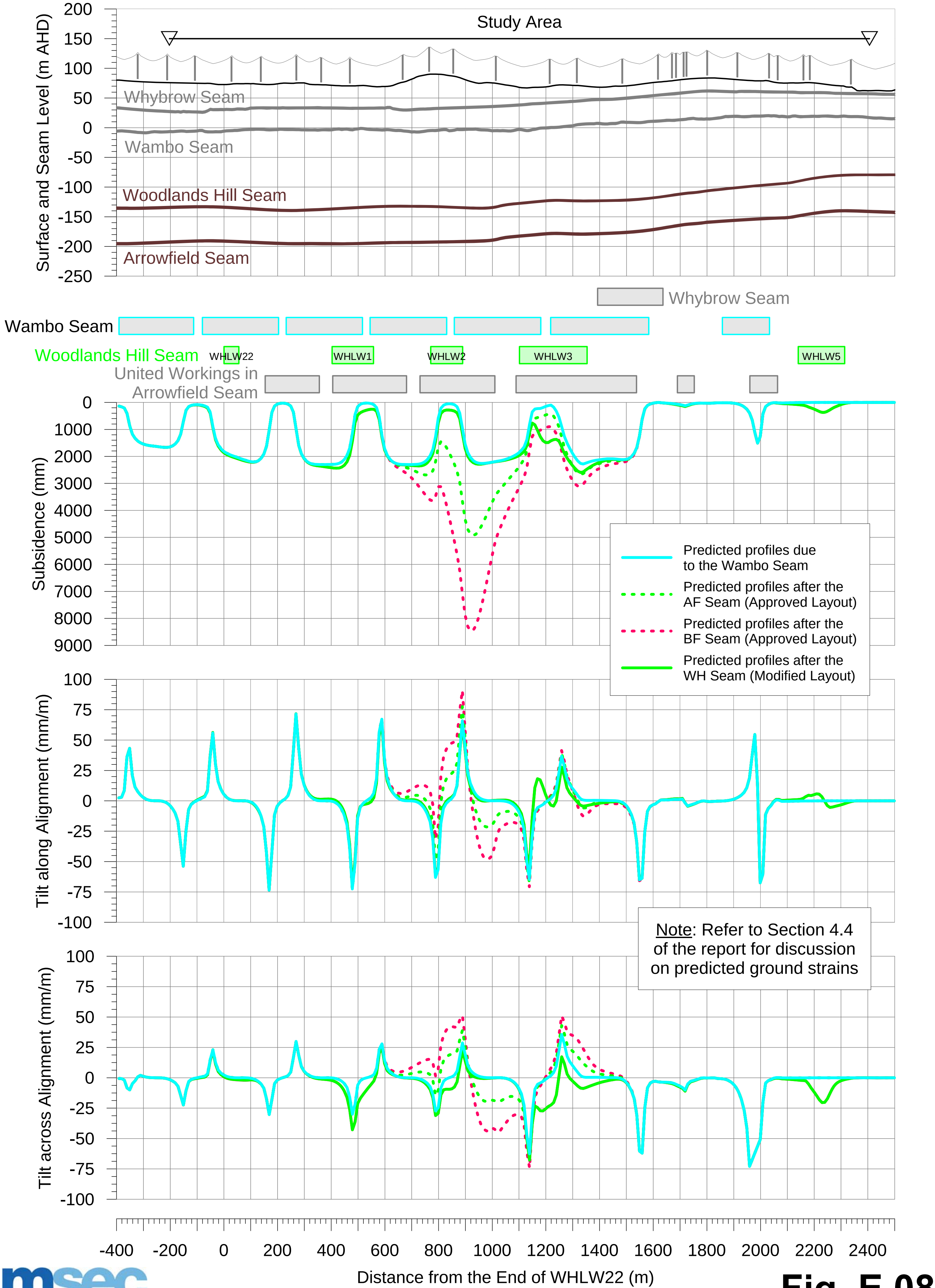
Predicted Profiles of Total Subsidence, Tilt and Curvature along Stony Creek due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams



msec

Fig. E.07

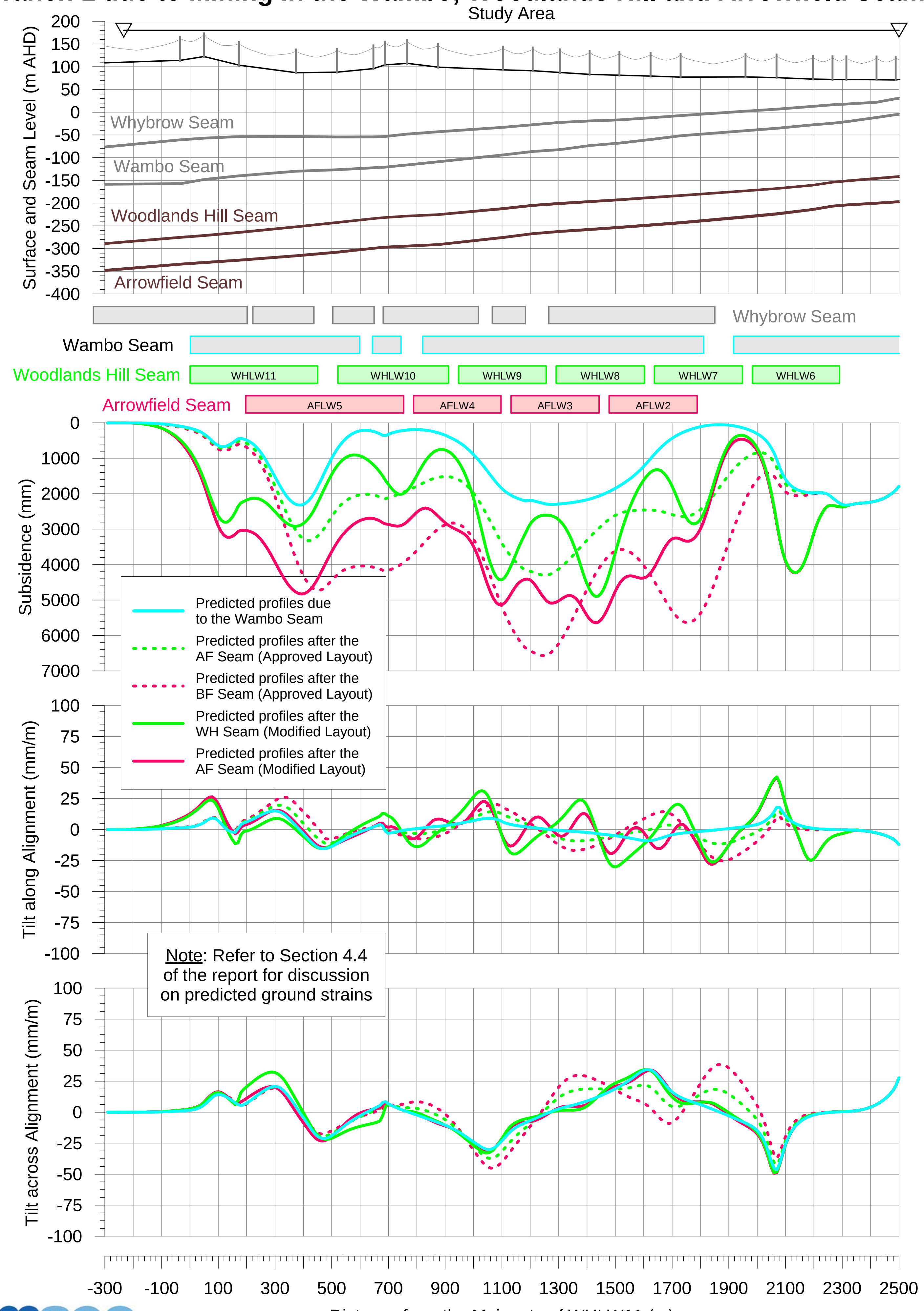
Predicted Profiles of Total Subsidence and Tilt for the 66 kV Powerline due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams



msec

Fig. E.08

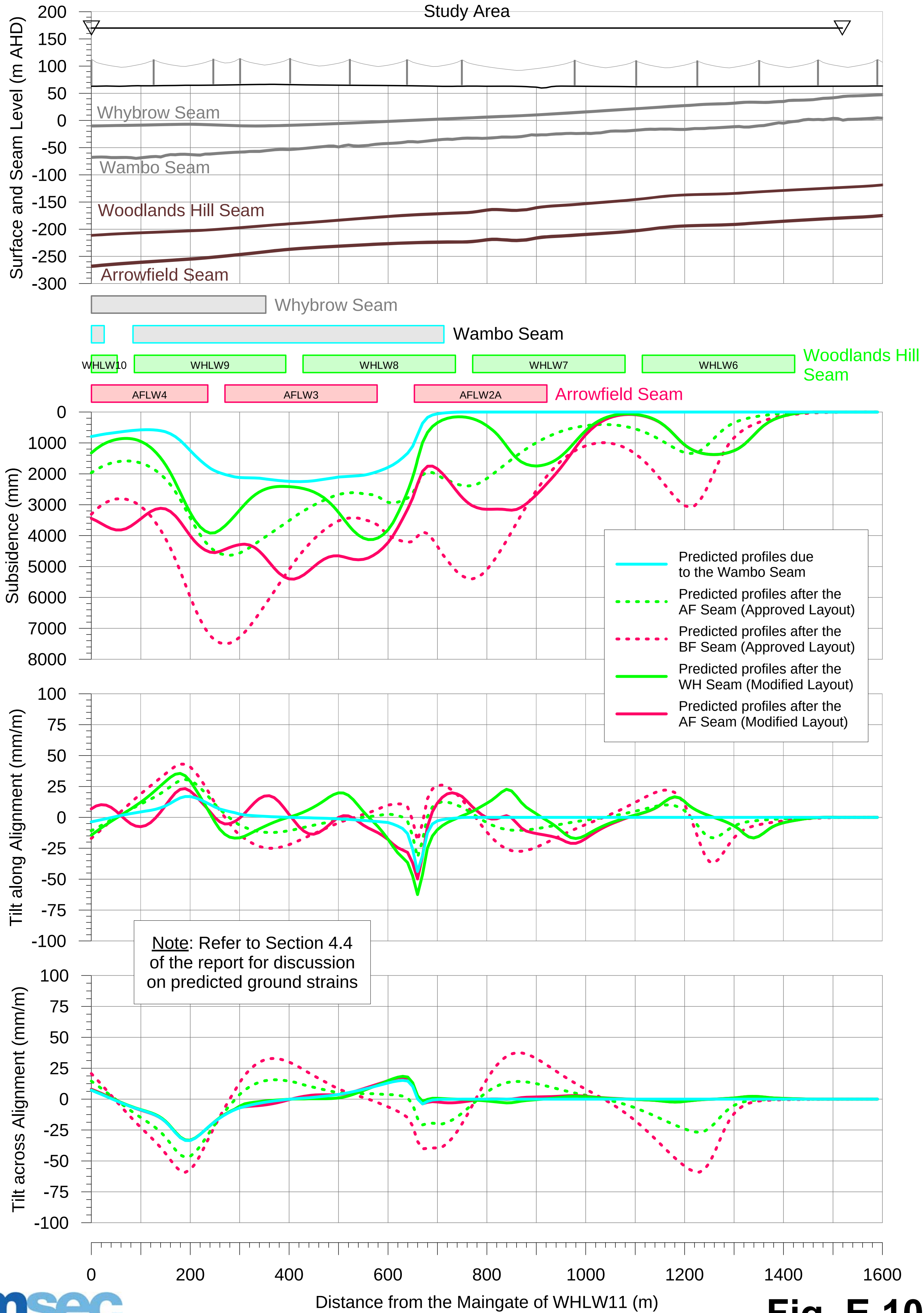
Predicted Profiles of Total Subsidence and Tilt for the 11 kV Powerline Branch 1 due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams



msec

Fig. E.09

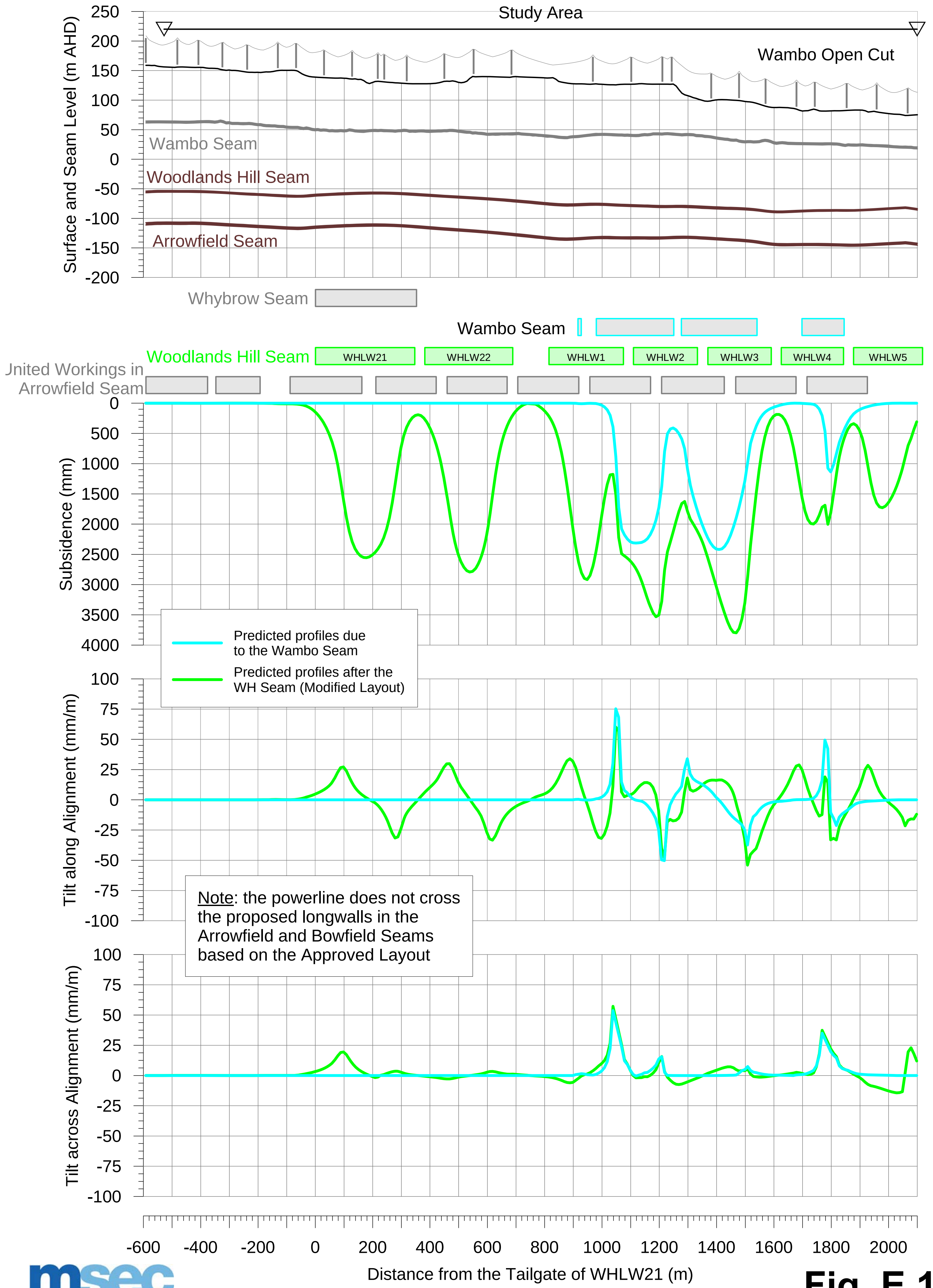
Predicted Profiles of Total Subsidence and Tilt for the 11 kV Powerline Branch 2 due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams



msec

Fig. E.10

Predicted Profiles of Total Subsidence and Tilt for the 11 kV Powerline Branch 3 due to Mining in the Wambo, Woodlands Hill and Arrowfield Seams

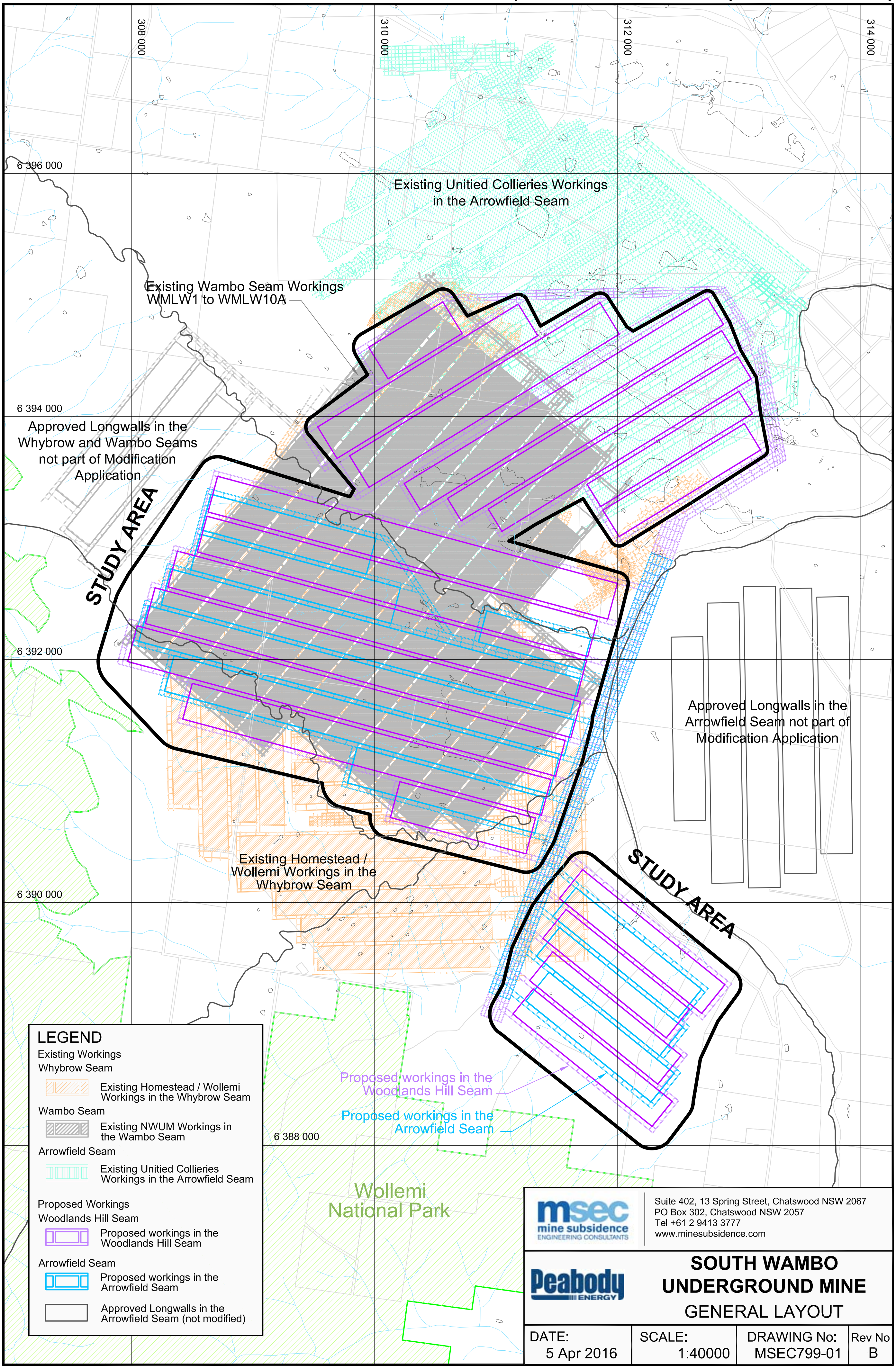


msec

Fig. E.11

APPENDIX F. DRAWINGS

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-01.dwg



msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

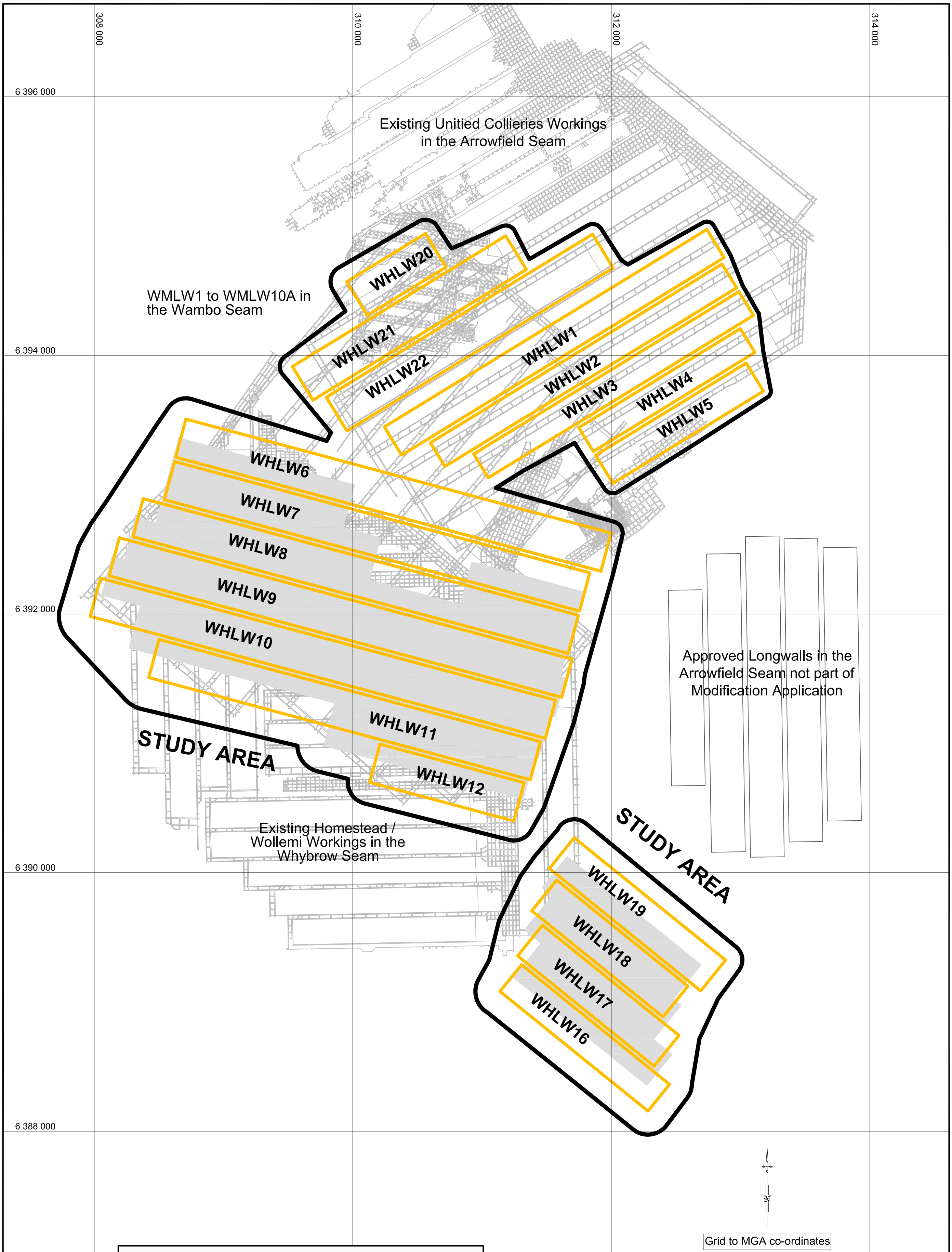
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

GENERAL LAYOUT

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40000	MSEC799-01	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-02.dwg



LEGEND

- Proposed Longwalls in the Woodlands Hill Seam
- Proposed Longwalls in the Arrowfield Seam
- Existing Workings in Whybrow, Wambo & Arrowfield Seams

msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

Peabody ENERGY

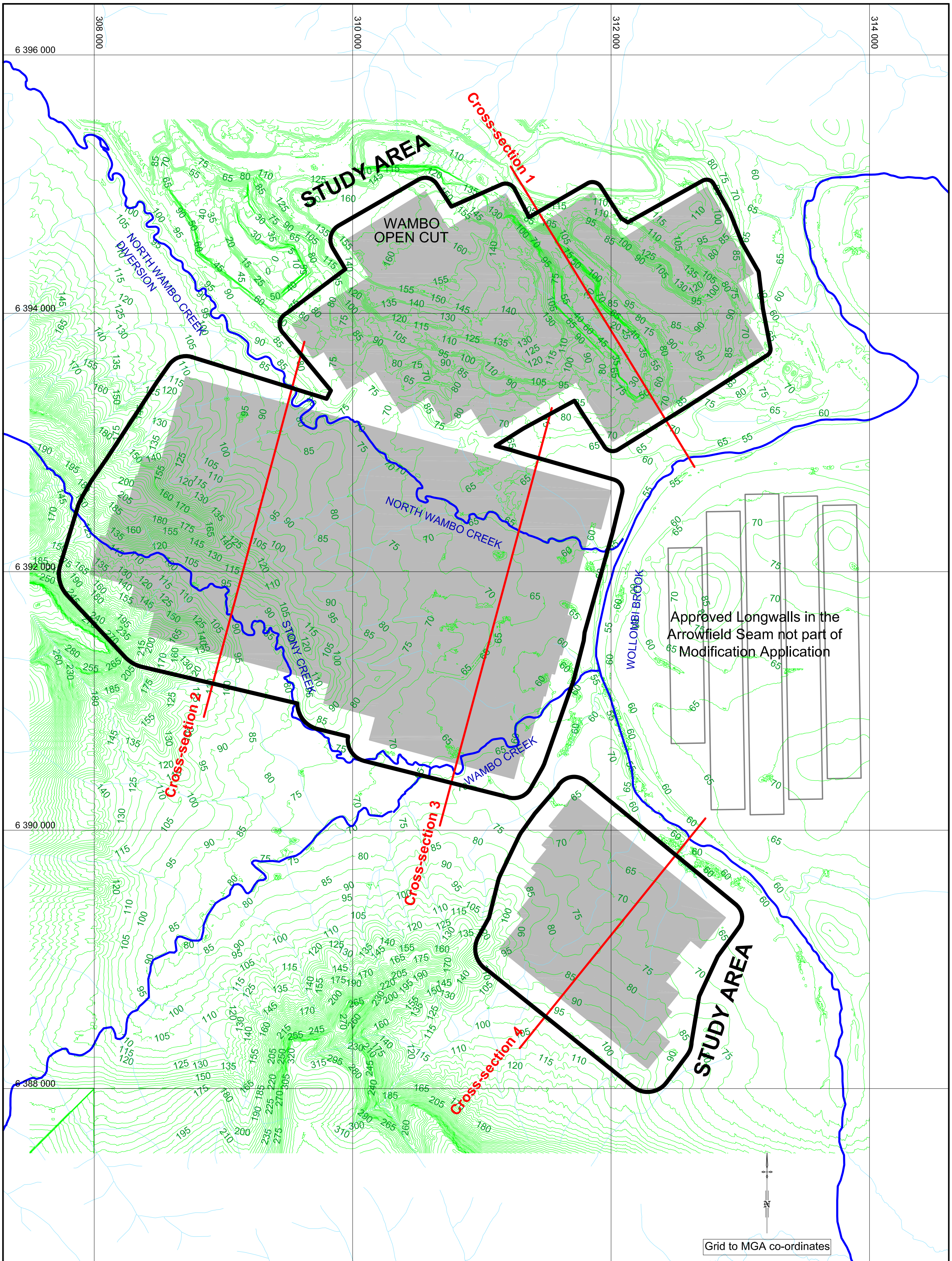
SOUTH WAMBO UNDERGROUND MINE

LAYOUT OF LONGWALLS IN THE WOODLANDS HILL SEAM

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-02	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-03.dwg

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-04.dwg



6 386 000

SURFACE LEVEL CONTOURS ARE IN m AHD

LEGEND

Proposed Longwalls in the Woodlands Hill Seam & Arrowfield Seam

msec mine subsidence ENGINEERING CONSULTANTS

Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

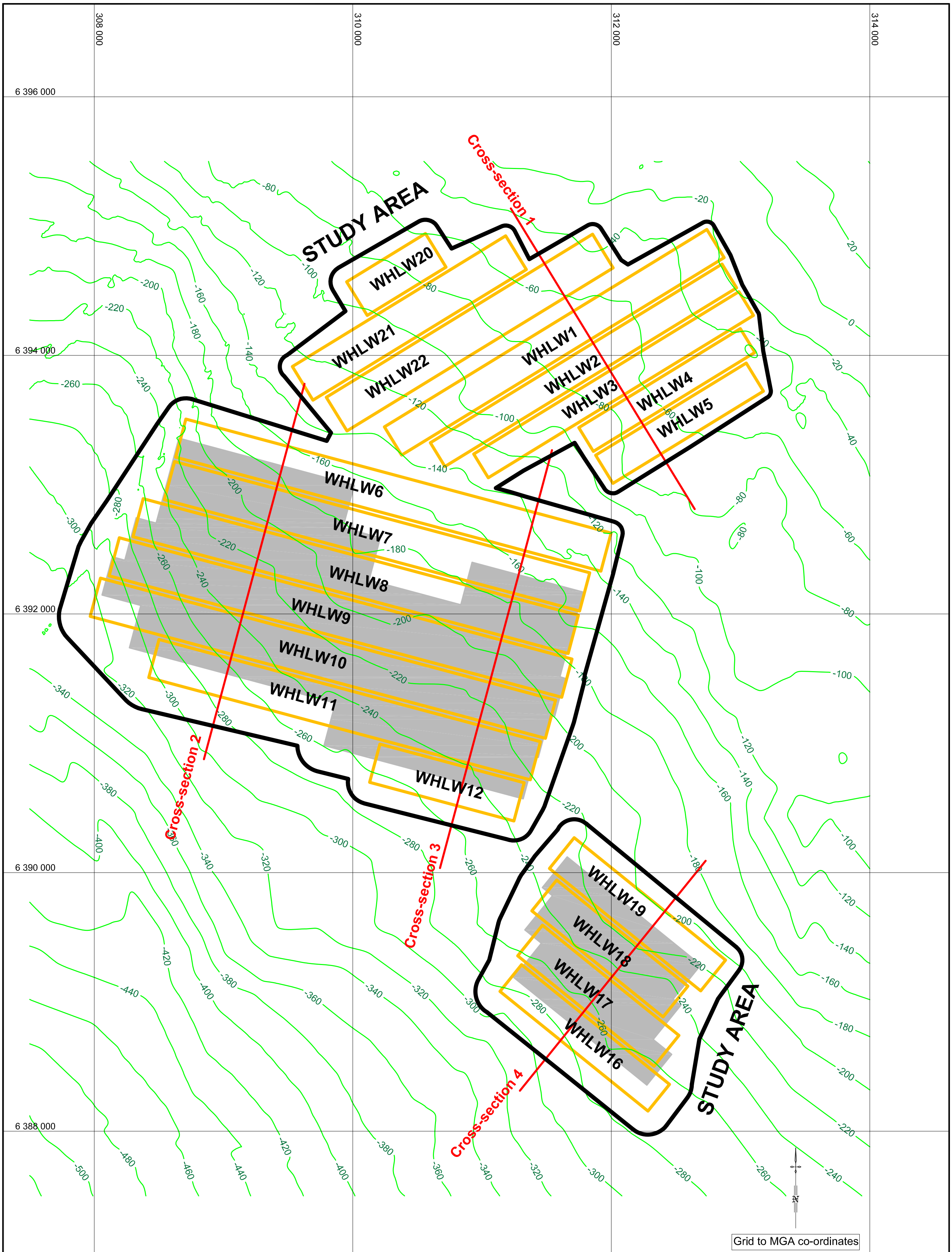
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

SURFACE LEVEL CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-04	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-05.dwg



SEAM FLOOR CONTOURS ARE IN m AHD

LEGEND

- Proposed Longwalls in the Woodlands Hill Seam
- Proposed Longwalls in the Arrowfield Seam

msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

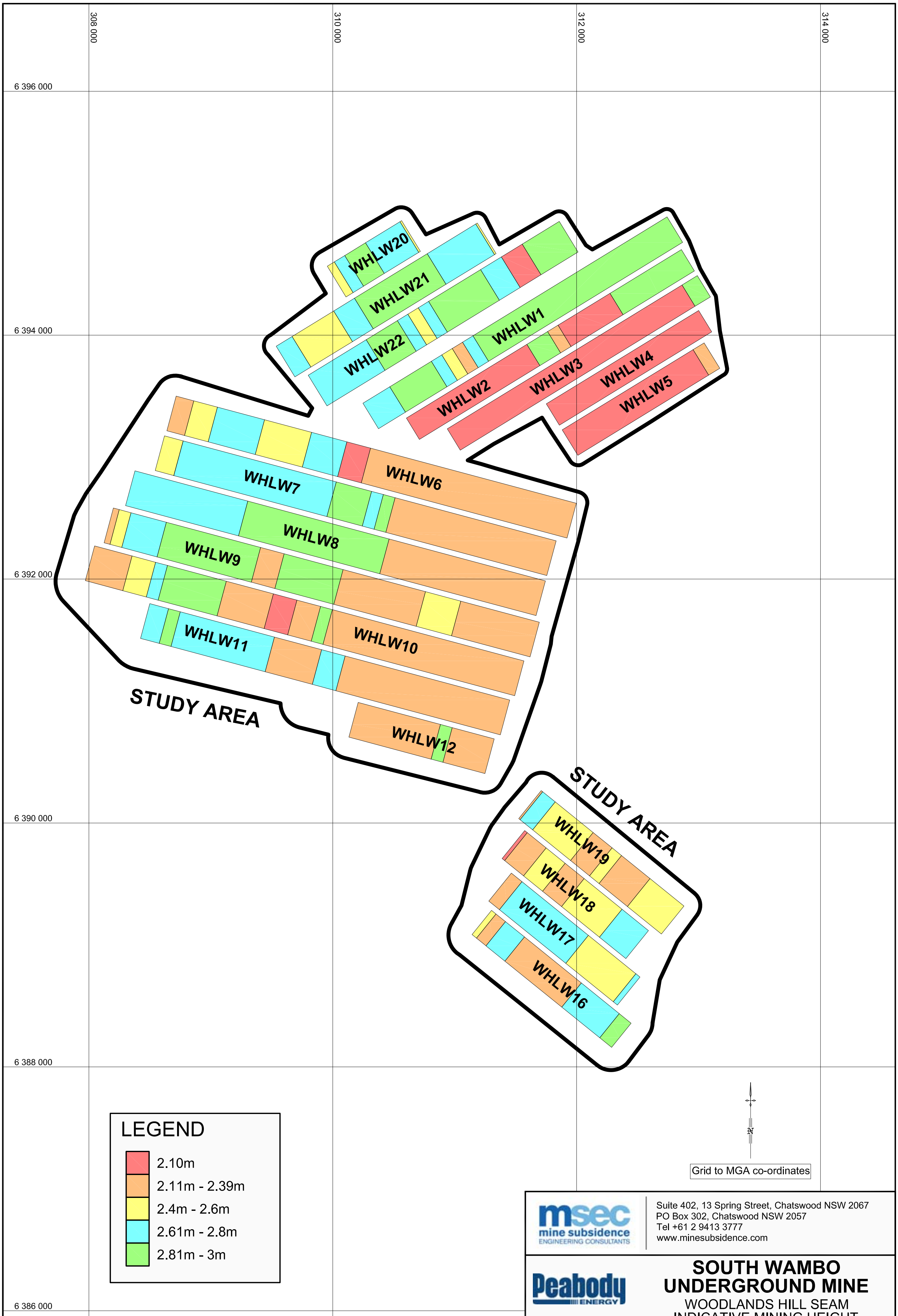
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

WOODLANDS HILL SEAM FLOOR

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-05	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-06.dwg



msec mine subsidence ENGINEERING CONSULTANTS

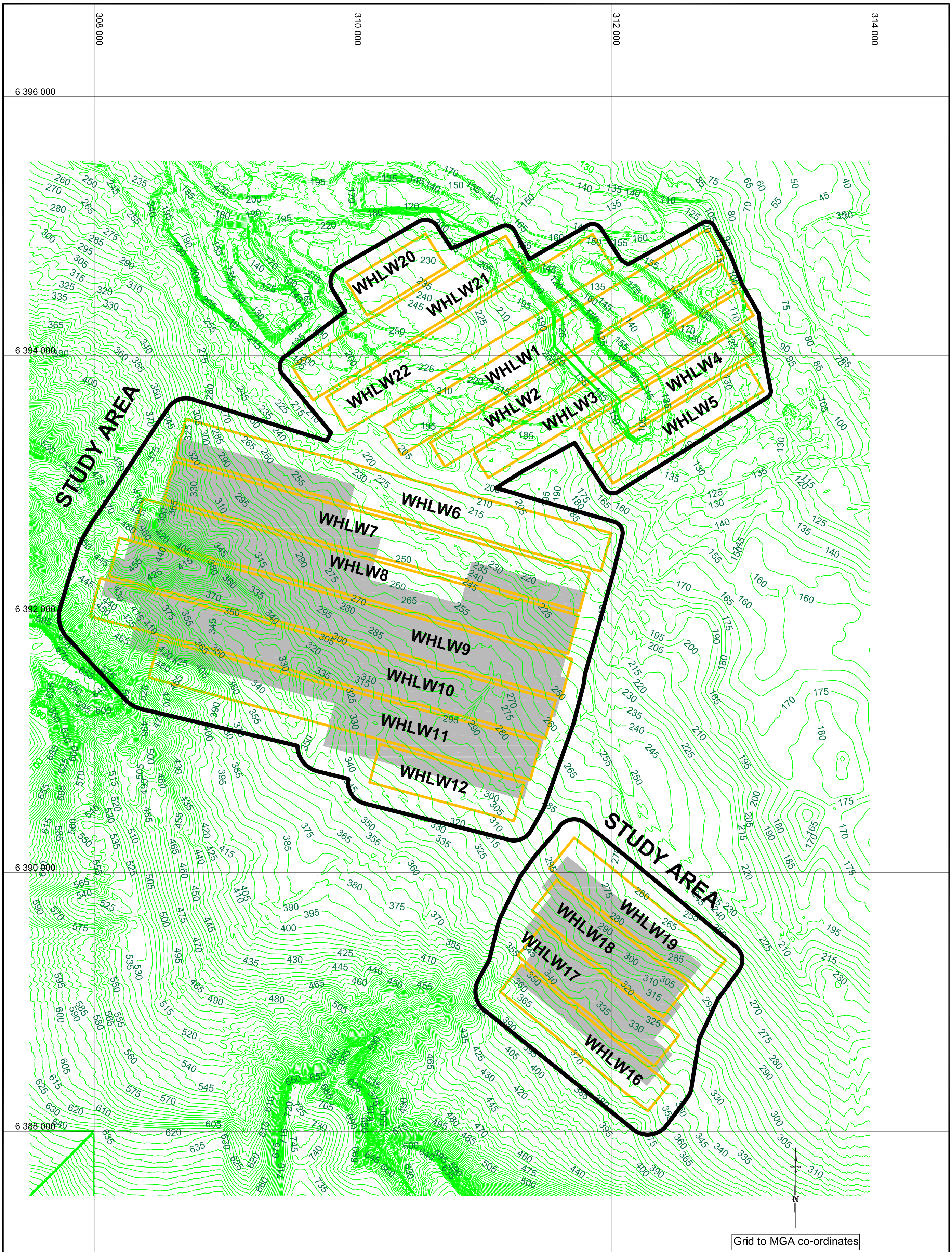
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE
WOODLANDS HILL SEAM
INDICATIVE MINING HEIGHT

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-06	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-07.dwg



DEPTH OF COVER CONTOURS ARE IN METRES

LEGEND

- Proposed Longwalls in the Woodlands Hill Seam
- Proposed Longwalls in the Arrowfield Seam

msec mine subsidence ENGINEERING CONSULTANTS

Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

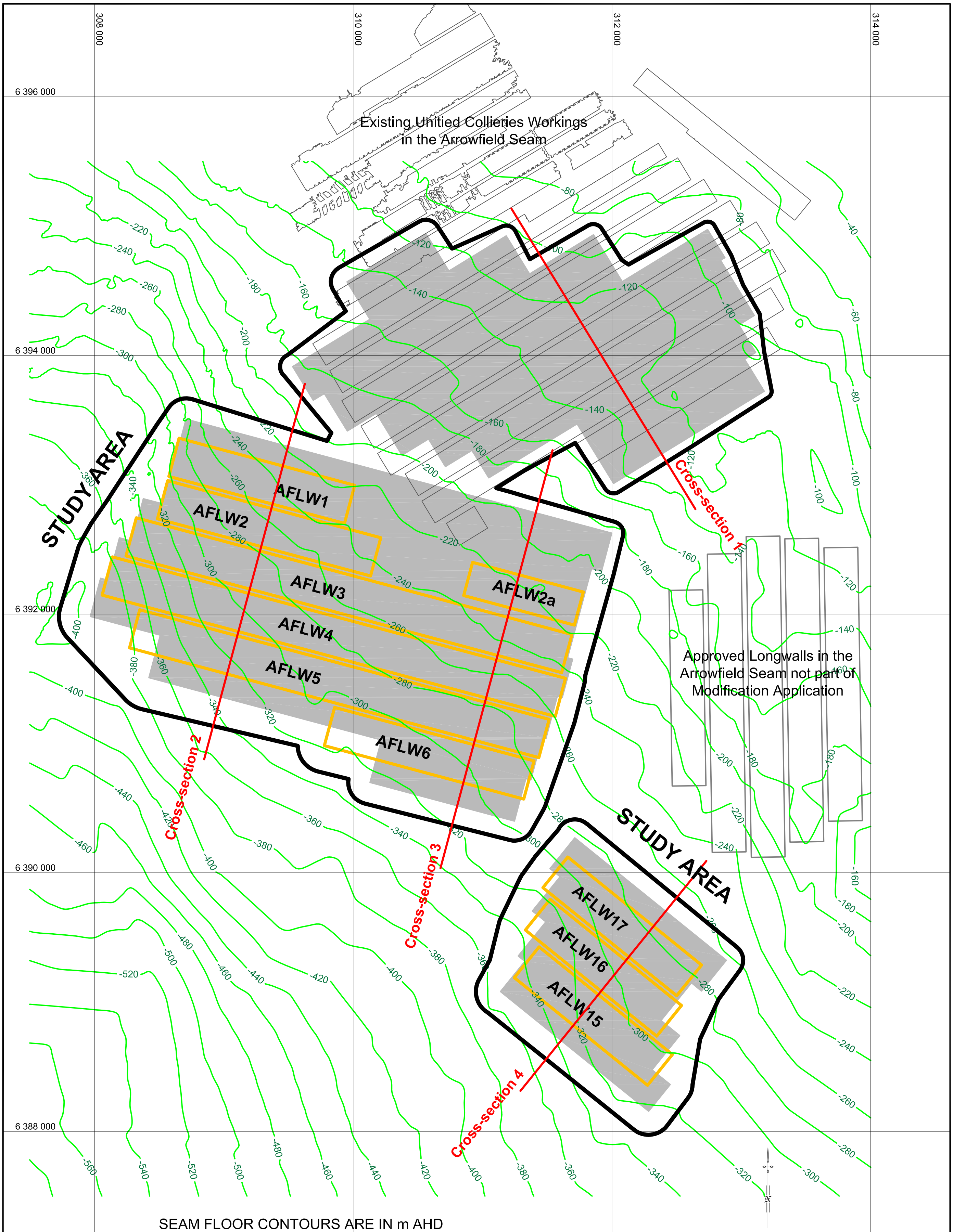
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

WOODLANDS HILL SEAM
DEPTH OF COVER CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-07	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-08.dwg



LEGEND

- Proposed Longwalls in the Arrowfield Seam
- Proposed Longwalls in the Woodlands Hill Seam
- Existing Unitied Collieries Workings in the Arrowfield Seam

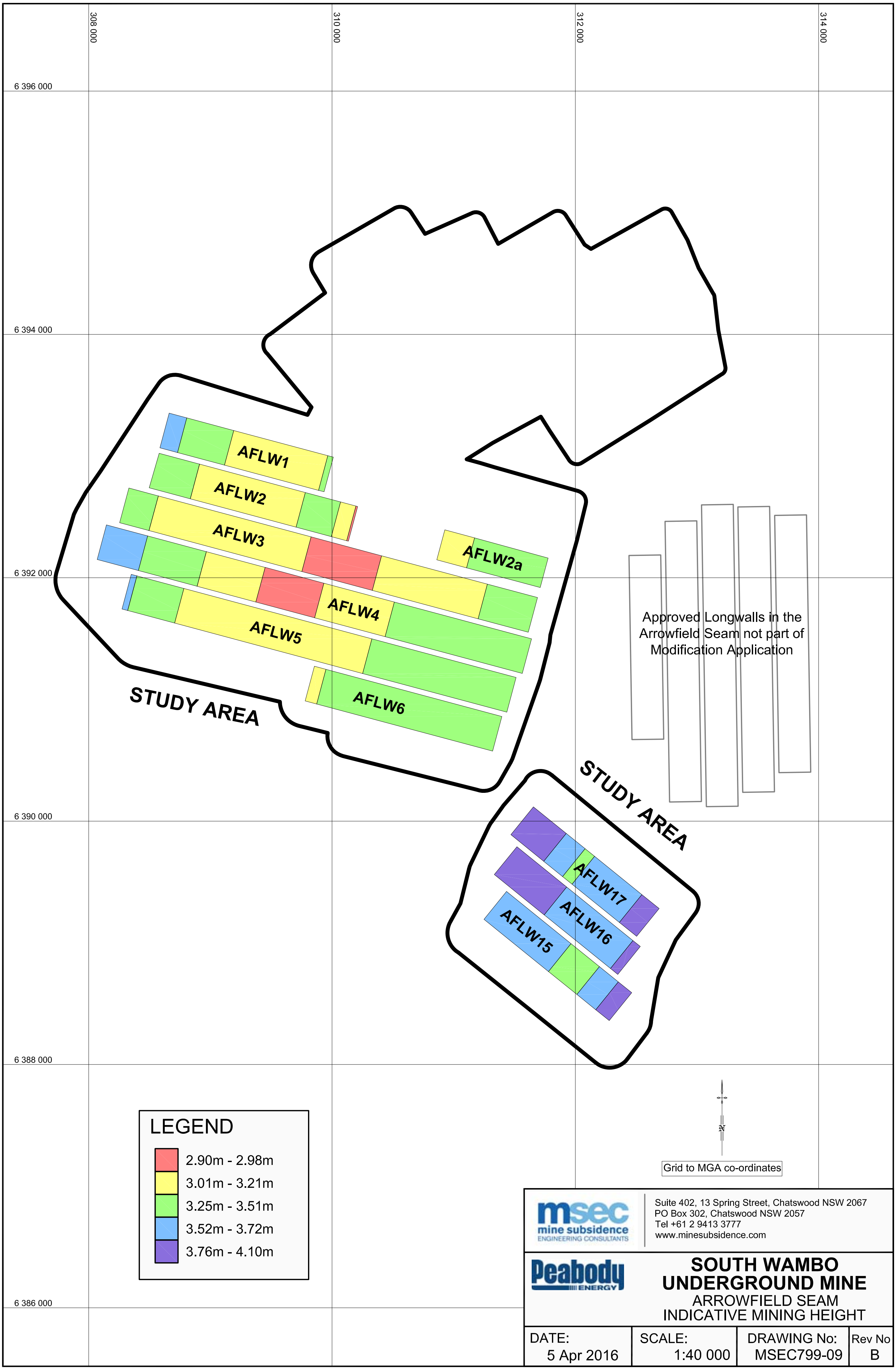
msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE
ARROWFIELD SEAM FLOOR CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-08	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-09.dwg



msec mine subsidence ENGINEERING CONSULTANTS

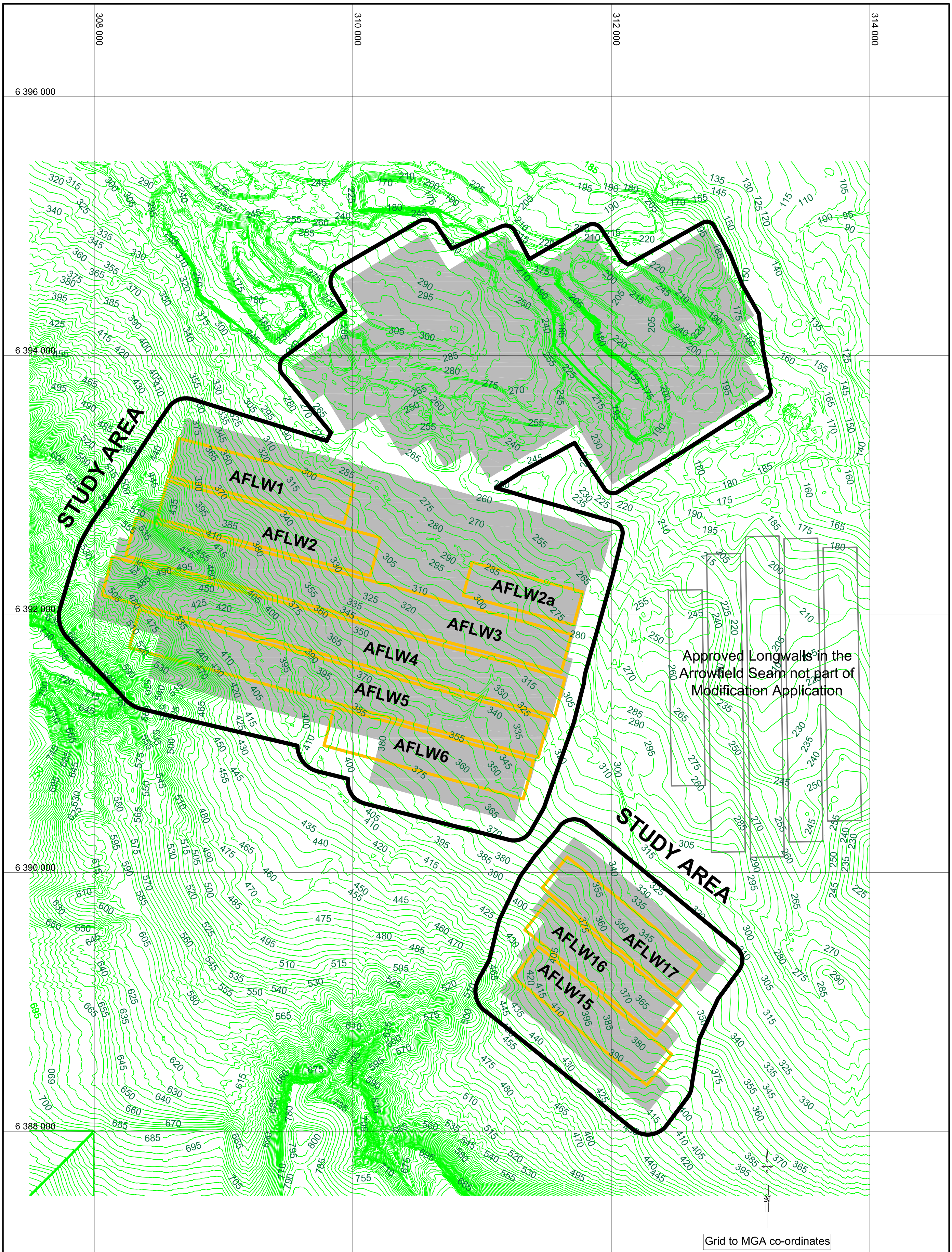
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE
ARROWFIELD SEAM
INDICATIVE MINING HEIGHT

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-09	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-10.dwg



6 386 000

DEPTH OF COVER CONTOURS ARE IN METRES

LEGEND

- Proposed Longwalls in the Arrowfield Seam
- Proposed Longwalls in the Woodlands Hill Seam

msec mine subsidence ENGINEERING CONSULTANTS

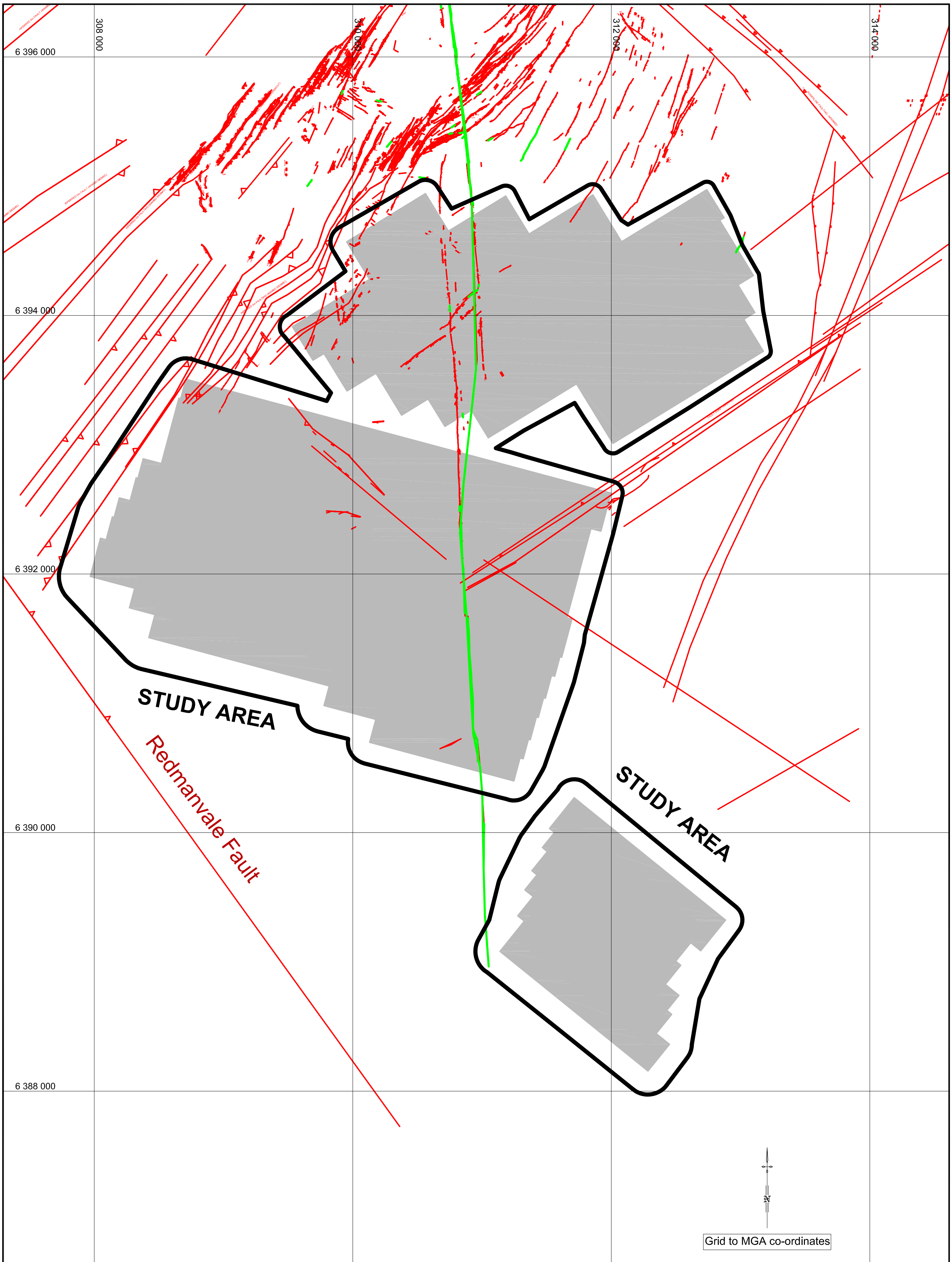
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

ARROWFIELD SEAM
DEPTH OF COVER CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-10	B



LEGEND

- Proposed Longwalls in the Woodlands Hill Seam & Arrowfield Seam
- Faults
- Dykes

msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

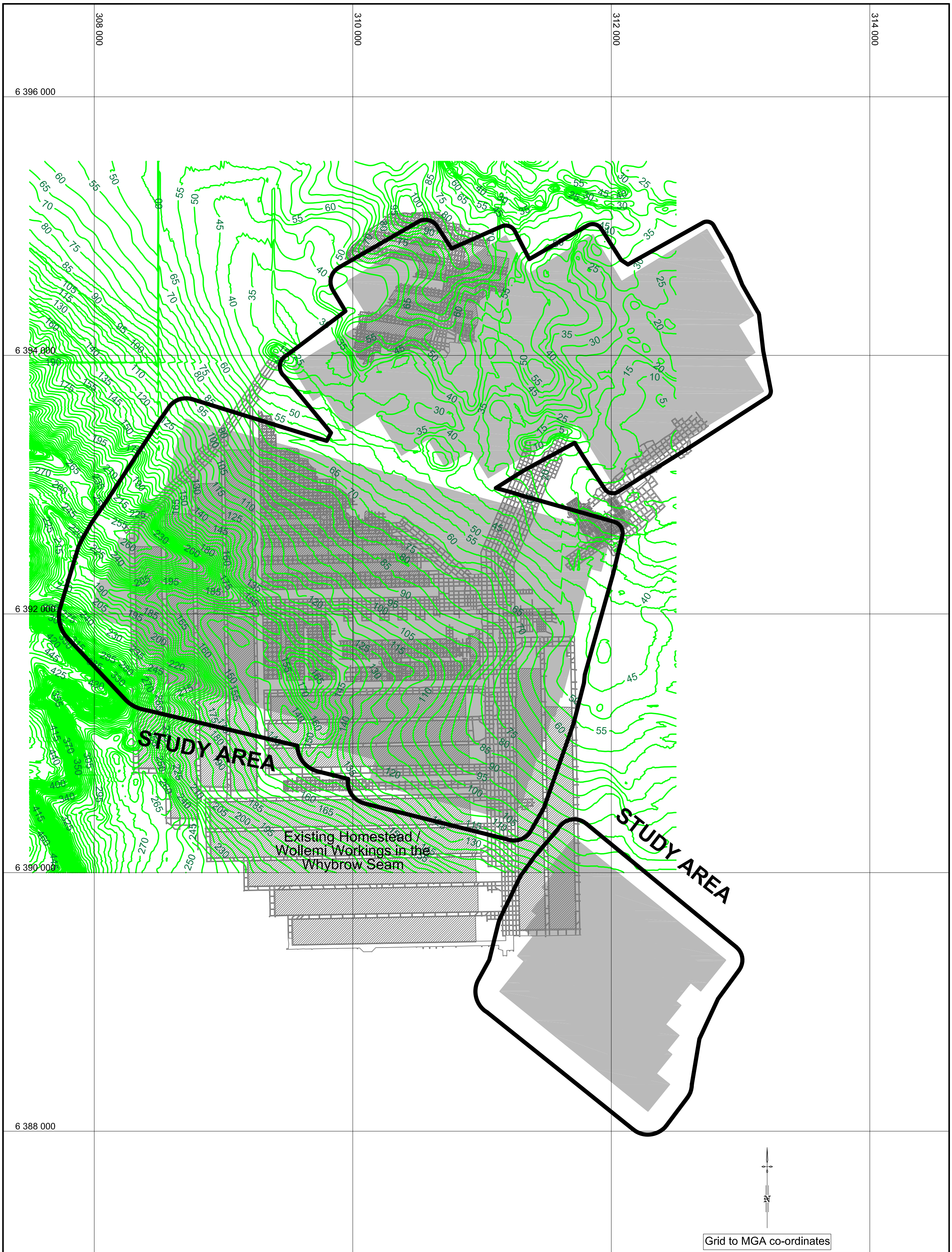
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

GEOLOGICAL STRUCTURES IDENTIFIED AT SEAM LEVEL

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-11	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-11.dwg



DEPTH OF COVER CONTOURS ARE IN METRES

LEGEND

- Existing Homestead / Wollemi Workings in the Whybrow Seam
- Proposed Longwalls in the Arrowfield Seam & Woodlands Hill Seam

msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

WHYBROW SEAM DEPTH OF COVER CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-12	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-13.dwg

DEPTH OF COVER CONTOURS ARE IN METRES

LEGEND

- Existing NWUM Workings in the Wambo Seam
- Proposed Longwalls in the Arrowfield Seam & Woodlands Hill Seam

msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

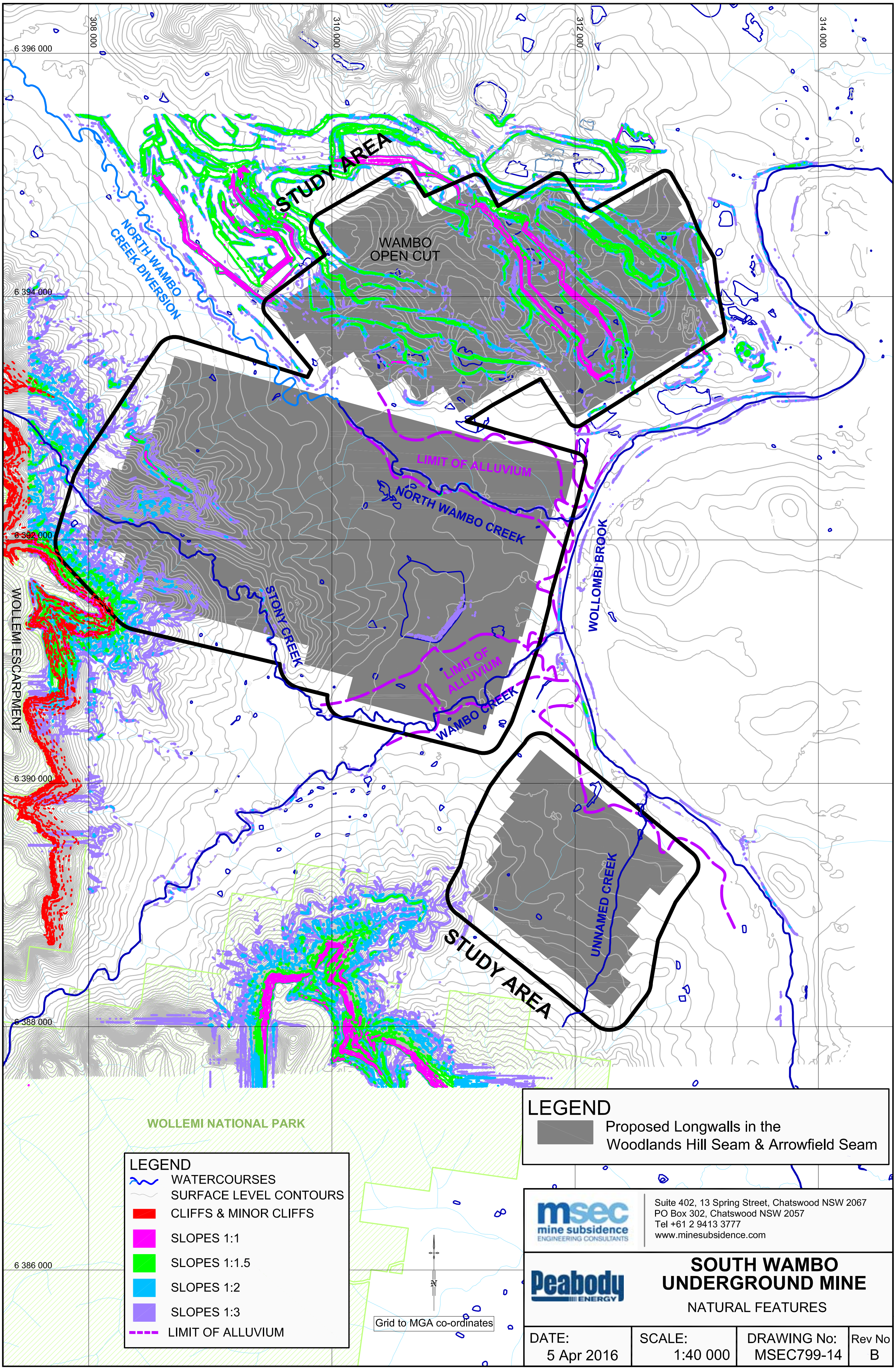
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

WAMBO SEAM
DEPTH OF COVER CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-13	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-14.dwg



msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

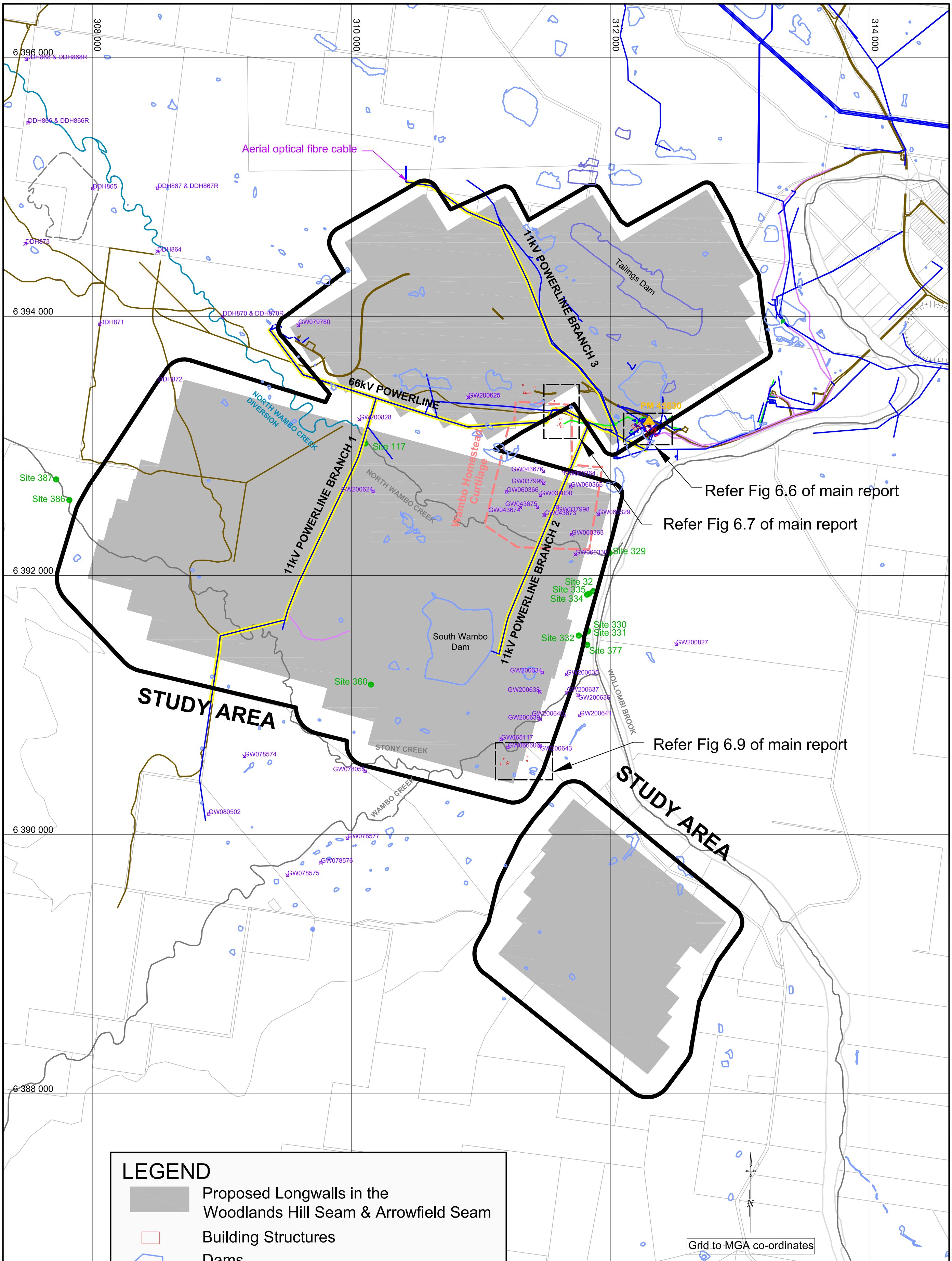
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

NATURAL FEATURES

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-14	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-15.dwg



LEGEND

- Proposed Longwalls in the Woodlands Hill Seam & Arrowfield Seam
- Building Structures
- Dams
- Roads & Tracks
- Powerlines & Power poles
- Telecommunication cables
- Archaeological Sites (Artefact scatter & isolated finds not shown)
- Groundwater bores
- Survey Marks

msec mine subsidence ENGINEERING CONSULTANTS

Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

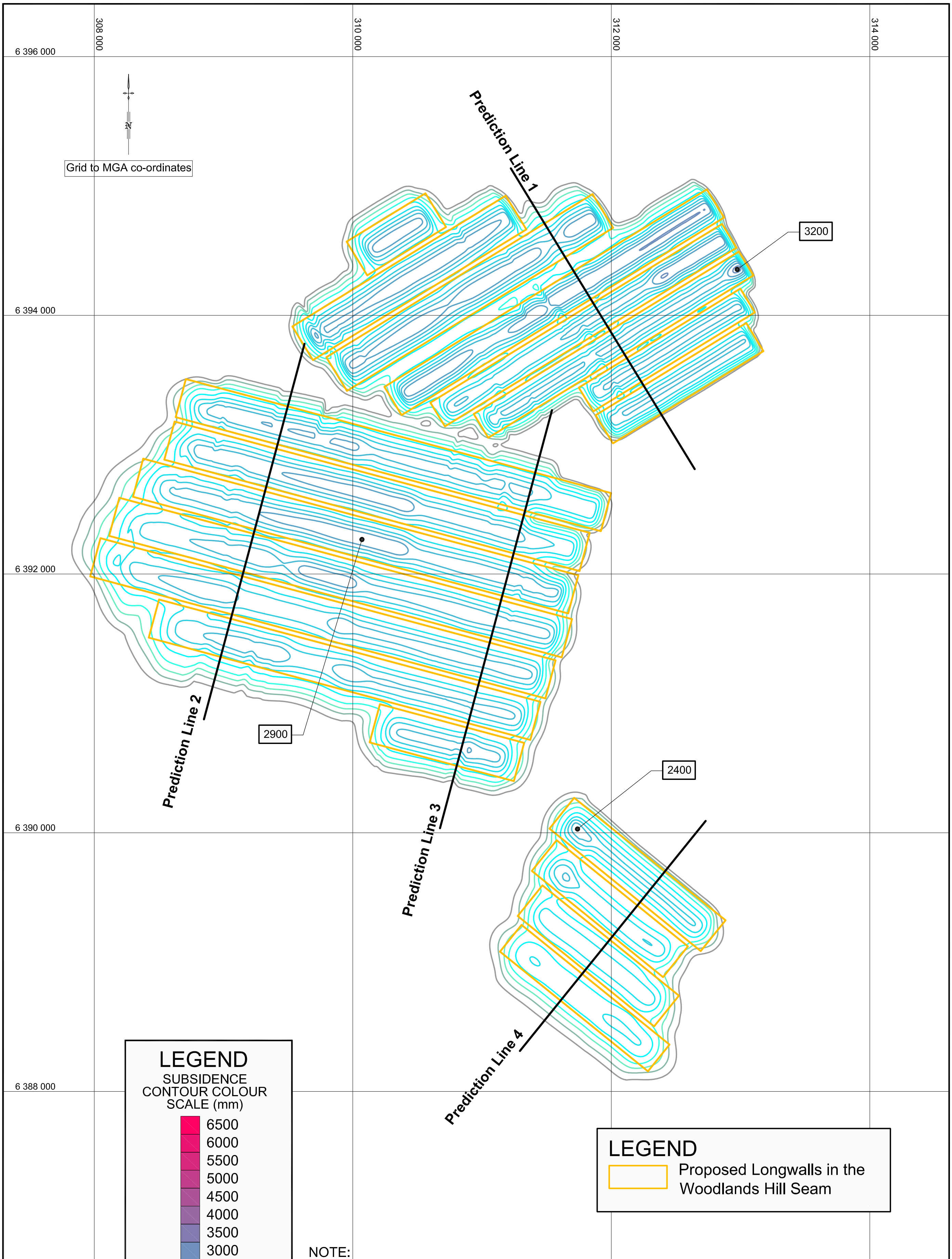
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

BUILT FEATURES

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-15	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-16.dwg



NOTE:
The value of the Subsidence Contours, from the outside to the inside of the panels, are 20mm, 50mm, 100mm, 200mm, 500mm and so forth, in 500mm increments.

2900 Denotes maximum predicted subsidence above longwalls (mm).

msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

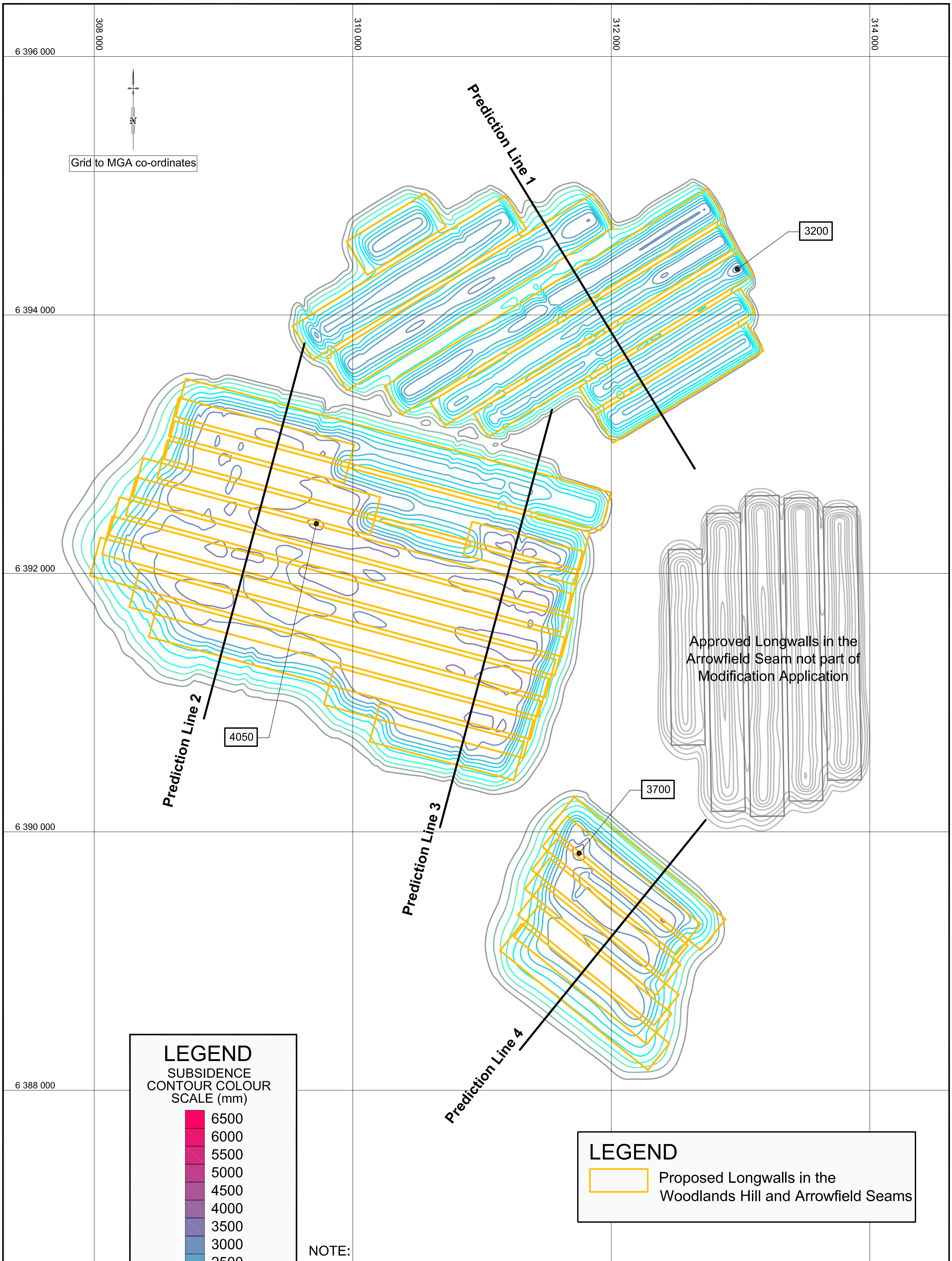
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

PREDICTED ADDITIONAL SUBSIDENCE CONTOURS DUE TO THE WOODLANDS HILL SEAM ONLY

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-16	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-17.dwg



LEGEND

SUBSIDENCE CONTOUR COLOUR SCALE (mm)

6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
200
100
50
20

LEGEND

Proposed Longwalls in the Woodlands Hill and Arrowfield Seams

NOTE:
The value of the Subsidence Contours, from the outside to the inside of the panels, are 20mm, 50mm, 100mm, 200mm, 500mm and so forth, in 500mm increments.

2900 Denotes maximum predicted subsidence above longwalls (mm).

msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

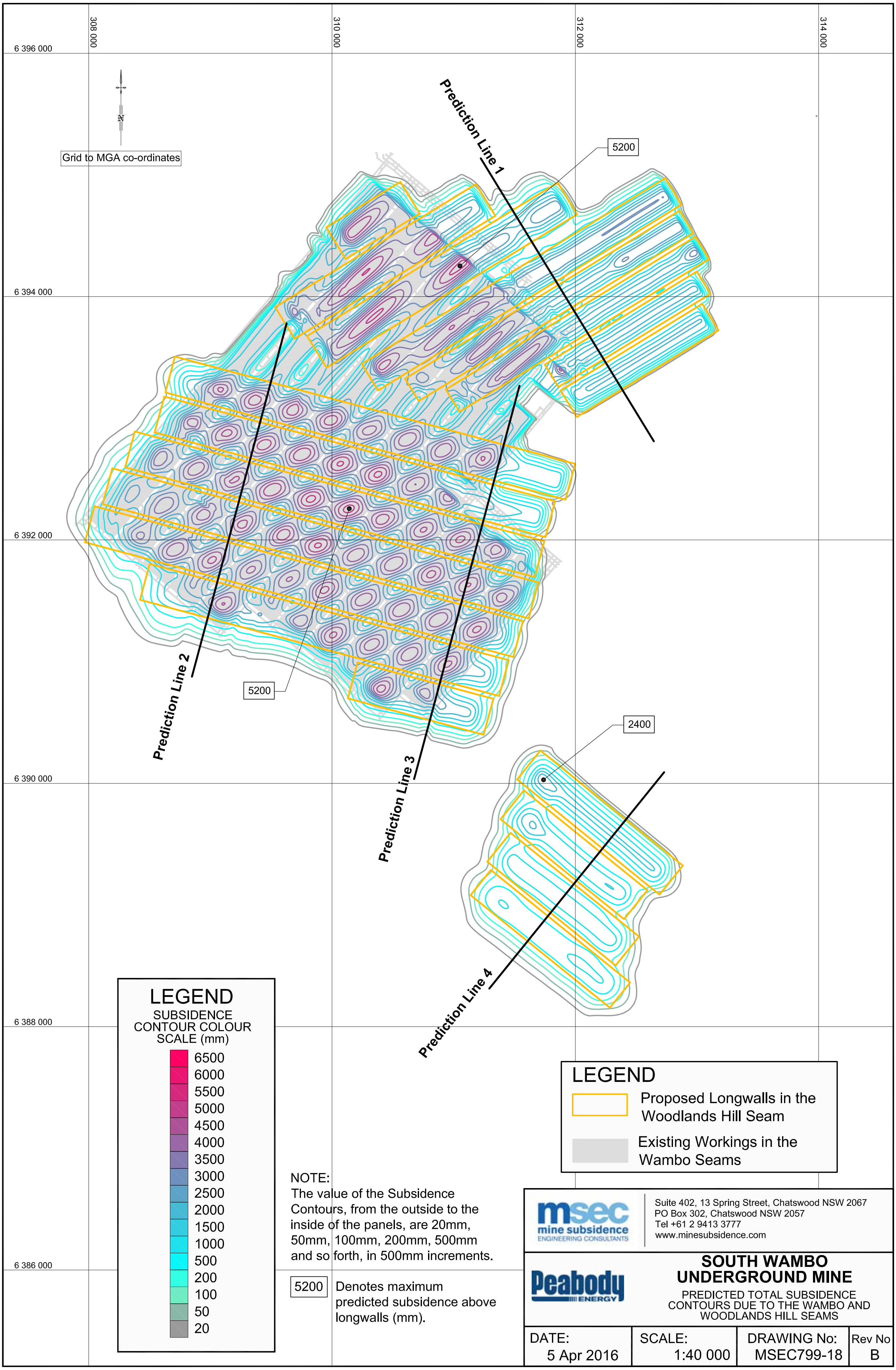
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

PREDICTED ADDITIONAL SUBSIDENCE CONTOURS DUE TO THE WOODLANDS HILL AND ARROWFIELD SEAMS

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-17	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-18.dwg



NOTE:
The value of the Subsidence Contours, from the outside to the inside of the panels, are 20mm, 50mm, 100mm, 200mm, 500mm and so forth, in 500mm increments.

5200 Denotes maximum predicted subsidence above longwalls (mm).

msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

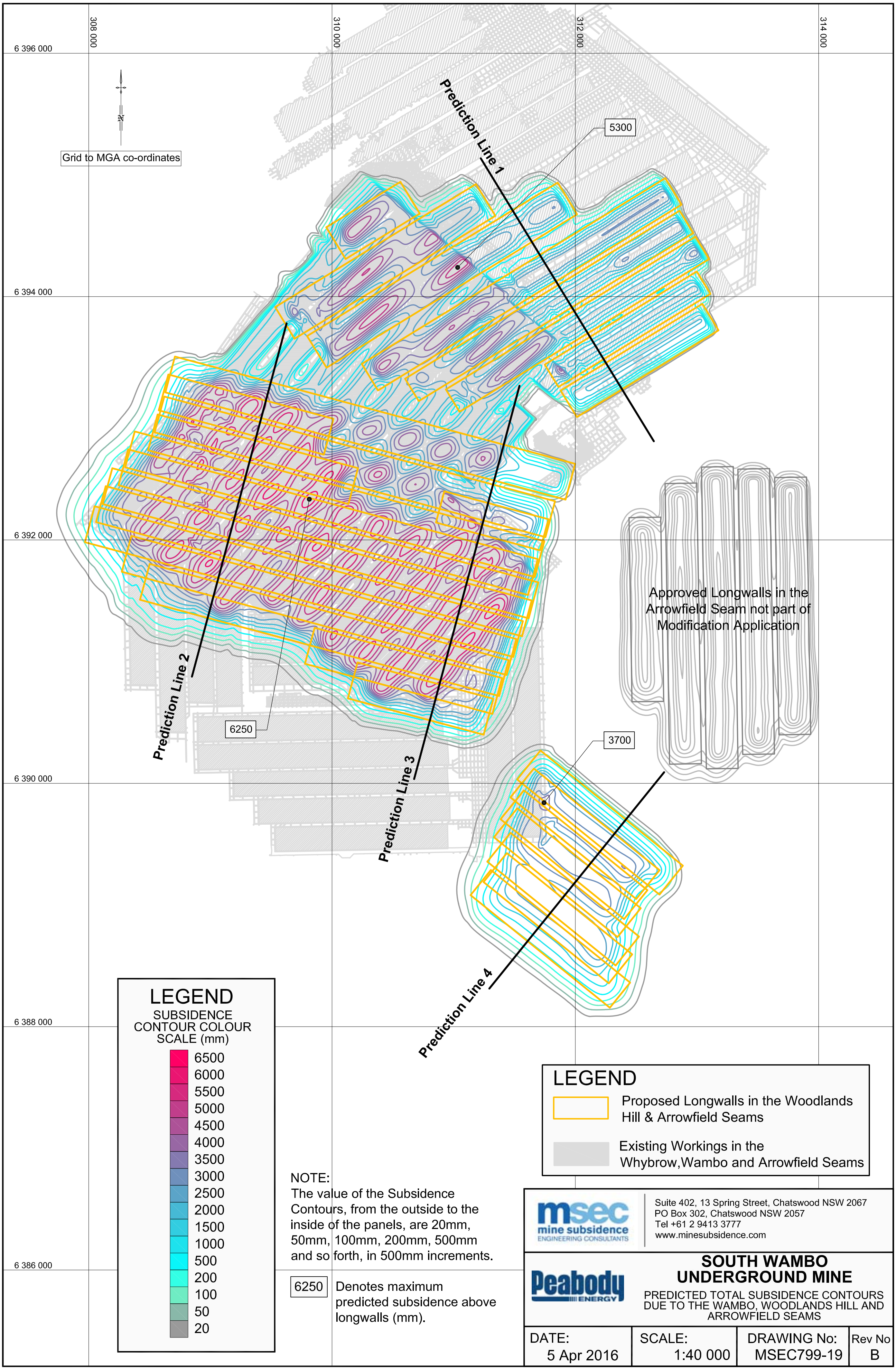
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

PREDICTED TOTAL SUBSIDENCE CONTOURS DUE TO THE WAMBO AND WOODLANDS HILL SEAMS

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-18	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-19.dwg



msec mine subsidence ENGINEERING CONSULTANTS
Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

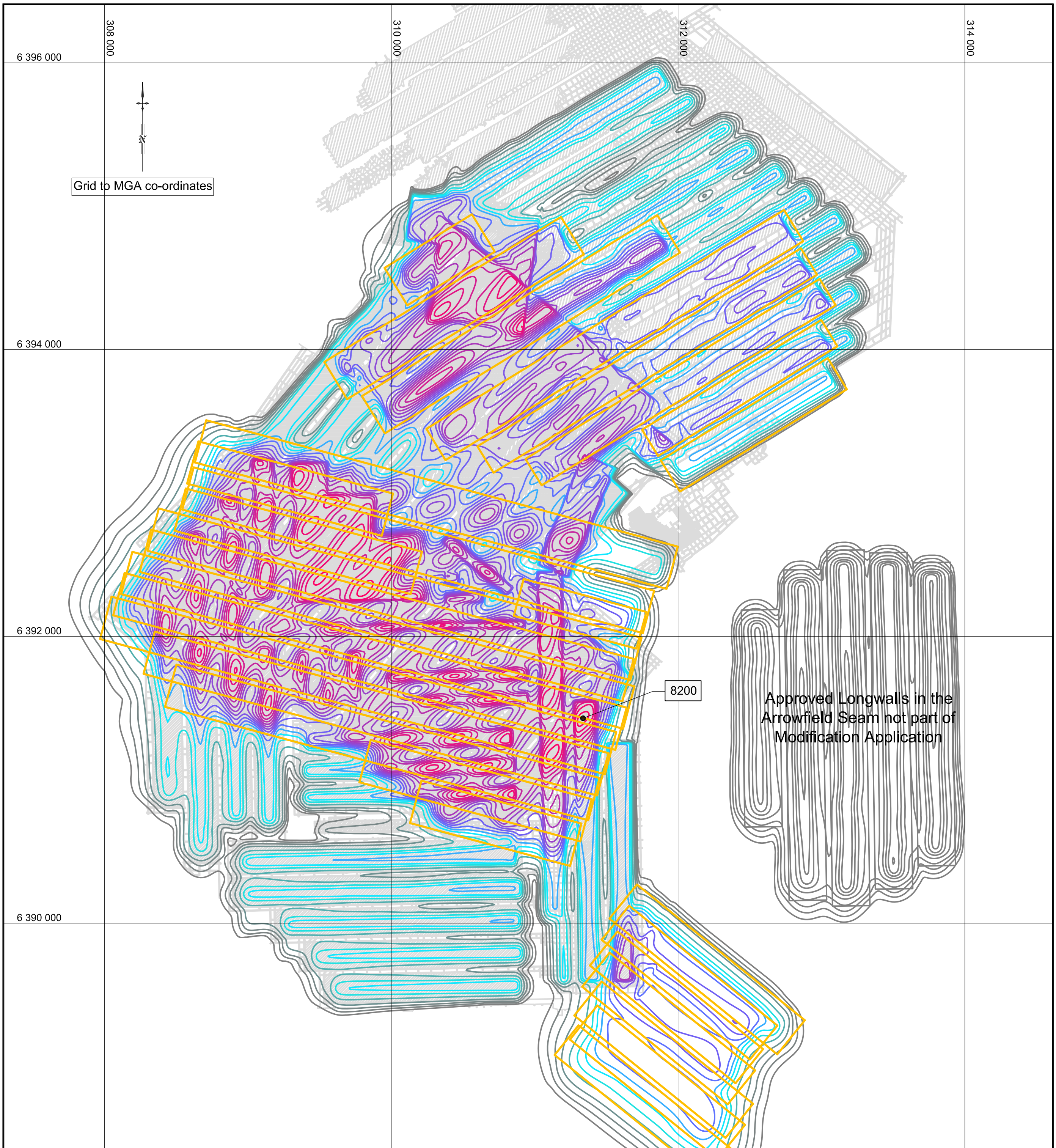
Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

PREDICTED TOTAL SUBSIDENCE CONTOURS DUE TO THE WAMBO, WOODLANDS HILL AND ARROWFIELD SEAMS

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-19	B

I:\Projects\Wambo\MSEC799 - South Wambo Underground\AcadData\MSEC799-20.dwg



LEGEND

SUBSIDENCE CONTOUR COLOUR SCALE (mm)

9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
200
100
50
20

NOTE:
The value of the Subsidence Contours, from the outside to the inside of the panels, are 20mm, 50mm, 100mm, 200mm, 500mm and so forth, in 500mm increments.

8200 Denotes maximum predicted subsidence above longwalls (mm).

LEGEND

Proposed Longwalls in the Woodlands Hill & Arrowfield Seams

Existing Workings in the Whybrow, Wambo and Arrowfield Seams

msec mine subsidence ENGINEERING CONSULTANTS

Suite 402, 13 Spring Street, Chatswood NSW 2067
PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
www.minesubsidence.com

Peabody ENERGY

SOUTH WAMBO UNDERGROUND MINE

PREDICTED TOTAL SUBSIDENCE CONTOURS DUE TO THE WHYBROW, WAMBO, WOODLANDS HILL AND ARROWFIELD SEAMS

DATE:	SCALE:	DRAWING No:	Rev No
5 Apr 2016	1:40 000	MSEC799-20	B