WAMBO COAL PTY LIMITED

SOUTH BATES EXTENSION MODIFICATION

ENVIRONMENTAL ASSESSMENT

APPENDIX A
Subsidence Assessment

Peabody ENERGY

WAMBO COAL:

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

DOCUMENT REGISTER

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Report produced to: Support the Modification Application for the South Bates Extension Modification for WYLW17 to WYLW25 in the Whybrow Seam.

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

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

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

Wambo Coal Pty Limited (WCPL) operates the Wambo Coal Mine, which is located in the Hunter Coalfield of New South Wales. The mine was approved under Part 4 of the *Environmental Planning and Assessment Act 1979*, in February 2004, which included the extraction of longwalls in the Whybrow, Wambo, Arrowfield and Bowfield Seams.

WCPL proposes to modify the Development Consent to allow for the extraction of nine additional longwalls in the Whybrow Seam, referred to as WYLW17 to WYLW25, located to the north-west of the currently approved longwalls at the South Bates Underground Mine, part of the Wambo Coal Mine.

WCPL is preparing a Modification Application for the proposed WYLW17 to WYLW25. Mine Subsidence Engineering Consultants (MSEC) has been engaged by WCPL to prepare a subsidence prediction and assessment report to support that application.

The predicted subsidence parameters for the proposed WYLW17 to WYLW25 have been determined using the Incremental Profile Method. The maximum predicted parameters are 1,950 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 proposed longwalls, where the depths of cover are the shallowest.

The Study Area has been defined, as a minimum, as the surface area enclosed by a 26.5° angle of draw line from the extents of secondary extraction and by the predicted total 20 mm subsidence contour resulting from the proposed 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: North Wambo Creek and ephemeral drainage lines; the North Wambo Creek Diversion; the Wollemi Escarpment; other cliffs, minor cliffs and pagodas; steep slopes; the Wollemi National Park; unsealed tracks and trails; farm dams; mine infrastructure such as the Montrose Open Cut Pit (part of the Wambo Coal Mine), exploration drill holes and the proposed 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:

- North Wambo Creek is located directly above the proposed WYLW23 to WYLW25. There are also ephemeral drainage lines located across the Study Area. Ponding areas are predicted to develop along these streams having depths up to approximately 1.4 m and overall lengths up to approximate 350 m. If adverse impacts were to develop as the result of increased ponding along the streams, these could be remediated by locally regrading the 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 proposed longwalls. The impacts are expected to be similar to those observed along the streams above the previously extracted Wambo Seam longwalls at the North Wambo Underground Mine and along the creek diversion above the previously extracted WYLW11 at the South Bates Underground Mine. It may be necessary to remediate the larger surface deformations by infilling with the surface soil or other suitable materials, or by locally regrading and recompacting the surface.

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

  The depth of cover along the alignment of the North Wambo Creek Diversion, directly above the proposed WYLW17, varies between 50 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 are remediated during active subsidence, which could include infilling with cohesive materials and by regrading and recompacting the surface soils.

- Cliffs have been identified within 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 proposed 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 of the proposed longwalls and are predicted to experience subsidence 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. It is unlikely, therefore, that these cliffs would experience any adverse impacts as a result of the proposed longwalls.

  The Low Level Cliffs are located directly above the proposed longwalls. 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 the proposed longwalls could be impacted. This equates to a length of disturbance of approximately 15 m, or a face area 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 the Study Area.

- Steep slopes are located above the south-western ends of the proposed longwalls. Surface cracking and compression heaving could develop along the areas of the steep slopes that are located directly above the proposed 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, 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 proposed longwalls, at minimum distances of 120 m. 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 130 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 12 farm dams located within the Study Area. Fracturing and buckling would 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, 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 proposed 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 is proposed to 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 37 archaeological sites located within the Study Area, comprising 27 Open Artefact Sites, three Open Potential Archaeological Deposits (PADs), six Rock Shelters with PADs and one Scarred Tree. It is unlikely that the artefact scatters, isolated finds and the scarred tree would be adversely impacted by the mining induced surface cracking.

  The rock shelters located directly above the proposed longwalls could be affected by fracturing and spalling of the bedrock. It has been assessed impacts are possible (i.e. greater than 25 %) for Wambo Site 499, very unlikely (i.e. less than 10 %) for Wambo Sites 500, 501, 502 and 504 and rare (i.e. less than 5 %) for Wambo Site 503.

- The Whynot Homestead and associated sheds are located above the proposed WYLW21 and other building structures are also located above the proposed WYLW25. The building structures are all unused and are in poor conditions.

  It is recommended that the building structures are visually monitored during active subsidence. If any structure is identified as unstable or unsafe during monitoring, then measures to stabilise it should be undertaken, such as packing of the timber pier supports, provision of temporary bracing or the installation of fencing to prevent access.

The assessments provided in this report indicate that the levels of impact on the natural and built features can be managed by the preparation and implementation of the appropriate management strategies. It should be noted, however, that more detailed assessments of some natural and built features have been undertaken by other specialist consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

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Tables

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

Figures

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

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Drawings

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

1.0 INTRODUCTION

1.1. Background

Wambo Coal Pty Limited (WCPL) operates the Wambo Coal Mine, which is located in the Hunter Coalfield of New South Wales (NSW). The mine was approved under Part 4 of the *Environmental Planning and Assessment Act 1979*, in February 2004, which included the extraction of longwalls in the Whybrow, Wambo, Arrowfield and Bowfield Seams.

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

WCPL proposes to modify the Development Consent to allow for the extraction of nine additional longwalls in the Whybrow Seam, referred to as WYLW17 to WYLW25, located to the north-west of the currently approved longwalls at the South Bates Underground Mine. The locations of the proposed and approved longwalls are shown in Drawings Nos. MSEC848-01 and MSEC848-02, which together with all other drawings, are included in Appendix D at the end of this report.

WCPL is preparing a Modification Application for WYLW17 to WYLW25 as part of the South Bates Extension Underground Mine Modification. Mine Subsidence Engineering Consultants (MSEC) has been commissioned by WCPL to provide:

- subsidence predictions for the proposed WYLW17 to WYLW25, including the cumulative subsidence due to the adjacent approved longwalls;
- subsidence predictions for the natural and built features in the mining area;
- impact assessments, in conjunction with other specialist consultants, for each of these natural and built features; and
- recommended management strategies and monitoring for WYLW17 to WYLW25.

This report has been prepared to support the Modification Application for the proposed longwalls 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 proposed and approved longwalls.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of the proposed WYLW17 to WYLW25.

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

The proposed WYLW17 to WYLW25 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.

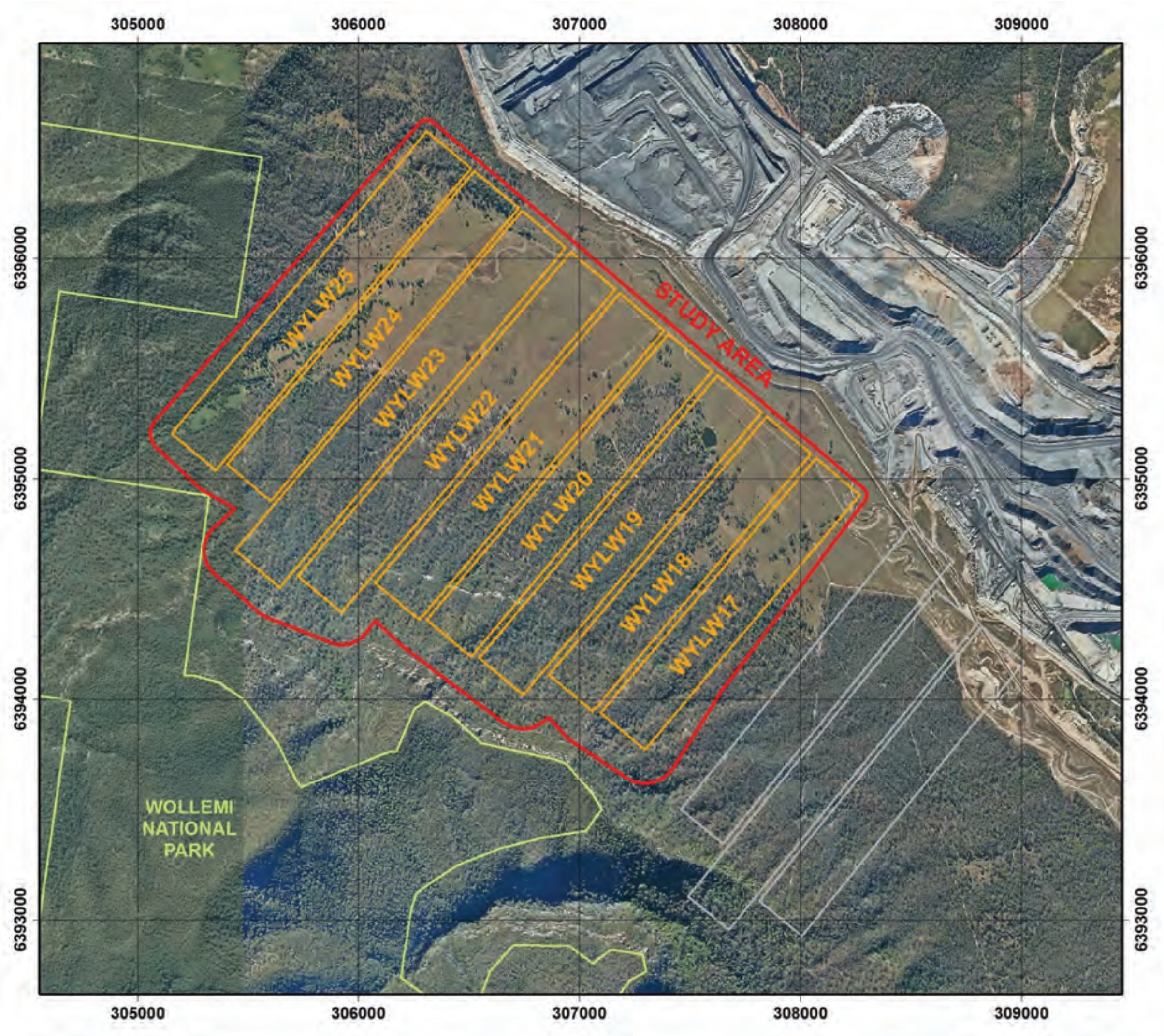

Fig. 1.1 Aerial Photograph Showing Locations of WYLW17 to WYLW25 and the Study Area

1.2. Mining Geometry

The layout of WYLW17 to WYLW25 is shown in Drawings Nos. MSEC848-01 and MSEC848-02. A summary of the dimensions for these longwalls is provided in Table 1.1.

Table 1.1 Geometry of WYLW17 to WYLW25

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
WYLW17	1510	261	-
WYLW18	1530	261	31
WYLW19	1675	261	30
WYLW20	1700	261	31
WYLW21	1720	261	26
WYLW22	1920	261	30
WYLW23	2015	261	29
WYLW24	1740	261	21
WYLW25	1795	261	21

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).

1.3. Surface and Seam Levels

The natural surface and the levels of the Whybrow 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. MSEC848-03 to MSEC848-05. The approved longwalls in the Whybrow and Wambo Seams are shown with the cyan outlines and the proposed longwalls in the Whybrow Seam are shown with the blue outlines.

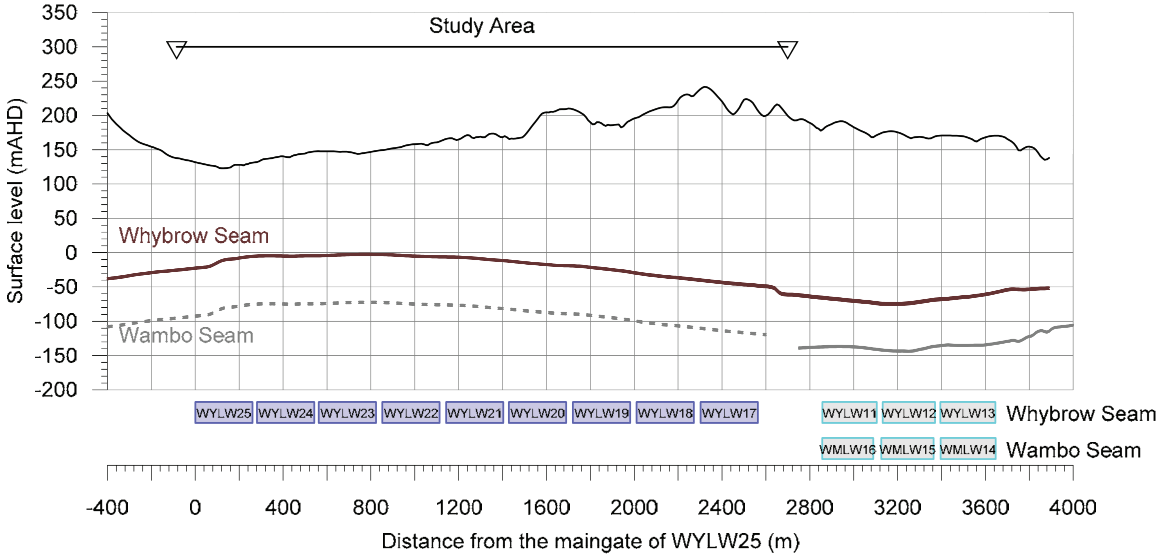

Fig. 1.2 Surface and Seam Levels along Cross-section 1 near the Longwall Commencing Ends

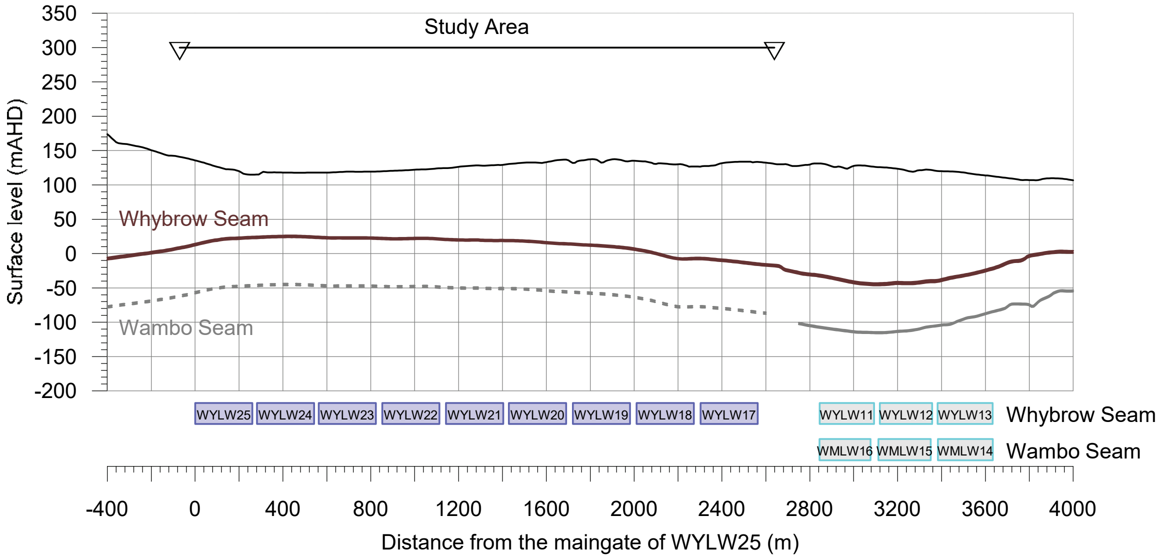

Fig. 1.3 Surface and Seam Levels along Cross-section 2 near the Middle of the Longwalls

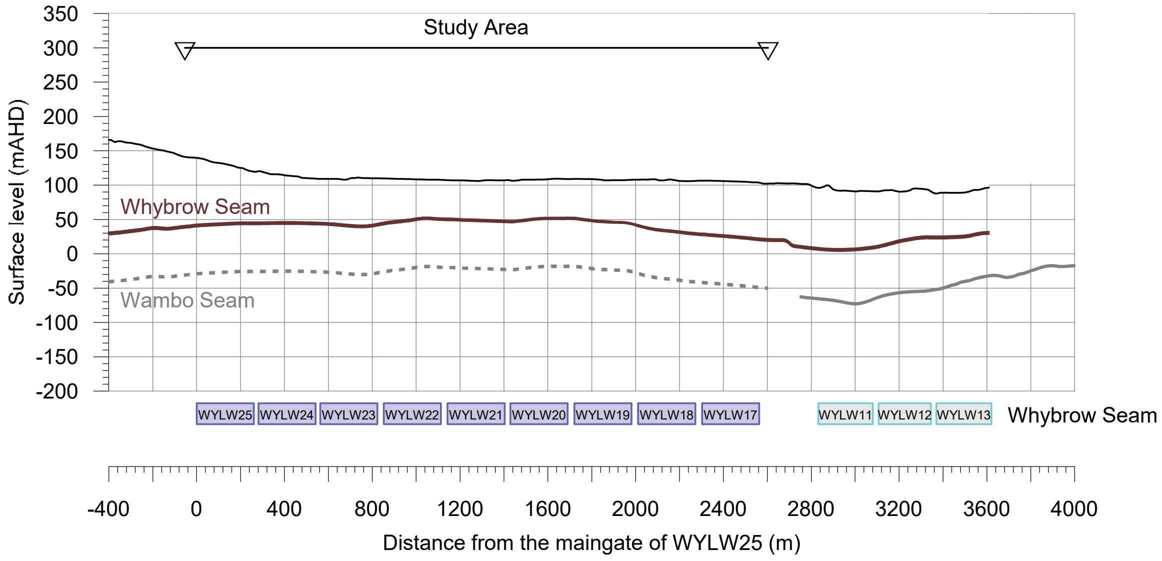

Fig. 1.4 Surface and Seam Levels along Cross-section 3 near the Longwall Finishing Ends

The surface level contours are shown in Drawing No. MSEC848-03. The major natural topographical feature in area is the Wollemi Escarpment, which is located to the south-west and to the west of the proposed longwalls. The Montrose Open Cut Pit is located to the north-east of the longwalls.

The surface levels directly above the proposed longwalls vary from a high point of 285 m above Australian Height Datum (mAHD) above the commencing (i.e. south-western) end of WYLW18, to a low point of 100 mAHD above the finishing (i.e. north-eastern) end of WYLW17.

The seam floor contours, seam thickness contours and depth of cover contours for the Whybrow Seam are shown in Drawings Nos. MSEC848-04, MSEC848-05, and MSEC848-06, respectively. The contours are based on the latest seam information provided by WCPL.

The depths of cover to the Whybrow Seam directly above the proposed longwalls vary 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.

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 proposed longwalls is around 6 %, or 1 in 17. The thickness of the Whybrow Seam within the extents of the proposed longwalls varies between 1.6 m and 3.6 m. The proposed mining heights for the longwalls are illustrated in Drawing No. MSEC848-05 and vary from less than 2.8 up to 3.0 m.

1.4. Geological Details

The South Bates Underground Mine lies in the Hunter Coalfield, within the Northern Sydney Basin. A typical stratigraphic section of the Hunter Coalfield, reproduced from the Department of Mineral Resources (DMR) *Hunter Coalfield Regional 1:100 000 Geology Map*, is shown in Table 1.2 (DMR, 1993). It is noted, that the DMR is now referred to as the Department of Industry – Division of Resources and Energy (DRE).

The Whybrow 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	
			Clifford Formation	
		Appletree Flat Subgroup	Charlton Formation	
			Abbey Green Coal	
		Watts Sandstone		
	Wittingham Coal Measures	Denman Formation		
		Jerrys Plains Subgroup	Mount Leonard Formation	**Whybrow Seam**
			Althorpe Formation	
			Malabar Formation	Redbank Creek Seam
				Wambo Seam
				Whynot Seam
				Blakefield Seam
			Mount Ogilvie Formation	Glen Munro Seam
				Woodlands Hill Seam
			Milbrodale Formation	
			Mount Thorley Formation	Arrowfield Seam
				Bowfield Seam
				Warkworth Seam
			Fairford Formation	
			Burnamwood Formation	Mount Arthur Seam
				Piercefield Seam
				Vaux Seam
				Broonie Seam
				Bayswater Seam
		Archerfield Sandstone		
		Vane Subgroup	Bulga Formation	
			Foybrook Formation	
			Saltwater Creek Formation	

WCPL provided the logs for typical drill holes located within the proposed mining area, which are shown in Drawing No. MSEC848-09. The geological section for drill hole UG139 is provided in Table 1.3.

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 proposed 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 proposed 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. MSEC848-07. The largest structure in the area is the *Redmanvale Fault* that is located south-west of the proposed longwalls. This normal fault dips towards the north-east and has a throw greater than 20 m.

The distance of the Redmanvale Fault from the commencing end of WYLW17 (i.e. the first proposed 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 75 m from the commencing end of WYLW23, at its closest point to the proposed longwalls.

The surface expression of the Redmanvale Fault is likely to be associated with the Wollemi Escarpment adjacent to the commencing ends of WYLW22 to WYLW24 and associated with the valley of the tributary to Stony Creek adjacent to the earlier longwalls in the series.

There is a series of north to south trending faults through the north-eastern ends of the proposed WYLW17 to WYLW21 and north-east to south-west trending faults through the south-western end of the proposed WYLW17. 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 proposed longwalls, above solid coal, but this low level subsidence is not predicted to be associated with any significant tilts, curvatures or strains.

The surface lithology in the area can be seen in Fig. 1.5, which shows the longwalls and the Study Area overlaid on the *Geological Map of Doyles Creek 9032-1-N*, which was published by the DMR (1988), now known as DRE.

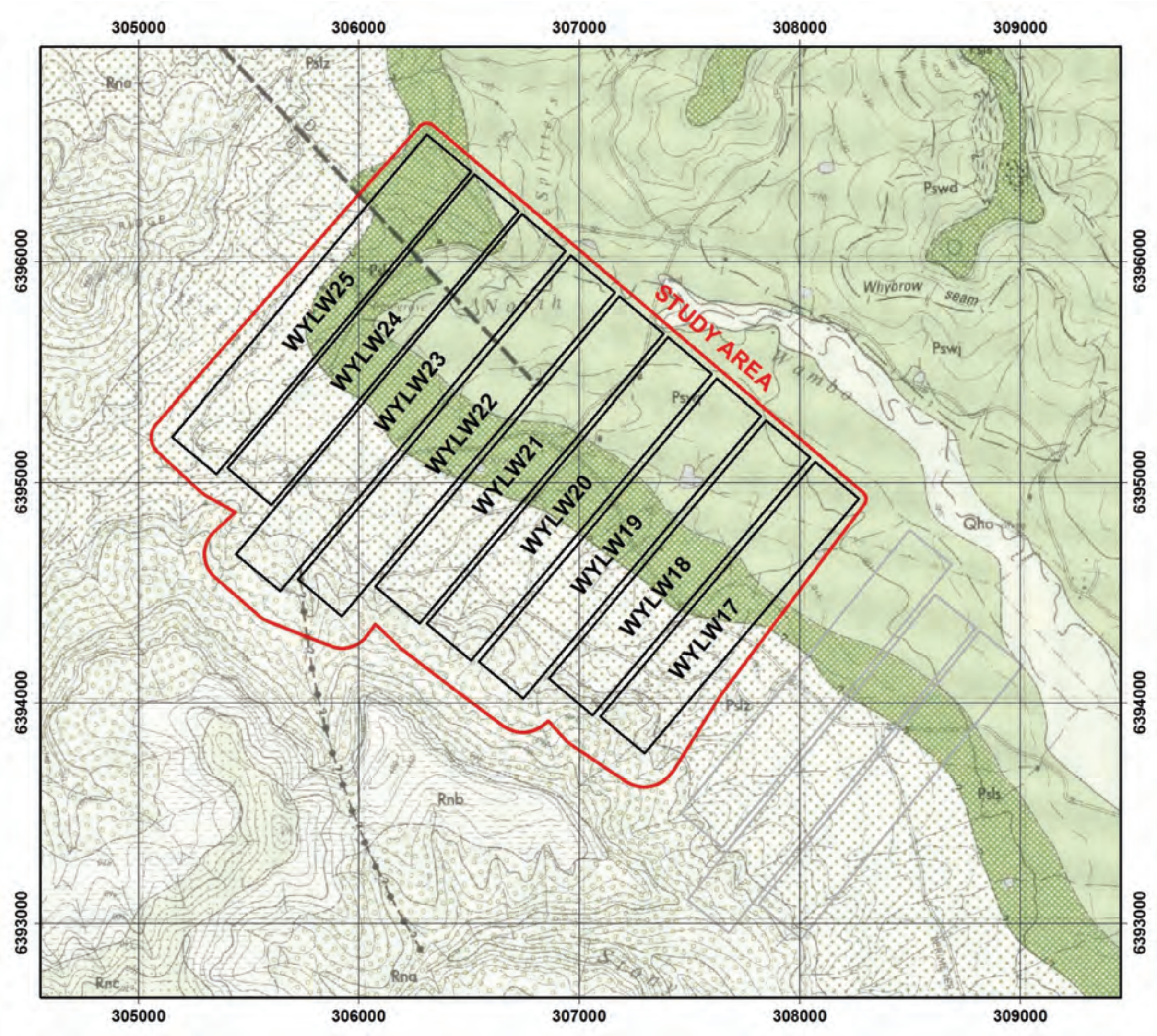

Fig. 1.5 WYLW17 to WYLW25 Overlaid on Geological Map Doyles Creek 9032-1-N

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 the proposed WYLW17 to WYLW25, the Watts Sandstone (Psls) above the middle parts of the proposed longwalls and the Newcastle Coal Measures (Pslz) and the Widden Brook Conglomerate (Rna) above the south-western ends of the proposed longwalls.

The surface lithology adjacent to the north-eastern ends of the proposed 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 the proposed WYLW17 to WYLW25 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 the proposed WYLW17 to WYLW25; and
- the predicted limit of vertical subsidence, taken as the 20 mm subsidence contour resulting from the extraction of the proposed WYLW17 to WYLW25.

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. MSEC848-06. It can be seen from this drawing that the depths of cover directly above the proposed 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 proposed longwalls.

The predicted limit of vertical subsidence, taken as the predicted 20 mm subsidence contour due to the extraction of the proposed WYLW17 to WYLW25, 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 20 mm subsidence contour, are shown in Drawing No. MSEC848-10.

A line has therefore been drawn defining the Study Area, based upon the 26.5° angle of draw line and the predicted 20 mm subsidence contour, whichever is furthest from the proposed WYLW17 to WYLW25, and is shown in Drawings Nos. MSEC848-01 and MSEC848-02.

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

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

A number of the 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 proposed longwalls and the Study Area have been overlaid on an extract of this CMA map in Fig. 2.1.

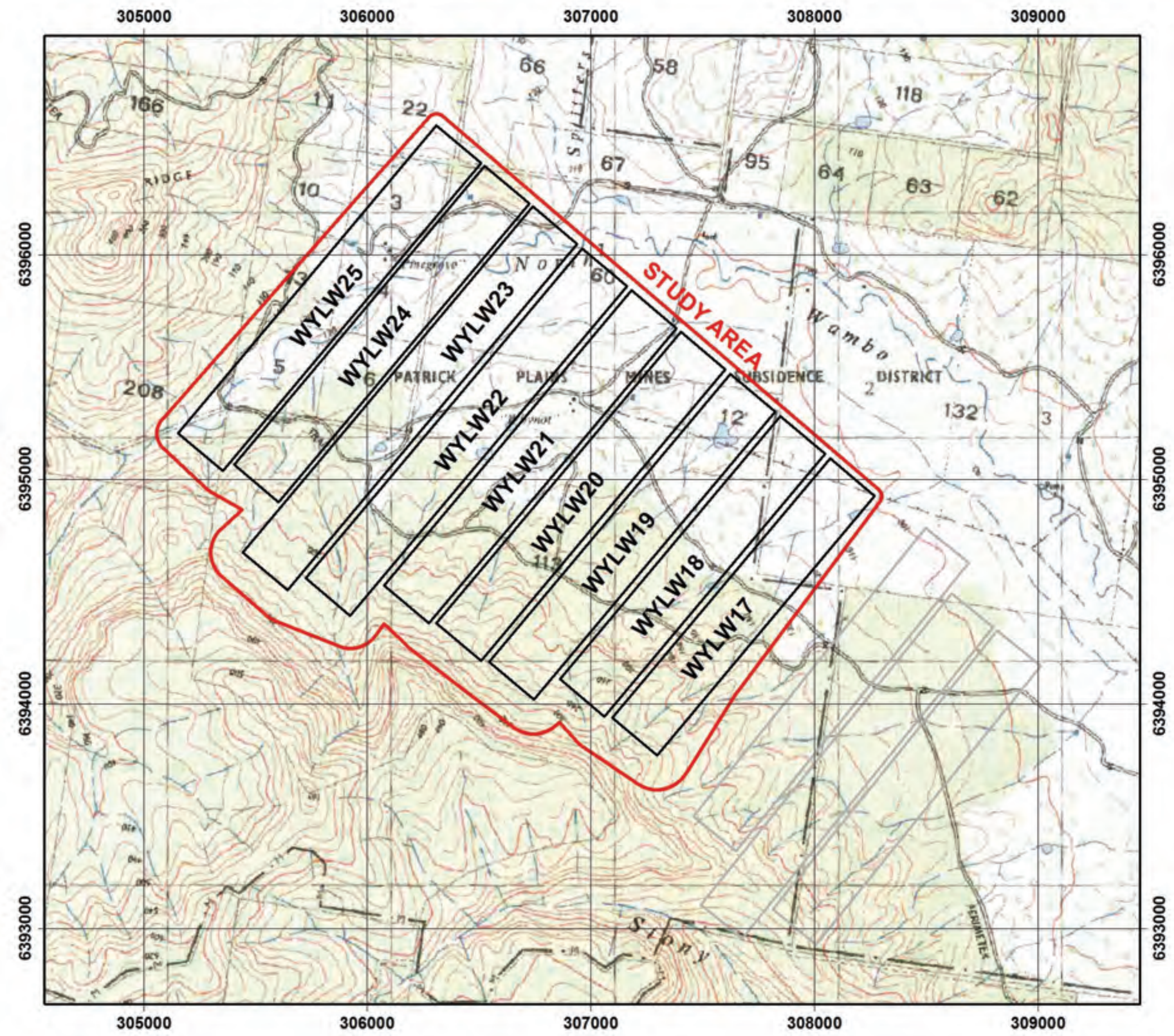

Fig. 2.1 WYLW17 to WYLW25 Overlaid on CMA Map No. Doyles Creek 9032-1-N

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. MSEC848-08 and MSEC848-09. 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
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	×	
Streams	✓	5.2 & 5.3
Aquifers or Known Groundwater Resources	×	
Springs or Groundwater Seeps	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.6 & 5.7
Steep Slopes	✓	5.8
Escarpments	✓	5.5
Land Prone to Flooding or Inundation	×	5.9
Swamps or Wetlands	×	
Water Related Ecosystems	✓	5.10
Threatened or Protected Species	✓	5.11
Lands Defined as Critical Habitat	×	
National Parks	✓	5.12
State Forests	×	
State Recreation or Conservation Areas	×	
Natural Vegetation	✓	5.13
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	×	
Roads (All Types)	✓	6.1.1
Bridges	×	
Tunnels	×	
Culverts	✓	6.1.1
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	×	
Telecommunication Lines or Associated Plants	×	
Water Tanks, Water or Sewage Treatment Works	×	
Dams, Reservoirs or Associated Works	×	
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	×	
Shopping Centres	×	
Community Centres	×	
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

Item	Within Study Area	Section Number
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	×	6.3.1
Farm Buildings or Sheds	✓	6.7
Tanks	✓	6.7
Gas or Fuel Storages	×	
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	✓	6.3.2
Farm Dams	✓	6.3.3
Wells or Bores	✓	6.3.4
Any Other Farm Features	×	
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Factories	×	
Workshops	×	
Business or Commercial Establishments or Improvements	×	
Gas or Fuel Storages or Associated Plants	×	
Waste Storages or Associated Plants	×	
Buildings, Equipment or Operations that are Sensitive to Surface Movements	×	
Surface Mining (Open Cut) Voids or Rehabilitated Areas	✓	6.4.1
Mine Related Infrastructure Including Exploration Bores and Gas Wells	✓	6.4.2 & 6.4.3
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL SIGNIFICANCE	✓	0
AREAS OF HISTORICAL SIGNIFICANCE	×	
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.6
RESIDENTIAL ESTABLISHMENTS		
Houses	✓	6.7
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

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3.1. Introduction

This chapter provides an overview of the methods that have been used to predict the mine subsidence movements resulting from the extraction of the proposed WYLW17 to WYLW25. Further details on methods of mine subsidence prediction are provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

3.2. The Incremental Profile Method

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

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

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

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

Based on the extensive empirical data, MSEC has developed standard subsidence prediction curves for the Southern, Newcastle and Hunter Coalfields. The prediction curves can then be further refined, for the local geology and local conditions, based on the available monitoring data from the area. Discussions on the calibration of the IPM for WYLW17 to WYLW25 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.

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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 WYLW17 to WYLW25. 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 the proposed WYLW17 to WYLW25 (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 proposed 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 observed subsidence varies greatly from point to point, at these very shallow depths of cover, as the result of variations in the overburden geology.

In the south-western part of the mining area, the width-to-depth ratios are less than 1.4 and, therefore, the longwalls are subcritical 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 observed subsidence movements along monitoring lines with those predicted using the standard IPM for the Hunter Coalfield.

The ground movements have been measured along the 7XL-Line and the CL11B-Line which are located above WYLW11 at the South Bates Mine. The location of these monitoring lines are shown in Drawing No. MSEC848-01. The profiles of observed subsidence, tilt and curvature along the 7XL-Line and the CL11B-Line are shown in Fig. 3.1 and Fig. 3.2, respectively. The predicted movements are also shown in these figures for comparison, based on the predictions provided in Report No. MSEC692, which supported the Extraction Plan for WYLW11 to WYLW13.

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

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

It is considered that the standard IPM for the Hunter Coalfield has provided acceptable predictions of subsidence, tilt and curvature along the 7XL-Line and CL11B-Line after the completion of WYLW11.

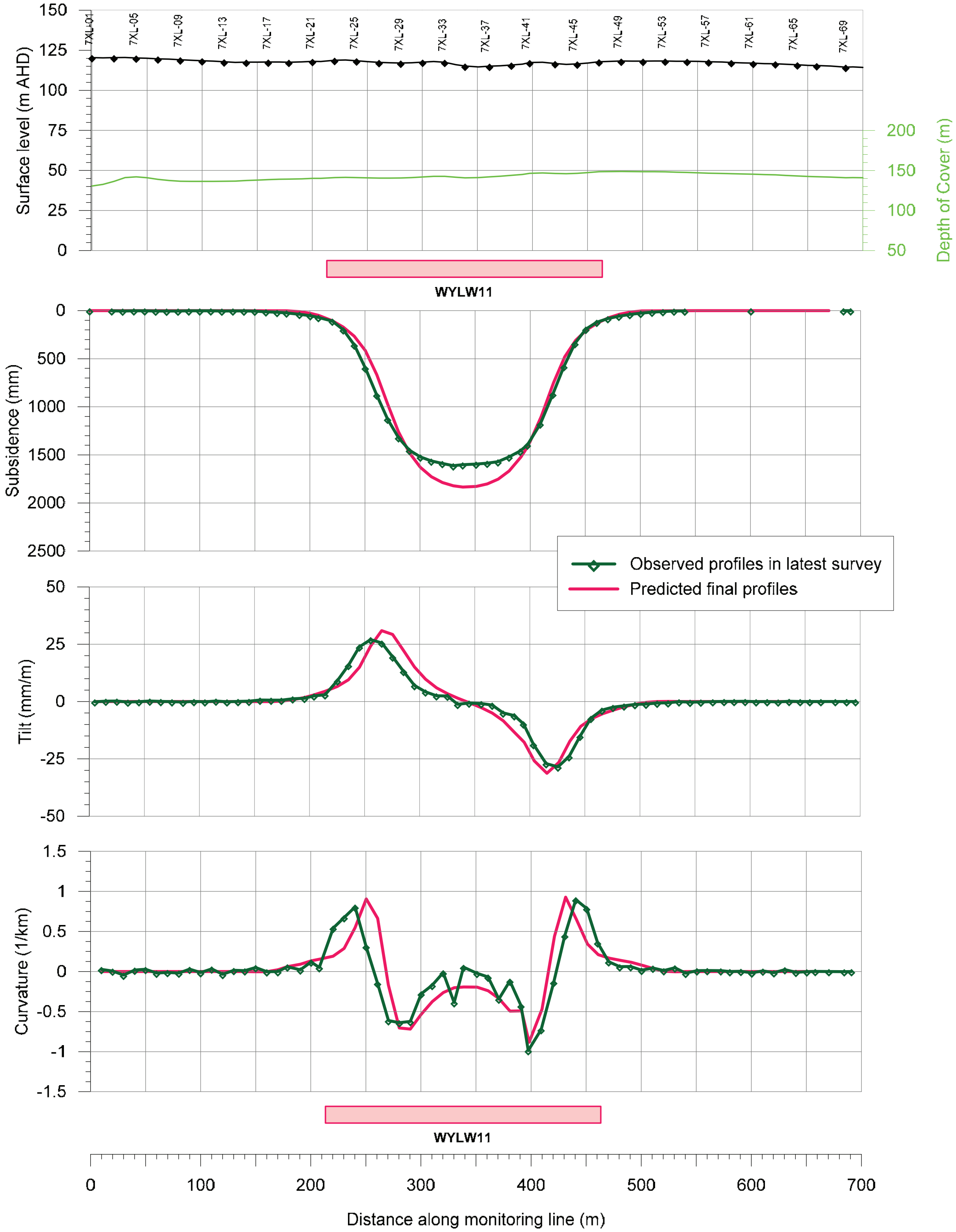

Fig. 3.1 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along the 7XL-Line at the South Bates Mine

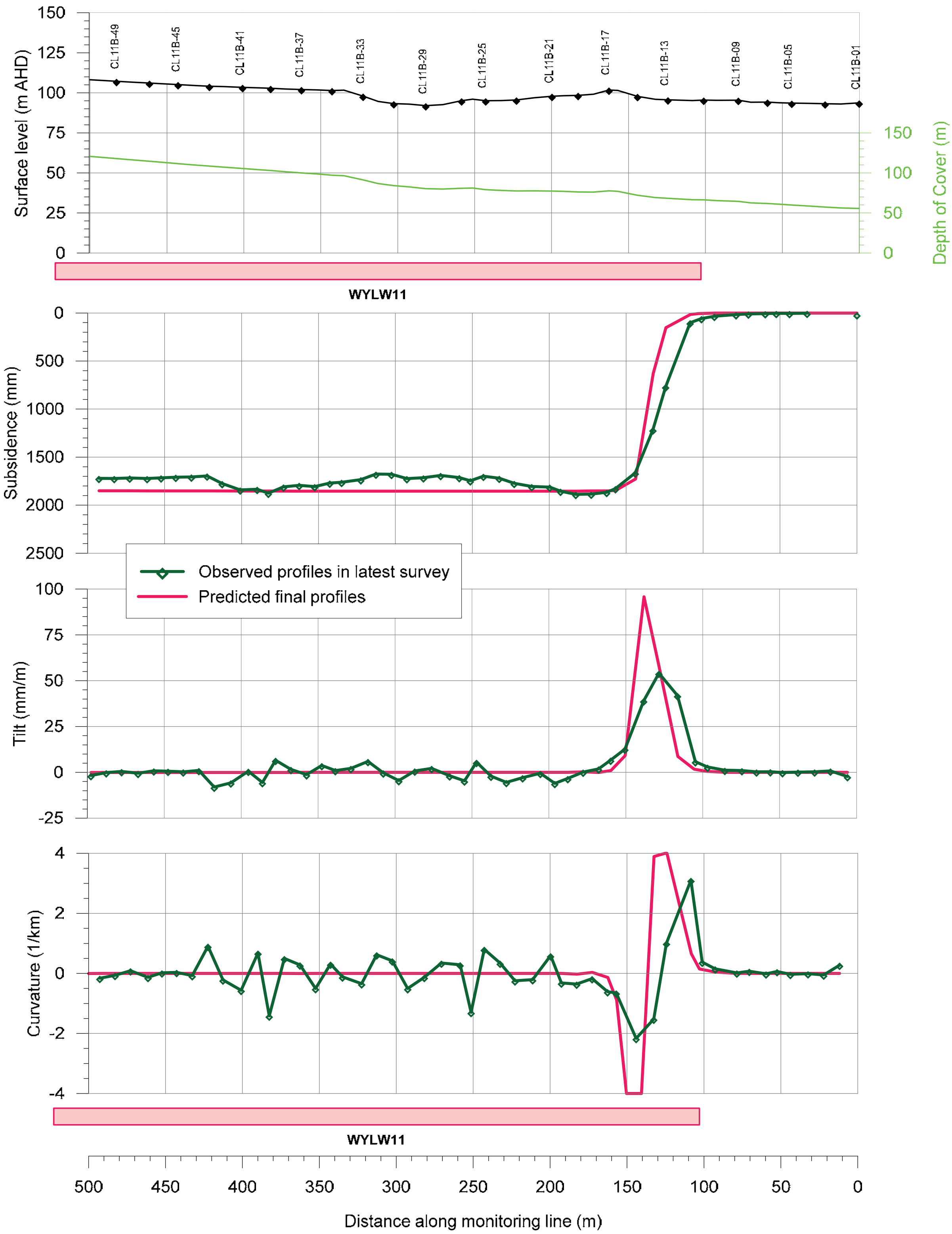

Fig. 3.2 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along the CL11B-Line at the South Bates Mine

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 Department of Industry). The existing workings at the NWUM and the locations of the monitoring lines are shown in Drawing No. MSEC848-01.

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 WYLW17 to WYLW25.

The profiles of observed 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. 3.3. The back-predicted movements, based on the standard IPM, are also shown in this figure for comparison. The observed 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 observed 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 observed and back-predicted 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. 3.4, Fig. 3.5 and Fig. 3.6, respectively.

It can be seen from Fig. 3.3 to Fig. 3.6, that the observed profiles of subsidence, tilt and curvature along these monitoring lines reasonably match those predicted using the standard IPM. There are small lateral shifts between the observed and predicted profiles, in some locations, which could be the result of surface dip, seam dip, or variations in the overburden geology.

The maximum observed 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 observed subsidence along the XL3-Line represents around 65 % of the extracted seam thicknesses.

The maximum observed subsidence along the other three monitoring lines from the Hunter Coalfield (i.e. Fig. 3.4 to Fig. 3.6) are less than the maxima predicted using the standard IPM. The maximum observed subsidence along these monitoring lines represents between 40 and 50 % of the extracted seam thicknesses.

The magnitudes of the observed tilts and curvatures along the monitoring lines are reasonably similar to those predicted using the standard IPM. It can be seen, however, that the observed tilts and curvatures are less than those predicted, in some locations, whilst the observed 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 observed 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 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 WYLW17 to WYLW25 based on single-seam mining conditions.

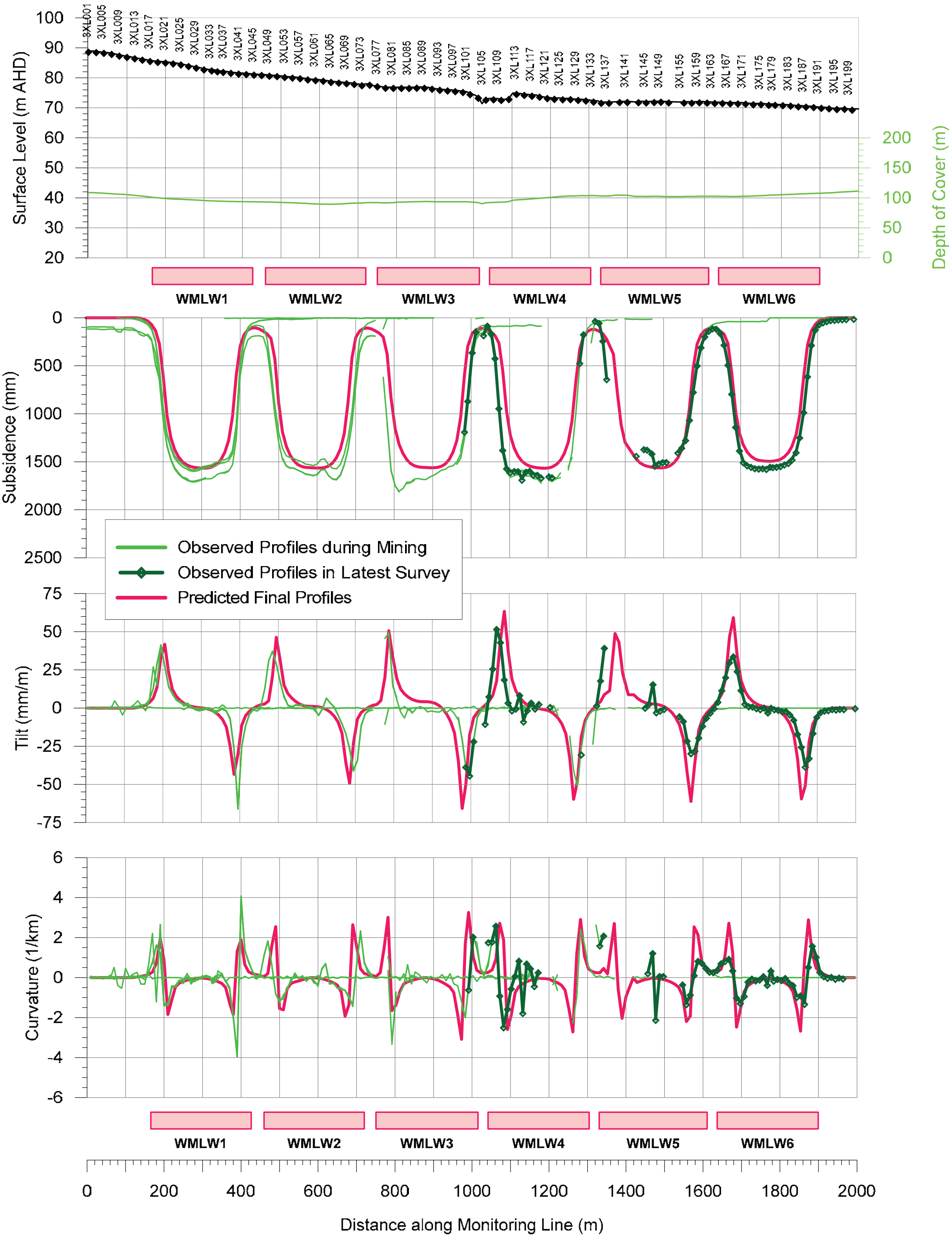

Fig. 3.3 Comparison of Observed and Back-Predicted Subsidence, Tilt and Curvature along the XL3-Line at the North Wambo Underground Mine

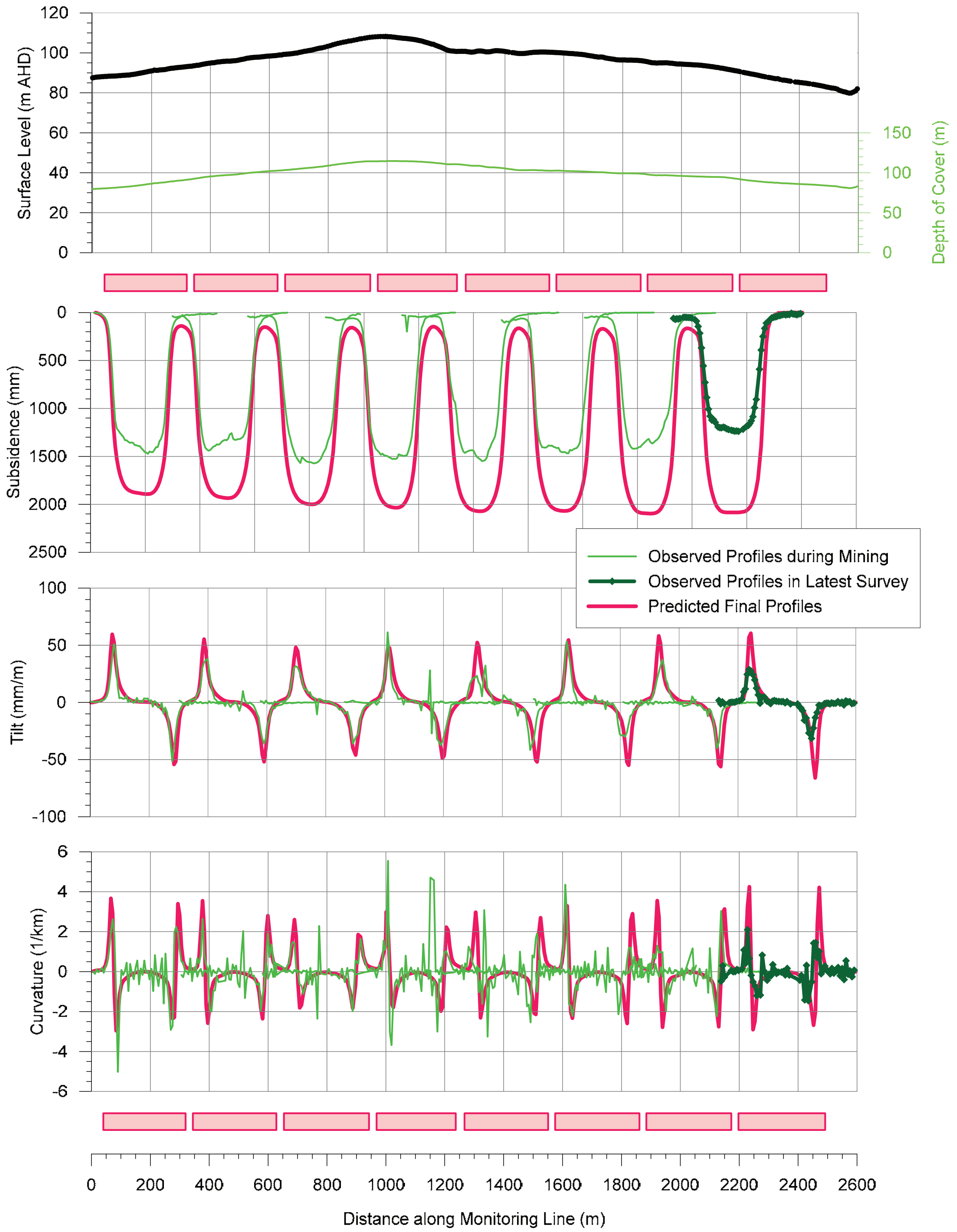

Fig. 3.4 Comparison of Observed and Back-Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with a Width-to-Depth Ratio of 3.0

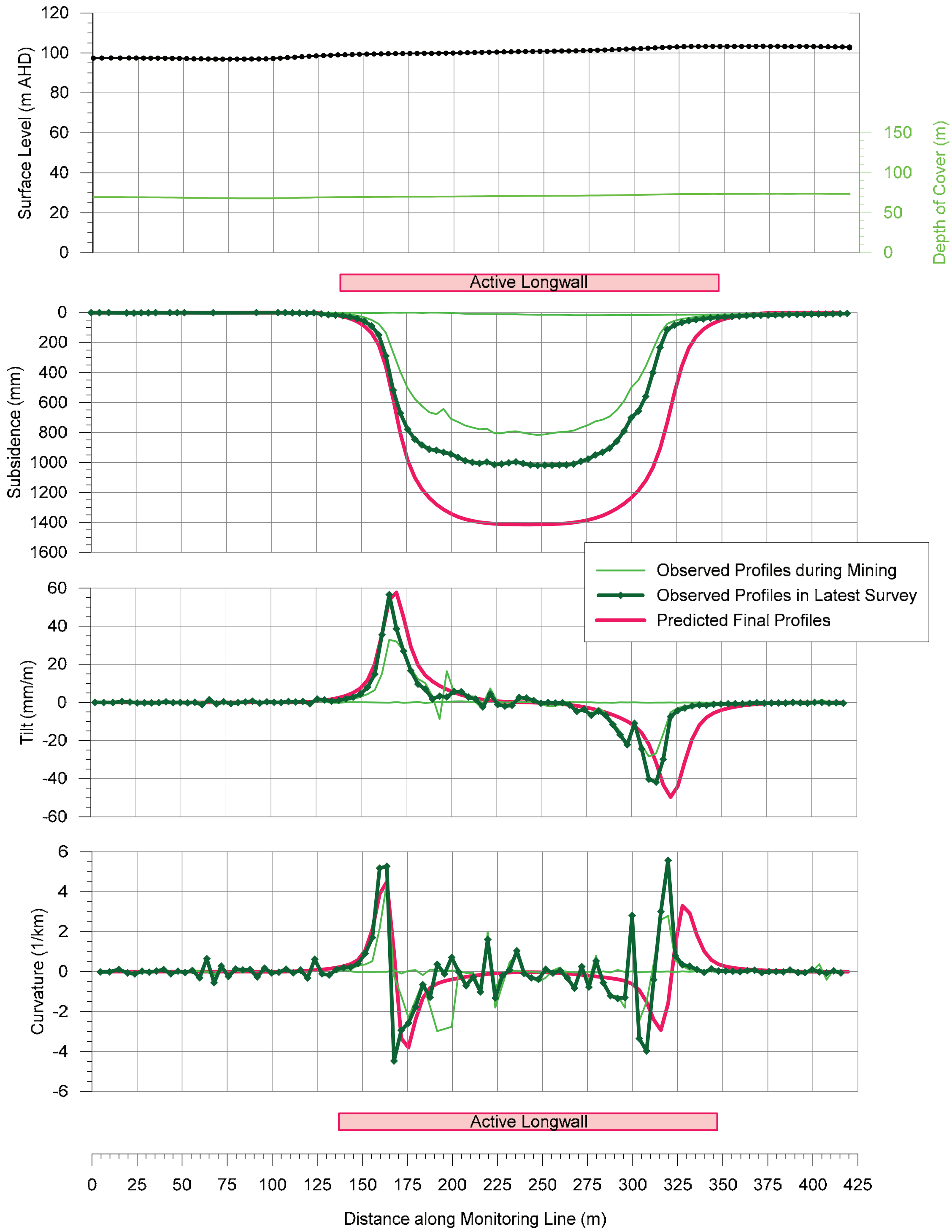

Fig. 3.5 Comparison of Observed and Back-Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with a Width-to-Depth Ratio of 2.0

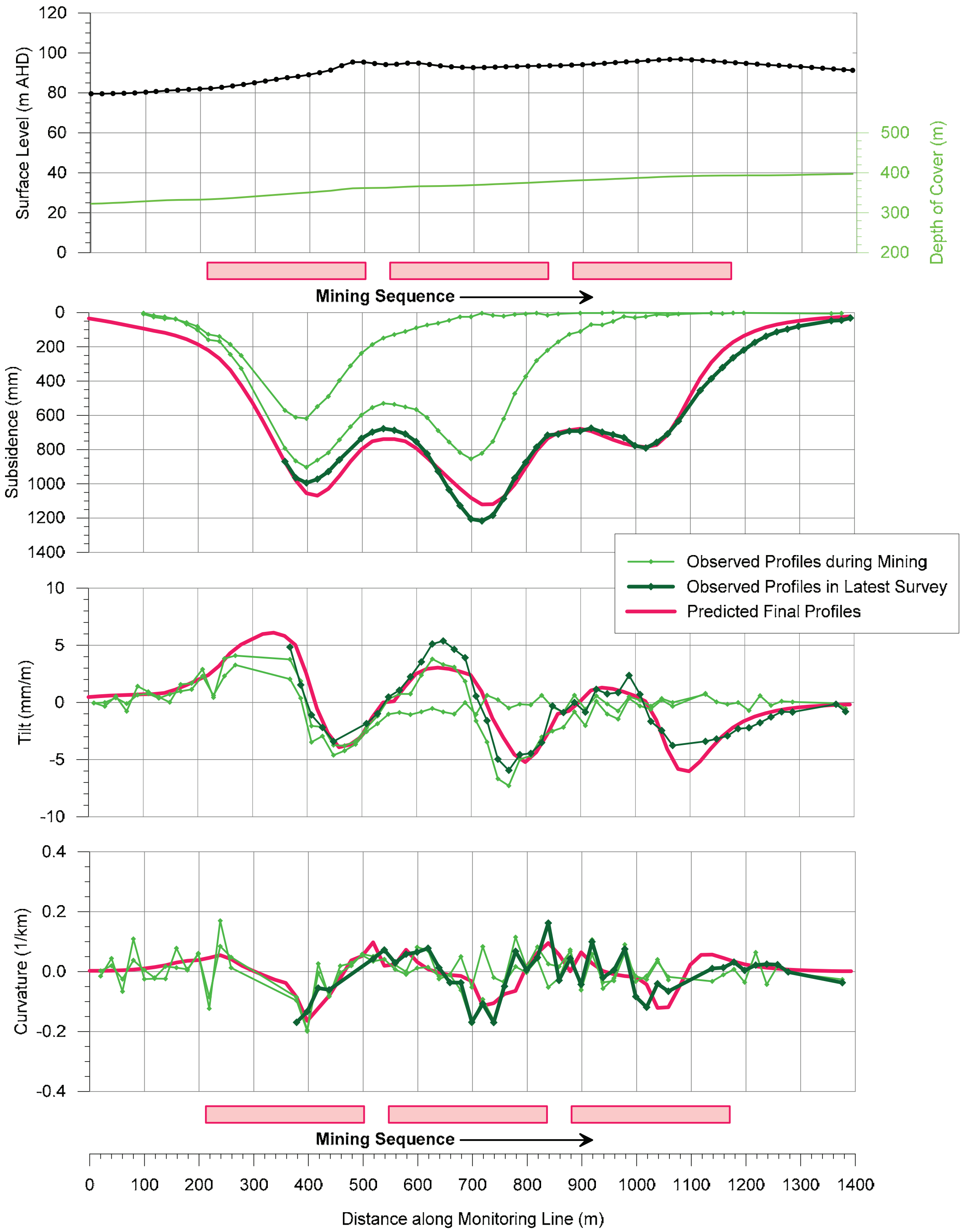

Fig. 3.6 Comparison of Observed and Back-Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with Width-to-Depth Ratio of 0.7

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 the proposed WYLW17 to WYLW25 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 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 NSW Collieries, where the mining geometries are similar to those for the proposed WYLW17 to WYLW25.

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

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

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

The predicted total conventional subsidence contours resulting from the extraction of the proposed WYLW17 to WYLW25 are shown in Drawing No. MSEC848-10. The predicted cumulative subsidence contours due to the extraction of the approved WYLW11 to WYLW13 and the approved WMLW14 to WMLW16 have also been shown in this drawing.

It can be seen in Drawing No. MSEC848-10, 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 proposed 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 proposed longwalls are primarily the result of the changes in the depths of cover, which are illustrated in Drawing No. MSEC848-06. To further illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along three predictions lines, the locations of which are shown in Drawing No. MSEC848-10.

The predicted profiles of conventional 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 proposed longwalls, are shown as blue lines. The predicted total profiles due to the extraction of the approved WYLW11 to WYLW13 and the approved WMLW14 to WMLW16 are shown as the cyan lines for comparison.

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature along the prediction lines, resulting from the extraction of the proposed WYLW17 to WYLW25, is provided in Table 4.1. The maximum predicted subsidence parameters anywhere above the proposed longwalls are also shown in this table, which occur near the finishing (i.e. north-eastern) ends of the longwalls.

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Table 4.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature Resulting from the Extraction of WYLW17 to WYLW25

Location	Depth of Cover to Whybrow Seam (m)	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Prediction Line 1	130 ~ 280	1,800	30	1.2	0.9
Prediction Line 2	90 ~ 150	1,900	55	3.0	3.0
Prediction Line 3	60 ~ 110	1,950	85	> 3.0	> 3.0
Anywhere above Longwalls	50 ~ 330	1,950	90	> 3.0	> 3.0

The maximum predicted total subsidence resulting from the extraction of the proposed WYLW17 to WYLW25 is 1,950 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 Maximum Predicted Conventional Subsidence Parameters

WCPL has approval to extract WYLW11 to WYLW13 in the Whybrow Seam and WMLW14 to WMLW16 in the Wambo Seam at the South Bates Mine. A comparison of the maximum predicted total conventional subsidence parameters for the proposed WYLW17 to WYLW25 with the maxima predicted for the approved longwalls is provided in Table 4.2.

Table 4.2 Comparison of Maximum Predicted Total Subsidence Parameters

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved WYLW11 to WYLW13 and WMLW14 to WMLW16	4,150	100	> 3.0	> 3.0
Proposed WYLW17 to WYLW25	1,950	90	> 3.0	> 3.0

The maximum predicted total subsidence for the proposed longwalls of 1,950 mm is less than the maximum predicted of 4,150 mm for the approved longwalls. The predicted vertical subsidence for the approved longwalls is greater due to mining in both the Whybrow and Wambo Seams (i.e. cumulative multi-seam subsidence).

The maximum predicted tilt for the proposed longwalls of 90 mm/m is slightly less than the maximum predicted tilt of 100 mm/m for the approved longwalls. The predicted tilt for the proposed longwalls is similar to that for the approved longwalls due to mining in the Whybrow Seam only.

The maximum predicted total curvature is greater than 3.0 km^{-1} for both the proposed and approved longwalls. 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 proposed 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 the proposed WYLW17 to WYLW25 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 proposed 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 proposed longwalls.

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

4.4.1. 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 depth of cover is shallowest above the commencing end of WYLW25 and is greatest above the commencing end of WYLW18. The width-to-depth ratios at the longwall commencing ends, therefore, typically range between 0.8 and 1.3.

The observed 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 the proposed WYLW17 to WYLW25.

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 observed tensile and compressive strains measured 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.

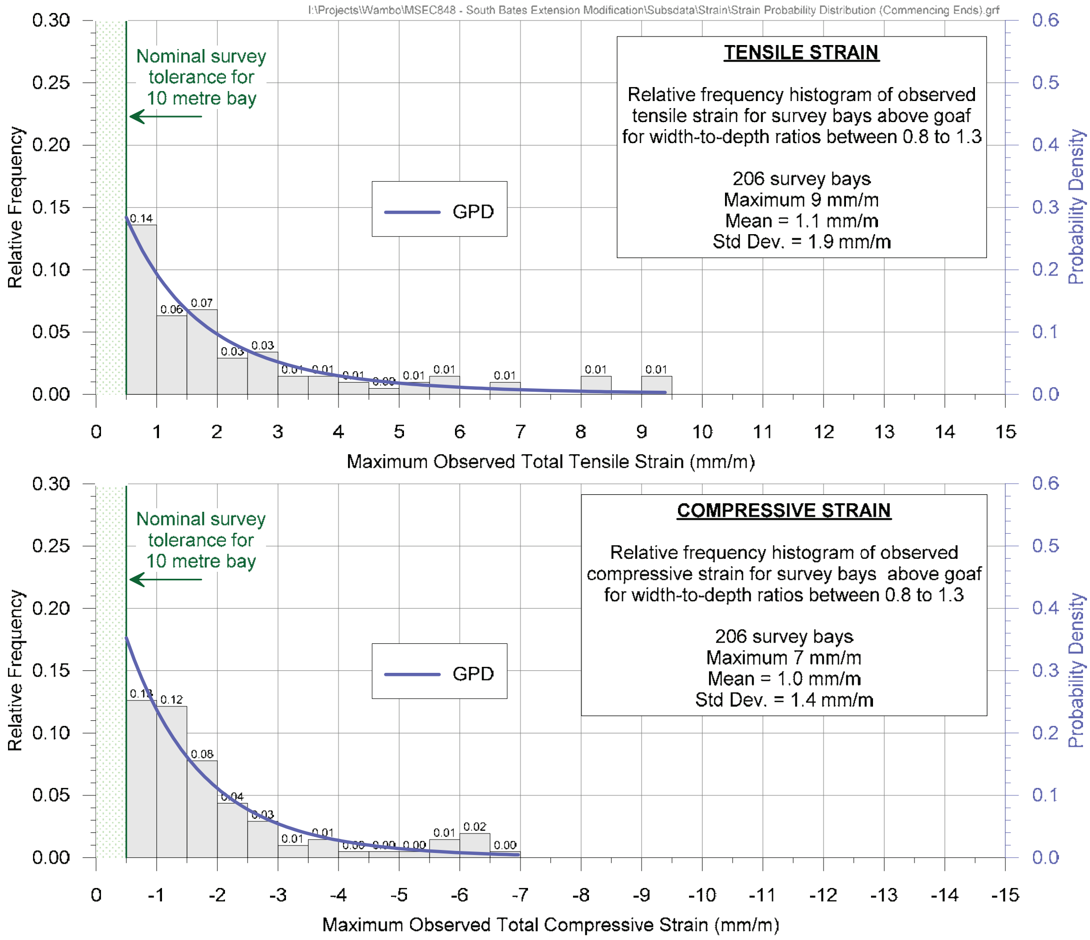

Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located above Longwalls with Width-to-Depth Ratios between 0.8 and 1.3

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 depth of cover is shallowest above the finishing ends of WYLW19 and WYLW20 and is greatest above the finishing end of WYLW25. 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 observed ground strains have been analysed for monitoring lines from the Hunter and Newcastle Coalfields, where the longwalls have been supercritical in width and where the depths of cover 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 the proposed WYLW17 to WYLW25.

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.

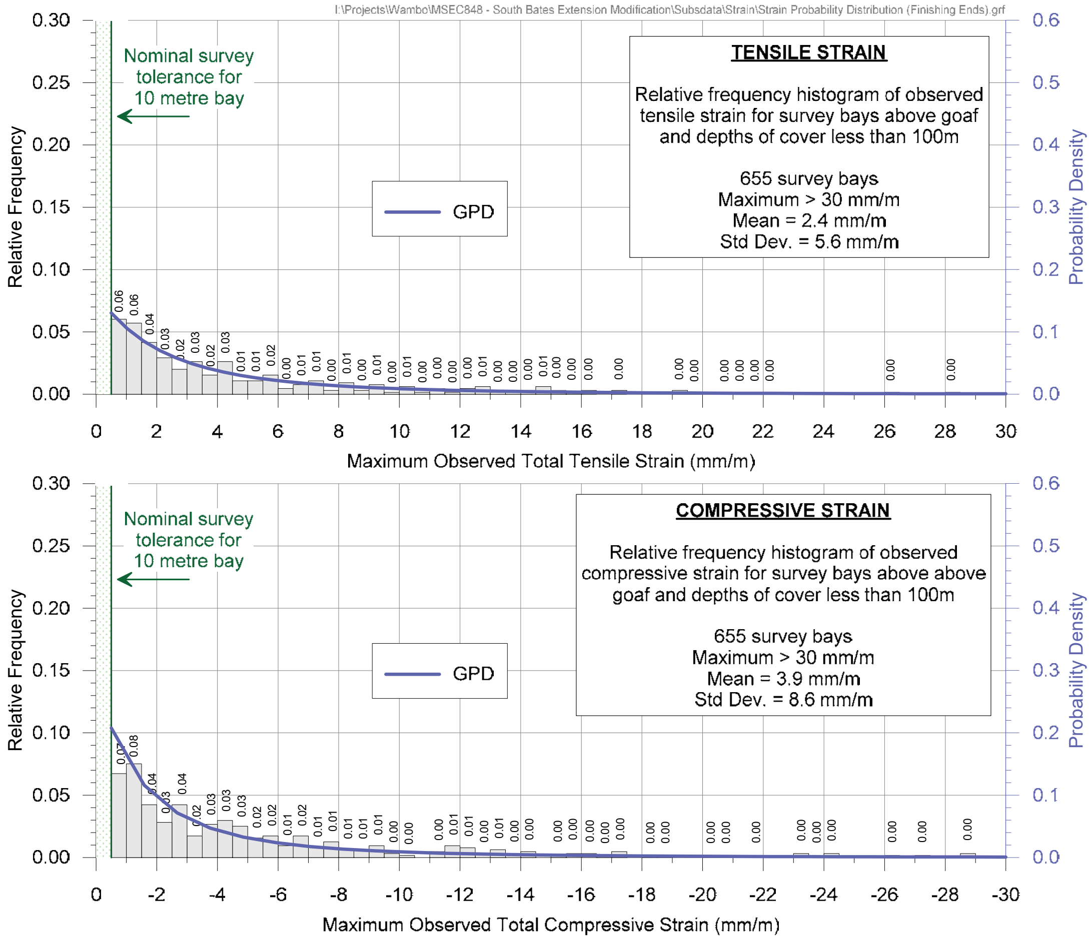

Fig. 4.2 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located above Supercritical Longwalls at Depths of Cover less than 100 m

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 17 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 proposed 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.

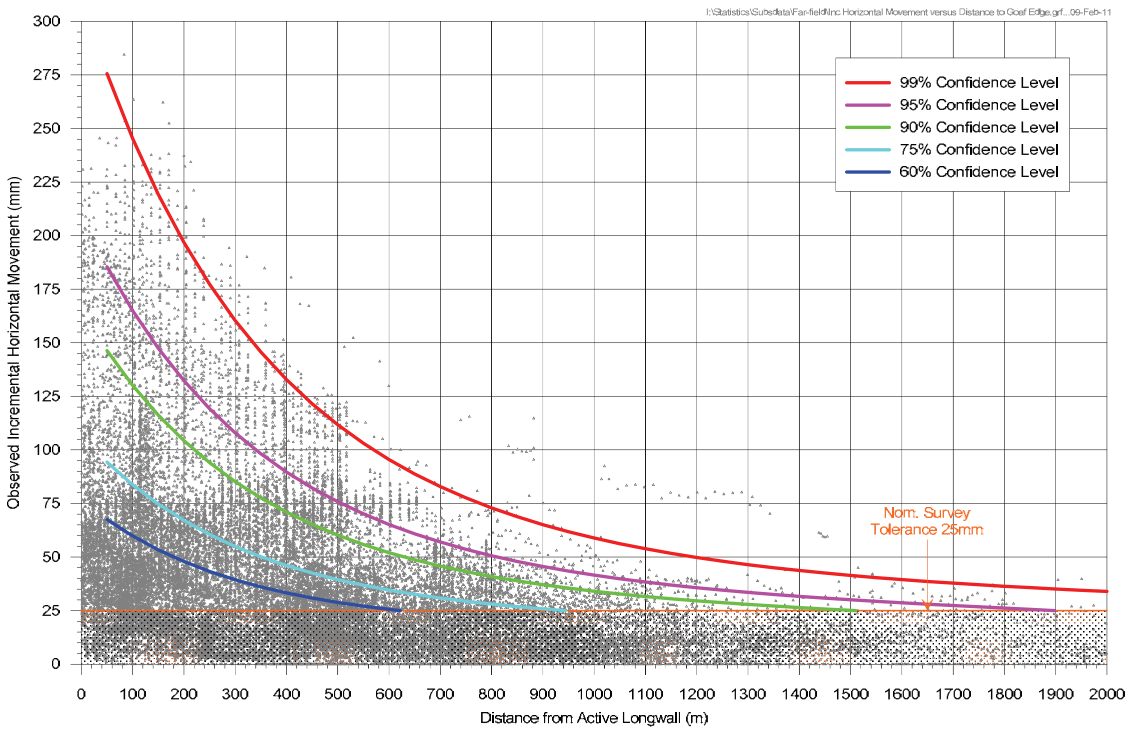

Fig. 4.3 Observed Incremental Far-Field Horizontal Movements

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 proposed longwalls as shown in Drawing No. MSEC848-01. 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 proposed longwalls are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than the order of survey tolerance (i.e. less than 0.3 mm/m).

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

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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.

There is a series of north to south trending faults through the north-eastern ends of the proposed WYLW17 to WYLW21 and north-east to south-west trending faults through the south-western end of the proposed WYLW17. 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 a number of factors, including the mine geometry, depth of cover, overburden geology, locations of natural joints in the bedrock and the presence of near surface geological structures.

Fractures and joints in bedrock occur naturally during the formation of the strata and from subsequent disturbance, tectonic movements, igneous intrusions, erosion and weathering processes. Longwall mining can result in additional fracturing in the bedrock, which tends to occur in the tensile zones, but fractures can also occur due to buckling of the surface beds in the compressive zones. The incidence of visible cracking at the surface is dependent on the pre-existing jointing patterns in the bedrock as well as the thickness and inherent plasticity of the soils that overlie the bedrock.

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

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

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

It has been found, from past longwall mining experience, that the surface crack widths in the order of 150 mm and step heights in the order of 100 mm have been observed at shallow depths of cover, say less than 100 m, such as the case above the north-eastern ends of the proposed longwalls. It has also been found, that surface crack widths and step heights reduced as the depth of cover increases, and crack widths in the order of 30 to 50 mm and step heights less than 50 mm are typically observed where the depths of cover are greater than 150 m, such as the case above the central and south-western ends of the proposed longwalls.

Photographs of the surface cracking and compression heaving along the North Wambo Creek Diversion due to the extraction of WYLW11 are provided in Fig. 4.4 and Fig. 4.5. The largest surface cracks occurred near the bend in the alignment above the longwall and were typically in the order of 25 to 50 mm, with isolated locations up to 100 mm in width. The compression heaving in this location were typically up to 200 mm in height. Elsewhere, the surface cracking in the base of the creek diversion was typically less than 50 mm in width and the compressive heaving was typically less than 50 mm in height.

Fig. 4.4 Surface cracking along the North Wambo Creek Diversion due to WYLW11

Fig. 4.5 Compression heaving along the North Wambo Creek Diversion due to WYLW11

Photographs of surface cracking along an unsealed road located above WYLW11 are provided in Fig. 4.6. The crack widths typically varied between 25 and 50 mm and were greater than 100 mm in some locations.

Fig. 4.6 Surface Cracking along an Unsealed Road above WYLW11

Photographs of surface cracking at the NWUM are also provided in Fig. 4.7. Similar cracking could develop above the north-eastern ends (i.e. shallowest depths of cover) and on the steep slopes above the south-western ends of the proposed WYLW17 to WYLW25.

Fig. 4.7 Photographs of Surface Cracking at the NWUM

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

4.8. Estimated Height of the Fractured Zone

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

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

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

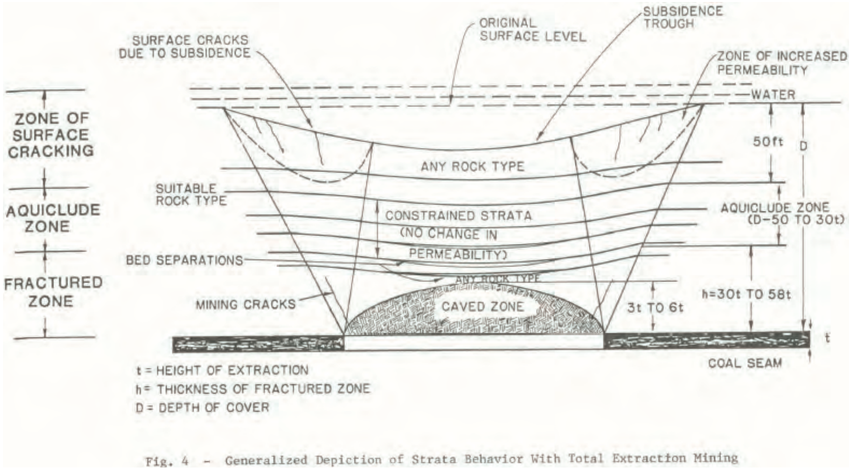

Fig. 4.8 Zones in the Overburden according to Singh and Kendorski (1981)

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

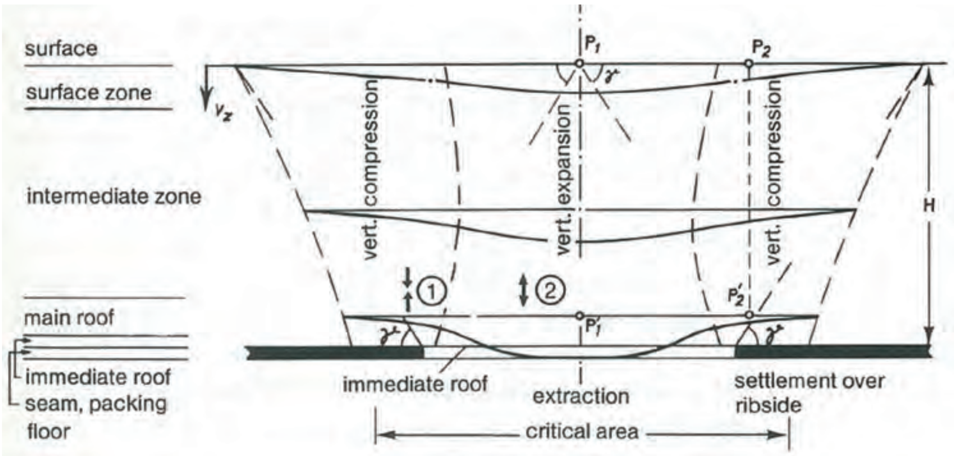

Fig. 4.9 Zones in the Overburden according to Kratzsch (1983)

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

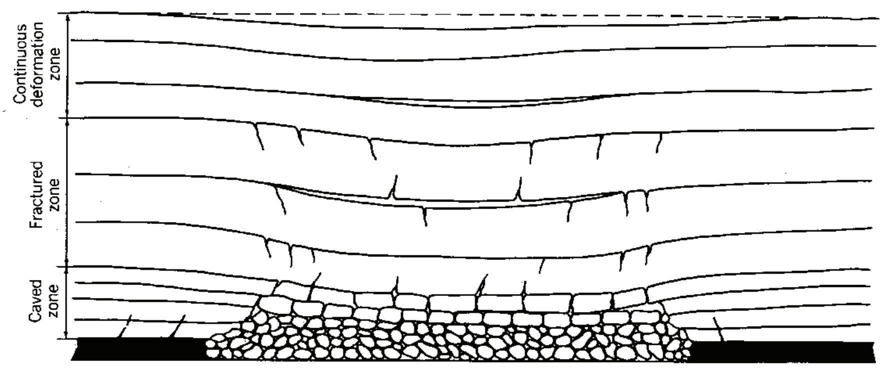

Fig. 4.10 Zones in the Overburden According to Peng and Chiang (1984)

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

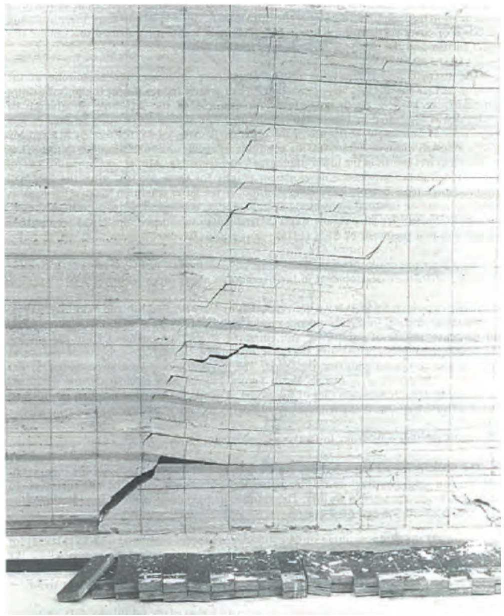

Fig. 4.11 Physical Modelling of the Overburden (Whittaker and Reddish, 1989)

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

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

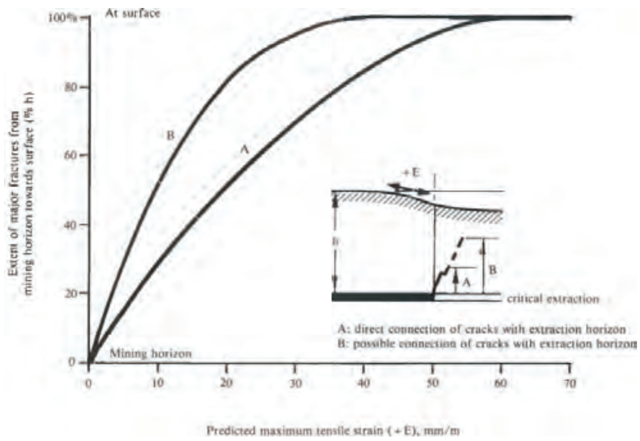

Fig. 4.12 Extent of Major Fractures from the Mining Horizon (Whittaker and Reddish, 1989)

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

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

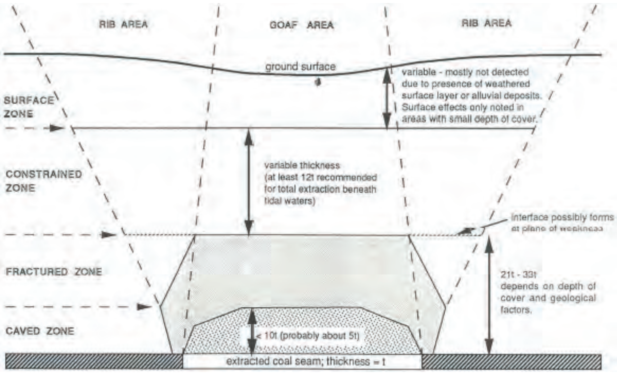

Fig. 4.13 Zones in the Overburden according to Forster and Enever (1992)

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

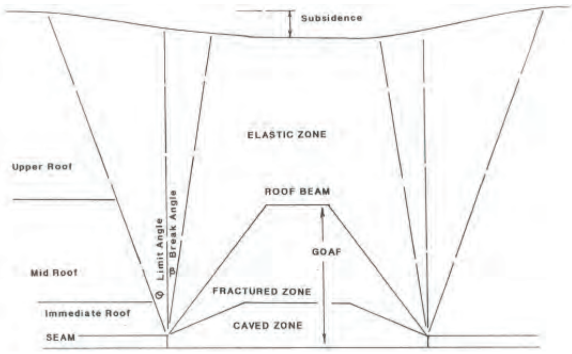

Fig. 4.14 Zones in the Overburden according to McNally et al (1996)

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

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

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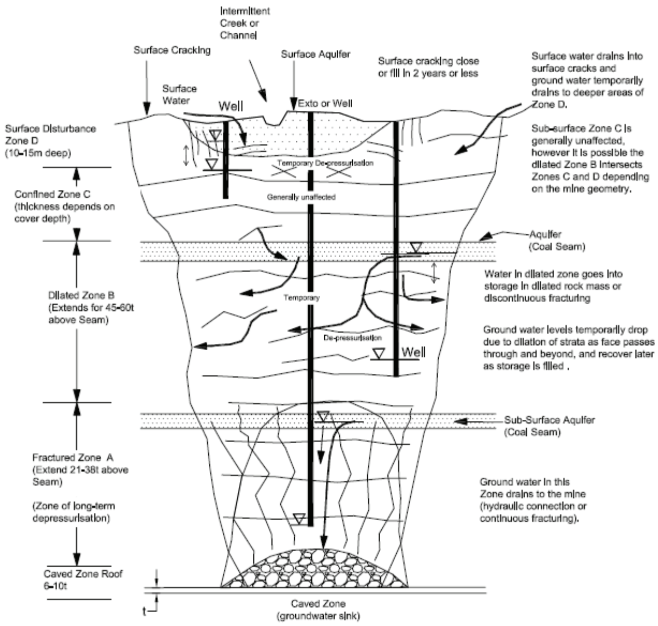

Fig. 4.15 Zones in the Overburden according to Ditton (2005)

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

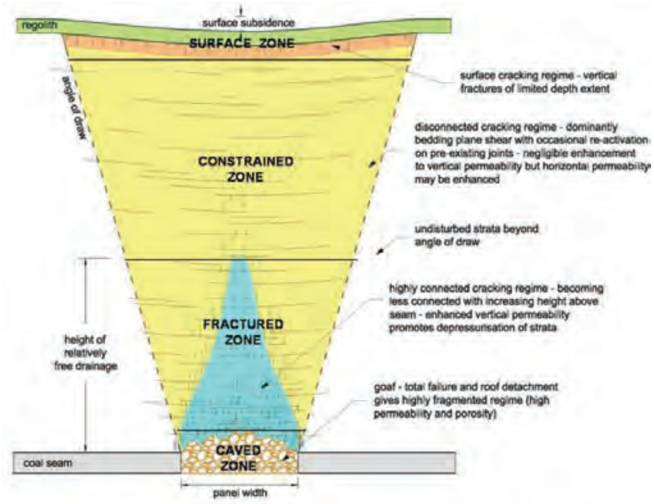

Figure 12: Conceptual Model of Caving and the Nature of Fracturing above a Mine Excavation

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

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

- *Caved* 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.

Just as the terminology differs between the various authors, the means of determining the extents of each of these zones also varies. Some of the difficulties in establishing the heights of the various zones of disturbance above extracted longwalls stem from: the imprecise definitions of the fractured and constrained zones; the differing zone names and clarity regarding whether the fractures were continuous, connected, discontinuous or not connected; the use of different extensometer borehole testing methods, the use of differing permeability or piezometer measuring methods and differing interpretations of monitoring data.

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

Geometrical and geotechnical equations can be developed to estimate the height of disconnected fracturing (HoF). However, MSEC is of the opinion that the height of connective fracturing (HoCF) can be difficult to accurately determined because it is affected by a number of factors including:

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

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

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

The height of disconnected or discontinuous fracturing (HoF) can extend 1 to 1.5 times the longwall width above the extracted seam. The overall void widths of the proposed WYLW17 to WYLW25 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 proposed 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 proposed 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* (2017). Further details on sub-surface strata movements are provided in the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

5.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE NATURAL FEATURES

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

5.1. Natural Features

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

- drinking water catchment areas or declared special areas;
- known springs or groundwater seeps;
- seas or lakes;
- shorelines;
- natural dams;
- swamps or wetlands;
- lands declared as critical habitat under the *Threatened Species Conservation Act 1995*;
- State Recreation Areas or State Conservation Areas;
- State Forests;
- areas of significant geological interest; and
- other significant natural features not described below.

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

5.2. Streams

5.2.1. Description of the Streams

The locations of the streams within the Study Area are shown in Drawing No MSEC848-08. The natural streams within the Study Area include North Wambo Creek and its associated tributaries. A diverted section of North Wambo Creek is also located within the Study Area.

North Wambo Creek commences along the Wollemi Escarpment to the west of the proposed longwalls. The upper section of the creek located outside of the proposed longwalls is formed within an incised valley at the base of the escarpment. The creek bed comprises a rounded gravel to sandy base. In some locations there is exposed bedrock that has formed into small cascades with isolated pools. There is also significant debris along this section of the creek, including boulders, tree branches and other vegetation.

North Wambo Creek crosses directly above the proposed WYLW23 to WYLW25. This section of creek is a fifth order ephemeral stream with a shallow incision into the natural surface soils. The total length of North Wambo Creek located directly above the proposed longwalls is 2.7 km. The natural surface level along the creek falls from a high point of 130 mAHD to a low point of 106 mAHD above the mining area, representing an average natural grade of approximately 9 mm/m (i.e. 0.9 % or 1 in 110).

The natural section of North Wambo Creek then joins the constructed North Wambo Creek Diversion immediately to the north of the finishing end of the proposed WYLW22. The creek diversion is generally located outside of the proposed longwalls, with small sections crossing above the finishing end of WYLW17. The creek diversion is discussed further in Section 5.3.

Photographs of the upper and lower sections of North Wambo Creek are provided in Fig. 5.1 and Fig. 5.2, respectively. The locations of the photographs are shown in Drawing No. MSEC848-08.

Fig. 5.1 Upper Section of North Wambo Creek (P0649 and P0595)

Fig. 5.2 Lower Section of North Wambo Creek (P0730 and P0745)

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 and the 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 is provided on the left side of Fig. 5.3. The natural surface between the Wollemi Escarpment of the North Wambo Creek Diversion is also shown on the right side of this figure.

Fig. 5.3 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) and 100 mm/m (i.e. 10 % or 1 in 10), 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 predicted profiles of conventional subsidence, tilt and curvature along North Wambo Creek are shown in Fig. C.04, in Appendix C. The predicted total profiles along the creek, after the extraction of each of the proposed longwalls, are shown as blue lines.

A summary of the maximum predicted total subsidence, tilt and curvature for North Wambo Creek, after the extraction of each of the proposed 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 Subsidence, Tilts and Curvatures for North Wambo Creek

Location	Longwall	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
North Wambo Creek	After WYLW21	< 20	< 0.5	< 0.01	< 0.01
	After WYLW22	50	4	0.8	< 0.01
	After WYLW23	1,850	80	> 3.0	> 3.0
	After WYLW24	1,950	80	> 3.0	> 3.0
	After WYLW25	1,950	80	> 3.0	> 3.0

The maximum predicted conventional strains for North Wambo Creek, 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 creek based on the 95 % confidence levels (refer to Section 4.4) are: 5 mm/m tensile and 4 mm/m compressive near the commencing end of WYLW25; and 12 mm/m tensile and 17 mm/m compressive near the finishing end of WYLW22.

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 section of North Wambo Creek located directly above the proposed longwalls has a shallow incision into the natural surface soils. The predicted valley related effects for the creek, therefore, are not significant when compared with the predicted conventional movements.

The upper reaches of North Wambo Creek outside of the proposed longwalls is formed within an incised valley and, therefore, could experience valley related movements. The maximum predicted valley related movements for the upper reaches of the creek, after the completion of all proposed longwalls, are 50 mm upsidence and 100 mm closure.

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

5.2.3. Impact Assessments for the Streams

The impact assessments for North Wambo Creek and the drainage lines located within the Study Area are provided in the following sections. The impact assessments for North Wambo Creek Diversion are provided in Section 5.3.

Potential for Increased Levels of Ponding, Flooding and Scouring

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

The natural and the predicted post-mining surface levels and grades along North Wambo Creek and two typical ephemeral drainage lines, referred to as Drainage Lines 1 and 2, are illustrated in Fig. 5.4 to Fig. 5.6. The locations of the drainage lines are shown in Drawing No. MSEC848-08. The final profiles shown in the figures below are after the completion of all proposed longwalls.

The predicted ponding areas for these streams are illustrated in Fig. 5.4 to Fig. 5.6. It is noted, that these ponding areas can differ from the topographical depressions discussed in Section 5.9 and indicated in plan in Fig. 5.25, as they have been based on the predicted changes in surface levels along the original alignments of the streams, i.e. they do not consider the natural grades across the alignments of the streams.

The extraction of the proposed longwalls will result in some changes in the stream alignments, due to the natural and mining induced cross-grades and, in consequence, the actual ponding areas are expected to be less than those illustrated in Fig. 5.4 to Fig. 5.6. The actual extents and depths of the ponding areas are also dependent on a number of other factors, including rainfall, catchment sizes, surface water runoff, infiltration and evaporation and, therefore, are expected to be smaller than the topographical depressions.

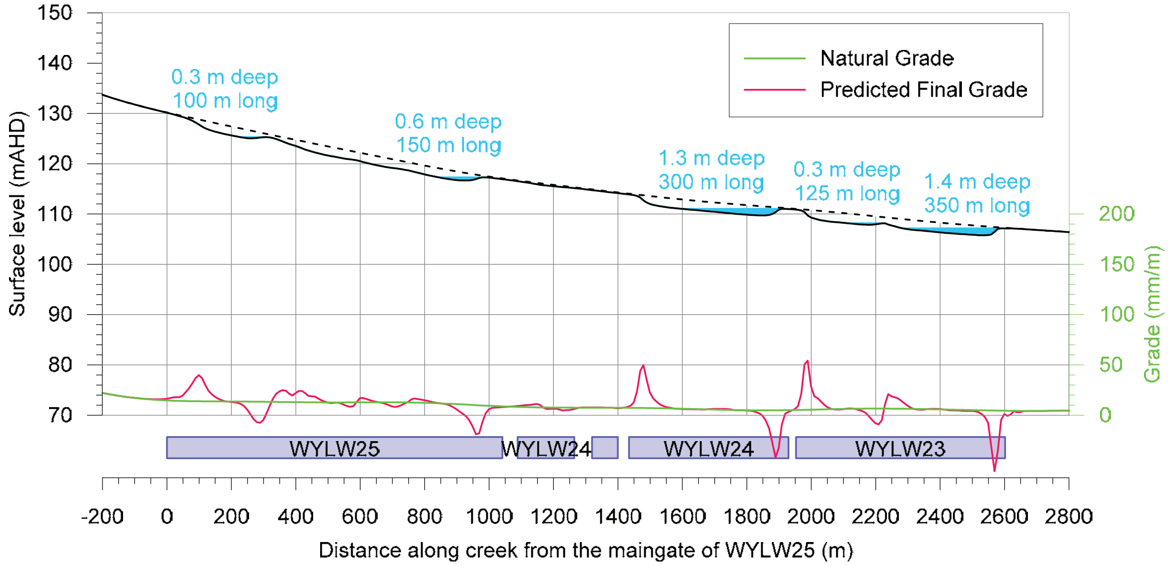

Fig. 5.4 Natural and Predicted Subsided Surface Levels and Grades along North Wambo Creek

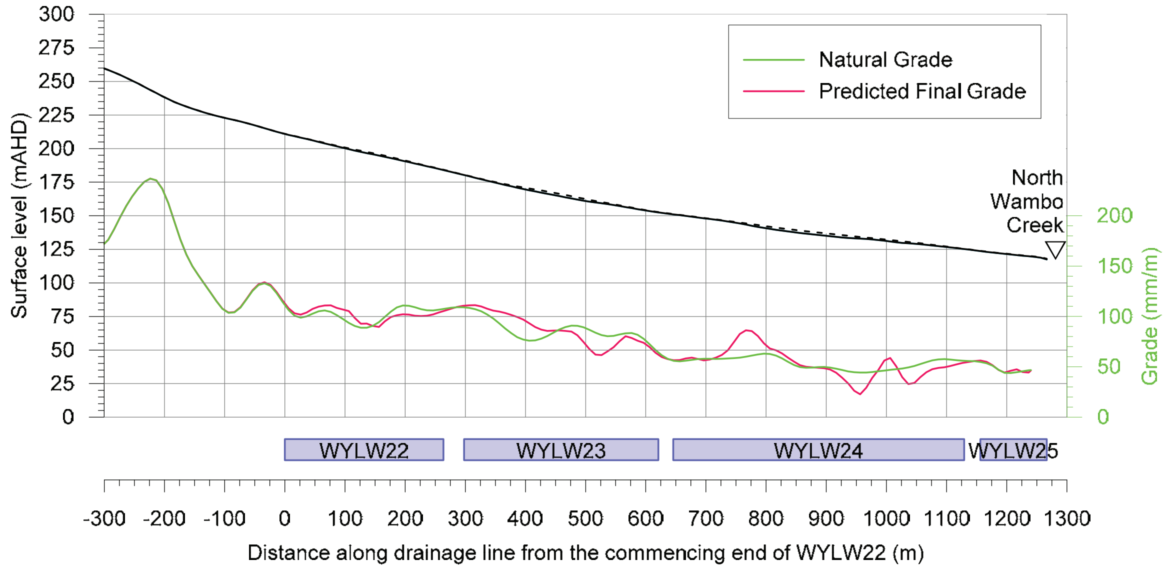

Fig. 5.5 Natural and Predicted Subsided Surface Levels and Grades along Drainage Line 1

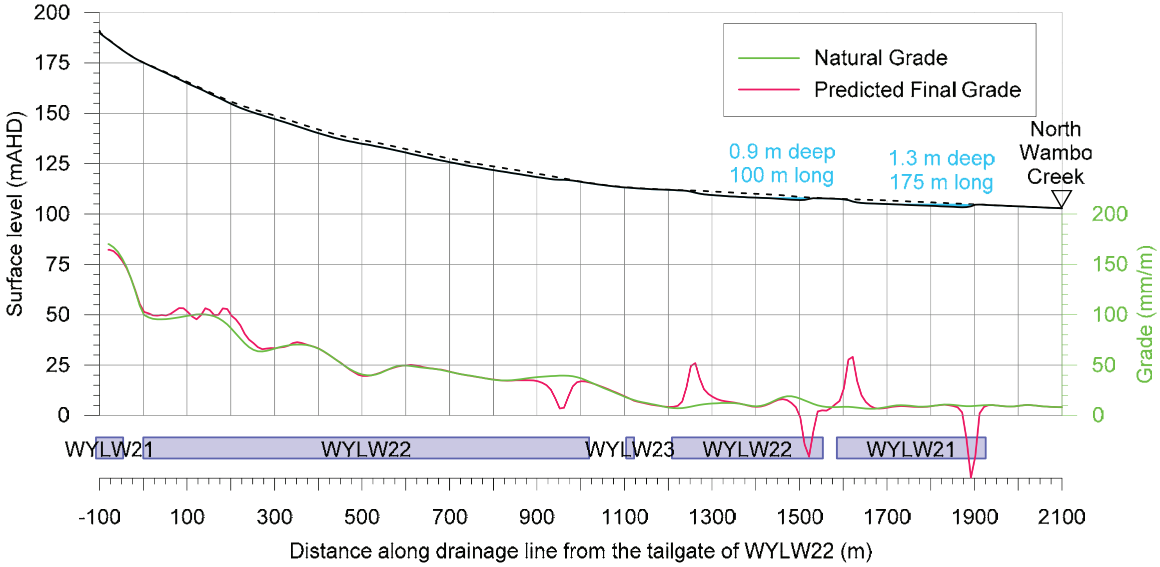

Fig. 5.6 Natural and Predicted Subsided Surface Levels and Grades along Drainage Line 2

It can be seen in Fig. 5.4 and Fig. 5.6, that there are predicted reversals of grade along North Wambo Creek and Drainage Line 2. Ponding areas are predicted to develop upstream of the chain pillars along these streams. There are no predicted reversals of grade along Drainage Line 1 due to the higher natural gradients.

There are five ponding areas predicted to develop along the North Wambo Creek, as a result of the proposed longwalls, having maximum depths varying between 0.3 and 1.4 m and overall lengths varying between 100 and 350 m. There are two ponding areas predicted to develop along Drainage Line 2, as a result of the proposed longwalls, having maximum depths of 0.9 and 1.3 m and overall lengths of 100 and 175 m. Ponding areas are also likely to develop along other drainage lines within the Study Area.

If adverse impacts were to develop as the result of increased ponding along the streams, 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 overlaying 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 streams located directly above the proposed longwalls. North Wambo Creek and the drainage lines have shallow incisions into the natural surface soils. Cracking in the beds of the streams 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.

North Wambo Creek has been previously mined beneath by Longwalls 1 to 8a at the NWUM. The surface cracking observed above these longwalls typically had widths within the range of 10 to 50 mm, with widths up to approximately 100 mm in some locations (WCPL, 2014). The impacts observed along the North Wambo Creek Diversion due to the extraction of WYLW11 are discussed in Section 4.7. The surface impacts along North Wambo Creek and the drainage lines due to the extraction of the proposed WYLW17 to WYLW25 are expected to be similar to those previously observed at the Wambo Coal Mine.

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

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

As described in Section 4.8, it is expected that the discontinuous fractured zone above the proposed longwalls 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 proposed longwalls, as this has not been previously observed at the Wambo Coal Mine. This includes the extraction of the Homestead/Wollemi workings in the Whybrow Seam directly beneath Stony Creek and the extraction of WMLW1 to WMLW8A in the Wambo Seam directly beneath both North Wambo and Stony Creeks.

Similar experiences have been found elsewhere in the Hunter and Newcastle Coalfields indicating that mining induced fracturing and dilation do not have long term adverse impacts on ephemeral streams comprising natural soil beds. For example, the ephemeral drainage lines at South Bulga and the Beltana No. 1 Underground Mine were previously mined beneath by longwalls in the Whybrow Seam, where the depths of cover varied between 40 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 streams after the extraction of the proposed longwalls directly beneath them. This would include regrading the beds and infilling the larger surface cracking. It is expected that there would be no long term adverse impacts on these streams after the completion of the necessary surface remediation.

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

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. MSEC848-08 and MSEC848-09.

North Wambo Creek has been diverted around the active open cut pit. The creek diversion is generally located outside of the proposed longwalls, with short sections crossing above the finishing end of WYLW17. The natural section of the creek is discussed in Section 5.2.

The North Wambo Creek Diversion is ephemeral. The creek diversion has been constructed within the natural surface soils, with the heights of the banks typically ranging between 3 to 5 m. There are some isolated locations with exposed bedrock along its alignment. Photographs of the North Wambo Creek Diversion are provided in Fig. 5.7.

Fig. 5.7 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 are discussed in Section 4.7.

5.3.2. Predictions for the North Wambo Creek Diversion

The predicted profiles of conventional subsidence, tilt and curvature along the North Wambo Creek Diversion are shown in Fig. C.05, in Appendix C. The predicted total profiles along the creek diversion, after the extraction of each of the proposed longwalls, are shown as blue lines. The predicted total profiles due to the extraction of the approved WYLW11 to WYLW13 and the approved WMLW14 to WMLW16 are shown as the cyan lines.

A summary of the maximum predicted total subsidence, tilt and curvature for North Wambo Creek Diversion is provided in Table 5.2. The values are the maxima for the section of the creek diversion located within the Study Area.

Table 5.2 Maximum Predicted Total Subsidence, Tilts and Curvatures for the North Wambo Creek Diversion Resulting from the Extraction of WYLW17 to WYLW25

Location	Longwall	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
North Wambo Creek Diversion	After WYLW17	300	25	> 3.0	< 0.01
	After WYLW25	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 proposed longwalls and, therefore, these predicted strains are only applicable for the sections of the diversion located directly above the longwalls, having a total length of approximately 150 m.

The predicted strains for the sections of the North Wambo Creek Diversion located outside of the proposed 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. 5.8. 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.

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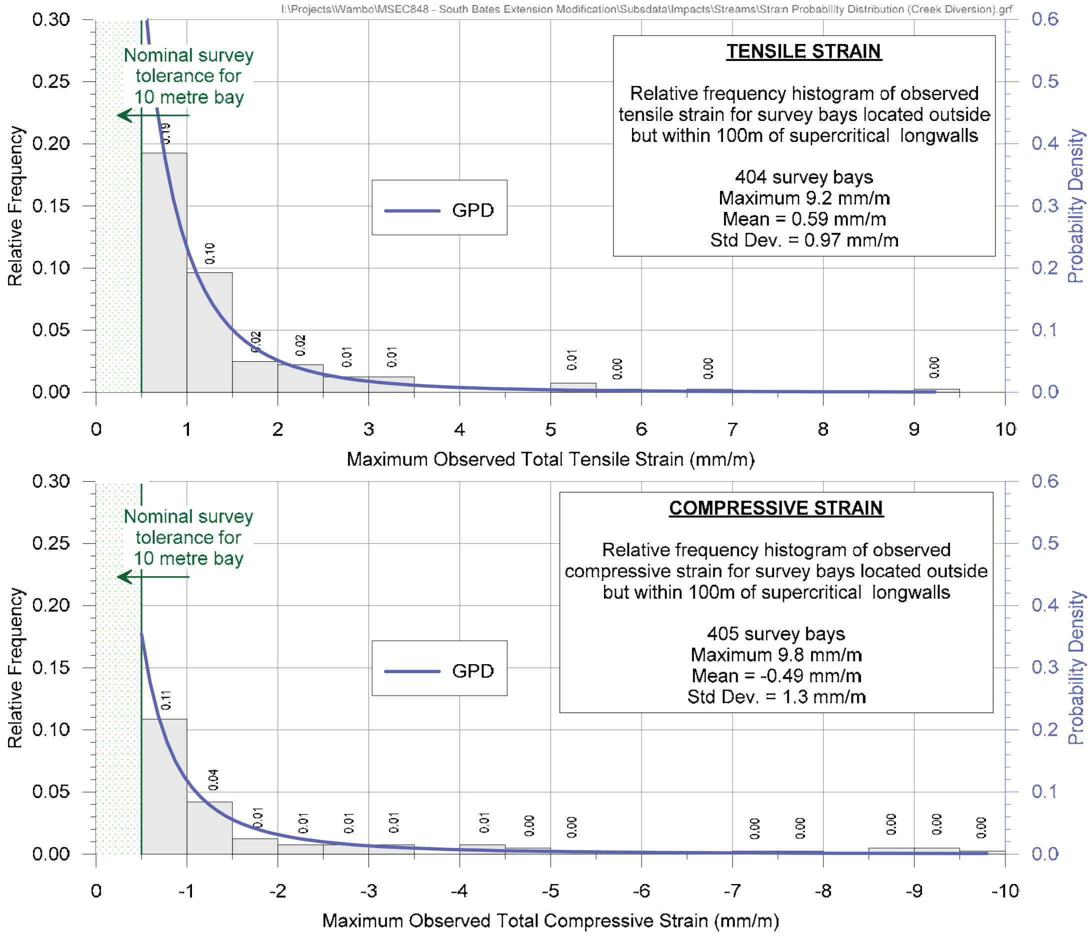

Fig. 5.8 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located Outside but Within 100 m of Supercritical Longwalls

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

5.3.3. Comparisons of the Predictions for North Wambo Creek

WCPL has approval to extract WYLW11 to WYLW13 directly beneath the North Wambo Creek Diversion and to extract WMLW14 to WMLW16 immediately adjacent to the creek diversion. A comparison of the maximum predicted total conventional subsidence parameters for the North Wambo Creek Diversion based on the approved and proposed longwalls is provided in Table 5.3.

Table 5.3 Comparison of Maximum Predicted Total Subsidence Parameters for the North Wambo Creek Diversion

Location	Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
North Wambo Creek Diversion	Approved WYLW11 to WMLW16	2,000	80	> 3.0	> 3.0
	Proposed WYLW17 to WYLW25	300	25	> 3.0	< 0.01

The maximum predicted vertical subsidence, tilt and sagging curvature for the North Wambo Creek Diversion, resulting from the extraction of the proposed WYLW17 to WYLW25, are considerably less than the maxima predicted resulting from the approved WYLW11 to WYLW13 and WMLW14 to WMLW16. The predicted hogging curvatures for the creek diversion are similar orders of magnitude for the proposed and approved longwalls. However, it is difficult comparing the maximum hogging curvatures, due to their magnitudes, as they are largely governed by the very localised irregular ground movements.

5.3.4. Impact Assessments for the North Wambo Creek Diversion

The North Wambo Creek Diversion is generally located outside of the proposed 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. 5.9. The final profiles are after the extraction of all proposed longwalls.

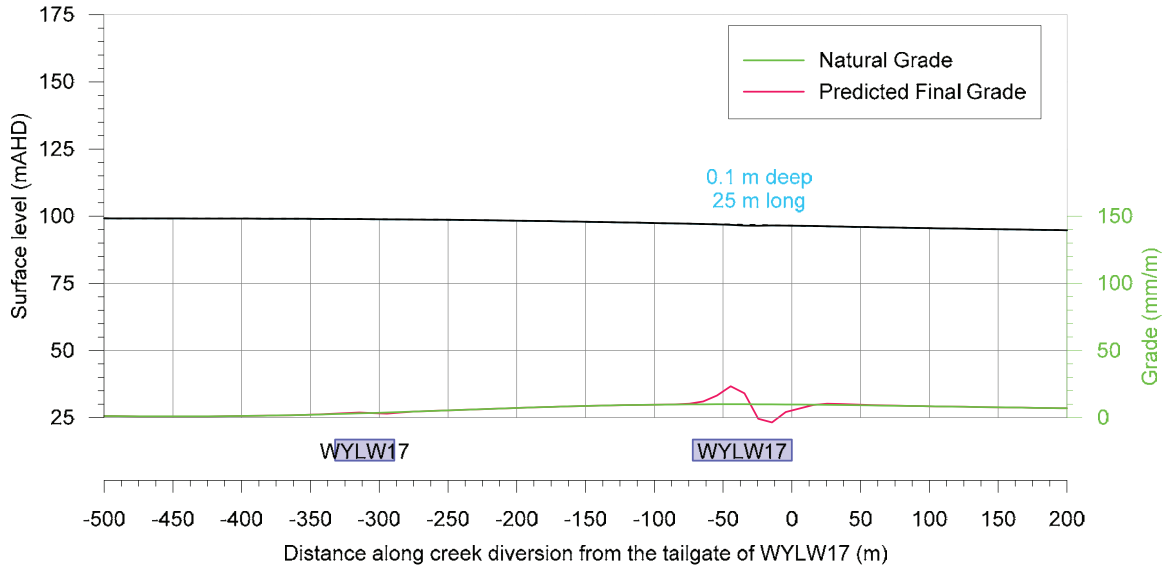

Fig. 5.9 Natural and Predicted Subsided Surface Levels and Grades along the Creek Diversion

It is possible that minor increased ponding could develop along the North Wambo Creek Diversion where is crosses above the proposed WYLW17. 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 the proposed WYLW17. 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 WYLW17, similar to that observed above WYLW11 (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 proposed longwalls. It is expected that the crack widths would be typically less than 25 mm outside of the mining area.

The depth of cover along the alignment of the North Wambo Creek Diversion, directly above the proposed WYLW17, 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 are 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. It is recommended that the existing management strategies for the creek diversion be reviewed and, where required, are revised to include the effects of the proposed longwalls.

5.4. Aquifers and Known Ground Water Resources

The descriptions, predictions and the assessment of potential impacts on the aquifers and groundwater resources within the Study Area are provided in the Groundwater Assessment report prepared by *HydroSimulations* (2017).

There are no *Ground Water Management Areas*, as defined by the Department of Primary Industries – Water, within the Study Area. WCPL owns two monitoring bores (Refs. GW200831 and GW200832) that are located directly above the proposed WYLW23 and WYLW24 which could be adversely impacted by subsidence. There were no other registered groundwater bores identified within the Study Area.

5.5. Escarpments

The *Wollemi Escarpment* is located to the south and to the west of the proposed 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 the 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. 5.10. All the cliffs within the Study Area, including those not associated with the escarpment, are shown in Drawing No. MSEC848-08.

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

The cliffs and minor cliffs were identified using the 1 m surface level contours generated from the Light Detection and Ranging (LiDAR) survey and from detailed site investigations. The locations of the cliffs in the vicinity of the proposed WYLW17 to WYLW25 are shown in Drawing No. MSEC848-08. The cliffs have also been shown in more detail in Fig. 5.10.

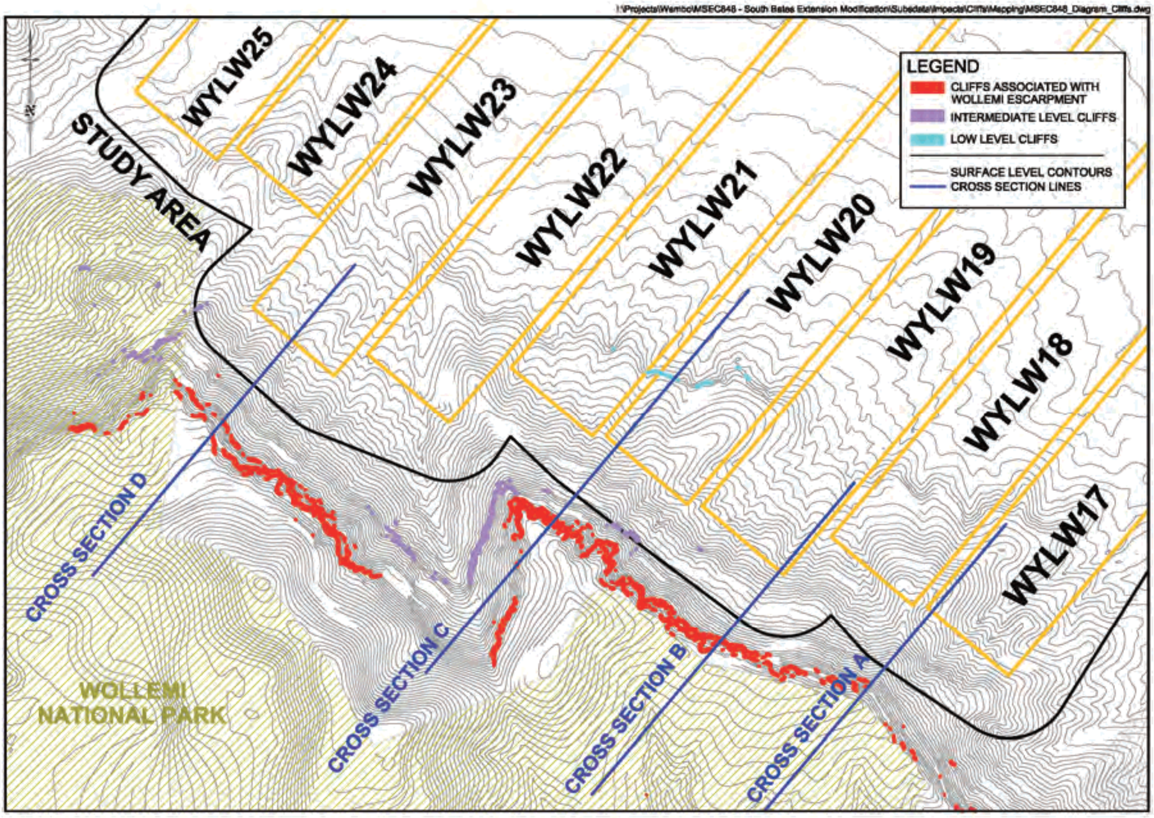

Fig. 5.10 Cliffs Located Adjacent to the Commencing Ends of WYLW17 to WYLW25

The cliffs have been categorised into three groups:

- *Cliffs Associated with the Wollemi Escarpment* (red hatch in Fig. 5.10*)* – are the higher level cliffs located along the boundary of the Wollemi National Park to the south-west of the proposed 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. 5.10*)* – are located part way down the steep slopes beneath the Wollemi Escarpment to the south-west of the proposed 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. 5.10*)* – are located near the bottom of the steep slopes above the south-western ends of the proposed longwalls. The larger low level cliffs are located above the proposed WYLW20 and WYLW21 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.

Sections A to D have been taken through the south-western ends of the proposed longwalls, showing the relative locations of the cliffs, in Fig. 5.11 to Fig. 5.14. The locations of these sections are shown in Fig. 5.10.

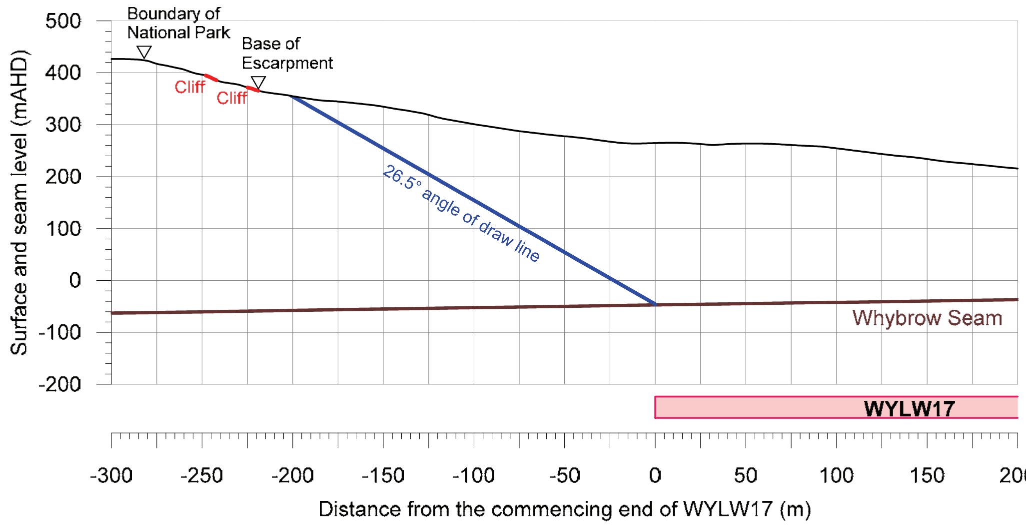

Fig. 5.11 Section A through the Wollemi Escarpment and the Commencing End of WYLW17

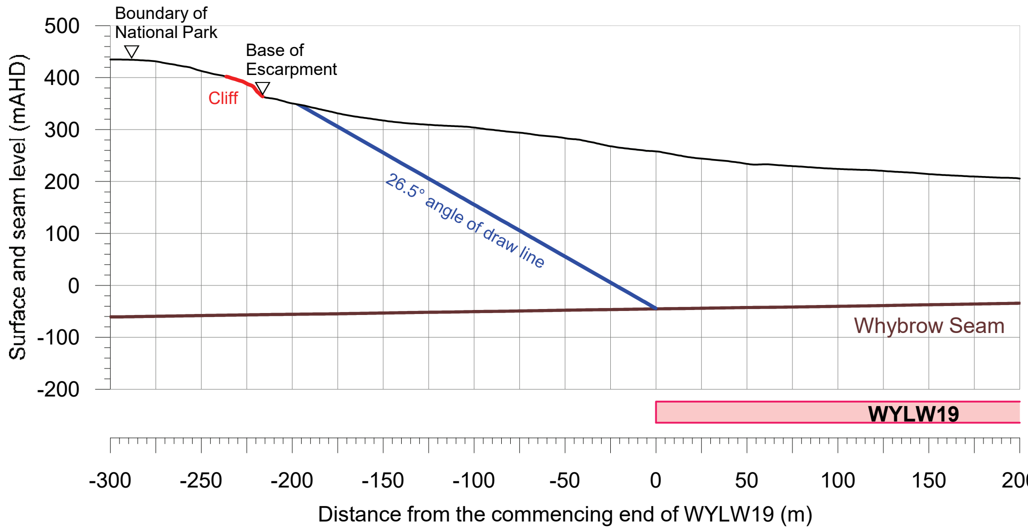

Fig. 5.12 Section B through the Wollemi Escarpment and the Commencing End of WYLW19

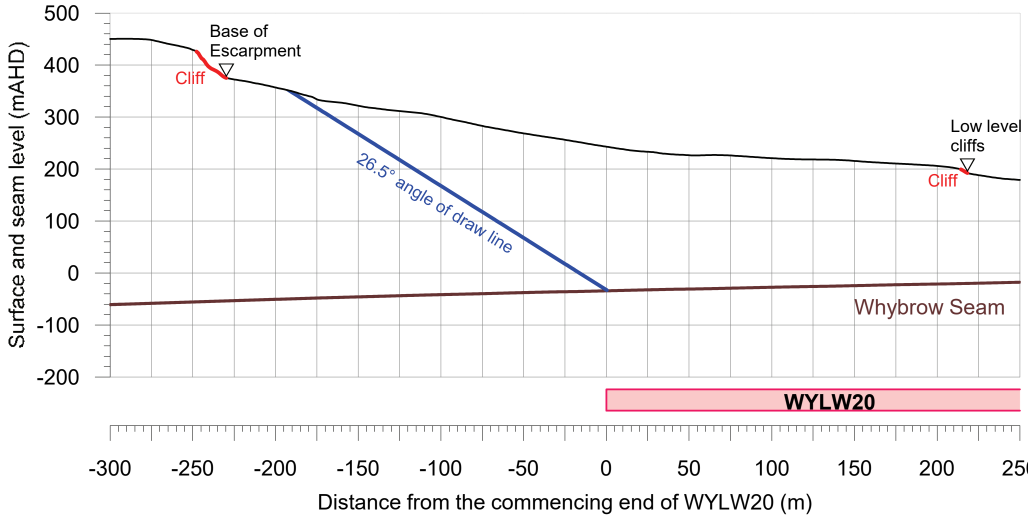

Fig. 5.13 Section C through the Wollemi Escarpment and the Commencing End of WYLW20

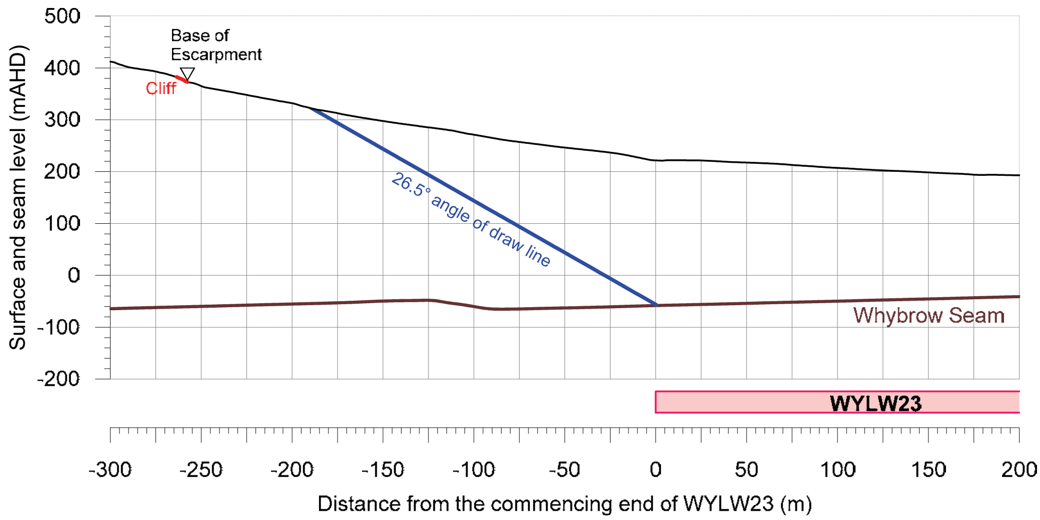

Fig. 5.14 Section D through the Wollemi Escarpment and the Commencing End of WYLW23

The Cliffs Associated with the Wollemi Escarpment are located outside of the 26.5° angle of draw line from the proposed WYLW17 to WYLW25. It is noted, that the Study Area differs from the 26.5° angles 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 proposed longwalls. For this reason, all the Cliffs Associated with the Wollemi Escarpment, immediately to the south-west of the longwalls, have been included as part of the Study Area and, hence, have been included in the impact assessments provided in this report.

The cliffs, minor cliffs and rock outcrops have formed from the Widden Brook Conglomerate of the Narrabeen Group, as can be seen in Fig. 1.5. Photographs of the Cliffs Associated with the Wollemi Escarpment are provided in Fig. 5.15 to Fig. 5.18. The locations and directions of the photographs are indicated in Drawing No. MSEC848-08.

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Fig. 5.15 Overall View of Cliffs Located to the South-West of the Proposed Longwalls (P2846 and P2847)

Fig. 5.16 Cliffs Located to the South-West of WYLW19 to WYLW23 (P2929, P2930 and P2927)

Fig. 5.17 Cliffs Located to the South-West of WYLW21 to WYLW25 (P0648, P0647 and P0646)

Fig. 5.18 Discontinuous Cliffs Located to the North West of WYLW25 (P0655 and P0731)

5.6.2. Predictions for the Cliffs

A summary of the maximum predicted total subsidence, tilts and curvatures for the cliffs is provided in Table 5.4. The values are the maximum predicted parameters within 20 m of their mapped extents.

Table 5.4 Maximum Predicted Total Subsidence, Tilts and Curvatures for the Cliffs

Location	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Cliffs Associated with the Wollemi Escarpment	< 20	< 0.5	< 0.01	< 0.01
Intermediate Level Cliffs	30	0.5	< 0.01	< 0.01
Low Level Cliffs	1,750	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.

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

The observed 3D horizontal movements at Dendrobium Mine outside the extents of the longwalls (i.e. above solid coal only) are illustrated in Fig. 5.19.

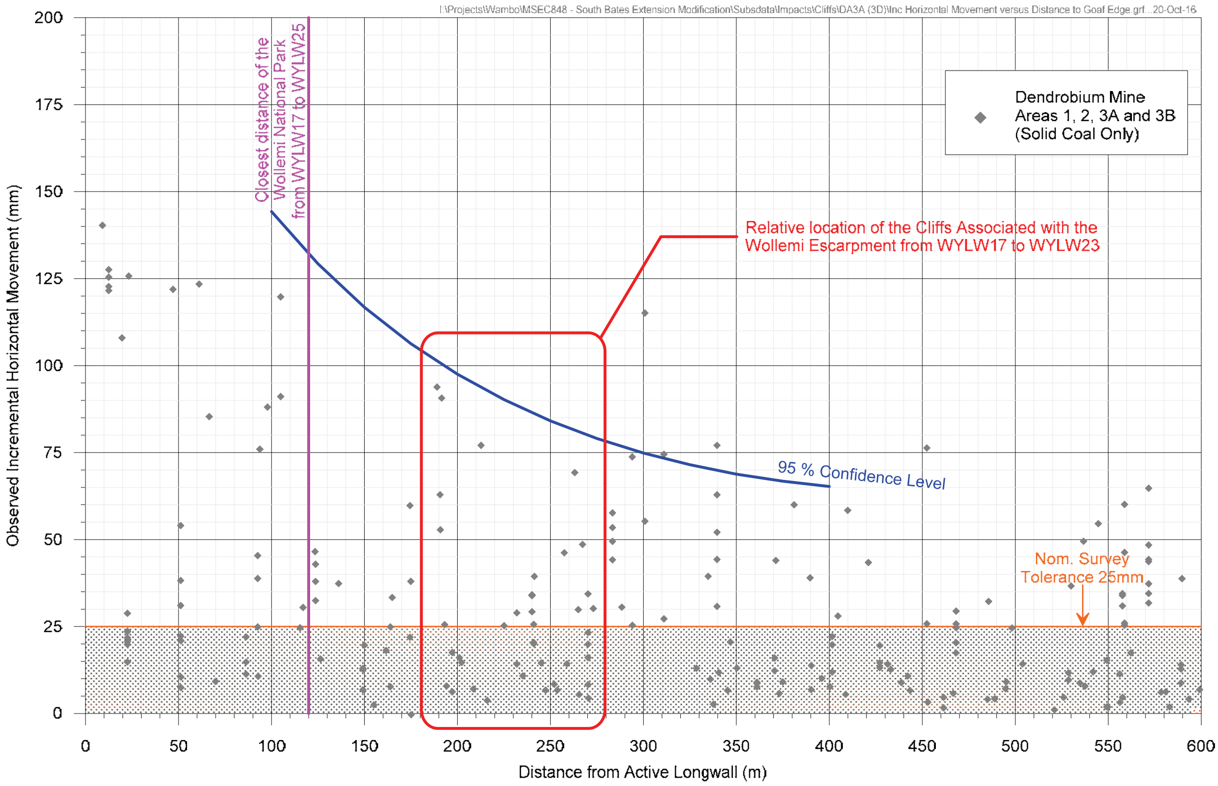

Fig. 5.19 Observed 3D Horizontal Movements in Areas 1, 2, 3A and 3B at Dendrobium Mine

It can be seen from Fig. 5.19, 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 WYLW17 to WYLW23. The predicted far-field horizontal movements for these cliffs based on the 95 % confidence level is 110 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 the proposed longwalls 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 the proposed 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.

5.6.3. Impact Assessments for the Cliffs Associated with the Wollemi Escarpment and the Intermediate Level Cliffs

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 around 110 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.

The existing Wollemi/Homestead workings in the Whybrow Seam were 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. 5.20.

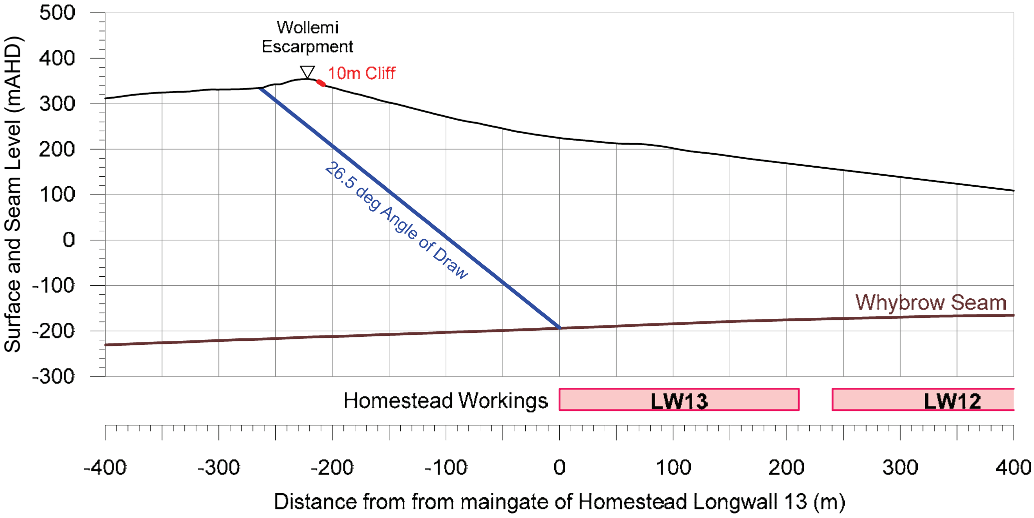

Fig. 5.20 Cross-section through the Wollemi Escarpment and the Homestead Workings

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.

WYLW11 at the South Bates Mine has also been extracted adjacent to the Wollemi Escarpment. An east-west cross-section through the commencing end of the approved longwall and the escarpment is provided in Fig. 5.21.

Fig. 5.21 Cross-section through the Wollemi Escarpment and WYLW11

WYLW11 was extracted to within a distance of 350 m from the Cliffs Associated with the Wollemi Escarpment, which is well outside the 26.5° angle of draw. There were no reported impacts for the Cliffs Associated with the Wollemi Escarpment resulting from the extraction of this longwall.

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 the proposed WYLW17 to WYLW25.

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

5.6.4. Impact Assessments for the Low Level Cliffs

The Low Level Cliffs are located directly above the south-western ends of the proposed longwalls. These cliffs are predicted to experience up to 1,750 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 1,800 to 2,000 m. It should be noted that there are two levels of cliffs in some locations and, therefore, the total length of cliffline is greater than the total plan length of the ridgeline.

The 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 proposed longwalls could be impacted. The total length of the Low Level Cliffs located above the proposed 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 the Study Area.

It is recommended that the Low Level Cliffs are periodically visually inspected during and after the extraction of the longwalls 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 proposed 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 the proposed WYLW17 to WYLW25.

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5.8. Steep Slopes

5.8.1. Descriptions of the Steep Slopes

The definition of a steep slope provided in the NSW DP&E *Standard and Model Conditions for Underground Mining* (DP&E, 2012) is: *"An area of land having a gradient between 1 in 3 (33% or 18.3º) and 2 in 1 (200% or 63.4º)"*. The locations of 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 the proposed WYLW17 to WYLW25. These steep slopes extend up to the Wollemi Escarpment which is located outside the 26.5° angle of draw line from the proposed longwalls. The natural surface gradients directly above the proposed longwalls typically range between 1 in 3 and 1 in 2. The slopes are locally steeper at the base of the Low Level Cliffs, above the proposed longwalls, with gradients up to approximately 1 in 1.5.

The natural slopes along Cross-section C through the commencing end of the proposed WYLW20 are illustrated in Fig. 5.22. The location of this cross-section is shown in Fig. 5.10.

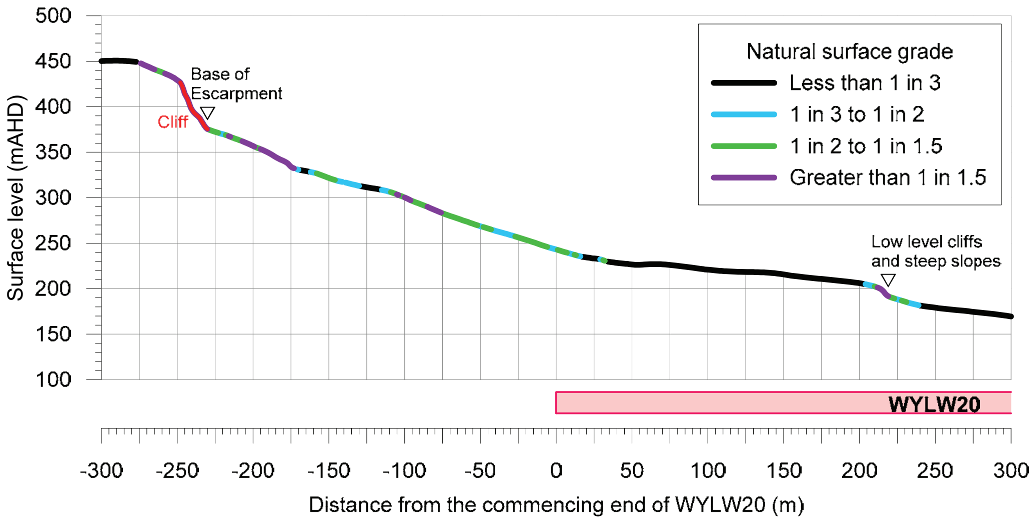

Fig. 5.22 Section C through the Steep Slopes and the Commencing End of WYLW20

The surface soils along the steep slopes above the commencing ends of the proposed longwalls are generally derived from the Widden Brook Conglomerate (Rna), as can be inferred from Fig. 1.5. The slopes are stabilised by the natural vegetation, which can be seen in Fig. 1.1.

There are also isolated steep slopes elsewhere above the proposed longwalls which are generally associated with the banks of the streams. An example is provided Fig. 5.2 showing the banks along North Wambo Creek near the finishing end of the proposed WYLW23.

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 5.5.

Table 5.5 Maximum Predicted Total Subsidence, Tilts and Curvatures for the Steep Slopes

Location	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Steep Slopes	1,950	30	1.0	1.0

The steep slopes are predicted to experience tilts up to 30 mm/m (i.e. 3 % or 1 in 33). The maximum predicted curvatures for the steep slopes are 1.0 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 1 km.

The maximum predicted conventional strains for the steep slopes, based on applying a factor of 10 to the maximum predicted curvatures, are 10 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 proposed 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. Impact Assessments for the Steep Slopes

The maximum predicted tilt for these steep slopes of 30 mm/m (i.e. 3.50 % or 1 in 33) 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 proposed longwalls are 1.0 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 1 km. The predicted curvatures and strains for the steep slopes are similar orders of magnitude to those predicted for Dendrobium Longwalls 1 and 2, which mined directly beneath a ridgeline with similar surface grades. The surface cracking observed from this case study, therefore, can be used to provide an indication of the potential surface cracking along the steep slopes located directly above the commencing ends of the proposed WYLW17 to WYLW25.

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

A number of surface cracks were observed along the steep slopes located directly above Dendrobium Longwalls 1 and 2 which are shown in Fig. 5.23.

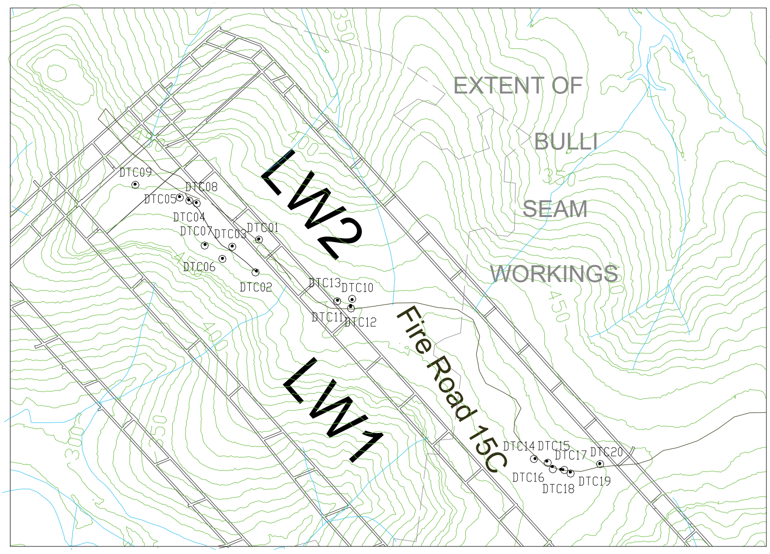

Fig. 5.23 Locations of Observed Surface Cracking above Dendrobium Longwalls 1 and 2

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

Photographs of the surface cracking at Dendrobium Mine are provided in Fig. 5.24.

Fig. 5.24 Surface Tension Cracking due to Downslope Movements at Dendrobium Mine

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 the proposed WYLW17 to WYLW25. 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 proposed longwalls, it is possible that soil erosion could occur if these cracks were left untreated.

It is possible, therefore, that some remediation might be required, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the 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 the proposed WYLW17 to WYLW25 are illustrated in Fig. 5.25. 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. 5.25, 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.

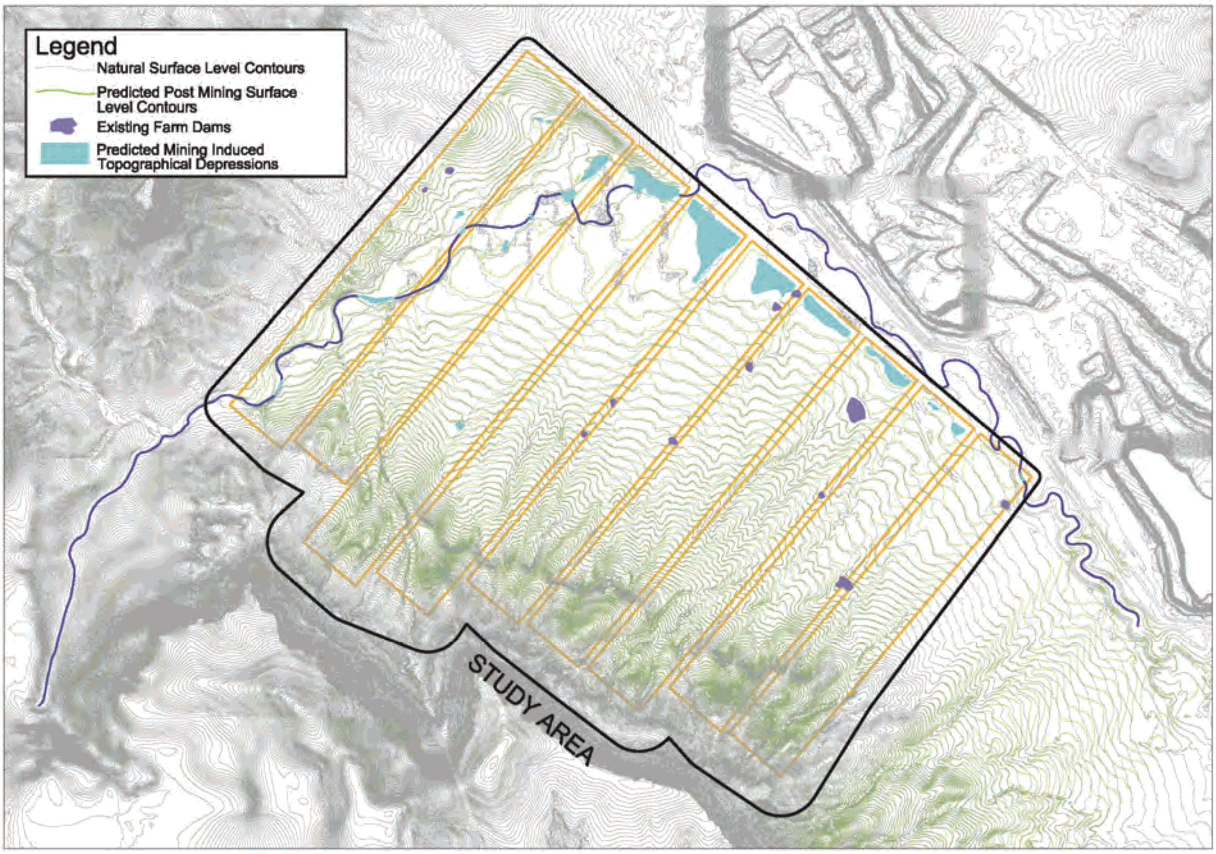

Fig. 5.25 Natural and Predicted Subsided Surface Levels and Predicted Mining Induced Topographical Depressions

It can be seen from Fig. 5.25, that mining induced topographical depressions are predicted to develop above the finishing (i.e. north-eastern) ends of the proposed longwalls, as indicated by the cyan hatching. Topographical depressions are also predicted to develop along the alignment of North Wambo Creek above the proposed WYLW23 to WYLW25.

The topographical depressions above the finishing ends of WYLW19 and WYLW23 are predicted to have maximum depths ranging between 1.2 and 1.4 m and surface areas ranging between 0.6 and 2.5 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 alignments of North Wambo Creek and typical drainage lines are 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 proposed longwalls, apart from the isolated locations along North Wambo Creek and the drainage lines. It is not considered, therefore, that the land across the Study Area is naturally susceptible to flooding or inundation.

5.10. Water Related Ecosystems

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

5.12. National Parks or Wilderness Areas

The *Wollemi National Park* is located to the south and to the west of the proposed longwalls. The boundary of the National Park is located at a minimum distance of 120 m from the commencing (i.e. south-western) end of WYLW24 and from the maingate of WYLW25, at its closest points. The location of the National Park is shown in Drawings Nos. MSEC848-01 and MSEC848-08.

The land within the National Park is predicted to experience less than 20 mm vertical subsidence resulting from the extraction of the proposed WYLW17 to WYLW25, 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. 5.19, that the National Park could experience far-field horizontal movements up to 130 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 drainage lines within the National Park are generally located at distances greater than 400 m from the proposed longwalls. There are small sections of drainage lines (total length of approximately 0.3 km) that are located at distances less than 400 m from the commencing ends of WYLW23 to WYLW25.

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 proposed longwalls.

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

5.13. Natural Vegetation

There is natural vegetation located above the south-western ends of the proposed 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 proposed longwalls. A detailed survey of the natural vegetation has been undertaken and is described and assessed in the report prepared by *FloraSearch* (2017).

6.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE BUILT FEATURES

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

6.1. Public Utilities

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

6.1.1. Unsealed Roads

There are unsealed tracks and fire trails located within the Study Area. The locations of these roads are shown in Drawing No. MSEC848-09. 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 proposed mining area and, therefore, could experience the full range of predicted subsidence movements. A summary of the maximum predicted mine subsidence parameters within the Study Area was provided in Chapter 4.

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

It is expected that cracking, 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 WYLW11 are provided in Fig. 4.6. The crack widths above this longwall typically varied between 25 and 50 mm and were greater than 100 mm in some locations

The impacts on the unsealed tracks and fire trails due to the proposed longwalls are expected to be similar to that observed due to WYLW11. 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 the proposed WYLW17 to WYLW25. 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 proposed 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 12 farm dams that have been identified within the Study Area and their locations are shown in Drawing No. MSEC848-09. The discussions on the proposed 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 5,000 m^2 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 the proposed WYLW19.

A summary of the maximum predicted total subsidence, tilts and curvatures for the farm dams 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 Subsidence, Tilts and Curvatures for the Farm Dams

Location	Ref.	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
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	1400	90	> 3.0	> 3.0
	d06	1700	75	> 3.0	> 3.0
	d07	1600	65	> 3.0	> 3.0
	d08	550	35	2.5	0.9
	d09	250	10	0.6	0.5
	d10	250	7	0.7	0.3
	d11	1800	50	> 3.0	> 3.0
	d12	1900	55	> 3.0	> 3.0

The maximum predicted conventional strains for the farm dams, based on applying a factor of 10 to the maximum predicted curvatures, vary between 5 mm/m are 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 predicted final tilts for the farm dams vary between 7 mm/m (i.e. 0.7 % or 1 in 143) and 90 mm/m (i.e. 9 % or 1 in 11). 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 0.7 m.

The greatest predicted changes in freeboard occur at Dams Refs. d06 and d07 of 0.7 and 0.5 m, respectively. The directions of the final tilts in the locations of these dams are transverse to the longwalls (i.e. NW-SE) and, therefore, are orientated parallel to the dam walls. 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, 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 registered groundwater bores within the Study Area were identified using the *Natural Resource Atlas* website (NRAtlas, 2016). WCPL owns two monitoring bores (Refs. GW200831 and GW200832) that are located directly above the proposed WYLW23 and WYLW24 which could be adversely impacted by subsidence. There were no other registered groundwater bores identified within the Study Area.

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 the proposed WYLW17 to WYLW25. The current extent of the pit is shown in Drawing No. MSEC848-01. It is recommended that a geotechnical assessment of the highwall be undertaken based on the effects of the proposed WYLW17 to WYLW25.

6.4.2. Exploration Drill Holes

The locations of the exploration drill holes within the Study Area are shown in Drawing No. MSEC848-09. The drill holes are located directly above and adjacent to the proposed 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 the proposed WYLW17 to WYLW19, as shown in Drawing No. MSEC848-09. The dam is proposed to 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 proposed mining.

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

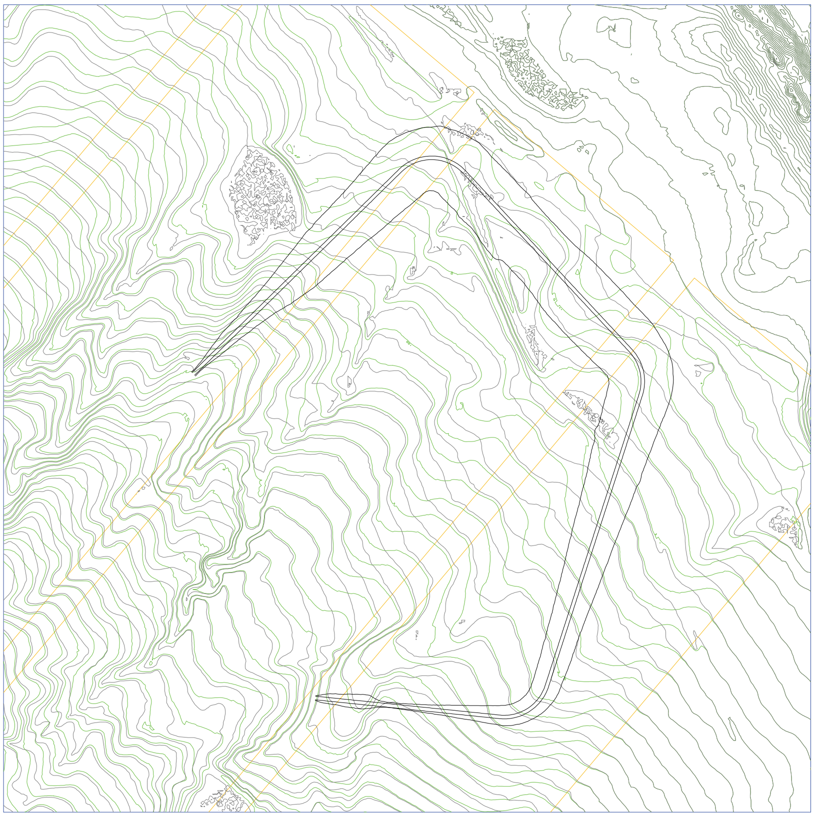

Fig. 6.1 Natural and Predicted Subsided Surface Levels at the Montrose Water Storage Dam

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

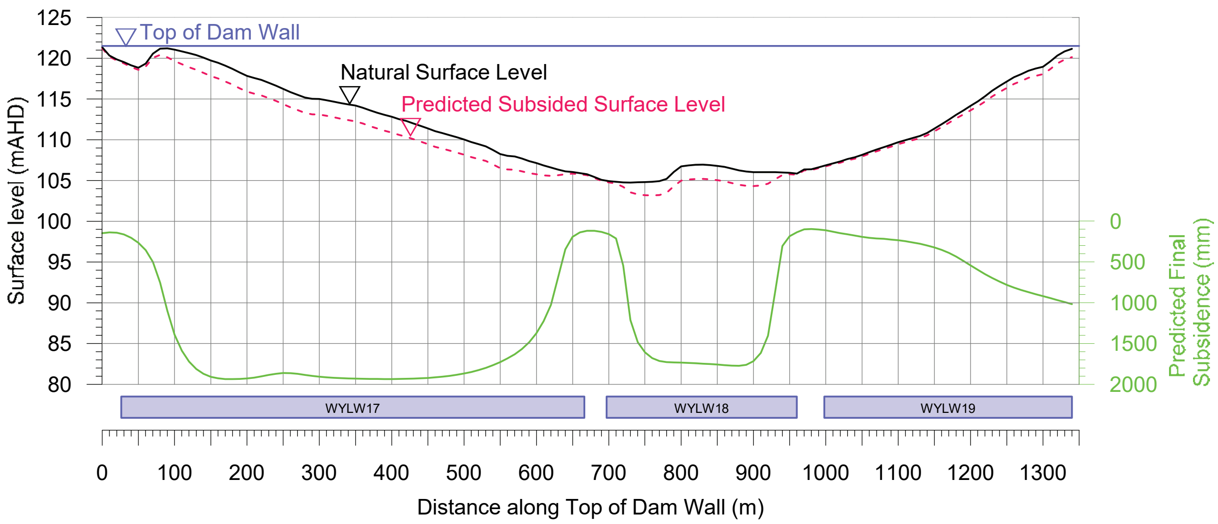

Fig. 6.2 Natural and Predicted Subsided Surface Levels along the Dam Wall

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 at RL121.5 mAHD, is 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 proposed 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 37 archaeological sites that have been identified within the Study Area, comprising 27 Open Artefact Sites, three Open Potential Archaeological Deposits (PADs), six Rock Shelters with PADs and one Scarred Tree.

The locations of these archaeological sites are shown in Drawing No. MSEC848-09. The types of site are included in Table 6.2. Further details on the archaeological sites are provided in the report by *South East Archaeology* (2017).

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 6.2. The values are the maximum predicted parameters within 20 m of the perimeters of each of the sites.

Table 6.2 Maximum Predicted Total Subsidence, Tilts and Curvatures for the Archaeological Sites

Site Reference	Site Type	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
South Bates Soil Test 2/A	Open Artefact Site	< 20	2	0.1	0.04
South Bates Soil Test 6/A	Open Artefact Site	1900	5	> 3.0	> 3.0
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
Wambo site 230	Open Artefact Site	1800	1	> 3.0	> 3.0
Wambo site 231	Open Artefact Site	1600	70	> 3.0	> 3.0
Wambo site 240	Open Artefact Site	1900	1	> 3.0	> 3.0
Wambo site 241	Open Artefact Site	1300	70	> 3.0	> 3.0
Wambo Site 308	Open Artefact Site	700	25	0.7	0.3
Wambo Site 309	Open Artefact Site	1700	20	0.7	0.9
Wambo Site 310	Open Artefact Site	250	9	0.5	0.03
Wambo Site 311	Open Artefact Site	1600	70	> 3.0	> 3.0
Wambo Site 317	Open Artefact Site	950	50	3	2.5
Wambo Site 320	Open Artefact Site	1900	10	> 3.0	> 3.0
Wambo Site 321	Open Artefact Site	1900	2	> 3.0	> 3.0
Wambo Site 324	Scarred Tree	1700	60	> 3.0	> 3.0
Wambo Site 483	Open Artefact Site	1800	60	> 3.0	> 3.0
Wambo Site 484	Open Artefact Site	50	4	0.3	0.2
Wambo Site 485	Open Artefact Site	< 20	< 0.5	0.05	< 0.01
Wambo Site 486	Open Artefact Site	1900	5	> 3.0	> 3.0
Wambo Site 487	Open Artefact Site	1900	15	> 3.0	> 3.0
Wambo Site 488	Open Artefact Site	1900	70	> 3.0	> 3.0
Wambo Site 489	Open Artefact Site	200	4	0.4	0.5
Wambo Site 490	Open Artefact Site	1800	1	> 3.0	> 3.0
Wambo Site 491	Open Artefact Site	1700	45	> 3.0	> 3.0
Wambo Site 493	Open Artefact Site	1600	20	0.4	0.6
Wambo Site 494	Open Artefact Site	200	4	0.2	0.04
Wambo Site 496	Open Artefact Site	1700	40	> 3.0	> 3.0
Wambo Site 497	Open Artefact Site	1100	50	3	2
Wambo Site 498	Open Artefact Site	1400	35	1.5	1.5
Wambo Site 499	Rock shelter with PAD	400	15	0.4	0.1
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 503	Rock shelter with PAD	25	< 0.5	< 0.01	< 0.01
Wambo Site 504	Rock shelter with PAD	1500	20	0.5	0.4

A summary of the maximum predicted total subsidence parameters for each type of archaeological site 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 Subsidence, Tilts and Curvatures for the Archaeological Sites

Site Type	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Open Artefact Sites	1900	70	3	2.5
Open PADs	1900	55	> 3.0	> 3.0
Rock Shelters with PADs	1700	20	0.6	0.6
Scarred Tree	1700	60	> 3.0	> 3.0

The maximum predicted conventional strains for the archaeological sites, based on applying a factor of 10 to the maximum predicted curvatures, are 30 mm/m tensile and 25 mm/m compressive for the Open Artefact Sites, greater than 30 mm/m tensile and compressive for the Open PADs, 6 mm/m tensile and compressive for the Rock Shelters with PADs and greater than 30 mm/m tensile and compressive for the Scarred Tree.

The range of strains will vary considerably across the extents of the proposed 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 proposed 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. Impact Assessments for the Open Artefact Sites and Open PADs

There are 27 sites within the Study Area comprising Open Artefact Sites, being South Bates Soil Test 2/A, South Bates Soil Test 6/A and Wambo Sites 230, 231, 240, 241, 308, 309, 310, 311, 317, 320, 321, 483, 484, 485, 486, 487, 488, 489, 490, 491, 493, 494, 496, 497 and 498. There are 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 70 mm/m (i.e. 7 %, or 1 in 143) for the Open Artefact Sites 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 are 3.0 km^{-1} hogging and 2.5 km^{-1} sagging, which represents a minimum radii of curvatures of 0.3 km and 0.4 km, respectively. The maximum predicted total curvatures for 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 mining induced curvatures and strains could result in surface cracking in the vicinity of the sites which are located directly above the proposed 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 locations of the Open Artefact Sites and the Open PADs.

Further discussions on the potential impacts on the Open Artefact Sites and the Open PADs are provided in the report by *South East Archaeology* (2017).

6.5.4. Impact Assessments for the Rock Shelters

Wambo Site 499 is located directly above Longwall 21 towards the commencing (i.e. south-western) end of this longwall. 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 0.4 km^{-1} hogging, which represents a minimum radius of curvature of 2.5 km.

Wambo Sites 500, 501 and 502 are located directly above Longwall 18 and Wambo Site 504 is located directly above Longwall 22. These sites are all located towards the commencing (i.e. south-western) ends of these proposed longwalls. 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. Wambo Sites 500, 501, 502 and 504 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.

The predicted curvatures and strains in the locations of Wambo Sites 499, 500, 501, 502 and 504 are likely to be sufficient to result in the fracturing of the conglomerate minor cliffs and rock outcrops. 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 proposed longwalls could be impacted (refer to Section 5.6.4). 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. The potential for adverse impacts at this rock shelter, therefore, has been assessed as possible (i.e. greater than 25 %). It is noted, that this assessment represents the likelihood of adverse fracturing and spalling being coincident with the rock shelter.

Wambo Sites 500, 501, 502 and 504 are considerably smaller rock shelters that have formed within minor cliffs and isolated rock outcrops. The potential for adverse impacts (i.e. fracturing and spalling) at these rock shelters, therefore, have been assessed as very unlikely (i.e. less than 10 %).

Wambo Site 503 is located outside the extents of the proposed longwalls at a distance of approximately 70 m from the commencing (i.e. south-western) end of Longwall 23. At this distance, the site is predicted to experience 25 mm of vertical subsidence. Whilst this site could experience very low levels of vertical subsidence, it is unlikely to experience measurable conventional tilts, curvatures or strains.

Wambo Site 503 is a small rock shelter (up to approximately 2.4 m wide, 3.6 m deep and 1.5 m high) formed within a conglomerate rock outcrop. The isolated rock feature is not expected to be sensitive to the predicted low level of subsidence in this location. The potential for adverse impacts (i.e. fracturing and spalling) at this rock shelter, therefore, have been assessed as rare (i.e. less than 5 %).

Further discussions on the potential impacts on the Rock Shelters with PADs are provided in the report prepared by *South East Archaeology* (2017).

6.5.5. Impact Assessments for the Scarred Tree

The Scarred Tree (Wambo Site 324 St 1) is located directly above Longwall 21 towards the finishing (i.e. north-eastern) end of this longwall.

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 depths of cover are shallow and/or where the surface terrain is very steep. The depth of cover to the Whybrow Seam in the location of the Scarred Trees is 75 m. The natural surface in the location of the Scarred Tree is relatively flat, with a natural gradient of approximately 1 in 30 (i.e. 3 % or 2°).

The sizes and extents of surface cracking in the vicinity of the Scarred Tree is expected to be similar to that observed within the Creek Diversion above WYLW11 (refer to Section 4.7). The likelihood that surface cracking would be coincident with the tree is considered low. It is considered very unlikely (i.e. less than 10 %), therefore, that the scarred tree would experience adverse impacts as a result of the proposed longwalls.

Further discussions on the potential impacts on the Scarred Tree are provided in the report prepared by *South East Archaeology* (2017).

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* (2016). There are two state survey control marks identified within the Study Area (Refs. SS119671 and TS12077), the locations of which are shown in Drawing No. MSEC848-09. 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 the Department of Lands 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

The Whynot Homestead is located above the proposed WYLW21. 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. There are additional building structures that are located above the proposed WYLW25, including timber framed sheds with metal sheet cladding. These structures are all unused.

6.7.2. Predictions for the Building Structures

A summary of the maximum predicted total subsidence, tilts and curvatures for the building structures is provided in Table 6.4. The values are the maximum predicted parameters within 20 m of the perimeters of the structures.

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Table 6.4 Maximum Predicted Total Subsidence, Tilts and Curvatures for the Building Structures

Location	Description	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Above WYLW21	Whynot Homestead	1,800	5	> 3.0	> 3.0
	Sheds	1,800	55	> 3.0	> 3.0
Above WYLW25	Sheds	1,900	60	> 3.0	> 3.0

The maximum predicted conventional strains for the building structures, based on applying a factor of 10 to the maximum predicted curvatures, are greater than 30 mm/m tensile and compressive. The depths of cover in the locations of these building structures vary between 90 and 100 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 building structures 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.

6.7.3. Impact Assessments for the Whynot Homestead and Associated Structures

The Whynot Homestead is predicted to experience a final tilt of 5 mm/m (i.e. 0.5 % or 1 in 200) at the completion of mining. The homestead is also predicted to experience a transient tilt of approximately 30 mm/m (i.e. 3 % or 1 in 33) as the extraction face of WYLW21 mines directly beneath it. The homestead is a single storey timber framed structure with lightweight cladding. It is unlikely, therefore, that the main structure would become unstable or unsafe as a result of the mining induced tilt. It is recommended, however, that the brick chimney is visually monitored during active subsidence to identify if the mining induced tilt adversely effects its integrity.

The homestead could experience curvatures greater than 3.0 km^{-1} (i.e. minimum radius of curvature less than 0.3 km) and strains greater than 30 mm/m. The structure is supported above the natural ground on timber piers. The predicted ground movements could result in the distortion of the timber frames and it is possible that the structure could become unsafe due to its poor existing condition. The mining induced impacts could be minimised by packing between the main structure and the piers during active subsidence so as to maintain the floor as planar.

The sheds associated with the Whynot Homestead could experience tilts up to 55 mm/m (i.e. 5.5 % or 1 in 18), curvatures greater than 3.0 km^{-1} (i.e. minimum radius of curvature less than 0.3 km) and strains greater than 30 mm/m. The predicted ground movements could result in the distortion of the timber frames and it is also possible that some structures become unsafe due to their poor existing conditions.

It is recommended that the Whynot Homestead and associated structures are visually monitored during active subsidence as WYLW21 mines directly beneath them. If any structure is identified as unstable or unsafe during monitoring, then measures should be undertaken to stabilise it (such as packing of the timber pier supports or the provision of temporary bracing), install fencing to prevent access or remove the structure.

6.7.4. Impact Assessments for the Structures Above WYLW25

The sheds located above the proposed WYLW25 could experience tilts up to 60 mm/m (i.e. 6 % or 1 in 17), curvatures greater than 3.0 km^{-1} (i.e. minimum radius of curvature less than 0.3 km) and strains greater than 30 mm/m. The predicted ground movements could result in the distortion of the timber frames and it is possible that some structures become unsafe due to their existing poor conditions.

It is recommended that the building structures located above the proposed WYLW25 are visually monitored during active subsidence as the longwall extraction face mines directly beneath them. If any structure is identified as unstable or unsafe during monitoring, then measures should be undertaken to stabilise it, such as the provision of temporary bracing, or prevent access to it with the installation of fencing. Alternatively, the structures could be removed prior to active subsidence.

APPENDIX A. REFERENCES

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

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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.

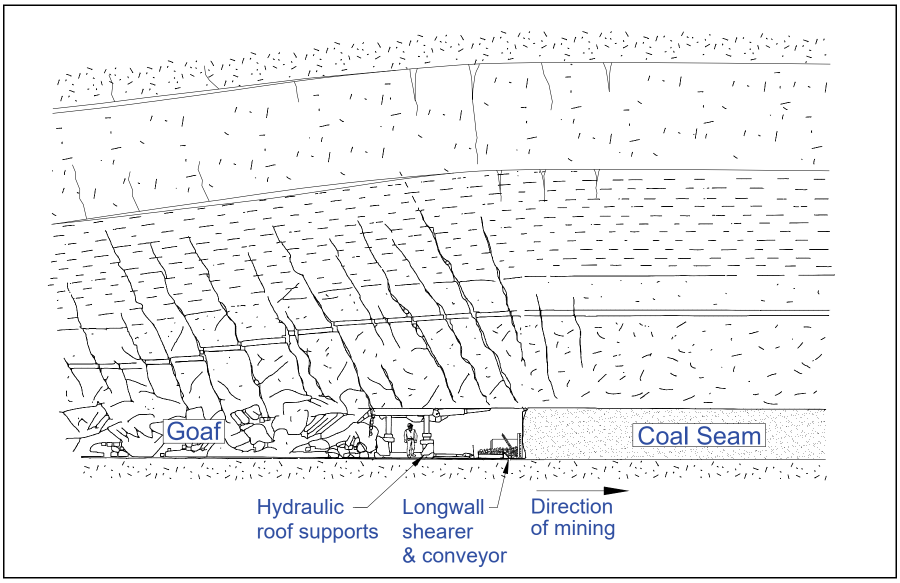

Fig. B. 1 Cross-section along the Length of a Typical Longwall at the Coal Face

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 factures, opening up of existing vertical fractures and bed separation. The amount of strata sagging, fracturing and bed separation reduces towards the surface.

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

B.3. Overview of Conventional Subsidence Parameters

The normal ground movements resulting from the extraction of longwalls are referred to as conventional or systematic subsidence movements. These movements are described by the following parameters:

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.
- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres* (km^{-1}), but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.
- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile Strains** occur where the distances between two points increase and **Compressive Strains** occur when the distances between two points decrease. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

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

- **Horizontal shear deformation** across monitoring lines can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. It is not possible, however, to determine the horizontal shear strain across a monitoring line using 2D or 3D monitoring techniques. High deformations along monitoring lines (i.e. normal strains) are generally measured where high deformations have been measured across the monitoring line (i.e. shear deformations), and vice versa.

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

B.4. Far-field Movements

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

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

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

B.5. Overview of Non-Conventional Subsidence Movements

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

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near surface strata layers. Irregular subsidence movements are generally associated with:

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

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

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

Irregular ground movements are commonly observed in shallow mining situations, where the collapsed zone, which develops above the extracted longwalls, extends near to the surface. This type of irregularity is generally only seen where panel widths are supercritical and where the depths of cover are less than 100 m, which occurs at the north-eastern ends of WYLW17 to WYLW25. These irregular movements appear as localised bumps and steps in the observed subsidence profiles, which are accompanied by elevated tilts, curvatures and ground strains.

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

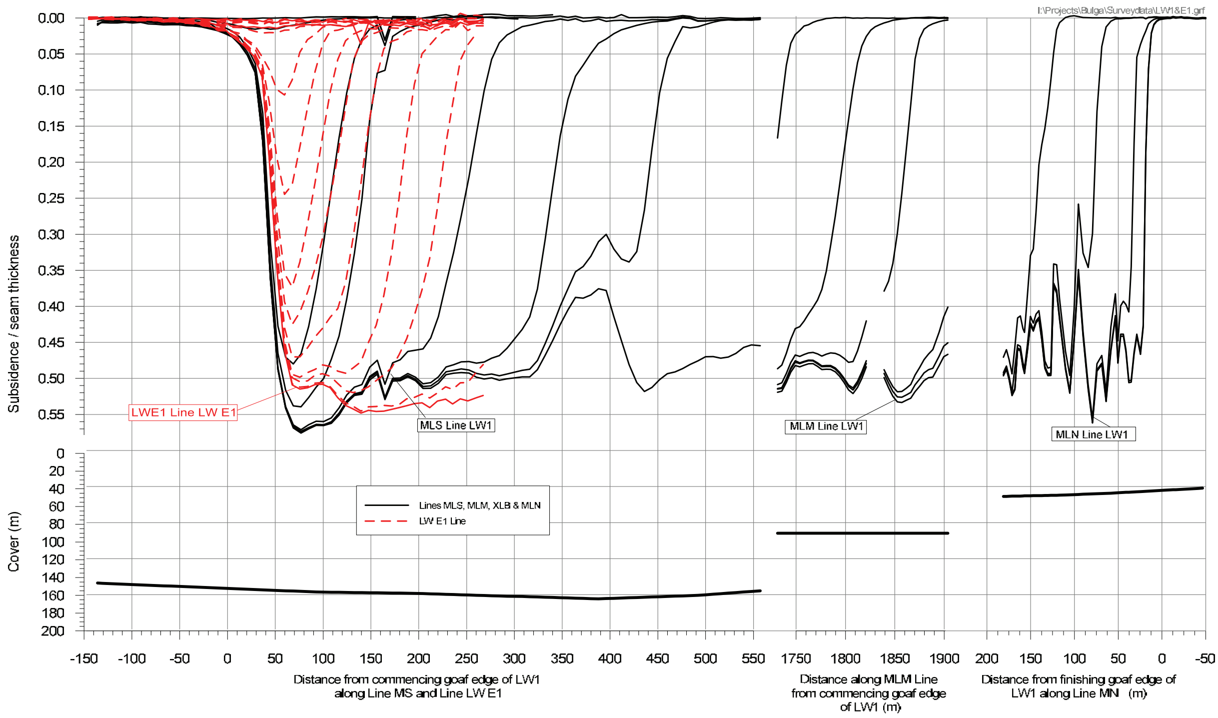

Fig. B. 2 Observed Subsidence Profiles at South Bulga Colliery

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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.

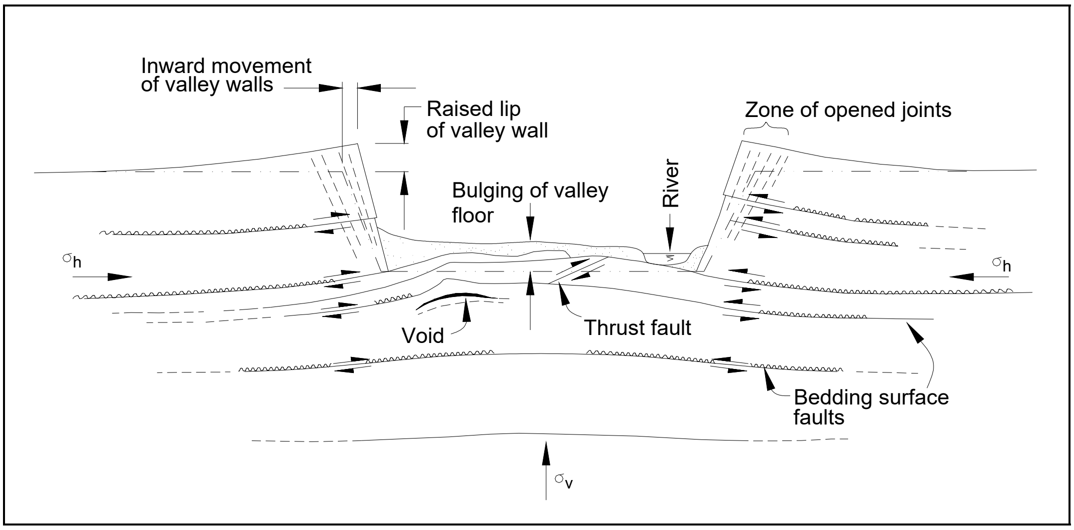

Fig. B. 3 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

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

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Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 1 due to WYLW17 to WYLW25 at the South Bates Mine

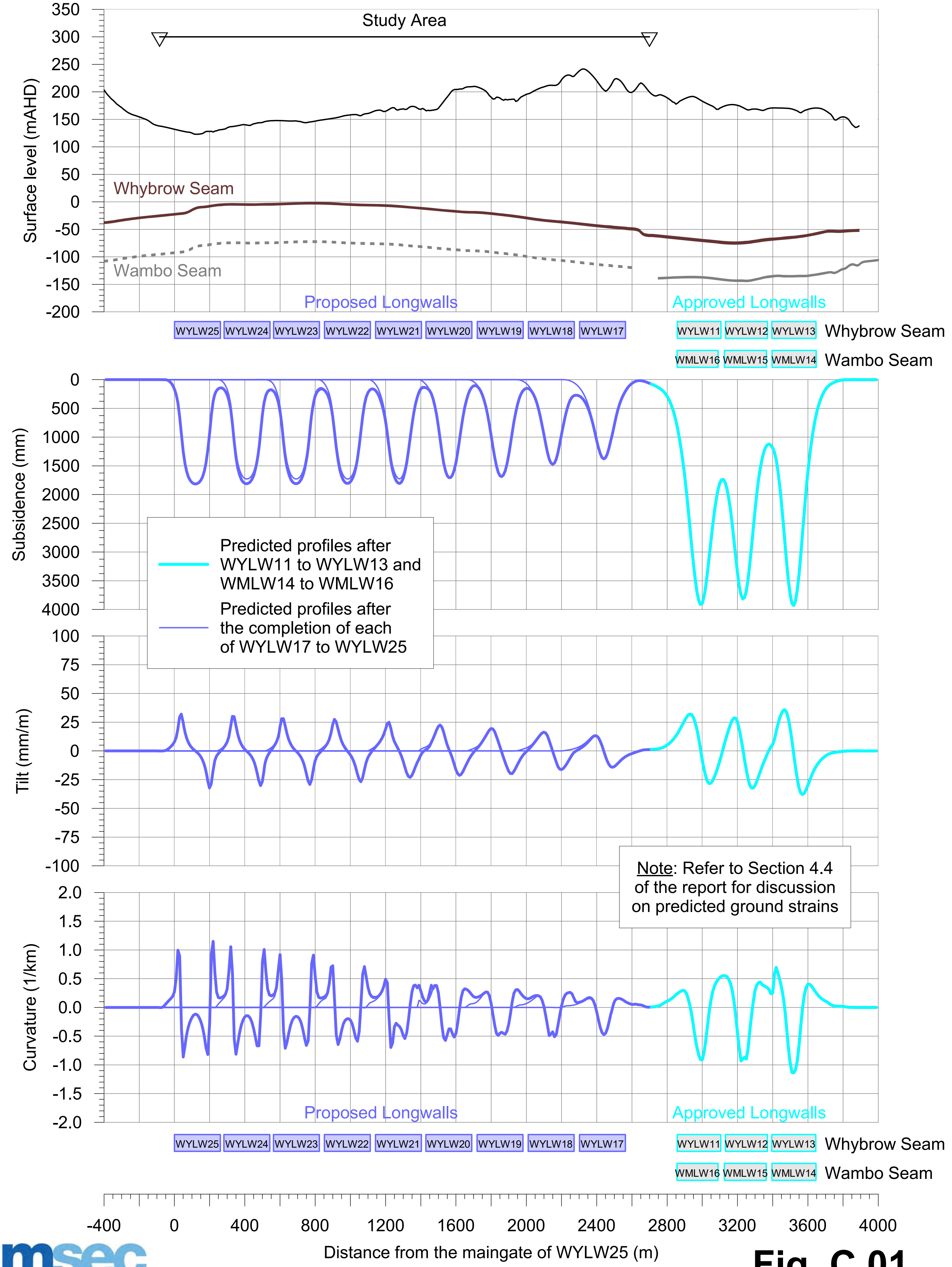

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Fig. C.01

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 2 due to WYLW17 to WYLW25 at the South Bates Mine

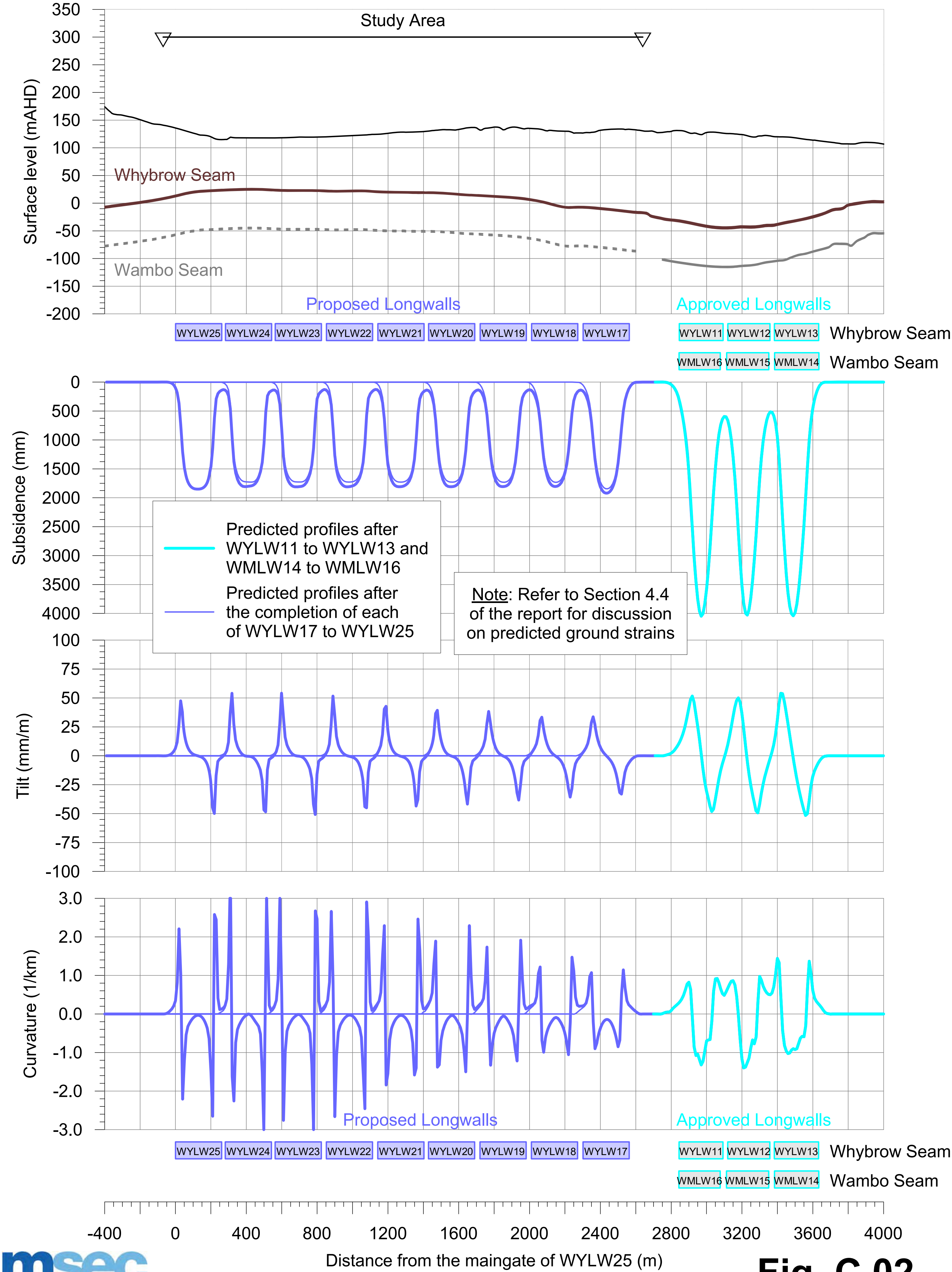

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Fig. C.02

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 3 due to WYLW17 to WYLW25 at the South Bates Mine

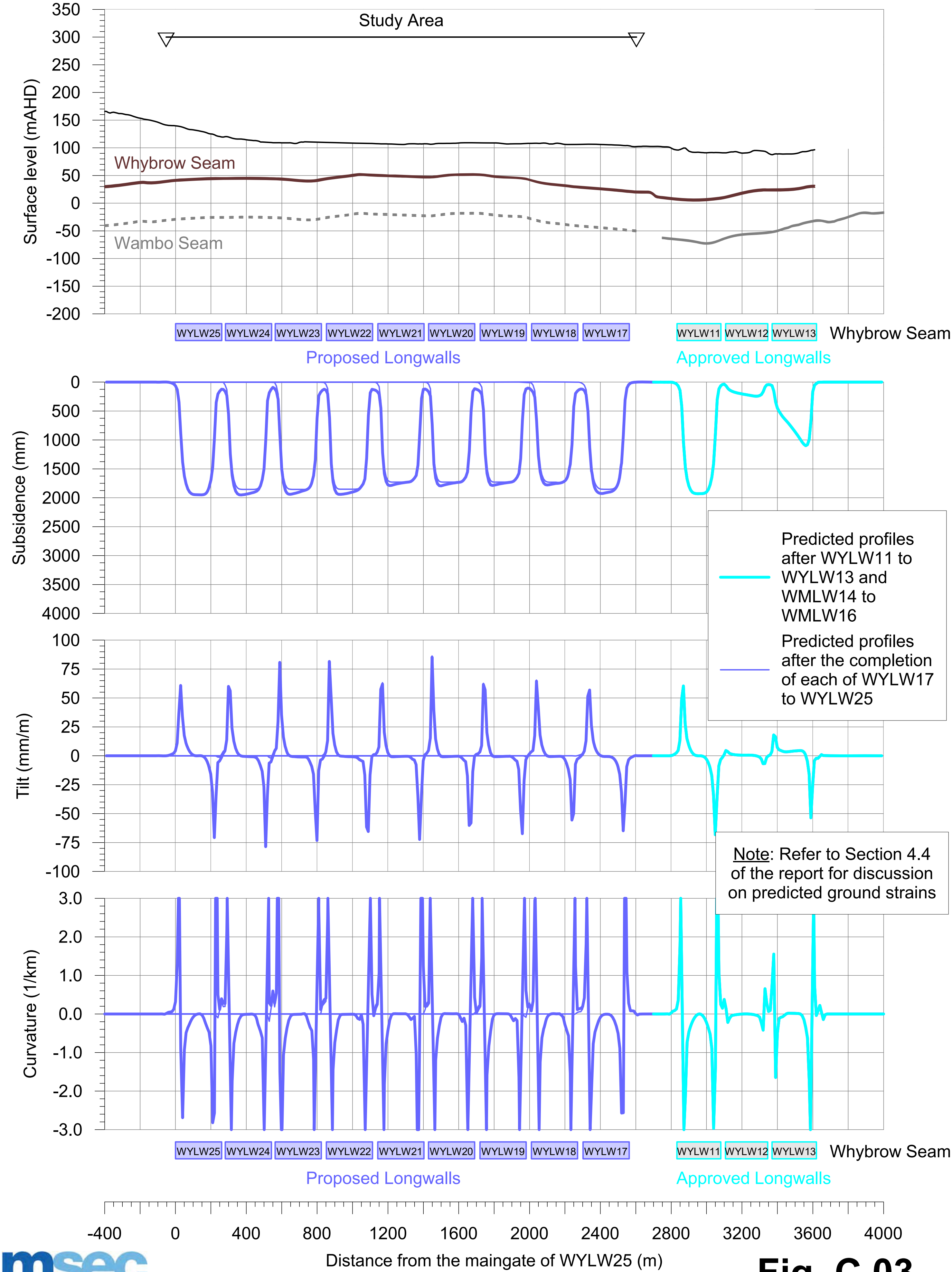

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Fig. C.03

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along North Wambo Creek due to WYLW17 to WYLW25 at the South Bates Mine

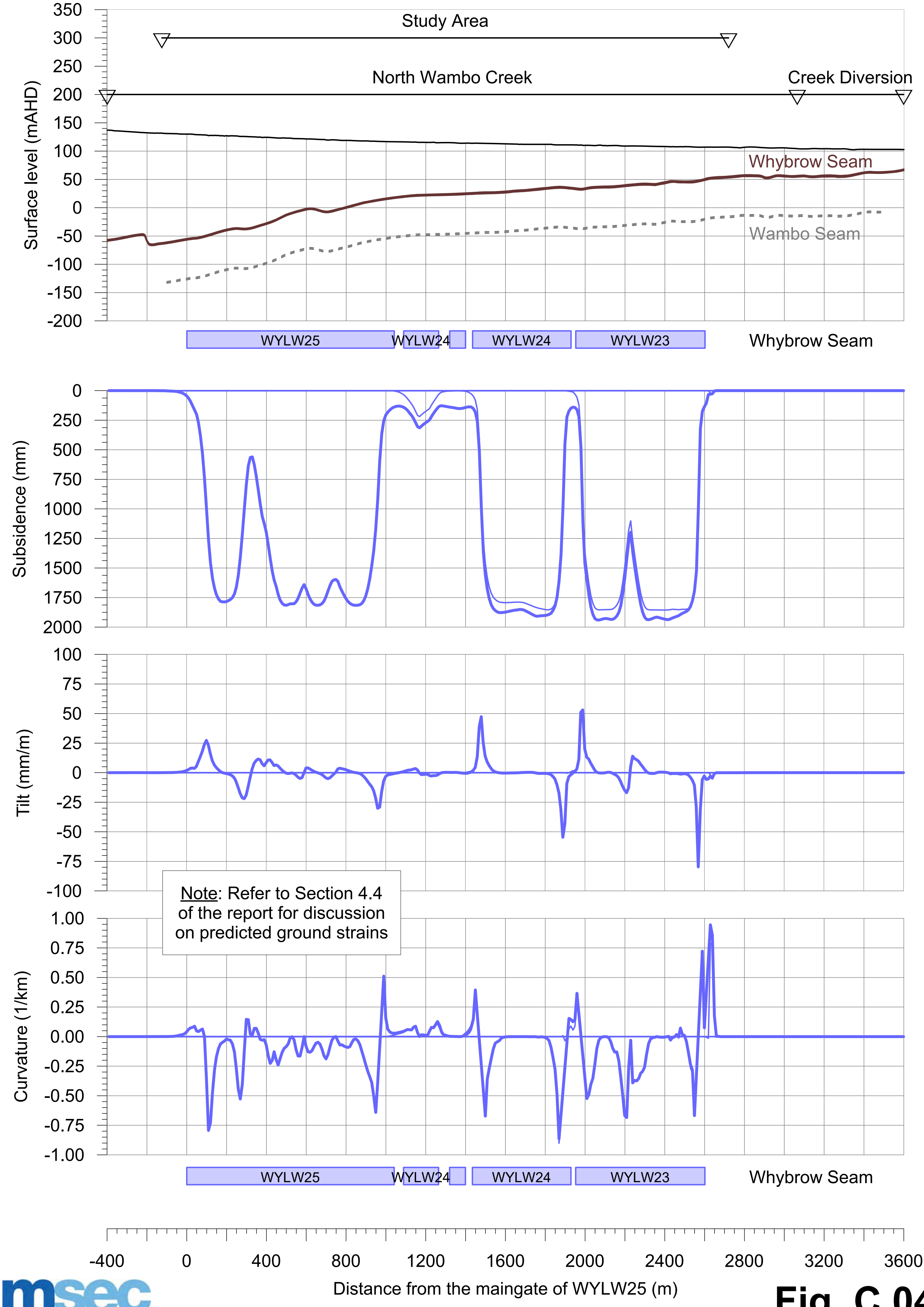

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Fig. C.04

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Creek Diversion due to WYLW17 to WYLW25 at the South Bates Mine

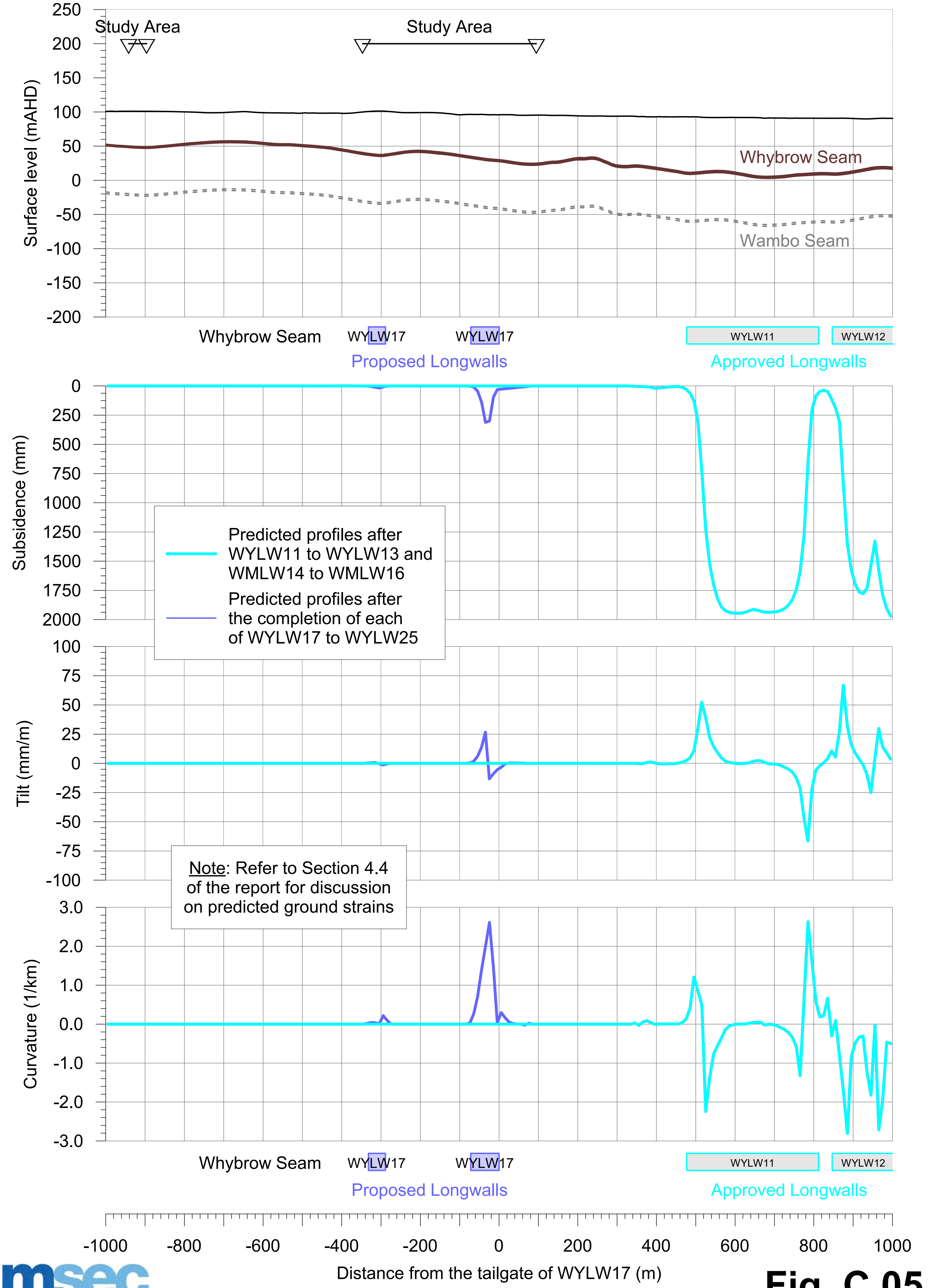

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Fig. C.05