WAMBO COAL PTY LIMITED

SOUTH BATES UNDERGROUND MINE

EXTRACTION PLAN
LONGWALLS 11 TO 16

REPORT 1
SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

WAMBO COAL:

South Bates Underground Mine Subsidence Assessment

Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan for WYLW11 to WYLW13 in the Whybrow Seam and WMLW14 to WMLW16 in the Wambo Seam

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Report produced to: Support the Extraction Plan for the South Bates WYLW11 to WYLW13 in the Whybrow Seam and WMLW14 to WMLW16 in the Wambo Seam

Previous reports: Report No. MSEC692 (Rev. A) – South Bates (Whybrow Seam) Subsidence Assessment – Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan for Longwalls 11 to 13 in the Whybrow Seam.

Report No. MSEC693 (Rev. A) – South Bates (Wambo Seam) Subsidence Assessment – Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Modification Application for Longwalls 14 to 16 in the Wambo Seam.

Report No. MSEC804 (Rev. A) – Addendum to South Bates (Whybrow Seam) Subsidence Assessment – The Effects of the Modified Commencing End of Longwall 11 on the Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan for Longwalls 11 to 13 in the Whybrow Seam.

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

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*, in February 2004, which included the extraction of longwalls in the Whybrow, Wambo, Arrowfield and Bowfield Seams.

The Development Consent (DA 305-7-2003, as modified) allows for the extraction of Longwalls 11 to 13 in the Whybrow Seam (WYLW11 to WYLW13) and Longwalls 14 to 16 in the Wambo Seam (WMLW14 to WMLW16) in the *South Bates Underground Mine* mining area of the Wambo Coal Mine.

WCPL is updating the approved Extraction Plan for WYLW11 to WYLW13 to include WMLW14 to WMLW16. The longwalls have been slightly modified including the shortened commencing ends of WYLW12, WYLW13 and WMLW14, slightly lengthened finishing end of WMLW14 and slightly shortened finishing end of WMLW16. The longwalls in the Wambo Seam are also proposed to be extracted in reverse order, from the south-eastern most longwall to the north-western most longwall.

Mine Subsidence Engineering Consultants (MSEC) has been engaged by WCPL to prepare an updated subsidence assessment report for WYLW11 to WYLW13 and WMLW14 to WMLW16 based on the *Revised Layout*. This report has been prepared to support the updated Extraction Plan for these longwalls that will be submitted to the Department of Planning and Environment (DP&E).

The maximum predicted subsidence parameters for WYLW11 to WYLW13 and WMLW14 to WMLW16, based on the Revised Layout, are the same as the maxima previously provided in Reports Nos. MSEC692, MSEC693 and MSEC804, which supported the approved Extraction Plan and Modification Application.

The predicted total subsidence movements resulting from mining in both the Whybrow and Wambo Seams are 4,150 mm vertical subsidence, 100 mm/m tilt (i.e. 10 %, or 1 in 10) and greater than 3.0 km^{-1} curvature (i.e. a minimum radius of curvature less than 0.3 km). The maximum predicted total subsidence parameters occur above the north-eastern parts of the longwalls, where the depths of cover are the shallowest.

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

A number of natural and built features have been identified within or in the vicinity of the Study Area including: Stony Creek and ephemeral drainage lines; the North Wambo Creek Diversion; the Wollemi Escarpment; other cliffs, minor cliffs and pagodas; steep slopes; the Wollemi National Park; unsealed tracks and trails; mine infrastructure such as the Bates South Open Cut Pit (part of the Wambo Coal Mine), exploration drill holes and a water pipeline; archaeological sites; and survey control marks.

The maximum predicted subsidence parameters for the natural and built features, based on the Revised Layout, are generally similar to or less than the maxima previously provided in Reports Nos. MSEC692, MSEC693 and MSEC804. The predicted subsidence parameters slightly increase for some surface features, but these changes are generally less than 5 %.

The assessed potential for impacts for the natural and built features, therefore, are the same or less than those provided in Reports Nos. MSEC692, MSEC693 and MSEC804, which supported the approved Extraction Plan and Modification Application. The recommended management strategies for these features do no change.

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.

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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*, in February 2004, which included the extraction of longwalls in the Whybrow, Wambo, Arrowfield and Bowfield Seams.

The Development Consent (DA 305-7-2003, as modified) allows for the extraction of Longwalls 11 to 13 in the Whybrow Seam (WYLW11 to WYLW13) and Longwalls 14 to 16 in the Wambo Seam (WMLW14 to WMLW16) in the *South Bates Underground Mine* mining area of the Wambo Coal Mine.

WCPL has an approved Extraction Plan for WYLW11 to WYLW13. Mine Subsidence Engineering Consultants (MSEC) prepared Report No. MSEC692 (Rev. A) that provided the subsidence predictions and impact assessments for these longwalls in support of the Extraction Plan Application.

The subsidence predictions and impact assessments for WMLW14 to WMLW16 are provided in Report No. MSEC693 (Rev. A) that supported the Modification Application for these longwalls (DA 305-7-2003 MOD 15).

The commencing end of WYLW11 was subsequently shortened by 363 m from that indicated in the approved Extraction Plan and Report No. MSEC692. MSEC prepared Report No. MSEC804 (Rev. A) that provided the subsidence predictions and impact assessments in support of the amendment to the Extraction Plan.

The longwall layout adopted in Reports Nos. MSEC693 and MSEC804 (i.e. including the shortened end of WYLW11) is referred to as the *Previous Layout* in this report.

WCPL is updating the Extraction Plan to include WYLW11 to WYLW13 as well as WMLW14 to WMLW16. The commencing ends of WYLW12 and WYLW13 have been shortened from those indicated in the approved Extraction Plan. The commencing end of WMLW14 has been shortened, the finishing end of WMLW14 has been slightly lengthened (by 23 m) and the finishing end of WMLW16 has been slightly shortened from that indicated in the Modification Application. The longwalls in the Wambo Seam are also proposed to be extracted in reverse order, from the south-eastern most longwall to the north-western most longwall.

The longwall layout adopted in this report, including the modified ends of WYLW12, WLLW13, WMLW14 and WMLW16 and the change in the extraction sequence for the longwalls in the Wambo Seam, is referred to as the *Revised Layout* in this report.

The locations of WYLW11 to WYLW13 and WMLW14 to WMLW16 at the South Bates Underground Mine are shown in Drawing No. MSEC855-01, which together with all other drawings, is included in Appendix E at the end of this report.

MSEC has been engaged by WCPL to prepare an updated subsidence assessment report for WYLW11 to WYLW13 and WMLW14 to WMLW16 based on the Revised Layout. This report has been prepared to support the updated Extraction Plan for these longwalls that will be submitted to the Department of Planning and Environment (DP&E).

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 WYLW11 to WYLW13 and WMLW14 to WMLW16, including the cumulative multi-seam effects.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16.

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.

WYLW11 to WYLW13 and WMLW14 to WMLW16 and the Study Area, as defined in Section 2.1, have been overlaid on an orthophoto of the area, which is shown in Fig. 1.1. The boundary of the Wollemi National Park has also been shown in this figure.

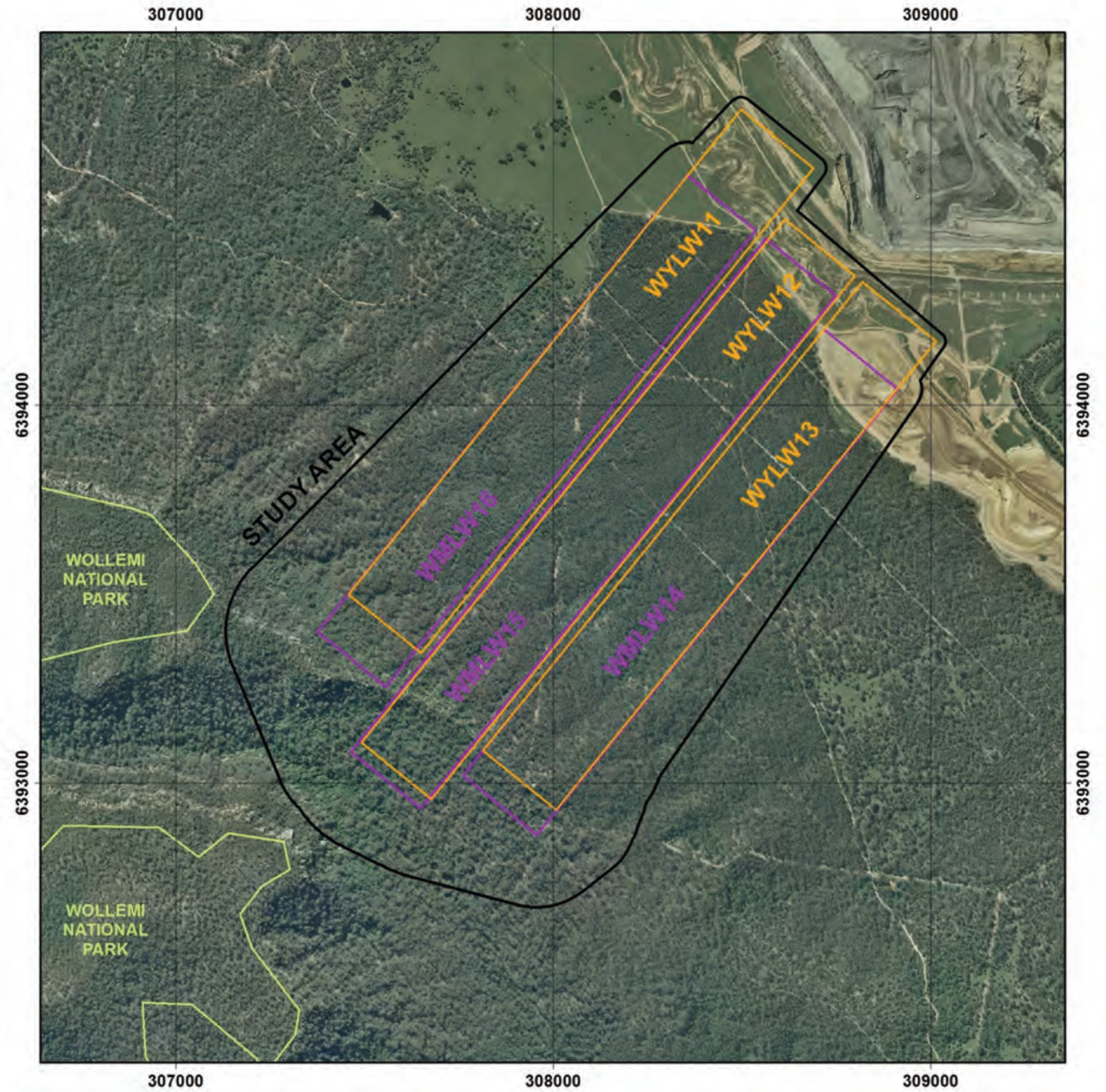

Fig. 1.1 Aerial Photograph Showing Locations of WYLW11 to WYLW13 in the Whybrow Seam and WMLW14 to WMLW16 in the Wambo Seam and the Study Area

1.2. Mining Geometry

The overall layout of the longwalls at the South Bates Underground Mine are shown in Drawing No. MSEC855-01. The layout of WYLW11 to WYLW13 is shown in Drawing No. MSEC855-02 and the layout of WMLW14 to WMLW16 is shown in Drawing No. MSEC855-03. A summary of the dimensions for these longwalls based on the Revised Layout is provided in Table 1.1.

Table 1.1 Geometry of WYLW11 to WYLW13 and WMLW14 to WMLW16

Seam	Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
Whybrow Seam	WYLW11	1,653	248	-
	WYLW12	1,784	238	27
	WYLW13	1,599	251	25
Wambo Seam	WMLW14	1,521	251	-
	WMLW15	1,749	238	32
	WMLW16	1,557	233	36

The commencing (i.e. south-western) ends of WYLW12 and WYLW13 have been shortened by 79 m and 378 m, respectively, from those previously indicated in the approved Extraction Plan and Report Nos. MSEC692 and MSEC804.

The longwalls in the Wambo Seam are proposed to be extracted in reverse order from that indicated in the Modification Application and Report No. MSEC693, from the south-eastern most longwall (i.e. WMLW14 previously referred to as WMLW16) to the north-western most longwall (i.e. WMLW16 previously referred to as WMLW14).

The commencing (i.e. south-western) end of WMLW14 has been shortened by 243 m from that previously indicated for WMLW16 in the Modification Application and Report No. MSEC693. The finishing (i.e. north-eastern) end of this longwall has also been slightly lengthened by 23 m. The finishing end of WMLW16 has been slightly shortened by 13 m from that previously indicated for WMLW14 in the Modification Application and Report No. MSEC693.

The lengths of longwall extraction (i.e. excluding the installation heading) are approximately 9 m shorter than the overall void lengths indicated in Table 1.1. The widths of the longwall extraction faces (i.e. excluding the first workings) are approximately 11 m narrower than the overall void widths indicated in this table.

1.3. Surface and Seam Levels

The surface levels and the levels for the Whybrow and Wambo Seams are illustrated along Cross-sections 1 to 3 and along Long-section 1 in Fig. 1.2 to Fig. 1.5 below. The locations of these sections are shown in Drawings Nos. MSEC855-04 to MSEC855-06, MSEC855-08 and MSEC855-09.

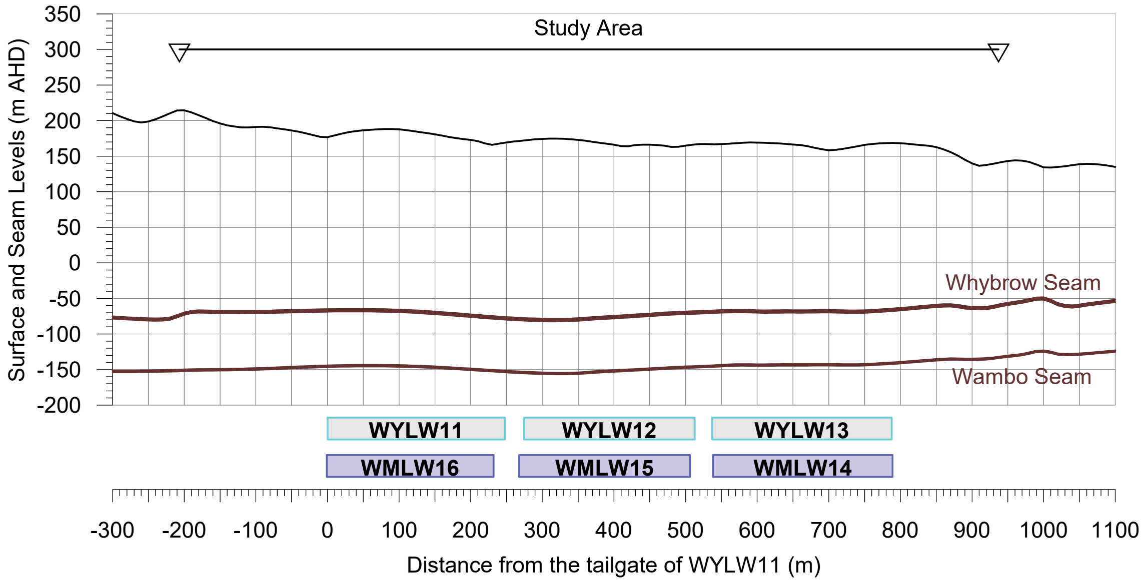

Fig. 1.2 Surface and Seam Levels along Cross-section 1

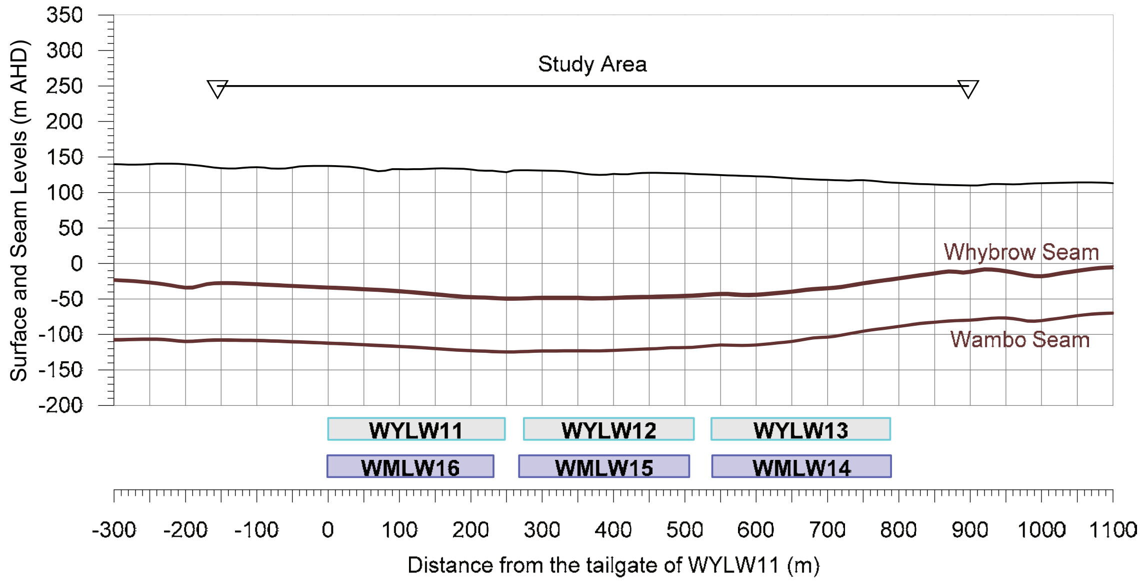

Fig. 1.3 Surface and Seam Levels along Cross-section 2

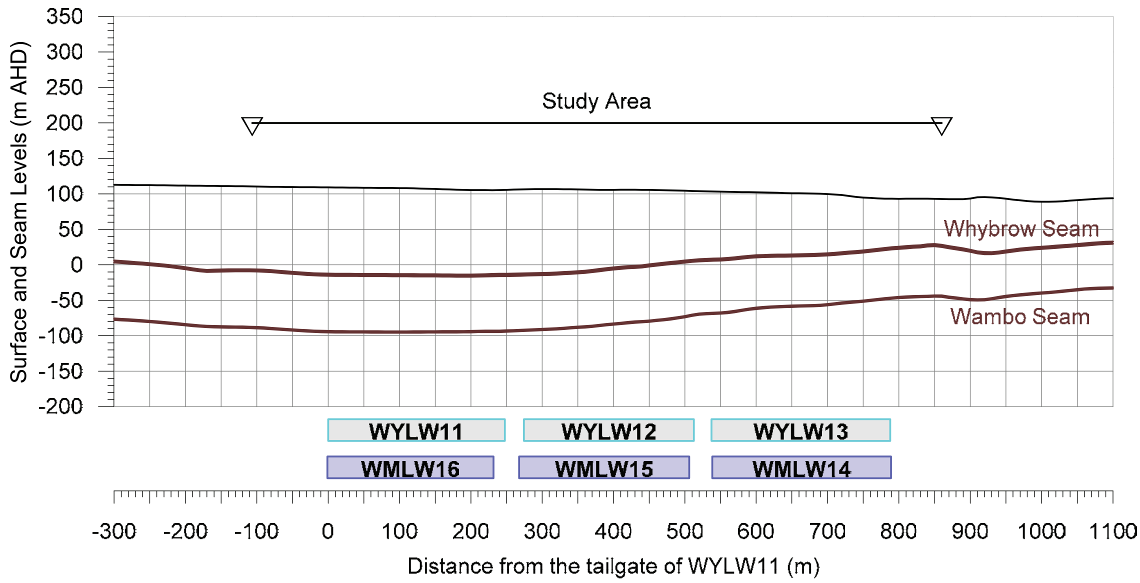

Fig. 1.4 Surface and Seam Levels along Cross-section 3

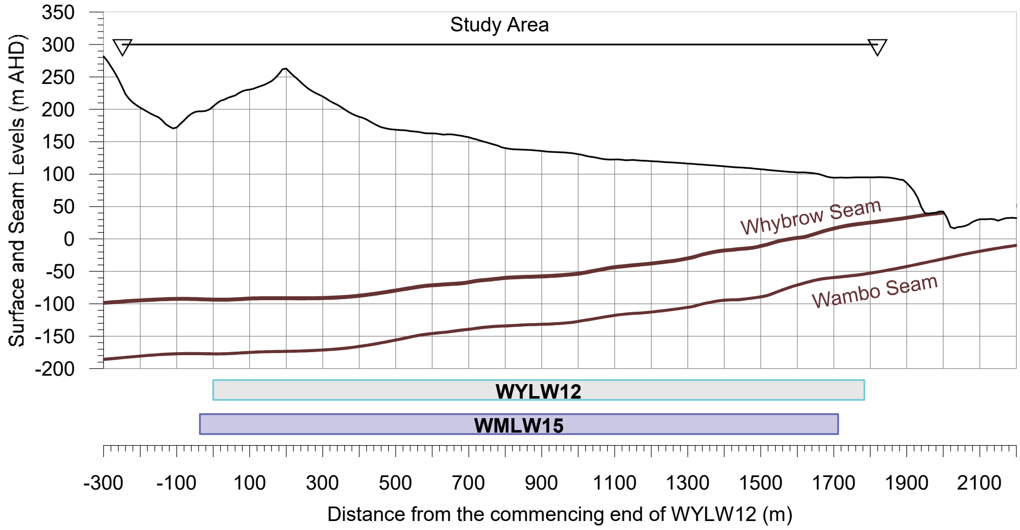

Fig. 1.5 Surface and Seam Levels along Long-section 1

The surface level contours in the vicinity of the longwalls are shown in Drawing No. MSEC855-04. The major natural topographical feature in area is the Wollemi Escarpment, which is located immediately to the south-west of the longwalls. A ridgeline off the main escarpment crosses above the south-western ends of the longwalls. The Bates South Open Cut Pit is located immediately to the north-east of the longwalls.

The surface levels directly above the longwalls vary from a high point of 300 m above Australian Height Datum (mAHD) above the commencing (i.e. south-western) end of WMLW16, to a low point of 90 mAHD at the finishing (i.e. north-eastern) end of WYLW13.

The seam floor contours, seam thickness contours and depth of cover contours for the Whybrow Seam are shown in Drawings Nos. MSEC855-05, MSEC855-06, and MSEC855-07, respectively. The depths of cover to the Whybrow Seam directly above the longwalls vary between a minimum of 55 m above the finishing (i.e. north-eastern) end of WYLW13 and a maximum of 375 m near the commencing (i.e. south-western) end of WYLW12.

The thickness of the Whybrow Seam within the extents of the longwalls varies between 2.9 and 3.6 m. WCPL is proposing to extract a constant height of 3.0 m.

The seam floor contours, seam thickness contours and depth of cover contours for the Wambo Seam are shown in Drawings Nos. MSEC855-08, MSEC855-09, and MSEC855-10, respectively. The depths of cover to the Wambo Seam directly above the longwalls vary between a minimum of 130 m above the finishing (i.e. north-eastern) end of WMLW14 and a maximum of 480 m above the commencing (i.e. south-western) end of WMLW16.

The thickness of the Wambo Seam within the extents of the longwalls varies between 1.85 and 2.15 m. WCPL is proposing to extract a constant height of 2.1 m in the Wambo Seam.

The interburden thickness contours between the Whybrow and Wambo Seams are shown in Drawing No. MSEC855-11. The interburden thickness within the extents of the longwalls varies between 70 and 80 m.

1.4. Geological Details

The South Bates Underground Mine 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 1.2 (DMR, 1993). It is noted, that the DMR is now referred to as the Department of Industry – Division of Resources and Energy (DRE).

The Whybrow and Wambo Seams both 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 m 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.

Table 1.2 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	

WCPL provided the logs for the boreholes located in the mining area, which are shown in Drawing No. MSEC855-14. The geological section for borehole DDH WA11 (which is located near the middle of the mining area), based on the drill log information provided by *Earth Data* (1997), is provided in Table 1.3.

The overburden to the Whybrow and Wambo Seams predominately comprises of interbedded sandstone and siltstone layers, with minor claystone, mudstone, shale, tuffaceous and coal layers throughout the overburden. The larger layers include a 25 m thick conglomerate unit near the surface and a number of 10 to 20 m thick sandstone units located up to around 60 m above the Whybrow Seam. Otherwise, the bedding thicknesses are typically less than 10 m throughout the overburden.

Other boreholes within the mining area indicate the presence of some larger sandstone units with thicknesses up to 20 m located at depths of cover typically ranging between 50 m and 100 m. The available boreholes indicate that the roof of the Whybrow Seam predominately comprises sandstone and that the floor of the seam comprises interbedded mudstone, sandstone and siltstone. The immediate roof and the floor of the Wambo Seam predominately comprise interbedded mudstone, sandstone and siltstone.

No adjustment factors have been applied in the subsidence prediction model for any massive strata units or for softer floor conditions, with the longwalls in the Whybrow and Wambo Seams predicted to achieve the maximum subsidence for single and multi-seam mining conditions, respectively.

Table 1.3 Geological Section of Borehole DDH WA11 (Earth Data, 1997)

Depth (m)	Thickness (m)	Lithology	Geological Description
0 ~ 1	1	Clay	Red brown, gritty
1 ~ 26	25	Conglomerate	Light grey brown, partly weathered, medium grained sand matrix, minor course grained siltstone interbeds
26 ~ 26.5	0.5	Coal	Approximate base of weathering
26.5 ~ 27.5	1	Sandstone	Grey, very fine grained to, silty
27.5 ~ 29	1.5	Conglomerate	Light grey, minor fine grained siltstone interbeds
29 ~ 31.5	2.5	Coal	Dull minor bright, very minor claystone and mudstone
31.5 ~ 32	0.5	Mudstone	Grey
32 ~ 34.5	2.5	Claystone	Cream, puggy, tuffaceous, very soft
34.5 ~ 35	0.5	Coal	Dull
35 ~ 36.5	1.5	Siltstone	Grey, sandy in part, hard
36.5 ~ 39	2.5	Sandstone	Grey to light grey, fine to medium grained, hard
39 ~ 41.5	2.5	Coal	Dull minor bright
41.5 ~ 57.5	16	Interbedded Sandstone and Siltstone	Light grey, medium to fine grained sandstone interbedded with dark grey shaley, occasionally coaly laminae, moderately hard siltstone.
57.5 ~ 70	2.5	Interbedded Shale, Coal and Sandstone	Dark grey, silty shale with dull coal interbedded with light grey, fine to medium grained, hard sandstone
70 ~ 80	10	Interbedded Sandstone and Claystone	Light grey, medium grained sandstone interbedded with cream, tuffaceous, soft, silty claystone
80 ~ 88	8	Interbedded Coal and Shale	Dull minor bright coal interbedded with dark to light grey, silty, fine grained shale
88 ~ 104	16	Interbedded Sandstone and Shale	Light grey, fine to medium grained, hard sandstone interbedded with dark grey, silty shale with coal laminae
104 ~ 115.5	11.5	Sandstone with Coal Bands	Light grey, fine to medium grained, very minor carbonaceous and tuffaceous laminae with coal bands
115.5 ~ 117.5	2	Interbedded Claystone, Siltstone and Sandstone	Tuffaceous, moderately soft claystone interbedded with light grey, fine grained siltstone, and light grey, fine grained sandstone
117.5 ~ 134.5	17	Claystone	Tuffaceous, interbedded, silty at top and sandy at base
134.5 ~ 142	7.5	Interbedded Claystone and Coal	Tuffaceous claystone interbedded with dull minor bright coal
142 ~ 170	28	Sandstone	Grey brown, grey, light grey to white, fine to very fine grained, pebbly conglomerate phases, tuffaceous, occasional claystone laminae
170 ~ 183	13	Mudstone	Grey, silty, interbedded
183 ~ 195.5	12.5	Sandstone	Light grey, fine grained, interbedded
195.5 ~ 200	4.5	Siltstone	Dark grey, laminated, moderately hard, interbedded
200 ~ 204.5	4.5	Sandstone	Light grey, very fine grained, thinly interlaminated, hard
204.5 ~ 205	0.5	Siderite	Dark brown to grey, brittle, calcite veining in parts
205 ~ 216.5	11.5	Shale	Dark grey, clayey, occasional very fine sandstone laminae
216.5 ~ 228	11.5	Sandstone	Light grey to white, fine grained, hard, occasional coarse grained and conglomerate interbeds at top and base, mainly massive
228 ~ 230	2	Coal	**Whybrow Seam**
230 ~ 236	6	Interbedded mudstone, sandstone and siltstone	Grey to light grey, occasional coal laminae
236 ~ 248	12	Siltstone	Finely laminated, occasional siderite phases, moderately hard
248 ~ 251	3	Interbedded Sandstone and Mudstone	Grey, very fine to fine grained, shaly, hard, laminated in parts by carbonaceous tracings
251 ~ 252	1	Siltstone	Grey, laminated in parts, moderately hard
252 ~ 268	16	Coal	Redbank Creek Seam with interbedded claystone, mudstone and shale layers and intermediate split
268 ~ 276	8	Interbedded Sandstone, Siltstone and Mudstone	Light grey, medium course grained sandstone, finely laminated in parts, occasional carbonaceous tracings and coaly wisps
276 ~ 301	25	Sandstone	Light grey, fine to coarse grained, occasionally silty interlaminations and thin beds
301 ~ 301.5	0.5	Mudstone	Grey, silty in part, sandy bed in midsection, moderately hard, occasionally coaly laminae
301.5 ~ 303.5	2	Coal	**Wambo Seam**

The geological features that have been identified at seam level are shown in Drawing No. MSEC855-12. The largest structure in the area is the *Redmanvale Fault* having a throw greater than 20 m. This fault is located more than 750 m south-west of the longwalls and, therefore, is unlikely to have any significant effect on the subsidence movements.

There is a series of north-northeast (NNE) to south-southwest (SSW) trending faults within and adjacent to the mining area with throws between 0.5 and 1 m. Some larger faults have been identified to the north-west and to the south-east of the longwalls with throws ranging between 3 and 12 m.

No adjustment factors have been applied in the subsidence prediction model for these minor faults, as the longwalls are generally supercritical in width and, therefore, are predicted to achieve the maximum subsidence for single and multi-seam mining conditions. These faults could result in slightly increased subsidence adjacent to the longwalls, above solid coal, but this low level subsidence is not predicted to be associated with any significant strains.

The surface lithology in the area can be seen in Fig. 1.6, which shows the longwalls and the Study Area overlaid on the *Geological Map of Doyles Creek 9032-1-N*, which was published by the DMR (1988), now known as DRE.

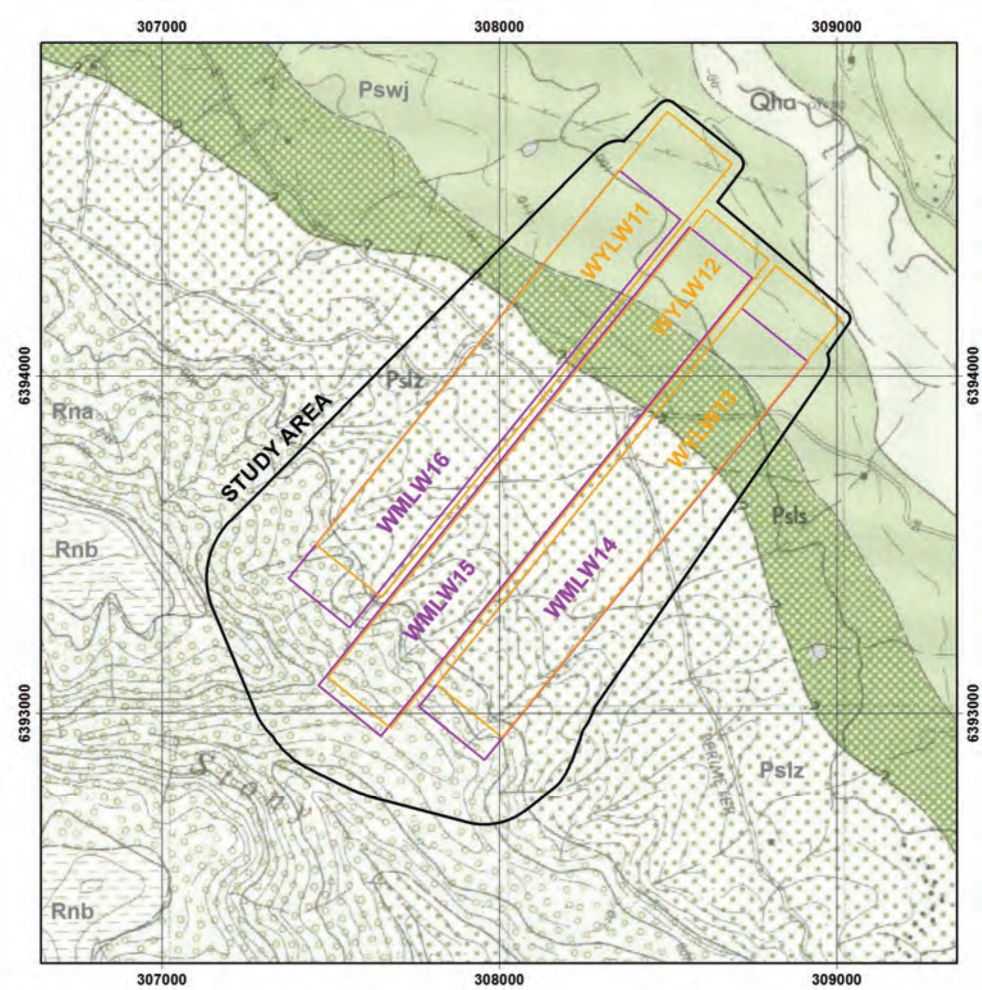

Fig. 1.6 The Longwalls Overlaid on Geological Map Doyles Creek 9032-1-N

The surface lithology above the north-eastern ends of the longwalls generally comprises the Jerrys Plains Subgroup of the Wittingham Coal Measures (Pswj) and the Watts Sandstone (Psls), above the middle parts of the longwalls comprises the overlying subgroups from the Newcastle Coal Measures (Pslz), and above the south-western ends of the longwalls comprises the Widden Brook Conglomerate (Rna).

The surface lithology above the north-eastern ends of the longwalls has been modified by the construction of the North Wambo Creek Diversion, due to the excavation and the placement of backfill. It is not expected that the predicted subsidence movements in this location would be affected by these surface earthworks.

2.1. Definition of the Study Area

The Study Area for this assessment is defined as the surface area that is likely to be affected by the mining of WYLW11 to WYLW13 in the Whybrow Seam and WMLW14 to WMLW16 in the Wambo Seam. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:

- the 26.5° angle of draw line from the extents of WYLW11 to WYLW13;
- the 26.5° angle of draw line from the extents of WMLW14 to WMLW16; and
- the predicted limit of vertical subsidence, taken as the additional 20 mm subsidence contour resulting from the extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16.

The 26.5° angle of draw line is described as the "*surface area defined by the cover depths, angle of draw of 26.5 degrees and the limit of the proposed extraction area in mining leases for all other NSW Coalfields*" (i.e. other than the Southern Coalfield), as stated in Section 6.2 of the Guideline for Applications for Subsidence Management Approvals (DMR, 2003).

The depths of cover to the Whybrow Seam vary between 55 and 375 m directly above WYLW11 to WYLW13. The depths of cover to the Wambo Seam vary between 130 and 480 m directly above WMLW14 to WMLW16. The 26.5° angle of draw lines, therefore, have been determined by drawing a line that is a horizontal distance varying between 28 and 240 m around the limits of the extraction areas, based on the depths of cover around the perimeters of the longwalls.

The predicted limit of vertical subsidence, taken as the predicted 20 mm subsidence contour due to the extraction of the WYLW11 to WYLW13 and WMLW14 to WMLW16, has been determined using the Incremental Profile Method (IPM), which is described in Chapter 3. The predicted total subsidence contours due to the extraction of these longwalls, including the predicted 20 mm subsidence contour, are shown in Drawing No. MSEC855-20.

A line has therefore been drawn defining the Study Area, based upon the 26.5° angle of draw lines and the predicted 20 mm subsidence contour, whichever is furthest from the longwalls, and is shown in Drawings Nos. MSEC855-01 to MSEC855-03.

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 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 9032-1-N. The longwalls and the Study Area have been overlaid on an extract of this CMA map in Fig. 2.1. The natural surface along the North Wambo Creek Diversion has been modified from that shown in this figure.

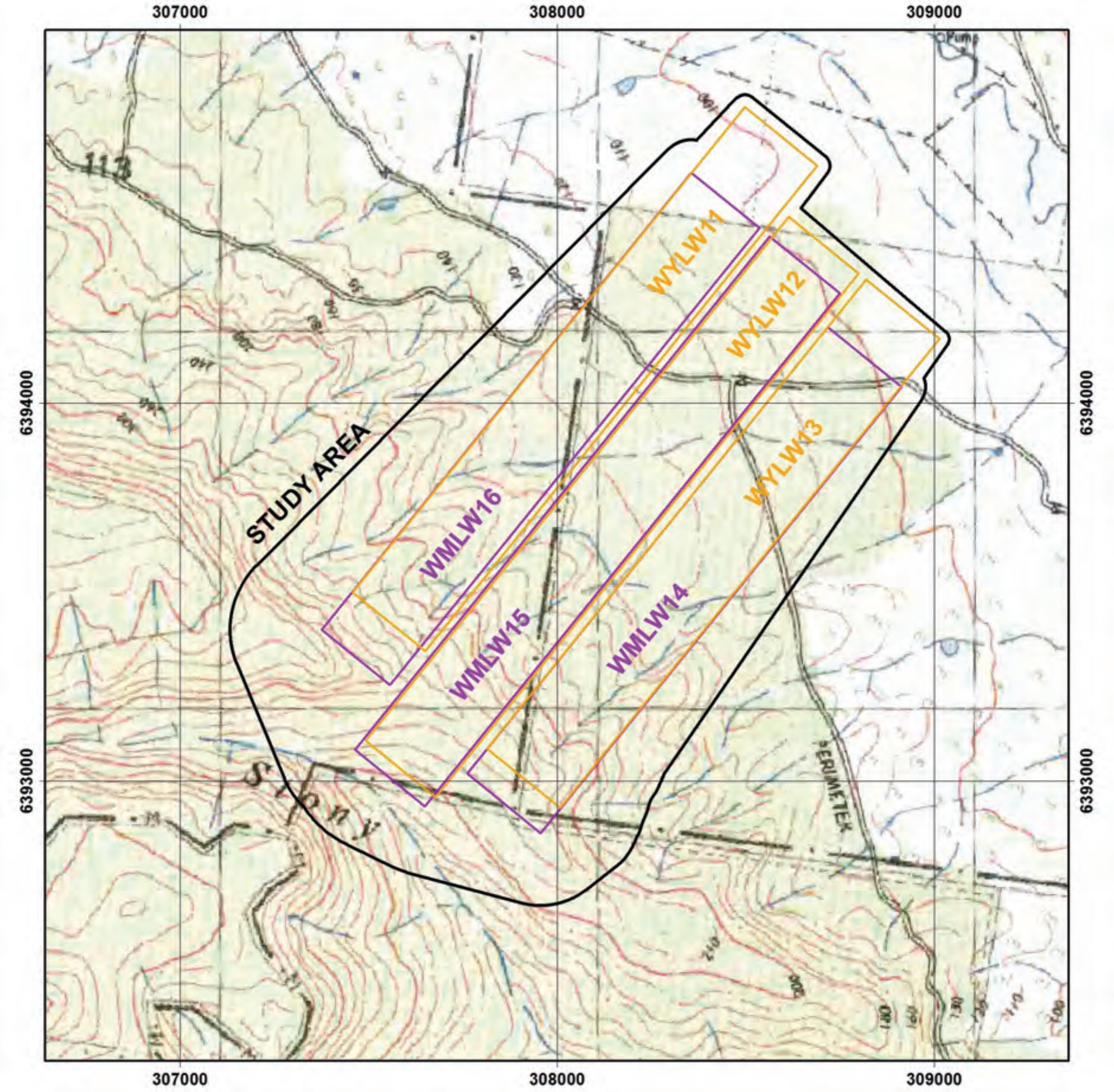

Fig. 2.1 The Longwalls and Study Area Overlaid on CMA Map No. Doyles Creek 9032-1-N

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. MSEC855-13 and MSEC855-14. 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	×	
Springs or Groundwater Seeps	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.6 & 5.7
Steep Slopes	✓	5.8
Escarpments	✓	0
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)	✓	6.1.1
Bridges	×	
Tunnels	×	
Culverts	✓	6.1.1
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	×	
Telecommunication Lines or Associated Plants	×	
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	×	
Farm Buildings or Sheds	×	
Tanks	×	
Gas or Fuel Storages	×	
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	✓	6.3.2
Farm Dams	×	
Wells or Bores	✓	6.3.3
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	✓	6.4.1
Mine Related Infrastructure Including Exploration Bores and Gas Wells	✓	6.4.2 to 6.4.5
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL SIGNIFICANCE	✓	6.5
AREAS OF HISTORICAL SIGNIFICANCE	×	
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	×	6.6
RESIDENTIAL ESTABLISHMENTS		
Houses	×	
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 WYLW11 to WYLW13 and WMLW14 to WMLW16. 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, between 1996 and 1998, after receiving extensive subsidence monitoring data from Centennial Coal for the Cooranbong Life Extension Project (Waddington and Kay, 1998). The subsidence monitoring data from many collieries in the Newcastle and Hunter Coalfields were reviewed and, it was found, that the incremental subsidence profiles resulting from the extraction of individual longwalls were consistent in shape and magnitude where the mining geometries and overburden geologies were similar.

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

Based on the extensive empirical data, MSEC has developed standard subsidence prediction curves for the Southern, Newcastle and Hunter Coalfields. The prediction curves can then be further refined, for the local geology and local conditions, based on the available monitoring data from the area. Discussions on the calibration of the IPM for WMLW14 to WMLW16 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 WMLW14 to WMLW16. 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 IPM, 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

WYLW11 to WYLW13 will be extracted first and there are no existing workings located above or below the Whybrow Seam, i.e. single-seam mining conditions. WMLW14 to WMLW16 will then be subsequently extracted in the Wambo Seam beneath the previously extracted WYLW11 to WYWL13, i.e. multi-seam mining conditions.

The IPM has been calibrated for both single-seam and multi-seam mining conditions using ground monitoring data from the North Wambo Underground Mine (NWUM), part of the Wambo Coal Mine, 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 IPM 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.

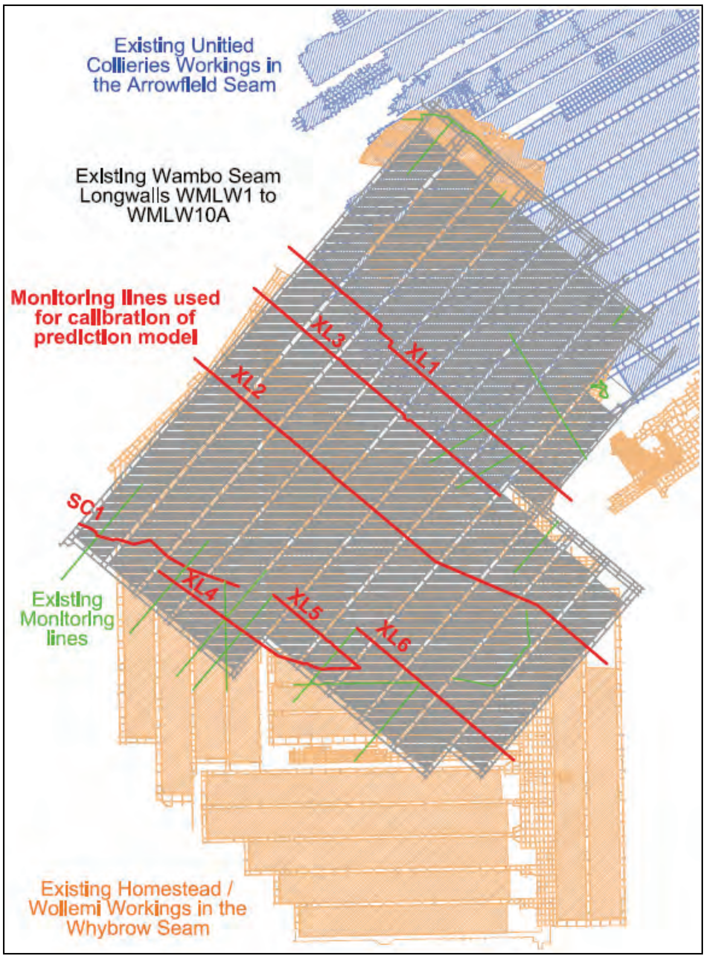

Fig. 3.1 Existing Workings and Monitoring Lines at the NWUM

The following sections describe the calibration of the IPM for single-seam and multi-seam conditions.

3.3.1. Calibration for Single-seam Mining Conditions

The depths of cover to the Whybrow Seam directly above WYLW11 to WYLW13 vary between 55 m above the finishing (i.e. north-eastern) end of WYLW13 and a maximum of 375 m near the commencing (i.e. south-western) end of WYLW12. The longwall width-to-depth ratios vary between 0.7 at the longwall commencing ends and greater than 4 at the longwall finishing ends. The magnitudes of subsidence and the shapes of the subsidence profiles, therefore, will vary considerably over the lengths of these longwalls.

In the north-eastern part of the mining area, the width-to-depth ratios are greater than 1.4 and, therefore, the longwalls are supercritical in width. The maximum predicted subsidence is expected to be the maximum achievable in the Hunter Coalfield for single-seam mining conditions, which has been found to be 60 % to 65 % of the extracted seam thickness. It has been identified, however, that the observed subsidence varies greatly from point to point, at these very shallow depths of cover, as the result of variations in the overburden geology.

In the south-western part of the mining area, the width-to-depth ratios are less than 1.4 and, therefore, the longwalls are subcritical. As a result, the predicted subsidence is expected to be less than the maximum achievable in the Hunter Coalfield and, hence, less than that predicted in the north-eastern part of the mining area. Similarly, the predicted tilts, curvatures and strains in the south-western part of the mining area are less than those predicted in the north-eastern part of the mining area.

The standard IPM for the Hunter Coalfield has been used to predict the mine subsidence movements for the monitoring lines at the Wambo Coal Mine 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 IPM 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 IPM, 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 IPM 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.

The ground movements have also been measured along the 7XL-Line and the CL11B-Line which are located above WYLW11 at the South Bates Mine. The location of these monitoring lines are shown in Drawing No. MSEC855-01. The profiles of observed subsidence, tilt and curvature along the 7XL-Line and the CL11B-Line are shown in C.11 and C.12, respectively, in Appendix C. The predicted movements are also shown in these figures for comparison, based on the predictions provided in Report No. MSEC692, which supported the Extraction Plan for WYLW11 to WYLW13.

The observed profiles of subsidence, tilt and curvature along the 7XL-Line and the CL11B-Line reasonably match those predicted using the standard IPM for the Hunter Coalfield. The observed maximum values are similar to the predicted maxima. There is a very slight lateral shift between the observed and predicted maxima of approximately 10 m along the 7XL-Line.

The observed profile of vertical subsidence along the CL11B-Line is slightly flatter than the predicted profile above the longwall finishing end and, therefore, the observed subsidence is slightly greater than that predicted in this location. There are also low level tilts and curvatures along this monitoring line, directly above WYLW11, due to the irregular ground movements that occur at the shallow depth of cover. The predicted profiles represent the conventional movements and do not include these localised irregular movements.

Based on these comparisons, it is considered that the standard IPM 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 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 IPM 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 WMLW10A in the Wambo Seam at the NWUM. The predictions obtained using the calibrated IPM 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 is 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 is 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 IPM 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 IPM, 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 IPM 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 IPM for multi-seam conditions provides reasonable predictions of subsidence, tilt and curvature in these available cases.

3.4. Reliability of the Predicted Conventional Subsidence Parameters

The IPM 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 IPM has been calibrated using local monitoring data from the NWUM, as well as from other nearby collieries in the Hunter Coalfield. The subsidence model has also been 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 IPM 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.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16, including the multi-seam effects. The predicted subsidence parameters and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

The predicted subsidence, tilt and curvature have been obtained using the IPM, which has been calibrated for multi-seam conditions, as described in Section 3.3. The predicted strains have been determined by analysing the strains measured at the NWUM, and other NSW Collieries, where the mining geometries are similar to those for the longwalls.

The maximum predicted subsidence parameters and the predicted subsidence contours provided in this report describe and show the conventional movements and do not include the valley related upsidence and closure movements, nor the effects of faults and other geological structures. Such effects have been addressed separately in the impact assessments for each feature provided in Chapters 5 and 6.

The reliability of the predictions of subsidence, tilt and curvature, obtained using the IPM, is discussed in Section 3.4.

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

The predicted total conventional subsidence contours after the extraction of each of the WYLW11 to WYLW13 are shown in Drawings Nos. MSEC855-15 to MSEC855-17, in Appendix E. The predicted total subsidence contours after the extraction of each of the WMLW14 to WMLW16, including the multi-seam effects due to the presence of the previously extracted and overlying longwalls, are shown in Drawings Nos. MSEC855-18 to MSEC855-20.

The magnitudes of the predicted subsidence vary between the commencing (i.e. south-western) ends and the finishing (i.e. north-eastern) ends of the longwalls. It can also be inferred from the spacing of the contours shown in these drawings, that the magnitudes of the predicted tilts and curvatures also vary over the lengths of the longwalls.

The variations in the predicted conventional subsidence parameters over the lengths of the longwalls are primarily the result of the changes in the depths of cover, which are illustrated in Drawings Nos. MSEC855-07 and MSEC855-10. To further illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along four prediction lines, the locations of which are shown in Drawings Nos. MSEC855-15 to MSEC855-20.

The predicted profiles of conventional subsidence, tilt and curvature along Prediction Lines 1 to 4, resulting from the extraction of the longwalls, are shown in Figs. D.01 to D.04, respectively, in Appendix D. The predicted total profiles after the extraction of each of the longwalls in the Whybrow Seam are shown as the cyan lines. The predicted total profiles after the extraction of each of the longwalls in the Wambo Seam are shown as blue lines. The predicted final profiles after the extraction of all longwalls based on the Previous Layout are shown as the dashed red lines for comparison.

A summary of the maximum predicted values of conventional subsidence, tilt and curvature along the transverse prediction lines (i.e. 1 to 3), resulting from the extraction of the longwalls in the Whybrow Seam only, is provided in Table 4.1. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature along these prediction lines, resulting from the extraction the longwalls in both the Whybrow and Wambo Seams, is provided in Table 4.2. The maximum predicted subsidence parameters anywhere above the longwalls are also shown in these tables and these occur near the finishing (i.e. north-eastern) ends of the longwalls where the depths of cover are the shallowest.

Table 4.1 Maximum Predicted Conventional Subsidence, Tilt and Curvature Resulting from the Extraction of WYLW11 to WYLW13 Only

Location	Depth of Cover to Whybrow Seam (m)	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Prediction Line 1	225 ~ 255	1,800	20	0.5	0.7
Prediction Line 2	135 ~ 180	1,950	30	0.9	0.9
Prediction Line 3	70 ~ 120	1,950	70	> 3.0	> 3.0
Anywhere above Longwalls	55 ~ 375	1,950	90	> 3.0	> 3.0

Table 4.2 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature Resulting from the Extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16

Location	Depth of Cover to Wambo Seam (m)	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Prediction Line 1	300 ~ 330	3,950	40	0.8	1.2
Prediction Line 2	205 ~ 255	4,050	55	1.2	1.4
Prediction Line 3	140 ~ 200	4,150	85	> 3.0	> 3.0
Anywhere above Longwalls	130 ~ 480	4,150	100	> 3.0	> 3.0

The maximum predicted total subsidence due to the extraction of WYLW11 to WYLW13 only is 1,950 mm and represents 65 % of the mining height of 3.0 m in the Whybrow Seam. The maximum predicted total subsidence due to the extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16 is 4,150 mm and represents 80 % of the total mining height of 5.1 m in both the Whybrow and Wambo Seams. The maximum predicted total subsidence occurs above the north-eastern ends of the longwalls, where the depths of cover are the shallowest.

The maximum predicted total conventional tilt is 100 mm/m (i.e. 10 %) and represents a change in grade of 1 in 10. The maximum predicted total conventional hogging and sagging curvatures are both greater than 3.0 km^{-1} and represent a minimum radius of curvature of less than 0.3 km. The maximum tilts and curvatures occur above the north-eastern ends of the longwalls, where the depths of cover are the shallowest.

4.3. Comparison of Maximum Predicted Conventional Subsidence Parameters

Comparisons of the maximum predicted total conventional subsidence parameters based on the Previous Layout and Revised Layout are provided in Table 4.3 after the completion of the Whybrow Seam and in Table 4.4 after the completion of the Wambo Seam.

Table 4.3 Comparison of Maximum Predicted Subsidence Parameters due to the Extraction of Whybrow Seam Only based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	1,950	90	> 3.0	> 3.0
Revised Layout (Report No. MSEC855)	1,950	90	> 3.0	> 3.0

Table 4.4 Comparison of Maximum Predicted Subsidence Parameters due to the Extraction of the Whybrow and Wambo Seams based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	4,150	100	> 3.0	> 3.0
Revised Layout (Report No. MSEC855)	4,150	100	> 3.0	> 3.0

The maximum predicted subsidence parameters based on the Revised Layout are the same as the maxima predicted based on the Previous Layout. The changes to the longwall commencing and finishing ends and the change in order of extraction in the Wambo Seam has not affected the maximum predicted subsidence parameters.

The locations of the predicted longitudinal tilts and curvatures based on the Revised Layout are in slightly different locations compared with the Previous Layout due to the modified commencing and finishing ends. The longitudinal tilts and curvatures, however, have smaller magnitudes than the maxima that occur transverse to the longwalls.

The surface area affected by subsidence based on the Revised Layout is less than that based on the Previous Layout. This is due to the shortened commencing ends of WYLW12, WYLW13 and WMLW14. The extent of subsidence at the south-western end of the mining area therefore reduces.

Comparisons of the predictions and impact assessments for the natural and built features in the Study Area are provided in Chapters 5 and 6.

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 range of potential strains resulting from the extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16 has been based on strains measured above previously extracted longwalls in the Hunter and Newcastle Coalfields. The monitoring data has been taken from locations where the mining geometry is reasonably similar to those for the longwalls.

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

4.4.1. Analysis of Strains for WYLW11 to WYLW13 (i.e. Single-seam Conditions)

The depths of cover to the Whybrow Seam vary considerably along the lengths of WYLW11 to WYLW13. The predicted strains therefore also vary along the lengths of these longwalls. The distributions of strains have been determined separately at the commencing and finishing ends of WYLW11 to WYLW13.

Distribution of Strain at the Commencing Ends of WYLW11 to WYLW13

The depths of cover near the commencing (i.e. south-western) ends of WYLW11 to WYLW13 typically vary between 200 and 350 m, with only a small area above WYLW12 having depths of cover up to 375 m. The longwall width-to-depth ratios near the longwall commencing ends, therefore, typically range between 0.7 and 1.2. The proposed mining height for the longwalls in the Whybrow Seam is 3.0 m.

The observed ground strains have been analysed for monitoring lines from the Hunter and Newcastle Coalfields, where the longwalls width-to-depth ratios were between 0.7 and 1.2. The seam thicknesses for these monitoring lines typically range between 2.2 and 4.9 m with an average thickness of 4.3 m.

The longwall width-to-depth ratios and seam thicknesses for the monitoring lines used in the strain analysis are similar to those at the commencing ends of WYLW11 to WYLW13. The range of strains determined from the strain analysis should, therefore, provide a reasonable indication of the range of potential strains at the commencing ends of these longwalls.

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

The histograms of the maximum observed tensile and compressive strains for survey bays located directly above goaf, for previously extracted longwalls in the Hunter and Newcastle Coalfields having width-to-depth ratios between 0.7 and 1.2, is provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

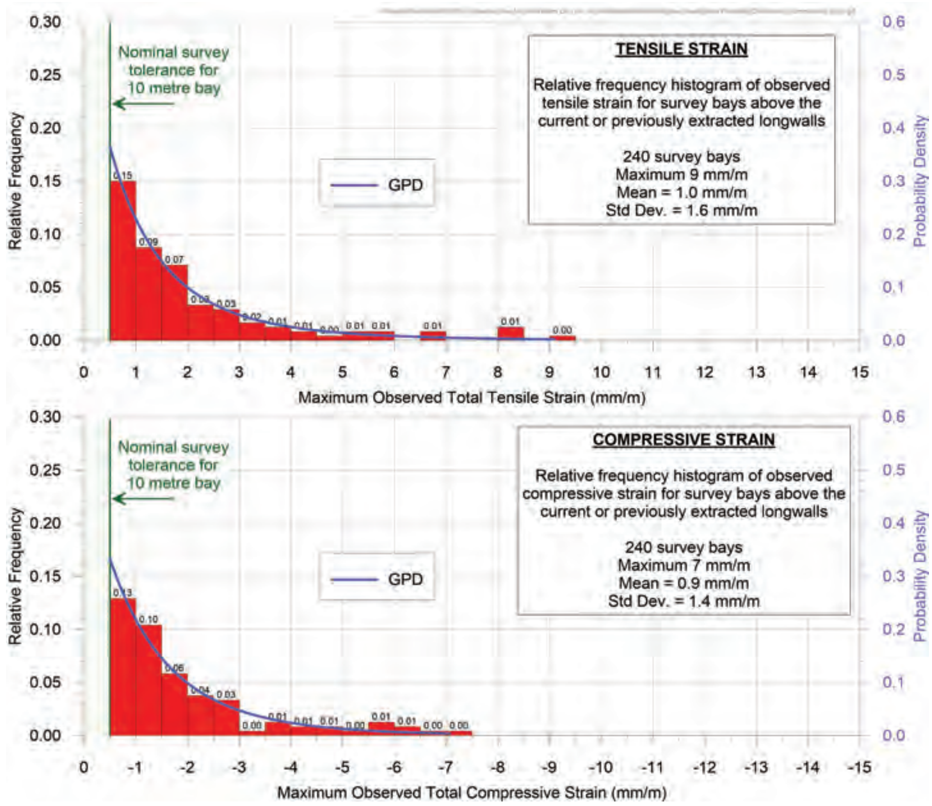

Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located above Longwalls with Width-to-Depth Ratios between 0.7 and 1.2

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 are 4 mm/m tensile and compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 8 mm/m tensile and 6 mm/m compressive.

Distribution of Strain at the Finishing Ends of WYLW11 to WYLW13

The depths of cover at the longwall finishing (i.e. north-eastern) ends of WYLW11 to WYLW13 typically vary between 55 and 150 m. The longwall width-to-depth ratios near the longwall finishing ends, therefore, typically range between 1.6 and greater than 4 and are supercritical in width. The proposed mining height in the Whybrow Seam is 3.0 m.

The observed ground strains have been analysed for monitoring lines from the Hunter and Newcastle Coalfields, where the longwalls have been supercritical in width and where the depths of cover were less than 150 m. The seam thicknesses for these monitoring lines typically range between 2.2 and 3.4 m with an average thickness of 2.7 m.

The longwall width-to-depth ratios and seam thicknesses for the monitoring lines used in the strain analysis are similar to those at the finishing ends of WYLW11 to WYLW13. The range of strains determined from the strain analysis should, therefore, provide a reasonable indication of the range of potential strains at the finishing ends of these longwalls.

The available monitoring lines have been analysed to extract the maximum tensile and compressive strains that have been measured at any time during mining, for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls. GPDs have been fitted to the raw strain data.

The histograms of the maximum observed tensile and compressive strains for survey bays located directly above goaf, for previously extracted supercritical longwalls in the Hunter and Newcastle Coalfields at depths of cover less than 150 m, is provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

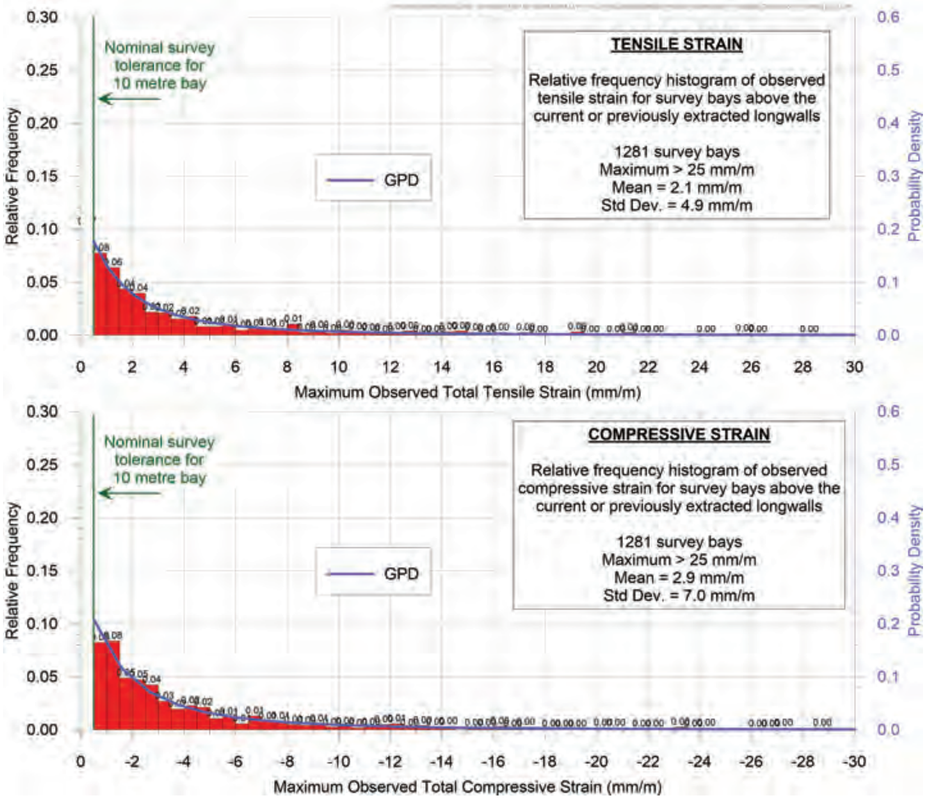

Fig. 4.2 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located above Supercritical Longwalls at Depths of Cover less than 150 m

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 are 10 mm/m tensile and 12 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are greater than 25 mm/m tensile and compressive.

4.4.2. Analysis of Strains for WMLW14 to WMLW16 (i.e. Multi-seam Conditions)

The depths of cover to the Wambo Seam above WMLW14 to WMLW16 vary between 130 m above the finishing (i.e. north-eastern) ends and 480 m above the commencing (i.e. south-western) end of the longwalls. The longwall width-to-depth ratios therefore vary between 0.5 and 1.7 with an average of 1.0. The interburden thickness between the Whybrow and Wambo Seams varies between 70 and 80 m. The proposed mining height in the Wambo Seam is 2.1 m.

The most extensive multi-seam strain data comes from the NWUM and the Blakefield South Mine.

The NWUM extracted WMLW1 to WMLW10A in the Wambo Seam beneath the existing Homestead/Wollemi workings in the overlying Whybrow Seam. The multi-seam subsidence movements were measured along five transverse monitoring lines, being the XL1-Line, XL2-Line, XL4-Line to XL6-Line and SC1-Line, and a further 18 diagonal or longitudinal monitoring lines. The Blakefield South Mine has extracted five longwalls in the Blakefield Seam (BSLW1 to BSLW5) beneath the existing South Bulga longwalls in the Whybrow Seam. The multi-seam subsidence movements at Blakefield South Mine were measured along 17 monitoring lines.

The depths of cover to the Wambo Seam above WMLW1 to WMLW10A vary between 60 and 420 m with an average of 180 m. The width-to-depth ratios for these longwalls vary between 0.6 and 4.0 with an average of 1.4. The interburden thickness between the Whybrow and Wambo Seams varies between 20 and 100 m with an average of 60 m. The thickness of the Wambo Seam for WMLW1 to WMLW10A varies between 2 and 2.6 m with an average of 2.4 m.

The depths of cover to the Blakefield Seam above BSLW1 to BSLW5 vary between 330 and 410 m with an average of 390 m. The width-to-depth ratios for these longwalls vary between 1.3 and 2.7 with an average of 1.9. The interburden thickness between the Whybrow and Blakefield Seams varies between 270 and 95 m with an average of 80 m. The thickness of the Blakefield Seam for BSLW1 to BSLW5 varies between 2.1 and 3.6 m with an average of 2.9 m.

The longwall width-to-depth ratios and seam thicknesses for the monitoring lines used in the strain analysis are, on average, greater than those for WMLW14 to WMLW16. The interburden thicknesses for these monitoring lines are also similar to those for these longwalls.

The range of strains determined from the strain analysis should, therefore, provide a reasonable indication of the range of potential strains above the north-eastern ends of WMLW14 to WMLW16 (i.e. where the depths of cover are the shallowest). The strain analysis is likely to provide a conservative indication of the range of potential strains above the south-western ends of these longwalls (i.e. where the depths of cover are higher).

The histograms of the maximum observed tensile and compressive strains measured in survey bays located above goaf, at the NWUM and Blakefield South Mine, are provided in Fig. 4.3. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

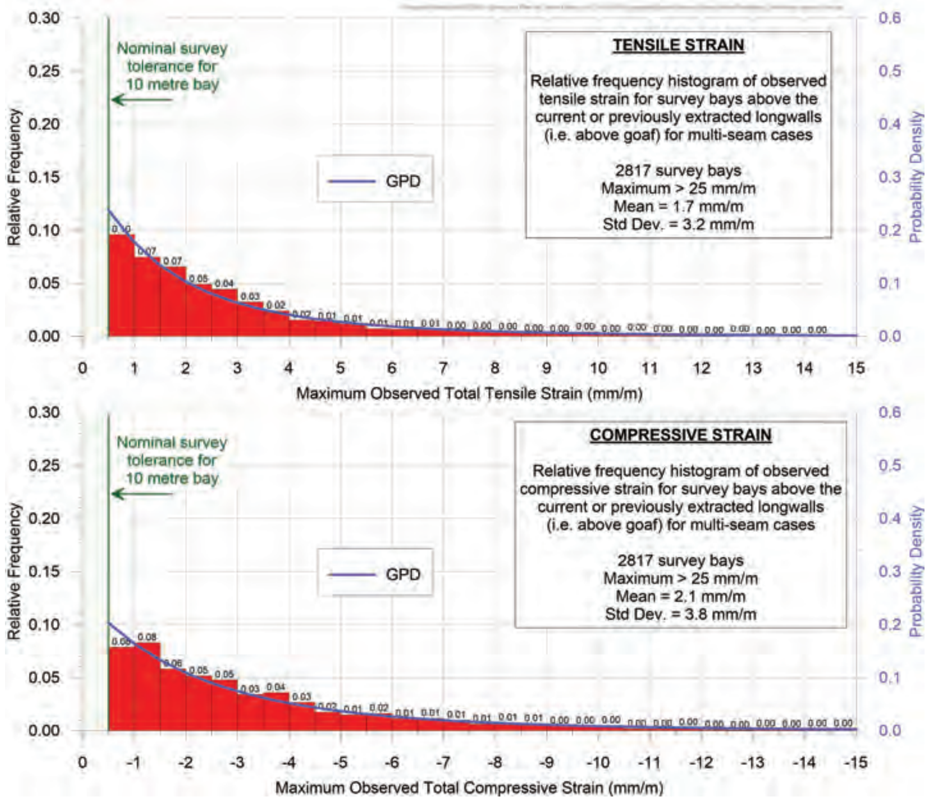

Fig. 4.3 Histograms of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located Directly Above Goaf at the NWUM and Blakefield South Mine

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 are 7 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 are 14 mm/m tensile and 17 mm/m compressive. The maximum strains measured along the monitoring lines were greater than 25 mm/m tensile and compressive.

The predicted strains for the Wambo Seam longwalls are slightly less than those predicted above the finishing ends of the Whybrow Seam longwalls for single-seam conditions. Whilst strains for multi-seam conditions are generally greater than for single-seam conditions, the peak strains above the finishing ends of the Whybrow Seam longwalls are predicted to be greater due to the very shallow depths of cover that vary down to a minimum of 55 m.

4.5. Predicted Far-field Horizontal Movements

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

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data from the NSW Coalfields, but predominately from the Southern Coalfield. The far-field horizontal movements resulting from longwall mining were generally observed to be orientated towards the extracted longwall. At very low levels of far-field horizontal movements, however, there was a high scatter in the orientation of the observed movements.

The observed incremental far-field horizontal movements, resulting from the extraction of a single longwall, are provided in Fig. 4.4. The confidence levels, based on fitted *Generalised Pareto Distributions* (GPDs), have also been shown in this figure to illustrate the spread of the data.

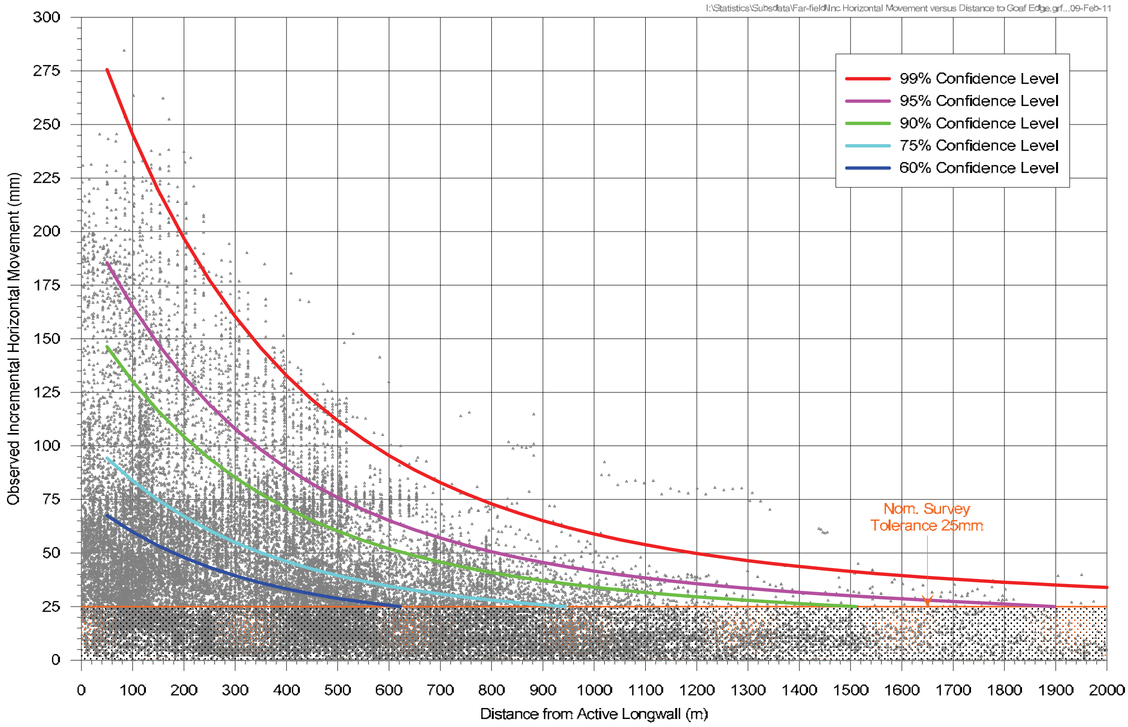

Fig. 4.4 Observed Incremental Far-Field Horizontal Movements

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

The predicted far-field horizontal movements resulting from the extraction of the 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 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 mining.

4.6. Non-Conventional Ground Movements

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

There is a series of NNE-SSW trending faults within the mining area with throws between 0.5 and 1 m. Some larger faults have been identified to the north-west and to the south-east of the longwalls with throws ranging between 3 and 12 m.

No adjustment factors have been applied in the subsidence prediction model for these minor faults, as the longwalls in the Whybrow and Wambo Seam have been predicted to achieve the maximum subsidence for single and multi-seam mining conditions. These faults could result in slightly increased subsidence adjacent to the longwalls, above solid coal, but this low level subsidence is not predicted to be associated with any significant strains.

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

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 surface cracking and compression heaving due to the mining of WYLW12 and WYLW13 are expected to be similar to those observed due to the mining of WYLW11. Discussions of the surface deformations that developed as a result of WYLW11 are provided below.

Photographs of the surface cracking and compression heaving along the North Wambo Creek Diversion due to the extraction of WYLW11 are provided in Fig. 4.5 and Fig. 4.6. The largest surface cracks occurred near the bend in the alignment above the longwall and were typically in the order of 25 to 50 mm, with isolated locations up to 100 mm in width. The compression heaving in this location were typically up to 200 mm in height. Elsewhere, the surface cracking in the base of the creek diversion was typically less than 50 mm in width and the compressive heaving was typically less than 50 mm in height.

Fig. 4.5 Surface cracking along the North Wambo Creek Diversion due to WYLW11

Fig. 4.6 Compression heaving along the North Wambo Creek Diversion due to WYLW11

Photographs of surface cracking along an unsealed road located above WYLW11 are provided in Fig. 4.7. The crack widths typically varied between 25 and 50 mm and were greater than 100 mm in some locations.

Fig. 4.7 Surface Cracking along an Unsealed Road above WYLW11

Photographs of typical surface cracking at the NWUM are also provided in Fig. 4.8. Similar cracking could develop above the north-eastern ends (i.e. shallowest depths of cover) and on the steep slopes above the south-western ends of WYLW11 to WYLW13 and WMLW14 to WMLW16.

Fig. 4.8 Photographs of Surface Cracking at the NWUM

Detailed crack mapping was undertaken above the Blakefield South Mine Longwalls 1 to 4 (BSLW1 to BSLW4), which were extracted beneath the existing South Bulga longwalls in the Whybrow Seam (i.e. multi-seam conditions). The void width of BSLW1 was 330 m and the void widths of BSLW2 to BSLW4 were 400 m. These longwalls were extracted in the Blakefield Seam at depths of cover ranging between 150 and 270 m. The interburden thickness between the Whybrow and Blakefield Seams typically varied between 75 and 95 m.

The cracking observed above BSLW1 to BSLW4 should provide a reasonable indication of the extent of cracking above the north-eastern ends of WMLW14 to WMLW16, i.e. multi-seam conditions where the depths of cover are the shallowest. It was found from the detailed crack mapping, that 80 % of the cracks had widths less than 100 mm, with the majority of these having widths less than 50 mm. The maximum observed crack width was around 500 mm.

There were more than 1,800 cracks recorded above BSLW1 to BSLW4 having a total length of around 38 km. The total surface area above these longwalls was around 3.2 km^2 and it is estimated that less than 0.06 % of this area was affected by cracking. The compression heaving and step heights observed during the extraction of BSLW1 to BSLW2 were typically less than 25 mm, but the maximum step height was around 800 mm which resulted from localised vertical ground shear.

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. 4.9.

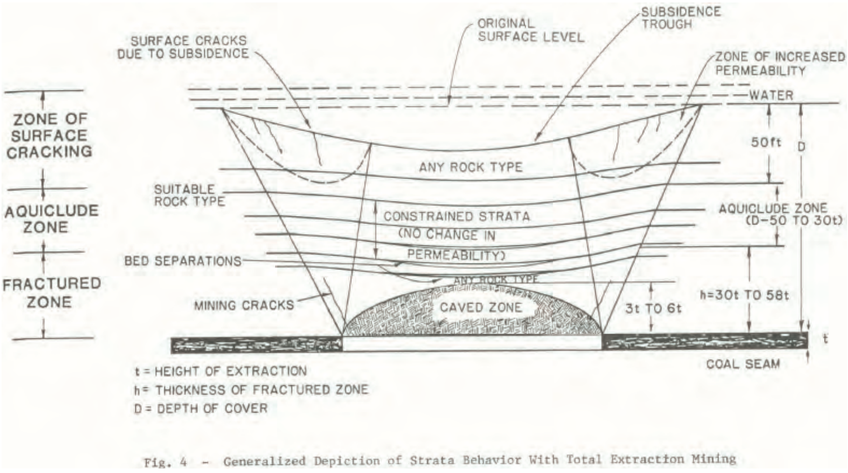

Fig. 4.9 Zones in the Overburden according to Singh and Kendorski (1981)

Kratzsch (1983) identified four zones, but named them the: immediate roof; main roof; intermediate zone; and surface zone. These zones are illustrated in Fig. 4.10.

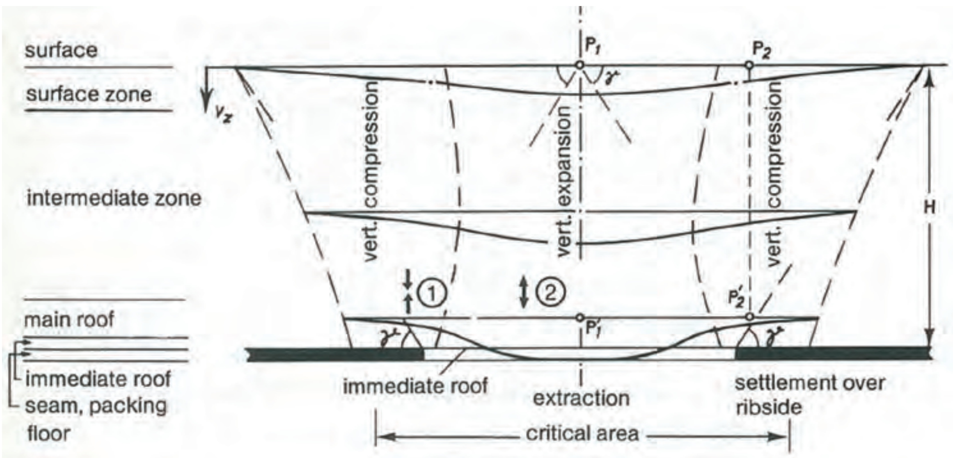

Fig. 4.10 Zones in the Overburden according to Kratzsch (1983)

Peng and Chiang (1984) recognised only three zones as reproduced in Fig. 4.11.

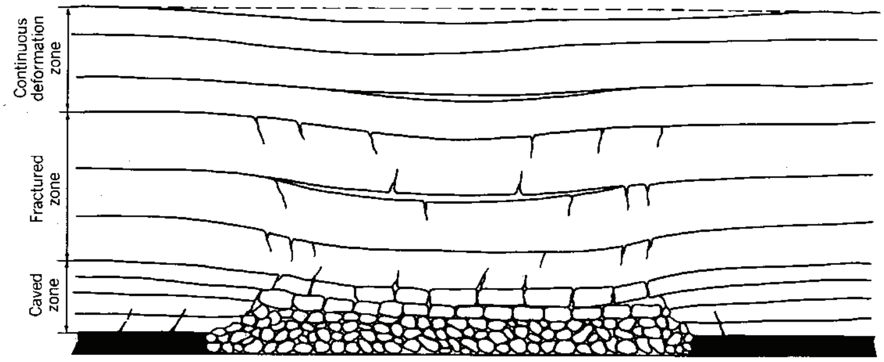

Fig. 4.11 Zones in the Overburden According to Peng and Chiang (1984)

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. 4.12.

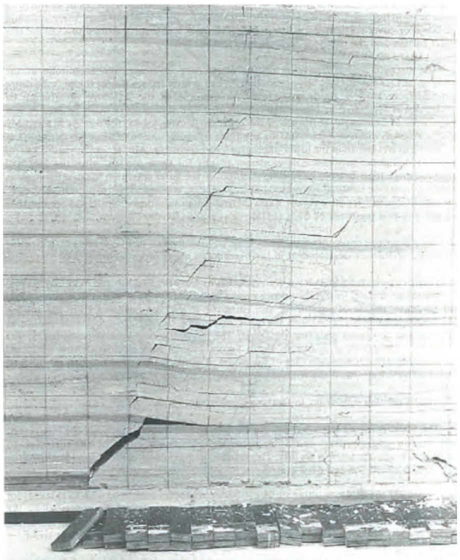

Fig. 4.12 Physical Modelling of the Overburden (Whittaker and Reddish, 1989)

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. 4.13 (Whittaker and Reddish, 1989).

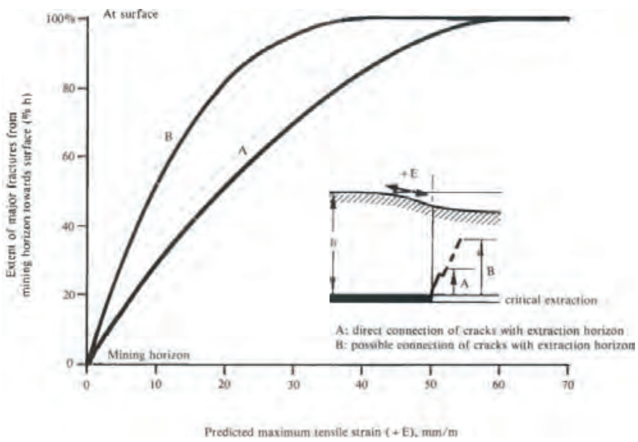

Fig. 4.13 Extent of Major Fractures from the Mining Horizon (Whittaker and Reddish, 1989)

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. 4.14, 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.

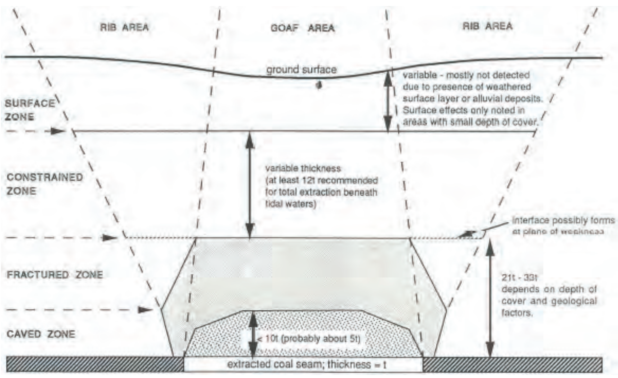

Fig. 4.14 Zones in the Overburden according to Forster and Enever (1992)

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. 4.15.

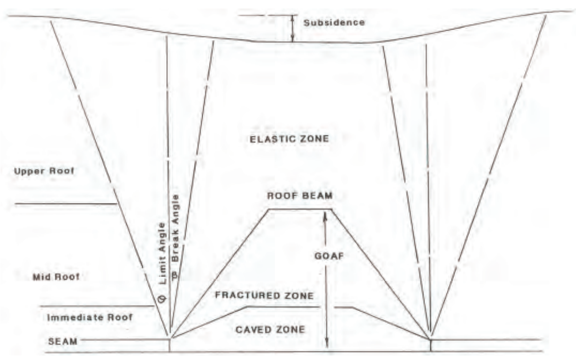

Fig. 4.15 Zones in the Overburden according to McNally et al. (1996)

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. 4.16. 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).

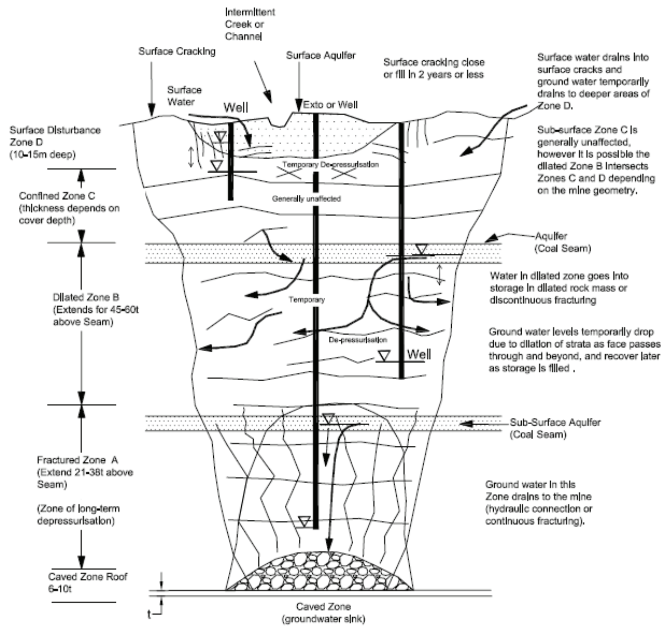

Fig. 4.16 Zones in the Overburden according to Ditton (2005)

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. 4.17.

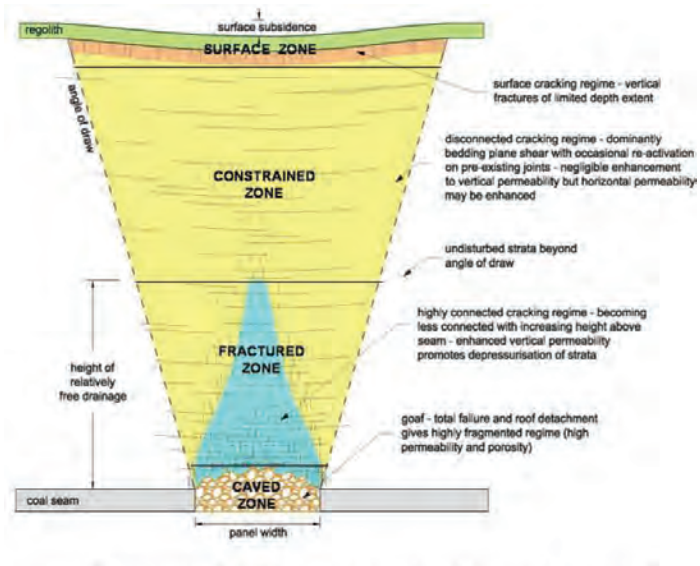

Figure 12: Conceptual Model of Caving and the Nature of Fracturing above a Mine Excavation

Fig. 4.17 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
- 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 WYLW11 to WYLW13 vary between 238 and 251 m and, therefore, the height of the Discontinuous Fracture Zone (B) could extend 250 to 375 m above the Whybrow Seam. The depths of cover above the longwalls in the Whybrow Seam vary between 55 and 375 m.

The overall void widths of WMLW14 to WMLW16 vary between 233 and 251 m and, therefore, the height of the Discontinuous Fracture Zone (B) could extend 250 to 375 m above the Wambo Seam. The interburden thickness between the Whybrow and Wambo Seams vary between 70 and 80 m.

It is expected, therefore, that the discontinuous fractured zone would extend from the longwalls in the Wambo Seam up to the longwalls in overlying Whybrow Seam and then extend up to the surface, above the north-eastern ends and central parts of the longwalls, where the depths of cover are the shallowest. It is recognised that this does not necessarily imply that there will be hydraulic connectivity between the surface and the mine, as the vertical fractures may be discontinuous due to the presence of strata layers with low permeability, such as claystones and tuffs.

It is not expected that there would be a hydraulic connection between the surface and seam over the majority of the longwalls, as none was observed after the extraction of the first seven longwalls at the NWUM, which were mined directly beneath North Wambo Creek at a depth of cover of around 100 m. It is possible that hydraulic connection between the surface and seam could develop above the finishing (i.e. north-eastern) ends of the longwalls, where the depths of cover to the overlying Whybrow Seam are less than 100 m, which is discussed in Section 5.3.

Further discussions on the heights of fracturing and specific geology and permeability of the overburden strata are provided in the report by *HydroSimulations* (2015). 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.

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 not described below.

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

5.2. Streams

5.2.1. Description of the Streams

The locations of the streams in the vicinity of the longwalls are shown in Drawing No MSEC855-13. The natural streams within the Study Area include Stony Creek and tributaries to North Wambo Creek. A diverted section of North Wambo Creek is also located within the Study Area.

The upper reaches of Stony Creek are located adjacent to the commencing ends of WYLW12 and WMLW15. The creek is located 65 m south-west of WMLW15 at its closest point to the longwalls. The section of Stony Creek within the Study Area is a fourth order ephemeral stream.

Stony Creek commences along the Wollemi Escarpment and flows in a south-easterly direction to where it joins Wambo Creek around 3.5 km from the longwalls. The lower reaches of the creek, to the south-east of the Study Area, have been directly mined beneath by WMLW1 to WMLW6 at the NWUM.

The bed of Stony Creek is formed in the natural surface soils with rounded gravel to a sandy base. In some locations there is exposed bedrock which has formed into small cascades with isolated pools. There is also significant natural debris along the creek, including boulders, tree branches and other vegetation. The natural grade along the section of Stony Creek within the Study Area varies between 50 mm/m (i.e. 5 %, or 1 in 20) and 200 mm/m (i.e. 20 %, or 1 in 5), with an average natural grade of approximately 100 mm/m (i.e. 10 %, or 1 in 10).

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

Fig. 5.1 Photographs of Stony Creek within the Study Area

The North Wambo Creek Diversion is located within the Study Area. The descriptions, predictions and impact assessments for the creek diversion are provided in Section 5.3. The natural section of the creek is located outside of the Study Area, at distances of 700 m east of the longwalls at the downstream end, and 1.8 km north-west of the longwalls at the upstream end.

Ephemeral drainage lines are also located directly above the longwalls. These drainage lines commence adjacent to the Wollemi Escarpment and flow in an easterly directly to where they join the North Wambo Creek Diversion and the natural section of this creek further downstream. The drainage lines have shallow incisions into the natural surface soils, with some isolated bedrock outcropping along the upper reaches. The natural grades within the Study Area vary between 20 mm/m (i.e. 2 %, or 1 in 50) and 400 mm/m (i.e. 40 %, or 1 in 2.5), with average natural grades of approximately 100 mm/m (i.e. 10 %, or 1 in 10).

5.2.2. Predictions for the Streams

The predicted profiles of conventional subsidence, tilt and curvature along Stony Creek are shown in Fig. D.05, in Appendix D. The predicted total profiles after the extraction of the longwalls in the Whybrow Seam are shown as the cyan lines. The predicted total profiles after the extraction of the longwalls in the Wambo Seam are shown as blue lines. The predicted final profiles after the extraction of all longwalls based on the Previous Layout are shown as the dashed red lines for comparison.

A summary of the maximum predicted total subsidence, tilt and curvatures for Stony Creek, after the extraction of each of the longwalls, is provided in Table 5.1. The values are the maxima anywhere along the creek within the Study Area.

Table 5.1 Maximum Predicted Total Subsidence, Tilts and Curvatures for Stony Creek Resulting from the Extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16

Location	Longwall	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})
Stony Creek	After WYLW11	< 20	< 0.5	< 0.01	< 0.01
	After WYLW12	20	< 0.5	< 0.01	< 0.01
	After WYLW13	30	< 0.5	< 0.01	< 0.01
	After WMLW14	30	< 0.5	< 0.01	< 0.01
	After WMLW15	125	1.0	< 0.01	< 0.01
	After WMLW16	150	1.0	< 0.01	< 0.01

Stony Creek is located at minimum distances of 100 m from WYLW12 and 65 m from WMLW15 at its closest point to the longwalls. A strain analysis has been undertaken based on survey bays located at distances between 50 and 150 m outside previously extracted longwalls in the Hunter and Newcastle Coalfields. The stream is located outside the longwalls in both the Whybrow and Wambo Seams and, therefore, the analysis has been based on single-seam mining conditions.

The 95 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 0.7 mm/m tensile and 0.6 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 2.1 mm/m tensile and 2.6 mm/m compressive.

The upper reaches of Stony Creek are located within an incised valley and, therefore, this section of creek could experience valley related movements. The maximum predicted valley related movements along the creek, after the completion of mining in both the Whybrow and Wambo Seams, are 350 mm upsidence and 500 mm closure.

The natural section of North Wambo Creek is located at a minimum distance of 700 m from the longwalls. At this distance, the creek is predicted to experience less than 20 mm of vertical subsidence. The predictions for the creek diversion are provided in Section 5.3.2.

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

5.2.3. Comparison of the Predictions for the Streams

The comparison of the maximum predicted total conventional subsidence parameters for Stony Creek based on the Previous Layout and Revised Layout is provided in Table 5.2. The values are the maxima anywhere along the section of creek within the Study Area due to the extraction of the longwalls in both the Whybrow and Wambo Seams.

Table 5.2 Comparison of Maximum Predicted Subsidence Parameters for Stony Creek based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	675	9.0	0.1	0.1
Revised Layout (Report No. MSEC855)	150	1.0	< 0.01	< 0.01

The maximum predicted conventional subsidence parameters for Stony Creek, based on the Revised Layout, are less than the maxima based on the Previous Layout. Similarly, the maximum predicted valley related upsidence and closure movements for Stony Creek, based on the Revised Layout, are less than the maxima based on the Previous Layout. The predicted subsidence parameters have reduced as WYLW12 and WMLW14 were previously located directly beneath the creek for the Previous Layout.

The natural section of North Wambo Creek is located at a minimum distance of 700 m from the longwalls. This creek is predicted to experience less than 20 mm of vertical subsidence and negligible tilts, curvatures and strains due to the extraction of the longwalls based on both the Previous and Revised Layouts.

The ephemeral drainage lines that are located directly above the longwalls could experience the full range of predicted subsidence parameters as summarised in Chapter 4. The maximum predicted subsidence parameters for these drainage lines, based on the Revised Layout, are the same as the maxima predicted based on the Previous Layout, as shown in Table 4.3 and Table 4.4.

The impact assessments for the streams based on the Revised Layout have been provided in the following section.

5.2.4. Impact Assessments for the Streams

The natural section of North Wambo Creek is located at a distance of 700 m east of the longwalls at its closest point. At this distance, the creek is predicted to experience less than 20 mm of vertical subsidence. While it is possible the creek could experience very low levels of subsidence and horizontal movements, it would not be expected to experience any measurable tilts, curvatures or ground strains. It is unlikely, therefore, that the natural section of North Wambo Creek would experience any adverse impacts resulting from the longwalls.

The impact assessments for the North Wambo Creek Diversion are provided in Section 5.3.4. The impact assessments for the upper reaches of Stony Creek and the ephemeral drainage lines located within the Study Area are provided in the following sections.

Potential for Increased Levels of Ponding, Flooding and Scouring

The maximum predicted subsidence parameters for Stony Creek, based on the Revised Layout, are less than the maxima based on the Previous Layout. The potential impacts for this section of creek therefore reduce. The maximum predicted subsidence parameters for the ephemeral drainage lines located above the longwalls, based on the Revised Layout, are the same as the maxima predicted based on the Previous Layout. The potential impacts for these drainage lines therefore do not change.

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 Stony Creek and a typical ephemeral drainage line, referred to as Drainage Line 1, are illustrated in Fig. 5.2 and Fig. 5.3, respectively. The location of Drainage Line 1 is shown in Drawing No. MSEC855-13. The final profiles are after the completion of mining in both the Whybrow and Wambo Seams.

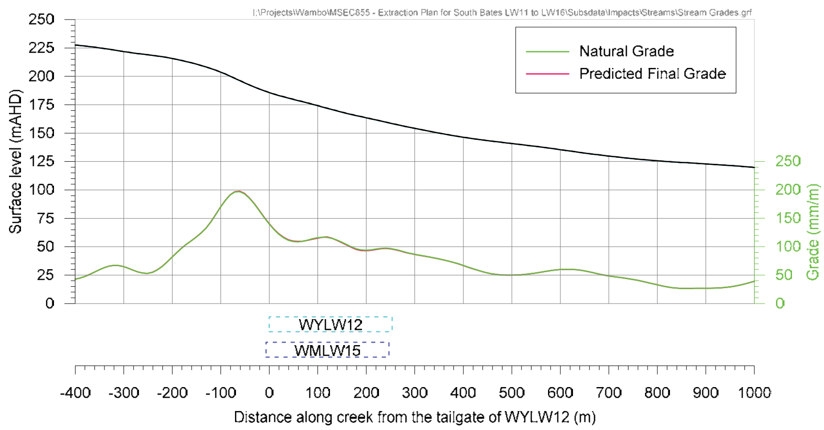

Fig. 5.2 Natural and Predicted Subsided Surface Levels and Grades along Stony Creek

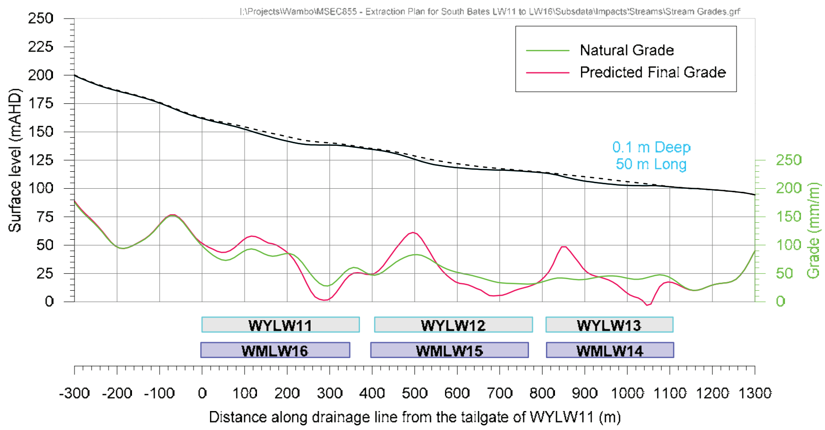

Fig. 5.3 Natural and Predicted Subsided Surface Levels and Grades along Drainage Line 1

It can be seen in Fig. 5.2, that the predicted post-mining grades along Stony Creek are similar to the natural grades. It is unlikely, therefore, that there would be any adverse changes in the levels of ponding or scouring along this creek as a result of mining.

It can be seen in Fig. 5.3, that the post mining grades are flat (i.e. near zero) upstream of the chain pillars in the Whybrow and Wambo Seams and it is possible that localised increased ponding could occur in these locations. It is predicted that the increased ponding would be localised along the alignments of the drainage lines, with depths of depressions up to around 0.1 m and lengths up to around 50 m.

If adverse impacts were to develop as the result of localised increased ponding along the ephemeral drainage lines, these could be remediated by locally regrading the beds, so as to re-establish the natural gradients. The drainage lines 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.

Potential for Cracking in the Creek Beds and Fracturing of Bedrock

Fracturing of the uppermost bedrock has been observed in the past, as a result of mining, where the tensile strains have been greater than 0.5 mm/m or where the compressive strains have been greater than 2 mm/m.

The predicted conventional strains along Stony Creek, resulting from the extraction of the longwalls, are 0.7 mm/m tensile and 0.6 mm/m compressive based on the 95 % confidence level. Localised and elevated compressive strains could also develop along this section of the creek due to valley related movements. Compressive strains in the order of 5 mm/m could occur along the section of Stony Creek located immediately adjacent to the longwalls due to the valley related movements. The ephemeral drainage lines are likely to experience the full range of predicted strains which were described in Chapter 4.

The sections of Stony Creek and the ephemeral drainage lines within the Study Area typically have shallow incisions into the natural surface soils. Cracking in the beds of the streams would only be visible at the surface where the depths of the surface soils are shallow, or where the bedrock is exposed.

Some sections of Stony Creek and the upper reaches of ephemeral drainage lines have exposed bedrock which have formed into small cascades with isolated pools. Fracturing of the exposed bedrock could result in spalling or dislodgement of rocks. There could also be some diversion of the surface water flows into the dilated strata beneath the beds, which could drain any ponded surface water upstream of the outcropping. It is expected that any diverted surface water would re-emerge further downstream due to the high natural grades in these locations.

It may be necessary, at the completion of mining, to remediate some sections of the ephemeral drainage lines, where the depths of cover are the shallowest. This could include regrading the beds and infilling the larger surface cracking. It is expected that there would be no long term adverse impacts on these streams after the completion of the necessary surface remediation.

5.2.5. Recommendations for the Streams

It is recommended that Stony Creek and the ephemeral drainage lines are periodically visually inspected during active subsidence as the longwalls are extracted adjacent to or directly beneath them. It is also recommended that the larger surface cracking along the alignments of the ephemeral drainage lines are remediated, which could include locally infilling the surface cracking, or regrading the stream beds, if required. It is expected that there would be no long term adverse impacts on these streams after the completion of the necessary surface remediation.

Management strategies have been developed for the sections of the creeks and drainage lines which have already been directly mined beneath at the NWUM. It is recommended that the existing management strategies are reviewed and, where required, are revised to include the effects of the longwalls on Stony Creek and the ephemeral drainage lines.

5.3. The North Wambo Creek Diversion

5.3.1. Description of the North Wambo Creek Diversion

The location of the North Wambo Creek Diversion is shown in Drawing No. MSEC855-13.

North Wambo Creek has been diverted around the active Bates South Open Cut Pit. The low flow channel of the creek diversion is located directly above the north-eastern ends of WYLW11 to WYLW13 and is located immediately adjacent to the finishing ends of WMLW14 to WMLW16. The natural section of the creek is located outside of the Study Area and is discussed in Section 5.2.

The North Wambo Creek Diversion is ephemeral. The creek diversion has been constructed within the natural surface soils, with the heights of the banks typically ranging between 3 to 5 m. Photographs of the creek diversion are provided in Fig. 5.4.

Fig. 5.4 Photographs of the North Wambo Creek Diversion

5.3.2. Predictions for the North Wambo Creek Diversion

The predicted profiles of conventional subsidence, tilt and curvature along the North Wambo Creek Diversion are shown in Fig. D.06, in Appendix D. The predicted total profiles after the extraction of the longwalls in the Whybrow Seam are shown as the cyan lines. The predicted total profiles after the extraction of the longwalls in the Wambo Seam are shown as blue lines. The predicted final profiles after the extraction of all longwalls based on the Previous Layout are shown as the dashed red lines for comparison.

A summary of the maximum predicted total subsidence, tilts and curvatures for the North Wambo Creek Diversion, after the extraction of each of the longwalls, is provided in Table 5.3. The values are the maxima anywhere along the creek diversion within the Study Area.

Table 5.3 Maximum Predicted Total Subsidence, Tilts and Curvatures for the North Wambo Creek Diversion Resulting from the Extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16

Location	Longwall	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	After WYLW11	1,850	65	> 3.0	> 3.0
	After WYLW12	1,950	70	> 3.0	> 3.0
	After WYLW13	1,950	75	> 3.0	> 3.0
	After WMLW14	1,950	80	> 3.0	> 3.0
	After WMLW15	2,000	80	> 3.0	> 3.0
	After WMLW16	2,000	80	> 3.0	> 3.0

The maximum predicted conventional strains for the creek diversion, based on applying a factor of 10 to the maximum predicted conventional curvatures, are greater than 30 mm/m tensile and compressive. The discussion on the distribution of strain at the finishing ends of the longwalls 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 Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The North Wambo Creek Diversion has a relatively shallow incision into the natural surface soils. It is unlikely, therefore, that the creek diversion would experience any significant valley related movements resulting from the extraction of the longwalls.

5.3.3. Comparison of the Predictions for the North Wambo Creek Diversion

The comparison of the maximum predicted total conventional subsidence parameters for the North Wambo Creek Diversion based on the Previous Layout and Revised Layout is provided in Table 5.4. The values are the maxima anywhere along the section of creek diversion within the Study Area due to the extraction of the longwalls in both the Whybrow and Wambo Seams.

Table 5.4 Comparison of Maximum Predicted Subsidence Parameters for the North Wambo Creek Diversion based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	2,000	80	> 3.0	> 3.0
Revised Layout (Report No. MSEC855)	2,000	80	> 3.0	> 3.0

The maximum predicted conventional subsidence parameters for the North Wambo Creek Diversion, based on the Revised Layout, are the same as the maxima based on the on the Previous Layout. It can also be seen from Fig. D.06, that the profiles of vertical subsidence, tilt and curvature, based on the Revised Layout, are similar to those based on the Previous Layout.

The potential impacts on the North Wambo Creek Diversion therefore are the same as those provided in Report Nos. MSEC692, MSEC693 and MSEC804. The impact assessments for the creek diversion based on the Revised Layout have been provided in the following section.

5.3.4. Impact Assessments for the North Wambo Creek Diversion

The low flow channel of the North Wambo Creek Diversion is located directly above WYLW11 to WYLW13 and immediately adjacent to WMLW14 to WMLW16. The natural and the predicted post-mining surface levels and grades along the creek diversion, based on mining in both the Whybrow and Wambo Seams, are illustrated in Fig. 5.5.

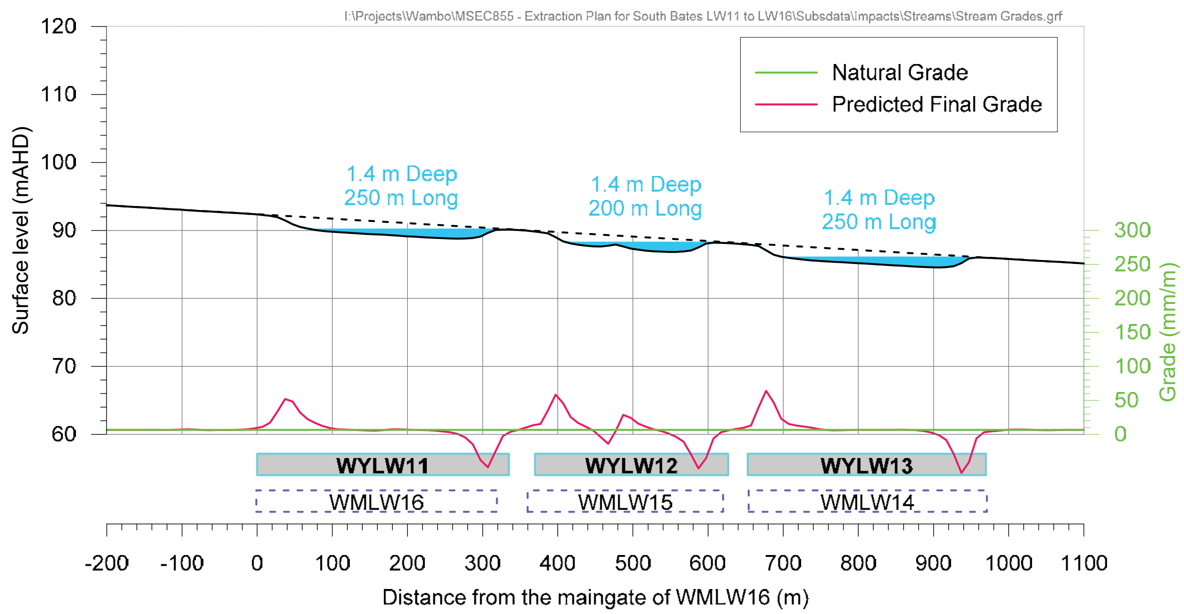

Fig. 5.5 Natural and Predicted Subsided Surface Levels and Grades along the Creek Diversion

There is potential for increased ponding along the North Wambo Creek Diversion directly above WYLW11 and WYLW13 and immediately adjacent to WMLW14 to WMLW16. The ponding areas along the creek diversion are estimated to be up to 1.4 m deep and up to 250 m long.

The increased ponding along the creek diversion is predicted to develop predominately due to mining in Whybrow Seam. The predicted additional ponding due to mining in the Wambo Seam is less than 100 mm adjacent to WMLW14 and WMLW15.

Surface tensile cracking and compression heaving developed along the North Wambo Creek Diversion due to the mining of WYLW11. Discussions and photographs of these impacts are provided in Section 4.7. It is expected that similar surface deformations would develop along the alignment of the North Wambo Creek Diversion due to mining of WYLW12 and WYLW13 directly beneath it. Further surface cracking could also develop along the creek diversion due to the mining of WMLW14 to WMLW16 immediately adjacent to the creek diversion.

The depths of cover along the alignment of the North Wambo Creek Diversion, directly above or immediately adjacent to the finishing ends of the longwalls, vary between 60 and 85 m to the Whybrow Seam and between 135 and 170 m to the Wambo Seam. It is likely, therefore, that fracturing would occur from the seams up to the surface in this location.

The North Wambo Creek Diversion is ephemeral, so surface water only flows during and for short periods after rain events. It is possible that some of the surface water flows in the creek diversion could flow into the workings. The longwalls will be extracted in the up-dip direction of the seam, so increased water flows into the mine will flow away from the extraction face.

It will be necessary, therefore, that the larger surface cracking within the alignment of the creek diversion are remediated during active subsidence, which could include infilling with cohesive materials and by regrading and recompacting the surface soils.

5.3.5. Recommendations for the North Wambo Creek Diversion

It is recommended that the larger surface cracking within the alignment of the North Wambo Creek Diversion be remediated during or after active subsidence. This remediation should be undertaken where there is increased potential for the diversion of surface water flows into the fractured and dilated strata beneath the creek diversion. The other surface deformations should also be remediated if they result in increased erosion or cause safety (i.e. trip) hazards.

The remediation strategies should consider the risk of the loss of water into the mine and incorporate the recommendations from the risk assessment undertaken as part of the Clause 33 notification.

5.4. Aquifers and Known Ground Water 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* (2015).

There are no *Ground Water Management Areas*, as defined by the Department of Primary Industries – Water, within the Study Area. WCPL owns a monitoring bore (Ref. GW200835) that is located directly above WMLW16 which could be adversely impacted by subsidence. There are no other registered groundwater bores identified in the vicinity of the longwalls.

5.5. Escarpments

The *Wollemi Escarpment* is located to the south-west of the longwalls.

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 cliffline, the cliffs along the spur above the south-western ends of the longwalls, 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 Fig. 5.6. All the cliffs within the Study Area, including those not associated with the escarpment, are shown in Drawing No. MSEC855-13.

The impact assessments for the cliffs associated with the Wollemi Escarpment are included in Section 5.6. The impact assessments for the Wollemi National Park are provided in Section 5.12.

5.6. Cliffs

5.6.1. 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 m surface level contours generated from the LiDAR survey and from detailed site investigations. The locations of the cliffs in the vicinity of the longwalls are shown in Drawing No. MSEC855-13. The cliffs have also been shown in more detail in Fig. 5.6, below, along with the minor cliffs and the larger rock outcrops.

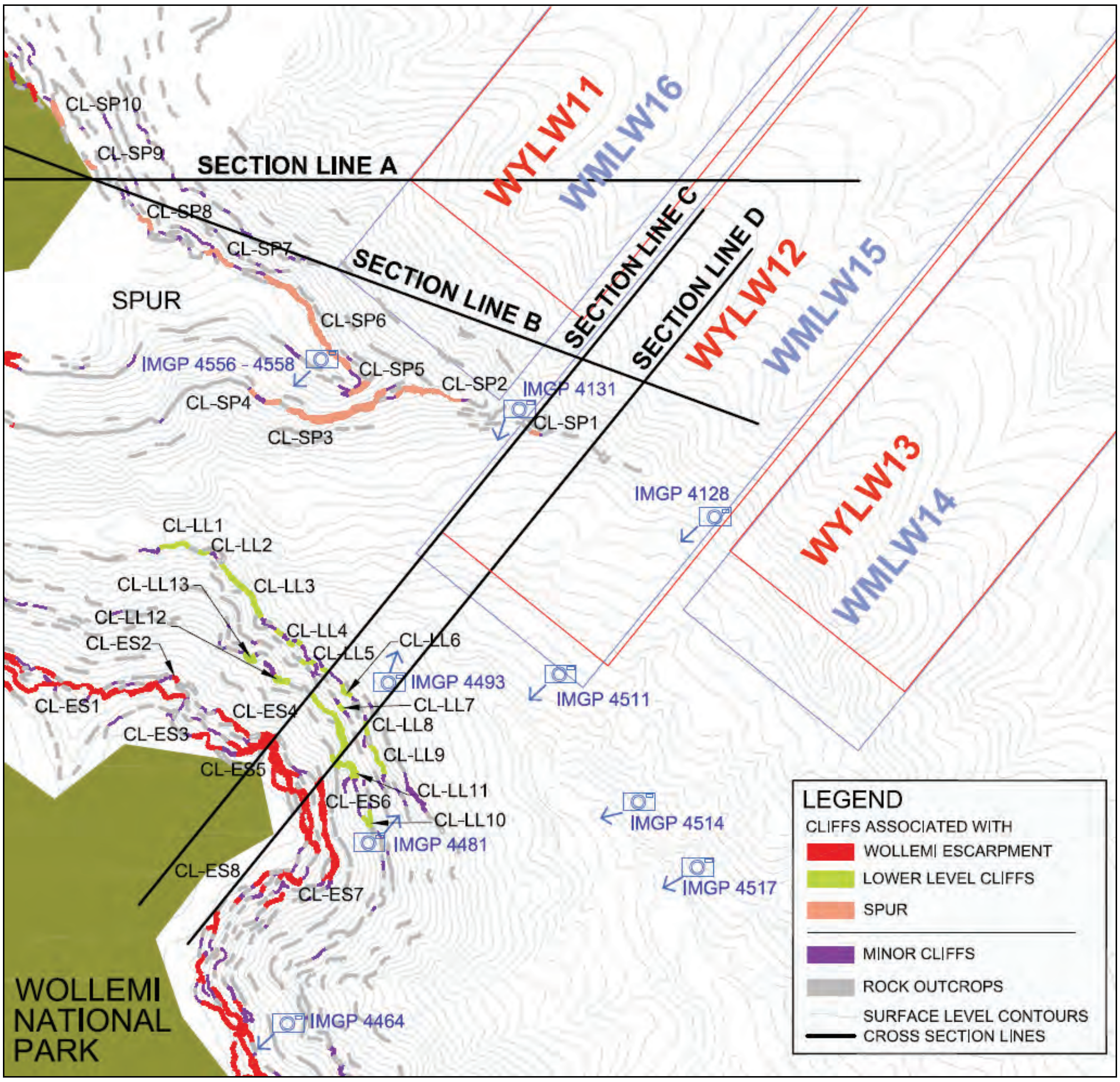

Fig. 5.6 Cliffs Located Adjacent to WYLW11 to WYLW13 and WMLW14 to WMLW16

The cliffs have been categorised into three groups:

- *Cliffs Associated with the Wollemi Escarpment (CL-ES1 to CL-ES8)* – are the higher level cliffs located along the boundary of the Wollemi National Park to the south-west of the longwalls;
- *Low Level Cliffs (CL-LL1 to CL-LL13)* – are located downslope of the Wollemi Escarpment (i.e. away from the National Park boundary) to the south-west of the longwalls; and
- *Cliffs along the Spur (CL-SP1 to CL-SP10)* – are located along the spur that crosses directly above the longwalls. It is noted, that Cliffs CL-SP9 and CL-SP10 are located adjacent to the National Park boundary.

Minor cliffs and rock outcrops have also been identified on various levels along the steep slopes and along the spur to the south-west of the longwalls.

Sections A to D have been taken through the south-western ends of the longwalls which show the relative locations of the cliffs in Fig. 5.7 to Fig. 5.10. The locations of these sections are shown in Fig. 5.6.

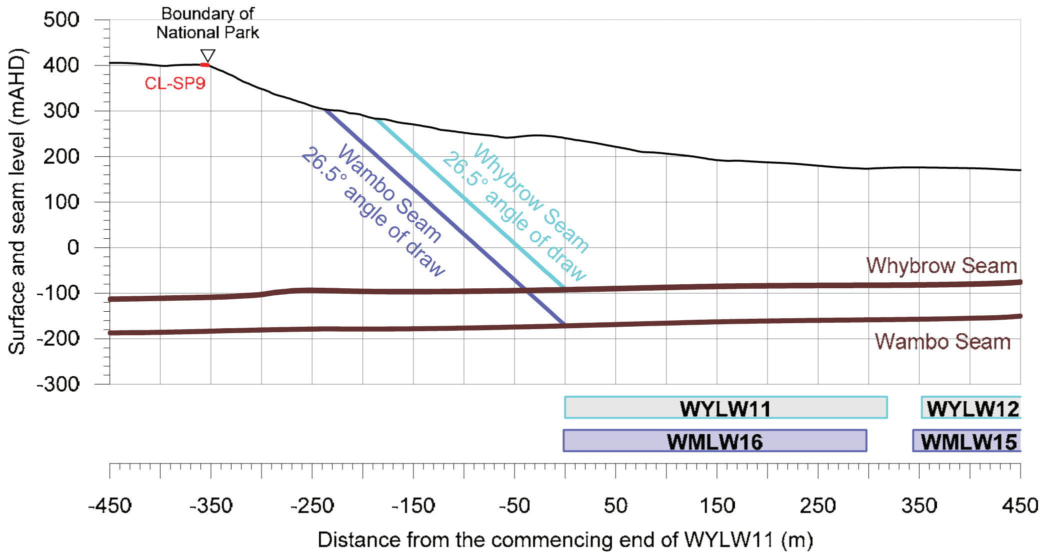

Fig. 5.7 Section A through the Wollemi Escarpment and the Longwalls

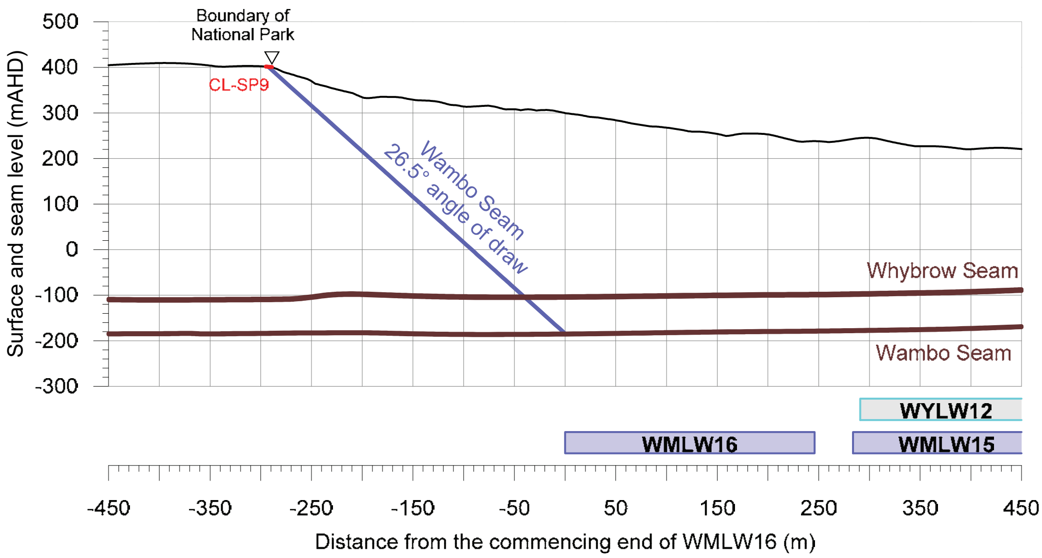

Fig. 5.8 Section B through the Wollemi Escarpment and the Longwalls

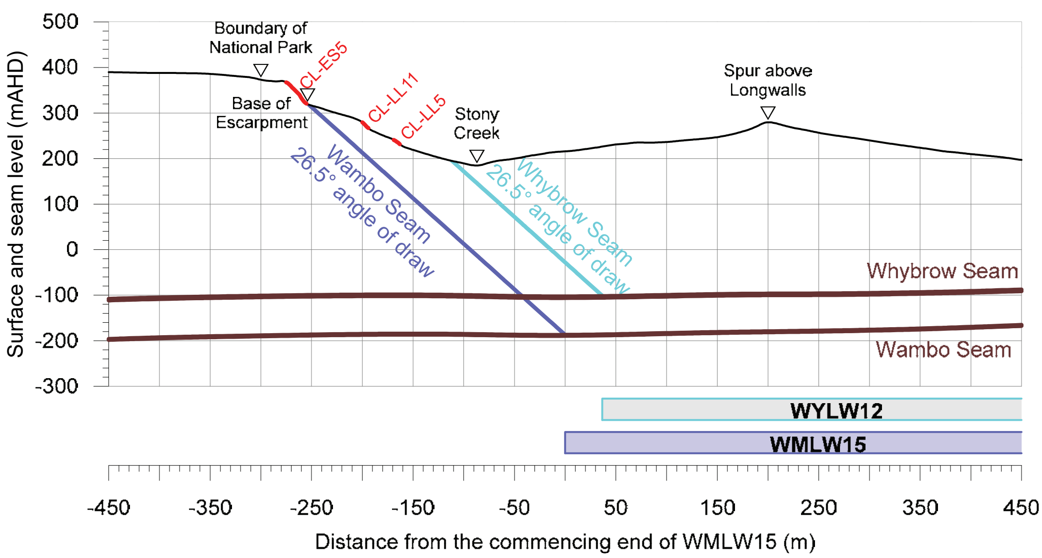

Fig. 5.9 Section C through the Wollemi Escarpment, Low Level Cliffs and the Longwalls

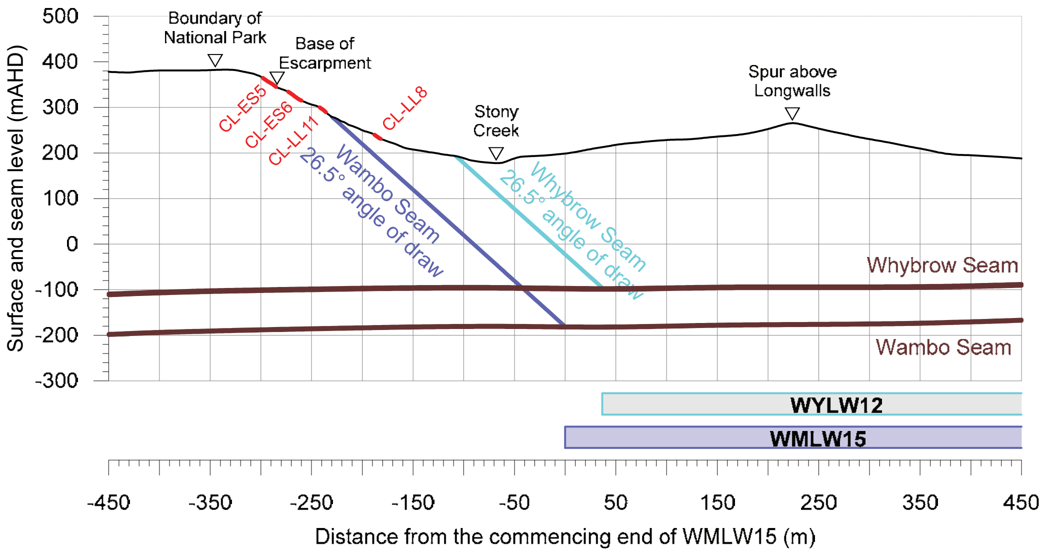

Fig. 5.10 Section D through the Wollemi Escarpment, Low Level Cliffs and the Longwalls

The *Cliffs Associated with the Wollemi Escarpment* are located outside of the 26.5° angles of draw lines from the longwalls in both the Whybrow and Wambo Seams. The *Low Level Cliffs* and the *Cliffs Along the Spur* (i.e. cliffs not associated with the escarpment) are partially located within the angles of draw lines from the longwalls.

It is noted, that the Study Area differs from the 26.5° 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 commencing ends 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 Study Area and, hence, have been included in the impact assessments provided in this report.

A summary of the overall lengths, typical heights and locations of the cliffs relative to the longwalls is provided in Table 5.5.

Table 5.5 Details of the Cliffs within the Study Area

Location	Label	Overall Length (m)	Typical Height (m)	Closest Distance to the Longwalls (m)
Cliffs Associated with the Wollemi Escarpment	CL-ES1	250 (Discontinuous at one or two levels)	10 ~ 25	300 to WMLW15
	CL-ES2	20	10	300 to WMLW15
	CL-ES3	50	10	300 to WMLW15
	CL-ES4	50	10 ~ 15	270 to WMLW15
	CL-ES5	200 (at one or two levels)	10 ~ 20 (over 100m length) 20 ~ 40 (over 50m length) 40 ~ 50 (over 50m length)	250 to WMLW15
	CL-ES6	125	10 ~ 20	260 to WMLW15
	CL-ES7	40	10 ~ 15	260 to WMLW15
	CL-ES8	20	10	380 to WMLW15
Low Level Cliffs	CL-LL1	40	10	250 to WMLW15
	CL-LL2	20	10	230 to WMLW15
	CL-LL3	80	10 ~ 15	180 to WMLW15
	CL-LL4	30 (Discontinuous)	10	170 to WMLW15
	CL-LL5	20	10 ~ 15	160 to WMLW15
	CL-LL6	20	10	160 to WMLW15
	CL-LL7	20 (Discontinuous)	10	180 to WMLW15
	CL-LL8	20	10	180 to WMLW15
	CL-LL9	40	10 ~ 15	190 to WMLW15
	CL-LL10	30	10 ~ 15	250 to WMLW15
	CL-LL11	125	15 ~ 25	190 to WMLW15
	CL-LL12	20	15	200 to WMLW15
	CL-LL13	20	15	210 to WMLW15
Cliffs along the Spur	CL-SP1	20	10	Above WYLW12 and WMLW15
	CL-SP2	80	10 ~ 20	25 to WMLW16
	CL-SP3	125	15 ~ 20	70 to WMLW16
	CL-SP4	30 (Discontinuous)	10 ~ 15	150 to WMLW16
	CL-SP5	30	15 ~ 20	70 to WMLW16
	CL-SP6	150	15	50 to WMLW16
	CL-SP7	40	10	110 to WMLW16
	CL-SP8	25	10	210 to WMLW16
	CL-SP9	20	10	290 to WMLW16
	CL-SP10	30	10 ~ 15	340 to WMLW16

The cliffs, minor cliffs and rock outcrops have formed from the Widden Brook Conglomerate of the Narrabeen Group, as can be seen in Fig. 1.6. Photographs of these features are provided in Fig. 5.11 to Fig. 5.14. The locations and directions of the photographs are indicated in Fig. 5.6.

Fig. 5.11 Photographs of the Cliffs Located South-West of WYLW11 and WMLW16 (IMGP4556 to IMGP4558)

Fig. 5.12 Photographs of the Cliffs Located along the Spur Adjacent to the Commencing End of WMLW16 (IMGP4481 and IMGP4493)

Fig. 5.13 Photographs of the Cliffs Located South-West of WYLW12 and WMLW15 (IMGP4128, IMGP4131 and IMGP4511)

Fig. 5.14 Photographs of the Cliffs Located South-West of WYLW13 and WMLW14 (IMGP4464, IMGP4514 and IMGP4517)

5.6.2. Predictions for the Cliffs

A summary of the maximum predicted total subsidence, tilts and curvatures for the cliffs within the Study Area, at any time during or after mining, is provided in Table 5.6. The values are the maximum predicted parameters within 20 m of their mapped extents, resulting from the extraction of the longwalls in both the Whybrow and Wambo Seams.

Table 5.6 Maximum Predicted Total Subsidence, Tilts and Curvatures for the Cliffs within the Study Area Resulting from the Extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16

Location	Label	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 Associated with the Wollemi Escarpment	CL-ES1	< 20	< 0.5	< 0.01	< 0.01
	CL-ES2	< 20	< 0.5	< 0.01	< 0.01
	CL-ES3	< 20	< 0.5	< 0.01	< 0.01
	CL-ES4	< 20	< 0.5	< 0.01	< 0.01
	CL-ES5	< 20	< 0.5	< 0.01	< 0.01
	CL-ES6	< 20	< 0.5	< 0.01	< 0.01
	CL-ES7	< 20	< 0.5	< 0.01	< 0.01
	CL-ES8	< 20	< 0.5	< 0.01	< 0.01
Low Level Cliffs	CL-LL1	< 20	< 0.5	< 0.01	< 0.01
	CL-LL2	< 20	< 0.5	< 0.01	< 0.01
	CL-LL3	30	< 0.5	< 0.01	< 0.01
	CL-LL4	40	0.5	< 0.01	< 0.01
	CL-LL5	40	0.5	< 0.01	< 0.01
	CL-LL6	50	0.5	< 0.01	< 0.01
	CL-LL7	40	0.5	< 0.01	< 0.01
	CL-LL8	40	0.5	< 0.01	< 0.01
	CL-LL9	30	< 0.5	< 0.01	< 0.01
	CL-LL10	< 20	< 0.5	< 0.01	< 0.01
	CL-LL11	30	< 0.5	< 0.01	< 0.01
	CL-LL12	30	< 0.5	< 0.01	< 0.01
	CL-LL13	< 20	< 0.5	< 0.01	< 0.01
Cliffs along the Spur	CL-SP1	2,700	17	0.08	0.15
	CL-SP2	1,300	12	0.10	0.07
	CL-SP3	575	6	0.05	0.04
	CL-SP4	100	2	0.03	< 0.01
	CL-SP5	475	5	0.03	0.03
	CL-SP6	375	4	0.02	0.02
	CL-SP7	90	1	< 0.01	< 0.01
	CL-SP8	< 20	< 0.5	< 0.01	< 0.01
	CL-SP9	< 20	< 0.5	< 0.01	< 0.01
	CL-SP10	< 20	< 0.5	< 0.01	< 0.01

The cliffs could also experience far-field horizontal movements. It can be seen from Drawing No. MSEC855-13, that the longwalls commence on the north-eastern side of Stony Creek and do not extend beneath the south-western side of this creek. The extraction of these longwalls is unlikely, therefore, to result in higher levels of horizontal movement due to downslope effects on the steep slopes on the south-western side of Stony Creek.

There is limited 3D ground monitoring 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 depths of cover and similar natural surface gradients.

Ten longwalls have been extracted in Areas 1, 2, 3A and 3B at Dendrobium Mine. The depths of cover vary between: 170 and 320 m in Area 1; 150 and 310 m in Area 2; 275 and 385 m in Area 3A; and 330 and 410 m in Area 3B. The longwalls were extracted in the Wongawilli Seam and had width-to-depth ratios typically ranging between 0.7 and 1.4. Escarpments were located directly above the longwalls in Areas 1 and 2 and the surface was highly undulating in Areas 3A and 3B, 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. 5.15.

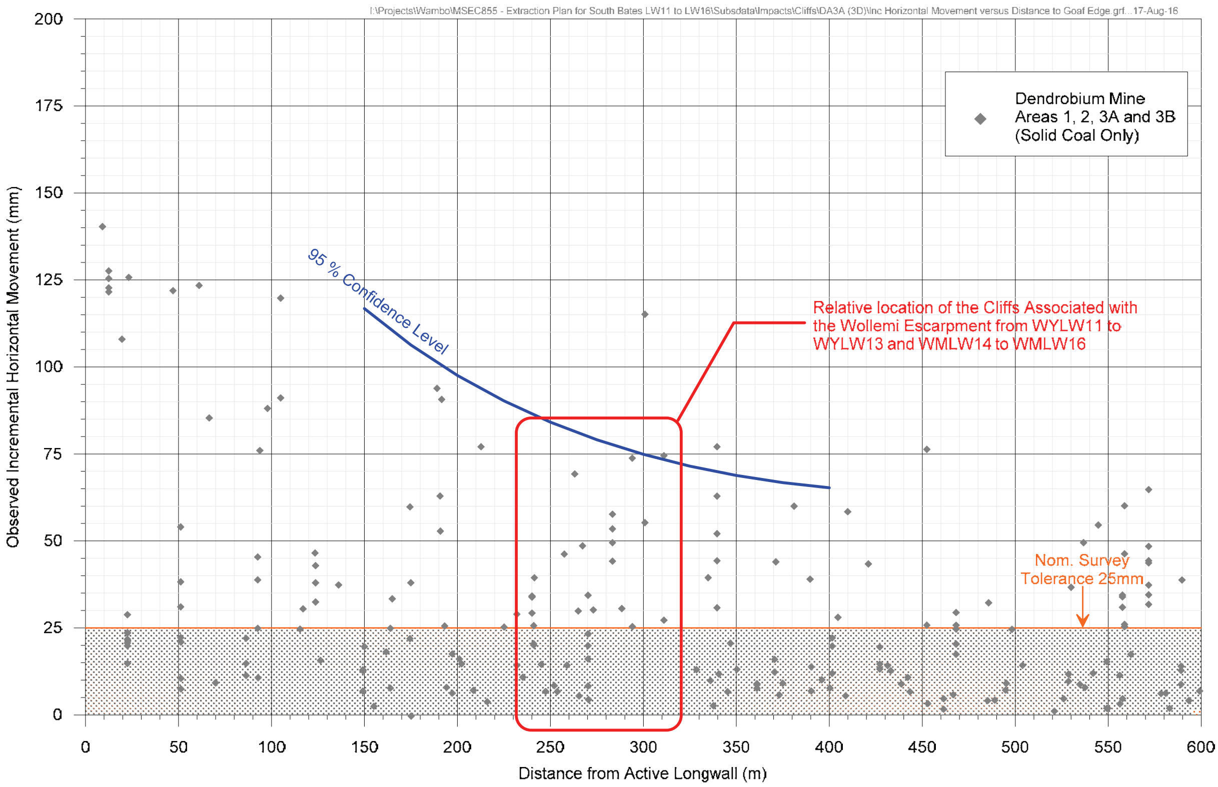

Fig. 5.15 Observed 3D Horizontal Movements in Areas 1, 2, 3A and 3B at Dendrobium Mine

It can be seen from Fig. 5.15, that the survey marks located above solid coal at Dendrobium Mine experience incremental horizontal movements up to around 75 mm at similar distances as the *Cliffs Associated with the Wollemi Escarpment* from WYLW11 to WYLW13 and WMLW14 to WMLW16. 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.

5.6.3. Comparisons of the Predictions for the Cliffs

Comparison of the maximum predicted total conventional subsidence parameters based on the Previous Layout and Revised Layout are provided in: Table 5.7 for the *Cliffs Associated with the Wollemi Escarpment*; Table 5.8 for the *Low Level Cliffs*; and Table 5.9 for the *Cliffs along the Spur*. The values are the maxima for these cliffs due to the extraction of the longwalls in both the Whybrow and Wambo Seams.

Table 5.7 Comparison of Maximum Predicted Subsidence Parameters for the Cliffs Associated with the Wollemi Escarpment based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	< 20	< 0.5	< 0.01	< 0.01
Revised Layout (Report No. MSEC855)	< 20	< 0.5	< 0.01	< 0.01

Table 5.8 Comparison of Maximum Predicted Subsidence Parameters for the Low Level Cliffs based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	70	1.0	0.01	< 0.01
Revised Layout (Report No. MSEC855)	50	0.5	< 0.01	< 0.01

Table 5.9 Comparison of Maximum Predicted Subsidence Parameters for the Cliffs along the Spur based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	2,750	18	0.12	0.15
Revised Layout (Report No. MSEC855)	2,700	17	0.10	0.15

The maximum predicted subsidence parameters for the cliffs, based on the Revised Layout, are the same or less than the maxima predicted based on the Previous Layout. The potential impacts on the cliffs therefore are similar to or less than those provided in Report Nos. MSEC692, MSEC693 and MSEC804. The impact assessments based on the Revised Layout have been provided in the following section.

5.6.4. Impact Assessments for the Cliffs Associated with the Wollemi Escarpment

The predicted vertical subsidence for the *Cliffs Associated with the Wollemi Escarpment* are all less than 20 mm. These cliffs are not predicted to experience any significant conventional tilts, curvatures or strains, even if the predicted vertical subsidence were exceeded by a factor of 2 times.

The cliffs could also experience low level far-field horizontal movements of up to around 75 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.

WYLW11 commenced in February 2016 and was completed in July 2016. This longwall is located at a minimum distance of 580 m from the *Cliffs Associated with the Wollemi Escarpment*. There have been no reported impacts on these cliffs as a result of mining WYLW11.

The existing Wollemi/Homestead workings in the Whybrow Seam were also extracted adjacent to the Wollemi Escarpment south-east of the Study Area. Longwall 13 was extracted at a distance of 210 m east of the cliffs, at its closest point. The location of these previous workings and the escarpment are illustrated in Fig. 5.16.

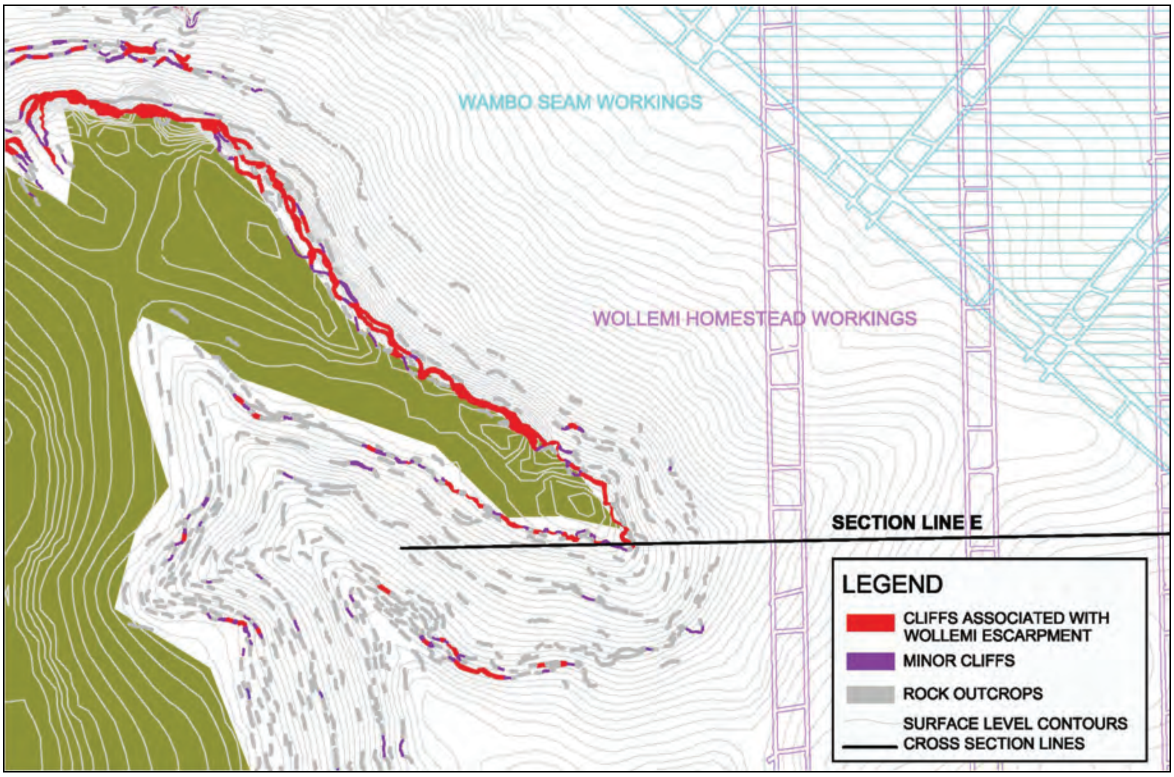

Fig. 5.16 Wollemi/Homestead Workings and the Wollemi Escarpment

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. 5.17.

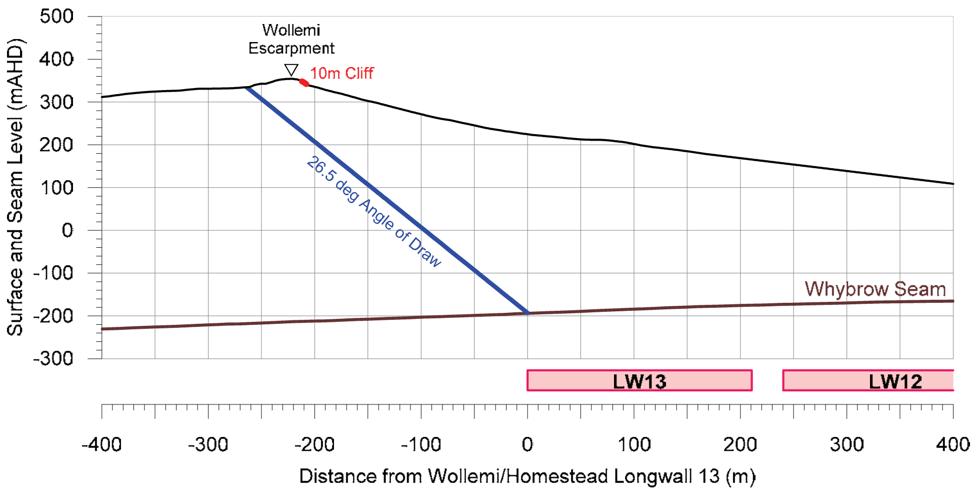

Fig. 5.17 Section E through the Wollemi Escarpment and the Wollemi/Homestead Workings

It can be seen from Fig. 5.17, that the Wollemi/Homestead workings were extracted to within a distance of 210 m from the cliffs associated with the Wollemi Escarpment, which is equivalent to a 21° angle of draw. 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 WYLW12, WYLW13 and WMLW14 to WMLW16.

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 end of WYLW12 and WMLW15, or other suitable monitoring methods. It is also recommended that the cliffs are periodically visually inspected during and after the completion of the longwalls.

5.6.5. Impact Assessments for the Low Level Cliffs

The *Low Level Cliffs* (i.e. CL-LL1 to CL-LL13) are predicted to experience up to 50 mm vertical subsidence resulting from the extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16. These low level vertical movements are expected to be associated with only small conventional tilts (up to 0.5 mm/m, or 1 in 2,000) and curvatures (less than 0.01 km^{-1}, or a minimum radius of curvature of 100 km).

These cliffs are discontinuous, having lengths typically between 20 and 40 m, except for CL-LL3 and CL-LL11 which have overall lengths of 80 and 125 m, respectively. The cliffs have overall heights typically between 10 and 15 m, except for Cliff CL-LL11 which has heights varying between 15 and 25 m.

The *Low Level Cliffs* are located at distances between 160 and 250 m from the longwalls. There is extensive experience of mining adjacent to (i.e. not directly beneath) cliffs in the NSW Coalfields which indicates that the likelihood of impacts is very low. Whilst minor and isolated rock falls have occurred at some cliffs that are located outside the extents of active longwalls, there have been no large cliff instabilities where the cliffs have been wholly located outside the extents of mining. These minor rock falls above solid coal represented less than 1 % of the total length of cliffline located within the 26.5° angle of draw from the active longwall.

As part of the National Energy Research, Development and Demonstration Program (NERDDP) Study 1446 (1991), an extensive study of the effects of mine subsidence movements on cliffs and escarpments was undertaken, including longwall and bord and pillar mining at collieries in the Western Coalfield including Angus Place, Baal Bone, Hassans Walls and Lithgow Valley, Katoomba and Newnes, and also included several collieries in the Southern Coalfield, including Dombarton, Nattai North and Huntley.

It was found from this study, that 96 % of the recorded cliff instabilities occurred directly above the workings, that is, after mining had occurred directly beneath the part or all of the clifflines. The remaining 4 % were recorded immediately adjacent to the workings and, although located above solid coal, had occurred after another section of the cliffline had been directly mined beneath.

In all cases, the recorded cliff instabilities had occurred within a 26.5° angle of draw line from the extents of mining. The cliff instabilities also occurred only after part of the cliffline was directly mined beneath, or after mining either side of the cliffline (i.e. behind the cliff as well as beneath the valley).

Based on the experience of mining close to, but not directly beneath cliffs in the NSW Coalfields, it is possible that minor and isolated rock falls could occur along the *Low Level Cliffs* as a result of the extraction of the longwalls. It is not expected, however, that any large cliff instabilities would occur as a result of the extraction of these longwalls, as they are not proposed to be extracted directly beneath these cliffs and are set back by distances between 160 and 250 m.

It is recommended that the *Low Level Cliffs* are periodically visually inspected during and after the extraction of the longwalls.

5.6.6. Impact Assessments for the Cliffs along the Spur

Cliff CL-SP1 is located directly above the WYLW12 and WMLW15 and Cliff CL-SP2 is located immediately adjacent to WMLW16. These two cliffs are predicted to experience up to 2,700 mm vertical subsidence, 17 mm/m tilt (i.e. 1.7 %, or 1 in 59) and 0.15 km^{-1} curvature (i.e. a minimum radius of curvature of 7 km) due to mining in both the Whybrow and Wambo Seams. The predicted subsidence parameters at these cliffs are less than the surrounding areas, as they are located at high levels along the spur where the depths of cover are the greatest.

Cliffs CL-SP3 to CL-SP7 are located at distances between 50 and 110 m from the longwalls. These cliffs are predicted to experience up to 575 mm vertical subsidence, 6 mm/m total tilt (i.e. 0.6 %, or 1 in 167) and 0.05 km^{-1} curvature (i.e. a minimum radius of curvature of 20 km).

Cliffs CL-SP8 to CL-SP10 are located at distances between 210 and 340 m from the longwalls. These cliffs are predicted to experience less than 20 mm vertical subsidence. Whilst these cliffs could experience low level vertical movements, they are not predicted to experience any measureable tilts, curvatures or strains.

It is extremely difficult to assess the likelihood of cliff instabilities based upon predicted ground movements. The likelihood of a cliff becoming unstable is dependent on a number of factors which are difficult to fully quantify. Some of these factors include jointing, inclusions, weaknesses within the rockmass, groundwater pressure and seepage flow behind the rockface. Even if these factors could be determined, it would still be difficult to quantify the extent to which these factors may influence the stability of a cliff naturally or when it is exposed to mine subsidence movements. It is therefore possible that cliff instabilities may occur during mining that may be attributable to either natural causes, mine subsidence, or both.

The likelihood of instabilities for Cliff CL-SP1, which is located directly above WMLW16, can be assessed using case studies where longwalls have been extracted directly beneath cliffs having similar mine subsidence parameters. The depth of cover to the Wambo Seam in the location of Cliff CL-SP1 is 450 m, which is similar to that in the Southern Coalfield, where the depths of cover typically range between 400 and 500 m.

Some examples of mining directly beneath clifflines from the Southern Coalfield are provided below:

- *Dendrobium Mine*

  Dendrobium Longwalls 1 and 2 had void widths of 250 m and a solid chain pillar width of 50 m. The longwalls were extracted from the Wongawilli Seam, at depths of cover varying between 170 and 320 m, and were also located beneath existing bord and pillar workings in the overlying Bulli Seam, i.e. partial multi-seam mining conditions. The maximum predicted conventional curvatures, resulting from the extraction of these longwalls, were 0.35 km^{-1} hogging and 0.75 km^{-1} sagging.

  These longwalls were extracted directly beneath a ridgeline and rock falls were observed in eight locations directly above mining. The total length of disturbance resulting from the extraction of Longwalls 1 and 2 was approximately 135 to 175 m. The total plan length of ridgeline located directly above the longwalls was between approximately 1,800 to 2,000 m. It should be noted that there are two levels of cliffs in some locations and, therefore, the total length of cliffline is greater than the total plan length of the ridgeline.

  The length of ridgeline disturbed as a result of the extraction of Longwalls 1 and 2 was, therefore, estimated to be between 7 % and 10 % of the total plan length of ridgeline directly above the longwalls. The length of rockfalls which occurred as a result of the extraction of Longwalls 1 and 2 was, however, less than the length of disturbed ridgeline.

- *Tower Colliery*

  Tower Colliery Longwalls 1 and 17 had void widths varying between 110 and 210 m and solid chain pillar widths varying between 35 and 50 m. The longwalls were extracted from the Bulli Seam at depths of cover varying between 400 and 540 m. The maximum predicted conventional curvatures, resulting from the extraction of these longwalls, were 0.05 km^{-1} hogging and 0.10 km^{-1} sagging.

  The total length of the cliffs that were located directly above these longwalls, or within a 35° angle of draw from these longwalls, was greater than 5 km. The overall heights of the cliffs varied between 10 and 60 m, which had formed from the Hawkesbury Sandstone Sedimentary Group.

  There were a total of 10 cliff instabilities recorded along the Cataract and Nepean Rivers, as a result of the extraction of Tower Longwalls 1 to 17, all of which occurred where the longwalls were mined directly beneath the cliffs. The total length of cliff instabilities, resulting from the extraction of Tower Colliery Longwalls 1 to 17, therefore, was approximately 3.5 % of the total length of cliffline.

- *Tahmoor Colliery*

  Tahmoor Colliery Longwalls 14 to 19 had void widths of 240 m and solid chain pillar widths of 37 m. The longwalls were extracted from the Bulli Seam at depths of cover varying between 380 and 390 m. The maximum predicted conventional curvatures, resulting from the extraction of these longwalls, were 0.05 km^{-1} hogging and 0.10 km^{-1} sagging.

Longwalls 14 to 19 were mined directly beneath the Bargo River. The total length of the cliffs that were located directly above these longwalls, or within a 35° angle of draw from these longwalls, was approximately 2.5 km. The overall heights of the cliffs varied between 10 and 25 m, which had been formed within the Hawkesbury Sandstone Sedimentary Group.

No cliff instabilities were observed during the mining period.

The maximum predicted curvatures for Cliff CL-SP1 are more similar to the maximum predicted curvatures at Tower and Tahmoor Collieries and are much less than those predicted at Dendrobium Mine. It is expected, therefore, that the rate of impacts on this cliff would be closer to those observed at Tower and Tahmoor Collieries and less than that observed at Dendrobium Mine.

Based on the above case studies, it has been estimated that less than 5 % of the length, or less than 3 % of the face area, of Cliff CL-SP1 would be impacted as a result of the extraction of these longwalls. These impacts would be more likely to occur during the extraction of WYLW12 and WMLW15 directly beneath this cliff.

It is predicted that only minor and isolated rock falls would occur at Cliffs CL-SP2 to CL-SP7, due to their distances from the longwalls, which would represent less than 1 % of the lengths of these cliffs. It is unlikely that Cliffs CL-SP8 to CL-SP10 would experience adverse impacts, as they are located at distances of more than 200 m from the longwalls and are expected to experience less than 20 mm of vertical subsidence. This is based on the extensive experience of mining near to but not directly beneath cliffs in the NSW Coalfields, where no large cliff falls have occurred when the cliffs are completely located outside the 26.5° angle of draw line from mining.

It is recommended that the *Cliffs along the Spur* are periodically visually inspected during and after the extraction of the longwalls directly beneath and immediately adjacent to these cliffs.

5.7. Pagodas

There are isolated pagodas along the spur that crosses directly above the southern ends of WYLW12, WMLW15 and WMLW16. There were no pagoda complexes identified within the Study Area. Photographs of typical pagodas are provided in Fig. 5.18. The pagodas have formed from the Widden Brook Conglomerate and have heights up to around 3 to 5 m.

Fig. 5.18 Photographs of the Isolated Pagodas

The pagodas are located directly and immediately adjacent to the longwalls 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.

The isolated pagodas that are located directly above the longwalls could experience some fracturing and, where the rock is marginally stable, could then result in spalling of the exposed rockfaces. The isolated pagodas are discontinuous and, therefore, are less susceptible to impacts when compared with cliffs and minor cliffs. It is expected that the impacts resulting from mining would represent less than 1 % of total surface area of the isolated pagodas which are located directly above 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 m surface level contours which were generated from the LiDAR survey of the area.

Steep slopes have been identified along the spur that crosses above the southern ends of the longwalls and beneath the Wollemi Escarpment to the south-west of the longwalls. The natural surface gradients typically range between 1 in 3 and 1 in 2 along the spur and between 1 in 2 and 1 in 1.5 along the slopes beneath the Wollemi Escarpment. The natural gradients increased up to around 1 in 1 on the higher levels of the spur and beneath the escarpment to the south-west of the longwalls.

The surface soils along the steep slopes are generally derived from the Widden Brook Conglomerate (Rna), as can be inferred from Fig. 1.6. The slopes are stabilised by the natural vegetation, which can be seen in Fig. 1.1.

5.8.2. Predictions for the Steep Slopes

A summary of the maximum predicted total subsidence, tilts and curvatures for the steep slopes, after the extraction of each of the longwalls, is provided in Table 5.10.

Table 5.10 Maximum Predicted Total Subsidence, Tilts and Curvatures for the Steep Slopes Resulting from the Extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16

Location	Longwall	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 along the Spur	After WYLW11	1,150	11	0.12	0.35
	After WYLW12	1,500	16	0.25	0.55
	After WYLW13	1,750	19	0.30	0.70
	After WMLW14	3,800	35	0.45	1.0
	After WMLW15	3,900	35	0.50	1.0
	After WMLW16	3,900	35	0.55	1.0
Steep Slopes beneath the Wollemi Escarpment	After WYLW11	< 20	< 0.5	< 0.01	< 0.01
	After WYLW12	< 20	< 0.5	< 0.01	< 0.01
	After WYLW13	< 20	< 0.5	< 0.01	< 0.01
	After WMLW14	< 20	< 0.5	< 0.01	< 0.01
	After WMLW15	90	< 0.5	0.01	< 0.01
	After WMLW16	100	< 0.5	0.01	< 0.01

The predicted strains for the steep slopes located directly above the longwalls have been based on the analysis of strains from previous longwall mining in the Hunter Coalfield, which is discussed in Section 4.4. The steep slopes located outside of the longwalls are predicted to experience strains less than 0.5 mm/m tensile and compressive.

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.

5.8.3. Comparisons of the Predictions for the Steep Slopes

Comparison of the maximum predicted total conventional subsidence parameters based on the Previous Layout and Revised Layout are provided in: Table 5.11 for the steep slopes along the spur; and Table 5.12 for the steep slopes beneath the Wollemi Escarpment to the south-west of the longwalls. The values are the maxima due to the extraction of the longwalls in both the Whybrow and Wambo Seams.

Table 5.11 Comparison of Maximum Predicted Subsidence Parameters for the Steep Slopes along the Spur based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	4,000	35	0.55	1.1
Revised Layout (Report No. MSEC855)	3,900	35	0.55	1.0

Table 5.12 Comparison of Maximum Predicted Subsidence Parameters for the Steep Slopes beneath the Wollemi Escarpment based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	700	6	0.55	0.16
Revised Layout (Report No. MSEC855)	100	< 0.5	0.01	< 0.01

The maximum predicted subsidence parameters for the steep slopes, based on the Revised Layout, are the same or less than the maxima predicted based on the Previous Layout. The potential impacts on the steep slopes therefore are less than those provided in Report Nos. MSEC692, MSEC693 and MSEC804. The impact assessments based on the Revised Layout have been provided in the following section.

5.8.4. Impact Assessments for the Steep Slopes along the Spur

The steep slopes along the spur are located directly above the south-western ends of WYLW11 to WYLW13 and WMLW14 to WMLW16. The maximum predicted total tilt for these steep slopes of 35 mm/m (i.e. 3.5 %, or 1 in 30) is 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 downslope movement of the ground, 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 curvatures for the steep slopes along the spur are 0.55 km^{-1} hogging and 1.0 km^{-1} sagging, which represent minimum radii of curvature of 1.8 km and 1 km, respectively. These predicted parameters are greater than those for the *Cliffs along the Spur*, as the steep slopes extend across a wider area where the depths of cover are shallower.

The maximum predicted curvatures and strains for the steep slopes along the spur are similar orders of magnitude to those predicted to have occurred for Dendrobium Longwalls 1 and 2, which mined directly beneath a ridgeline with similar surface grades. The surface cracking observed resulting from downslope movement from this case study can, therefore, be used to provide an indication of the potential surface cracking along the steep slopes located directly above WYLW11 to WYLW13 and WMLW14 to WMLW16.

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. 5.19.

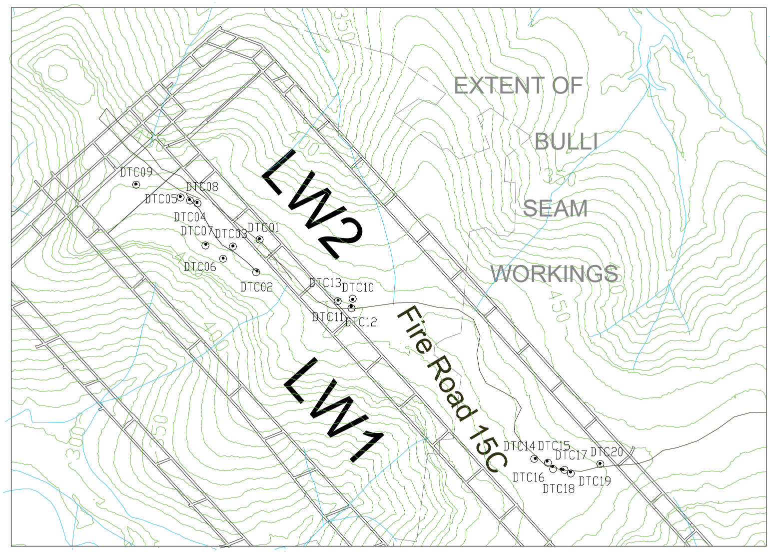

Fig. 5.19 Locations of Observed Surface Cracking above Dendrobium Longwalls 1 and 2

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 downslope 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. 5.20.

Fig. 5.20 Surface Tension Cracking due to Downslope Movements at Dendrobium Mine

It is expected, therefore, that the downslope movement of the ground would also occur along steep slopes along the spur, which are located directly above the south-western ends of WYLW11 to WYLW13 and WMLW14 to WMLW16. The steep slopes are heavily vegetated and natural erosion due to soil instability (i.e. natural downslope movements) was not readily apparent from the site investigations undertaken. If tension cracks were to develop, as the result of the extraction of WYLW11 to WYLW13 and WMLW14 to WMLW16, it is possible that soil erosion could occur if these cracks were left untreated.

It is possible, therefore, that some remediation might be required, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the surface soils 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. Impact Assessments for the Steep Slopes beneath the Wollemi Escarpment

It can be seen from Drawing No. MSEC855-13, that WYLW11 to WYLW13 and WMLW14 to WMLW16 commence on the north-eastern side of Stony Creek, i.e. the longwalls do not mine directly beneath the creek or the steep slopes located directly beneath the Wollemi Escarpment. The extraction of these longwalls is unlikely, therefore, to result in higher levels of horizontal movement due to downslope effects on the steep slopes beneath the escarpment on the south-western side of Stony Creek.

WYLW12 and WMLW15 are located at minimum distances of 100 and 65 m, respectively, from Stony Creek. The steep slopes near the base of the creek could experience some minor surface cracking resulting from these longwalls. It is unlikely, however, that significant surface cracking would occur further upslope and outside the extents of these longwalls.

It is not expected that surface remediation would be required for the steep slopes located beneath the Wollemi Escarpment to the south-west of the longwalls. Some surface remediation could be required near the base of Stony Creek near the commencing ends of WYLW12 and WMLW15. These impacts could be remediated by infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface.

5.8.6. Recommendations for the Steep Slopes

It is recommended that the steep slopes are periodically visually monitored during the mining period and until any necessary remedial measures are completed, 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 surface soils in the longer term.

5.9. Land Prone to Flooding or Inundation

The land within the Study Area generally falls towards the north-east. The land above the commencing ends of the longwalls (i.e. south-west of the spur) falls towards Stony Creek. The natural surface level contours (grey lines) and the predicted post-mining surface level contours (green lines) after the completion of mining in both the Whybrow and Wambo Seams are illustrated in Fig. 5.21.

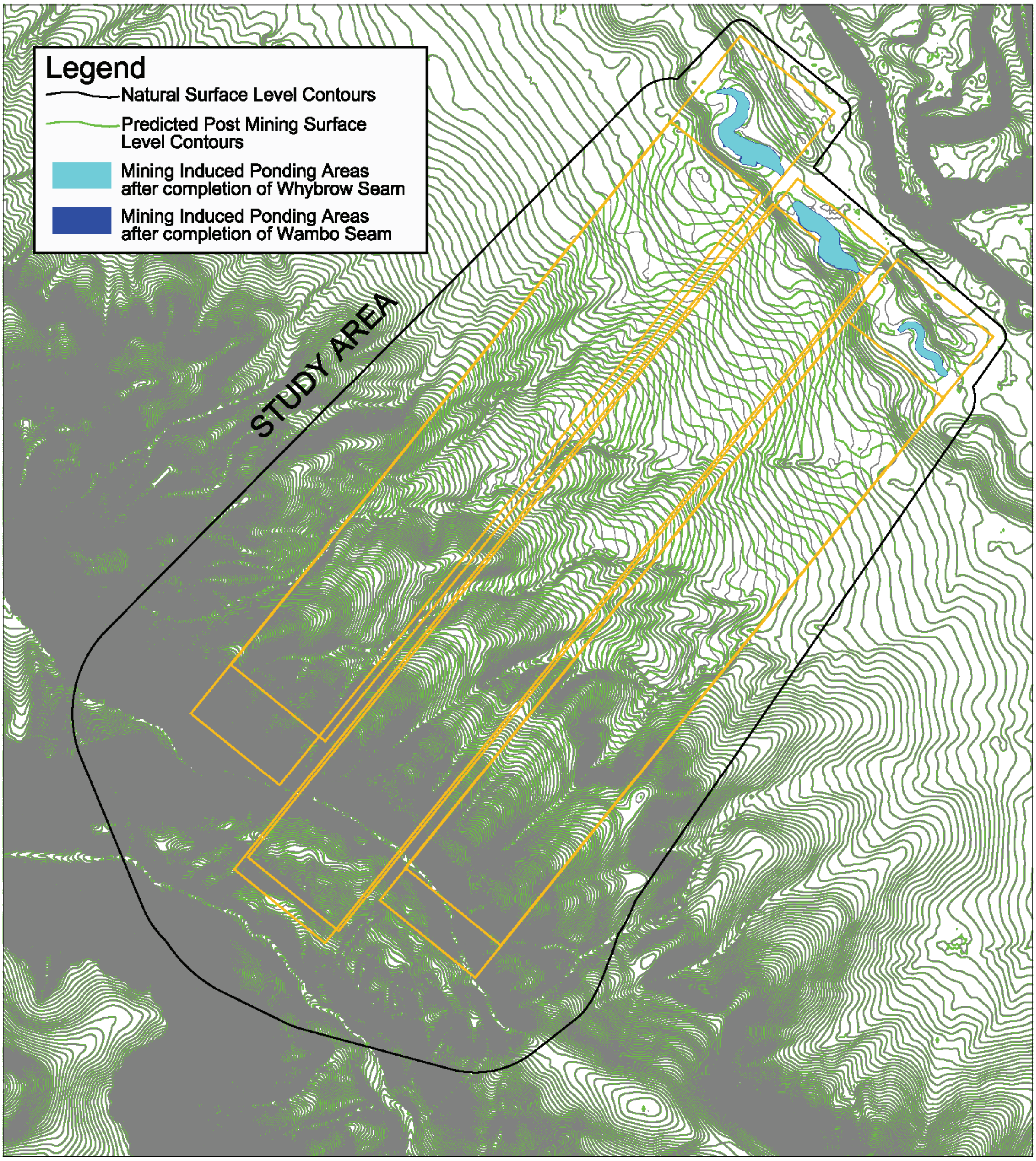

Fig. 5.21 Natural and Predicted Subsided Surface Levels and Ponding Areas

It can be seen from Fig. 5.21 that, increased ponding areas are predicted to develop above the finishing (i.e. north-eastern) ends of WYLW11 to WYLW13 in the vicinity of the North Wambo Creek Diversion after the completion of these longwalls, which is indicated by the cyan hatching. The extents of these ponding areas are not expected to increase significantly due to the mining in the Wambo Seam, as indicated by the blue hatching.

The predicted ponding areas are also illustrated along the alignment of the North Wambo Creek Diversion in Fig. 5.5. These ponding areas are estimated to be up to 1.4 m deep and up to 250 m long after the completion of mining in the Wambo Seam.

There are no predicted topographical depressions (i.e. areas of increased ponding) away from the finishing ends of the longwalls. It is not, therefore, considered that the land across the Study Area is naturally susceptible to flooding or inundation. There are localised areas with the potential for increased ponding along the alignments of the ephemeral drainage lines, which is discussed in Sections 5.2 and 5.3.

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 *FloraSearch* (2015) and the Biodiversity Management Plan.

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 report prepared by *FloraSearch* (2015) and the Biodiversity Management Plan.

5.12. National Parks or Wilderness Areas

The *Wollemi National Park* is located to the south-west and to the west of the longwalls. The boundary of the National Park is located at minimum distances of 250 m south-west of the commencing ends of WYLW11 and WYLW12 and 275 m west of the tailgate of WYLW11, at its closest points. The location of the National Park is shown in Drawings Nos. MSEC855-01 and MSEC855-13.

The land within the National Park is predicted to experience less than 20 mm vertical subsidence resulting from the extraction of the longwalls, i.e. the boundary is located outside of the limit of vertical subsidence. The sections of the National Park boundary located closest to the longwalls could experience very low levels of vertical subsidence, but are not predicted to experience any significant conventional tilts, curvatures or strains.

The National Park could experience low level far-field horizontal movements. As described in Section 5.6.2, the Wollemi Escarpment (i.e. the cliffs on the boundary of the National Park) are predicted to experience horizontal movements of up to around 75 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 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 5.6.

The drainage lines within the National Park are located at distances greater than 400 m from the longwalls. Whilst minor and isolated fracturing have been observed up to around 400 m from longwall mining, these have occurred within very incised river valleys within the Southern Coalfield and have 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 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

There is natural vegetation across the majority of the Study Area, as can be seen from the aerial photograph in Fig. 1.1. The land has only been cleared in the north-eastern part of the Study Area in the location and adjacent to the North Wambo Creek Diversion and the Bates South Open Cut Pit. A detailed survey of the natural vegetation has been undertaken and is described and assessed in the report prepared by *FloraSearch* (2015) and the Biodiversity Management Plan.

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.

6.1. Public Utilities

As listed in Table 2.1, there were no Public Utilities identified within the Study Area, apart from the unsealed roads and the associated drainage culverts, which are described below.

6.1.1. Unsealed Roads and Drainage Culverts

There are unsealed tracks and fire trails across the Study Area. The locations of these roads are shown in Drawing No. MSEC855-14. The tracks in the north-eastern part of the Study Area are used for the mining operations and the trails in the south-western part of the Study Area are used for firefighting activities. Circular concrete culverts have been constructed, in some locations, where the roads cross the drainage lines.

The unsealed tracks and trails 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.

It is expected that cracking and rippling of the unsealed road surfaces would occur as each of the longwalls mine beneath them. The largest impacts will occur in the north-eastern part of the Study Area, where the depths of cover are the shallowest. It is expected that the 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.

There are existing management strategies for maintaining the unsealed roads which are located above the previously extracted longwalls at the NWUM. It is expected that these same strategies could be used to maintain the unsealed roads which are located directly above WYLW11 to WYLW13 and WMLW14 to WMLW16. It is recommended that these roads are periodically visually monitored during active subsidence.

The management strategies for unsealed roads should be incorporated into the Built Features Management Plan.

6.2. Public Amenities

As listed in Table 2.1, there were no Public Amenities identified within the Study Area.

6.3. Farm Land and Facilities

6.3.1. Agricultural Utilisation

There is no major farm land or agricultural utilisation identified within the Study Area. There is natural vegetation across the majority of the Study Area, as can be seen from the aerial photograph in Fig. 1.1. The land has only been cleared in the north-eastern part of the Study Area for the North Wambo Creek Diversion and the Bates South Open Cut Pit.

6.3.2. Fences

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. 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 strategies for the fences should be incorporated into the Built Features Management Plan.

6.3.3. Registered Groundwater Bores

The registered groundwater bores within the Study Area were identified using the *Natural Resource Atlas* website (NRAtlas, 2014). WCPL owns a monitoring bore (Ref. GW200835) that is located directly above WMLW16 which could be adversely impacted by subsidence. There were no other registered groundwater bores identified in the vicinity of the longwalls.

6.4. 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 the mine related infrastructure, which are described below.

6.4.1. Bates South Open Cut Pit

The Bates South Open Cut Pit, part of the Wambo Coal Mine, is located immediately to the north-east of the longwalls. The current extent of the pit is shown in Drawing No. MSEC855-01. A geotechnical assessment of the highwall including effects of the WYLW11 to WYLW13 and WMLW14 to WMLW16 has been undertaken by *Golder* (2014).

6.4.2. Exploration Drill Holes

The locations of the exploration drill holes within the Study Area are shown in Drawing No. MSEC855-14. The drill holes are located directly above and adjacent to the longwalls and, therefore, could experience the full range of predicted subsidence movements described in Chapter 4. It is likely, therefore, that fracturing and shearing would occur in the drill holes as the result of mining. It is recommended that the exploration drill holes are capped (if not already completed) prior to being directly mined beneath.

6.4.3. Water Pipeline

There is an above ground polyethylene water pipeline that crosses directly above the finishing ends of WYLW11 and WYLW13 and is located outside and to the north-east of WMLW14 to WMLW16. The location of this pipeline is shown in Drawing No. MSEC855-14. The pipeline is owned by WCPL and is used for the mining operations.

The water pipeline could experience the maximum predicted subsidence movements resulting from the extraction of the longwalls in the Whybrow Seam. A summary of the maximum predicted mine subsidence parameters within the Study Area was provided in Chapter 4. The pipeline is predicted to experience less than 20 mm additional vertical subsidence due to mining in the Wambo Seam.

The water pipeline is a pressure main and is unlikely, therefore, to be affected to any great extent by changes in gradient due to vertical subsidence or tilt. The pipeline is also resting on the natural ground and, therefore, it is unlikely that the localised curvatures or ground strains would be transferred into it.

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 it were 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.

6.4.4. Power and Telecommunications Cables

There are direct buried 11 kilovolt (kV) powerlines, optical fibre and copper telecommunications cables that cross directly above the finishing ends of WYLW11 and WYLW13 and are located outside and to the north-east of WMLW14 to WMLW16. The locations of these cables are shown in Drawing No. MSEC85514. The cables are owned by WCPL and are used for the mining operations.

The cables could experience the maximum predicted subsidence movements resulting from the extraction of the longwalls in the Whybrow Seam. A summary of the maximum predicted mine subsidence parameters within the Study Area was provided in Chapter 4. The cables are predicted to experience less than 20 mm additional vertical subsidence due to mining in the Wambo Seam.

The power and copper telecommunications cables are flexible and, therefore, are unlikely to be adversely impacted by the mining induced curvatures or strains. The optical fibre cable could be adversely affected by localised curvatures or compressive strains, which could attenuate the transmission or result in signal loss. The adverse impacts on the cable could be remediated by locally exposing, straightening and reburying the cable.

6.4.5. The Proposed Montrose East Dam

The proposed Montrose East Dam is located outside the Study Area, at a distance of 350 m north-west of WYLW11 and WMLW16, at its closest point to the longwalls. The location of this approved dam is shown in Drawing No. MSEC855-14. At this distance, the dam is predicted to experience less than 20 mm vertical subsidence and is not expected to experience any measurable tilts, curvatures or strains. It is unlikely that the dam would be adversely impacted by the proposed mining, even if the predictions were exceeded by a factor of 2 times.

6.5. Archaeological Sites

6.5.1. Descriptions of the Archaeological Sites

There are no lands within the Study Area declared as an Aboriginal Place under the *National Parks and Wildlife Act 1974*. There are five archaeological sites which have been identified within the Study Area which are shown in Drawing No. MSEC855-14. A summary of these archaeological sites is provided in Table 6.1 below.

Table 6.1 Archaeological Sites within the Study Area

Site Reference	Location	Description
297	Above WYLW11 and WMLW16	Isolated Find
382	Above WYLW11 and WMLW16	Artefact Scatter
383	Above WYLW11 and WMLW16	Artefact Scatter
384	Above the tailgate of WYLW11 and the maingate of WMLW16	Isolated Find
385	Above WYLW12 and WMLW15	Artefact Scatter

Further details on the archaeological sites are provided in the report by *RPS* (2015).

6.5.2. Predictions for the Archaeological Sites

Summaries of the maximum predicted total subsidence, tilts and curvatures for the archaeological sites are provided in Table 6.2 after the completion of the Whybrow Seam and Table 6.3 after the completion of the Wambo Seam. The values are the maxima that occur at any time during or after the extraction of the longwalls.

Table 6.2 Maximum Predicted Total Subsidence, Tilts and Curvatures for the Archaeological Sites Resulting from WYLW11 to WYLW13 (i.e. Whybrow Seam Only)

Site Reference	Type	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})
297	Isolated Find	800	20	0.30	0.20
382	Artefact Scatter	1,900	35	1.50	1.50
383	Artefact Scatter	850	30	0.90	0.60
384	Isolated Find	250	10	0.40	0.20
385	Artefact Scatter	1,200	20	0.30	0.20

Table 6.3 Maximum Predicted Total Subsidence, Tilts and Curvatures for the Archaeological Sites Resulting from WYLW11 to WYLW13 and WMLW14 to WMLW16 (i.e. Whybrow and Wambo Seams)

Site Reference	Type	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})
297	Isolated Find	2,400	40	0.40	0.20
382	Artefact Scatter	4,100	55	1.50	1.50
383	Artefact Scatter	1,800	50	1.00	0.60
384	Isolated Find	650	20	0.70	0.20
385	Artefact Scatter	2,900	35	0.50	0.30

The predicted strains for the archaeological sites located directly above the longwalls have been based on the analysis of strains from previous longwall mining in the Hunter Coalfield, which is discussed in Section 4.4.

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

6.5.3. Comparisons of the Predictions for the Archaeological Sites

Comparison of the maximum predicted total conventional subsidence parameters based on the Previous Layout and Revised Layout are provided in Table 6.4 for the artefact scatters and Table 6.5 for the isolated finds. The values are the maxima due to the extraction of the longwalls in both the Whybrow and Wambo Seams.

Table 6.4 Comparison of Maximum Predicted Subsidence Parameters for the Artefact Scatters based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	4,000	55	1.5	1.5
Revised Layout (Report No. MSEC855)	4,100	55	1.5	1.5

Table 6.5 Comparison of Maximum Predicted Subsidence Parameters for the Isolated Finds based on the Previous and Revised Layouts

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Previous Layout (Reports Nos. MSEC692, MSEC693 and MSEC804)	2,300	35	0.6	0.2
Revised Layout (Report No. MSEC855)	2,400	40	0.7	0.2

The maximum predicted vertical subsidence for the artefact scatters and isolated finds, based on the Revised Layout, is slightly greater than the maxima based on the Previous Layout. The increase in vertical subsidence is less than 5 % and is due to change in mining sequence in the Wambo Seam. In any case, the potential for impacts do not result from the absolute vertical subsidence, but rather from the differential movements, represented by tilt, curvature and strain.

The maximum predicted tilt and the maximum predicted hogging curvature for the isolated finds, based on the Revised Layout, are also slightly greater than the maxima based on the Previous Layout. Again, the increase in these parameters is small and is due to change in mining sequence in the Wambo Seam.

The remaining maximum predicted subsidence parameters for the archaeological sites, based on the Revised Layout, are the same or less than the maxima predicted based on the Previous Layout.

The impact assessments based on the Revised Layout have been provided in the following sections.

6.5.4. Impact Assessments for the Artefact Scatters and Isolated Finds

There are three sites within the Study Area comprising artefact scatters, being Sites 382, 383 and 385. There are also two sites within the Study Area comprising isolated finds, being Sites 297 and 384.

The maximum predicted total tilts are 55 mm/m (i.e. 5.5 %, or 1 in 18) for the artefact scatters and 40 mm/m (i.e. 4.0 %, or 1 in 25) for the isolated finds. It is unlikely that these sites would experience adverse impacts resulting from the mining induced tilts.

The maximum predicted total curvatures for the artefact scatters are 1.5 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 0.7 km. The maximum predicted total curvatures for the isolated finds are 0.7 km^{-1} hogging and 0.2 km^{-1} sagging, which represent minimum radii of curvatures of 1.4 km and 5 km, respectively.

The mining induced curvatures and strains could result in surface cracking in the vicinity of the sites which are located directly above the longwalls. It is unlikely, however, that the scattered artefacts or isolated finds themselves would be adversely impacted by the 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.

Management of the potential impacts on the artefact scatters and isolated finds is described in the Heritage Management Plan.

6.6. 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* (2014). 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, at distances greater than 1.5 km from the longwalls.

The survey control marks located in the area could be affected by far-field horizontal movements, up to 3 km outside the extents of the longwalls. Far-field horizontal movements and the methods used to predict such movements are described further in Sections 4.5 and B.4.

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.

APPENDIX A. REFERENCES

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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. 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.

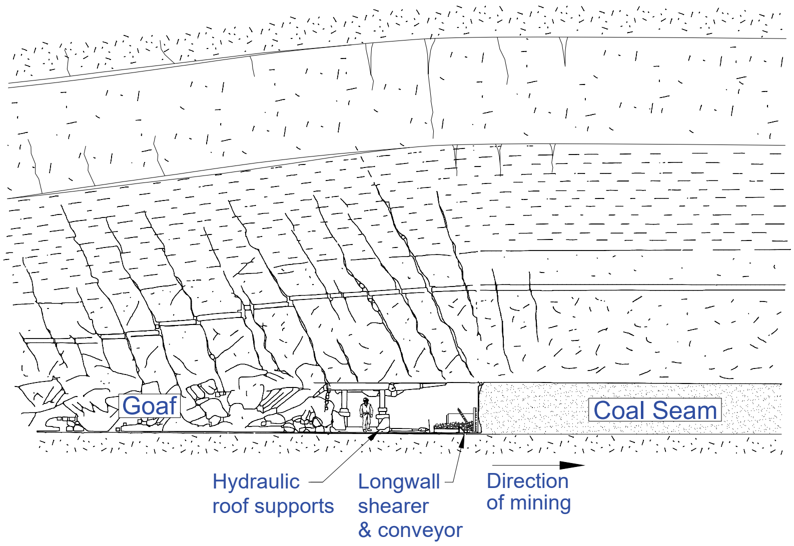

Fig. B. 1 Cross-section along the Length of a Typical Longwall at the Coal Face

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 remain 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.

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 1000.

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

- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile Strains** occur where the 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 **incremental** subsidence, tilts, curvatures and strains are those which result from the extraction of each of the individual longwalls. The **total** subsidence, tilts, curvatures and strains are the accumulated parameters after the completion of each of the longwalls. 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 at the north-eastern ends of WMLW14 to WMLW16. 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.

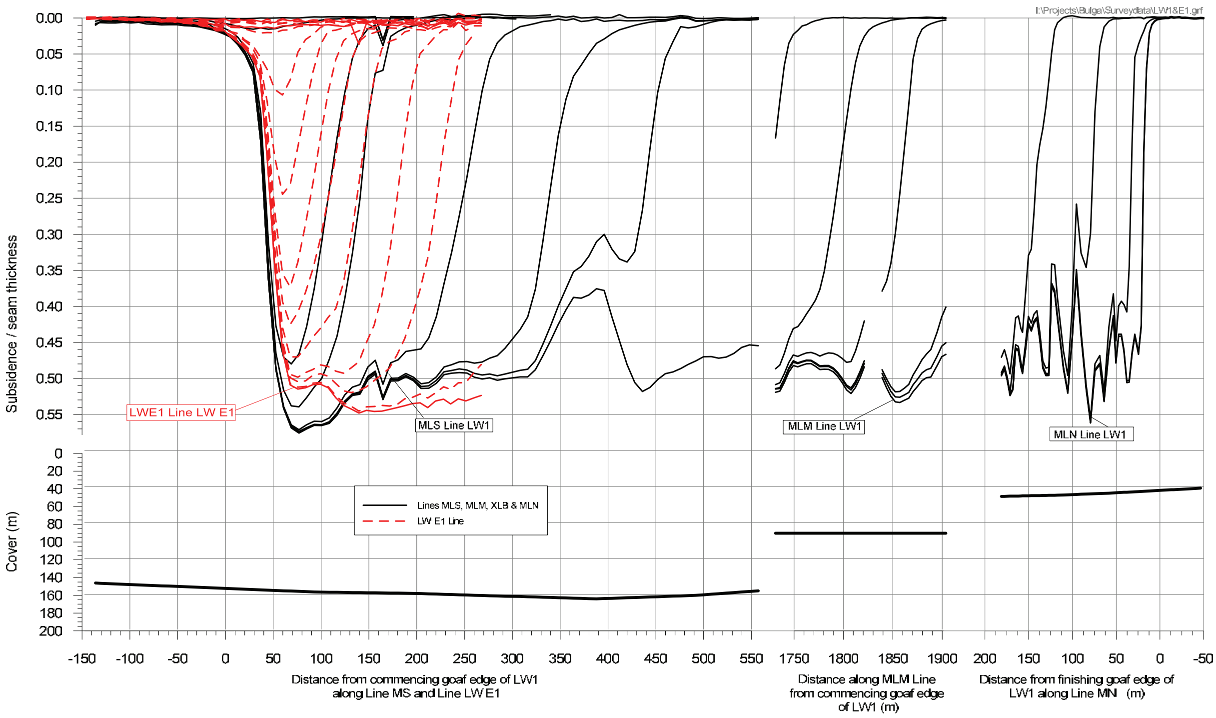

Fig. B. 2 Observed Subsidence Profiles at South Bulga Colliery

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 from downslope movements where longwalls are extracted beneath steep slopes. In these cases, elevated tensile strains develop near the tops of the steep slopes and elevated compressive strains develop near the bases of the steep slopes. The potential impacts resulting from 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.

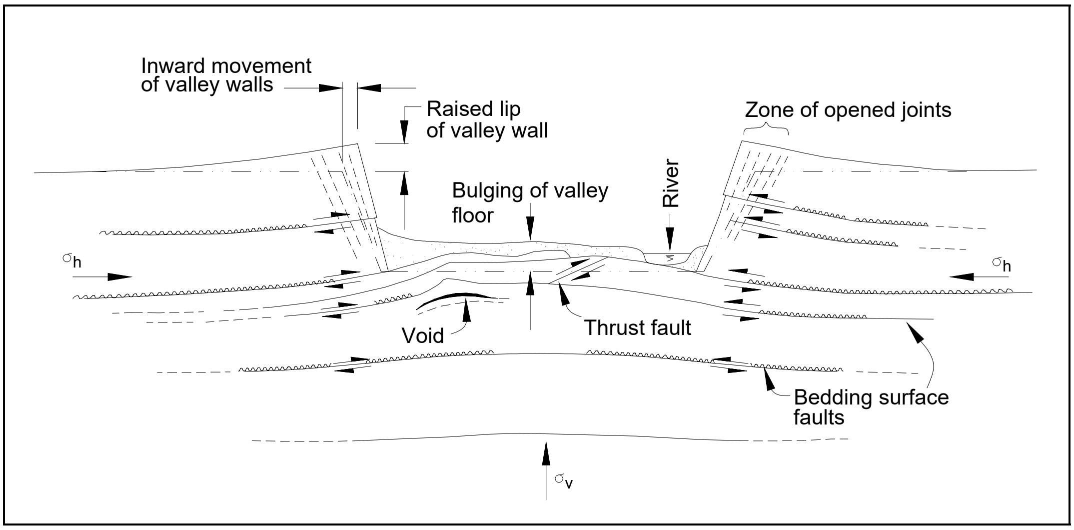

Fig. B. 3 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

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 downslope movements. Valley related movements are normally described by the following parameters:

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

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

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

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

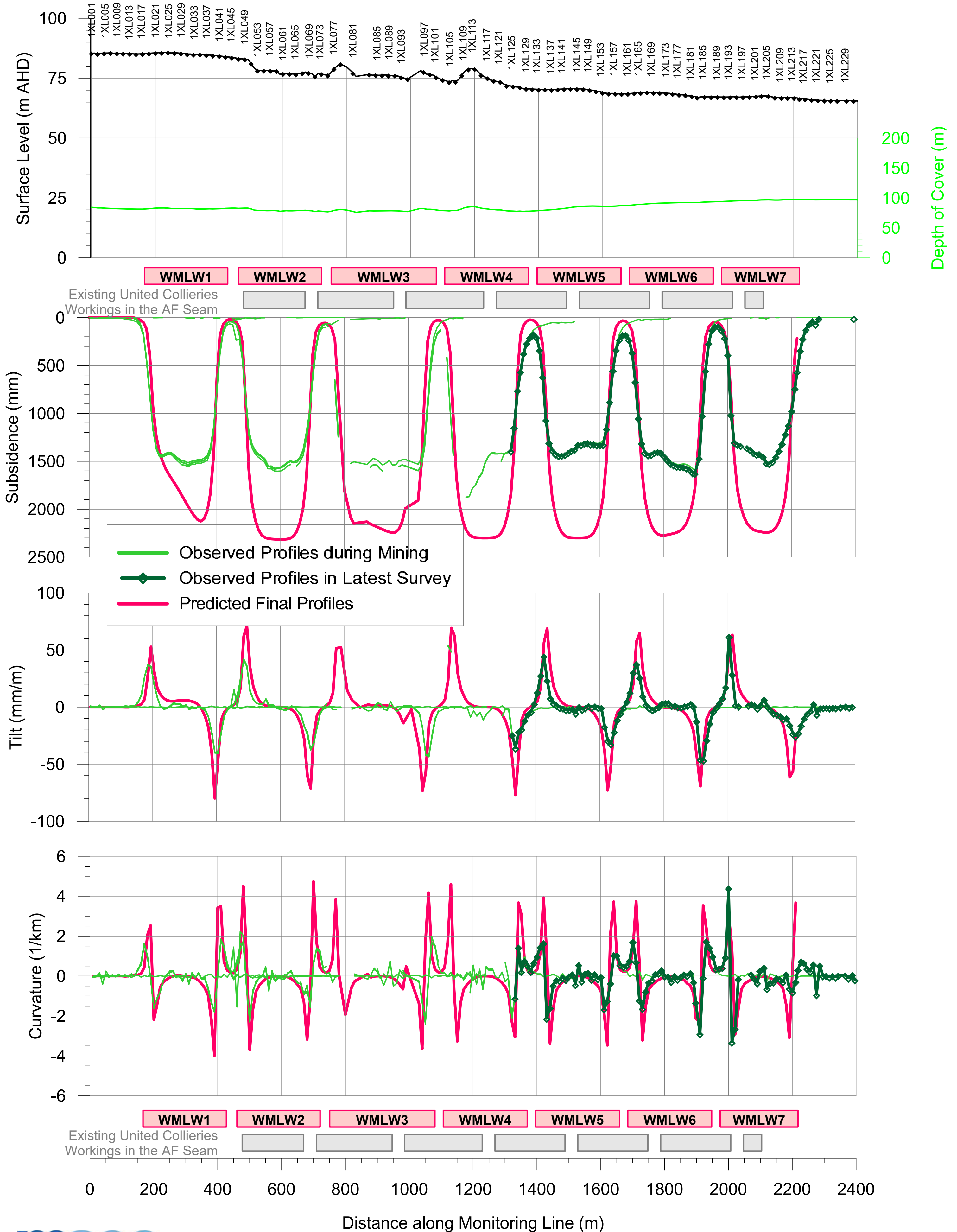

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Fig. C.01

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

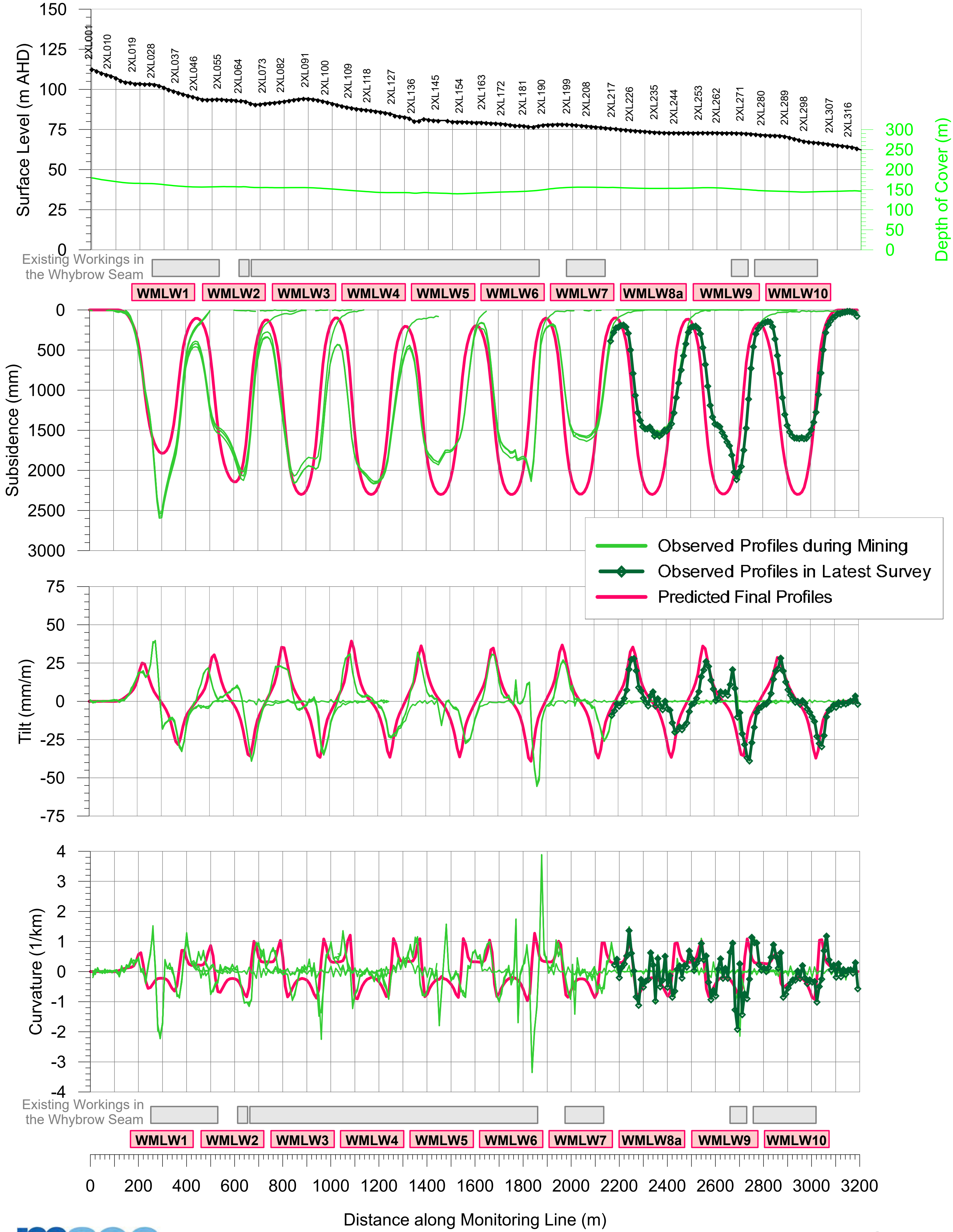

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Fig. C.02

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

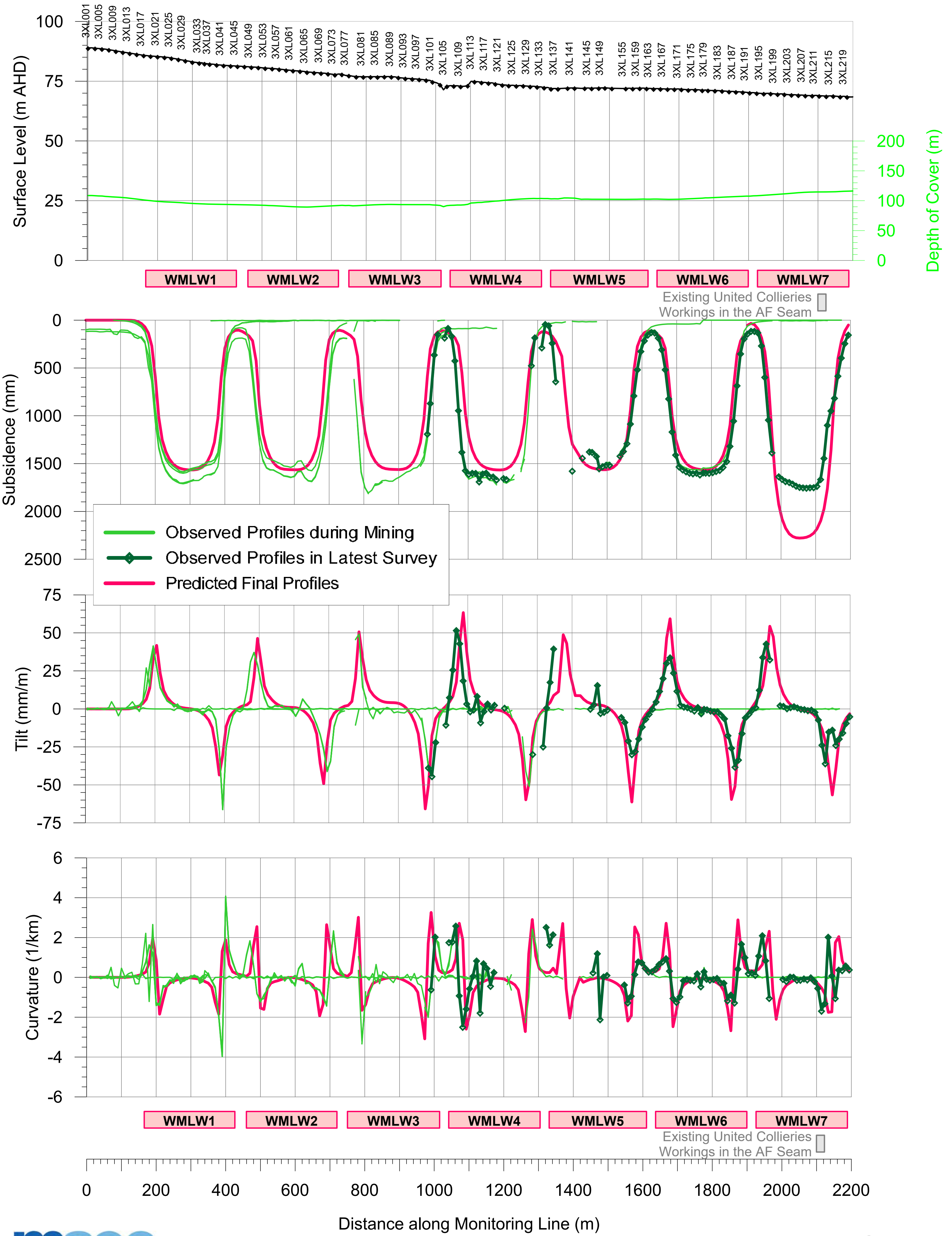

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Fig. C.03

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

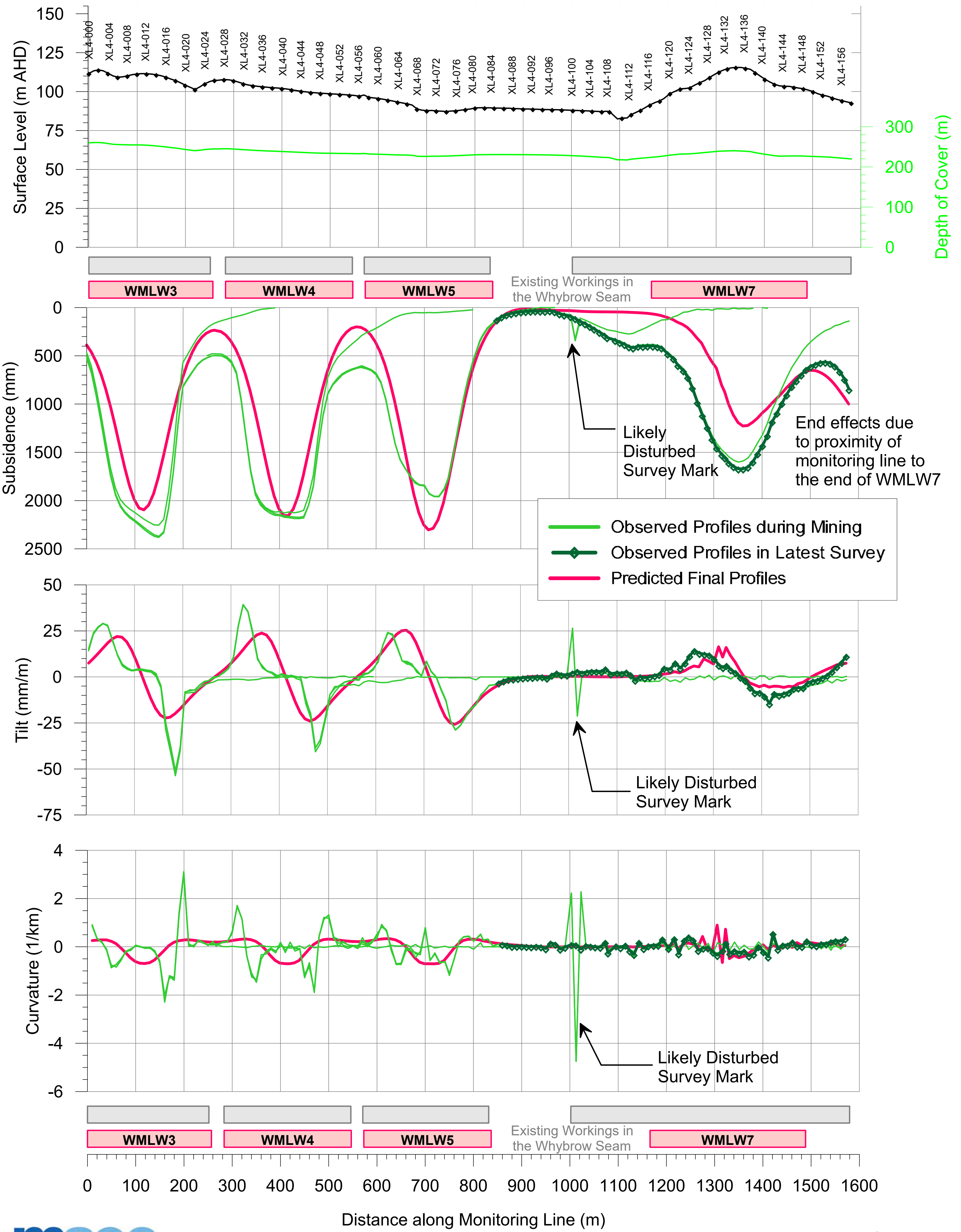

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Fig. C.04

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

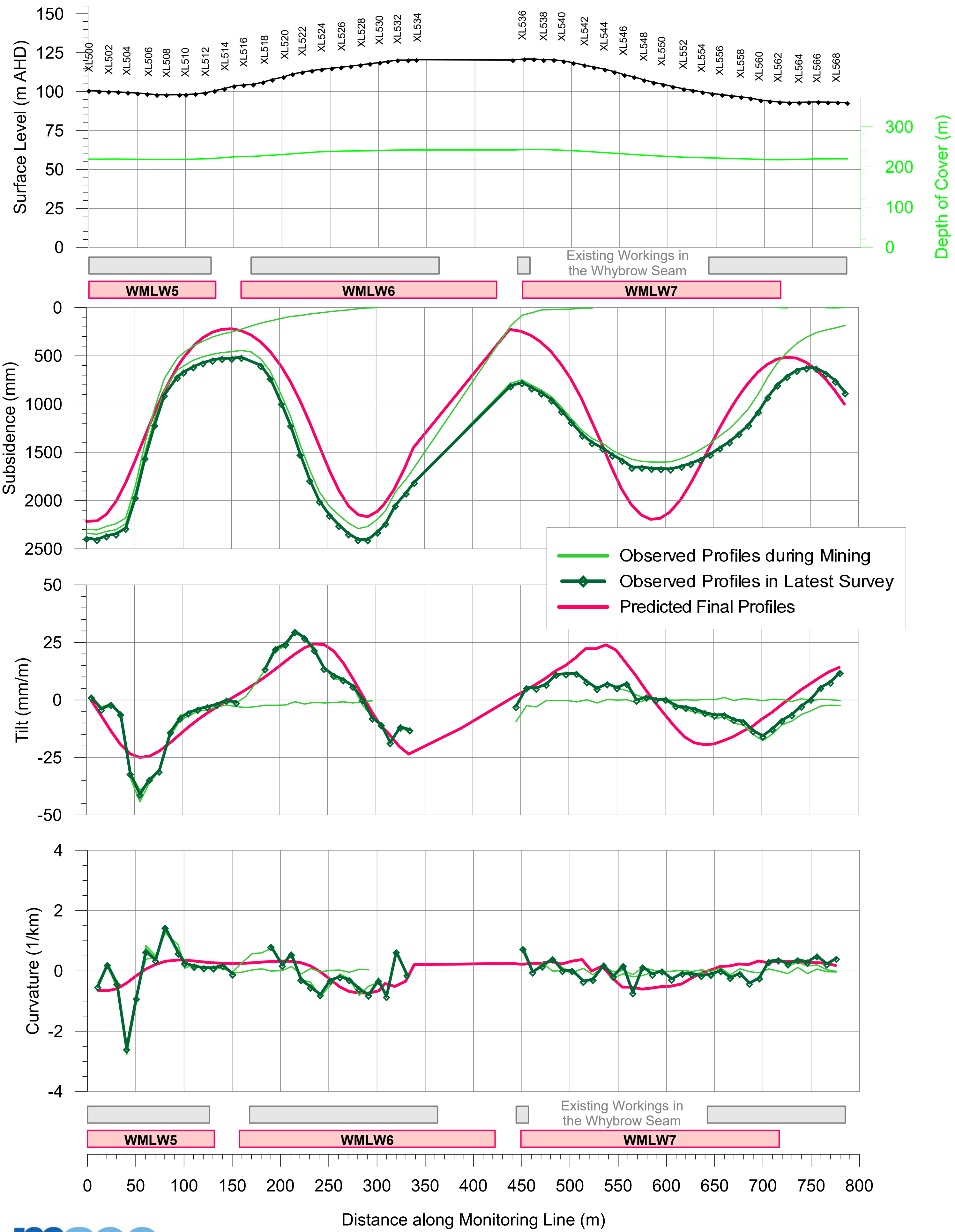

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Fig. C.05

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

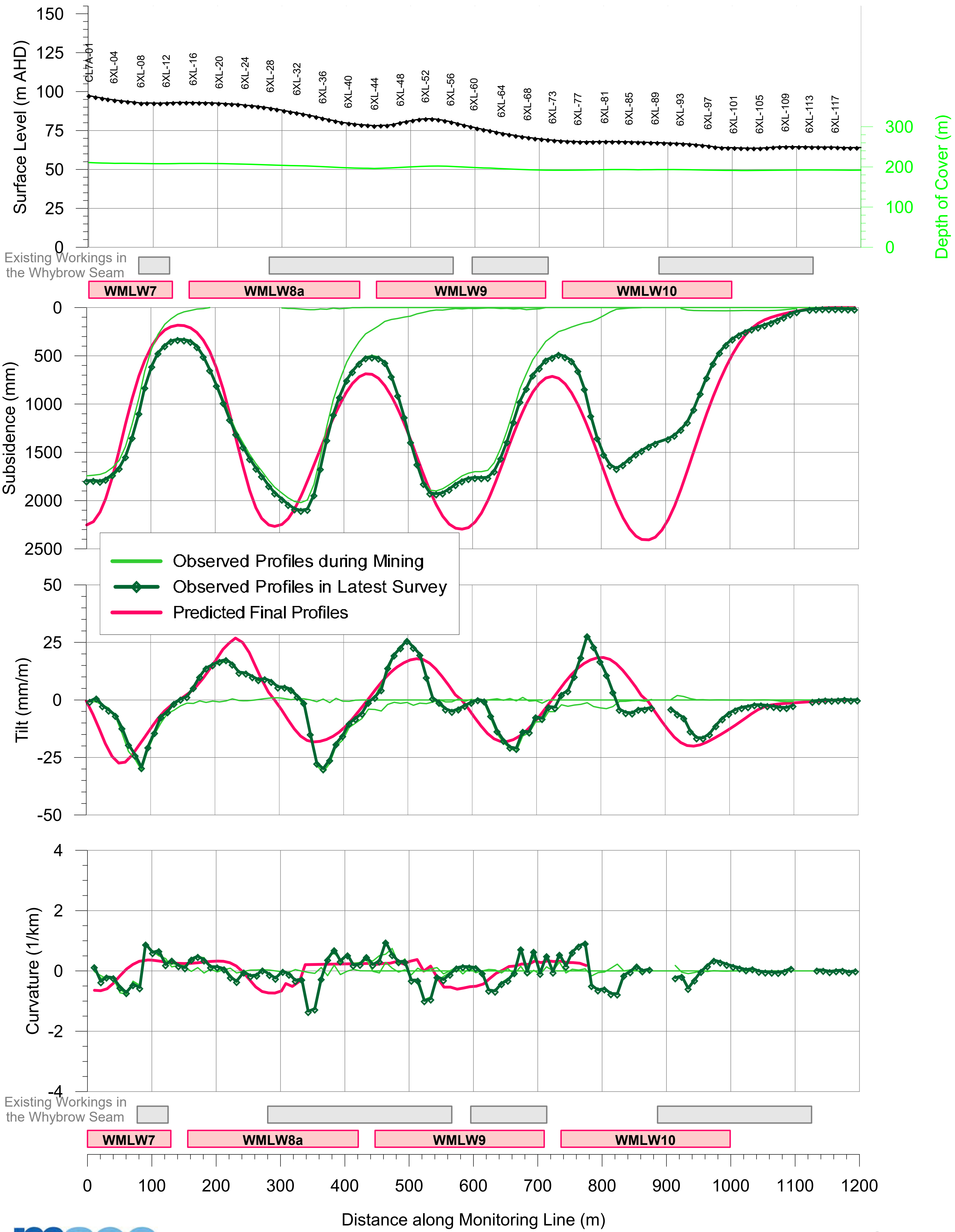

Fig. C.06

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

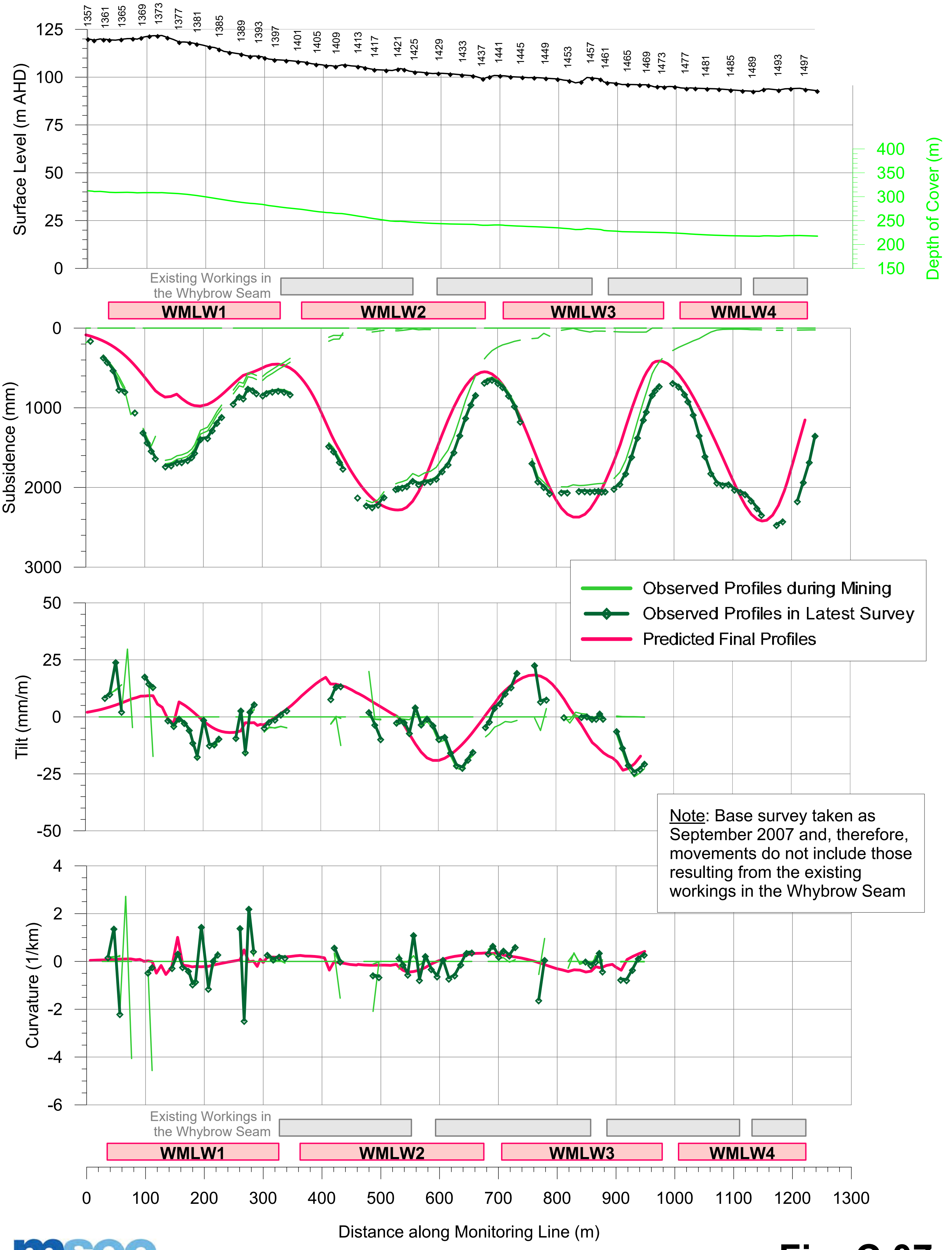

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Fig. C.07

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

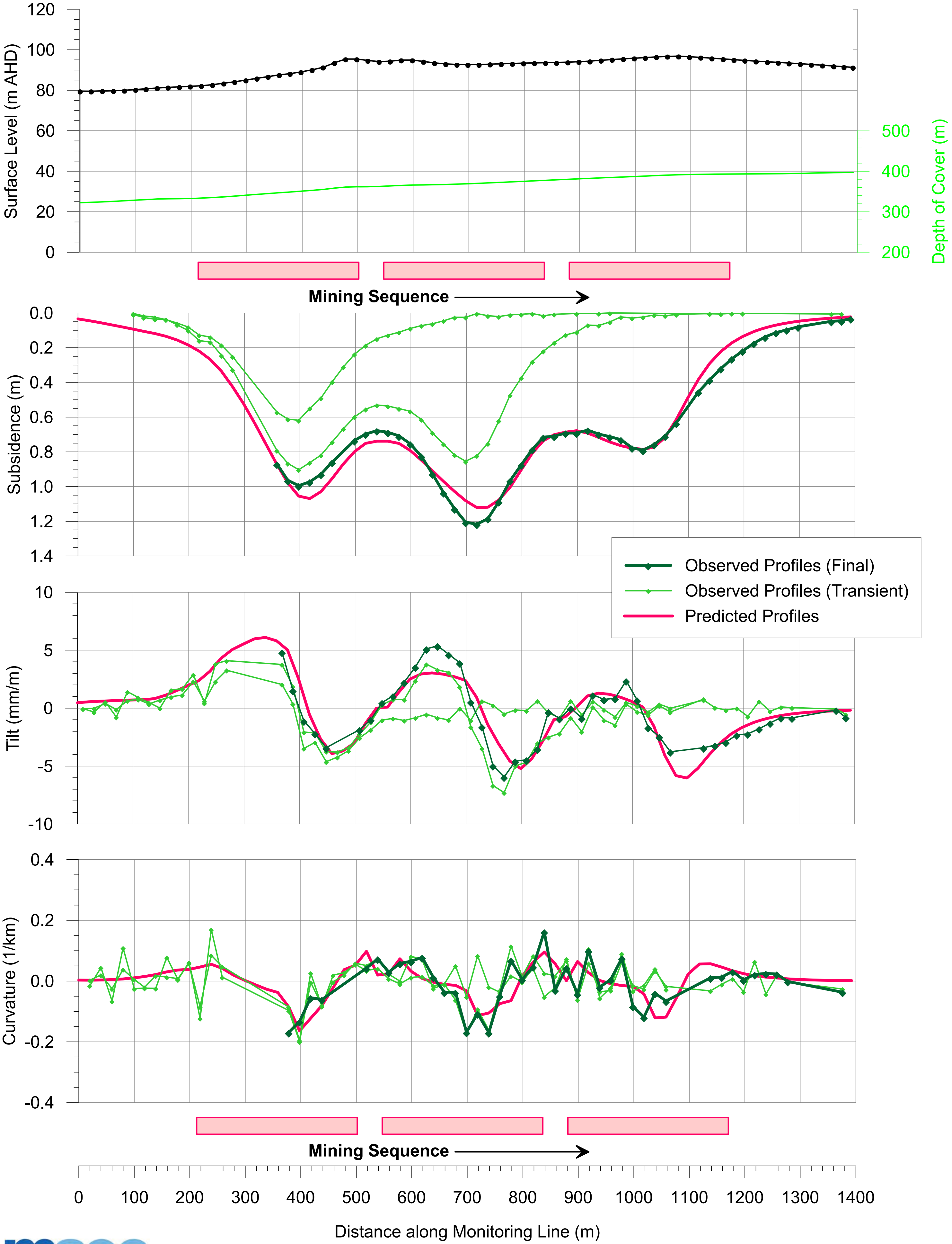

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Fig. C.08

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

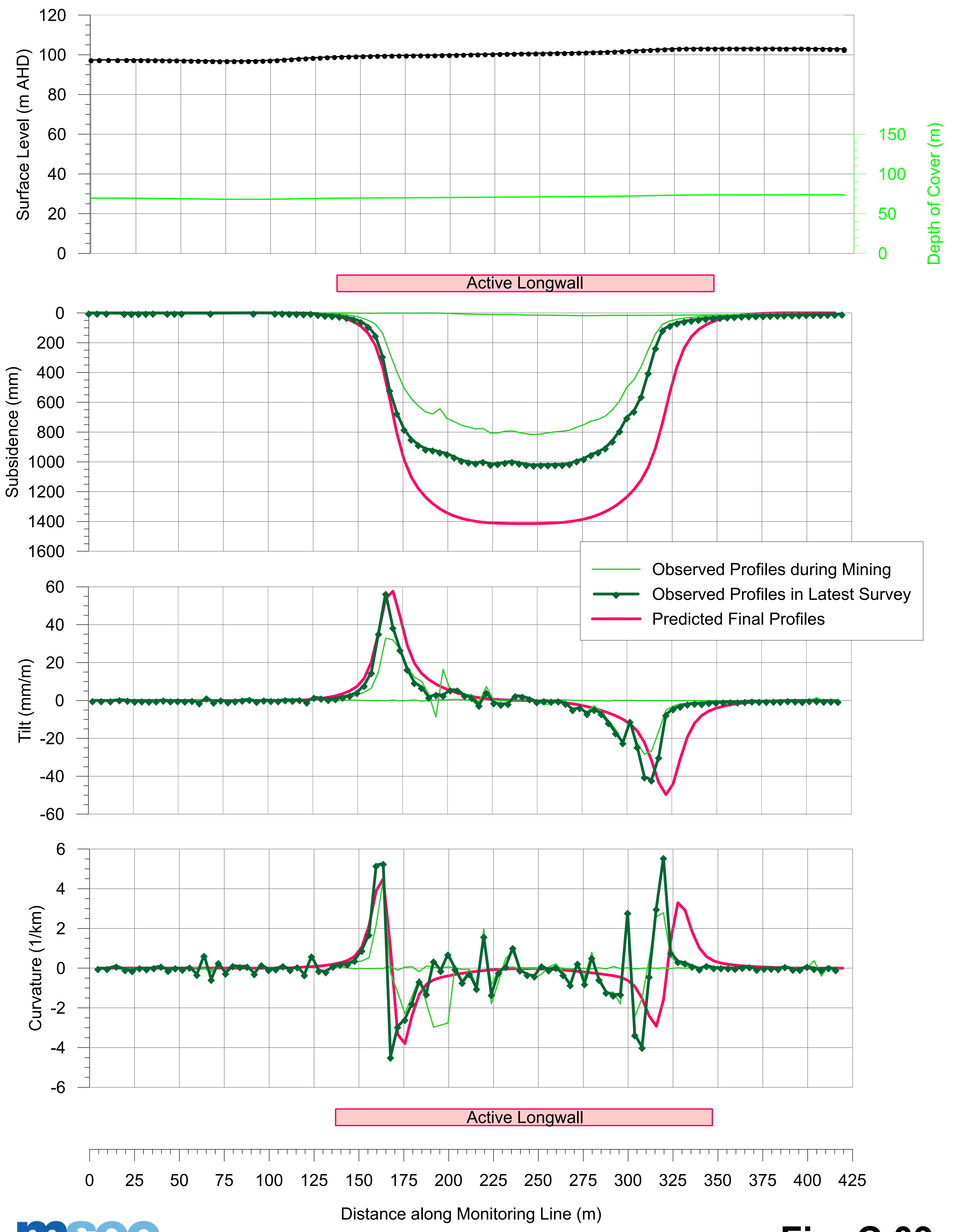

Fig. C.09

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

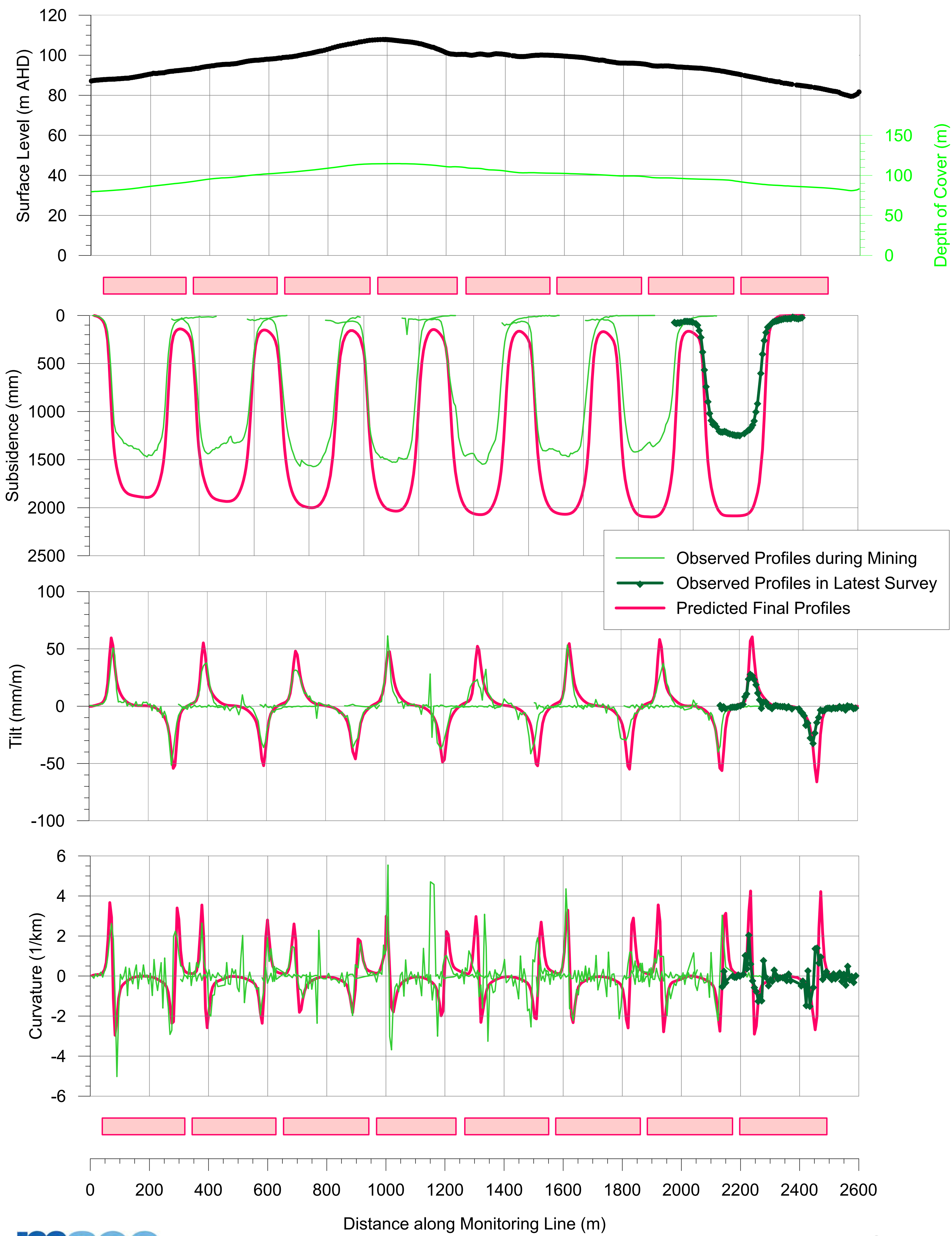

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Fig. C.10

Profiles of Observed and Predicted Total Subsidence, Tilt and Curvature along the 7XL-Line at the South Bates Mine

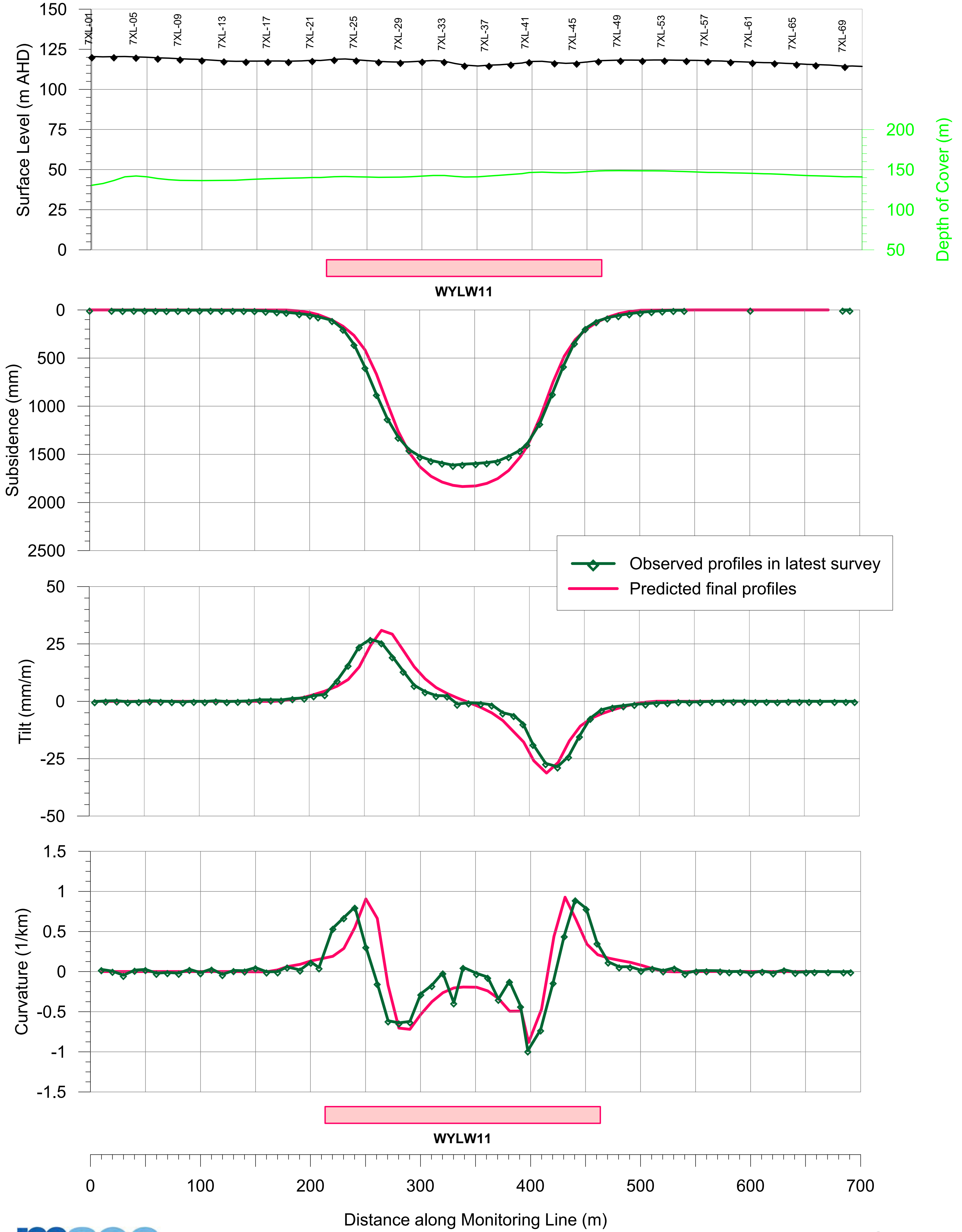

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Fig. C.11

Profiles of Observed and Predicted Total Subsidence, Tilt and Curvature along the CL11B-Line South Bates Mine

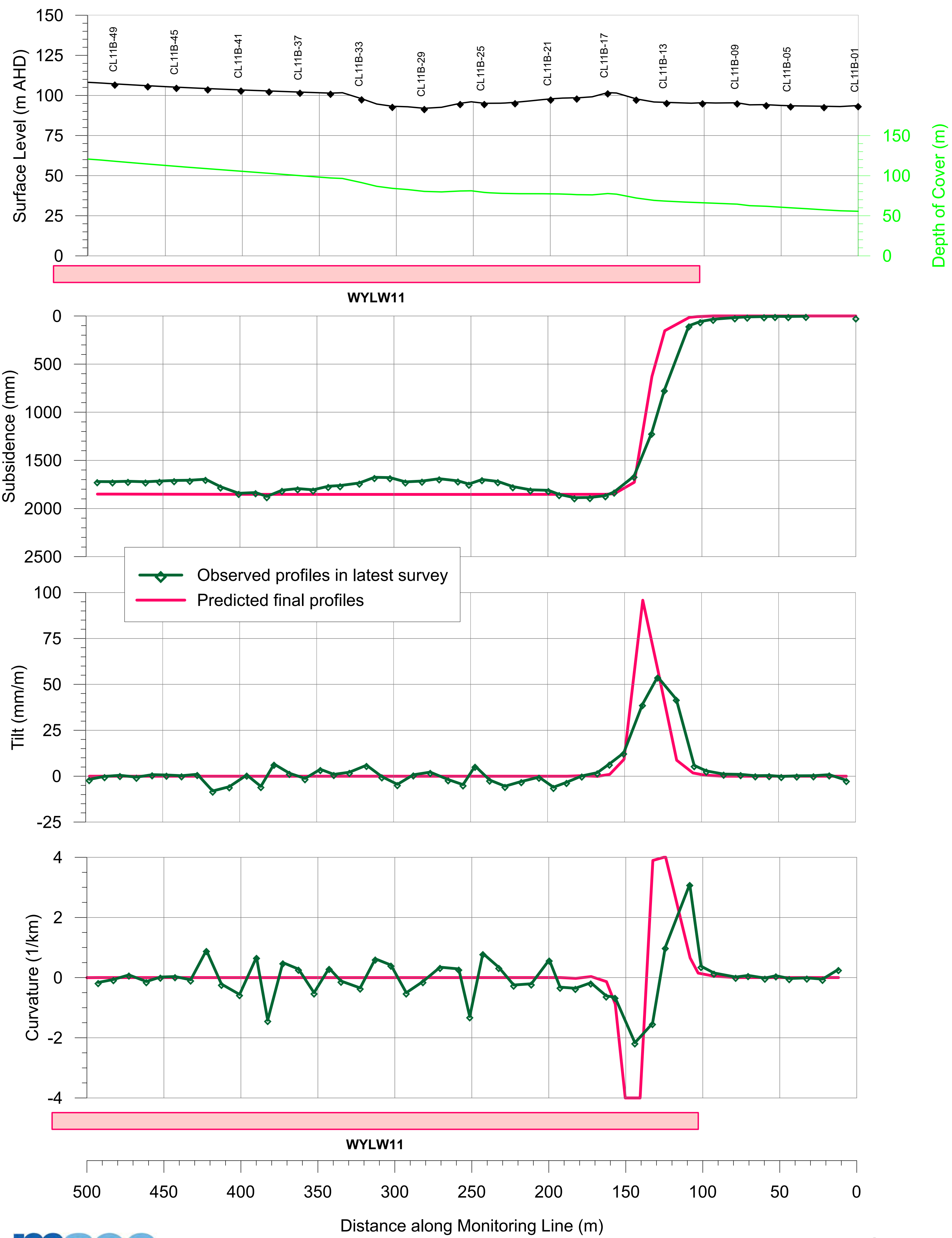

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Fig. C.12

APPENDIX D. FIGURES

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 1 Resulting from Mining in the Whybrow and Wambo Seams

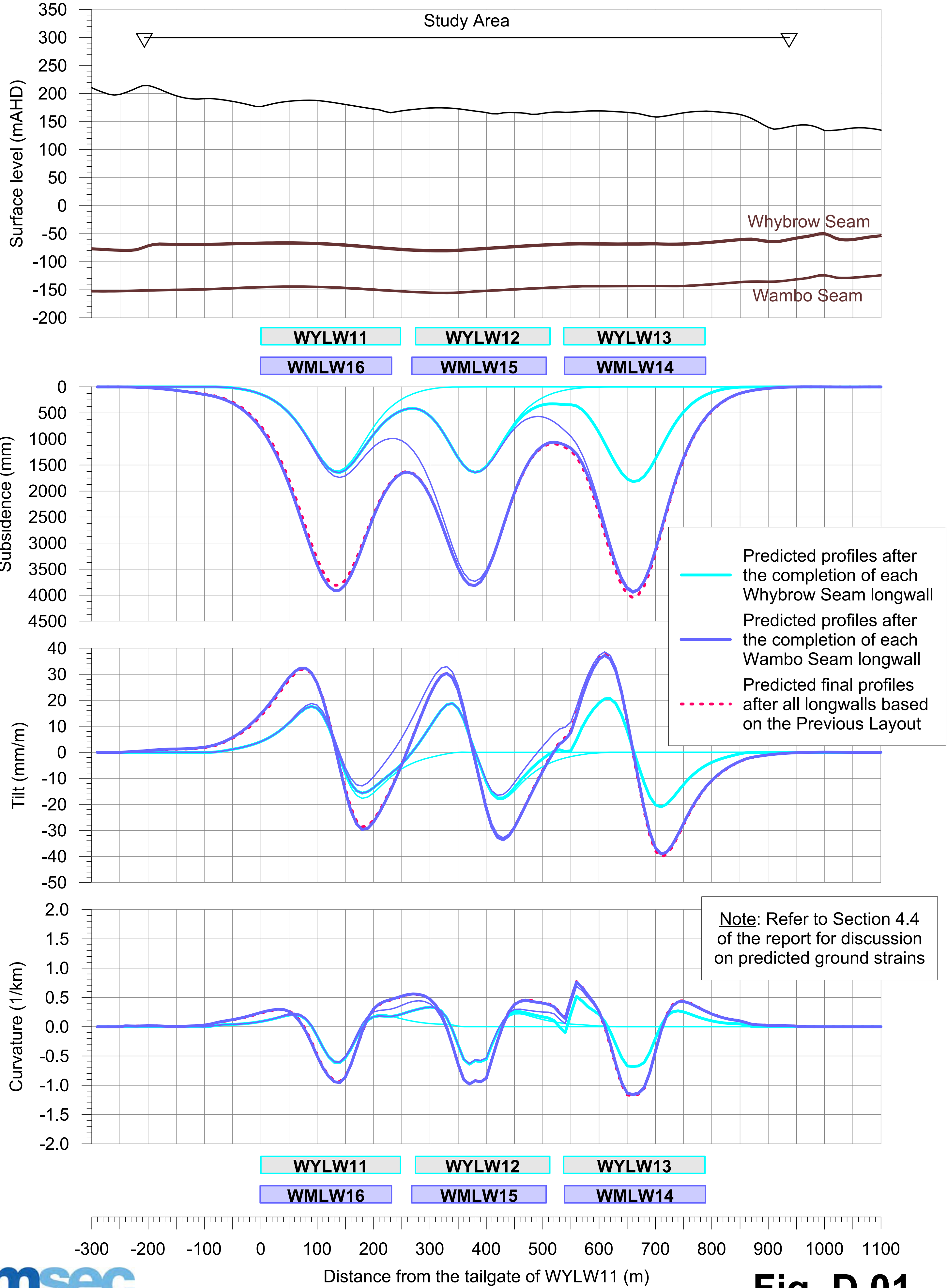

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Fig. D.01

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 2 Resulting from Mining in the Whybrow and Wambo Seams

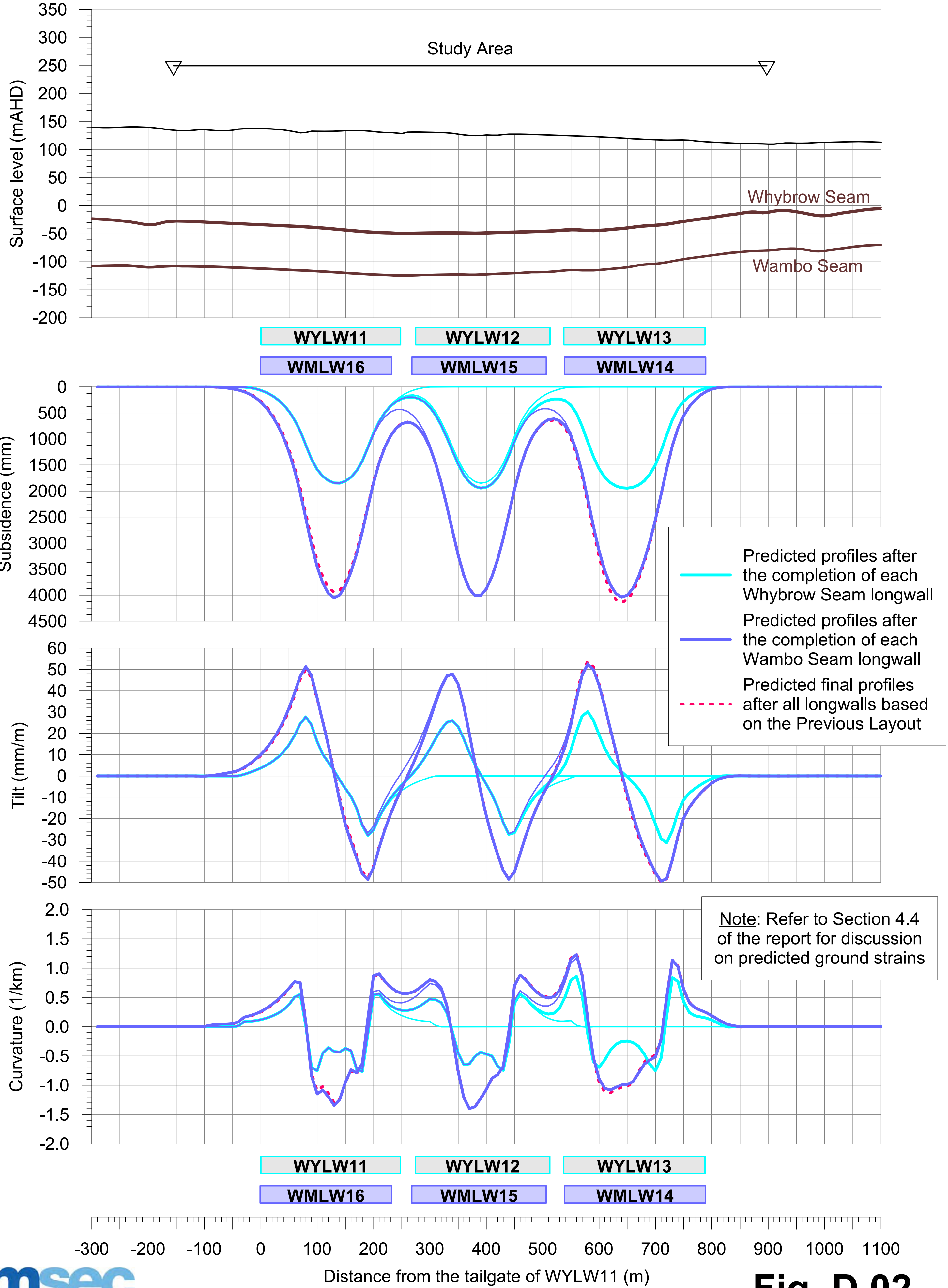

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Fig. D.02

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 3 Resulting from Mining in the Whybrow and Wambo Seams

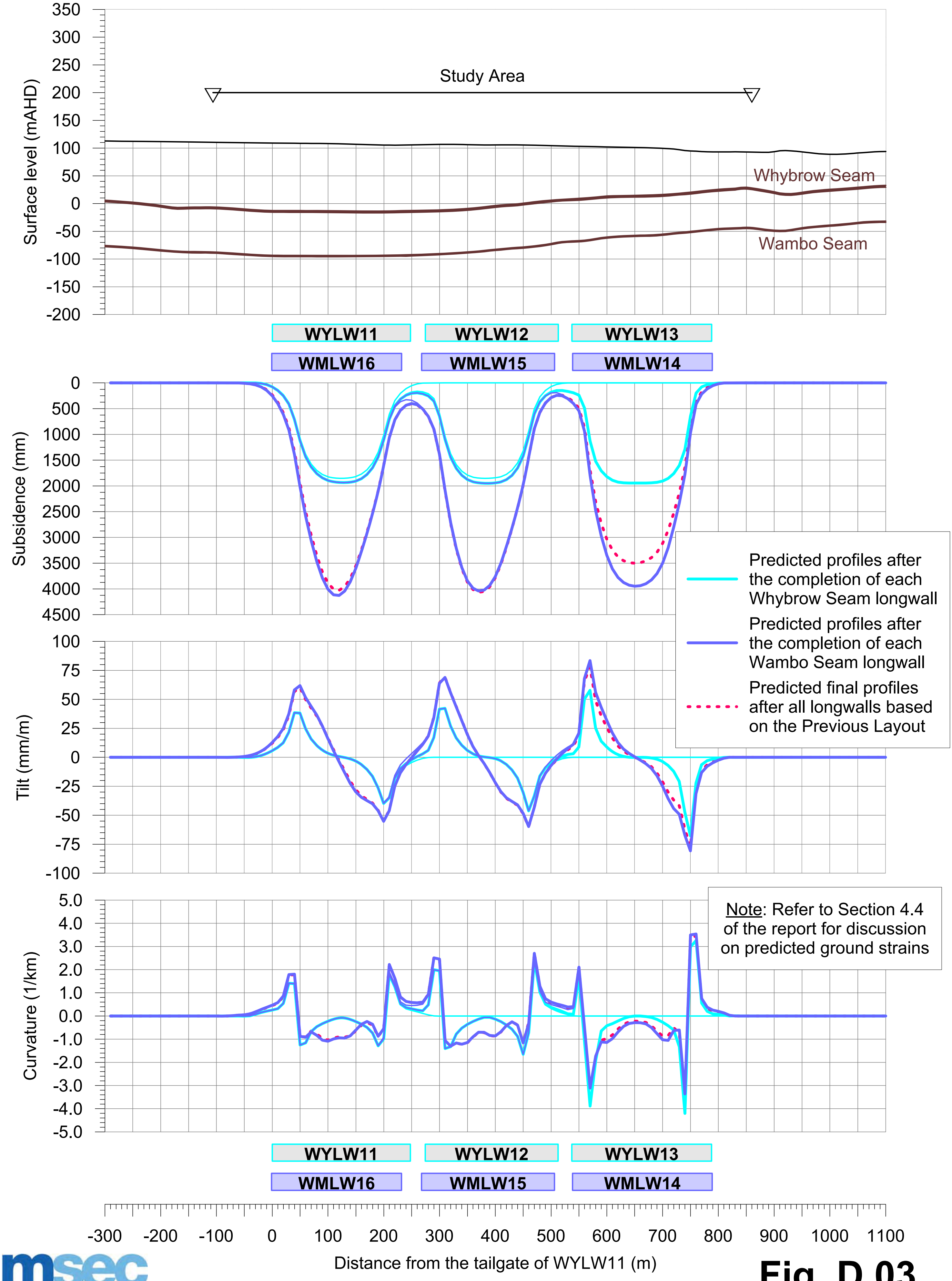

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Fig. D.03

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 4 Resulting from Mining in the Whybrow and Wambo Seams

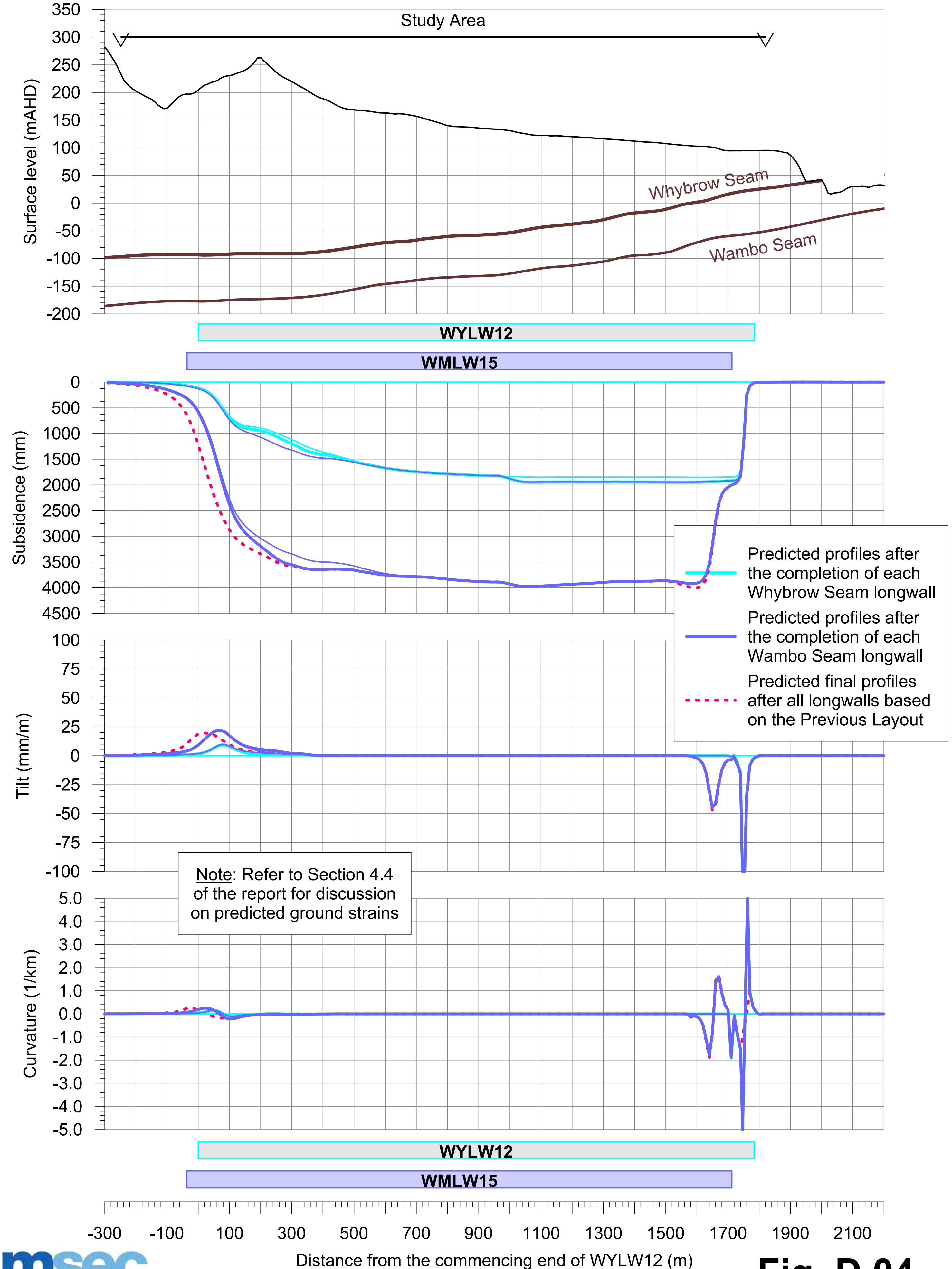

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Fig. D.04

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Stony Creek Resulting from Mining in the Whybrow and Wambo Seams

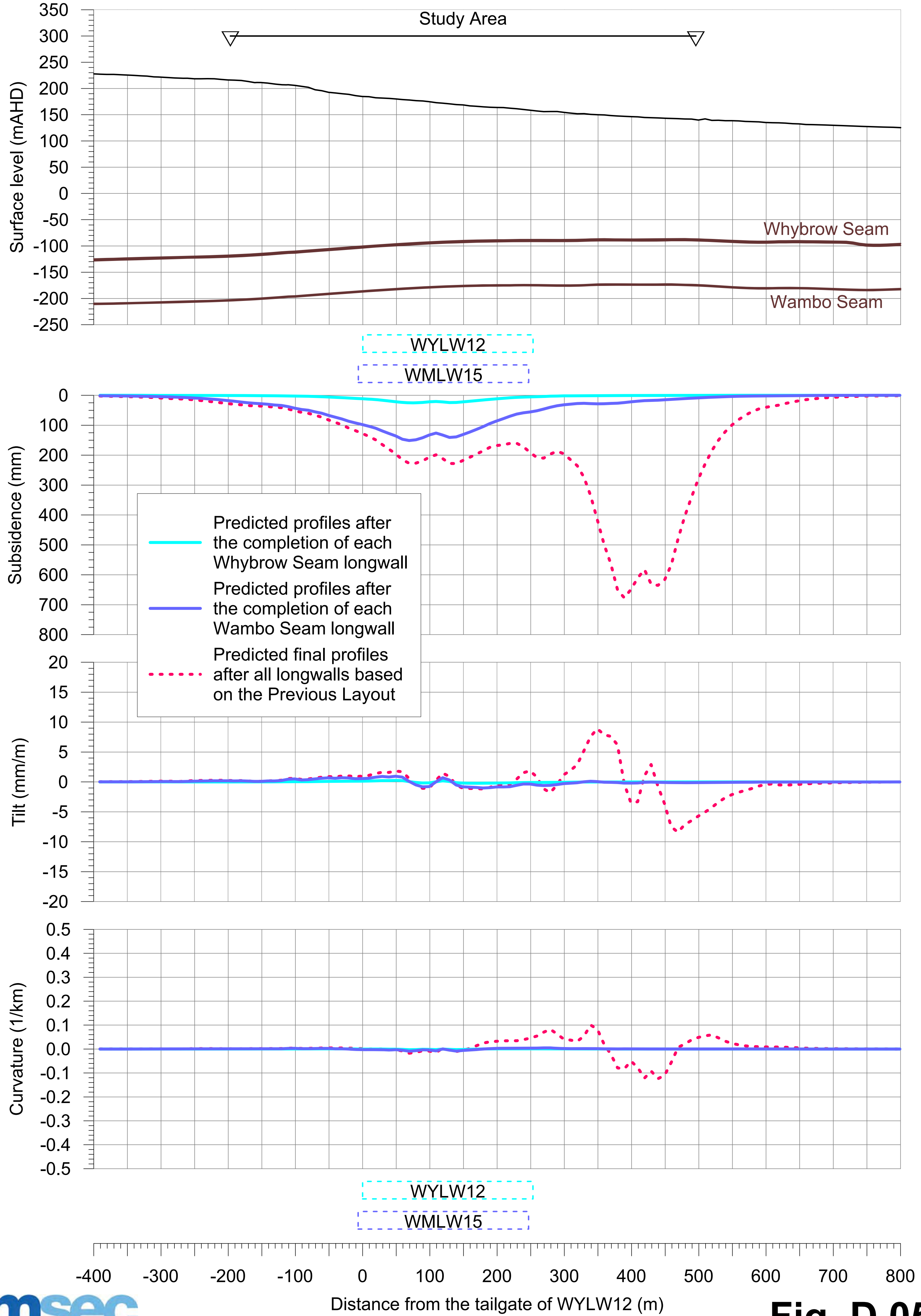

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Fig. D.05

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along the North Wambo Creek Diversion Resulting from Mining in the Whybrow and Wambo Seams

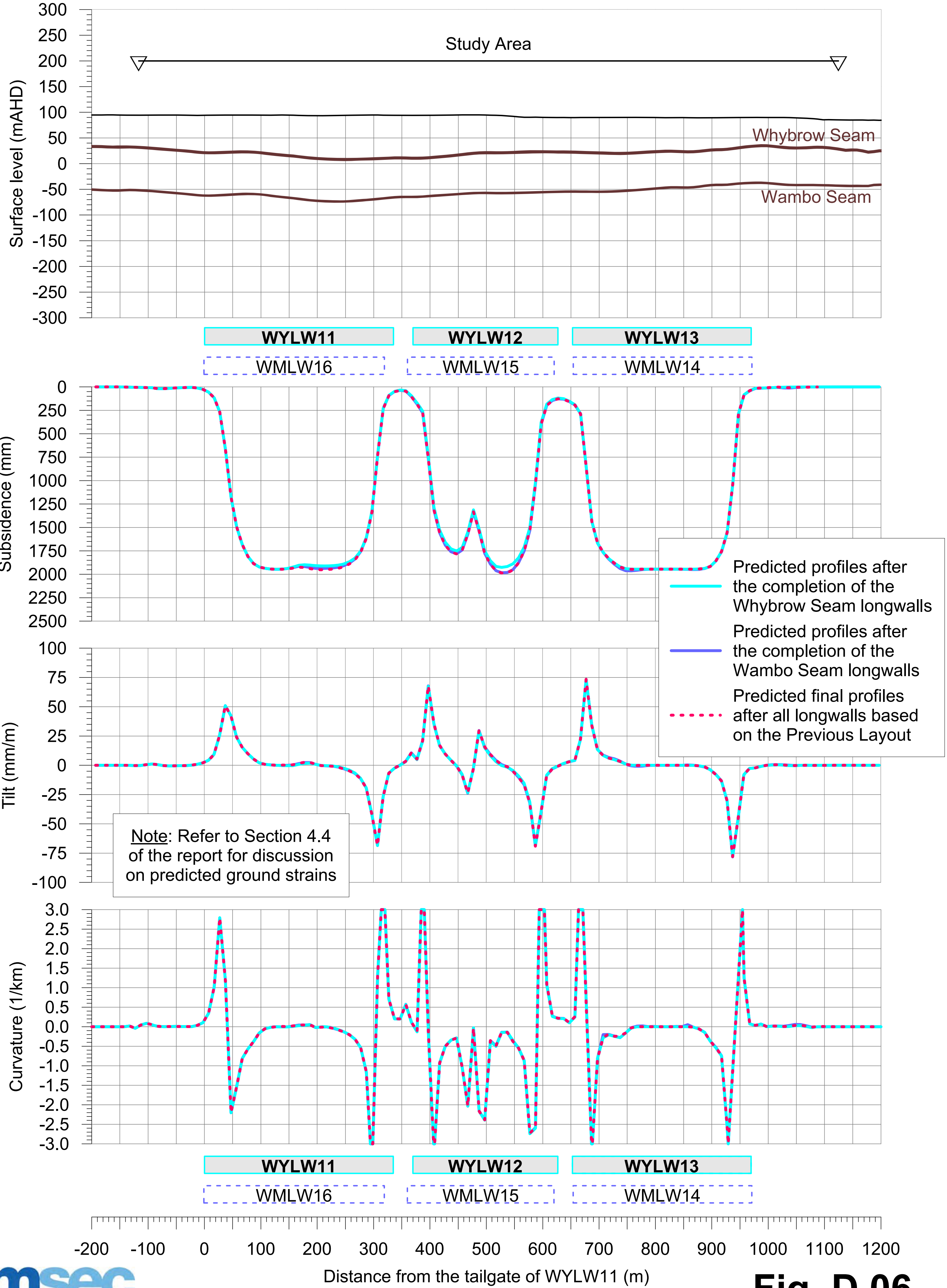

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Fig. D.06

APPENDIX E. DRAWINGS

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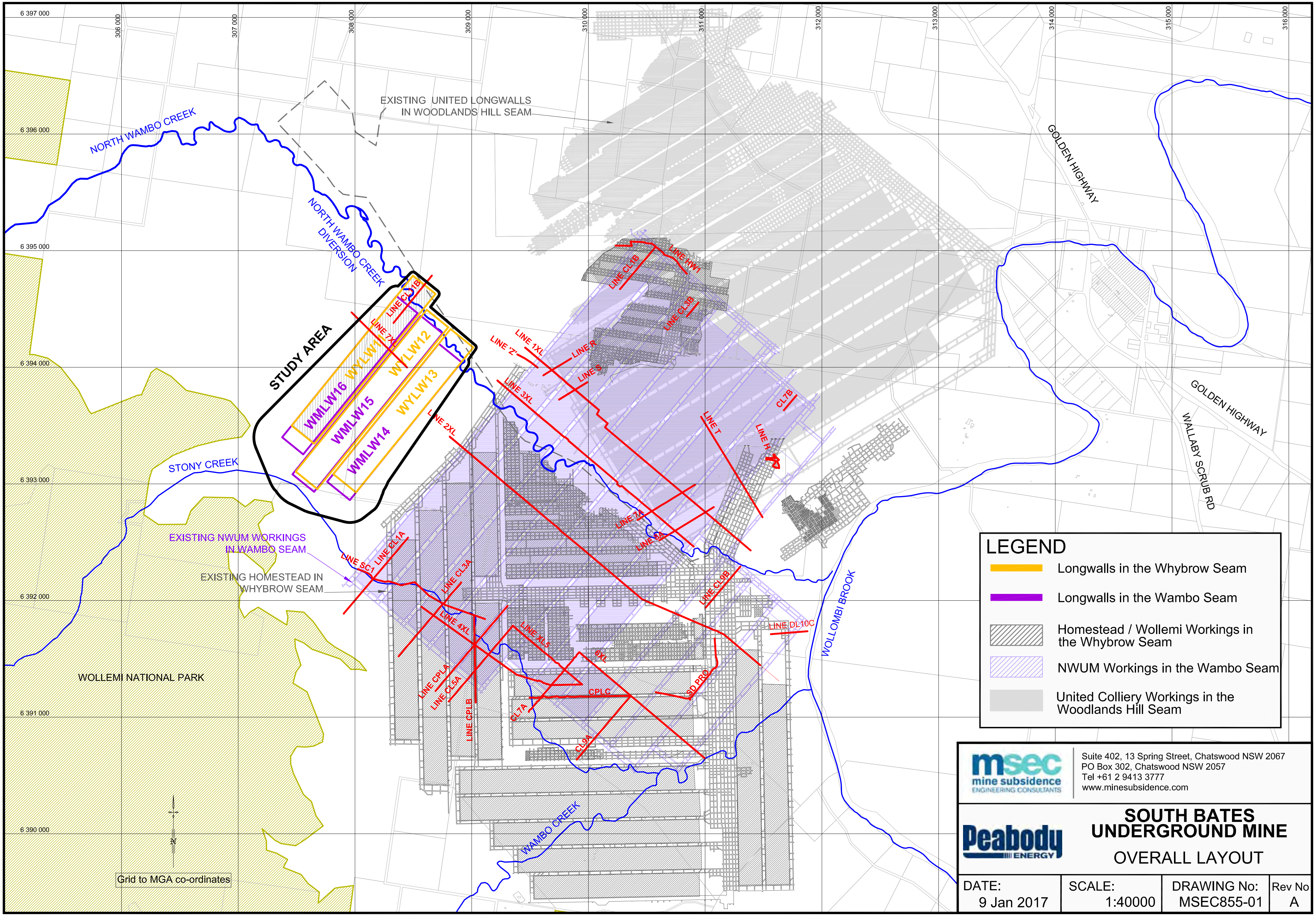

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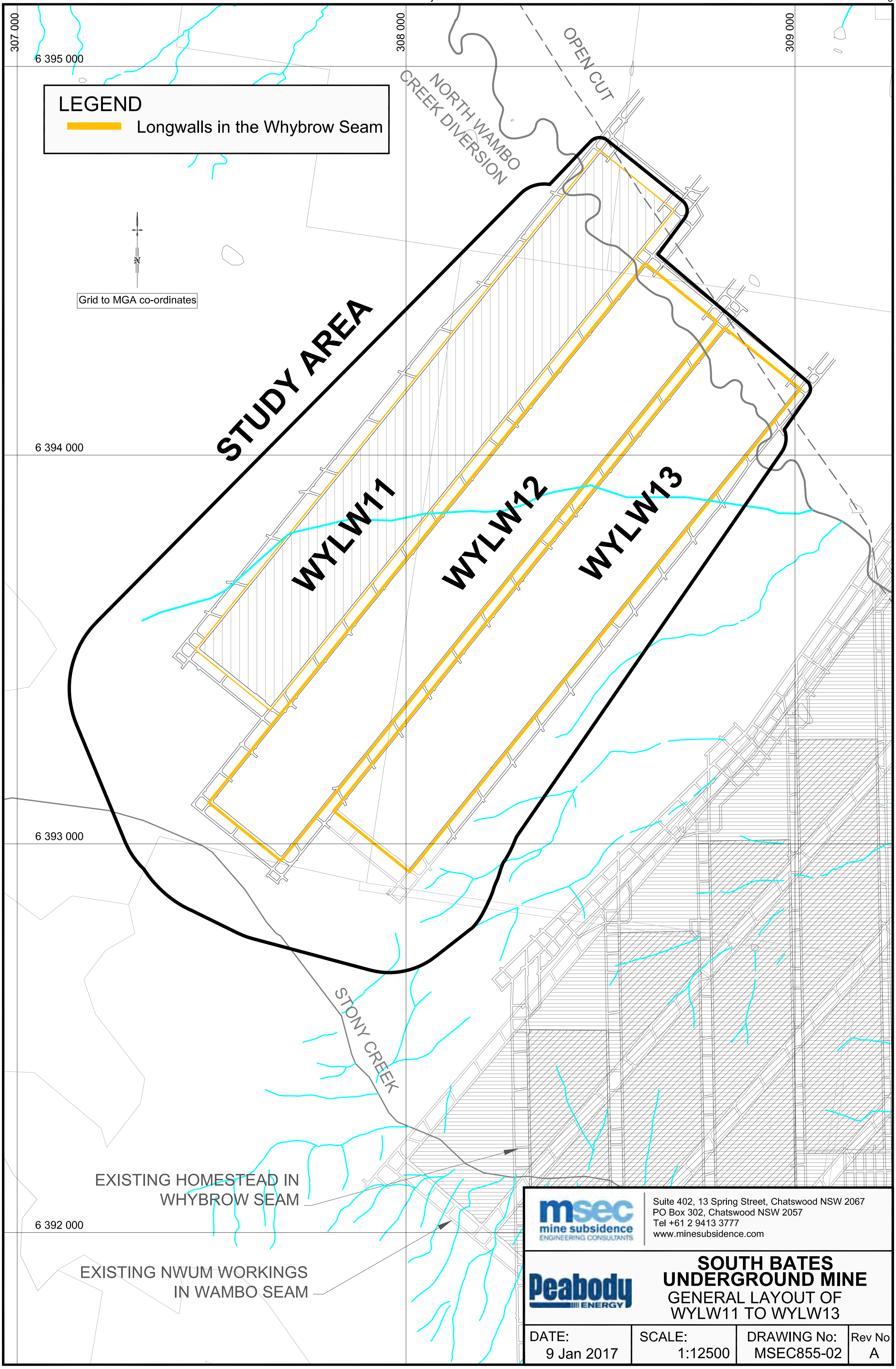

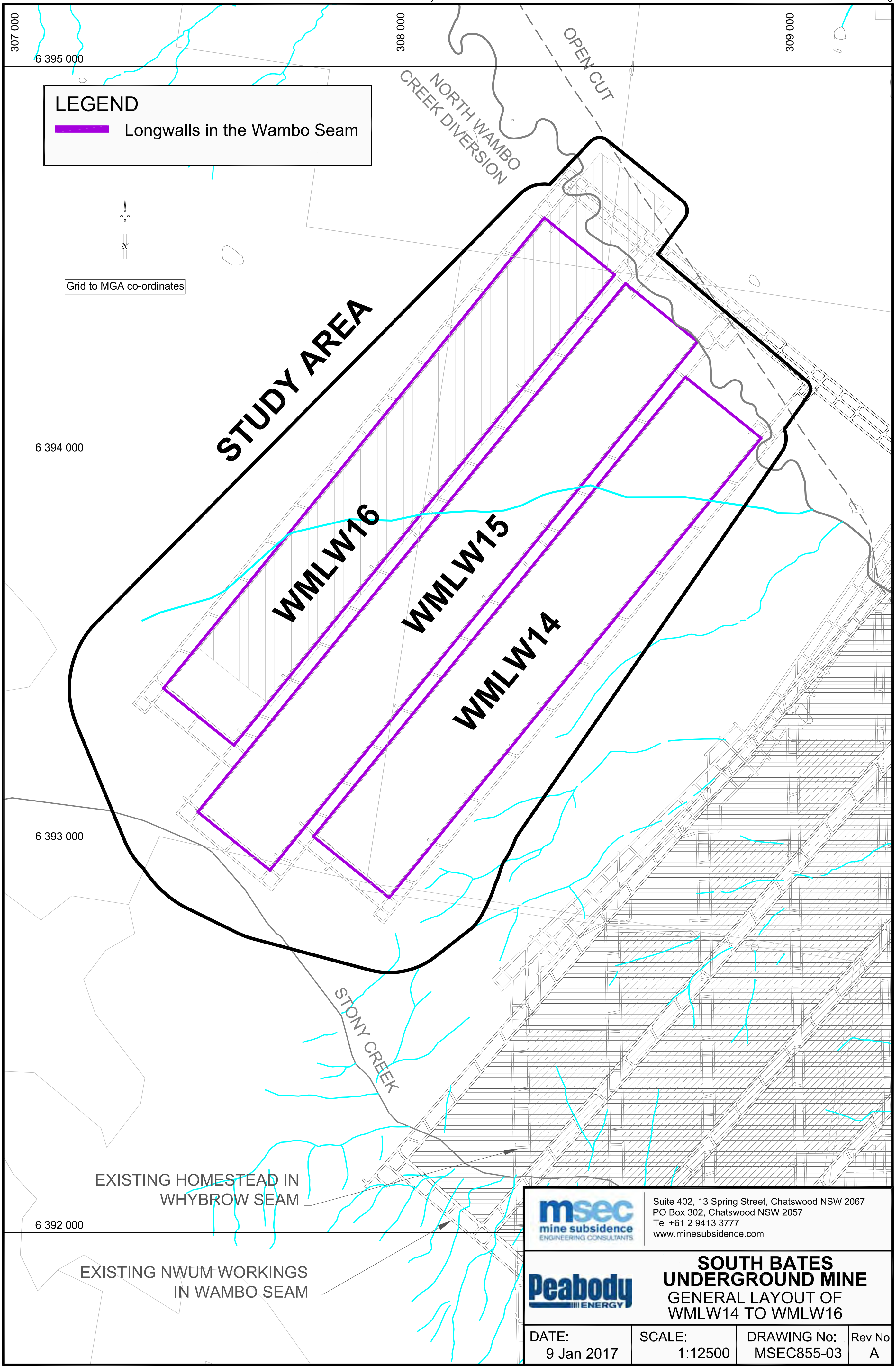

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SOUTH BATES UNDERGROUND MINE
GENERAL LAYOUT OF WMLW14 TO WMLW16

DATE:	SCALE:	DRAWING No:	Rev No
9 Jan 2017	1:12500	MSEC855-03	A

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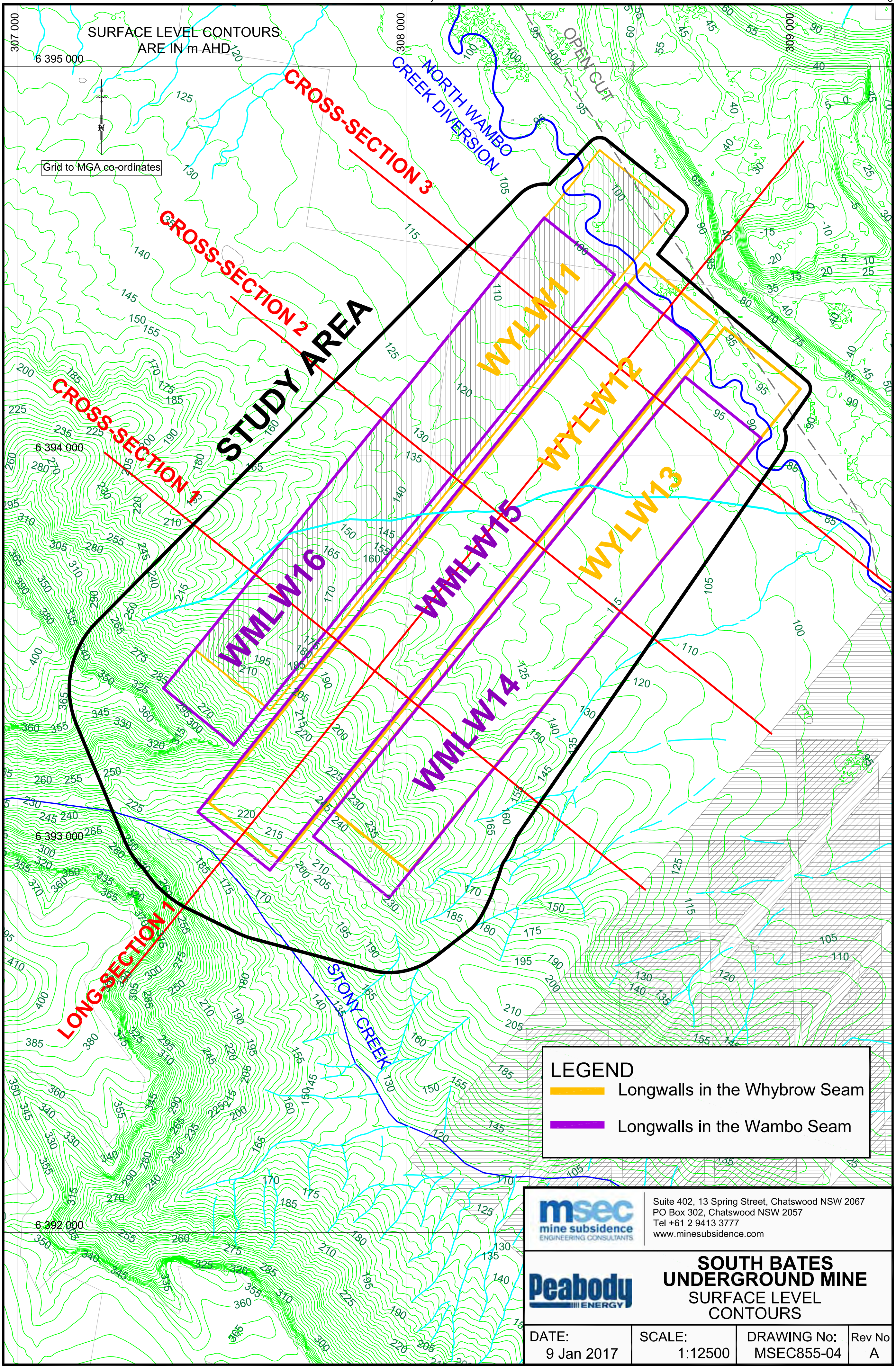

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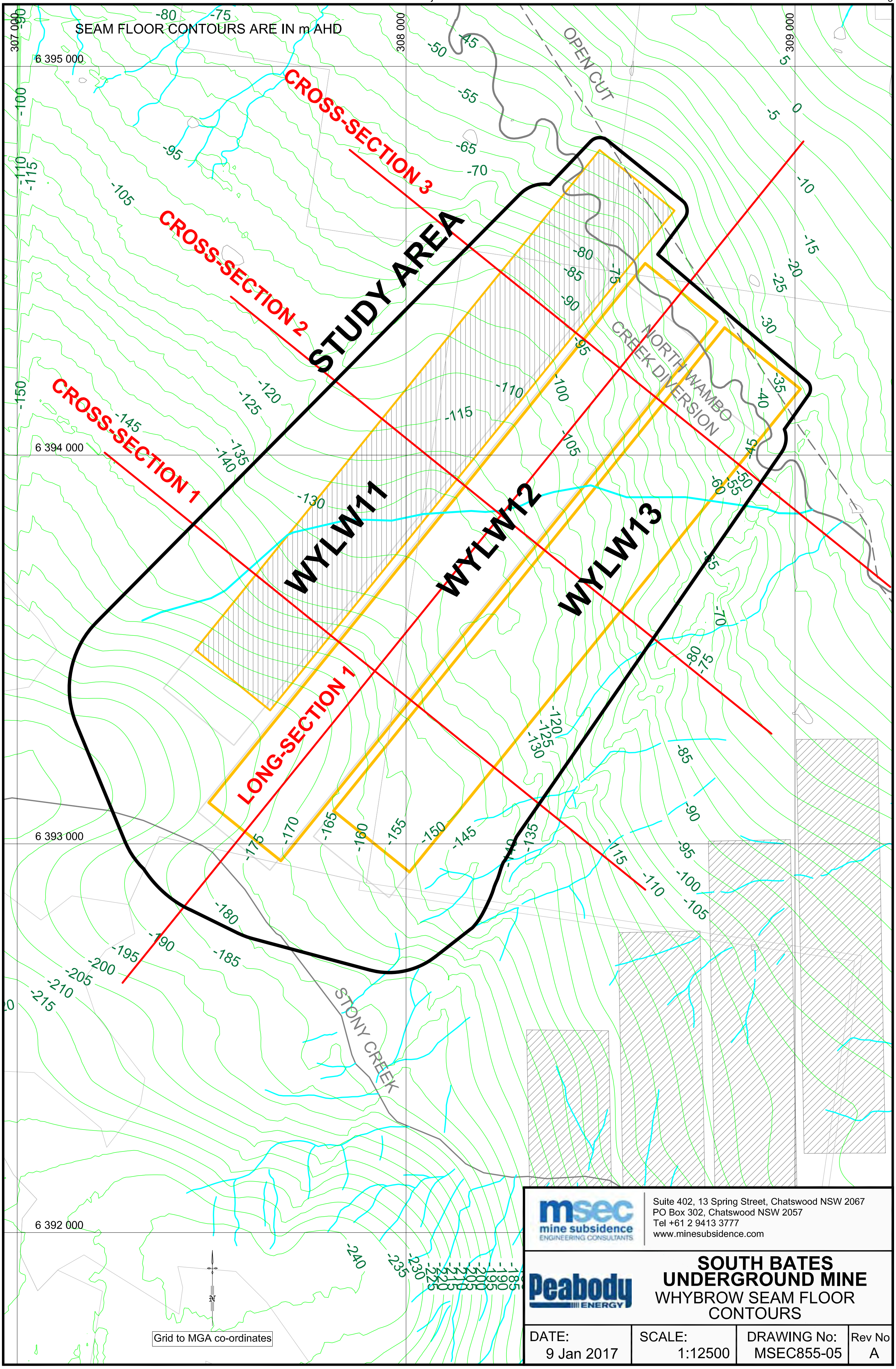

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WHYBROW SEAM FLOOR CONTOURS

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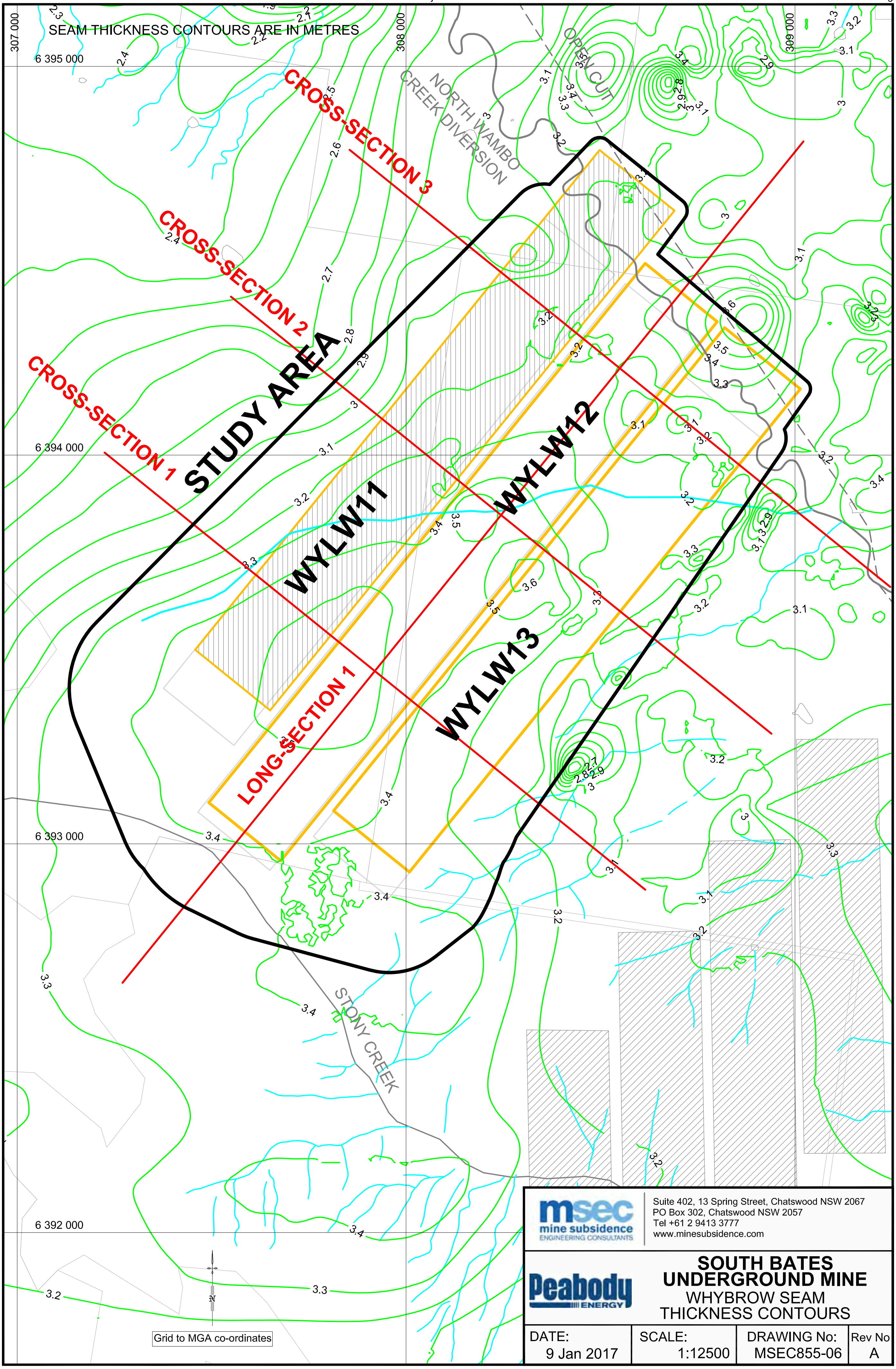

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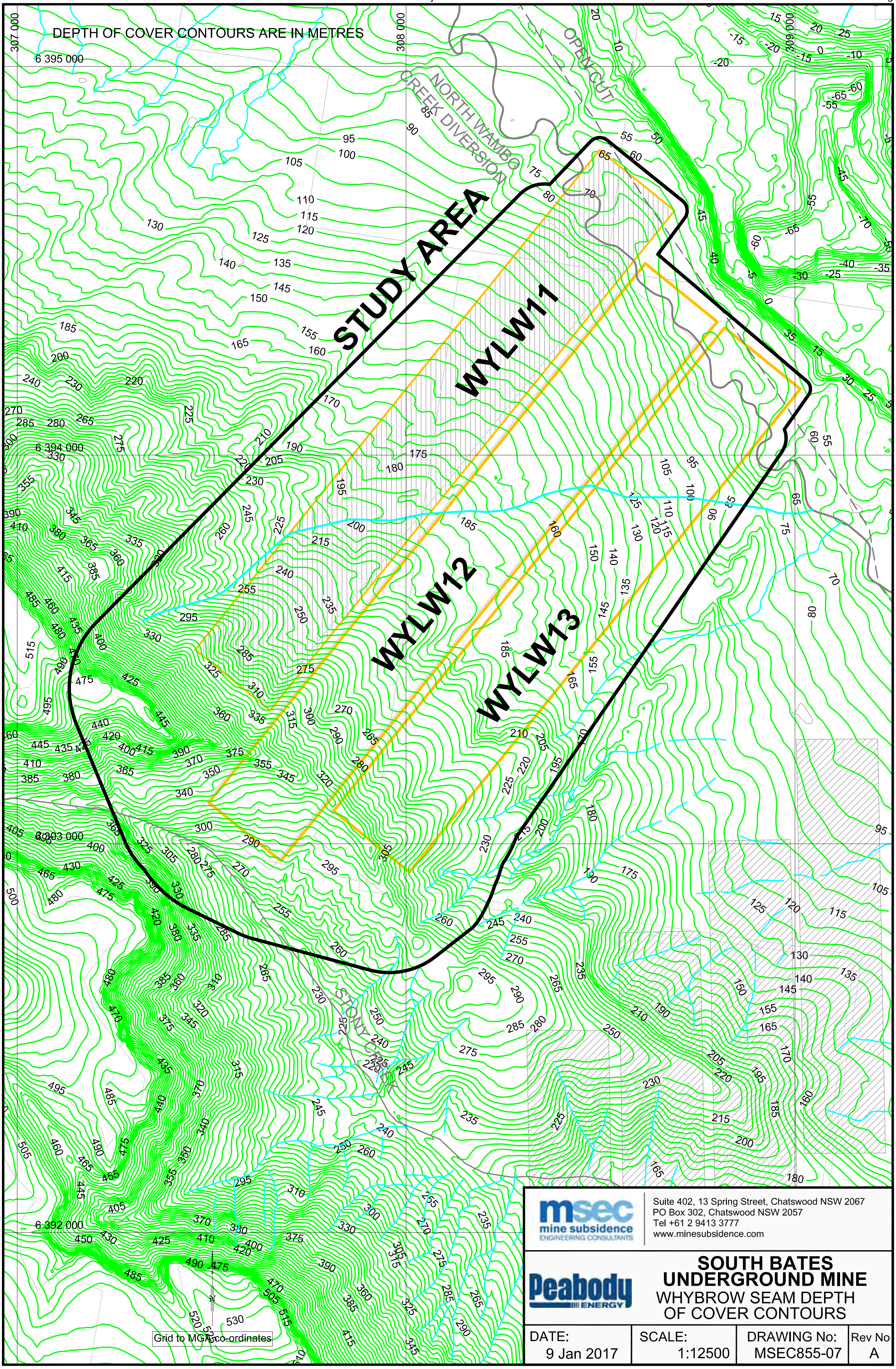

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WHYBROW SEAM DEPTH OF COVER CONTOURS

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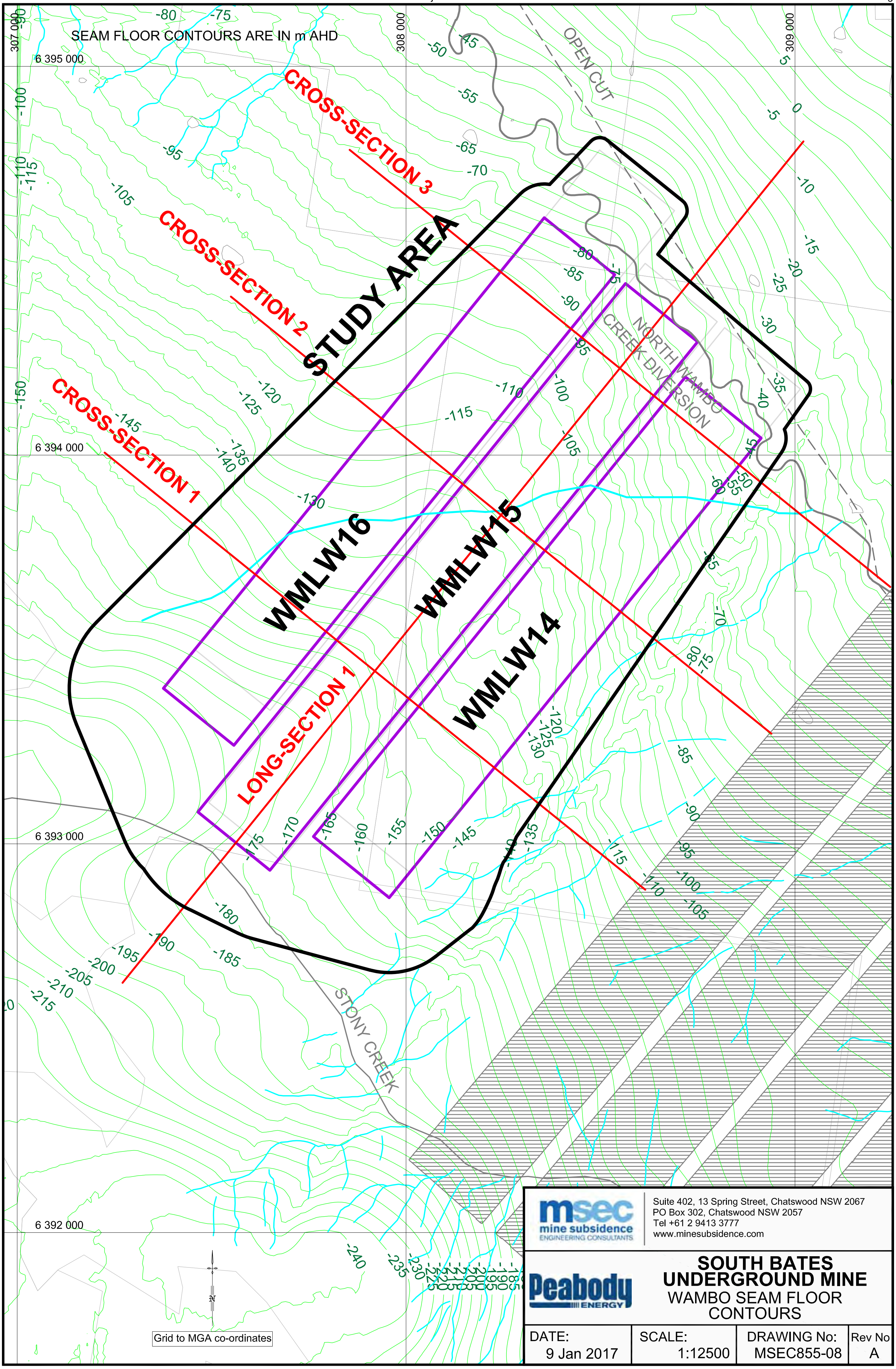

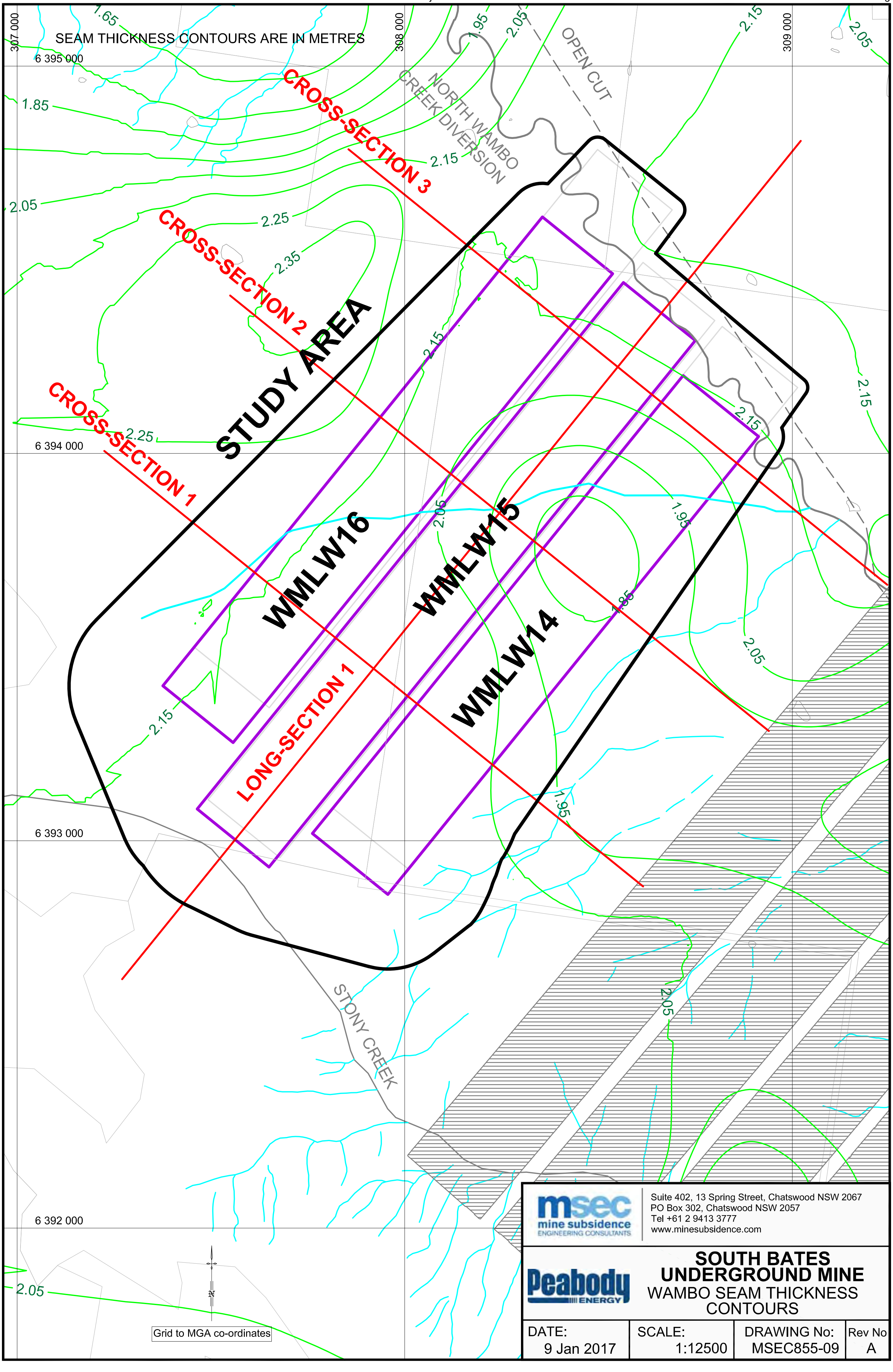

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WAMBO SEAM THICKNESS CONTOURS

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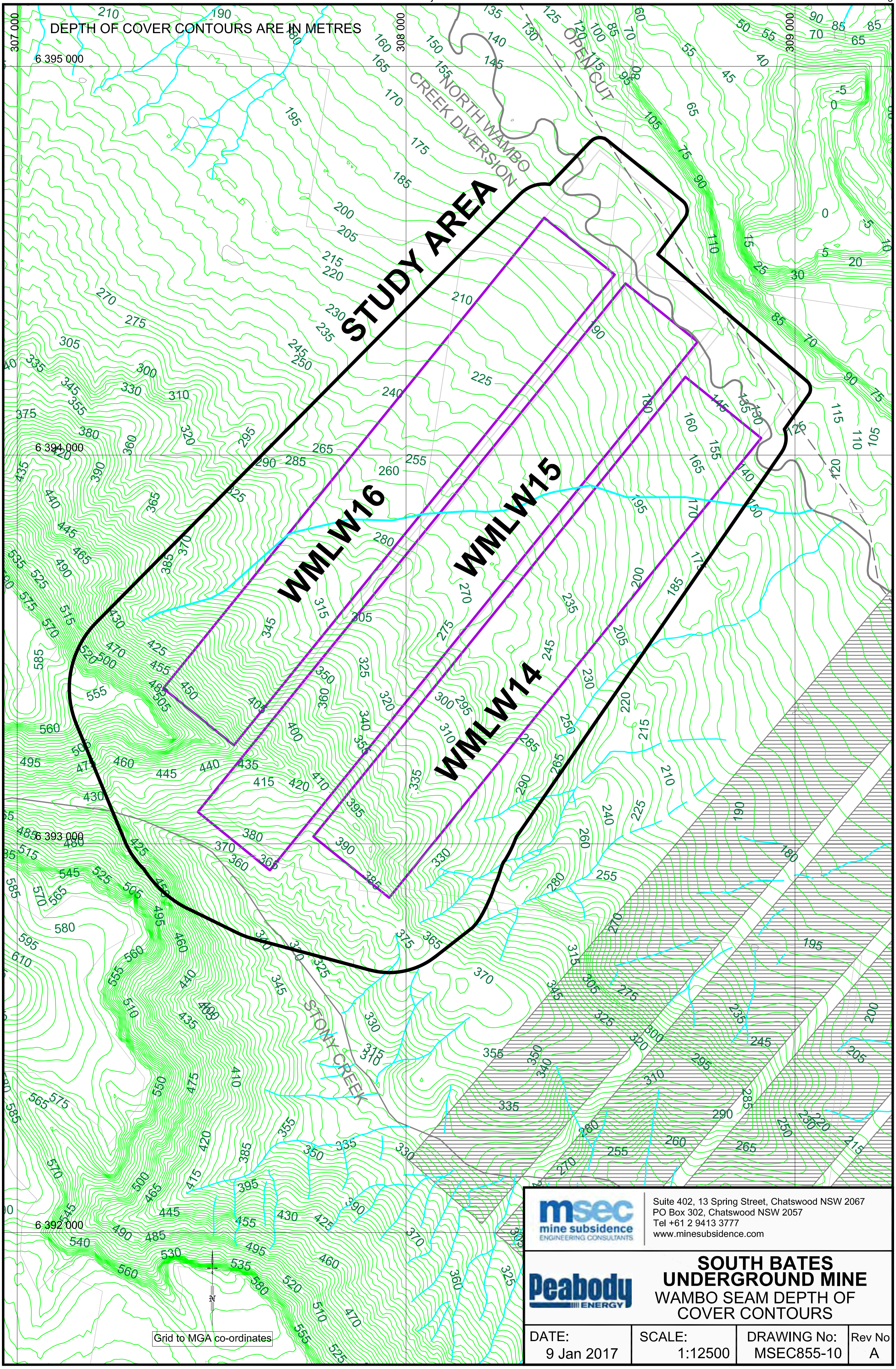

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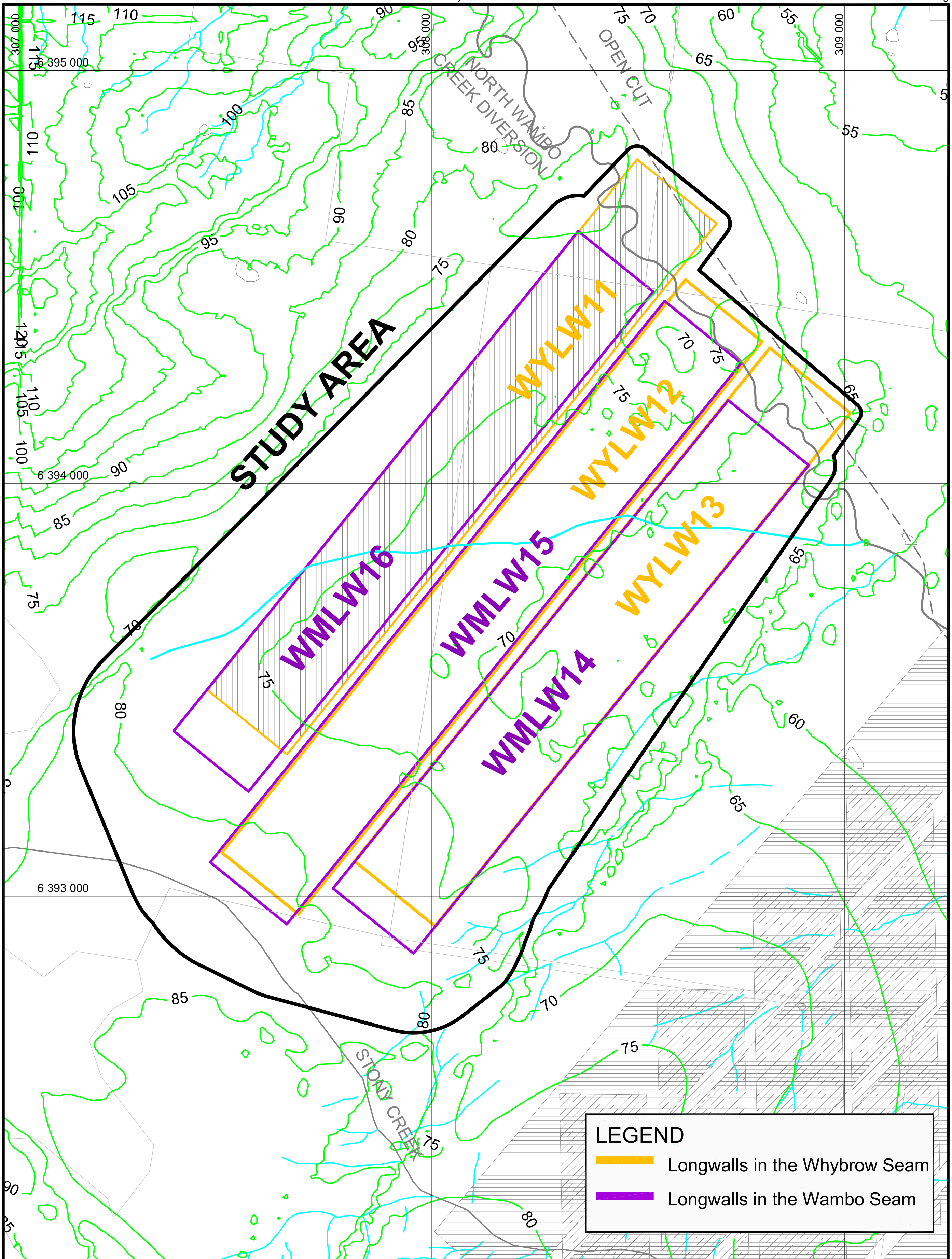

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INTERBURDEN THICKNESS CONTOURS

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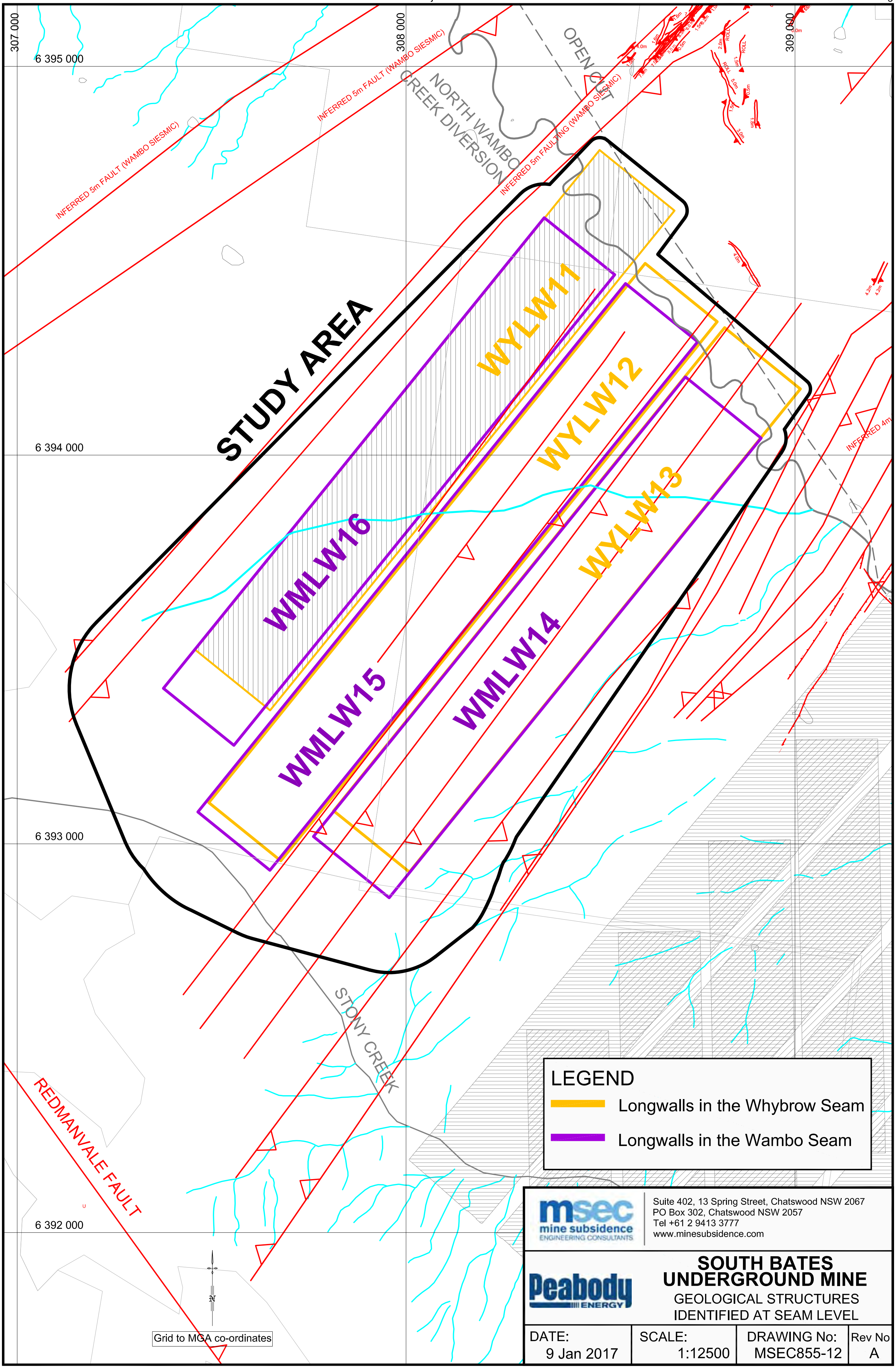

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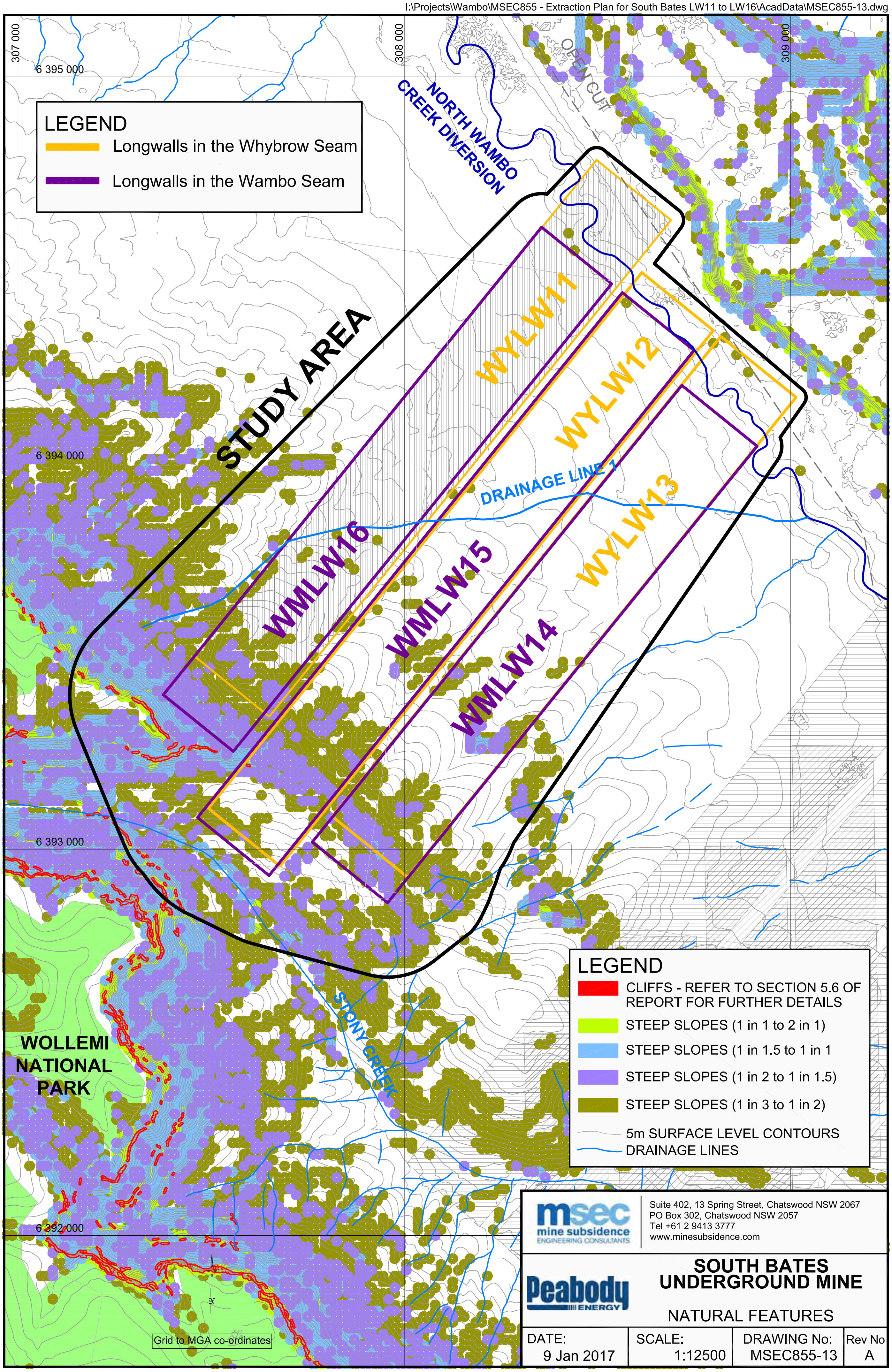

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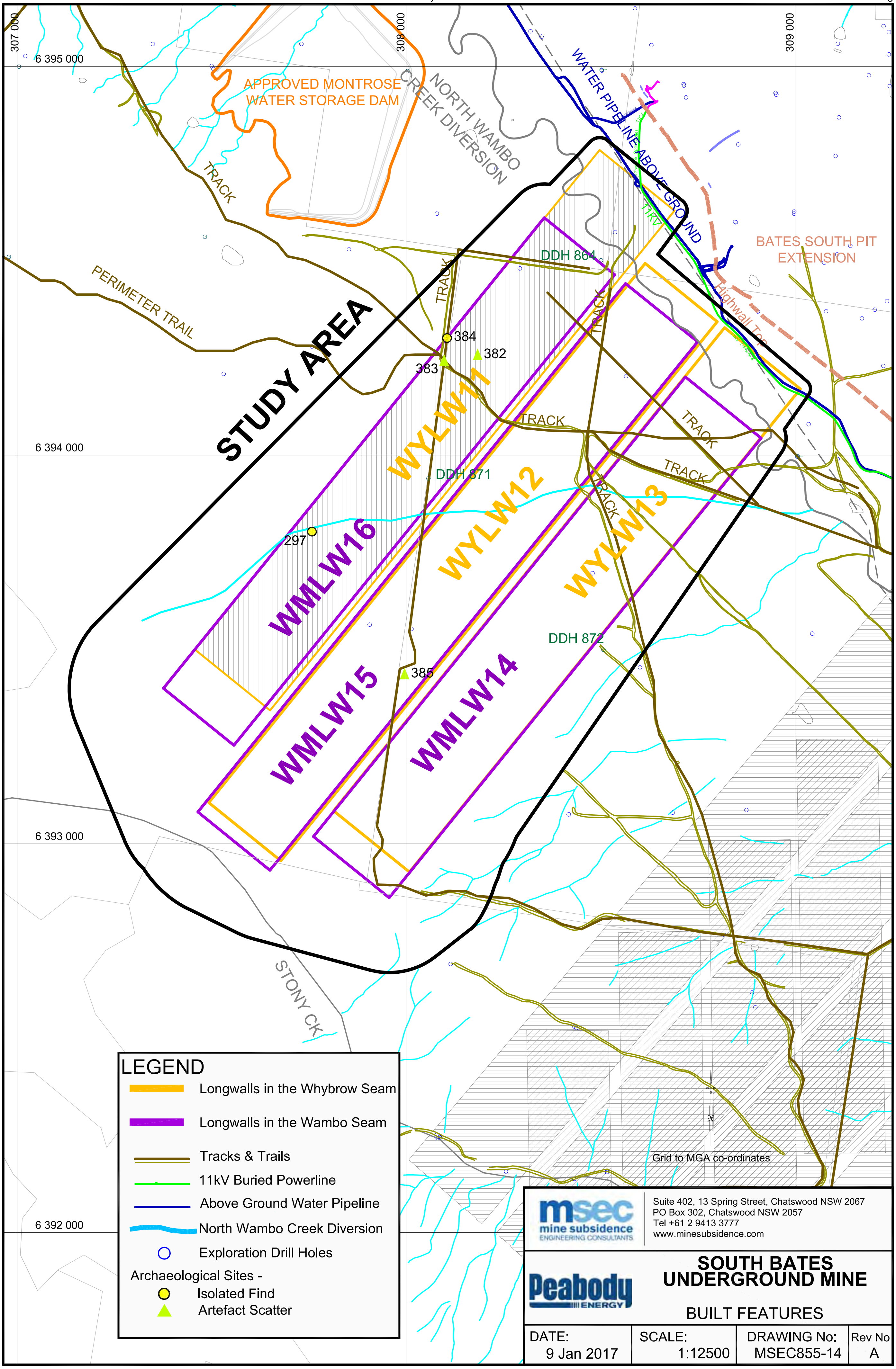

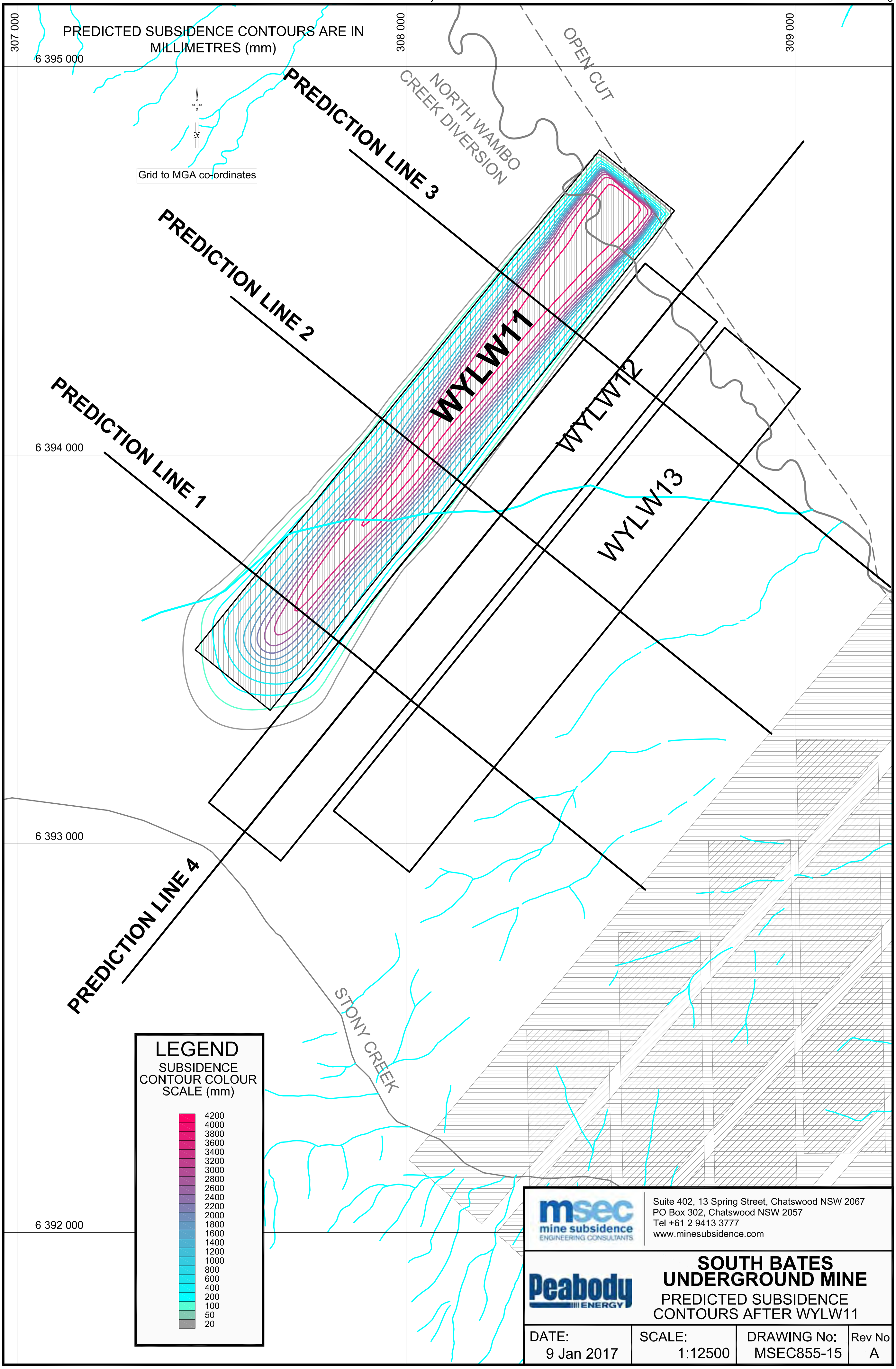

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PREDICTED SUBSIDENCE CONTOURS AFTER WYLW11

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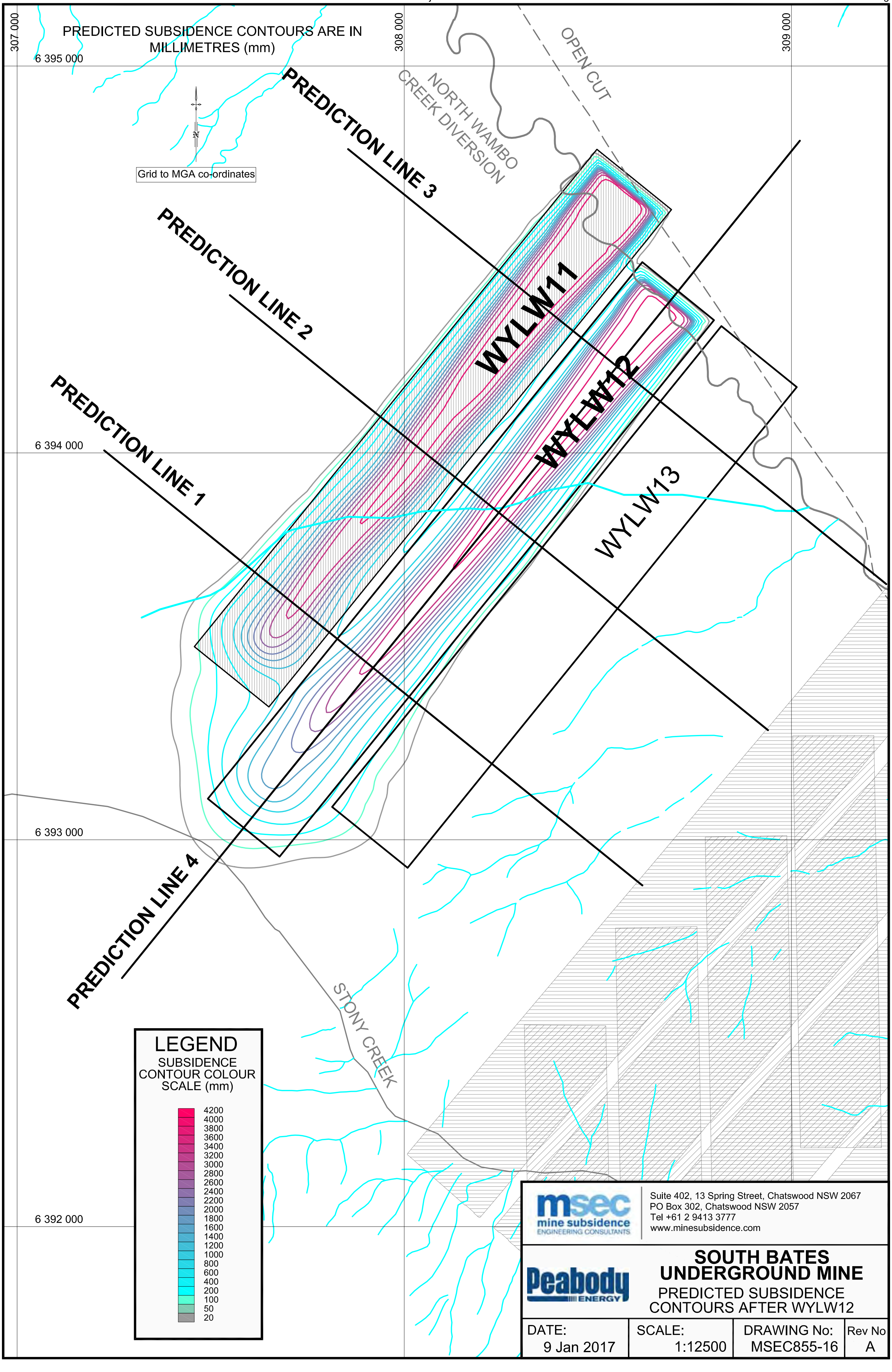

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PREDICTED SUBSIDENCE CONTOURS AFTER WYLW12

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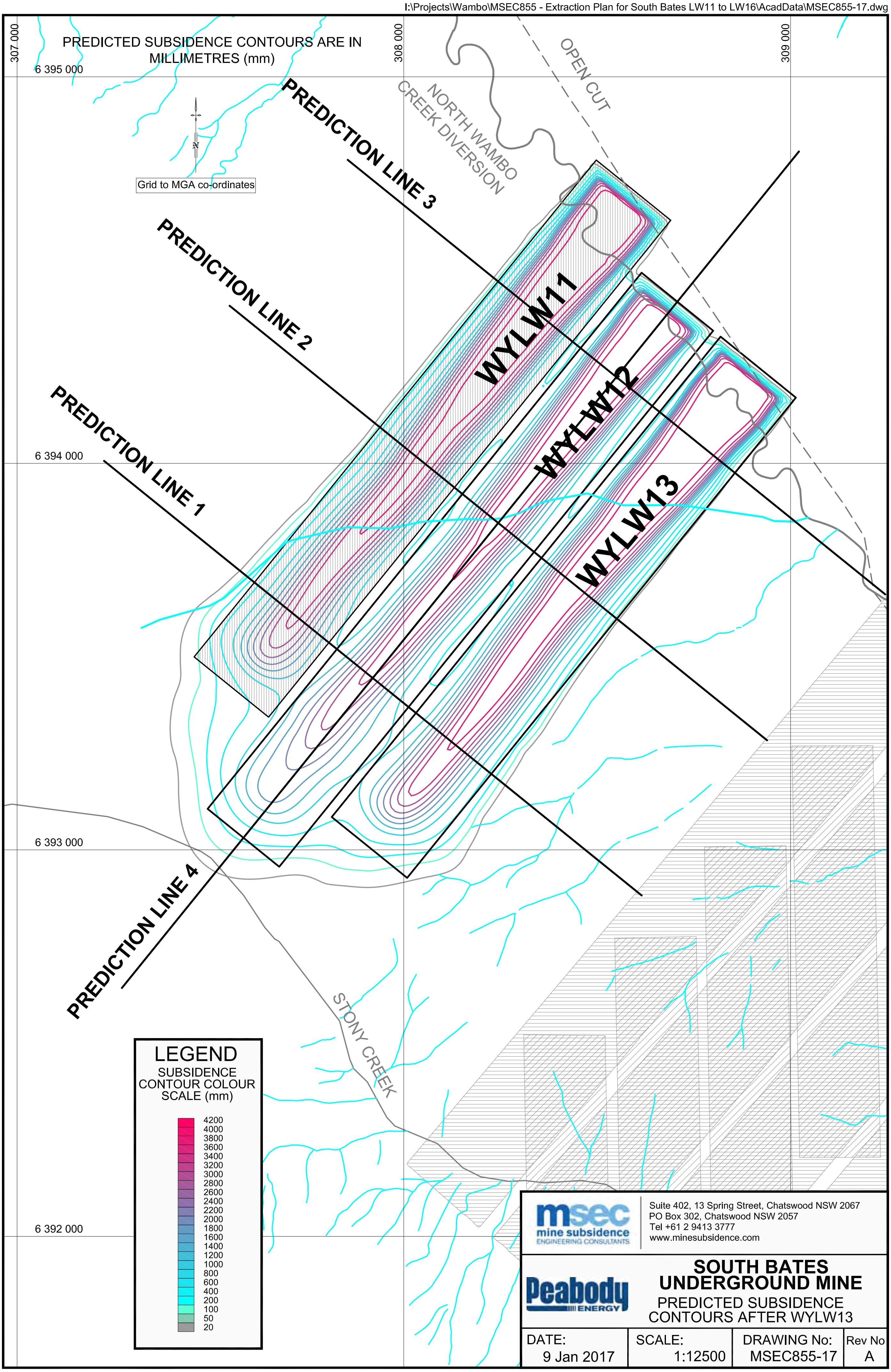
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PREDICTED SUBSIDENCE CONTOURS ARE IN MILLIMETRES (mm)
307 000
308 000
309 000
6 395 000
6 394 000
6 393 000
6 392 000
Grid to MGA co-ordinates
OPEN CUT
NORTH WAMBO CREEK DIVERSION
PREDICTION LINE 3
PREDICTION LINE 2
PREDICTION LINE 1
PREDICTION LINE 4
WYLW11
WYLW12
WYLW13
STONY CREEK
LEGEND
SUBSIDENCE CONTOUR COLOUR SCALE (mm)
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
100
50
20
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PREDICTED SUBSIDENCE CONTOURS AFTER WYLW13
DATE: 9 Jan 2017
SCALE: 1:12500
DRAWING No: MSEC855-17
Rev No A

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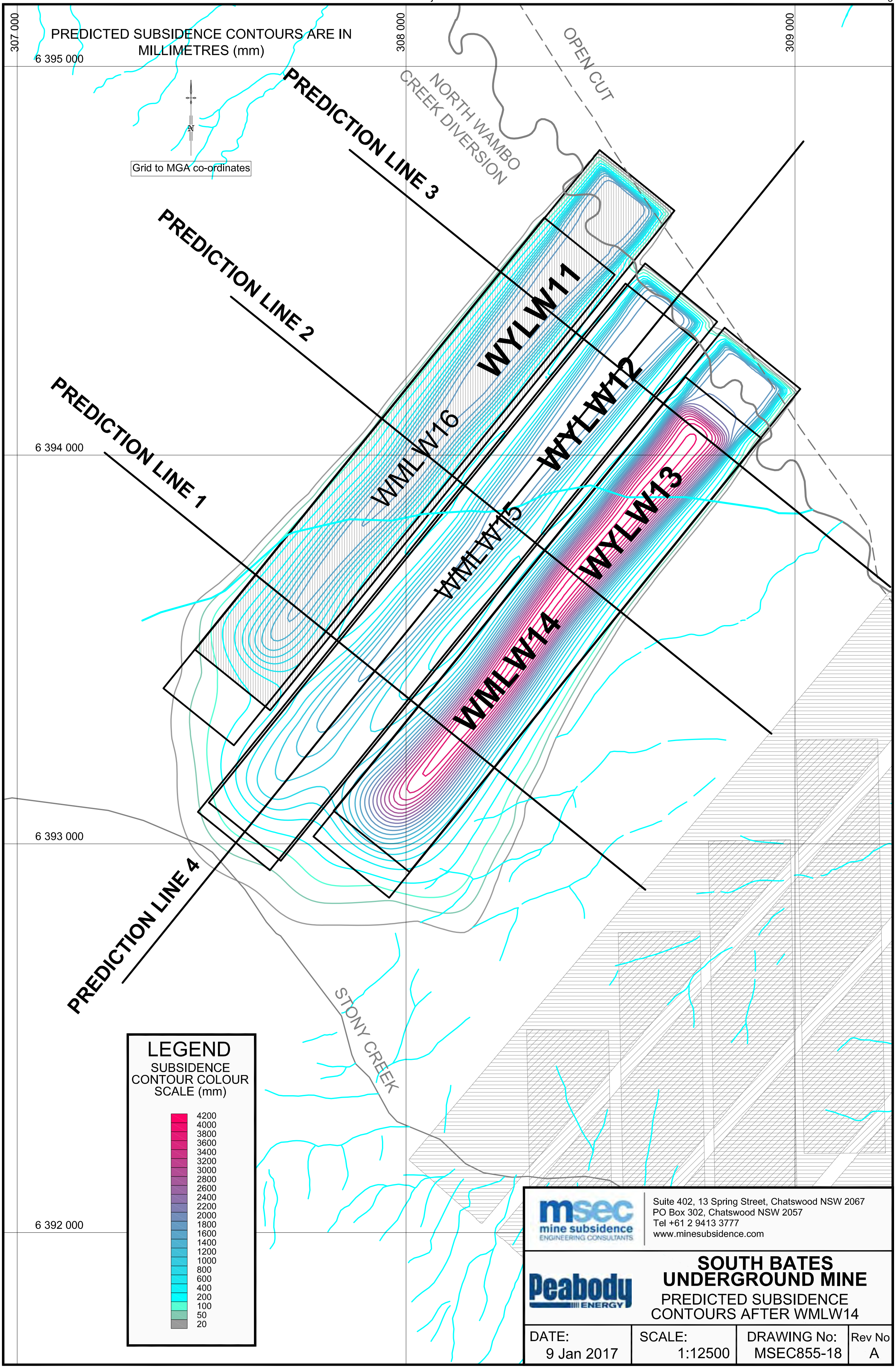

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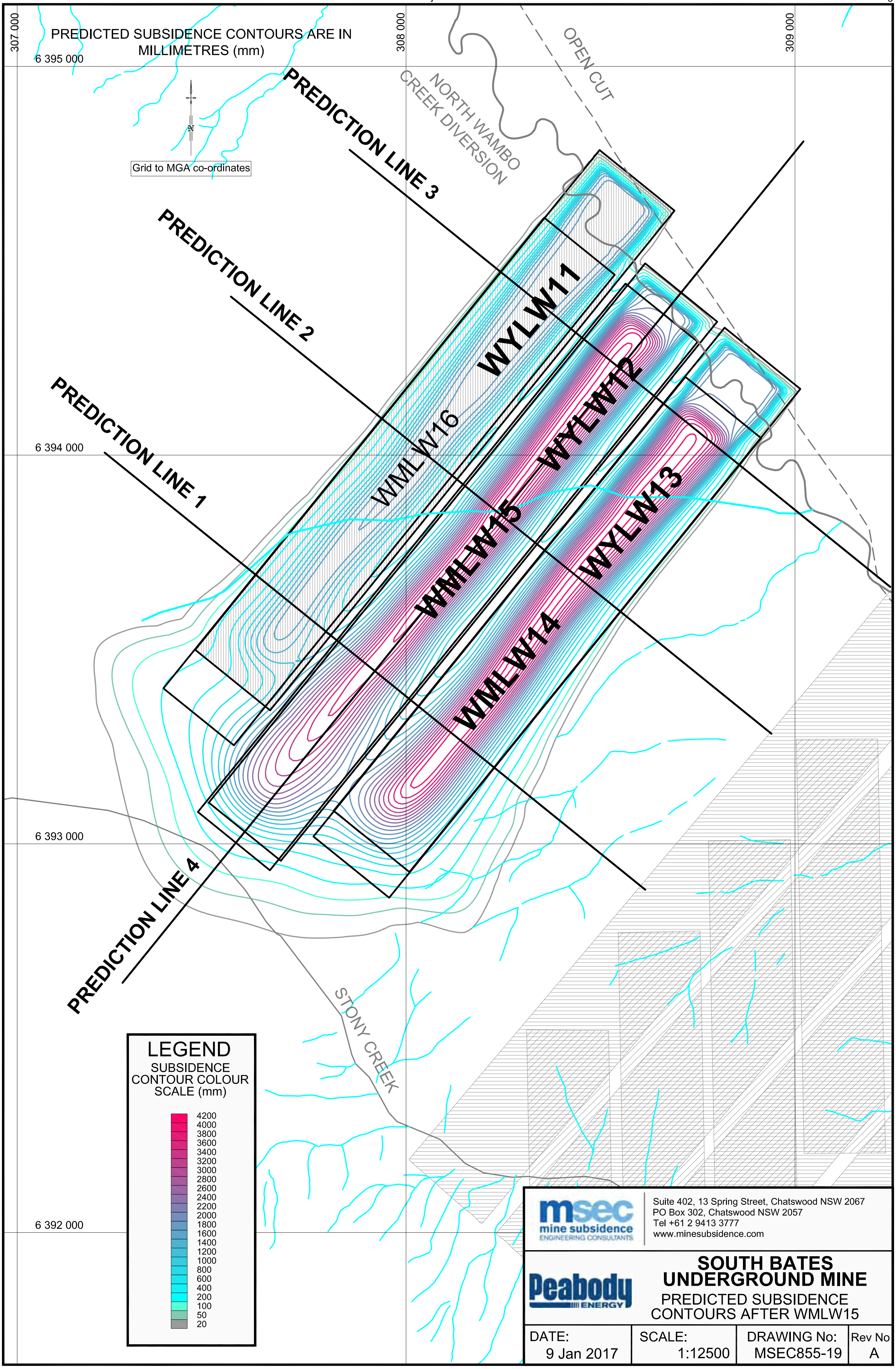

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