

WAMBO COAL PTY LIMITED



SOUTH BATES EXTENSION UNDERGROUND MINE

EXTRACTION PLAN
LONGWALLS 17 TO 20

REPORT 1
SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

Peabody



WAMBO COAL:

South Bates Extension Subsidence Assessment

Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan Application for the South Bates Extension WYLW17 to WYLW20

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Report produced to: Support the Extraction Plan Application for the South Bates Extension WYLLW17 to WYLLW20 in the Whybrow Seam.

Previous reports: MSEC848 (Rev. A) – South Bates Extension Modification Subsidence Assessment – Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Modification Application for the South Bates Extension Modification (issued on the 11th January 2017).

Background reports available at www.minesubsidence.com¹:

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. The mine was approved under Part 4 of the *Environmental Planning and Assessment Act 1979*, in February 2004, and through subsequent modifications. WCPL has approval to extract longwalls in the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams.

WCPL previously submitted a Modification Application for the extraction of Longwalls 17 to 25 in the Whybrow Seam (WYLLW17 to WYLLW25) at the *South Bates Extension Underground Mine*, part of the Wambo Coal Mine. The Planning Assessment Commission approved the extraction of these longwalls on the 20th December 2017.

WCPL is preparing an Extraction Plan Application for WYLLW17 to WYLLW20 at the South Bates Extension Underground Mine. Mine Subsidence Engineering Consultants (MSEC) has been engaged by WCPL to prepare a subsidence prediction and assessment report to support this application. The layout of these longwalls is the same as that adopted in the Modification Application.

The predicted subsidence parameters for WYLLW17 to WYLLW20 have been determined using the Incremental Profile Method. The maximum predicted subsidence parameters for these longwalls are the same as those presented in the Modification Application.

The maximum predicted parameters for WYLLW17 to WYLLW20 are 1950 mm vertical subsidence (i.e. 65 % of the maximum extraction height of 3.0 m), 90 mm/m tilt (i.e. 9 % or 1 in 11) 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 ends of the longwalls, where the depths of cover are the shallowest.

The Study Area has been defined as the surface area enclosed by the greater of the 26.5° angle of draw line from the extents of secondary extraction and the predicted total 20 mm subsidence contour due to mining these 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: 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; farm dams; mine infrastructure such as the Montrose Open Cut Pit (part of the Wambo Coal Mine), exploration drill holes and the future Montrose Water Storage Dam; archaeological sites; survey control marks; and unused building structures.

The assessments and recommendations provided in this report should be read in conjunction with those provided in the reports by other specialist consultants on the project. The main findings from this report are as follows:

- The natural section of North Wambo Creek is located outside of the Study Area, at a minimum distance of 400 m north-west of the finishing end of WYLLW20. At this distance, it is unlikely that the natural section of the creek would experience adverse impacts due to the extraction of the longwalls.
- Ephemeral drainage lines are located across the Study Area. Localised ponding areas could occur where the drainage lines cross the chain pillars and the edges of the longwalls. Larger topographical depressions are also predicted to develop above the finishing ends of the longwalls, having depths up to 1.2 m and surface areas up to 0.8 hectares. If adverse impacts were to occur due to the increased ponding above the longwalls, these could be remediated by locally regrading the stream beds, so as to re-establish the natural gradients.

Fracturing and compression heaving are expected to develop along the sections of the streams located directly above the longwalls. The impacts are expected to be similar to those observed along the streams located above the previously extracted WYLLW11 to WYLLW13 at the South Bates Underground Mine. It may be necessary to remediate the larger surface deformations by infilling with surface soil or other suitable materials, or by locally regrading and recompacting the surface.

- The North Wambo Creek Diversion is generally located outside the extents of the longwalls, with small sections crossing above the finishing end of WYLW17. The diversion is also located partially within the Study Area adjacent to the finishing end of WYLW18. Surface cracking could develop along the section of the creek diversion located directly above WYLW17, similar to that observed above the completed WYLW11 to WYLW13. Minor cracking could also develop along the section of the North Wambo Creek Diversion located outside the extents of the longwalls.

The depth of cover along the alignment of the North Wambo Creek Diversion, directly above WYLW17, varies between 60 and 70 m. It is likely, therefore, that fracturing would occur from the seam up to the surface in this location. It will be necessary, therefore, that the larger surface cracking within the alignment of the creek diversion is remediated during active subsidence, which could include infilling with cohesive materials and by regrading and recompacting the surface soils.

- Cliffs have been identified within and in the vicinity of the Study Area, which have been categorised into three groups, being the: *Cliffs Associated with the Wollemi Escarpment*; the *Intermediate Level Cliffs* (i.e. located beneath the escarpment); and *Low Level Cliffs* (i.e. near the base of the steep slopes directly above the south-western ends of the longwalls).

The Cliffs Associated with the Wollemi Escarpment are located outside the 26.5° angle of draw line and are predicted to experience less than 20 mm vertical subsidence. The Intermediate Level Cliffs are located outside the extents of the longwalls and are predicted to experience subsidence up to 30 mm.

Whilst the Cliffs Associated with the Wollemi Escarpment and the Intermediate Level Cliffs could experience very low-levels of vertical subsidence, they are unlikely to experience measurable conventional tilts, curvatures or strains. It is unlikely, therefore, that these cliffs would experience adverse impacts due to the extraction of the longwalls.

The Low Level Cliffs are located directly above WYLW20. It has been assessed that 7 % to 10 % of the total length, or approximately 3 % to 5 % of the total face area, of the cliffs located directly above and immediately adjacent to the longwalls could be impacted. This equates to a length of disturbance of approximately 15 m, or a face area of approximately 100 m². This represents a very small percentage (i.e. less than 1 %) of the total length and face area of the cliffs located within and immediately adjacent to the Study Area.

- Steep slopes are located above the south-western ends of the longwalls. Surface cracking and compression heaving could develop along the areas of the steep slopes that are located directly above the longwalls. Impacts are not anticipated along the steep slopes located outside and to the south-west of the mining area. Surface remediation might be required above the longwalls, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface.
- The Wollemi National Park is located to the south and to the west of the longwalls, at a minimum distance of 255 m from the commencing (i.e. south-western) end of WYLW19. The land within the National Park is predicted to experience less than 20 mm vertical subsidence and is not expected to experience measurable conventional tilts, curvatures or strains. The National Park could experience far-field horizontal movements up to 100 mm, but these bodily movements are not expected to be associated with any measurable strains. It is unlikely, therefore, that the Wollemi National Park would be adversely impacted by the vertical or far-field horizontal movements.
- There are unsealed tracks and trails located across the Study Area which are used for the mining operations and for firefighting activities. It is expected that these roads could be maintained in safe and serviceable conditions using normal road maintenance techniques.
- There are eight farm dams located within the Study Area. Fracturing and buckling could occur in the uppermost bedrock beneath the farm dams, which could adversely affect the water holding capacities of the farm dams. It may be necessary to remediate some of the farm dams, if their continuing use is required, at the completion of mining, by excavating and re-establishing cohesive material in the beds of the farm dams to reduce permeability.
- The WCPL mining related infrastructure within the Study Area includes the: Montrose Open Cut Pit; exploration drill holes; and approved Montrose Water Storage Dam. It is recommended that the exploration drill holes are capped (if not already done) prior to being directly mined beneath. The water storage dam would be constructed after the extraction of the longwalls beneath its location and, therefore, the design should account for the post mining surface level contours and fractured bedrock.

- There are 16 archaeological sites located within or immediately adjacent to the Study Area, comprising five Open Artefact Sites, two Isolated Artefacts, three Open Potential Archaeological Deposits (PADs), five Rock Shelters with PADs and one Scarred Tree. It is unlikely that the artefact scatters, isolated finds, Open PADs and the scarred tree would be adversely impacted by the mining-induced surface cracking.

The four rock shelters that are located directly above the longwalls and the one rock shelter that is located outside but immediately adjacent to the mining area could be affected by fracturing and spalling of the bedrock. It has been assessed that the potential for adverse impacts are very unlikely (i.e. less than 10 %) for each of these sites.

- The Whynot Homestead and associated sheds are located north-west of the longwalls, at distances ranging between 160 m to 180 m. The building structures are all unused and are in poor conditions. At these distances, it is unlikely that the building structures would experience adverse impacts due to the extraction of WYLV17 to WYLV20.

The assessments provided in this report indicate that the level 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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Drawings

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

<i>Drawing No.</i>	<i>Description</i>	<i>Revision</i>
MSEC935-01	Overall layout	A
MSEC935-02	General layout	A
MSEC935-03	Surface level contours	A
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MSEC935-05	Whybrow Seam thickness contours	A
MSEC935-06	Whybrow Seam depth of cover contours	A
MSEC935-07	Geological structures at seam level	A
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MSEC935-12	Predicted total subsidence contours after WYLLW19	A
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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, and through subsequent modifications. WCPL has approval to extract longwalls in the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams.

WCPL has completed the extraction of Longwalls 11 to 13 in the Whybrow Seam (WYLLW11 to WYLLW13) and is currently mining Longwalls 14 to 16 in the Wambo Seam (WMLW14 to WMLW16) at the *South Bates Underground Mine* mining area of the Wambo Coal Mine.

WCPL previously submitted a Modification Application for the extraction of Longwalls 17 to 25 in the Whybrow Seam (WYLLW17 to WYLLW25) at the *South Bates Extension Underground Mine*. These longwalls are located to the north-west of the completed and currently active longwalls at the South Bates Underground Mine. Mine Subsidence Engineering Consultants (MSEC) issued Report No. MSEC848 (Rev. A) in support of that Modification Application.

The Planning and Assessment Commission approved the extraction of WYLLW17 to WYLLW25 on the 20th December 2017. The Development Consent has been modified (DA 305-7-2003, MOD17) to include the extraction of these longwalls.

The locations of the existing WYLLW11 to WYLLW13 and WMLW14 to WMLW16 at the South Bates Underground Mine and the approved WYLLW17 to WYLLW20 at the South Bates Extension Underground Mine are shown in Drawings Nos. MSEC935-01 and MSEC935-02, in Appendix D, at the end of this report.

WCPL is preparing an Extraction Plan Application for WYLLW17 to WYLLW20, being the first four longwalls at the South Bates Extension Underground Mine. MSEC has been commissioned by WCPL to:

- provide subsidence predictions for WYLLW17 to WYLLW20, including the cumulative subsidence due to the adjacent existing and approved longwalls;
- compare the predictions with those presented in the Modification Application for the South Bates Extension Underground Mine and Report No. MSEC848;
- update the subsidence predictions for the natural and built features in the mining area;
- review and update the impact assessments, in conjunction with other specialist consultants, for each of these natural and built features; and
- recommend management strategies and monitoring for WYLLW17 to WYLLW20.

This report has been prepared to support the Extraction Plan Application for WYLLW17 to WYLLW20 at the South Bates Extension Underground Mine which 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 of the existing and approved longwalls.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of WYLLW17 to WYLLW20.

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 the management of each of these features are also provided, which have been based on the predictions and impact assessments.

WYLLW17 to WYLLW20 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.

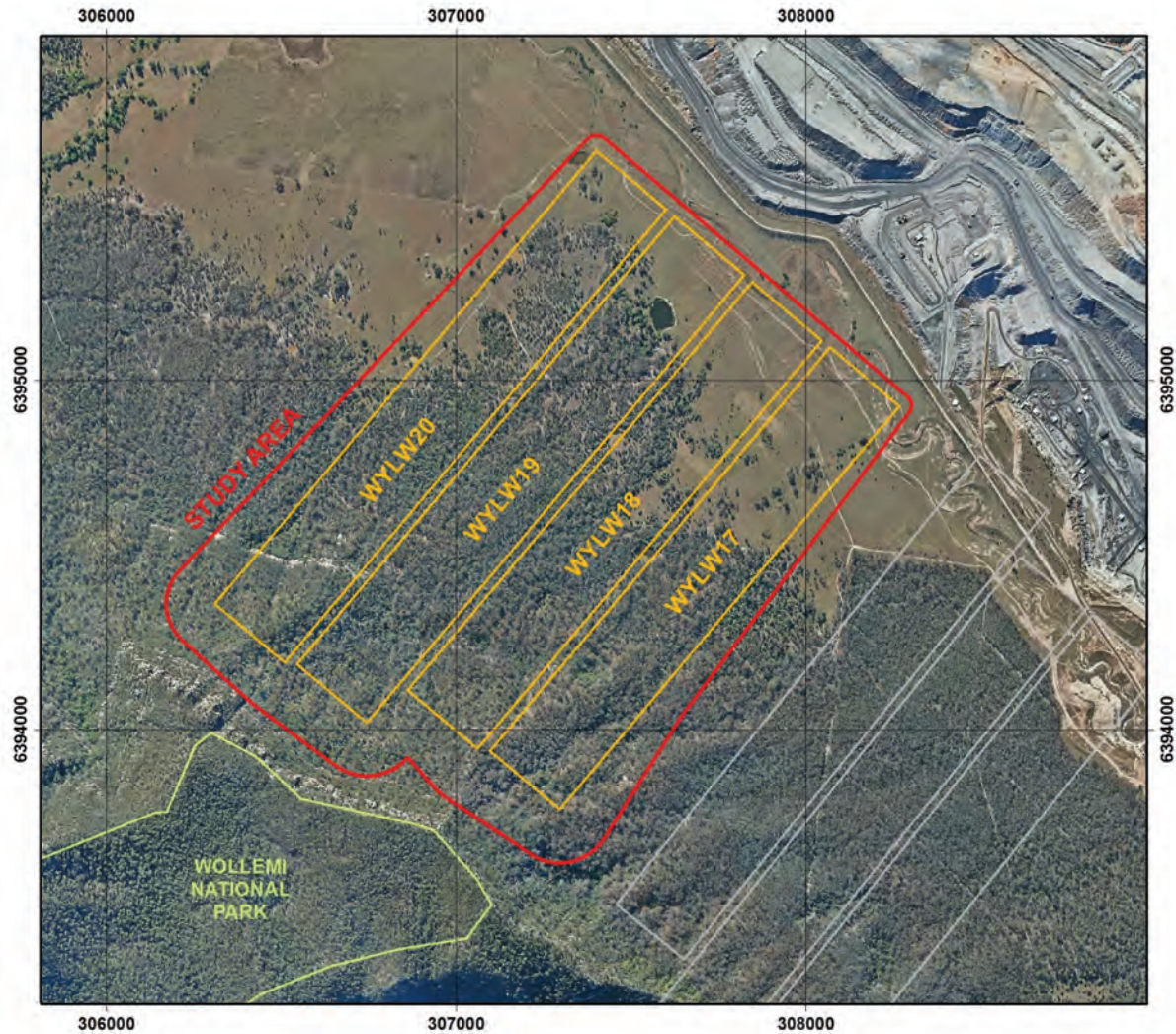


Fig. 1.1 Aerial photograph showing locations of WYLLW17 to WYLLW20 and the Study Area

1.2. Mining geometry

The layout of WYLLW17 to WYLLW20 is shown in Drawings Nos. MSEC935-01 and MSEC935-02. A summary of the dimensions for these longwalls is provided in Table 1.1.

Table 1.1 Geometry of WYLLW17 to WYLLW20

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
WYLLW17	1510	261	-
WYLLW18	1530	261	31
WYLLW19	1675	261	30
WYLLW20	1700	261	31

The widths of the longwall extraction faces (i.e. excluding the first workings) are 250 m. The lengths of extraction (i.e. excluding the installation heading) are approximately 8.5 m less than the overall void lengths provided in the above table. The longwalls will be extracted from the south-west towards the north-east (i.e. towards the Montrose Open Cut Pit).

The dimensions of WYLLW17 to WYLLW20 adopted in this Extraction Plan Application, as provided in Table 1.1, are the same as those previously presented in the Modification Application and in Report No. MSEC848 for these longwalls.

1.3. Surface and seam levels

The natural surface and the levels of the Whybrow Seam and the Wambo Seam are illustrated along Cross-sections 1 to 3 in Fig. 1.2 to Fig. 1.4 below. The locations of these sections are shown in Drawings Nos. MSEC935-03 to MSEC935-05. The completed and approved longwalls in the Whybrow and Wambo Seams at the South Bates Underground Mine are shown as the cyan outlines. The longwalls in the Whybrow Seam at the South Bates Extension Underground Mine are shown as the blue outlines.

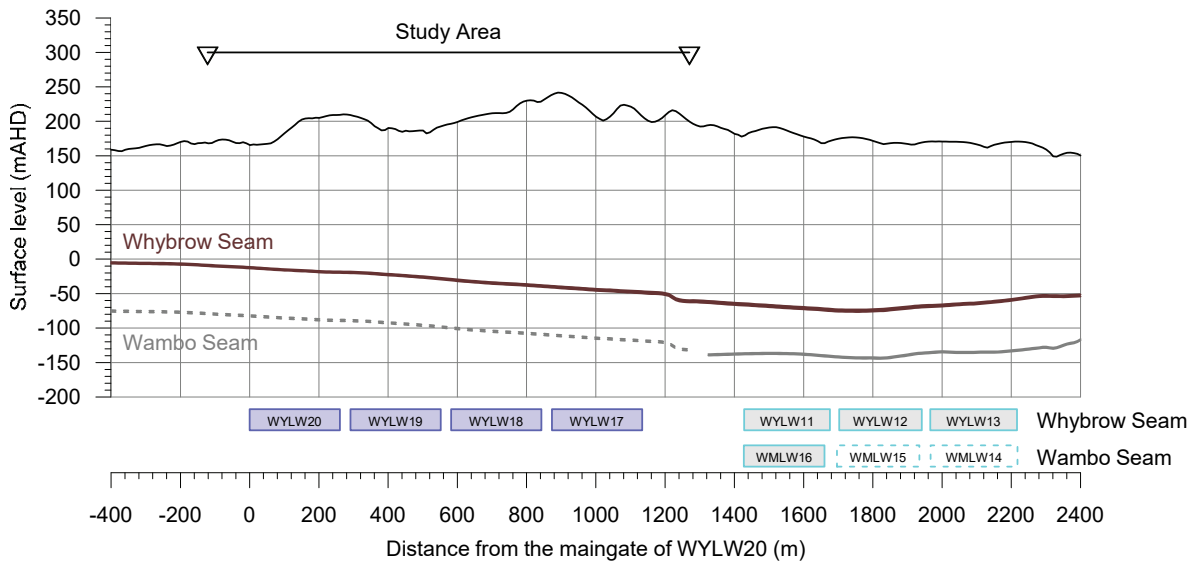


Fig. 1.2 Surface and seam levels along Cross-section 1 near the longwall commencing ends

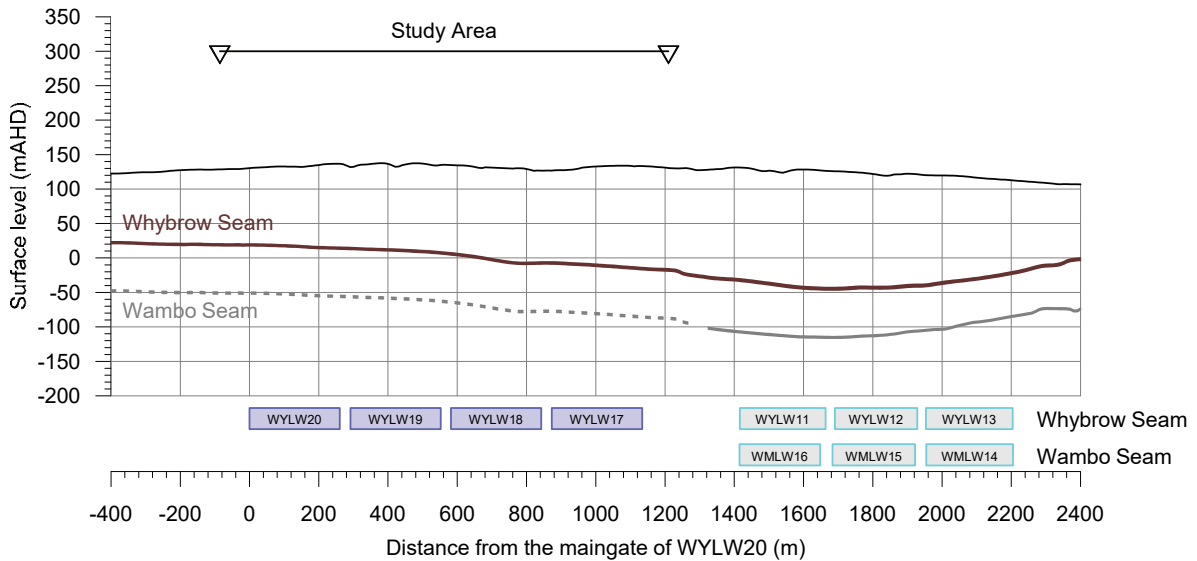


Fig. 1.3 Surface and seam levels along Cross-section 2 near the middle of the longwalls

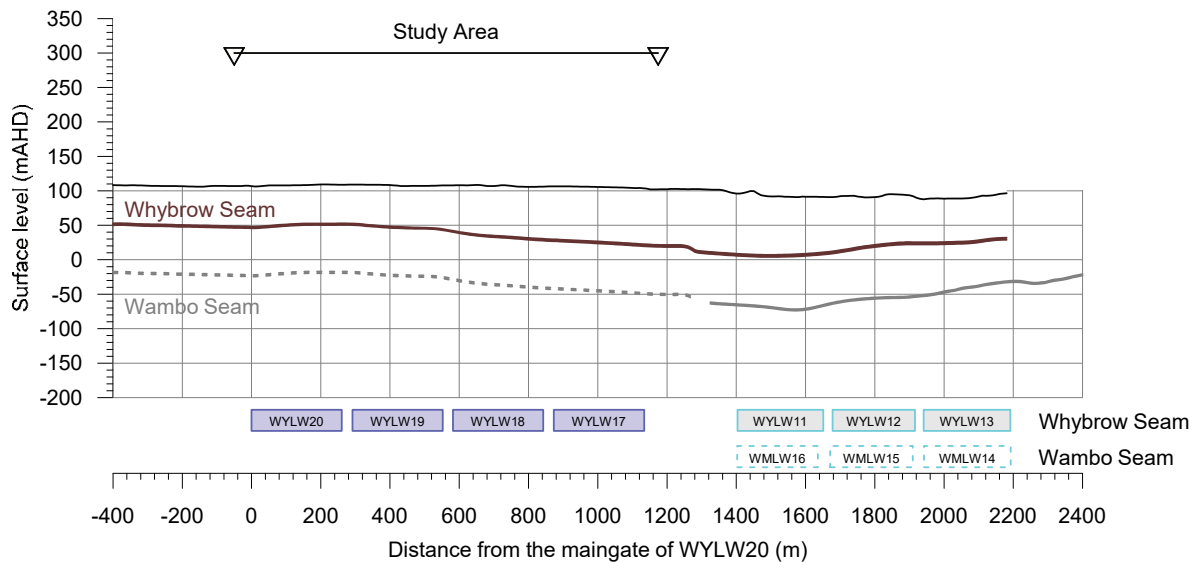


Fig. 1.4 Surface and seam levels along Cross-section 3 near the longwall finishing ends

The surface level contours are shown in Drawing No. MSEC935-03. The major natural topographical feature in the area is the Wollemi Escarpment, which is located to the south-west and to the west of the longwalls. The Montrose Open Cut Pit is located to the north-east of the longwalls.

The surface levels directly above the longwalls vary from a high point of 285 m above Australian Height Datum (mAHD) above the commencing (i.e. south-western) end of WYWL18, to a low point of 100 mAHD above the finishing (i.e. north-eastern) end of WYWL17.

The seam floor contours, seam thickness contours and depth of cover contours for the Whybrow Seam are shown in Drawings Nos. MSEC935-04, MSEC935-05, and MSEC935-06, respectively. The contours are based on the latest seam information provided by WCPL.

The depths of cover to the Whybrow Seam directly above the longwalls vary between a minimum of 50 m above the finishing (i.e. north-eastern) ends of WYWL19 and WYWL20 and a maximum of 330 m above the commencing (i.e. south-western) end of WYWL18.

The seam floor within the mining area generally dips from the north-east towards the south-west, with the seam being shallowest at the Montrose Open Cut Pit and deepest beneath the escarpment. The average dip of the seam within the extents of the longwalls is around 6 %, or 1 in 17. The thickness of the Whybrow Seam within the extents of the longwalls varies between 1.6 m and 3.2 m. The mining heights for the longwalls are illustrated in Drawing No. MSEC935-05 and vary from less than 2.8 up to 3.0 m.

1.4. Geological details

The South Bates Extension 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 Planning and Environment – Division of Resources and Geosciences (DRG).

The Whybrow Seam lies 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 formations 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	
	Appletree Flat Subgroup		Clifford Formation	
			Charlton Formation	
			Abbey Green Coal	
			Watts Sandstone	
			Denman Formation	
			Mount Leonard Formation	Whybrow Seam
			Althorpe Formation	
		Jerrys Plains Subgroup	Malabar Formation	Redbank Creek Seam
				Wambo Seam
				Whynot Seam
				Blakefield Seam
				Glen Munro Seam
			Mount Ogilvie Formation	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 typical drill holes located within the mining area, which are shown in Drawing No. MSEC935-09. The geological section for drill hole UG139 is provided in Table 1.3. This drill hole is located approximately 250 m north-west of the maingate of WYLW20.

The overburden of the Whybrow Seam predominately comprises of interbedded sandstone and siltstone layers, with minor claystone, mudstone, shale, tuffaceous and coal layers. The immediate roof of the Whybrow Seam comprises a 22 m thick claystone layer. The immediate floor of the seam comprises interbedded claystone, sandstone, siderite and siltstone.

There are no massive sandstone or conglomerate units within the overburden. The largest is a 17 m thick sandstone layer located approximately 30 m above the Whybrow Seam. Otherwise, the thicknesses of the formations within the overburden are typically less than 10 m. Other boreholes in the vicinity of the mining area indicate the presence of other larger sandstone units with thicknesses up to 20 m in the lower part of the overburden.

No adjustment factors have been applied in the subsidence prediction model for any massive strata units or for softer floor conditions, as the longwalls are supercritical in width and therefore are predicted to achieve the maximum subsidence for single-seam mining conditions.

Table 1.3 Geological section of Drill Hole UG139

Depth (m)	Thickness (m)	Lithology
0 ~ 0.5	0.5	Soil
0.5 ~ 9	8.5	Clay
9 ~ 15.5	6.5	Sandstone
15.5 ~ 17	1.5	Siltstone
17 ~ 18	1	Sandstone
18 ~ 20	2	Sandstone (70 %) and Siltstone (30 %)
20 ~ 21	1	Sandstone (70 %) and Claystone (30 %)
21 ~ 22.5	1.5	Claystone
22.5 ~ 24	1.5	Sandstone (70 %) and Siltstone (30 %)
24 ~ 25	1	Sandstone
25 ~ 26	1	Claystone
26 ~ 49	23	Sandstone
49 ~ 54	5	Sandstone (80 %) and Siltstone (20 %)
54 ~ 57	3	Sandstone
57 ~ 62	5	Siltstone (70 %) and Sandstone (30%)
62 ~ 64	2	Siltstone
64 ~ 81	17	Sandstone
81 ~ 82	1	Siltstone
82 ~ 87	5	Siltstone (80 %) and Sandstone (20%)
87 ~ 88.5	1.5	Siltstone
88.5 ~ 110.5	22	Claystone
110.5 ~ 113	2.5	Coal (Whybrow Seam)
113 ~ 114	1	Claystone
114 ~ 115	1	Sandstone (70 %) and Claystone (30 %)
115 ~ 116	1	Sandstone (50 %) and Siderite (50 %)
116 ~ 117	1	Sandstone
117 ~ 122	5	Sandstone (70 %) and Siltstone (30 %)
122 ~ 127	5	Sandstone

The geological features that have been identified at seam level are shown in Drawing No. MSEC935-07. The largest structure in the area is the *Redmanvale Fault* which is located south-west of the longwalls. This normal fault has a strike of approximately 325° and dips towards the north-east. The dip angle of normal faults is typically in the range of 70° and 85°. The throw of the Redmanvale Fault is greater than 20 m.

The distance of the Redmanvale Fault from the commencing end of WYLV17 (i.e. the first longwall in the series) is approximately 985 m at seam level. The distance of this fault from mining decreases with successive longwalls in the series. The Redmanvale Fault is located approximately 590 m from the commencing end of WYLV20, at its closest point to the longwalls.

Two sections have been taken through the Redmanvale Fault and the commencing (i.e. south-western) ends of WYLV19 and WYLV20 and are shown in Fig. 1.5 and Fig. 1.6, respectively. The assumed fault plane is based on a dip angle of 70°. These sections have been taken where the fault is located closest to the longwalls, as shown in Drawing No. MSEC935-07.

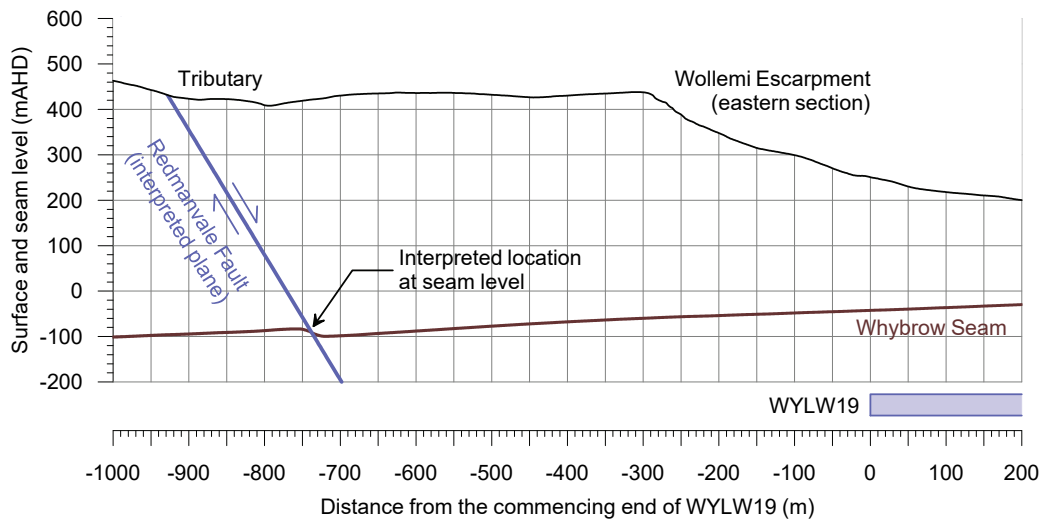


Fig. 1.5 Section through the Redmanvale Fault and the commencing end of WYLV19

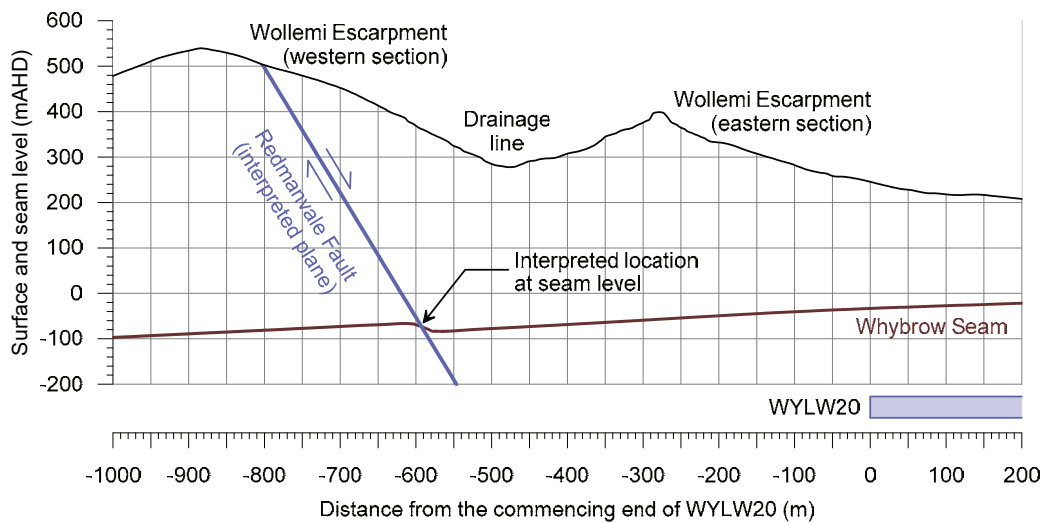


Fig. 1.6 Section through the Redmanvale Fault and the commencing end of WYLV20

The surface expression of the Redmanvale Fault appears to be associated with a tributary to Stony Creek adjacent to the earlier longwalls, i.e. WYLV17 to WYLV19, as shown in Fig. 1.5. To the west and north-west of WYLV20, the surface expression appears to be associated with the Wollemi Escarpment (western section), as shown in Fig. 1.6.

The assumed surface expression of the Redmanvale Fault, based on a 70° dip, is located at a horizontal distance varying between 800 and 1100 m from WYLV17 to WYLV20. The component of vertical subsidence at the assumed surface expression of the fault is expected to be negligible (i.e. not measurable) due to the extraction of the longwalls. The potential for differential vertical subsidence to develop at the assumed surface expression of the fault is considered to be very low, due to the footwall block restraining the vertical movement of the hanging block and due to the low-levels of predicted vertical subsidence.

The absolute horizontal movements at the assumed surface expression of the fault are predicted to be in the order of 30 to 60 mm due to the extraction of WYLV17 to WYLV20. These far-field horizontal movements are due to the redistribution of horizontal stress and are directed towards the mining area.

The potential for far-field horizontal movements has been reduced as the horizontal in situ stress has already been redistributed due to the mining in the Montrose Open Cut Pit on the north-eastern side of the longwalls. Also, normal faults are formed through tension in the strata and, therefore, there is likely to be a reduced compressive stress across this fault plane.

The potential for mining-induced shear movements across the fault is expected to be very low due to the fault being located outside of the mining area, the dip direction of the fault (i.e. towards the mining area), the dip angle of the fault (i.e. greater than 70°) and the direction of the far-field horizontal movements, with the footwall block pushing against the hanging block, with the resultant vertical action opposing gravity. The potential for irregular ground movements at the surface, therefore, is considered to be very low.

The differential movements at the assumed surface expression of the fault due to the far-field horizontal movements is expected to be negligible (i.e. not measurable) due to the extraction of WYLV17 to WYLV20. The potential for impacts on the Wollemi Escarpment, therefore, is considered to be very low as it is parallel to the alignment of the fault and there is low potential for differential movements.

The first longwall in the series (i.e. WYLV17) is located at a distance of 985 m from the interpreted location of the Redmanvale Fault at seam level. The successive longwalls in the series progressively approach the fault, with WYLV20 located closest to the fault at a distance of 590 m at seam level. The progressive mining of longwalls towards the fault will allow the surface movements in the vicinity of the fault to be continually monitored and reviewed.

There is a series of north to south trending faults through the north-eastern ends of WYLV17 to WYLV20 and north-east to south-west trending faults through the south-western end of WYLV17. These minor faults have throws up to approximately 5 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-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 significant tilts, curvatures or strains.

The surface lithology in the area can be seen in Fig. 1.7, 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 DRG.

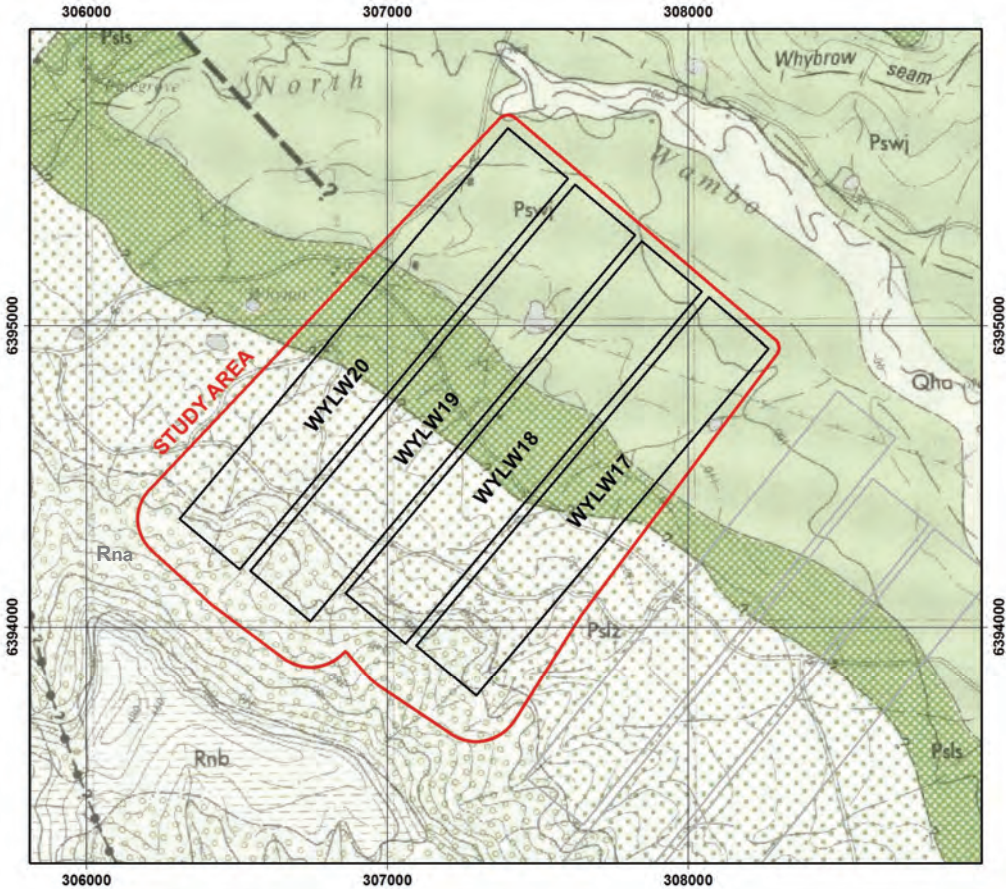


Fig. 1.7 WYLV17 to WYLV20 overlaid on Geological Map Doyles Creek 9032-1-N (DMR, 1988)

It can be seen from the above figure, that the surface lithology generally comprises the Jerrys Plains Subgroup of the Wittingham Coal Measures (Pswj) above the north-eastern ends of WYLW17 to WYLW20, the Watts Sandstone (Psls) above the middle parts of the longwalls and the Newcastle Coal Measures (Pslz) and the Widden Brook Conglomerate (Rna) above the south-western ends of the longwalls.

The surface lithology adjacent to the north-eastern ends of the longwalls has been modified by the construction of the North Wambo Creek Diversion, which included 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 WYLV17 to WYLV20 in the Whybrow 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 WYLV17 to WYLV20; and
- the predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour resulting from the extraction of WYLV17 to WYLV20.

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 contours for the Whybrow Seam are shown in Drawing No. MSEC935-06. It can be seen from this drawing that the depths of cover directly above the longwalls vary between 50 and 330 m. The 26.5° angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 25 and 165 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 total 20 mm subsidence contour due to the extraction of WYLV17 to WYLV20, 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, which includes the predicted total 20 mm subsidence contour, are shown in Drawing No. MSEC935-13.

A line has therefore been drawn defining the Study Area, based upon the 26.5° angle of draw line and the predicted total 20 mm subsidence contour, whichever is furthest from WYLV17 to WYLV20, and is shown in Drawings Nos. MSEC935-01 and MSEC935-02. In this case, the Study Area is governed by the 26.5° angle of draw line in all locations.

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 and built features located 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.

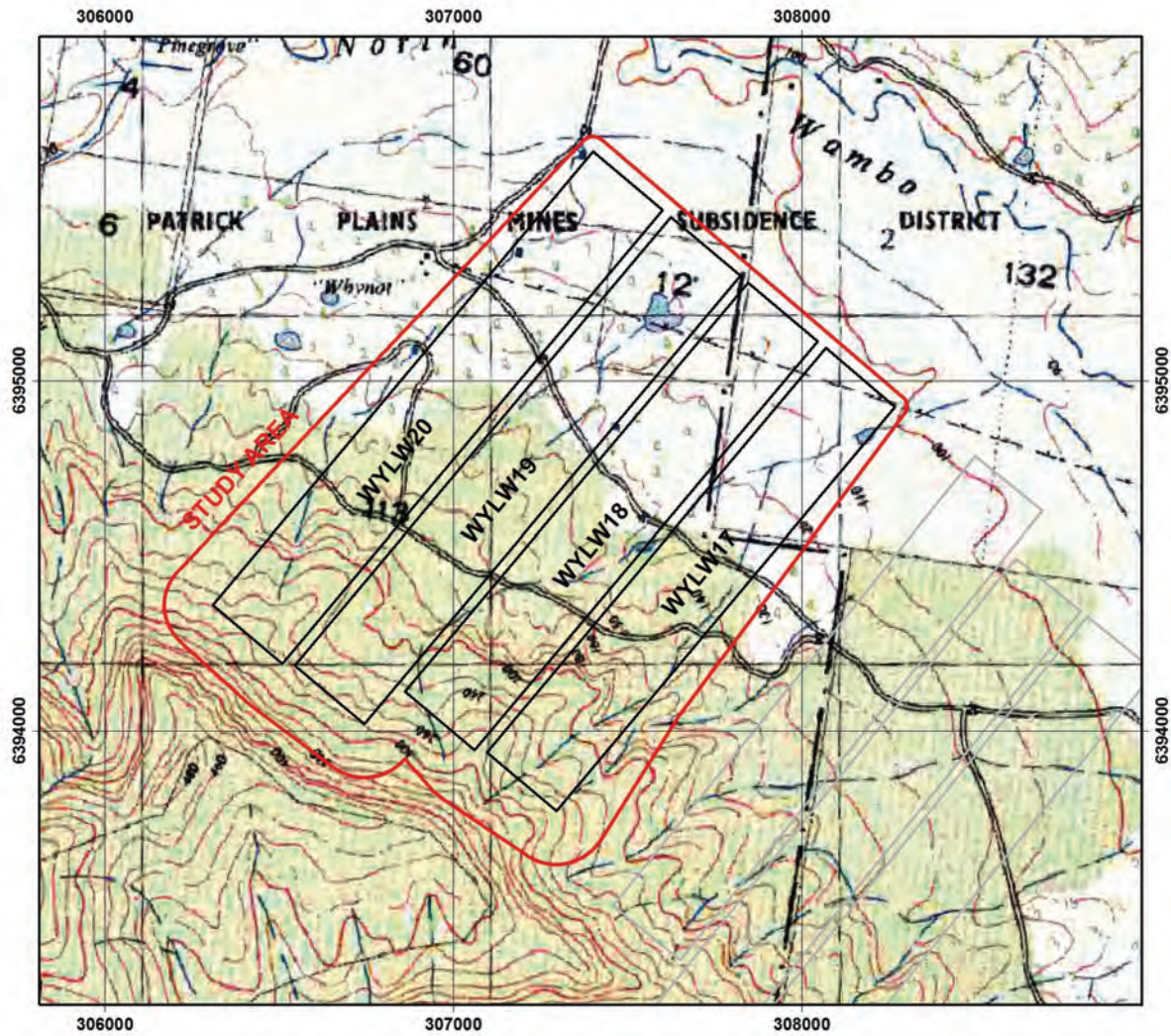


Fig. 2.1 WYLW17 to WYLW20 overlaid on CMA Map No. Doyles Creek 9032-1-N

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. MSEC935-08 and MSEC935-09. 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	Item	Within Study Area	Section number
NATURAL FEATURES			FARM LAND AND FACILITIES		
Catchment Areas or Declared Special Areas	x		Agricultural Utilisation or Agricultural Suitability of Farm Land	x	6.3.1
Streams	✓	5.2 & 5.3	Farm Buildings or Sheds	✓	6.7
Aquifers or Known Groundwater Resources	x		Tanks	✓	6.7
Springs or Groundwater Seeps	x		Gas or Fuel Storages	x	
Sea or Lake	x		Poultry Sheds	x	
Shorelines	x		Glass Houses	x	
Natural Dams	x		Hydroponic Systems	x	
Cliffs or Pagodas	✓	5.6 & 5.7	Irrigation Systems	x	
Steep Slopes	✓	5.8	Fences	✓	6.3.2
Escarpments	x	5.5	Farm Dams	✓	6.3.3
Land Prone to Flooding or Inundation	x	5.9	Wells or Bores	✓	6.3.4
Swamps or Wetlands	x		Any Other Farm Features	x	
Water Related Ecosystems	x	5.10			
Threatened or Protected Species	✓	5.11	INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Lands Defined as Critical Habitat	x		Factories	x	
National Parks	x	5.12	Workshops	x	
State Forests	x		Business or Commercial Establishments or Improvements	x	
State Recreation or Conservation Areas	x		Gas or Fuel Storages or Associated Plants	x	
Natural Vegetation	✓	5.13	Waste Storages or Associated Plants	x	
Areas of Significant Geological Interest	x		Buildings, Equipment or Operations that are Sensitive to Surface Movements	x	
Any Other Natural Features Considered Significant	x		Surface Mining (Open Cut) Voids or Rehabilitated Areas	✓	6.4.1
			Mine Related Infrastructure Including Exploration Bores and Gas Wells	✓	6.4.2 & 6.4.3
			Any Other Industrial, Commercial or Business Features	x	
PUBLIC UTILITIES			AREAS OF ARCHAEOLOGICAL SIGNIFICANCE		
Railways	x			✓	6.5
Roads (All Types)	✓	6.1.1	AREAS OF HISTORICAL SIGNIFICANCE		
Bridges	x			x	
Tunnels	x		ITEMS OF ARCHITECTURAL SIGNIFICANCE		
Culverts	✓	6.1.1		x	
Water, Gas or Sewerage Infrastructure	x		PERMANENT SURVEY CONTROL MARKS		
Liquid Fuel Pipelines	x			✓	6.6
Electricity Transmission Lines or Associated Plants	x		RESIDENTIAL ESTABLISHMENTS		
Telecommunication Lines or Associated Plants	x		Houses	✓	6.7
Water Tanks, Water or Sewage Treatment Works	x		Flats or Units	x	
Dams, Reservoirs or Associated Works	x		Caravan Parks	x	
Air Strips	x		Retirement or Aged Care Villages	x	
Any Other Public Utilities	x		Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	x	
			Any Other Residential Features	x	
PUBLIC AMENITIES			ANY OTHER ITEM OF SIGNIFICANCE		
Hospitals	x			x	
Places of Worship	x		ANY KNOWN FUTURE DEVELOPMENTS		
Schools	x			x	
Shopping Centres	x				
Community Centres	x				
Office Buildings	x				
Swimming Pools	x				
Bowling Greens	x				
Ovals or Cricket Grounds	x				
Race Courses	x				
Golf Courses	x				
Tennis Courts	x				
Any Other Public Amenities	x				

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 WYLW17 to WYLW20. 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 mines in 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 WYLW17 to WYLW20 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 WYLLW17 to WYLLW20. 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

There are no existing workings located above or below WYLLW17 to WYLLW20 (i.e. single-seam mining conditions). The depths of cover to the Whybrow Seam directly above these longwalls vary between 50 and 330 m. The depths of cover are shallowest above the finishing (i.e. north-eastern) ends and are greatest above the commencing (i.e. south-western) ends of the longwalls.

The longwall width-to-depth ratios vary between 0.8 at the longwall commencing ends and greater than 5 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 measured 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 in width. 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 IPM has been calibrated to local conditions using ground monitoring data from the Wambo Coal Mine and from other nearby collieries. This has been achieved by comparing the subsidence movements measured along monitoring lines with those predicted using the standard IPM for the Hunter Coalfield.

The ground movements have been measured along the 7XL-Line, CL11B-Line and CL13B-Line which are located above WYLLW11 to WYLLW13 at the South Bates Underground Mine. The locations of these monitoring lines are shown in Drawing No. MSEC935-01.

The profiles of measured vertical subsidence, tilt and curvature along the 7XL-Line are shown in Fig. 3.1. The predicted movements are also shown for comparison, based on the predictions provided in Report No. MSEC855, which supported the Extraction Plan for WYLLW11 to WYLLW13 and WMLW14 to WMLW16.

The measured profiles of vertical subsidence and tilt reasonably match the predicted profiles along the 7XL-Line. There is a very slight lateral shift between the measured and predicted maxima of approximately 10 m.

The maximum measured vertical subsidence and tilt for the 7XL-Line are less than the maxima predicted. The ratio of the maximum measured to maximum predicted vertical subsidence is 0.86 above WYLLW11, 0.87 above WYLLW12 and 0.85 above WYLLW13. The measured vertical subsidence above the chain pillar is similar to that predicted.

The profile of measured curvature is irregular (i.e. more erratic) due to survey tolerance, localised irregular ground movements and possibly due to disturbed survey marks. The observed zones of hogging curvature and sagging curvature reasonably match the predicted zones.

The measured curvature represents the localised (i.e. micro) movements at each of the survey marks, whereas the predicted curvature represents the overall (i.e. macro) curvature of the ground. The measured curvature has been smoothed using local-weighting over three survey marks, to provide a more realistic representation of the overall/macro curvature, and this is shown as the dashed blue line in Fig. 3.1. The smoothed profile of measured curvature reasonably matches the predicted profile. It has been considered, therefore, that the observed overall/macro curvature reasonably matches that predicted.

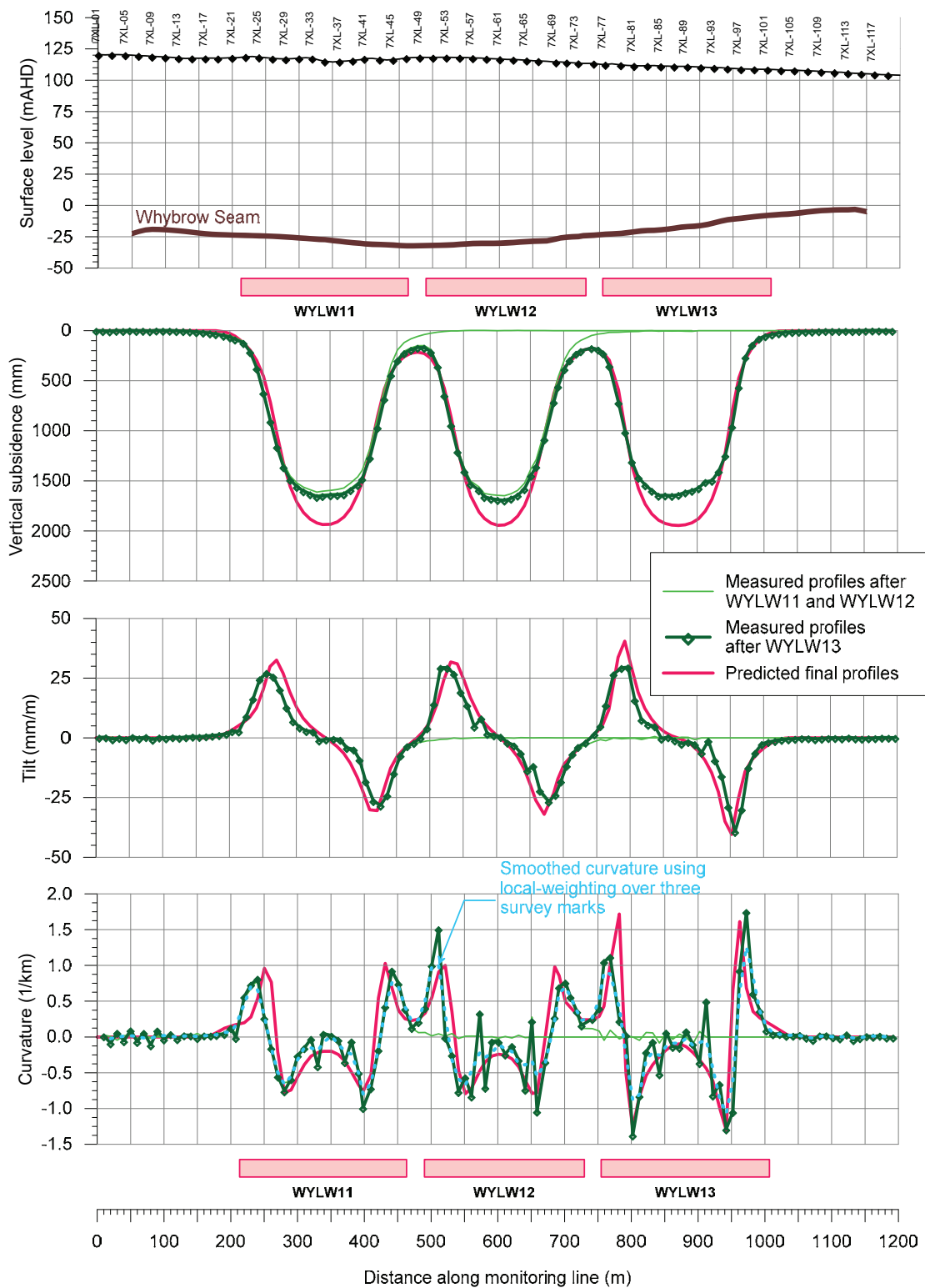


Fig. 3.1 Comparison of measured and predicted vertical subsidence, tilt and curvature along the 7XL-Line at the South Bates Underground Mine

The profiles of measured vertical subsidence, tilt and curvature along the CL11B-Line and CL13B-Line are shown in Fig. 3.2 and Fig. 3.3, respectively. The predicted movements are also shown in these figures, based on the predictions provided in Report No. MSEC855.

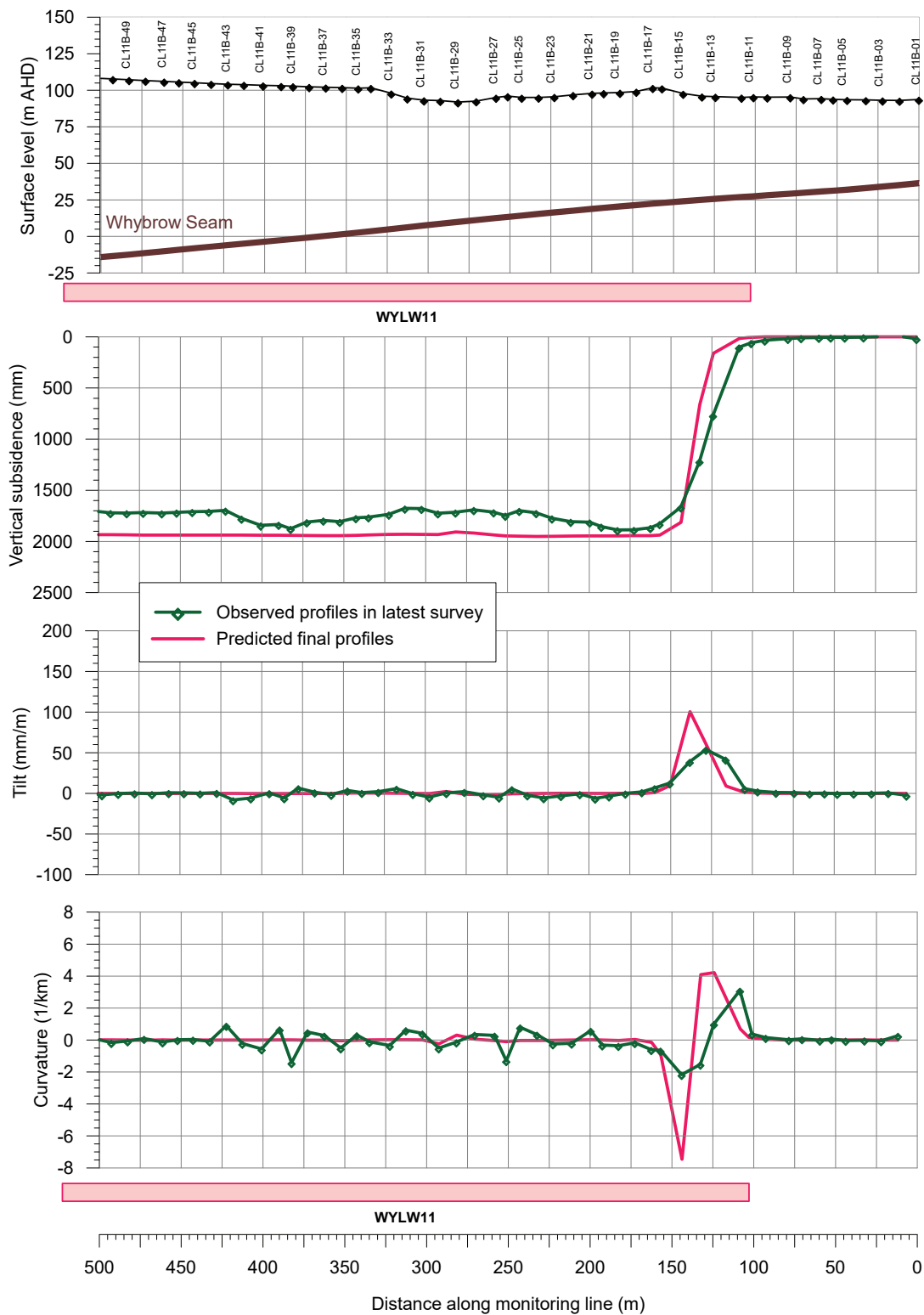


Fig. 3.2 Comparison of measured and predicted vertical subsidence, tilt and curvature along the CL11B-Line at the South Bates Underground Mine

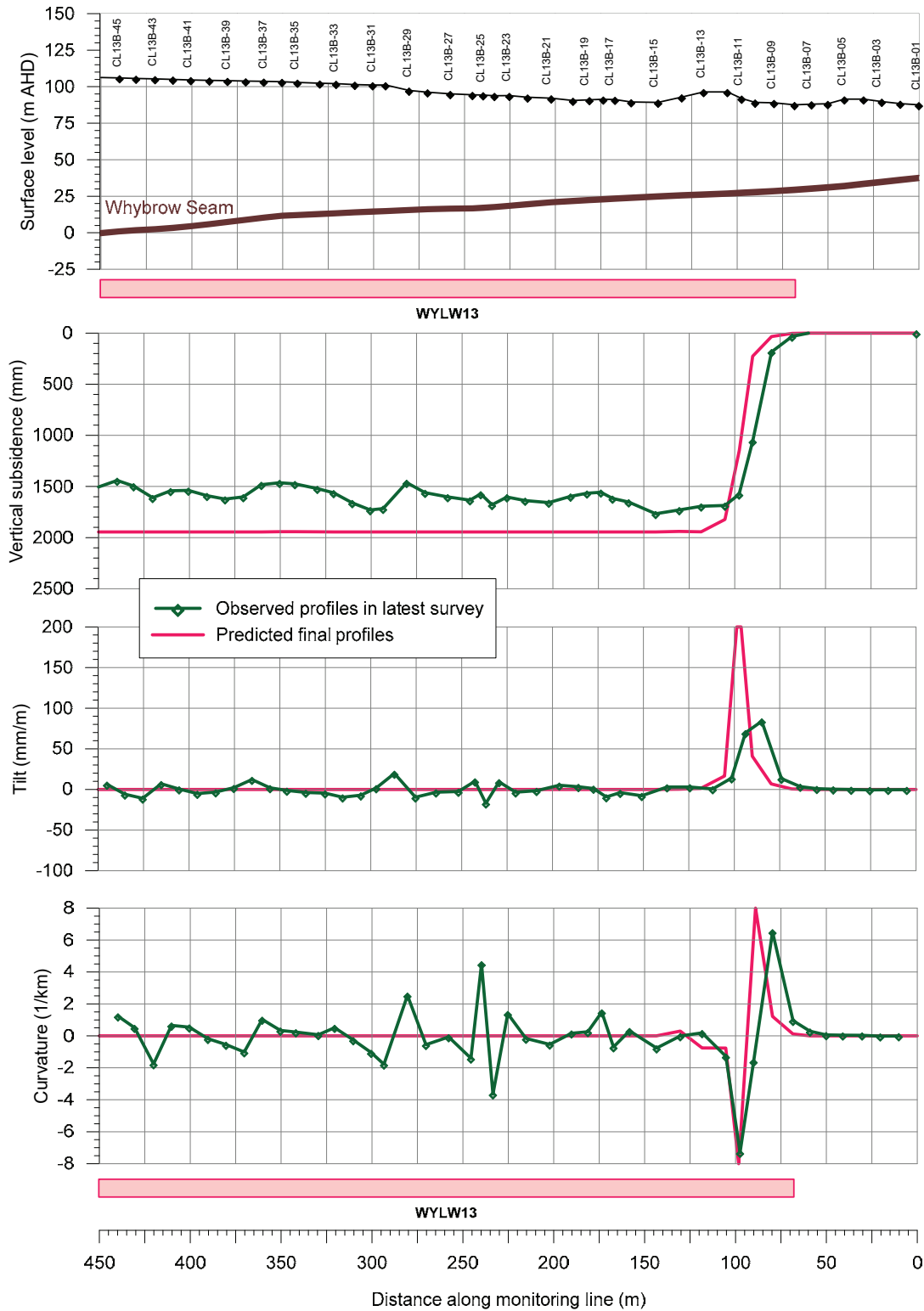


Fig. 3.3 Comparison of measured and predicted vertical subsidence, tilt and curvature along the CL13B-Line at the South Bates Underground Mine

The measured profiles of vertical subsidence along the CL11B-Line and CL13B-Line are slightly flatter than the predicted profiles above the longwall finishing ends and, therefore, the magnitudes of measured vertical subsidence are slightly greater than those predicted in these locations. There are low-level tilts and curvatures along these monitoring lines, directly above the longwalls, due to the irregular ground movements that occur at the shallow depths of cover. The predicted profiles represent the conventional movements and do not include these localised irregular movements.

It is considered that the standard IPM for the Hunter Coalfield has provided acceptable predictions of vertical subsidence, tilt and curvature along the 7XL-Line, CL11B-Line and CL13B-Line due to the extraction of WYLLW11 to WYLLW13 at the South Bates Underground Mine.

WCPL has also provided MSEC with the data for a number of ground monitoring lines located above the completed longwalls in the Wambo Seam at the North Wambo Underground Mine (NWUM). These longwalls have generally been extracted beneath the Homestead/Wollemi workings in the Whybrow Seam and above the United Collieries longwalls in the Woodlands Hill Seam (as defined by United Collieries, which is the Arrowfield Seam as defined by WCPL and the DRE). The existing workings at the NWUM and the locations of the monitoring lines are shown in Drawing No. MSEC935-01.

The XL3-Line is located between the existing Homestead workings and United Collieries workings and, therefore, is effectively in the location of single-seam mining conditions. The remaining monitoring lines at the NWUM are located above existing workings (i.e. multi-seam mining conditions) and, therefore, cannot be used to calibrate the subsidence model for WYLLW17 to WYLLW20.

The profiles of measured vertical subsidence, tilt and curvature along the XL3-Line resulting from the extraction of Longwalls 1 to 6 in the Wambo Seam (WMLW1 to WMLW6) are shown in Fig. 3.4. The back-predicted movements, based on the standard IPM, are also shown in this figure for comparison. The measured and predicted profiles above WMLW7 have not been shown as the monitoring line is partially located above existing United Collieries workings in the Woodlands Hill Seam in this location and, therefore is affected by multi-seam conditions.

The comparisons between the measured and back-predicted mine subsidence movements have also been made along three monitoring lines that are located at nearby collieries in the Hunter Coalfield. The profiles of measured and back-predicted vertical subsidence, tilt and curvature for monitoring lines above longwalls which have width-to-depth ratios of approximately 3.0, 2.0 and 0.7 and illustrated Fig. 3.5, Fig. 3.6 and Fig. 3.7, respectively.

It can be seen from Fig. 3.4 to Fig. 3.7, that the measured profiles of vertical subsidence, tilt and curvature along these monitoring lines reasonably match those predicted using the standard IPM. There are small lateral shifts between the measured and predicted profiles, in some locations, which could be the result of surface dip, seam dip, or variations in the overburden geology.

The maximum measured vertical subsidence along the XL3-Line is similar to, but, slightly greater than the maxima predicted using the standard IPM. These slight exceedances could be partially due to the influence of the nearby Homestead and United Collieries workings (i.e. some multi-seam effects) which are located at distances varying between zero and 200 m from the monitoring line. The maximum measured vertical subsidence along the XL3-Line represents around 65 % of the extracted seam thicknesses.

The maximum measured vertical subsidence along the other three monitoring lines from the Hunter Coalfield (i.e. Fig. 3.5 to Fig. 3.7) are less than the maxima predicted using the standard IPM. The maximum measured vertical subsidence along these monitoring lines represents between 40 and 50 % of the extracted seam thicknesses.

The magnitudes of the measured tilts and curvatures along the monitoring lines are reasonably similar to those predicted using the standard IPM. It can be seen, however, that the measured tilts and curvatures are less than those predicted, in some locations, whilst the measured tilts and curvatures exceed those predicted in other locations. This demonstrates the difficulty in predicting tilts and curvatures at a point, especially at shallow depths of cover. It is important then to recognise that there is greater potential for variation between measured and predicted movements at a point, as the depth of cover decreases.

Based on these comparisons, it would appear that the standard IPM for the Hunter Coalfield provides reasonable predictions of vertical subsidence, tilt and curvature in these cases, for single-seam mining conditions, where the longwall width-to-depth ratios varied between 0.7 and 3.0. It has not been considered necessary, therefore, to provide any specific calibration of the standard model for WYLLW17 to WYLLW20 based on single-seam mining conditions.

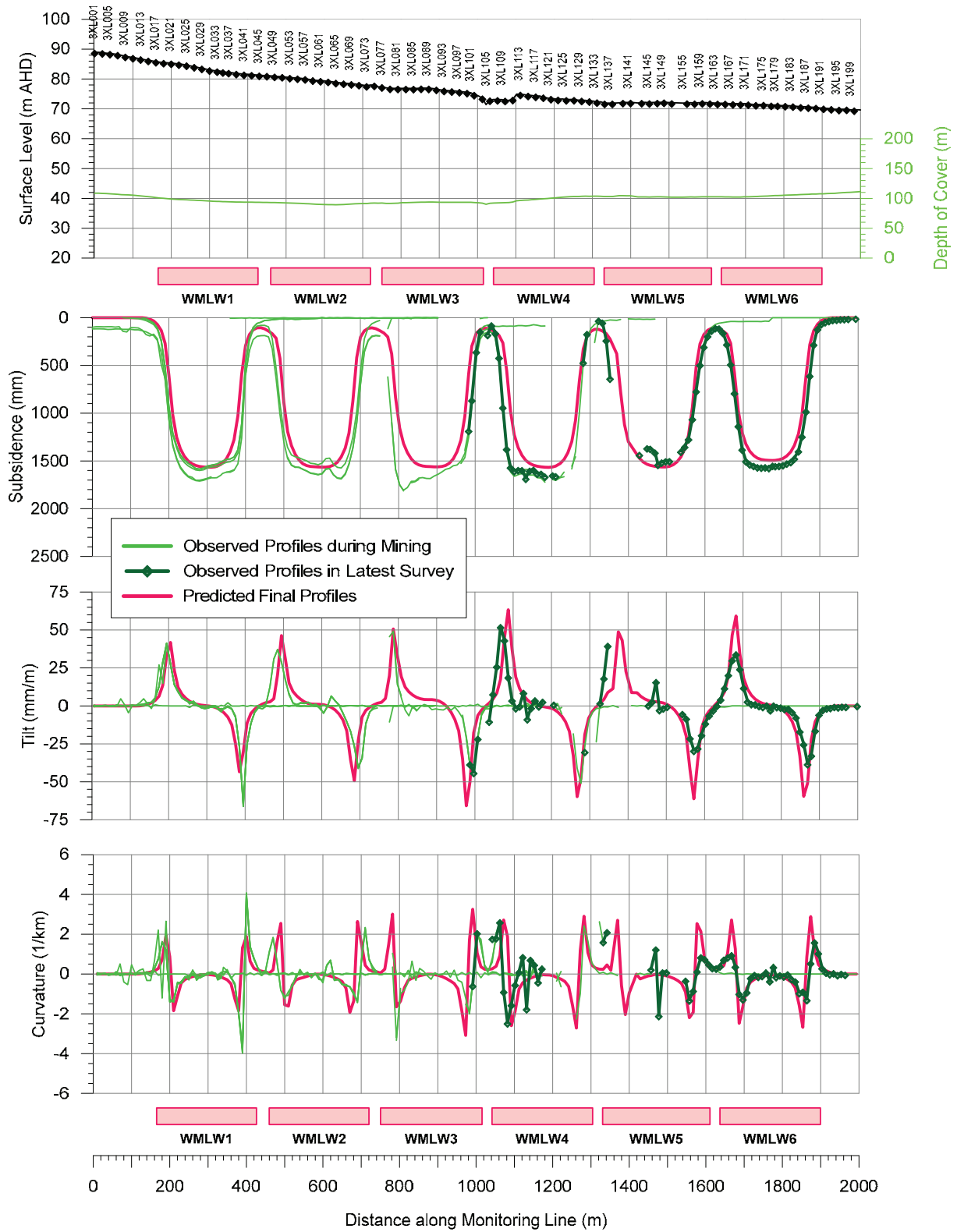


Fig. 3.4 Comparison of measured and back-predicted vertical subsidence, tilt and curvature along the XL3-Line at the North Wambo Underground Mine

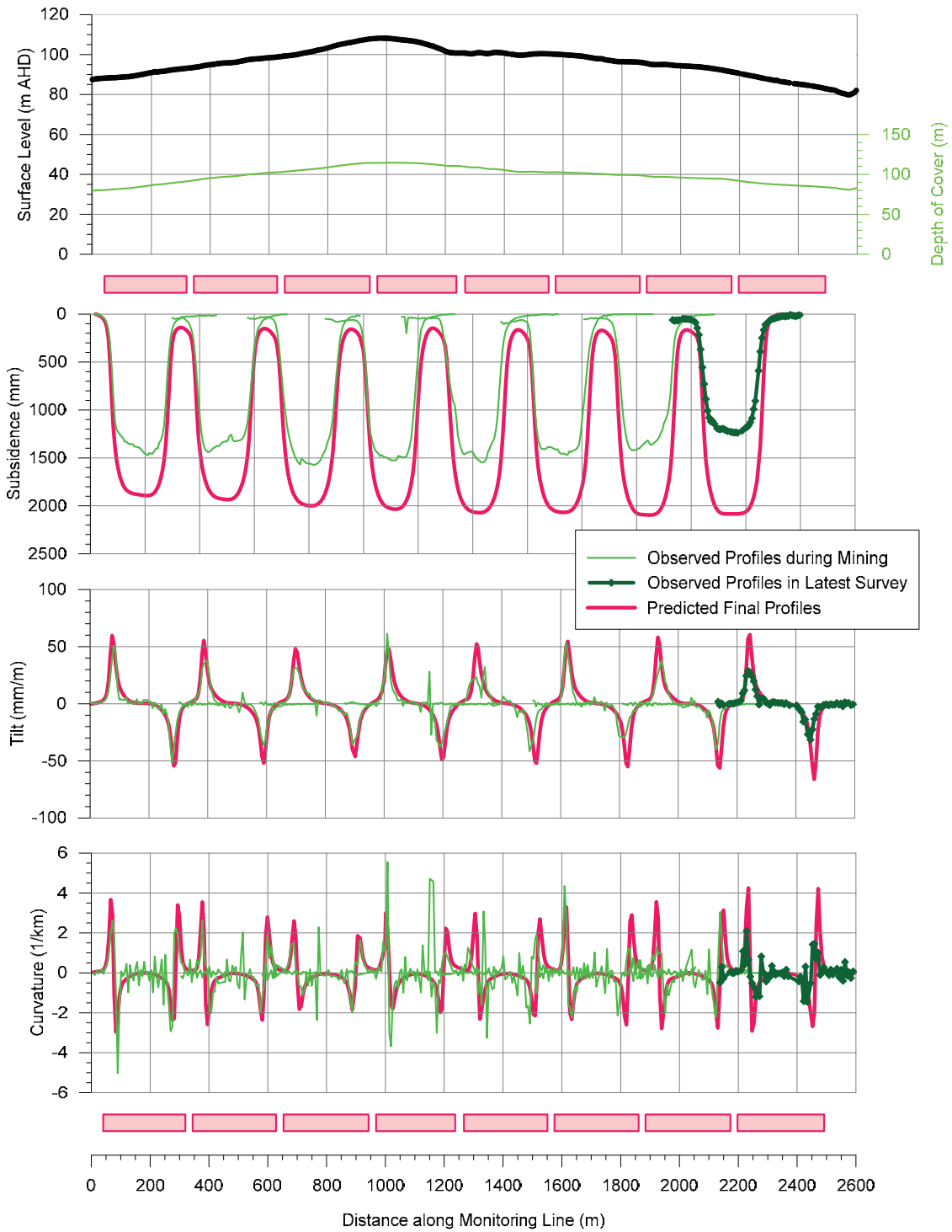


Fig. 3.5 Comparison of measured and back-predicted vertical subsidence, tilt and curvature along a monitoring line in the Hunter Coalfield with a width-to-depth ratio of 3.0

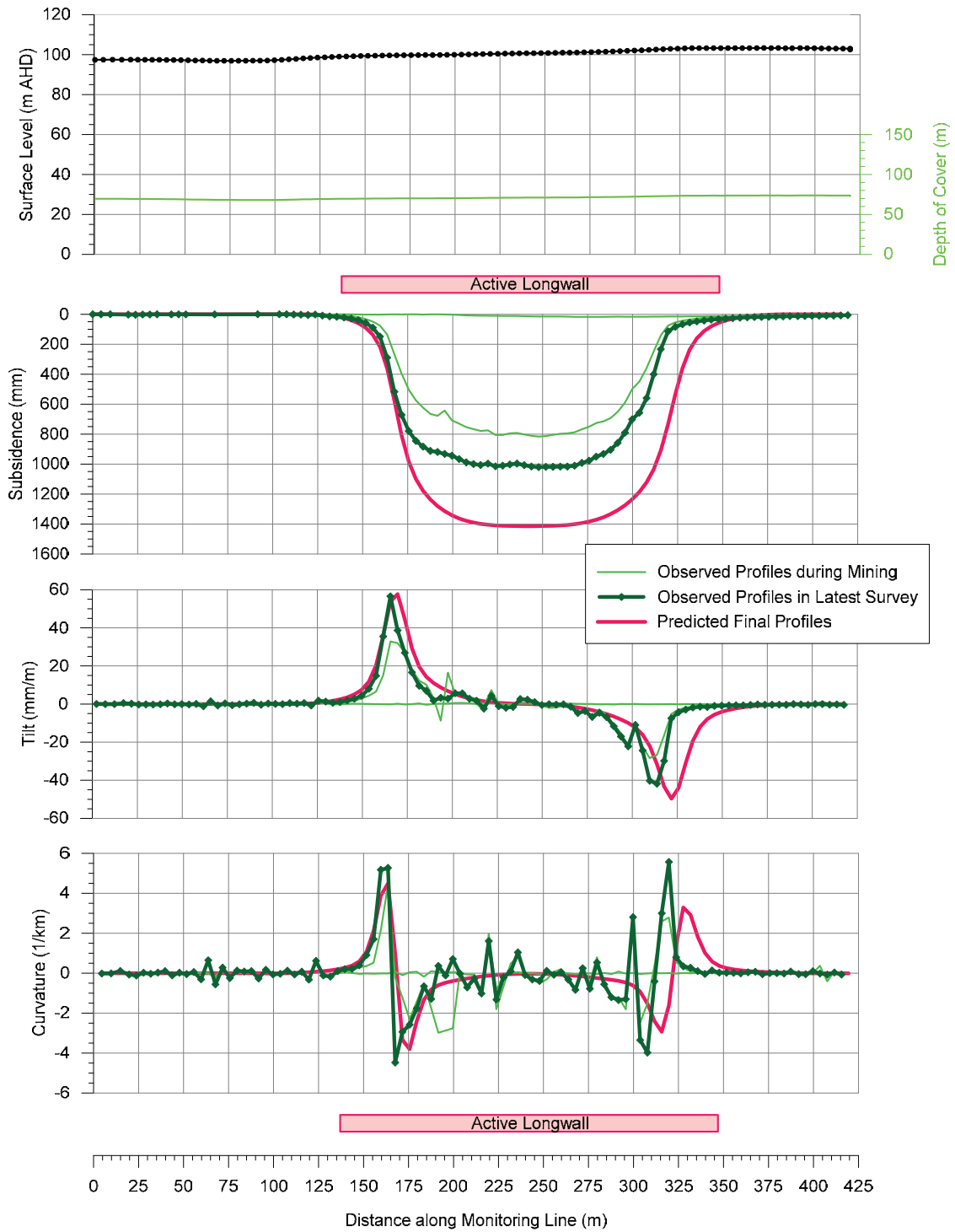


Fig. 3.6 Comparison of measured and back-predicted vertical subsidence, tilt and curvature along a monitoring line in the Hunter Coalfield with a width-to-depth ratio of 2.0

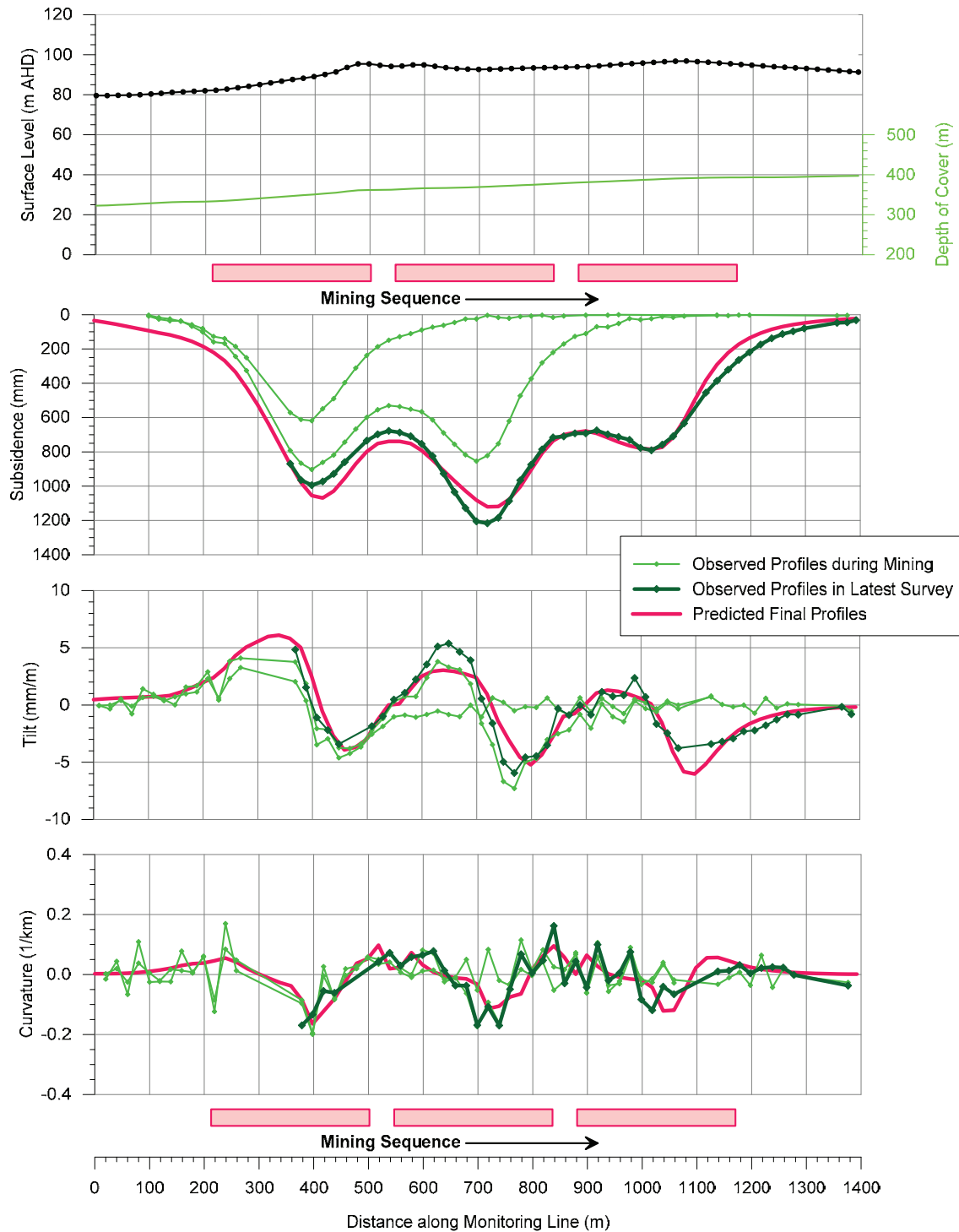


Fig. 3.7 Comparison of measured and back-predicted vertical subsidence, tilt and curvature along a monitoring line in the Hunter Coalfield with a width-to-depth ratio of 0.7

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.

The IPM has been reviewed using local monitoring data from the Wambo Coal Mine, as well as from other nearby collieries in the Hunter Coalfield. It has been found that the standard IPM for the Hunter Coalfield provides reasonable predictions for vertical subsidence, tilt and curvature based on these comparisons.

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. 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 WYLLW17 to WYLLW20 in the Whybrow Seam. The predicted subsidence parameters and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

The predicted vertical subsidence, tilt and curvature have been obtained using the standard IPM for the Hunter Coalfield, which is described in Section 3.3. The predicted strains have been determined by analysing the strains measured at the Wambo Coal Mine, and other collieries in the NSW coalfields, where the mining geometries are similar to those for WYLLW17 to WYLLW20.

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 vertical 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 resulting from the extraction of WYLLW17 to WYLLW20 are shown in Drawings Nos. MSEC935-10 to MSEC935-13. The predicted cumulative subsidence contours due to the extraction of the completed WYLLW11 to WYLLW13 and WYLLW14 and the approved WMLW15 and WMLW16 have also been shown in this drawing.

It can be seen in Drawings Nos. MSEC935-10 to MSEC935-13, that 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 this drawing, 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 Drawing No. MSEC935-06. To further illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along three prediction lines, the locations of which are shown in Drawings Nos. MSEC935-10 to MSEC935-13.

The predicted profiles of vertical subsidence, tilt and curvature along Prediction Lines 1 to 3 are shown in Figs. C.01 to C.03, respectively, in Appendix C. The predicted total profiles along the prediction lines, after the extraction of each of the longwalls, are shown as blue lines. The predicted total profiles due to the extraction of the completed and approved WYLLW11 to WYLLW13 and WMLW14 to WMLW16 are shown as the cyan lines for comparison.

A summary of the maximum predicted values of total conventional vertical subsidence, tilt and curvature along the prediction lines, resulting from the extraction of WYLLW17 to WYLLW20, is provided in Table 4.1. The maximum predicted subsidence parameters anywhere above the longwalls are also shown in this table, which occur near the finishing (i.e. north-eastern) ends of the longwalls.

Table 4.1 Maximum predicted total conventional vertical subsidence, tilt and curvature resulting from the extraction of WYLLW17 to WYLLW20

Location	Depth of cover to the Whybrow Seam (m)	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
Prediction Line 1	180 ~ 280	1800	25	0.4	0.6
Prediction Line 2	110 ~ 150	1900	45	2.5	2.5
Prediction Line 3	60 ~ 90	1900	85	> 3.0	> 3.0
Anywhere above the longwalls	50 ~ 330	1950	90	> 3.0	> 3.0

The maximum predicted total subsidence resulting from the extraction of WYLLW17 to WYLLW20 is 1950 mm, which represents 65 % of the maximum extraction height of 3.0 m. The maximum predicted subsidence occurs above the north-eastern (i.e. finishing) ends of the longwalls, where the depths of cover are the shallowest.

The maximum predicted total conventional tilt is 90 mm/m (i.e. 9 %), which represents a change in grade of 1 in 11. The maximum predicted total conventional hogging and sagging curvatures are both greater than 3.0 km⁻¹, which represents a minimum radius of curvature of less than 0.3 km. The maximum tilts and curvatures occur at the north-eastern (i.e. finishing) ends of the longwalls, where the depths of cover are the shallowest.

The maximum predicted curvatures are very localised and therefore do not necessarily represent the overall (i.e. macro) ground movements. The magnitudes of the localised curvatures greater than 3.0 km⁻¹ become less meaningful and, therefore, the specific values have not been presented.

4.3. Comparison of the maximum predicted conventional subsidence parameters

The comparison of the maximum predicted total conventional subsidence parameters for the longwalls, based on the layouts presented in the Modification Application (MSEC848) and the Extraction Plan Application (MSEC935), is provided in Table 4.2.

Table 4.2 Comparison of the maximum predicted total subsidence parameters

Layout	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
MSEC848	1950	90	> 3.0	> 3.0
MSEC935	1950	90	> 3.0	> 3.0

The maximum predicted subsidence parameters for WYLLW17 to WYLLW20, based on the Extraction Plan Layout (MSEC935), are the same as the maxima presented in Report No. MSEC848, which supported the Modification Application for WYLLW17 to WYLLW25. The predicted subsidence parameters do not change since the layout of WYLLW17 to WYLLW20 adopted in the Extraction Plan is the same as that presented in the Modification Application.

A comparison of the maximum predicted total conventional subsidence parameters for WYLLW17 to WYLLW20 with the maxima predicted for the existing and approved WYLLW11 to WYLLW13 and WMLW14 to WMLW16 is provided in Table 4.3.

Table 4.3 Comparison of the maximum predicted total subsidence parameters with those for the South Bates Underground

Layout	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
South Bates Underground (WYLLW11 to WYLLW13 and WMLW14 to WMLW16)	4150	100	> 3.0	> 3.0
South Bates Extension (WYLLW17 to WYLLW20)	1950	90	> 3.0	> 3.0

The maximum predicted total subsidence for WYLLW17 to WYLLW20 of 1950 mm is less than the maximum predicted value of 4150 mm for the existing and approved WYLLW11 to WYLLW13 and WMLW14 to WMLW16. The predicted vertical subsidence for the existing and approved longwalls at the South Bates Underground Mine is greater than that for WYLLW17 to WYLLW20 due to mining in both the Whybrow and Wambo Seams (i.e. cumulative multi-seam subsidence).

The maximum predicted tilt for WYLLW17 to WYLLW20 of 90 mm/m is slightly less than the maximum predicted tilt of 100 mm/m for the existing and approved WYLLW11 to WYLLW13 and WMLW14 to WMLW16. The predicted tilt for the longwalls is similar to that for the completed WYLLW11 to WYLLW13, i.e. due to mining in the Whybrow Seam only.

The maximum predicted total curvature is greater than 3.0 km⁻¹ for both WYLLW17 to WYLLW20 and the existing and approved WYLLW11 to WYLLW13 and WMLW14 to WMLW16. It is difficult comparing the maximum curvatures, due to their magnitudes, as they are largely governed by the very localised irregular ground movements. The overall (i.e. macro) curvatures for the longwalls are less than the overall curvatures for the approved longwalls due to the single-seam mining conditions.

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 and the depth of bedrock. Survey tolerance can also represent a substantial portion of the measured strain, in cases where the strains are of a low order of magnitude. The profiles of observed strain, therefore, can be irregular even when the profiles of observed subsidence, tilt and curvature are relatively smooth.

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 maximum 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. The maximum predicted strains, therefore, are greater than 30 mm/m above the longwall finishing ends.

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.

The range of strains above WYLW17 to WYLW20 has been determined using monitoring data from the previously extracted longwalls in the Hunter and Newcastle Coalfields, where the mining geometry is reasonably similar to those for the longwalls. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains for these 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. Distribution of strain at the longwall commencing ends

The depths of cover near the longwall commencing (i.e. south-western) ends typically vary between 200 and 330 m. The width-to-depth ratios at the longwall commencing ends, therefore, typically range between 0.8 and 1.3.

The measured ground strains have been analysed for monitoring lines from the Hunter and Newcastle Coalfields, where the longwalls width-to-depth ratios are between 0.8 and 1.3. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains above the commencing ends of WYLW17 to WYLW20.

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)* provided a good fit to the raw strain data.

The histograms of the maximum measured tensile and compressive strains for the survey bays located directly above goaf, for previously extracted longwalls in the Hunter and Newcastle Coalfields having width-to-depth ratios between 0.8 and 1.3, is provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

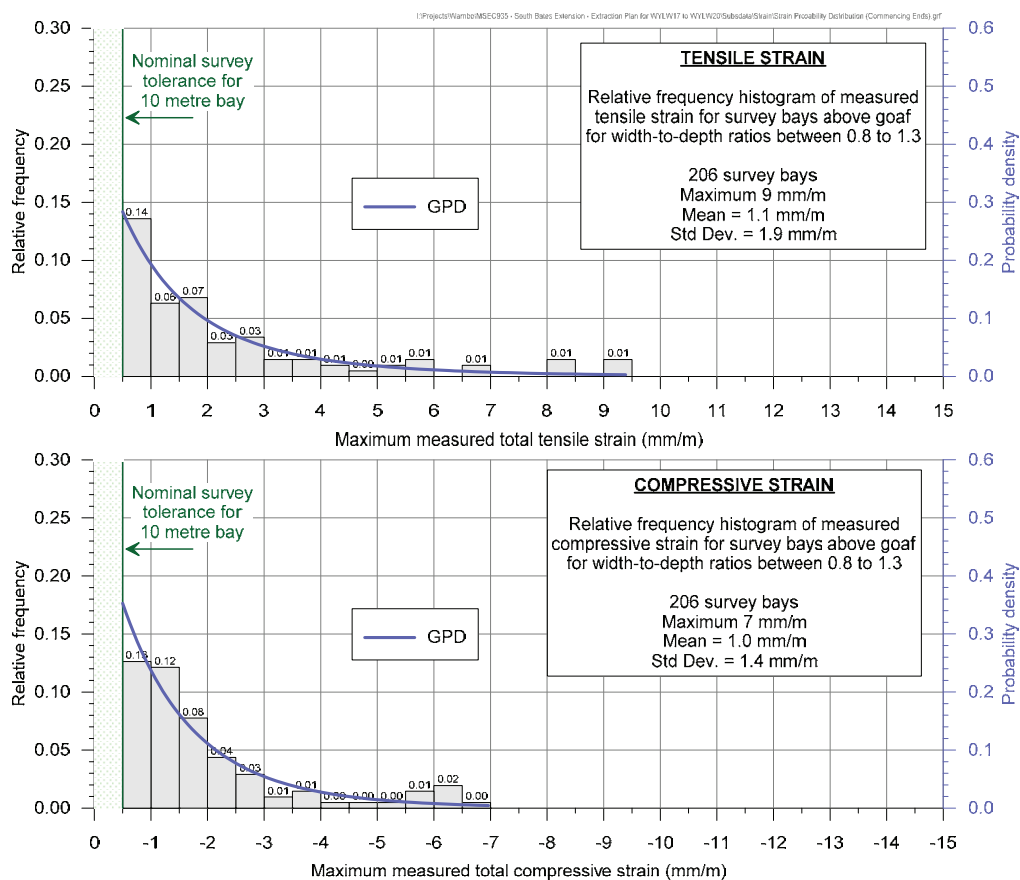


Fig. 4.1 Distributions of the measured maximum tensile and compressive strains for survey bays located above longwalls with width-to-depth ratios between 0.8 and 1.3

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 5 mm/m tensile and 4 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 10 mm/m tensile and 7 mm/m compressive.

4.4.2. Distribution of strain at the longwall finishing ends

The depths of cover near the longwall finishing (i.e. north-eastern) ends typically vary between 50 and 100 m. The longwall width-to-depth ratios near the longwall finishing ends, therefore, typically range between 2.6 and greater than 5 and, therefore, are supercritical in width.

The measured 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 are less than 100 m. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains at the finishing ends of WYLV17 to WYLV20.

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 GPD provided a good fit to the raw strain data.

The histograms of the maximum observed tensile and compressive strains measured for the survey bays located directly above goaf, for previously extracted supercritical longwalls in the Hunter and Newcastle Coalfields at depths of cover less than 100 m, is provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

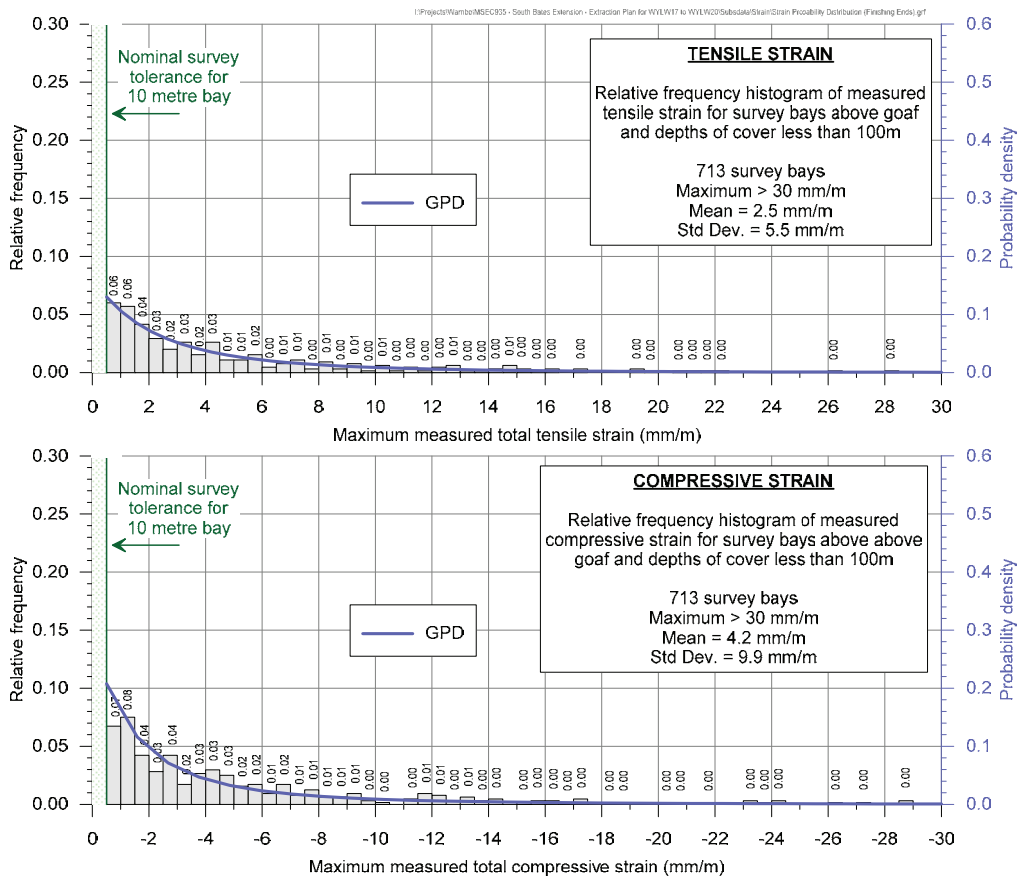


Fig. 4.2 Distributions of the measured maximum tensile and compressive strains for survey bays located above supercritical longwalls at depths of cover less than 100 m

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 12 mm/m tensile and 18 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 28 mm/m tensile and greater than 30 mm/m compressive.

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 develop as a result of mining these longwalls.

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

The observed incremental far-field horizontal movements, resulting from the extraction of a single longwall, are provided in Fig. 4.3. The confidence levels, based on fitted GPDs, have also been shown in this figure to illustrate the spread of the data.

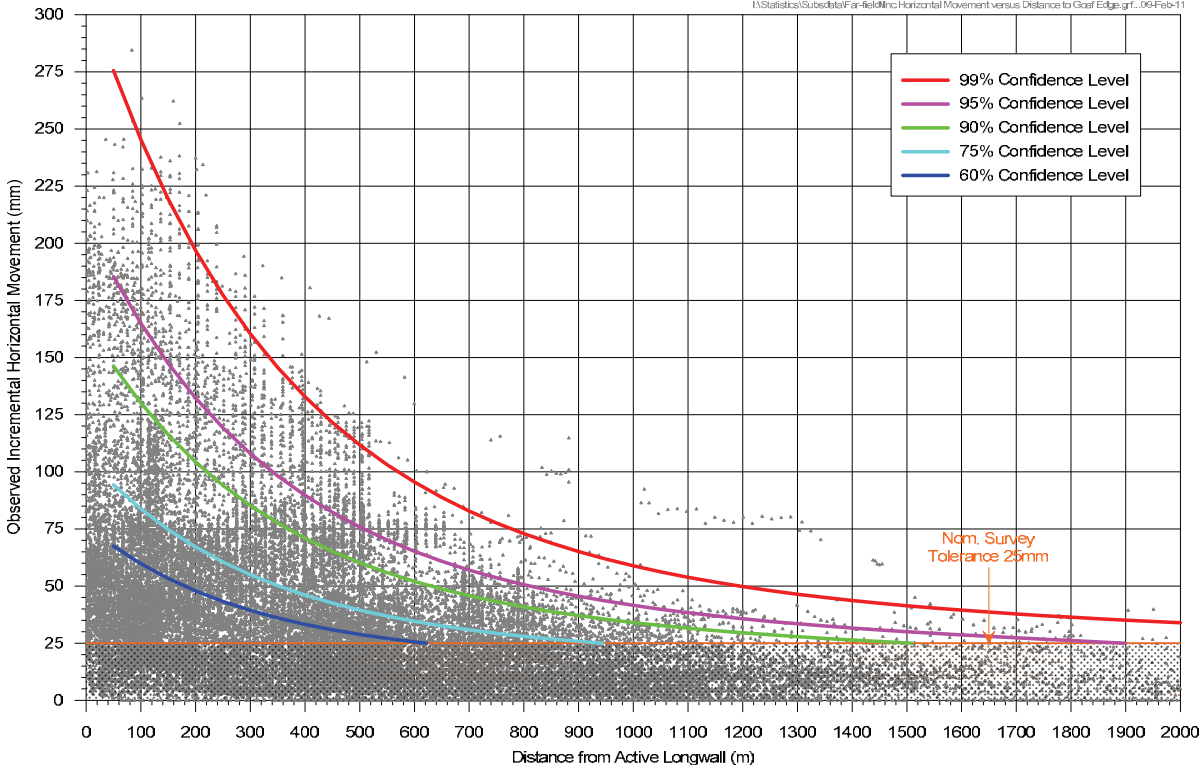


Fig. 4.3 Observed incremental far-field horizontal movements

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 Montrose Open Cut Pit is located to the north-east of the longwalls as shown in Drawing No. MSEC935-01. The open cut pit has extracted the overburden material above the Whybrow Seam. The removal of this material would have relieved and redistributed much of the horizontal in situ stress in the overburden strata adjacent to the pit. The potential for far-field horizontal movements in the vicinity of the Montrose Open Cut Pit, therefore, is reduced.

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 the mining of WYLLW17 to WYLLW20.

4.6. Non-conventional ground movements

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

The Redmanvale Fault is located south-west of the longwalls. This normal fault has strike of approximately 325° and dips towards the north-east. The dip angle of normal faults is typically in the range of 70° and 85°. The throw of the Redmanvale Fault is greater than 20 m.

The Redmanvale Fault is located at a distance varying between 590 m and 985 m from the commencing ends of WYLLW17 to WYLLW20 at seam level. At this distance, the fault is unlikely to affect the mine subsidence movements directly above the longwalls.

The surface expression of the Redmanvale Fault is located at a horizontal distance varying between 800 and 1100 m from WYLLW17 to WYLLW20. As discussed in Section 1.4, it is unlikely that measurable non-conventional movements would develop at the surface expression of this fault due to the extraction of the longwalls.

There is a series of north to south trending faults through the north-eastern ends of WYLLW17 to WYLLW20 and north-east to south-west trending faults through the south-western end of WYLLW17. These minor faults have throws up to approximately 5 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-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 tilts, curvatures or 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 many 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 surface cracks will occur behind 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 later undergoes a compressive phase, as the longwall face moves further away, and can form compressive ridges at the surface. Heaving of the surface can also occur parallel or perpendicular to the longwall due to compression near the base of the subsidence trough.

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 mining geometry (i.e. width-to-depth ratios, depths of cover and seam thicknesses) for WYLR17 to WYLR20 are similar to those for the adjacent WYLR11 to WYLR13. The surface deformations due to the extraction of the longwalls, therefore, are expected to be similar to those observed above these previously extracted longwalls.

The surface impacts were identified and recorded by the WCPL field team during the extraction of WYLR11 to WYLR13. The largest surface deformations occurred towards the finishing (i.e. north-eastern) ends of the longwalls due to the shallower depths of cover. More isolated cracking was recorded towards the commencing (i.e. south-western) ends of the longwalls due to the higher depths of cover and less accessible terrain. However, large surface cracks were observed at the tops and on the sides of the steep slopes.

The mapped locations of the surface cracking above WYLR11 to WYLR13 are shown by the blue lines in Fig. 4.4 (Source: WCPL).

The larger surface deformations predominately developed towards the finishing (i.e. north-eastern) ends of WYLR11 to WYLR13 and adjacent to and parallel to the inside of the tailgate and maingate of WYLR11. The surface crack widths were typically between 25 and 50 mm, with localised crack widths up to approximately 300 mm. Compression heaving has also developed with heights up to approximately 300 mm. Fracturing and spalling of the exposed bedrock developed within the North Wambo Creek Diversion.

Surface cracking also occurred along the spur that crosses directly above WYLR12, near the south-western end of the longwall, having widths up to approximately 400 mm. The cracking near the top and on the sides of the spur have developed due to the steep slopes that have resulted in increased horizontal movements in the downslope direction. The surface cracking reduces further down the sides of the spur, with widths generally less than 100 mm.

More isolated surface cracking developed above the central and south-western ends of WYLR11 to WYLR13. The crack widths were typically between 10 and 50 mm, with localised crack widths up to approximately 100 mm. Minor potholes were also observed along the steep slopes near the access tracks.

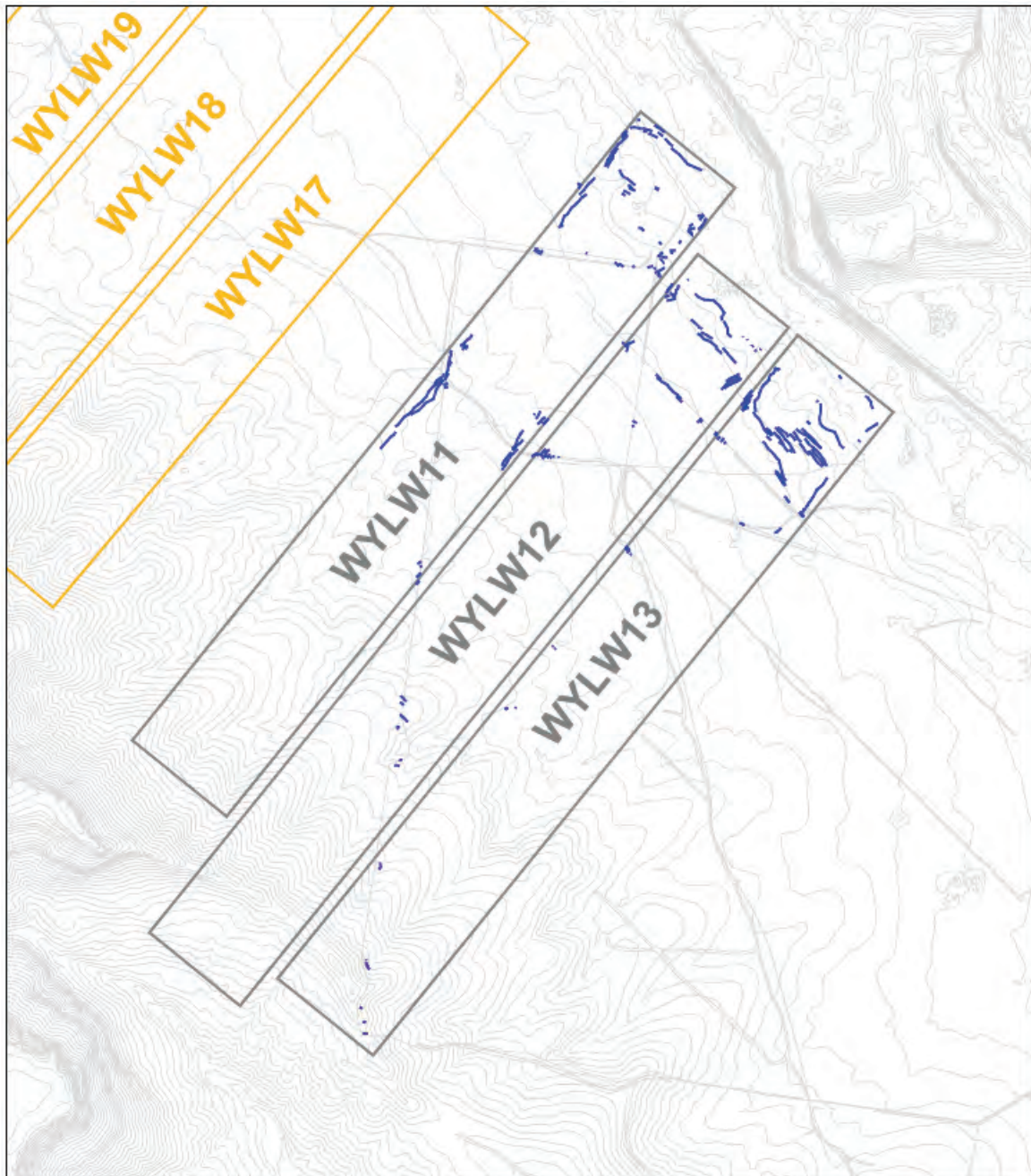


Fig. 4.4 Mapped surface cracking above WYLR11 to WYLR13

Photographs of the surface cracking and compression heaving that developed along the North Wambo Creek Diversion above the north-eastern end of WYLR11 are provided in Fig. 4.5 and Fig. 4.6. Photographs of the surface deformations that developed above central and south-western ends of WYLR12 and WYLR13 are provided in Fig. 4.7 to Fig. 4.9.



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



Fig. 4.7 Cracking along the fire trails above WYLW12 (Source: WCPL)



Fig. 4.8 Cracking and compression heaving along the tracks above WYLLW12 (Source: WCPL)



Fig. 4.9 Cracking along the access tracks above the central part of WYLLW13 (Source: WCPL)

The total length of the mapped surface cracking directly above WYLLW11 to WYLLW13 was approximately 3.9 km. The recorded crack widths (determined by the accumulated crack length) were 25 mm or less in 40 % of cases, between 25 mm and 50 mm in 54 % of cases, between 50 mm and 100 mm in 6 % of cases and greater than 200 mm in less than 1 % of cases.

It is expected, therefore, that the surface cracking above WYLLW17 to WYLLW20 would typically have widths ranging from less than 25 mm up to 50 mm, with isolated cracking with widths ranging up to approximately 400 mm. Compression heaving is expected to be in the order of 100 mm to 300 mm. The largest surface deformations are expected to occur at the north-eastern ends of WYLLW17 to WYLLW20, where the depths of cover are shallowest, and along the steep slopes elsewhere above the longwalls.

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. Sub-surface movements

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.

The following definitions have been adopted to describe the height of fracturing:

- *Caved or Collapsed Zone* comprises loose blocks of rock detached from the roof and occupying the cavity formed by mining. This zone can contain large voids. It should be noted, that some authors describe primary and secondary caving zones.

- *Disturbed or 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. It should be noted, that some authors include the secondary caving zone in this zone.
- *Constrained Zone* 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 Zone* comprises unconfined strata at the ground surface in which mining-induced tensile and compressive strains may result in the formation of surface cracking or ground heaving.

The height of disconnected or discontinuous fracturing (HoF) can extend 1 to 1.5 times the longwall width above the extracted seam. The overall void widths of WYLW17 to WYLW20 are 261 m and, therefore, the disconnected fracturing (HoF) could extend 260 to 390 m above the Whybrow Seam.

The depth of cover above the Whybrow Seam varies between a minimum of 50 m above the finishing (i.e. north-eastern) ends of WYLW19 and WYLW20 and a maximum of 330 m above the commencing (i.e. south-western) end of WYLW18. It is expected, therefore, that the disconnected or discontinuous fracturing (HoF) resulting from the extraction of the longwalls would extend up to the surface above the majority of the mining area.

It is not expected that there would be a hydraulic connection between the surface and seam over the majority of the mining area, as none was observed after the extraction of the first seven longwalls at the NWUM, which were extracted directly beneath North Wambo Creek at a depth of cover down to approximately 75 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 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* (2018). 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 *Biodiversity Conservation Act 2016*;
- 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 within the Study Area are shown in Drawing No. MSEC935-08.

The natural section of North Wambo Creek is located outside of the Study Area, at a minimum distance of 400 m to the north-west of the finishing end of WYLW20. The North Wambo Creek Diversion is located above and adjacent to the finishing ends of WYLW17 to WYLW20. The creek diversion is discussed further in Section 5.3.

Ephemeral drainage lines are also located across the Study Area. These drainage lines commence on the Wollemi Escarpment and flow in a north to north-easterly direction to where they join the North Wambo Creek Diversion. The drainage lines have shallow incisions into the natural surface soils, with some isolated bedrock outcropping along the upper reaches.

A photograph of the upper reaches of a typical drainage line in the area is provided on the left side of Fig. 5.1. The natural surface between the Wollemi Escarpment of the North Wambo Creek Diversion is also shown on the right side of this figure. The locations of these photographs are shown in Drawing No. MSEC935-08.



Fig. 5.1 Upper reaches of a typical drainage line (left side, P0689) and the natural surface between the Wollemi Escarpment of the North Wambo Creek Diversion (right side, P0723)

The natural grades of the drainage lines within the Study Area typically vary between 5 mm/m (i.e. 0.5 % or 1 in 200) near the longwall finishing ends and 100 mm/m (i.e. 10 % or 1 in 10) near the longwall commencing ends, with average natural grades of approximately 30 to 60 mm/m (i.e. 3 to 6 % or 1 in 33 to 1 in 17).

5.2.2. Predictions for the streams

The natural section of North Wambo Creek is located 400 m from WYLW20, at its closest point to the longwalls. At this distance, the creek is predicted to experience less than 20 mm vertical subsidence. It is unlikely that the natural section of North Wambo Creek would experience measurable tilts, curvatures or strains.

The predicted profiles of vertical subsidence, tilt and curvature along a typical drainage line, referred to as Drainage Line 3, are shown in Fig. C.04, in Appendix C. The predicted total profiles along the drainage line, after the extraction of each of the longwalls, are shown as blue lines. The location of the drainage line is shown in Drawing No. MSEC935-08.

A summary of the maximum predicted total subsidence, tilt and curvature for Drainage Line 3, after the extraction of each of the longwalls, is provided in Table 5.1. The values are the maxima for the natural section of the creek located within the Study Area.

Table 5.1 Maximum predicted total vertical subsidence, tilts and curvatures for Drainage Line 3

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
Drainage Line 3	After WYLW17	1850	40	2.0	1.5
	After WYLW18	1950	40	2.0	1.5
	After WYLW19	1950	40	2.0	1.5
	After WYLW20	1950	40	2.0	1.5

The maximum predicted conventional strains for Drainage Line 3, based on applying a factor of 10 to the maximum predicted curvatures, are greater than 30 mm/m tensile and compressive. The predicted strains for the drainage line based on the 95 % confidence levels (refer to Section 4.4) are: 5 mm/m tensile and 4 mm/m compressive near the commencing ends of WYLW18 and WYLW19; and 12 mm/m tensile and 18 mm/m compressive near the finishing end of WYLW17.

The remaining 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.

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 sections of the drainage lines located directly above the longwalls have shallow incisions into the natural surface soils. The predicted valley related effects for the drainage lines, therefore, are not significant when compared with the predicted conventional movements.

5.2.3. Comparison of the predictions for the streams

The comparison of the maximum predicted total conventional subsidence parameters for the natural section of North Wambo Creek, based on the layouts presented in the Modification Application (MSEC848) and the Extraction Plan Application (MSEC935), is provided in Table 5.2.

Table 5.2 Maximum predicted total vertical subsidence, tilts and curvatures for natural section of North Wambo Creek

Layout	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
MSEC848	1950	80	> 3.0	> 3.0
MSEC935	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted subsidence parameters for the natural section of North Wambo Creek, based on the Extraction Plan Layout (i.e. MSEC935), are less than those presented in the Modification Application and Report No. MSEC848. The creek is located directly above the future WYLLW23 to WYLLW25, which are included in the Modification Application and, therefore, it was expected to experience the full range of predicted subsidence movements from these future longwalls. The natural section of North Wambo Creek is located well outside the extents of WYLLW17 to WYLLW20, considered in the Extraction Plan Application and, therefore, it is predicted to experience less than 20 mm vertical subsidence due to WYLLW17 to WYLLW20.

The maximum predicted subsidence parameters for the drainage lines, due to the extraction of WYLLW17 to WYLLW20, are the same as those presented in the Modification Application and Report No. MSEC848. The predicted subsidence parameters for WYLLW17 to WYLLW20 do not change since the layout of these longwalls has not changed.

The assessments of the ground movements for the streams due to the mining of WYLLW21 to WYLLW25 will be considered in future Extraction Plan Applications.

5.2.4. Impact assessments and recommendations for the streams

The natural section of North Wambo Creek is located outside of the Study Area, at a minimum distance of 400 m to the north-west of the finishing end of WYLLW20. At this distance, the creek is not predicted to experience measurable conventional tilts, curvature or strains. It is unlikely, therefore, that the North Wambo Creek would experience adverse impacts due to the extraction of WYLLW17 to WYLLW20. The impact assessments for North Wambo Creek Diversion are provided in Section 5.3.

Ephemeral drainage lines are located directly above the longwalls. The assessed impacts for the drainage lines are the same as those presented in the Modification Application and Report No. MSEC848. The impact assessments for the drainage lines located within the Study Area are provided in the following sections.

Potential for increased levels of ponding, flooding and scouring

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

The natural and the predicted post-mining surface levels and grades along Drainage Line 3 are illustrated in Fig. 5.2. The location of the drainage line is shown in Drawing No. MSEC935-08. The final profiles shown in the figures below are after the completion of WYLV17 to WYLV20.

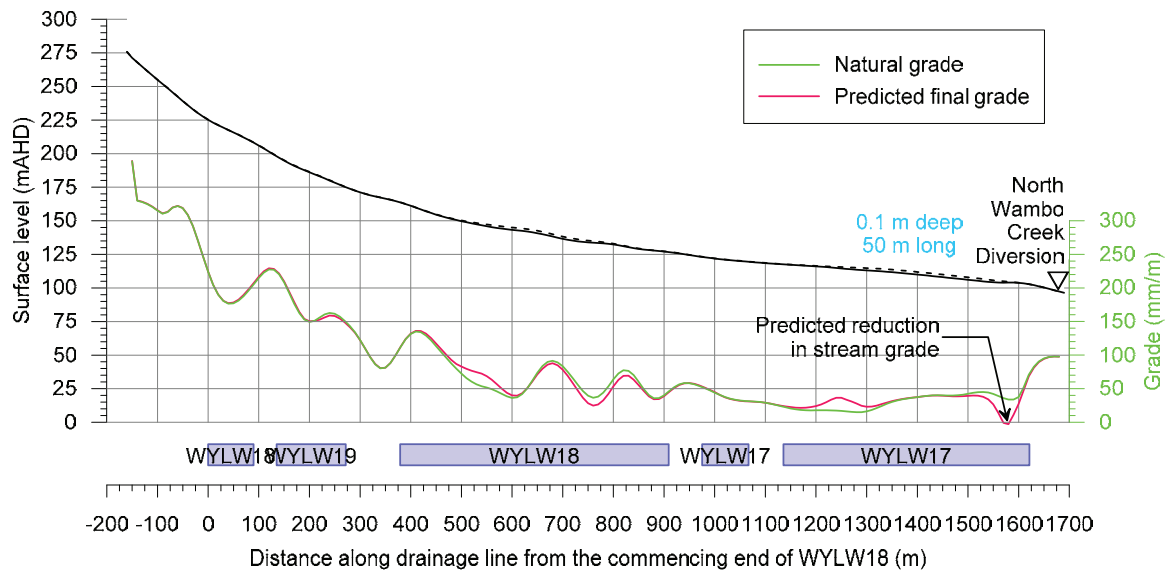


Fig. 5.2 Natural and predicted subsided surface levels and grades along Drainage Line 3

There is a predicted reduction in stream grade along Drainage Line 3 upstream of where it crosses the tailgate of WYLV17. The ponding area is predicted to be approximately 0.1 m deep and 50 m long. Similar ponding areas could also occur where other drainage lines cross the chain pillars and edges of the longwalls. Larger ponding areas are also predicted to develop above the finishing ends of the longwalls, as described in Section 5.9, having depths up to 1.2 m and surface areas up to 0.8 hectares (ha).

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

Potential for cracking in the stream beds and fracturing of bedrock

It is expected that fracturing of the topmost bedrock would develop along the sections of the drainage lines located directly above the longwalls. The drainage lines within the Study Area have shallow incisions into the natural surface soils. Cracking in the beds of the drainage lines would be visible at the surface where the depths of the surface soils are shallow, or where the bedrock is exposed.

The mining-induced compression can also result in dilation and the development of bed separation in the topmost bedrock. The dilation is expected to develop predominately within the top 10 to 20 m of the bedrock. Compression can also result in buckling of the topmost bedrock resulting in heaving in the overlying surface soils.

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

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

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

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

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

Management strategies have previously been developed for the sections of the drainage lines that have already been directly mined beneath at the Wambo Coal Mine as a component of the WCPL Site Water Management Plan.

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 Drawings Nos. MSEC935-08 and MSEC935-09.

North Wambo Creek has been diverted around the active open cut pit. The North Wambo Creek Diversion is generally located outside of the longwalls, with short sections crossing above the finishing end of WYLW17. The natural section of the creek is located at a minimum distance of 400 m from the commencing end of WYLW20, at its closest point to the longwalls.

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. There are some isolated locations with exposed bedrock along its alignment. Photographs of the North Wambo Creek Diversion are provided in Fig. 5.3. The locations of these photographs are shown in Drawing No. MSEC935-08.



Fig. 5.3 Photographs of the North Wambo Creek Diversion (P0756 and P0767)

The impacts observed along the North Wambo Creek Diversion due to the extraction of WYLW11 to WYLW13 are discussed in Section 4.7.

5.3.2. Predictions for the North Wambo Creek Diversion

The predicted profiles of vertical subsidence, tilt and curvature along the North Wambo Creek Diversion are shown in Fig. C.05, in Appendix C. The predicted total profiles along the creek diversion, after the extraction of each of the longwalls, are shown as blue lines. The predicted total profiles due to the extraction of the completed and approved WYLR11 to WYLR13 and WMLR14 to WMLR16 are shown as the cyan lines.

A summary of the maximum predicted total vertical subsidence, tilt and curvature for North Wambo Creek Diversion is provided in Table 5.3. The values are the maxima for the section of the creek diversion located within the Study Area.

Table 5.3 Maximum predicted total vertical subsidence, tilts and curvatures for the North Wambo Creek Diversion resulting from the extraction of WYLR17 to WYLR20

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
North Wambo Creek Diversion	After WYLR17	300	25	> 3.0	< 0.01
	After WYLR20	300	25	> 3.0	< 0.01

The maximum predicted conventional strains for the North Wambo Creek Diversion, based on applying a factor of 10 to the maximum predicted curvatures, are greater than 30 mm/m tensile and less than 1 mm/m compressive. The creek diversion is typically located outside of the extents of the longwalls and, therefore, these predicted strains are only applicable for the sections of the diversion located directly above WYLR17, having a total length of approximately 150 m.

The predicted strains for the sections of the North Wambo Creek Diversion located outside of the longwalls has been determined from the analysis of 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 100 m.

The histograms of the maximum observed tensile and compressive strains measured for the survey bays located outside but within 100 m of the longwalls (i.e. above solid coal) is provided in Fig. 5.4. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

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 2 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 greater than 5 mm/m tensile and 7 mm/m compressive.

The North Wambo Creek Diversion is 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.

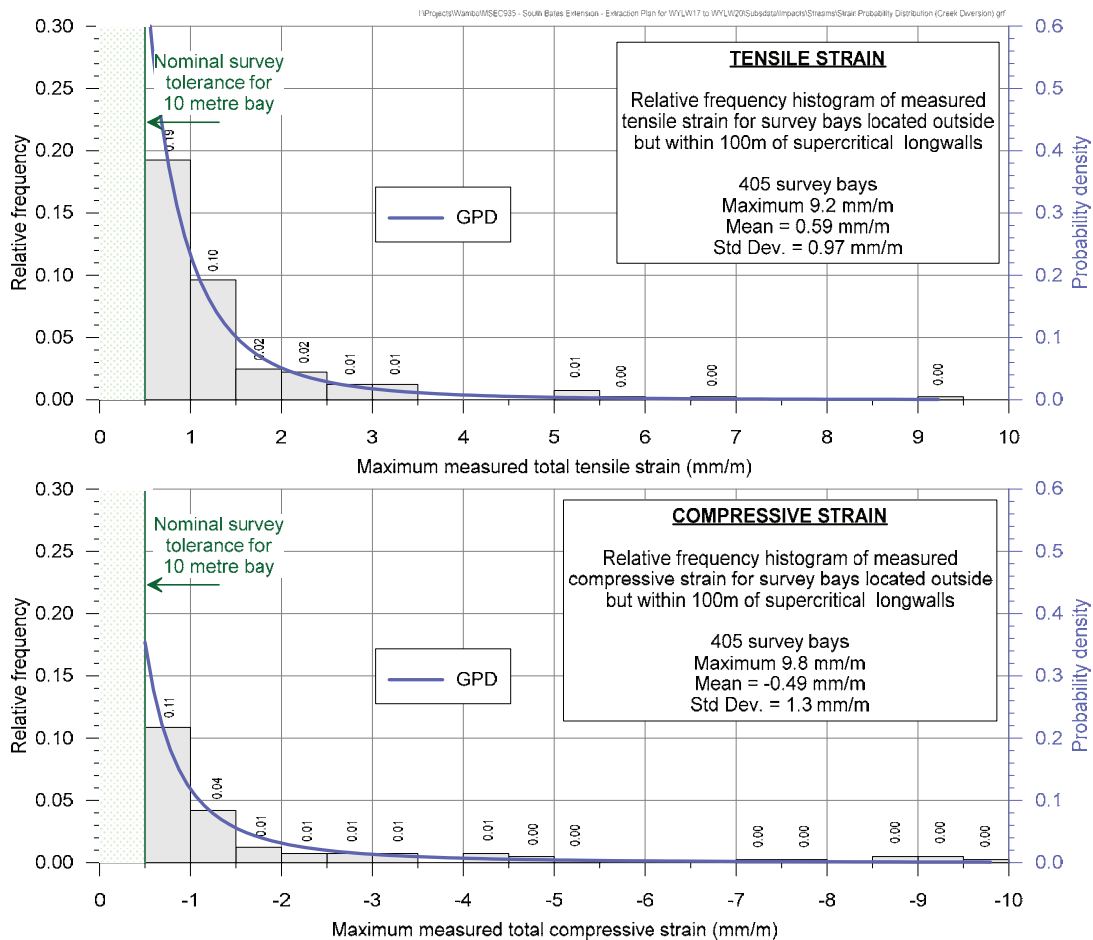


Fig. 5.4 Distributions of the measured maximum tensile and compressive strains for survey bays located outside but within 100 m of supercritical longwalls

5.3.3. Comparisons of the predictions for North Wambo Creek Diversion

The maximum predicted subsidence parameters for the North Wambo Creek Diversion, due to the extraction of WYLW17 to WYLW20, are the same as those presented in the Modification Application and Report No. MSEC848. The predicted subsidence parameters for WYLW17 to WYLW20 do not change since the layout of these longwalls has not changed.

5.3.4. Impact assessments for the North Wambo Creek Diversion

The assessed impacts for the North Wambo Creek Diversion are the same as those presented in the Modification Application and Report No. MSEC848. The impact assessments for the creek diversion due to the extraction of WYLW17 to WYLW20 are provided below.

The North Wambo Creek Diversion is generally located outside of the longwalls, with short sections crossing above the finishing end of WYLW17. The natural and the predicted post-mining surface levels and grades along the creek diversion are illustrated in Fig. 5.5. The final profiles are after the extraction of all longwalls.

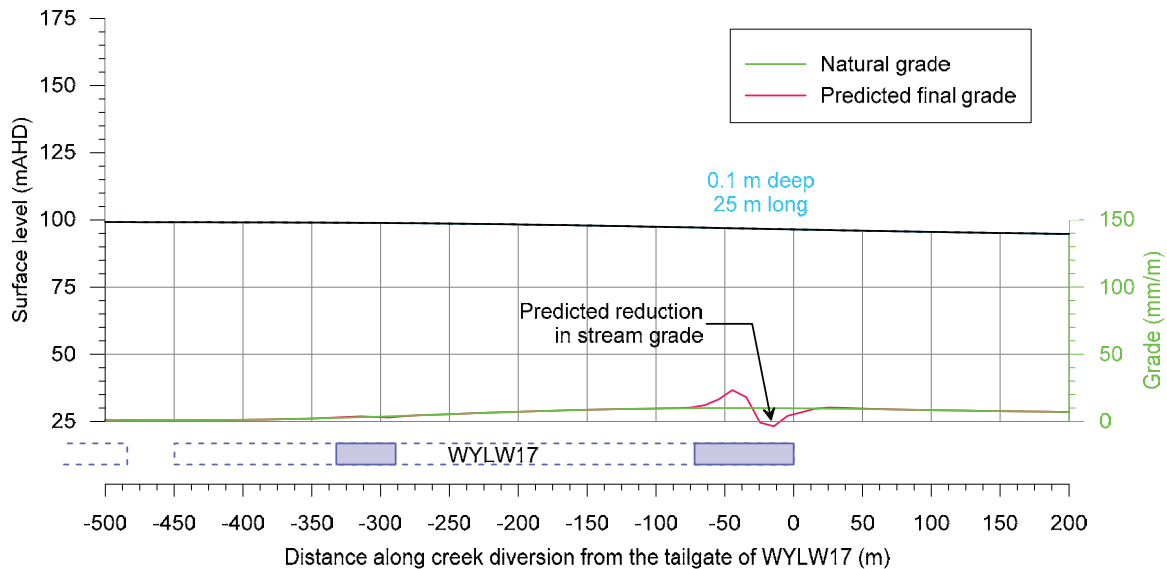


Fig. 5.5 Natural and predicted subsided surface levels and grades along the Creek Diversion

It is possible that minor increased ponding could develop along the North Wambo Creek Diversion where it crosses above WYLLW17. The topographical depression is predicted to have a maximum depth of approximately 0.1 m and an overall length of approximately 25 m.

The North Wambo Creek Diversion only partially extends above WYLLW17. Whilst the maximum predicted vertical subsidence is only 300 mm, the creek diversion extends across the tensile zone located above the longwall finishing end. Surface cracking could develop along the section of the North Wambo Creek Diversion located directly above WYLLW17, similar to that observed above WYLLW11 to WYLLW13 (refer to Section 4.7).

Minor cracking could also develop along the section of the North Wambo Creek Diversion located outside the extents of the longwalls. It is expected that, outside the mining area, the crack widths would be typically less than 25 mm.

The depth of cover along the alignment of the North Wambo Creek Diversion, directly above WYLLW17, varies between 50 and 70 m. It is likely, therefore, that fracturing would occur from the seam 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 is remediated during active subsidence, which could include infilling with cohesive materials and by regrading and recompacting the surface soils.

Management strategies have previously been developed for the sections of the North Wambo Creek Diversion that have already been directly mined beneath at the Wambo Coal Mine as a component of the WCPL Site Water Management Plan.

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 (HydroSimulations, 2017) prepared for the Modification Application and in the Groundwater Review (HydroSimulations, 2018) prepared for the Extraction Plan Application.

There are no *Ground Water Management Areas*, as defined by the Department of Primary Industry, Crown Lands and Water Division, within the Study Area. There were no registered groundwater bores identified within the Study Area. WCPL owns two monitoring bores (Refs. GW200831 and GW200832) which are located approximately 0.7 km north-west of the longwalls.

5.5. Escarpments

The *Wollemi Escarpment* is located to the south and to the 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 cliffs and minor cliffs, 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 on 21st July 2016, 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. MSEC935-08.

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	<i>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 (>63.4°)</i>
Minor Cliff	<i>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 (>63.4°); or a rock face having a maximum length of 20 metres and a minimum height of 10 metres”</i>

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 WYLW17 to WYLW20 are shown in Drawing No. MSEC935-08. The cliffs have also been shown in more detail in Fig. 5.6.

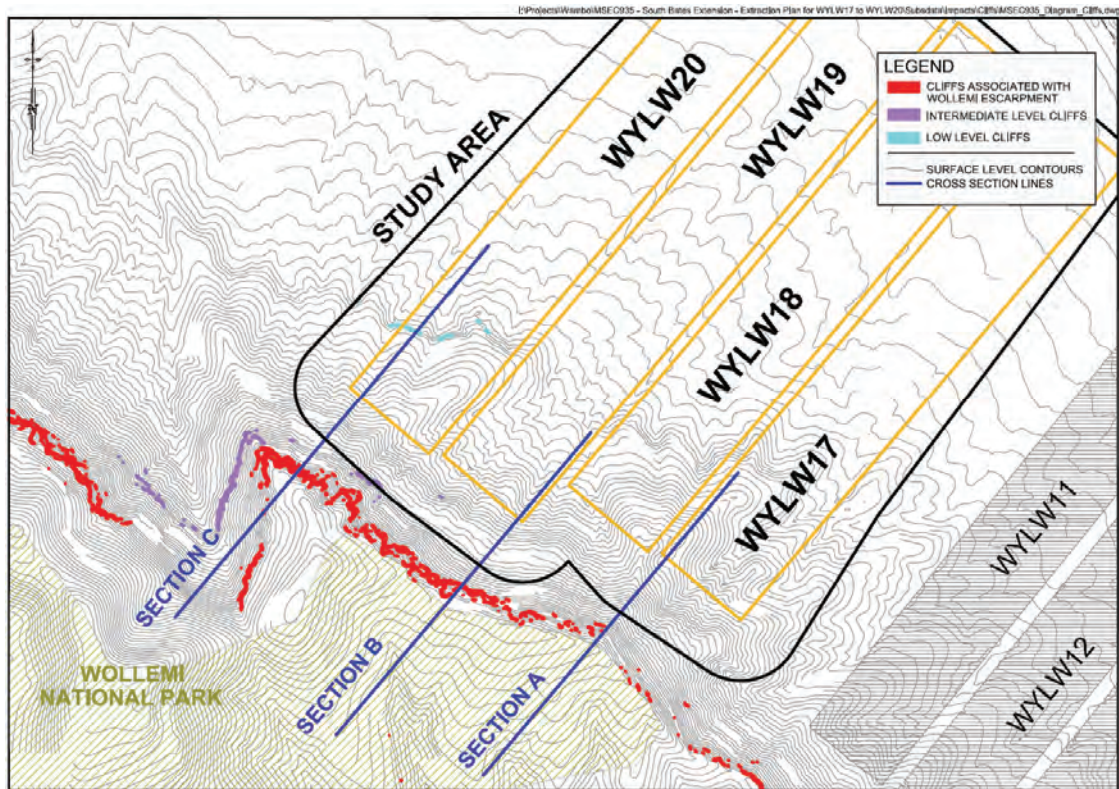


Fig. 5.6 Cliffs located adjacent to the commencing ends of WYLLW17 to WYLLW20

The cliffs have been categorised into three groups:

- *Cliffs Associated with the Wollemi Escarpment* (red hatch in Fig. 5.6) – are the higher-level cliffs located along the boundary of the Wollemi National Park to the south-west of the longwalls. These higher-level cliffs outcrop at one or two horizons each having overall heights ranging between 10 and 40 m. The cliff lines are discontinuous and are separated with sections of minor cliffs and rock outcrops;
- *Intermediate Level Cliffs* (purple hatch in Fig. 5.6) – are located part way down the steep slopes beneath the Wollemi Escarpment to the south-west of the longwalls. These cliffs have not been considered part of the Wollemi Escarpment. The intermediate level cliffs have heights varying between 10 and 20 m and continuous lengths up to approximately 50 m; and
- *Low Level Cliffs* (cyan hatch in Fig. 5.6) – are located near the bottom of the steep slopes above the south-western ends of the longwalls. The larger Low Level Cliffs are located above WYLLW20 having heights varying between 10 and 15 m and continuous lengths up to approximately 50 m. These cliffs are discontinuous and are separated with sections of minor cliffs and rock outcrops.

A summary of the distances of the cliffs from WYLLW17 to WYLLW20 is provided in Table 5.4. The values represent the horizontal distances between the longwalls and points directly beneath the cliffs at seam level.

Table 5.4 Minimum distances between the longwalls and the cliffs

Cliffs	Longwall	Minimum distance from the longwalls (m)
Cliffs Associated with the Wollemi Escarpment	WYLLW17	230
	WYLLW18	220
	WYLLW19	200
	WYLLW20	190
Intermediate Level Cliffs	WYLLW20	140
Low Level Cliffs	WYLLW20	Directly above longwall

Sections A to C have been taken through the south-western ends of the longwalls, showing the relative locations of the cliffs, in Fig. 5.7 to Fig. 5.9. The locations of these sections are shown in Fig. 5.6.

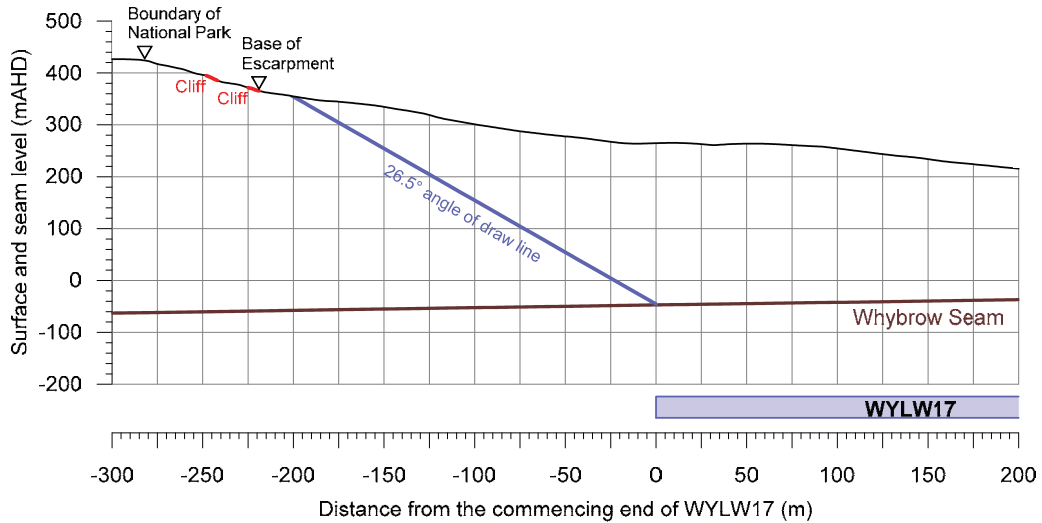


Fig. 5.7 Section A through the Wollemi Escarpment and the commencing end of WYLR17

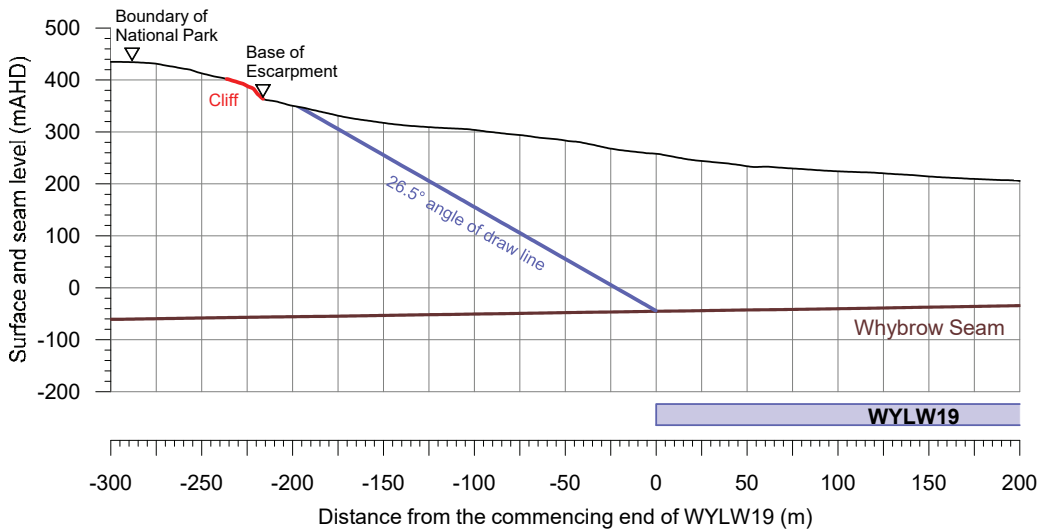


Fig. 5.8 Section B through the Wollemi Escarpment and the commencing end of WYLR19

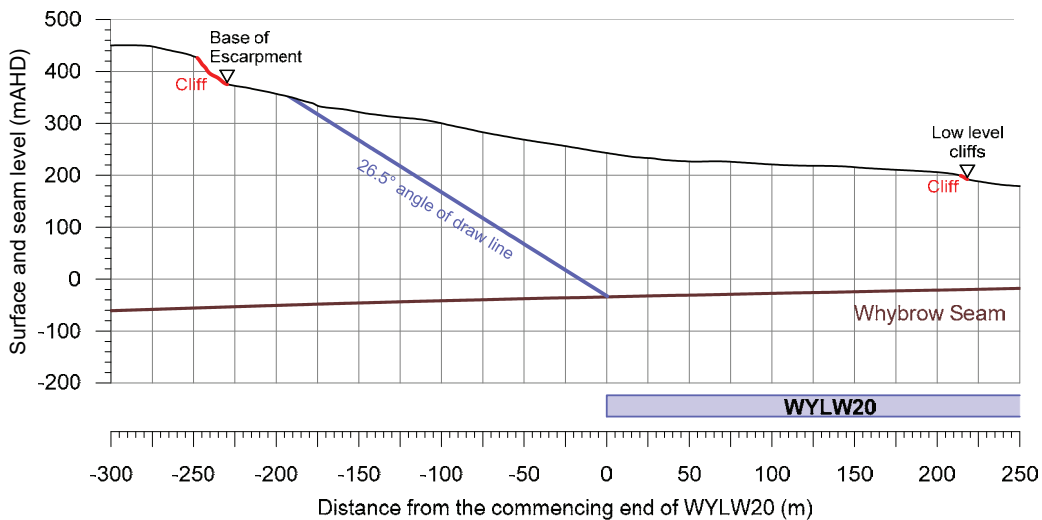


Fig. 5.9 Section C through the Wollemi Escarpment and the commencing end of WYLR20

The Cliffs Associated with the Wollemi Escarpment are located outside of the 26.5° angle of draw line from WYLW17 to WYLW20. It is noted, that the Study Area differs from the 26.5° angle of draw line, 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 surface elevation to the south-west of the longwalls. In any case, the Cliffs Associated with the Wollemi Escarpment have been included in the impact assessments provided in this report.

The cliffs, minor cliffs and rock outcrops have formed from the Widden Brook Conglomerate of the Narrabeen Group, as can be seen in Fig. 1.7. Photographs of the Cliffs Associated with the Wollemi Escarpment are provided in Fig. 5.10 and Fig. 5.11. The locations of these photographs are shown in Drawing No. MSEC935-08.



Fig. 5.10 Overall view of cliffs located to the south-west and further to the west of the longwalls (P2846 and P2847)



Fig. 5.11 Cliffs located to the south-west and further to the west of WYLW19 and WYLW20 (P2929, P2930 and P2927)

5.6.2. Predictions for the cliffs

A summary of the maximum predicted total vertical subsidence, tilts and curvatures for the cliffs is provided in Table 5.5. The values are the maximum predicted parameters within 20 m of their mapped extents.

Table 5.5 Maximum predicted total vertical subsidence, tilts and curvatures for the cliffs

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
Cliffs Associated with the Wollemi Escarpment	< 20	< 0.5	< 0.01	< 0.01
Intermediate Level Cliffs	30	0.5	< 0.01	< 0.01
Low Level Cliffs	1750	25	0.7	0.7

The Cliffs Associated with the Wollemi Escarpment are predicted to experience less than 20 mm vertical subsidence and the Intermediate Level Cliffs are predicted to experience up to 30 mm vertical subsidence. Whilst these cliffs could experience low-level vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

These higher-level cliffs could experience far-field horizontal movements. There is no 3D ground monitoring data available at the NWUM along the steep slopes beneath the Wollemi Escarpment. The predicted far-field horizontal movements, therefore, have been based on the observations at Dendrobium Mine, which has similar or shallower depths of cover and similar natural surface gradients.

Twelve 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 undulating to incised 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. 5.12.

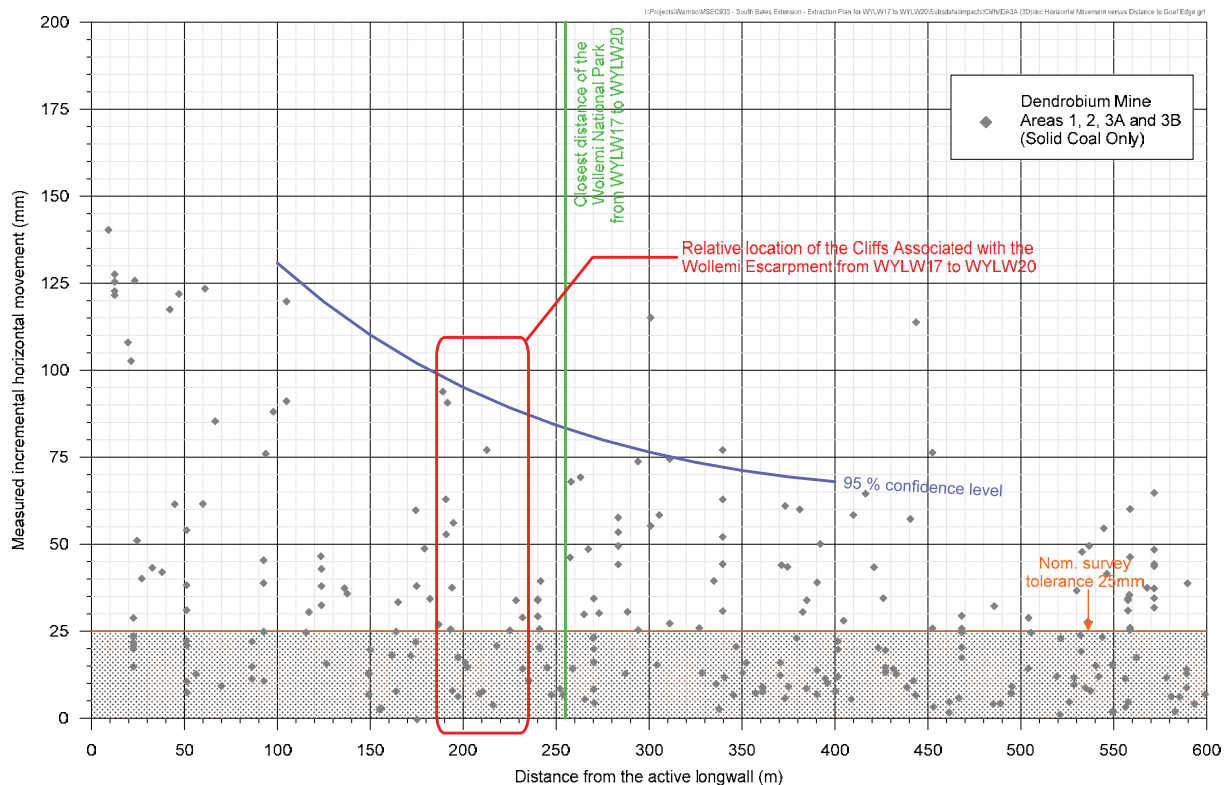


Fig. 5.12 Measured 3D horizontal movements in Areas 1, 2, 3A and 3B at Dendrobium Mine

It can be seen from Fig. 5.12, that the survey marks located above solid coal at Dendrobium Mine experience incremental horizontal movements up to around 90 mm at similar distances as the Cliffs Associated with the Wollemi Escarpment from WYLLW17 to WYLLW20. The predicted far-field horizontal movements for these cliffs based on the 95 % confidence level is 100 mm. 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.

The Low Level Cliffs located directly above WYLLW20 are predicted to experience tilts up to 25 mm/m (i.e. 2.5 % or 1 in 40). The maximum predicted curvatures for these cliffs are 0.7 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 1.4 km.

The maximum predicted conventional strains for the Low Level Cliffs, based on applying a factor of 10 to the maximum predicted curvatures, are 7 mm/m tensile and compressive. The analysis of strain measured above previously extracted longwalls in the Hunter and Newcastle Coalfields having similar width-to-depth ratios as the south-western ends of WYLLW17 to WYLLW20 is provided in Section 4.4.1. The 95 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 5 mm/m tensile and 4 mm/m 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.

5.6.3. Comparisons of the predictions for the cliffs

The maximum predicted subsidence parameters for the cliffs, due to the extraction of WYLLW17 to WYLLW20, are the same as those presented in the Modification Application and Report No. MSEC848. The predicted subsidence parameters for WYLLW17 to WYLLW20 do not change since the layout of these longwalls has not changed.

5.6.4. Impact assessments for the cliffs associated with the Wollemi Escarpment and the intermediate level cliffs

The assessed impacts for the cliffs are the same as those presented in the Modification Application and Report No. MSEC848. The impact assessments for the cliffs due to the extraction of WYLLW17 to WYLLW20 are provided below.

The predicted vertical subsidence for the Cliffs Associated with the Wollemi Escarpment are less than 20 mm and the Intermediate Level Cliffs are up to 30 mm. Whilst these cliffs could experience very low-levels of vertical subsidence, they are unlikely to experience measurable conventional tilts, curvatures or strains, even if the predicted vertical subsidence was exceeded by a factor of 2 times.

The higher-level cliffs could also experience far-field horizontal movements of up to approximately 100 mm based on the 95 % confidence level. These movements are expected to be bodily movements towards the extracted longwalls and are not expected to be associated with any measurable strains. It is unlikely, therefore, that the Cliffs Associated with the Wollemi Escarpment and the Intermediate Level Cliffs would be adversely impacted by the far-field horizontal movements, even if these predictions were exceeded by a factor of 2 times.

WYLLW11 to WYLLW13 and WMLW14 at the South Bates Underground Mine were extracted adjacent to the Wollemi Escarpment to the south-east of the Study Area. A section through the commencing end of WYLLW12 and the escarpment, where the completed longwalls are located closest to the cliffs, is provided in Fig. 5.13.

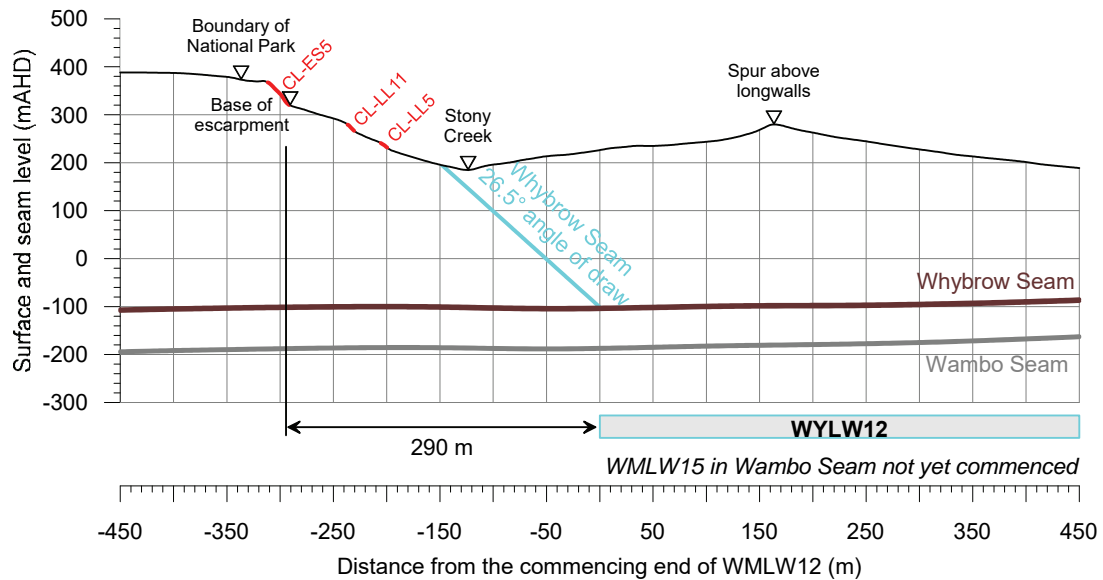


Fig. 5.13 Cross-section through the Wollemi Escarpment and WYLW12

The Cliffs Associated with the Wollemi Escarpment are located at a minimum distance of 290 m from these completed WYLW11 to WYLW13 and WMLW14. There were no adverse impacts observed due to the extraction of these longwalls.

The existing Wollemi/Homestead workings in the Whybrow Seam were also extracted adjacent to the Wollemi Escarpment to the south-east of the Study Area. An east-west cross-section through Homestead Longwall 13 and the escarpment is provided in Fig. 5.14.

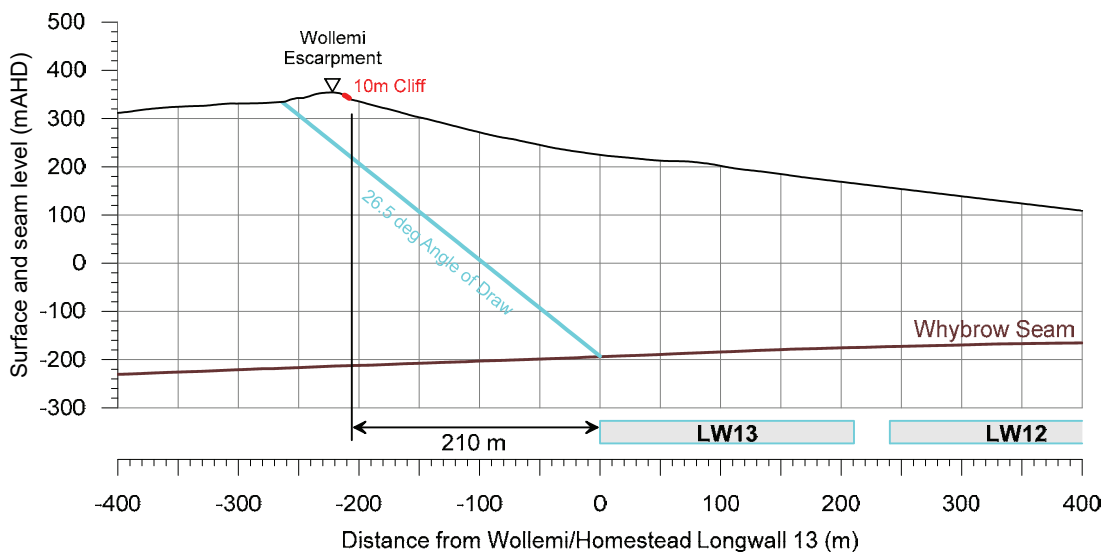


Fig. 5.14 Cross-section through the Wollemi Escarpment and the Homestead Workings

The 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 adverse impacts on the Cliffs Associated with the Wollemi Escarpment or the Intermediate Level Cliffs resulting from the extraction of WYLW17 to WYLW20.

It is recommended that monitoring of the Cliffs Associated with the Wollemi Escarpment is carried out during active subsidence. Periodic visual monitoring can be carried out from the fire trails beneath the cliffs. It is also recommended that Unmanned Aerial Vehicle (UAV) monitoring is carried out after the completion of each longwall.

It is difficult establishing ground monitoring lines at the commencing ends of the longwalls due to the steep slopes and heavy vegetation beneath the escarpment. Consideration should be given to the use of Global Navigation Satellite System (GNSS) points near the top of the cliff line. These points can provide continuous measurements of vertical subsidence and absolute horizontal movement due to mining. The locations of these points would need to be determined based on access and available reception.

5.6.5. Impact assessments for the Low Level Cliffs

The Low Level Cliffs are located directly above the south-western end of WYLW20. These cliffs are predicted to experience up to 1750 mm vertical subsidence, 25 mm/m tilt (i.e. 2.5 %, or 1 in 40) and 0.7 km^{-1} curvature (i.e. a minimum radius of curvature of 1.4 km).

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. 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 the Low Level Cliffs have been assessed based on the experience at Dendrobium Mine, as the maximum predicted subsidence parameters are similar orders of magnitude. Longwalls 1 and 2 at Dendrobium Mine 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. The maximum predicted conventional curvatures due to 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 width of disturbance resulting from the extraction of Dendrobium Longwalls 1 and 2 was approximately 135 to 175 m. The total plan length of ridgeline located directly above the longwalls was between approximately 1800 to 2000 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 width of ridgeline disturbed as a result of the extraction of Dendrobium 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 width of rockfalls which occurred as a result of the extraction of Longwalls 1 and 2, however, was less than the width of disturbed ridgeline.

Based on this case study, it has been estimated that approximately 7 to 10 % of the total length, or approximately 3 to 5 % of the total face area, of the Low Level Cliffs located directly above the longwalls could be impacted. The total length of the Low Level Cliffs located above or immediately adjacent to the longwalls is approximately 150 m based on the LiDAR surface level contours. This equates to a length of disturbance of approximately 15 m, or a face area of disturbance of approximately 100 m^2 . This represents a very small percentage (i.e. less than 1 %) of the total length and face area of the cliffs located within and immediately adjacent to the Study Area.

It is recommended that the Low Level Cliffs are periodically visually inspected during and after the extraction of WYLW20 directly beneath them.

5.7. Pagodas

There are no pagoda complexes identified within the Study Area. There are isolated pagodas associated with the Wollemi Escarpment that are located outside of the longwalls. The pagodas have formed from the Widden Brook Conglomerate and have heights typically up to around 3 to 5 m.

The pagodas are predicted to typically experience vertical subsidence less than 20 mm. Whilst the pagodas could experience very low-levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains. It is unlikely, therefore, that the isolated pagodas would experience adverse impacts as a result of the extraction of WYLW17 to WYLW20.

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 18.3°) and 2 in 1 (200% or 63.4°)”. The locations of the 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 above the commencing (i.e. south-western) ends of WYLW17 to WYLW20. These steep slopes extend up to the Wollemi Escarpment which is located outside the 26.5° angle of draw line from the longwalls. The natural surface gradients directly above the longwalls typically range from less than 1 in 3 and up to 1 in 2. The slopes are locally steeper at the base of the Low Level Cliffs, above the longwalls, with gradients up to approximately 1 in 1.5.

The natural slopes along Cross-section C through the commencing end of WYLW20 are illustrated in Fig. 5.15. The location of this cross-section is shown in Fig. 5.6.

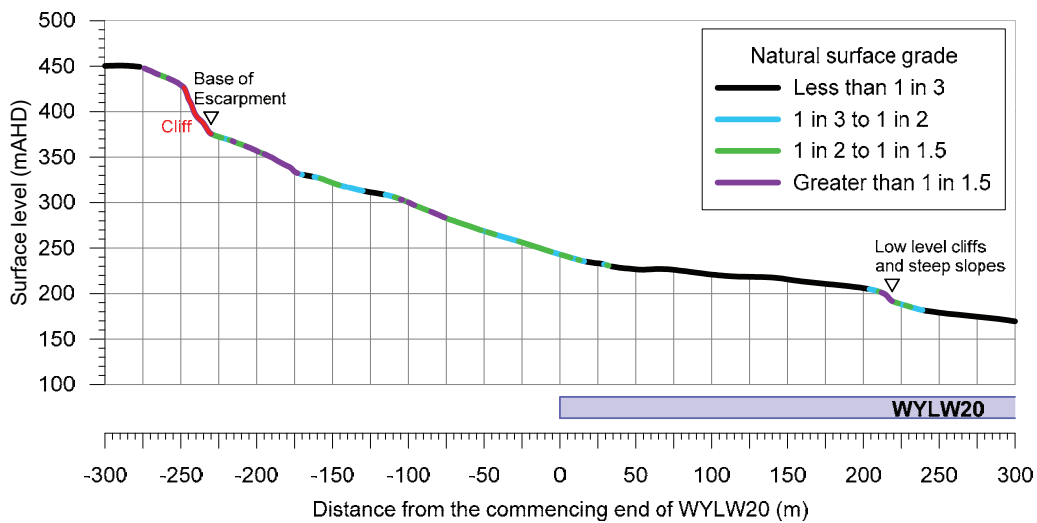


Fig. 5.15 Section C through the steep slopes and the commencing end of WYLW20

The surface soils along the steep slopes above the commencing ends of the longwalls are generally derived from the Widden Brook Conglomerate (Rna), as can be inferred from Fig. 1.7. The slopes are stabilised by natural vegetation, which can be seen in Fig. 1.1.

There are also isolated steep slopes elsewhere above the longwalls which are generally associated with the banks of the drainage lines and the North Wambo Creek Diversion.

5.8.2. Predictions for the steep slopes

A summary of the maximum predicted total subsidence, tilts and curvatures for the steep slopes is provided in Table 5.6.

Table 5.6 Maximum predicted total vertical subsidence, tilts and curvatures for the steep slopes

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
Steep Slopes	1950	25	0.8	0.8

The steep slopes are predicted to experience tilts up to 25 mm/m (i.e. 2.5 % or 1 in 40). The maximum predicted curvatures for the steep slopes are 0.8 km⁻¹ hogging and sagging, which represents a minimum radius of curvature of 1.2 km.

The maximum predicted conventional strains for the steep slopes, based on applying a factor of 10 to the maximum predicted curvatures, are 8 mm/m tensile and compressive. The analysis of strain measured above previously extracted longwalls in the Hunter and Newcastle Coalfields having similar width-to-depth ratios as the south-western ends of the longwalls is provided in Section 4.4.1. The 95 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 5 mm/m tensile and 4 mm/m 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

The comparison of the maximum predicted total conventional subsidence parameters for the steep slopes, based on the layouts presented in the Modification Application (MSEC848) and the Extraction Plan Application (MSEC935), is provided in Table 5.7.

Table 5.7 Comparison of the maximum predicted total vertical subsidence, tilts and curvatures for the steep slopes

Layout	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
MSEC848	1950	30	1.0	1.0
MSEC935	1950	25	0.8	0.8

The maximum predicted tilt and curvatures for the steep slopes, due to the extraction of WYLLW17 to WYLLW20, are less than those presented in the Modification Application and Report No. MSEC848. The predicted subsidence parameters for the steep slopes above WYLLW17 to WYLLW20 are slightly less, as the maximum predicted values presented in Report MSEC848 for the steep slopes located above the subsequent longwalls in the series, i.e. above the future WYLLW21 to WYLLW25.

5.8.4. Impact assessments for the steep slopes

The assessed impacts for the steep slopes are similar to those presented in the Modification Application and Report No. MSEC848. The potential impacts slightly reduce due to the lower predicted maximum tilts, curvatures and strains and due to the smaller mining area based on the first four longwalls in the series only. The impact assessments for the steep slopes due to the extraction of WYLLW17 to WYLLW20 are provided below.

The maximum predicted tilt for these steep slopes of 25 mm/m (i.e. 2.5 % or 1 in 40) 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 movement of the natural surface in the downslope direction, resulting in tension cracks appearing at the tops and on the sides of the steep slopes and compression ridges forming at the bottoms of the steep slopes.

The maximum predicted total curvatures for the steep slopes above the longwalls are 0.8 km⁻¹ hogging and sagging, which represents a minimum radius of curvature of 1.2 km. The predicted curvatures and strains for the steep slopes are similar orders of magnitude to those predicted for the steep slopes located directly above the completed WYLLW11 to WYLLW13 at the South Bates Underground Mine.

As described in Section 4.7, surface cracking occurred along the spur that crosses directly above WYLLW12, near the south-western end of the longwall, having widths up to approximately 400 mm. The cracking near the top and on the sides of the spur have developed due to the steep slopes that have resulted in increased horizontal movements in the downslope direction. The surface cracking reduces further down the sides of the spur, with widths generally less than 100 mm.

Photographs of the surface deformations that developed above the central and south-western ends of WYLLW12 and WYLLW13 are provided in Fig. 4.7 to Fig. 4.9.

The predicted curvatures and strains for the steep slopes within the Study Area are also similar orders of magnitude to those predicted for Dendrobium Longwalls 1 and 2, which mined directly beneath a ridgeline with similar surface grades. 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.

It is expected, therefore, that downslope movement of the ground would also occur along steep slopes that are located directly above the south-western ends of WYLV17 to WYLV20. 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 the longwalls, it is possible that soil erosion could occur if these cracks were left untreated.

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

5.9. Land prone to flooding or inundation

The land within the Study Area generally falls in a north-easterly direction from the Wollemi Escarpment to the North Wambo Creek Diversion. The natural surface level contours (grey lines) and the predicted post-mining surface level contours (green lines) above WYLV17 to WYLV20 are illustrated in Fig. 5.16. The alignment of North Wambo Creek and the creek diversion is shown as the blue line in this figure.

The predicted extents of the predicted mining-induced topographical depressions are also illustrated in Fig. 5.16, as the cyan hatching, based on the predicted post mining surface level contours. The actual extents and depths of increased ponding in these locations are dependent on a number of other factors, including rainfall, catchment sizes, surface water runoff, infiltration and evaporation and, therefore, these are expected to be smaller than the topographical depressions.

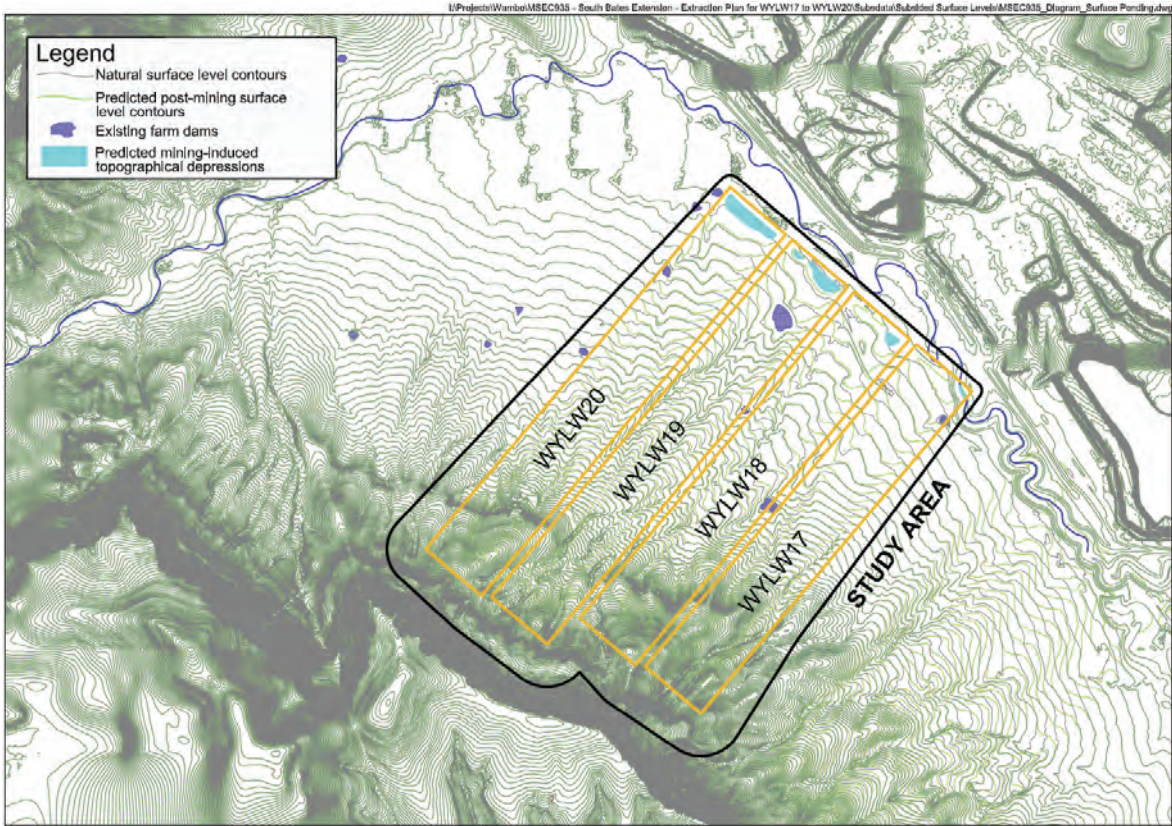


Fig. 5.16 Natural and predicted subsided surface levels and predicted mining-induced topographical depressions

It can be seen from Fig. 5.16, that mining-induced topographical depressions are predicted to develop above the finishing (i.e. north-eastern) ends of WYLLW17 to WYLLW20, as indicated by the cyan hatching. Localised topographical depressions are also predicted to develop along the alignments of the drainage lines upstream of where they cross the finishing ends of the longwalls.

The topographical depressions above the finishing ends of WYLLW17 and WYLLW20 are predicted to have maximum depths ranging between 0.4 and 1.2 m and surface areas ranging from less than 0.1 ha up to 0.8 ha. The actual extents and depths of increased ponding in these locations are expected to be less than the predicted topographical depressions due to the various other factors described previously. The increased ponding along the alignment of a typical drainage line is discussed further in Section 5.2.3.

There are no predicted topographical depressions (i.e. areas of increased ponding) away from the finishing ends of the longwalls, apart from the isolated locations along the drainage lines. It is not considered, therefore, that the land across the Study Area is naturally susceptible to flooding or inundation. Further detail is provided in the report prepared by *Alluvium Consulting* (2018).

5.10. Water related ecosystems

There are no water related ecosystems associated with the drainage lines located within the Study Area (FloraSearch, 2017).

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* (2017) and *Eco Logical Australia* (2017).

Monitoring and management of flora and fauna at the Wambo Coal Mine is undertaken in accordance with the site-wide Biodiversity Management Plan.

5.12. National Parks or Wilderness Areas

The *Wollemi National Park* is located to the south and to the west of WYLLW17 to WYLLW20. A summary of the distances of the National Park from the longwalls is provided in Table 5.8. The values represent the horizontal distances between the longwalls and points directly beneath the boundary of the National Park at seam level.

Table 5.8 Minimum distances between the longwalls and the National Park

Location	Longwall	Minimum distance from the longwalls (m)
Wollemi National Park	WYLLW17	280
	WYLLW18	265
	WYLLW19	255
	WYLLW20	275

The boundary of the National Park is located at a minimum distance of 255 m from the commencing (i.e. south-western) end of WYLLW19. The location of the National Park is shown in Drawings Nos. MSEC935-01 and MSEC935-08. Whilst the Wollemi National Park is located outside the Study Area, it has been included in the impact assessments provided in this report.

The land within the National Park is predicted to experience less than 20 mm vertical subsidence resulting from the extraction of WYLLW17 to WYLLW20, i.e. the boundary is located outside of the limit of vertical subsidence. The magnitude of the predicted vertical subsidence is similar to the natural movements that occur due to the wetting and drying of the surface soils. Whilst the National Park could experience very low-levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains.

The Wollemi National Park could experience low-level far-field horizontal movements. It can be seen from Fig. 5.12, that the National Park could experience far-field horizontal movements up to 85 mm, based on the 95 % confidence level. These movements are expected to be bodily movements towards the extracted longwalls and are not expected to be associated with any measurable strains.

It is unlikely, therefore, that the Wollemi 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 maximum predicted subsidence parameters for the Wollemi National Park, due to the extraction of WYLLW17 to WYLLW20, are the same as those presented in the Modification Application and Report No. MSEC848. The predicted subsidence parameters for WYLLW17 to WYLLW20 do not change since the layout of these longwalls has not changed.

The drainage lines within the National Park are typically located at distances greater than 400 m from WYLLW17 to WYLLW20. The upper reaches of some drainage lines (total length of less than 0.2 km) are located at distances slightly less than 400 m from the commencing ends of 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 located above the south-western ends of the longwalls, as can be seen from the aerial photograph in Fig. 1.1. The land has been largely cleared above the north-eastern ends of the longwalls. A detailed survey of the natural vegetation has been undertaken and is described and assessed in the report prepared by *FloraSearch* (2017).

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

There are unsealed tracks and fire trails located within the Study Area. The locations of these roads are shown in Drawing No. MSEC935-09. The unsealed roads are used for the mining operations and 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 mining area and, therefore, could experience the full range of predicted subsidence movements. A summary of the maximum predicted mine subsidence parameters within the Study Area 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.

The maximum predicted subsidence parameters for the unsealed roads, due to the extraction of WYLV17 to WYLV20, are the same as those presented in the Modification Application and Report No. MSEC848. The assessed impacts for the road, therefore, are the same as those presented in the Modification Application and Report No. MSEC848.

It is expected that cracking, rippling and stepping 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. Examples of impacts observed along the tracks located above WYLV11 to WYLV13 are provided in Fig. 4.7 to Fig. 4.9. The crack widths above these longwalls typically varied between 25 and 50 mm and were greater than 300 mm in some locations.

The impacts on the unsealed tracks and fire trails due to the longwalls are expected to be similar to that observed due to the extraction of WYLV11 to WYLV13 and WMLW14. 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 that are located above the previously extracted longwalls at the Wambo Coal Mine. It is expected that these same strategies could be used to maintain the unsealed roads which are located directly above WYLV17 to WYLV20. It is recommended that these roads are periodically visually inspected during active subsidence.

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. The land above the north-eastern ends of the longwalls has been cleared and is used for light grazing. There are also some farm features located within the Study Area, which are described in the following sections.

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. Farm dams

There are eight farm dams that have been identified within the Study Area and their locations are shown in Drawing No. MSEC935-09. The discussions on the future Montrose Water Storage Dam are provided in Section 6.4.3.

The farm dams are typically of earthen construction and have been established by localised cut and fill operations within the natural drainage lines. The surface areas of the dams vary between 300 and 5000 m² and the maximum lengths vary between 22 and 92 m. The largest dam (Ref. d04) is located near the finishing (i.e. north-eastern) end of WYLLW19.

A summary of the maximum predicted total vertical subsidence, tilts and curvatures for the farm dams within the Study Area is provided in Table 6.1. The values are the maximum predicted parameters within 20 m of the perimeters of the dams.

Table 6.1 Maximum predicted total vertical subsidence, tilts and curvatures for the farm dams

Location	Ref.	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
Farm dams	d01	1500	70	> 3.0	> 3.0
	d02	1100	35	1.5	1.0
	d03	500	35	> 3.0	1.0
	d04	1800	20	> 3.0	> 3.0
	d05	300	60	> 3.0	> 3.0
	d06	50	0.5	0.01	< 0.01
	d07	1600	70	> 3.0	> 3.0
	d08	150	10	0.5	0.2

The maximum predicted conventional strains for the farm dams, based on applying a factor of 10 to the maximum predicted curvatures, vary from less than 0.5 mm/m and greater than 30 mm/m tensile and compressive.

The farm dams are generally located between the longwall finishing ends and the mid-lengths of the longwalls. The depths of cover in the locations of these dams vary between 55 and 135 m. The distribution of strain therefore is similar to but slightly less than that predicted above the longwall finishing ends, as described in Section 4.4.2. The predicted strains for the farm dams based on the 95 % confidence levels are 12 mm/m tensile and 17 mm/m 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.

The maximum predicted subsidence parameters for Dams d01 to d04, due to the extraction of WYWL17 to WYWL20, are the same as those presented in the Modification Application and Report No. MSEC848. The predicted parameters do not change for these farm dams as they are located directly above the longwalls.

The maximum predicted tilt for Dam d07 slightly reduces from 70 mm/m to 65 mm/m. The predicted vertical subsidence, tilt and curvature for Dams d05, d06 and d08 also reduce from those presented in the Modification Application and Report No. MSEC848. The predicted subsidence parameters are less for these dams, as they are located above or outside the maingate of WYWL20 and, therefore, they have not yet experienced the additional subsidence from the future WYWL21 to WYWL25.

The predicted final tilts for the farm dams vary up to 70 mm/m (i.e. 7 % or 1 in 14). Mining-induced tilts can affect the water levels around the perimeters of farm dams, with the freeboard increasing on one side and decreasing on the other. The predicted final changes in freeboard for the farm dams vary from less than 0.1 m to 0.6 m. The predicted changes in freeboard are similar to or less than those presented in the Modification Application and Report No. MSEC848.

The greatest predicted change in freeboard of 0.6 m occurs at Dam d07 located adjacent to the maingate of WYWL20. The direction of the final tilt in the location of this dam is transverse to the longwalls (i.e. NW-SE) and, therefore, is orientated parallel to the dam wall. The predicted changes in freeboard for the remaining dams are all less than 0.5 m. It is unlikely, therefore, that the predicted tilts would adversely impact on the water storage capacities of the farm dams.

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

It is recommended that consideration is given to dewatering the larger farm dams prior to active subsidence. It is also recommended that the dams are visually inspected during active subsidence to identify any adverse impacts.

6.3.4. Registered groundwater bores

The locations of registered groundwater bores were investigated using the *Natural Resource Atlas* website (NRAtlas, 2018). There are no registered groundwater bores located within the Study Area.

WCPL owns two monitoring bores (Refs. GW200831 and GW200832) which are located approximately 0.7 km north-west of the longwalls. At this distance, it is unlikely that these monitoring bores would experience measurable ground movements due to the extraction of WYWL17 to WYWL20.

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. Montrose Open Cut Pit

The Montrose Open Cut Pit, part of the Wambo Coal Mine, is located immediately to the north-east of WYWL17 to WYWL20. The current extent of the pit is shown in Drawing No. MSEC935-01. It is recommended that a geotechnical assessment of the highwall be undertaken based on the effects of WYWL17 to WYWL20.

6.4.2. Exploration drill holes

The locations of the exploration drill holes within the Study Area are shown in Drawing No. MSEC935-09. The drill holes are located directly above and adjacent to the longwalls and, therefore, could experience the full range of predicted subsidence movements, which were described in Chapter 4. It is likely, therefore, that fracturing and shearing would occur in the 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. The Montrose Water Storage Dam

The approved Montrose Water Storage Dam is located above the north-eastern ends of WYLW17 to WYLW19, as shown in Drawing No. MSEC935-09. The dam would be constructed after the completion of these longwalls. The design of the dam, therefore, should consider the subsided surface levels and the fractured bedrock resulting from the mining.

The natural surface level contours (grey lines) and the predicted post-mining surface level contours (green lines) in the location of the future Montrose Water Storage Dam are illustrated in Fig. 6.1. The approved location of the storage dam is also shown in this figure.

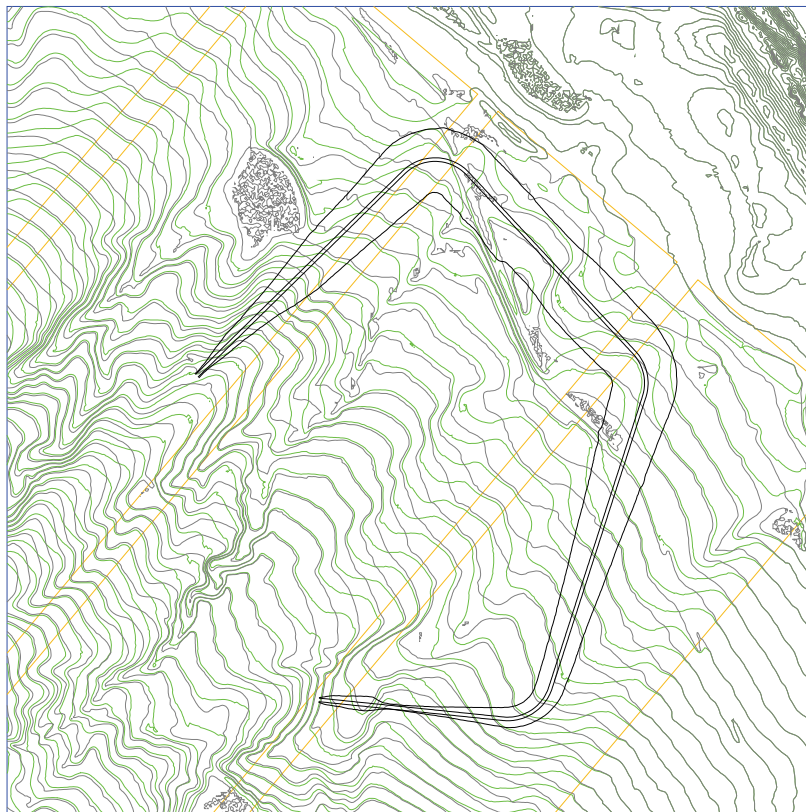


Fig. 6.1 Natural and predicted subsided surface levels at the Montrose Water Storage Dam

The natural and predicted subsided surface levels along the future dam wall (taken in an anti-clockwise direction) are illustrated in Fig. 6.2. The predicted vertical subsidence at the completion of the longwalls is also shown at the bottom of this figure (i.e. green line).

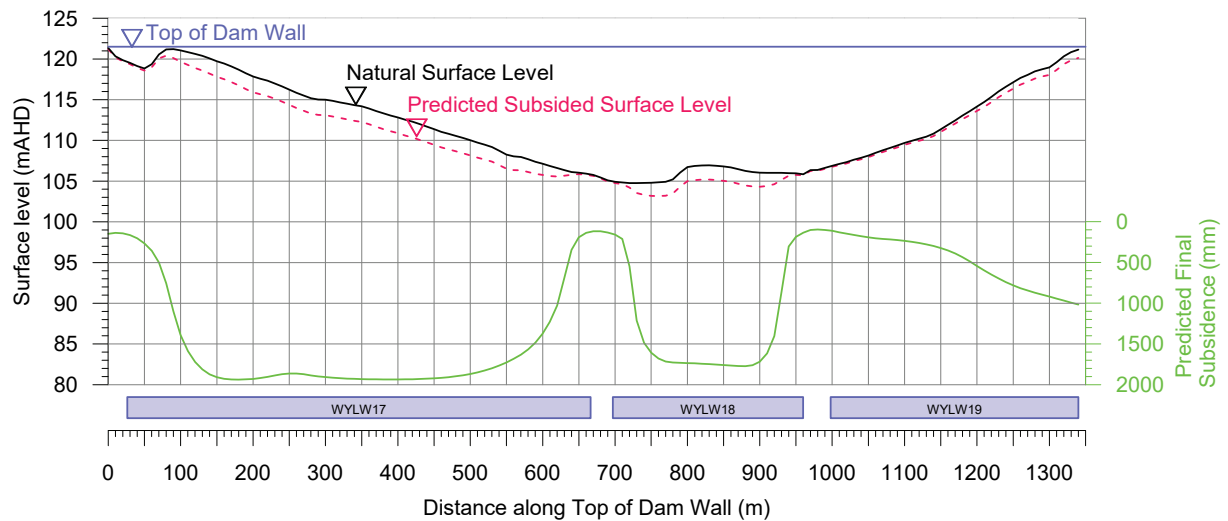


Fig. 6.2 Natural and predicted subsided surface levels along the Dam Wall

The overall height of the dam wall will need to be increased by up to 2 m, to account for the predicted subsided surface levels, so as to maintain the design crest of the dam wall. The maximum height of the dam wall, assuming the top of the dam wall is at RL121.5 mAHD, will be approximately 16.7 m based on the natural surface level contours and approximately 18.3 m based on the predicted subsided surface level contours.

The predicted storage capacity of the dam, assuming a maximum water storage level of RL121.0 mAHD, is approximately 1.4 ML based on the natural surface level contours and 1.6 ML based on the predicted subsided surface level contours. The post-mining water storage capacity, therefore, is approximately 0.2 ML greater than the pre-mining water storage capacity, based on the assumed maximum water storage level.

The extraction of the longwalls will result in fracturing and buckling of the topmost bedrock. The design of the dam base should comprise a sufficient thickness of cohesive materials to provide the required water holding capacity.

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 16 archaeological sites that have been identified within or immediately adjacent to the Study Area, as shown in Drawing No. MSEC935-09.

A summary of the archaeological sites located within or immediately adjacent to the Study Area is provided in Table 6.2. There are three additional sites that have been identified since the Modification Application, being Wambo Sites 505, 506 and 507.

Table 6.2 Archaeological sites located within or immediately adjacent to the Study Area

Reference	Type	Location
Wambo Site 230	Open Artefact Site	Directly above WYLLW19
Wambo Site 231	Open Artefact Site	Directly above WYLLW20
Wambo Site 324 St 1	Scarred Tree	80 m north-west of the maingate of WYLLW20
Wambo Site 494	Open Artefact Site	Directly above the maingate of WYLLW18
Wambo Site 496	Open Artefact Site	80 m north-west of the maingate of WYLLW20
Wambo Site 497	Open Artefact Site	Directly above WYLLW18
Wambo Site 499	Rock shelter with PAD	40 m north-west of the maingate of WYLLW20
Wambo Site 500	Rock shelter with PAD	Directly above WYLLW18
Wambo Site 501	Rock shelter with PAD	Directly above WYLLW18
Wambo Site 502	Rock shelter with PAD	Directly above WYLLW18
Wambo Site 505	Isolated Artefact	Directly above WYLLW19
Wambo Site 506	Isolated Artefact	Directly above WYLLW19
Wambo Site 507	Rock shelter with PAD	Directly above WYLLW19
Wambo PAD J	Open PAD	Directly above WYLLW17
Wambo PAD K	Open PAD	Directly above WYLLW17
Wambo PAD L	Open PAD	Directly above WYLLW19

The archaeological sites located within or immediately adjacent to the Study Area comprise five Open Artefact Sites, two Isolated Artefacts, three Open Potential Archaeological Deposits (PADs), five Rock Shelters with PADs and one Scarred Tree. Further details on the archaeological sites are provided in the reports by *South East Archaeology* (2017a and 2017b) and the Heritage Management Plan.

6.5.2. Predictions for the archaeological sites

A summary of the maximum predicted total subsidence, tilts and curvatures for each of the archaeological sites is provided in Table 6.3. The values are the maximum predicted parameters within 20 m of the perimeters of each of the sites.

Table 6.3 Maximum predicted total vertical subsidence, tilts and curvatures for the archaeological sites

Site reference	Site type	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
Wambo Site 230	Open Artefact Site	1800	1	> 3.0	> 3.0
Wambo Site 231	Open Artefact Site	1700	75	> 3.0	> 3.0
Wambo Site 324 St 1	Scarred Tree	< 20	< 0.5	0.01	< 0.01
Wambo Site 494	Open Artefact Site	200	4	0.2	0.04
Wambo Site 496	Open Artefact Site	< 20	< 0.5	< 0.01	< 0.01
Wambo Site 497	Open Artefact Site	1100	50	3	2
Wambo Site 499	Rock shelter with PAD	50	2	0.1	< 0.01
Wambo Site 500	Rock shelter with PAD	1700	10	0.6	0.6
Wambo Site 501	Rock shelter with PAD	1600	20	0.4	0.6
Wambo Site 502	Rock shelter with PAD	1200	20	0.3	0.3
Wambo Site 505	Isolated Artefact	1400	20	0.4	0.3
Wambo Site 506	Isolated Artefact	1700	20	0.5	0.5
Wambo Site 507	Rock shelter with PAD	1500	20	0.3	0.4
Wambo PAD J	Open PAD	1900	1	> 3.0	> 3.0
Wambo PAD K	Open PAD	1700	55	> 3.0	> 3.0
Wambo PAD L	Open PAD	1800	2	> 3.0	> 3.0

A summary of the maximum predicted total subsidence parameters for each type of archaeological site is provided in Table 6.4. The values are the maximum predicted parameters within 20 m of the perimeters of each of the sites.

Table 6.4 Maximum predicted total vertical subsidence, tilts and curvatures for the archaeological sites

Site Type	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km ⁻¹)	Maximum predicted total sagging curvature (km ⁻¹)
Open Artefact Sites	1800	75	> 3.0	> 3.0
Isolated Artefacts	1700	20	0.5	0.5
Open PADs	1900	55	> 3.0	> 3.0
Rock Shelters with PADs	1700	20	0.6	0.6
Scarred Tree	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted conventional strains for the archaeological sites, based on applying a factor of 10 to the maximum predicted curvatures, are greater than 30 mm/m tensile and compressive for the Open Artefact Sites and the Open PADs, 5 mm/m tensile and compressive for the Isolated Artefacts, 6 mm/m tensile and compressive for the Rock Shelters with PADs and less than 0.5 mm/m tensile and compressive for the Scarred Tree.

The range of strains will vary considerably across the extents of the longwalls due to, amongst other factors, variation in the depth of cover. The greatest strains are predicted to occur near the longwall finishing (i.e. north-eastern) ends where the depths of cover are shallowest. Lower strains are predicted to occur towards the longwall commencing (i.e. south-western) ends where the depths of cover are higher.

The distributions of strain above the longwalls are described in Section 4.4. The predicted strains for the archaeological sites located near the longwall commencing ends (refer to Section 4.4.1) are 5 mm/m tensile and 4 mm/m compressive based on the 95 % confidence levels. The predicted strains for the sites located near the longwall finishing ends (refer to Section 4.4.2) are 12 mm/m tensile and 17 mm/m compressive based on the 95 % confidence levels.

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

6.5.3. Comparison of the predictions for the archaeological sites

The maximum predicted subsidence parameters for archaeological sites located directly above WYLLW17 to WYLLW20 are the same as those presented in the Modification Application and Report No. MSEC848. The predicted parameters do not change for these sites as they are located directly above the longwalls.

There are three additional sites that have been identified since the Modification Application, being Wambo Sites 505, 506 and 507, which are located directly above WYLLW19. Whilst the predicted subsidence parameters for these sites were not presented in Report No. MSEC848, the predictions based on the layout adopted in the Modification Application are the same as those based on the layout adopted in the Extraction Plan Application.

The maximum predicted subsidence parameters for Wambo Site 324 St 1, Wambo Site 496 and Wambo Site 499, due to the extraction of WYLLW17 to WYLLW20, are less than those presented in the Modification Application and Report No. MSEC848. The predicted subsidence parameters are less for these sites, as they are located outside the maingate of WYLLW20 and, therefore, have not yet experienced the additional subsidence from the future WYLLW21 to WYLLW25.

6.5.4. Impact assessments for the Open Artefact Sites, Isolated Artefacts and Open PADs

There are five sites within the Study Area comprising Open Artefact Sites, being Wambo Site 230, Wambo Site 231, Wambo Site 494, Wambo Site 496 and Wambo Site 497. There are two Isolated Artefacts at Wambo Site 505 and Wambo Site 506. There are also three sites within the Study Area comprising Open PADs, being Wambo PAD J, Wambo PAD K and Wambo PAD L.

The maximum predicted total tilts are 75 mm/m (i.e. 7.5 %, or 1 in 13) for the Open Artefact Sites, 20 mm/m (i.e. 2.0 %, or 1 in 50) for the Isolated Artefacts and 55 mm/m (i.e. 5.5 %, or 1 in 18) for the Open PADs. It is unlikely that these sites would experience adverse impacts resulting from the mining-induced tilts.

The maximum predicted total curvatures for the Open Artefact Sites and the Open PADs are greater than 3.0 km^{-1} hogging and sagging, which represents a minimum radius of curvature of less than 0.3 km. The maximum predicted total curvatures for the Isolated Artefacts are 0.5 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 2.0 km.

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 artefacts or deposits 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 vicinity of the Open Artefact Sites, Isolated Artefacts and the Open PADs.

Further discussions on the potential impacts on the Open Artefact Sites, Isolated Artefacts and the Open PADs are provided in the reports by *South East Archaeology* (2017a and 2017b) and the Heritage Management Plan.

6.5.5. Impact assessments for the Rock Shelters

Wambo Site 499 is located 40 m north-west of the maingate of WYLLW20. The rock shelter is up to approximately 20 m wide, 17 m deep and 6 m high and has formed within a conglomerate minor cliff. Wambo Site 499 is predicted to experience a maximum curvature of 0.1 km^{-1} hogging, due to the extraction of WYLLW17 to WYLLW20, which represents a minimum radius of curvature of 10 km.

Wambo Sites 500, 501 and 502 are located directly above the south-western end of WYLLW18. The rock shelters are up to 6 m wide, 5 m deep and 2 m high and have formed within conglomerate minor cliffs and rock outcrops. These sites are predicted to experience maximum curvatures of 0.6 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 1.7 km.

Wambo Site 507 is located directly above the south-western end of WYLLW19. The rock shelter is 3.5 m wide, 4.5 m deep and up to 2.5 m high and has formed within the conglomerate rock outcropping. This site is predicted to experience curvatures of 0.3 km^{-1} hogging and 0.4 km^{-1} sagging, which represent minimum radii of curvature of 3.3 km and 2.5 km, respectively.

The predicted curvatures and strains in the locations of Wambo Sites 500, 501, 502 and 507 are likely to be sufficient to result in the fracturing of the conglomerate minor cliffs and rock outcrops. The predicted ground movements at Wambo Site 499, which is located outside but immediately adjacent to the maingate of WYLLW20, could also be sufficient to result in fracturing.

It is extremely difficult to assess the likelihood of instabilities for the rock shelters based upon predicted ground movements. The likelihood of the shelters becoming unstable is dependent on a number of factors which are difficult to fully quantify. 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 the shelter naturally or when it is exposed to mine subsidence movements.

It has been estimated that approximately 7 to 10 % of the total length, or approximately 3 to 5 % of the total face area, of the Low Level Cliffs located directly above the longwalls could be impacted (refer to Section 5.6.5). The potential impacts on the isolated rock outcrops is considerably less due to their discontinuous nature.

Wambo Site 499 is up to approximately 20 m wide and represents a large proportion of the length of the discontinuous minor cliff. However, the site is located outside but immediately adjacent to WYWLW20. The potential for adverse impacts at this rock shelter, therefore, has been assessed as very unlikely (i.e. less than 10 %). It is noted, that this assessment represents the likelihood of adverse fracturing and spalling being coincident with the rock shelter. The future WYWLW21 will mine directly beneath this site and the assessed impacts due to that longwall will be considered in a future Extraction Plan Application.

Wambo Sites 500, 501, 502 and 507 are considerably smaller rock shelters that have formed within minor cliffs and isolated rock outcrops. These sites are located directly above WYWLW18 and WYWLW19. The potential for adverse impacts (i.e. fracturing and spalling) at these rock shelters, therefore, have also been assessed as very unlikely (i.e. less than 10 %).

Further discussions on the potential impacts on the Rock Shelters with PADs are provided in the reports prepared by *South East Archaeology* (2017a and 2017b) and the Heritage Management Plan.

6.5.6. Impact assessments for the Scarred Tree

The Scarred Tree (Wambo Site 324 St 1) is located 80 m north-west of the maingate of WYWLW20. At this distance, the site is predicted to experience less than 20 mm vertical subsidence due to the extraction of the longwalls. Whilst the site could experience very low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains.

It has been found, from past longwall mining experience, that the incidence of impacts on trees is extremely rare. Impacts in the Hunter and Newcastle Coalfields have been observed where the trees are directly mined beneath at shallow depths of cover and/or where the surface terrain is very steep.

Wambo Site 324 St 1 is located outside the extents of WYWLW17 to WYWLW20. The natural surface in the location of this site is also relatively flat, with a natural gradient of approximately 1 in 30 (i.e. 3 % or 2°). The potential for adverse impacts on the Scarred Tree, therefore, has been assessed as rare (i.e. less than 5 %). The future WYWLW21 will mine directly beneath this site and the assessed impacts due to that longwall will be considered in a future Extraction Plan Application.

Further discussions on the potential impacts on the Scarred Tree are provided in the reports prepared by *South East Archaeology* (2017a and 2017b) and 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 Information* using the *Six Viewer* (2018). The locations of the survey control marks are shown in Drawing No. MSEC935-09.

There is one state survey control mark identified within the Study Area (Ref. TS12077), which is located above the maingate of WYWLW20. There are additional state survey control marks identified further afield, including within the Montrose Open Cut Pit.

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 Spatial Services – Department of Finance, Services and Innovation will be required to ensure that these survey control marks are reinstated at the appropriate time, as required.

6.7. Building structures

6.7.1. Description of the building structures

There are no building structures located within the Study Area. The Whynot Homestead and associated structures are located outside the Study Area, to the north-west of the longwalls. The locations of these structures are shown in Drawing No. MSEC935-09.

The Whynot Homestead structure is located 170 m from the maingate of WYLW20. The homestead is a single storey timber framed structure, supported on timber piers, with timber and fibro wall claddings and a metal sheeted roof. An external brick chimney is located on the southern façade of the homestead. The structure is in poor condition and is currently unoccupied. Photographs of the Whynot Homestead are provided in Fig. 6.3.



Fig. 6.3 Whynot Homestead

There are other building structures associated with the Whynot Homestead, including timber framed sheds with metal sheet cladding and water storage tanks. These structures are located between 160 m and 180 m from the maingate of WYLW20. The homestead and associated structures are all unused.

The Whynot Homestead and associated structures are predicted to experience less than 20 mm vertical subsidence due to the extraction of WYLW17 to WYLW20. Whilst these structures could experience very low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

It is unlikely that the Whynot Homestead and associated structures would experience adverse impacts due to the extraction of the longwalls. The future WYLW21 will mine directly beneath this site and the assessed impacts due to that longwall will be considered in a future Extraction Plan Application.

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, Woodlands Hill and Arrowfield 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.

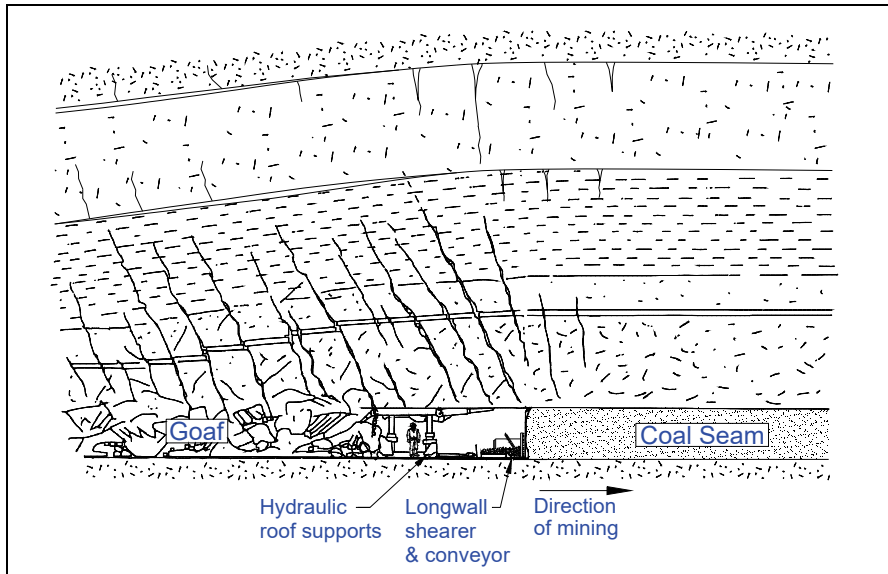


Fig. B. 1 Cross-section along the length of a typical longwall at the coal face

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 bend into the void, resulting in new vertical fractures, 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 m, which occurs at the north-eastern ends of WYLW17 to WYLW20. 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.

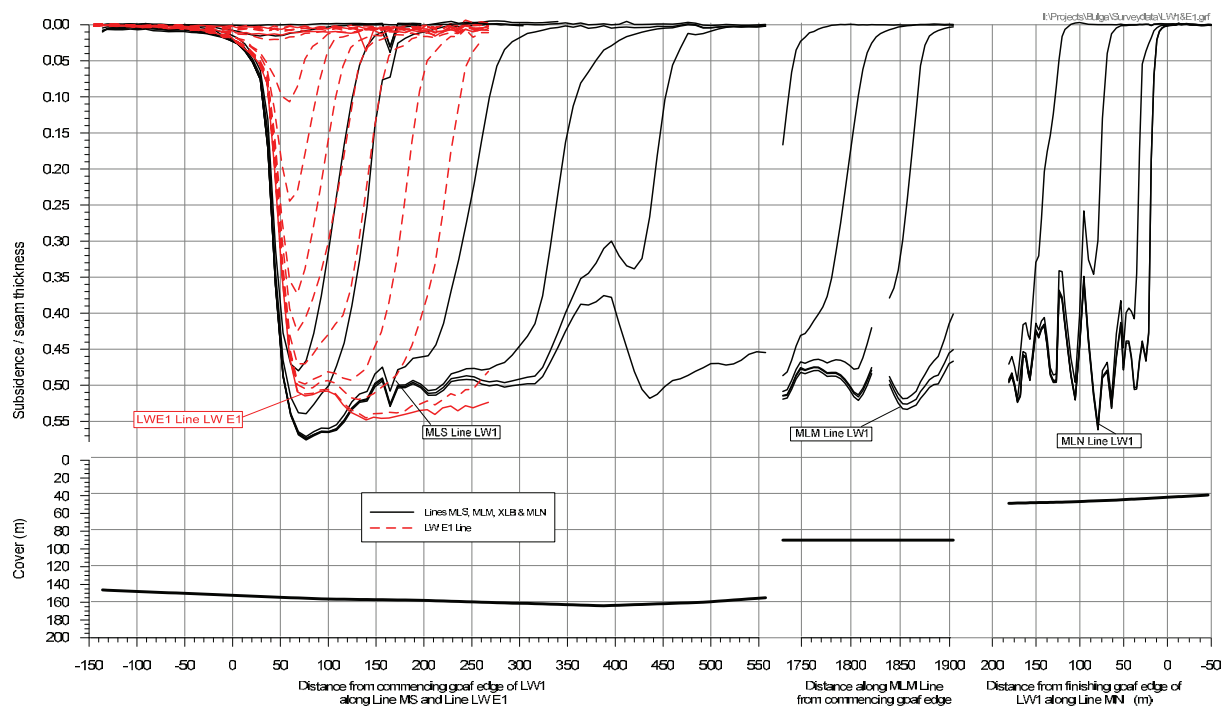


Fig. B. 2 Observed vertical subsidence profiles at South Bulga Colliery

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 m, 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 m, 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 m, 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 m. The observed subsidence profile is still relatively smooth along the MLM monitoring line, where the depth of cover is just less than 100 m. 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 m.

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.

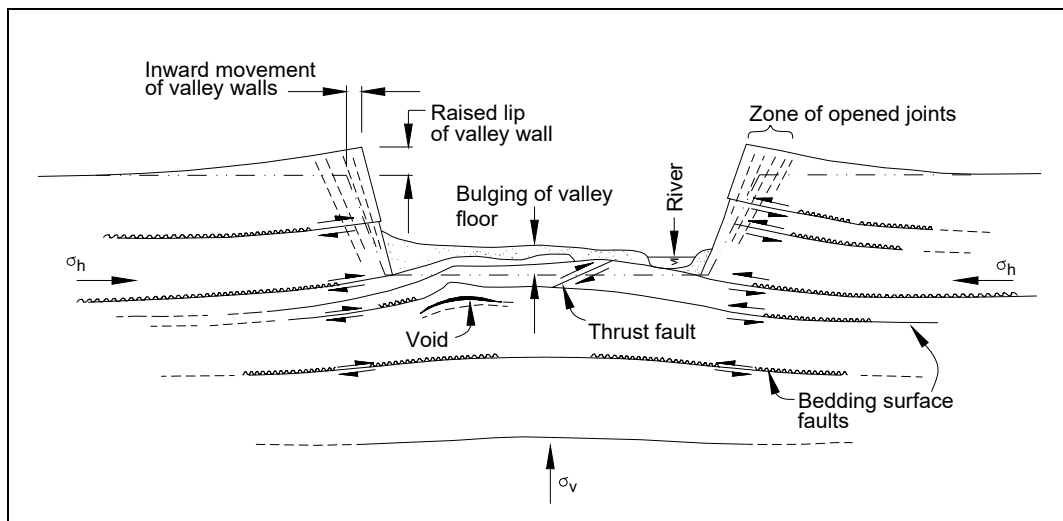


Fig. B. 3 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

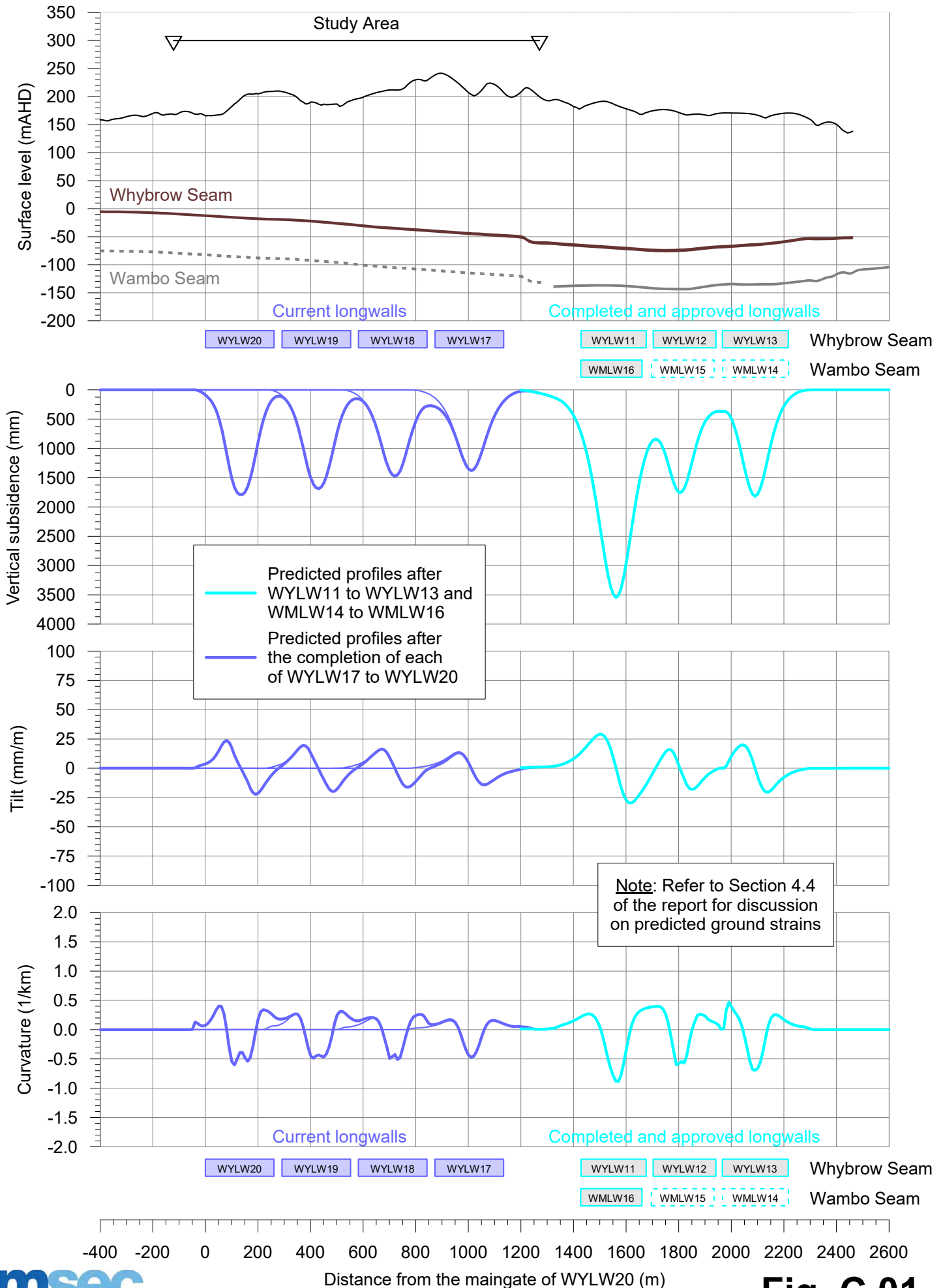
Valley related movements can be caused by or accelerated by mine subsidence as the result of a number of factors, including the redistribution of horizontal in-situ stresses and downslope movements. Valley related movements are normally described by the following parameters:

- **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.

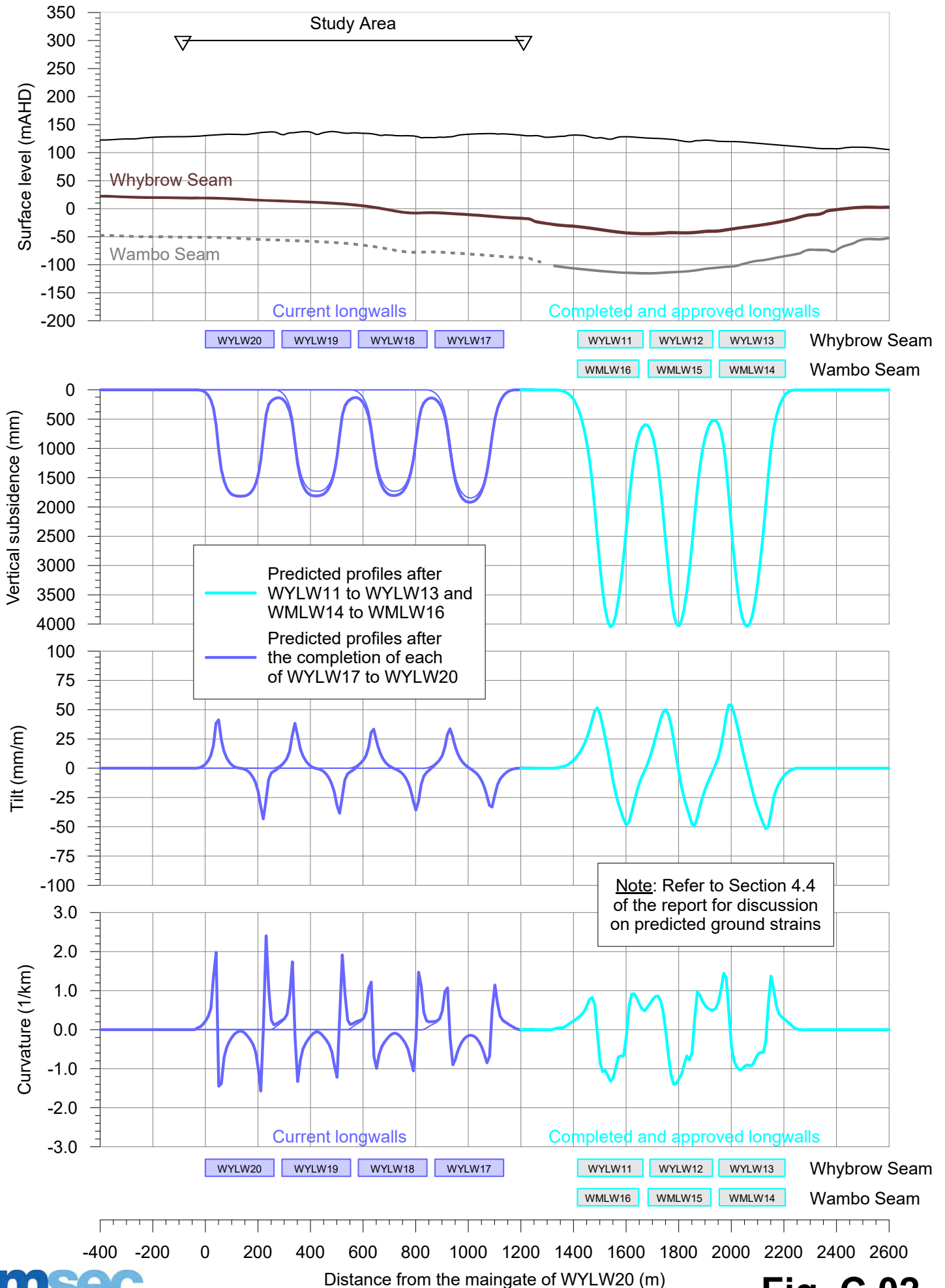
The predicted valley related movements resulting from the extraction of the longwalls were made using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002). Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence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

APPENDIX C. FIGURES

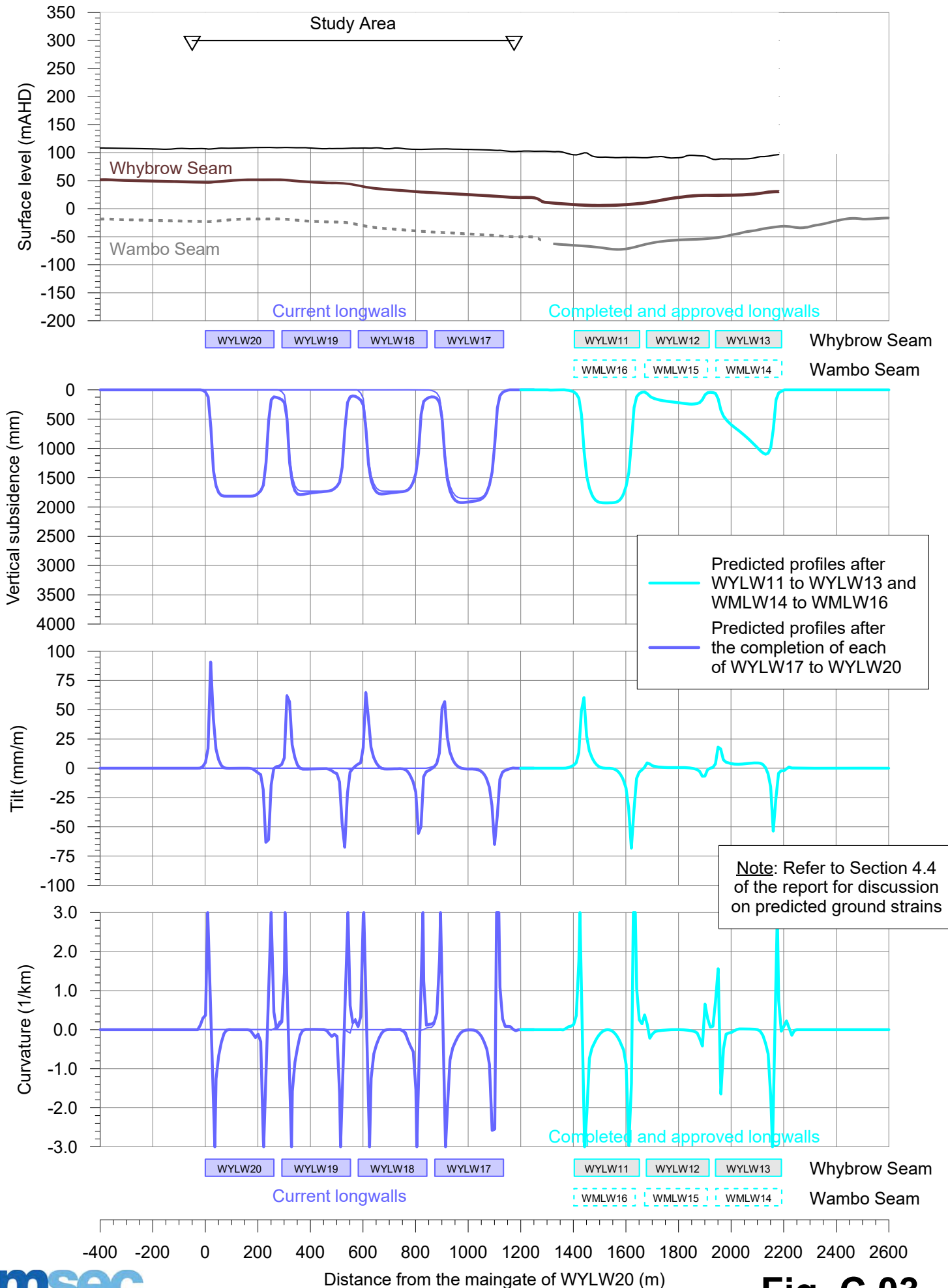
Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to WYLW17 to WYLW20 at South Bates Extension



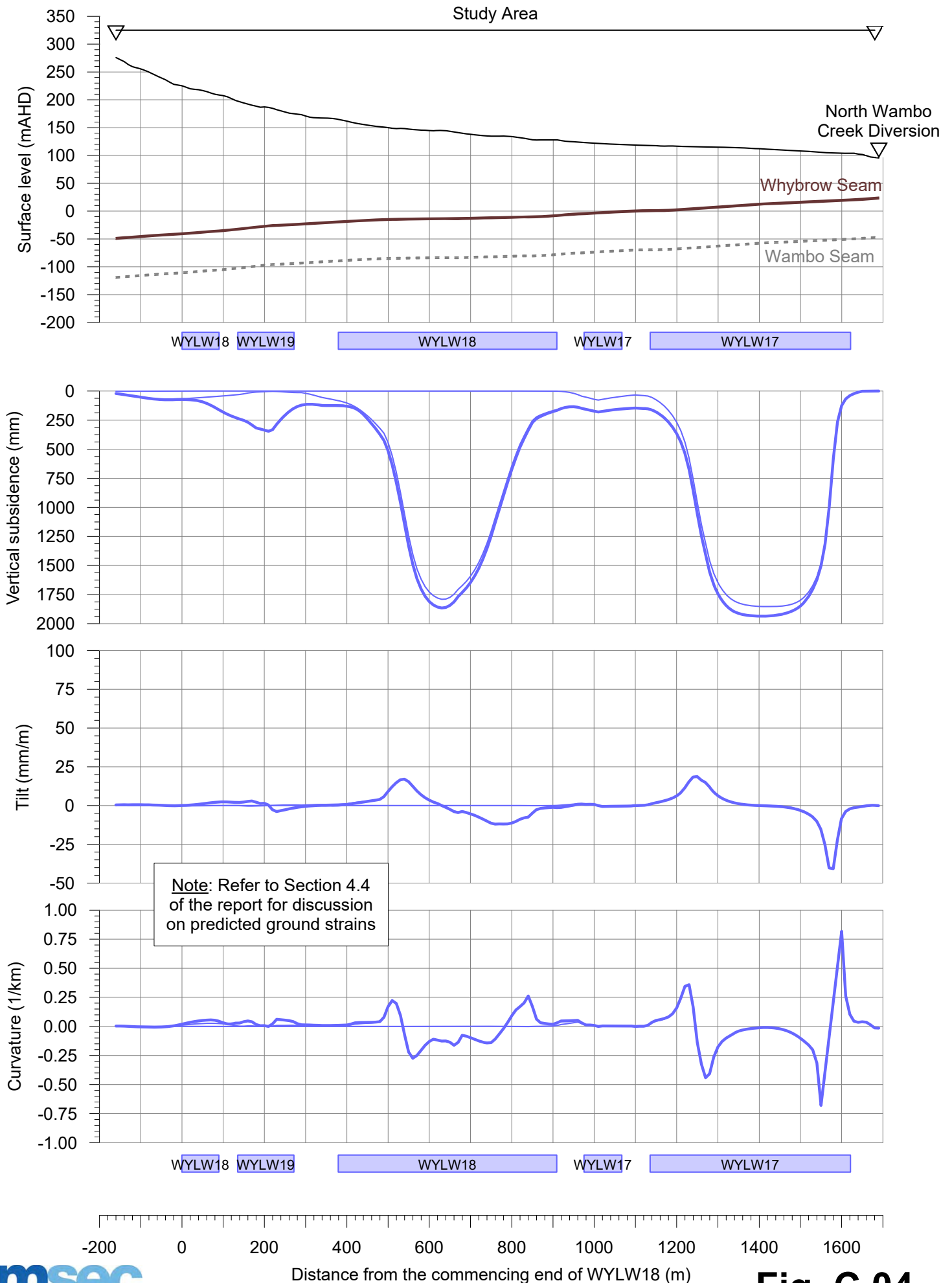
Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to WYLW17 to WYLW20 at South Bates Extension



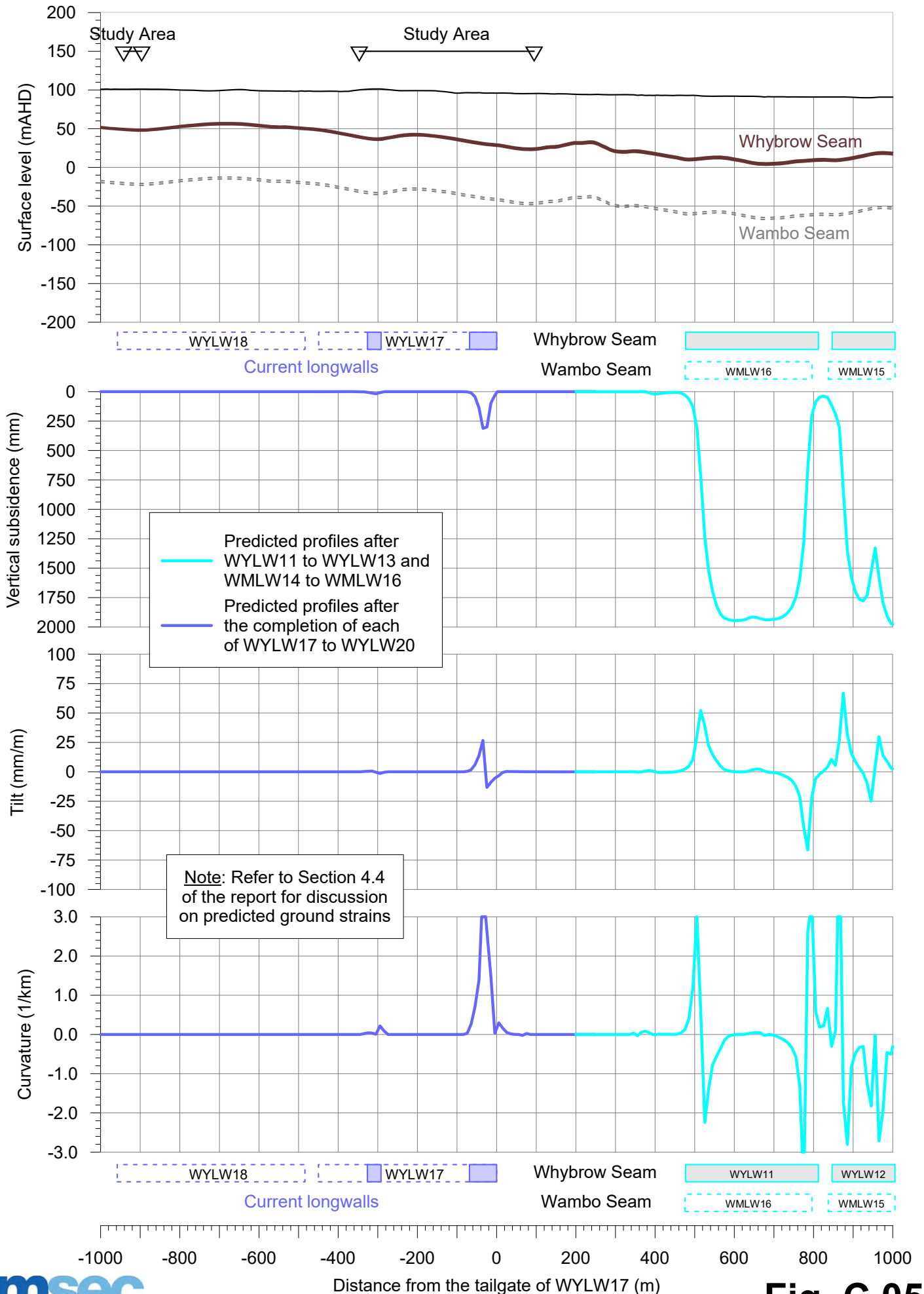
Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 3 due to WYLW17 to WYLW20 at South Bates Extension



Predicted Profiles of vertical subsidence, tilt and curvature along Drainage Line 3 due to WYLW17 to WYLW20 at South Bates Extension

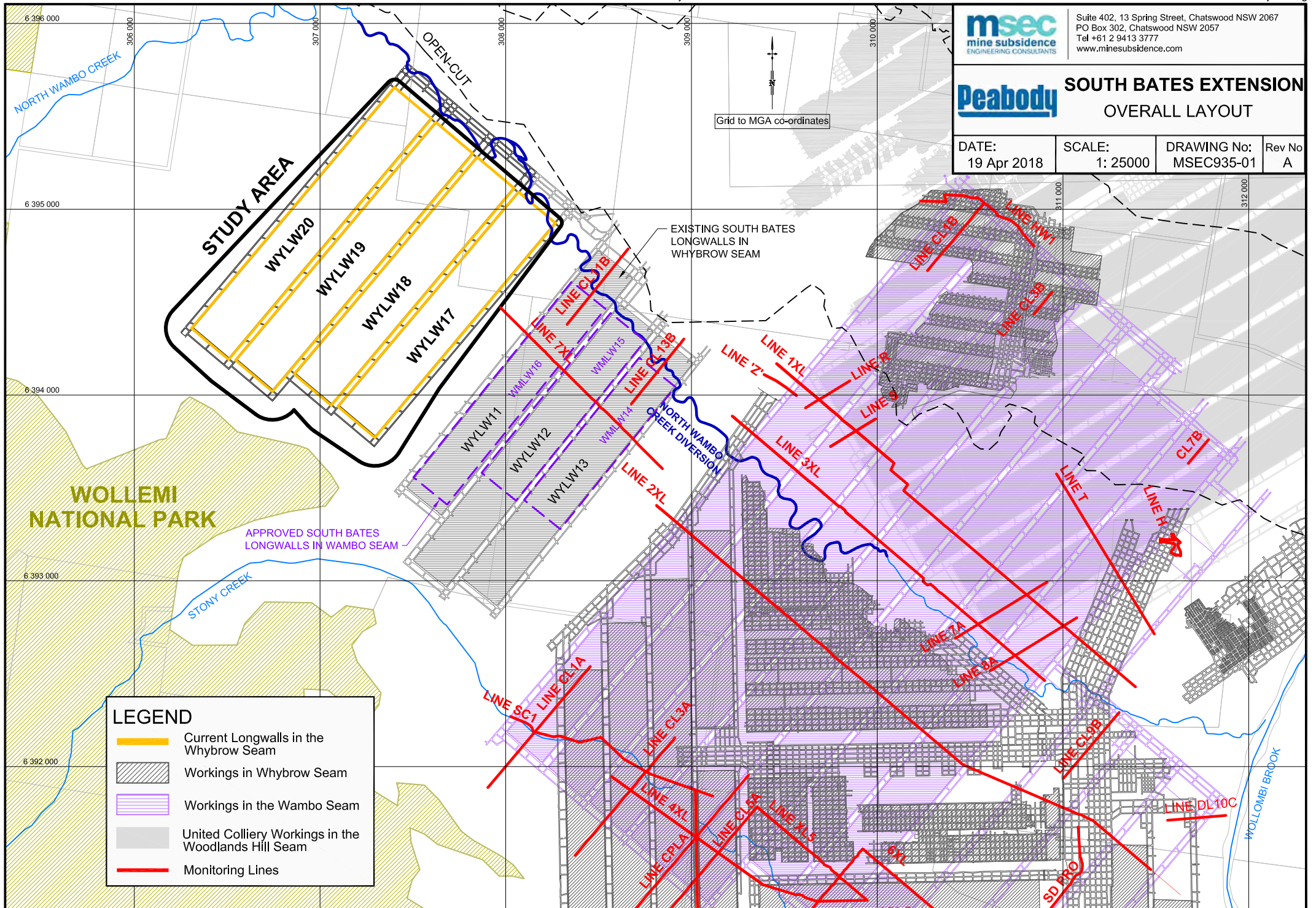


Predicted profiles of vertical subsidence, tilt and curvature along the North Wambo Creek Diversion due to WYLW11 to WYLW20 at South Bates Extension



APPENDIX D. DRAWINGS

DATE: 19 Apr 2018	SCALE: 1: 25000	DRAWING No: MSEC935-01	Rev No A
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LEGEND

- Current Longwalls in the Whybrow Seam
- Workings in Whybrow Seam
- Workings in the Wambo Seam
- United Colliery Workings in the Woodlands Hill Seam
- Monitoring Lines



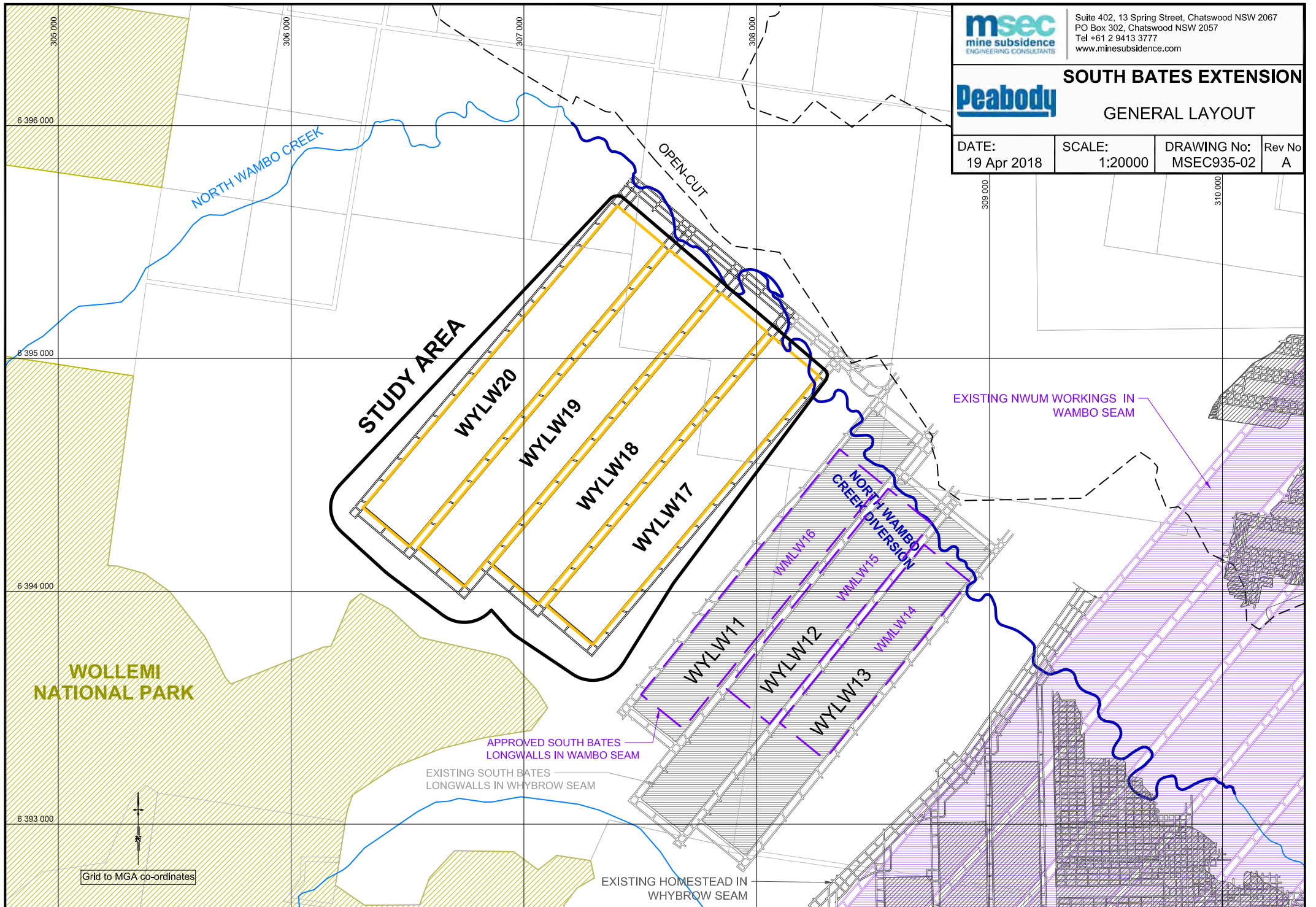
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SOUTH BATES EXTENSION

GENERAL LAYOUT

DATE: 19 Apr 2018	SCALE: 1:20000	DRAWING No: MSEC935-02	Rev No: A
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Note: Approved South Bates Longwalls in the Wambo Seam are not shown

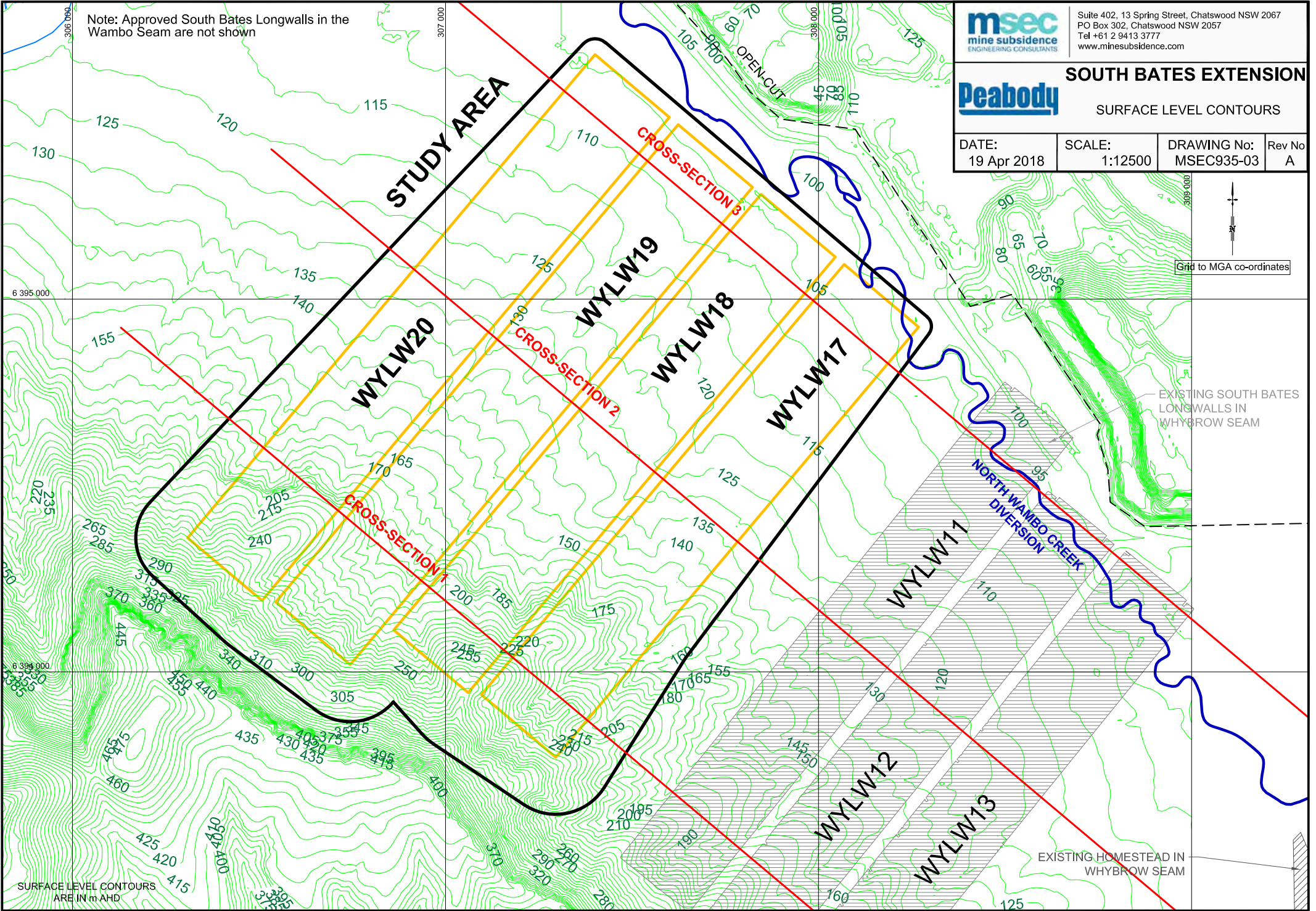
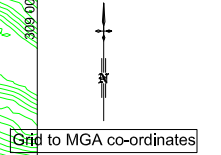


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SOUTH BATES EXTENSION
 SURFACE LEVEL CONTOURS

DATE: 19 Apr 2018	SCALE: 1:12500	DRAWING No: MSEC935-03	Rev No A
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SURFACE LEVEL CONTOURS ARE IN m AHD



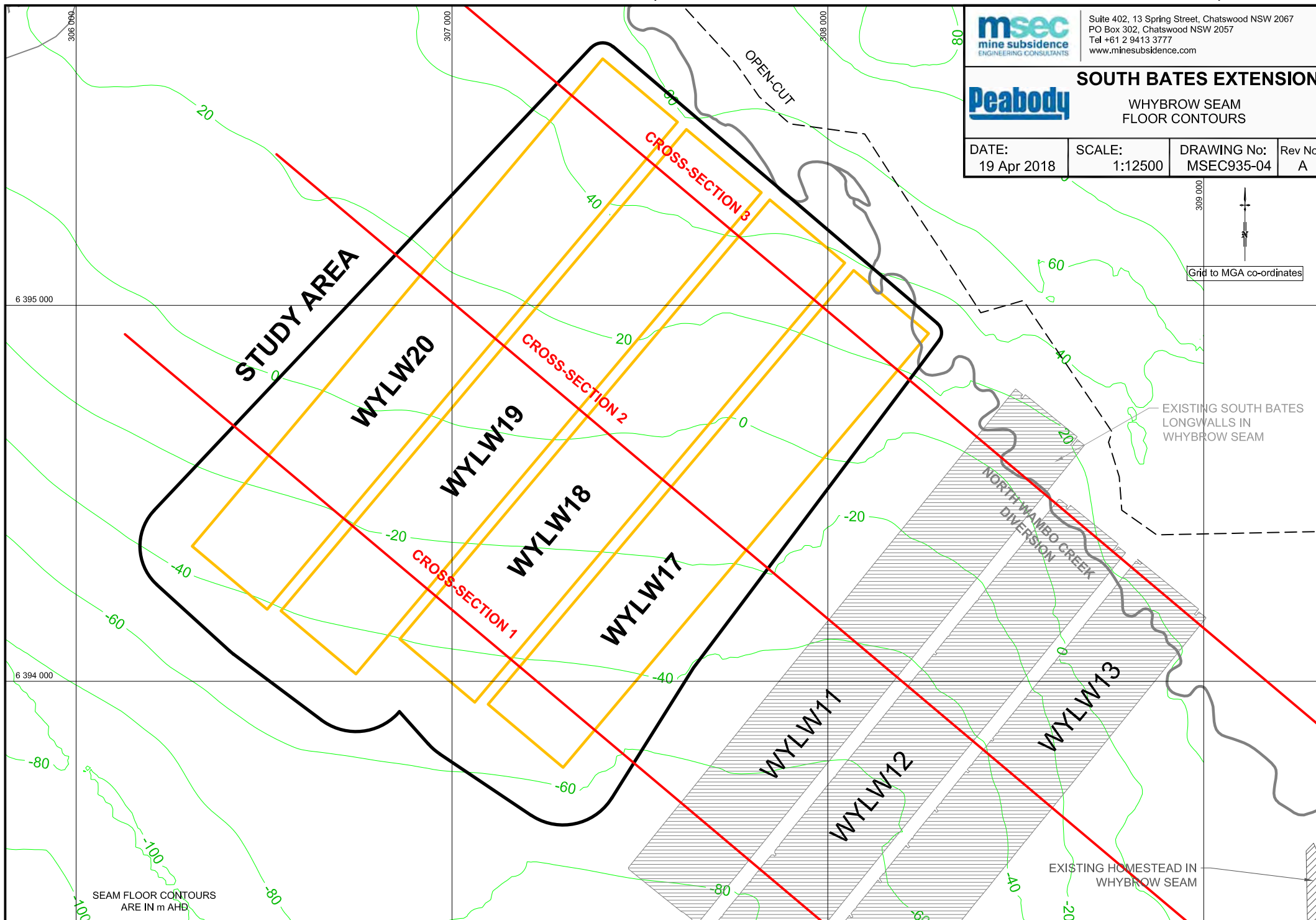
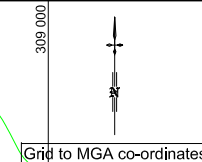
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SOUTH BATES EXTENSION

WHYBROW SEAM
FLOOR CONTOURS

DATE: 19 Apr 2018	SCALE: 1:12500	DRAWING No: MSEC935-04	Rev No A
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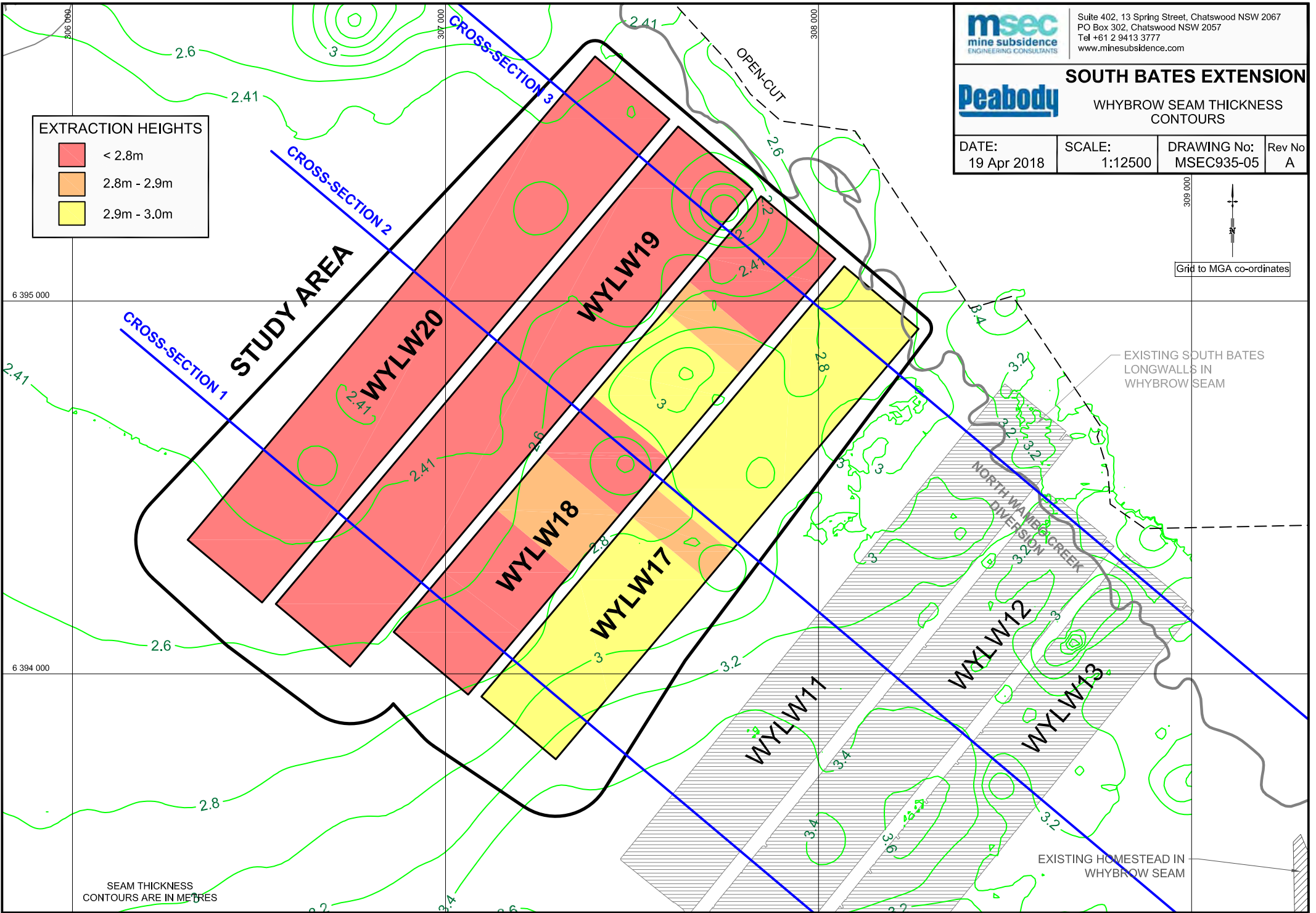
SOUTH BATES EXTENSION

WHYBROW SEAM THICKNESS
 CONTOURS

DATE: 19 Apr 2018	SCALE: 1:12500	DRAWING No: MSEC935-05	Rev No A
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EXTRACTION HEIGHTS

- < 2.8m
- 2.8m - 2.9m
- 2.9m - 3.0m



SEAM THICKNESS
 CONTOURS ARE IN METRES



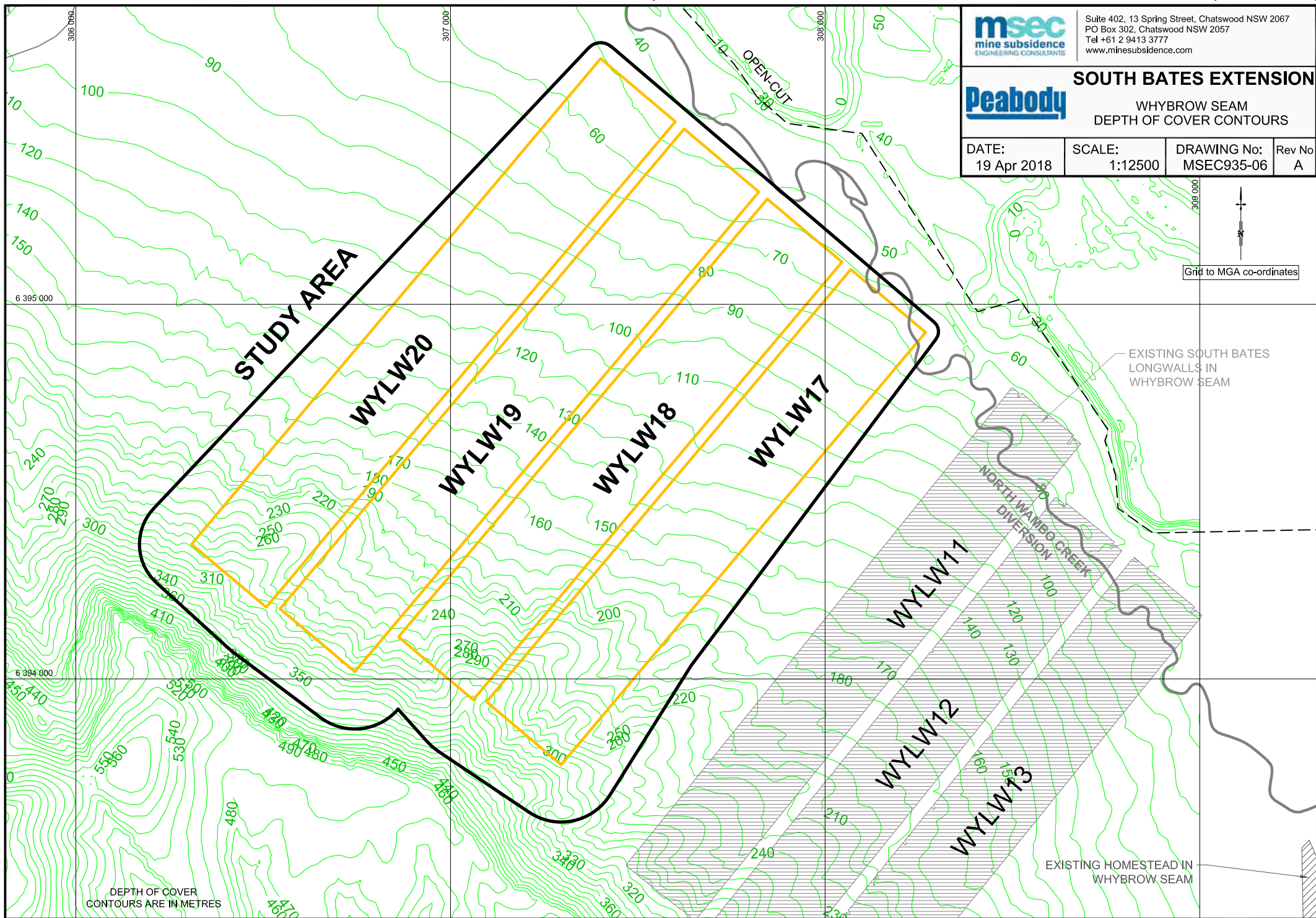
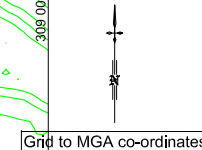
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SOUTH BATES EXTENSION

WHYBROW SEAM
 DEPTH OF COVER CONTOURS

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Note: Approved South Bates Longwalls in the Wambo Seam are not shown



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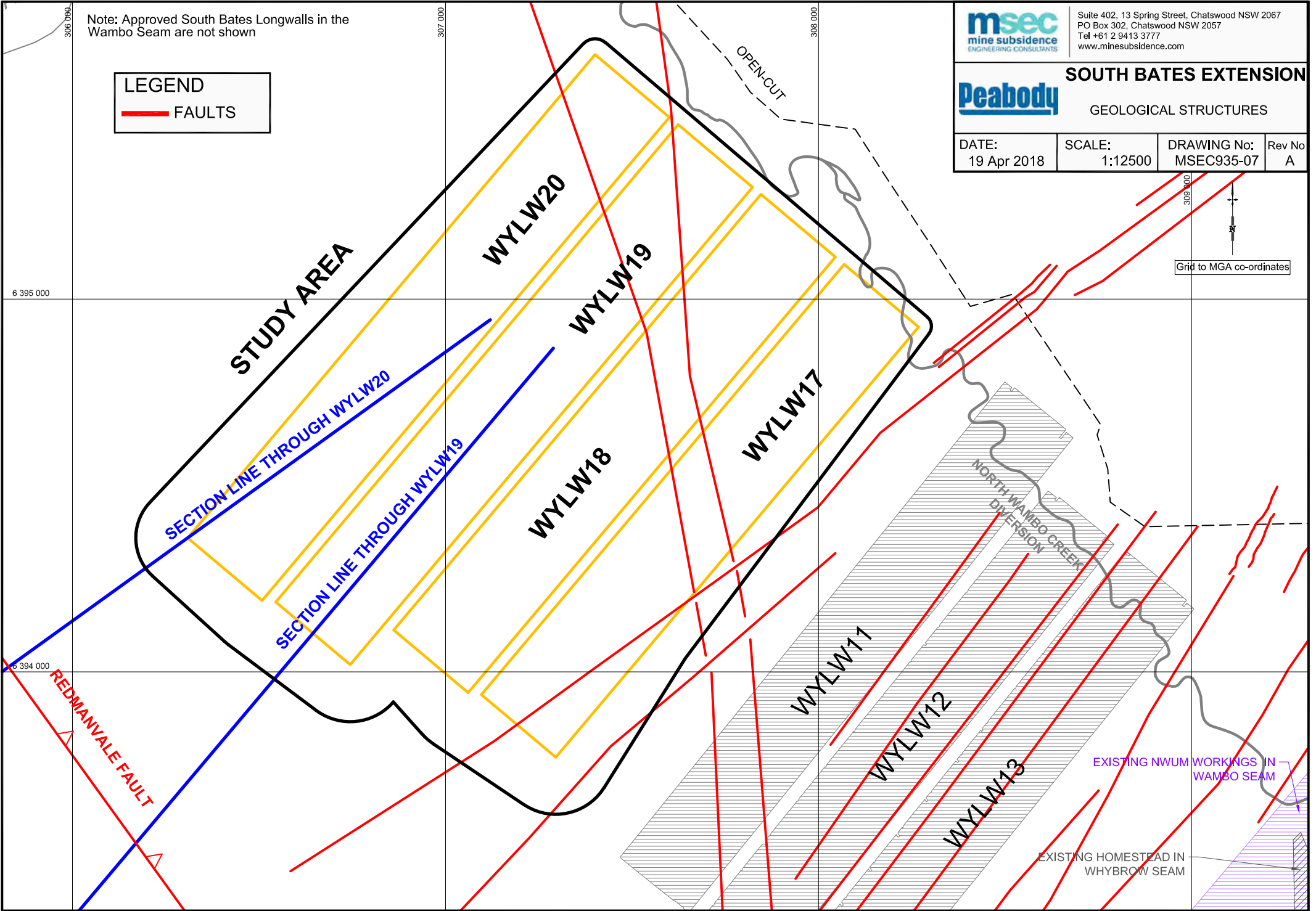
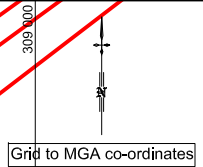
SOUTH BATES EXTENSION

GEOLOGICAL STRUCTURES

LEGEND

 **FAULTS**

DATE: 19 Apr 2018	SCALE: 1:12500	DRAWING No: MSEC935-07	Rev No A
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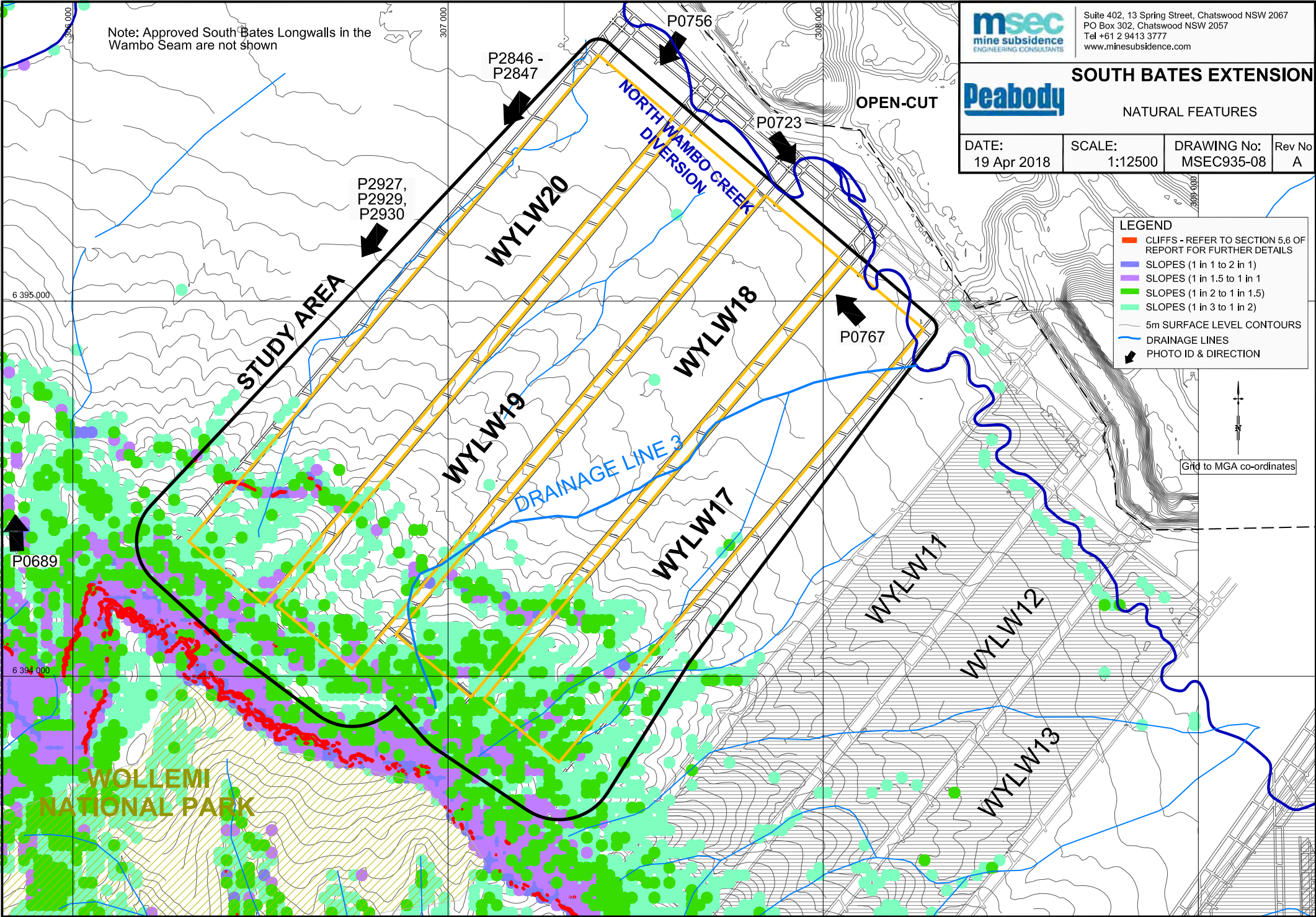
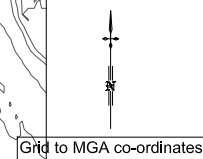
SOUTH BATES EXTENSION

NATURAL FEATURES

DATE: 19 Apr 2018	SCALE: 1:12500	DRAWING No: MSEC935-08	Rev No A
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LEGEND

- █ CLIFFS - REFER TO SECTION 5.6 OF REPORT FOR FURTHER DETAILS
- █ SLOPES (1 in 1 to 2 in 1)
- █ SLOPES (1 in 1.5 to 1 in 1)
- █ SLOPES (1 in 2 to 1 in 1.5)
- █ SLOPES (1 in 3 to 1 in 2)
- 5m SURFACE LEVEL CONTOURS
- DRAINAGE LINES
- ➔ PHOTO ID & DIRECTION



Note: Approved South Bates Longwalls in the Wambo Seam are not shown

6 395.000

6 394.000

307.000

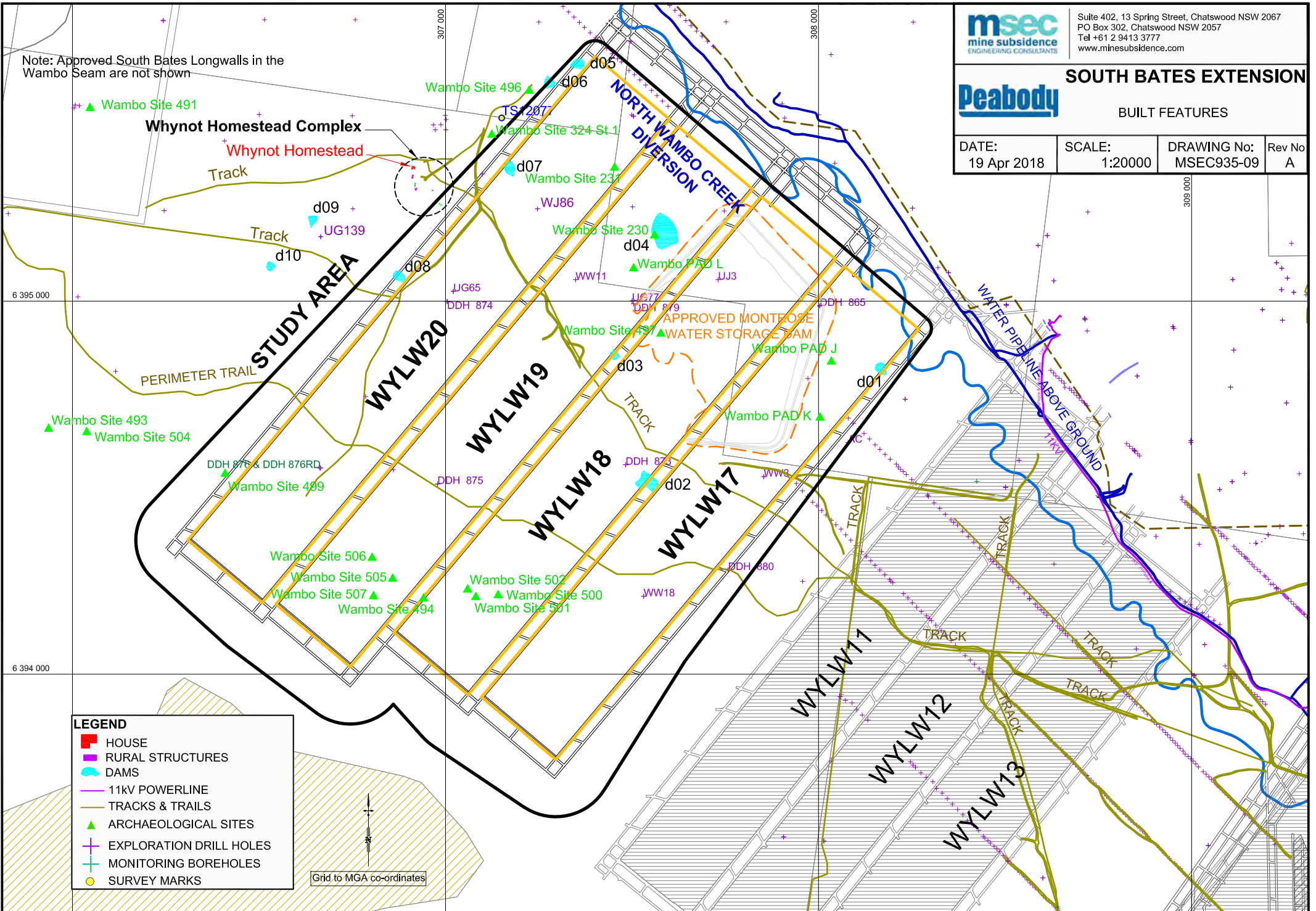
308.000

309.000

Grid to MGA co-ordinates

DATE: 19 Apr 2018	SCALE: 1:20000	DRAWING No: MSEC935-09	Rev No A
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Note: Approved South Bates Longwalls in the Wambo Seam are not shown



LEGEND

- HOUSE
- RURAL STRUCTURES
- DAMS
- 11kV POWERLINE
- TRACKS & TRAILS
- ▲ ARCHAEOLOGICAL SITES
- + EXPLORATION DRILL HOLES
- + MONITORING BOREHOLES
- SURVEY MARKS

Grid to MGA co-ordinates



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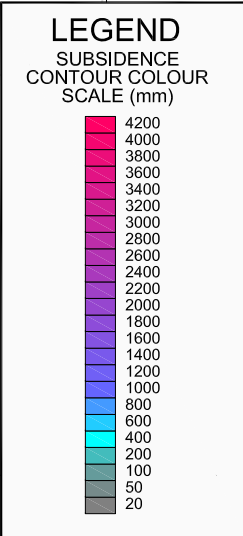
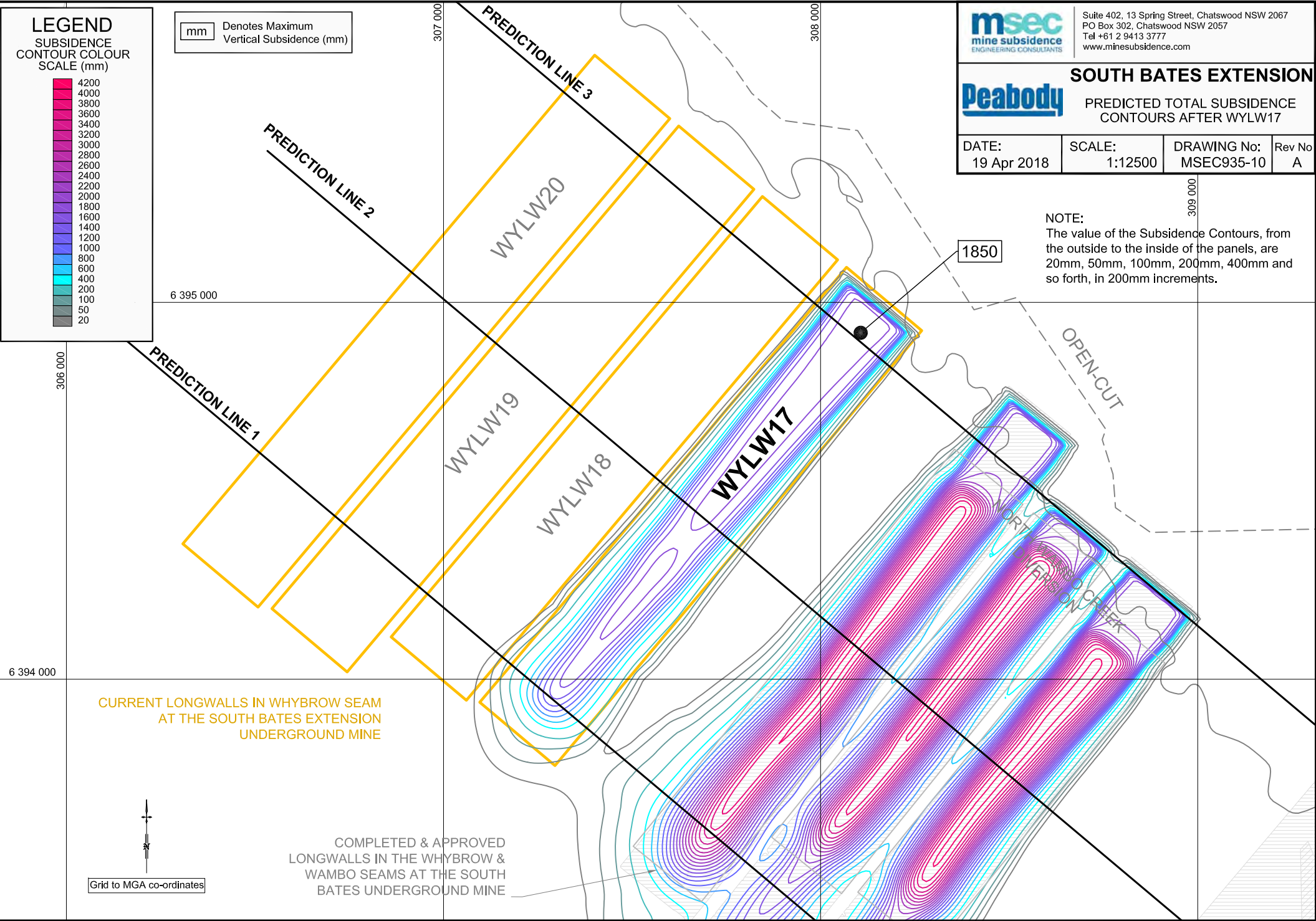


SOUTH BATES EXTENSION

PREDICTED TOTAL SUBSIDENCE
 CONTOURS AFTER WYLV17

DATE: 19 Apr 2018	SCALE: 1:12500	DRAWING No: MSEC935-10	Rev No A
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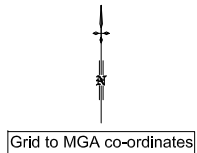
NOTE:
 The value of the Subsidence Contours, from
 the outside to the inside of the panels, are
 20mm, 50mm, 100mm, 200mm, 400mm and
 so forth, in 200mm increments.



mm Denotes Maximum
 Vertical Subsidence (mm)

CURRENT LONGWALLS IN WHYBROW SEAM
 AT THE SOUTH BATES EXTENSION
 UNDERGROUND MINE

COMPLETED & APPROVED
 LONGWALLS IN THE WHYBROW &
 WAMBO SEAMS AT THE SOUTH
 BATES UNDERGROUND MINE





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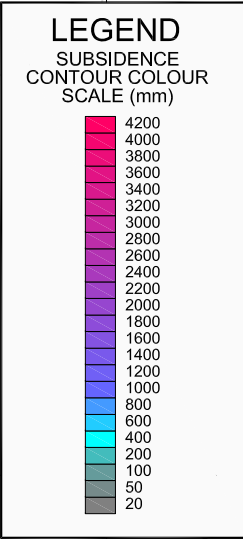
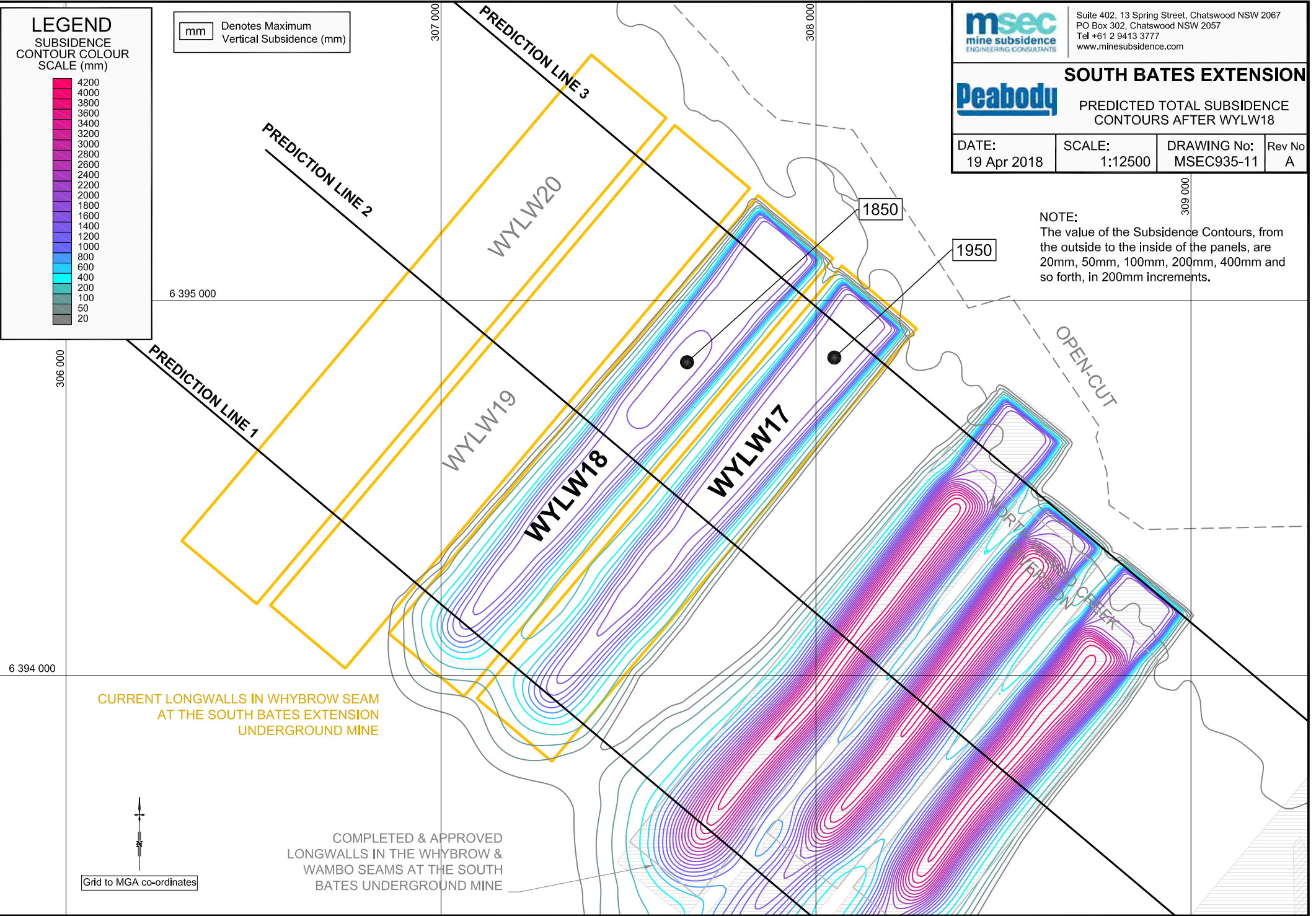


SOUTH BATES EXTENSION

PREDICTED TOTAL SUBSIDENCE
 CONTOURS AFTER WYLV18

DATE: 19 Apr 2018	SCALE: 1:12500	DRAWING No: MSEC935-11	Rev No A
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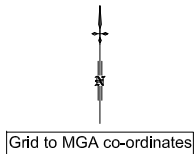
NOTE:
 The value of the Subsidence Contours, from the outside to the inside of the panels, are 20mm, 50mm, 100mm, 200mm, 400mm and so forth, in 200mm increments.



mm Denotes Maximum Vertical Subsidence (mm)

CURRENT LONGWALLS IN WHYBROW SEAM
 AT THE SOUTH BATES EXTENSION
 UNDERGROUND MINE

COMPLETED & APPROVED
 LONGWALLS IN THE WHYBROW &
 WAMBO SEAMS AT THE SOUTH
 BATES UNDERGROUND MINE





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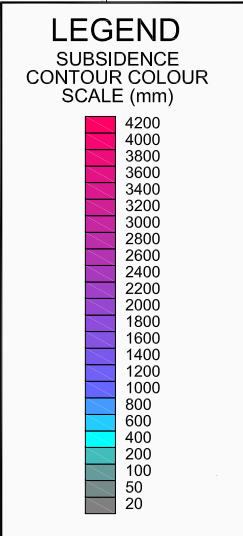
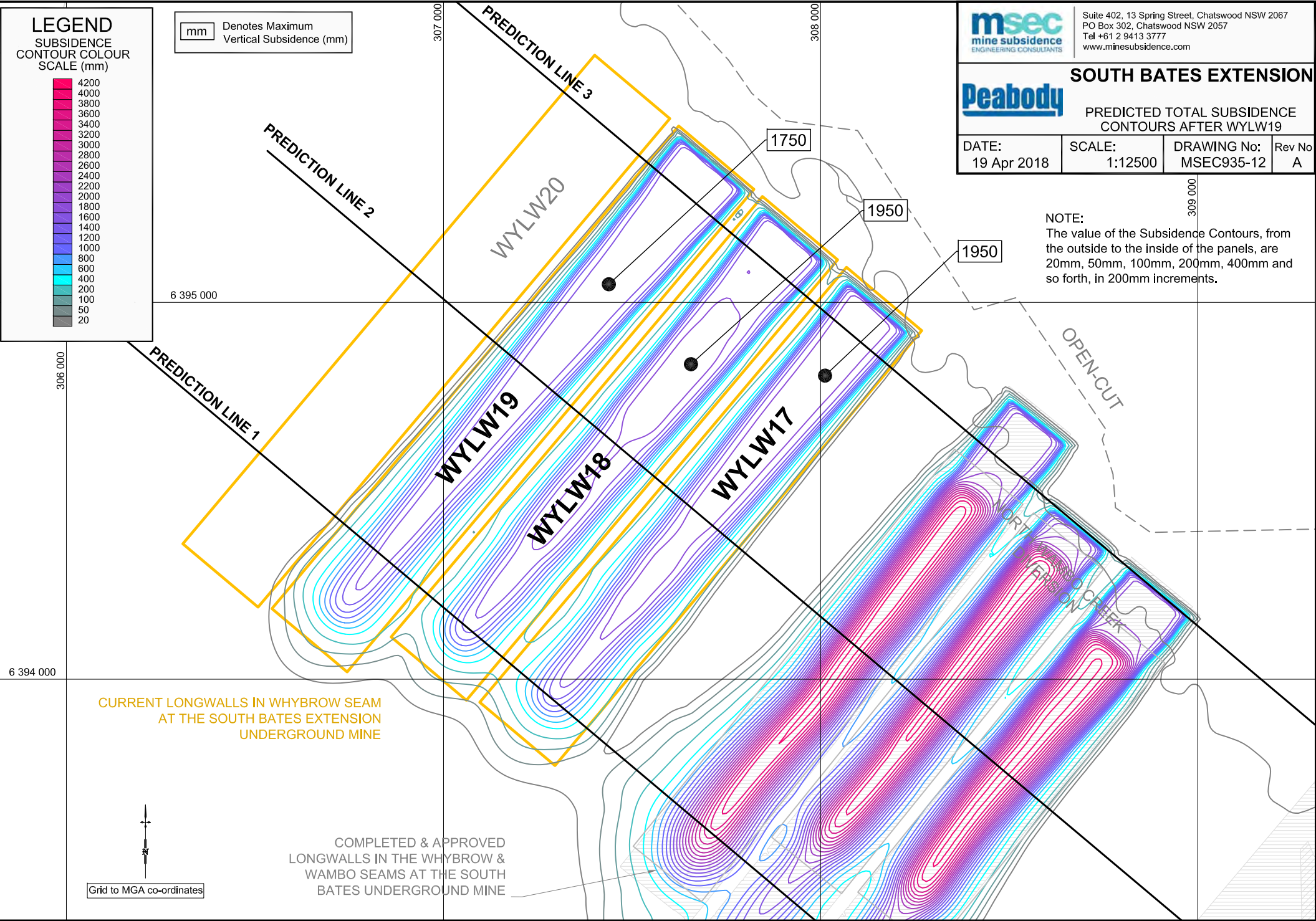


SOUTH BATES EXTENSION

PREDICTED TOTAL SUBSIDENCE
 CONTOURS AFTER WYLV19

DATE: 19 Apr 2018	SCALE: 1:12500	DRAWING No: MSEC935-12	Rev No A
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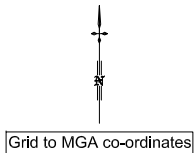
NOTE:
 The value of the Subsidence Contours, from
 the outside to the inside of the panels, are
 20mm, 50mm, 100mm, 200mm, 400mm and
 so forth, in 200mm increments.



mm Denotes Maximum
 Vertical Subsidence (mm)

CURRENT LONGWALLS IN WHYBROW SEAM
 AT THE SOUTH BATES EXTENSION
 UNDERGROUND MINE

COMPLETED & APPROVED
 LONGWALLS IN THE WHYBROW &
 WAMBO SEAMS AT THE SOUTH
 BATES UNDERGROUND MINE





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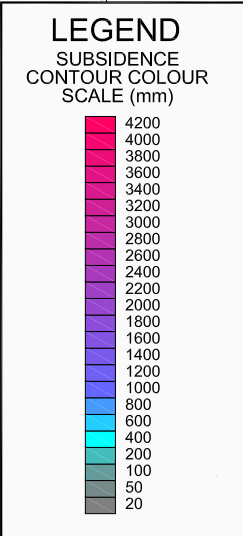
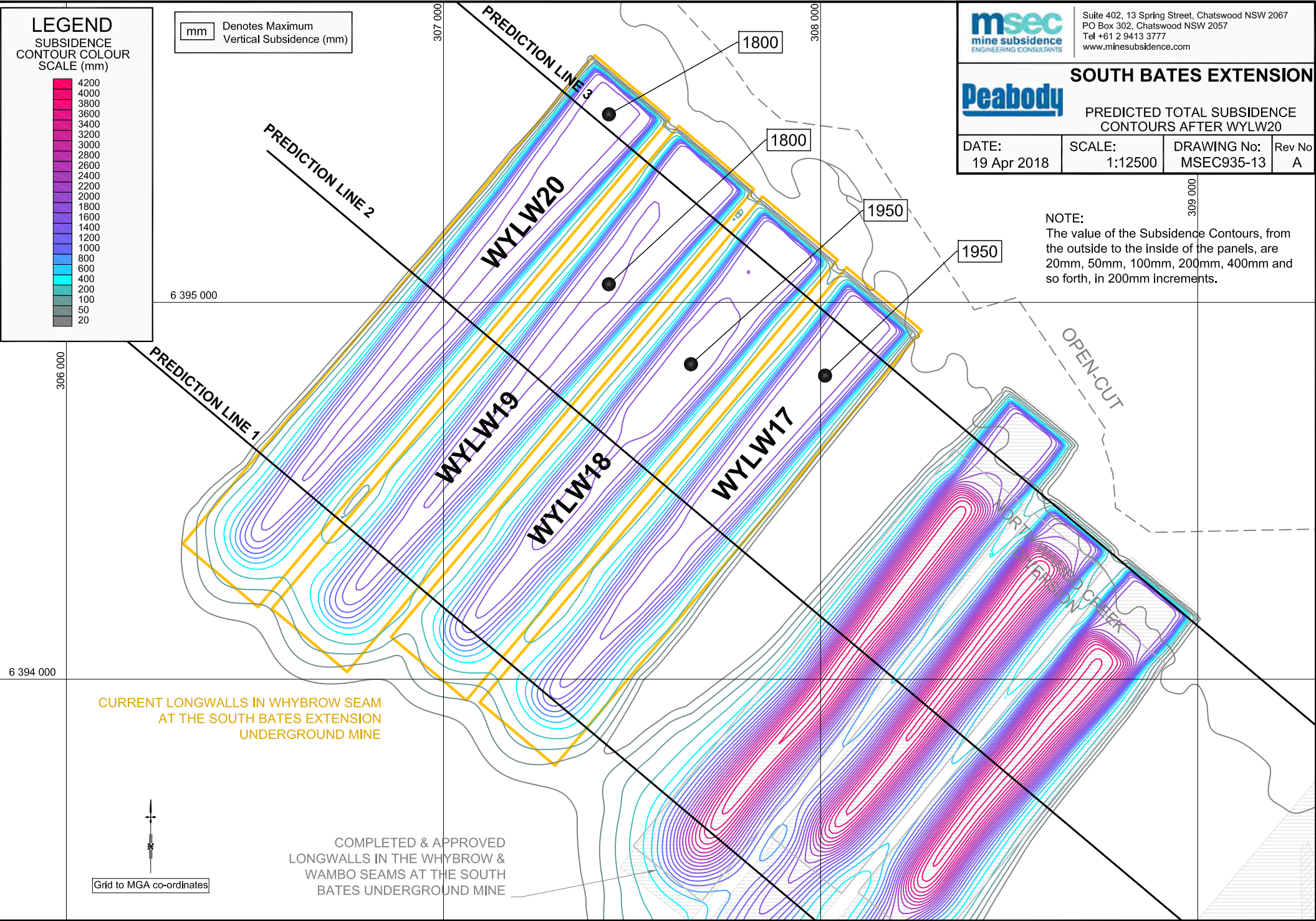


SOUTH BATES EXTENSION

PREDICTED TOTAL SUBSIDENCE
 CONTOURS AFTER WYLV20

DATE: 19 Apr 2018	SCALE: 1:12500	DRAWING No: MSEC935-13	Rev No A
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NOTE:
 The value of the Subsidence Contours, from
 the outside to the inside of the panels, are
 20mm, 50mm, 100mm, 200mm, 400mm and
 so forth, in 200mm increments.



mm Denotes Maximum
 Vertical Subsidence (mm)

CURRENT LONGWALLS IN WHYBROW SEAM
 AT THE SOUTH BATES EXTENSION
 UNDERGROUND MINE

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