MALABAR COAL

MAXWELL PROJECT

Agricultural Impact Assessment

In Support of an Application for a Gateway Certificate

ATTACHMENT B

Subsidence Assessment

August 2018

MAXWELL PROJECT:

Gateway Application – Subsidence Assessment

Subsidence Predictions and Impact Assessments for Natural and Built Features due to Multi-seam Mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams, in Support of the Application for a Gateway Certificate

DOCUMENT REGISTER

Revision	Description	Author	Checker	Date
01	Draft Issue	JB	BM	07 Jun 18
02	Draft Issue	JB	BM	13 Jun 18
03	Draft Issue	JB	BM	18 Jun 18
04	Draft Issue	JB	BM	23 Jul 18
A	Final Issue	JB	BM	20 Aug 18

Report produced to: support the Gateway Application for the Maxwell Project.

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

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

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

EXECUTIVE SUMMARY

Malabar Coal Limited (Malabar) is seeking consent to develop an underground coal mining operation within Exploration Licence (EL) 5460, referred to as the Maxwell Project (the Project). Malabar proposes to extract bord and pillar panels (with partial pillar extraction) in the Whynot Seam and longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams.

Malabar is applying for a Gateway Certificate (the Gateway Application) as the proposed mining area includes land mapped as Biophysical Strategic Agricultural Land. This report has been issued to support the Gateway Application for the Maxwell Project.

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

- review the currently proposed panel and longwall layouts in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams;
- prepare predicted subsidence contours after the extraction of the proposed panels and longwalls within each of the seams;
- identify and describe the natural and built features within EL5460, with particular focus on those relevant to the Gateway Application;
- provide subsidence predictions and impact assessments for the natural and built features identified within EL5460, with particular focus on those relevant to the Gateway Application; and
- provide recommendations for strategies to manage the potential impacts resulting from mining.

The assessments provided in this report should be read in conjunction with the assessments provided in the Agricultural Impact Assessment. The main findings from this report are as follows:

- The subsidence predictions provided in this report were obtained using the Incremental Profile Method, which has been calibrated for multi-seam mining conditions using the available data from the NSW coalfields. The maximum predicted subsidence effects, resulting from the proposed mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams, are as follows:
  - vertical subsidence of 5800 mm;
  - tilt of 50 mm/m (i.e. 5 %, or 1 in 20);
  - hogging and sagging curvatures of 2.0 per kilometre (km^{-1}, i.e. minimum radius of curvature of 0.5 km); and
  - strains typically between 10 mm/m and 20 mm/m, with localised strains greater than 20 mm/m.
- The surface cracking in the flatter areas (i.e. away from the steep slopes) above the proposed mining area is expected to be typically between 25 mm and 50 mm, with some localised cracking around 100 mm or greater. The surface cracking along the steeper slopes above the proposed mining area is expected to be typically in the order of 50 mm to 100 mm, with localised cracking around 200 mm or greater. Detailed mapping from the Beltana No. 1 Underground Mine found that the surface cracking affected less than 0.02 % of the surveyed area.

  Management and remediation measures can be developed for the surface cracking, which could include visual monitoring, the establishment of methods for surface remediation, and the development of management plans and remedial measures.
- It is expected that localised topographical depressions will develop above the proposed longwalls, particularly along the alignments of the drainage lines and in the flatter areas. These areas have the potential for increased surface water ponding.

  The largest final topographical depression occurs in the north-western part of the proposed mining area, where the depth of cover is the shallowest, and it has a maximum depth of 3.2 m. The topographical depressions on the southern boundary of the proposed mining area vary up to 2.7 m deep. Elsewhere, the topographical depressions are predicted to be less than 2 m deep.

  After the completion of mining in each seam in a particular area, surface remediation can be undertaken to re-establish the natural grades along the drainage lines, so as to reduce the potential for increased ponding within EL5460.
- Biophysical Strategic Agricultural Land (BSAL) has been identified above the western part of the proposed mining area. The Australian Soil Classification is Eutrophic Brown Chromosol. Of the total proposed mining area of 2134 hectares (ha), the total verified BSAL surface area located directly above the mining area is 72 ha.

The BSAL could be affected by surface cracking and the development of topographical depressions due to the proposed mining. The topographical depressions within the BSAL are predicted to be up to 3.2 m deep and the total affected surface area is 2.5 ha. If this area were to be adversely affected by surface cracking or increased ponding, these effects could be reduced by surface remediation to repair the cracking and to re-establish the natural gradients.

- The Hunter River is located to the south of the proposed mining area. The thalweg (i.e. centreline) of the river channel is 525 m from the proposed WHLW12, at its closest point to the proposed longwalls. At this distance from the longwalls, it is not expected that there would be adverse surface impacts on the river channel due to the proposed mining.

  The 50 m buffer to the mapped limit of alluvium for the Hunter River is located outside the 26.5° angle of draw lines from the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. At this distance, the alluvium is predicted to experience less than 20 mm vertical subsidence and is not expected to experience measurable tilts, curvatures or strains. The potential impacts on the alluvium and associated aquifer are discussed in the Agricultural Impact Assessment.

- Saddlers Creek is located to the north of the proposed mining area. The thalweg of the creek channel is 240 m from WHLW4, at its closest point to the proposed longwalls. At this distance, the creek channel is not expected to experience adverse surface impacts due to the proposed mining. Further discussions are provided in the Agricultural Impact Assessment.

- The ephemeral[2] drainage lines above the southern part of the proposed mining area are tributaries to the Hunter River and the drainage lines above the northern part of the proposed mining area are tributaries to Saddlers Creek. The upper reaches are first and second order streams and some parts of the lower reaches are third order streams.

  Increased potential for ponding is expected to develop along these drainage lines, which are estimated to be up to around 2.3 m deep and 500 m long, after the completion of mining. Some deeper but more localised ponding could occur in the locations of the existing farm dams. After the completion of mining in each seam in a particular area, surface remediation could be undertaken to re-establish the natural grades along the drainage lines, if beneficial, so as to reduce the potential for increased ponding within EL5460.

  It is also expected that surface cracking would occur in the soil beds or the exposed bedrock along the drainage lines due to the proposed mining. The larger surface cracks along the drainage line beds could be remediated by infilling with the surface soils or other suitable materials, or by locally regrading and recompacting the surface.

- The agricultural land utilisation above the proposed mining area comprises light grazing on Malabar owned land. The potential impacts on this land utilisation include surface cracking and changes in surface water drainage.

  Management strategies can be developed for the mining-induced surface cracking, to manage the potential impacts on the land use and associated infrastructure. It may also be necessary to install temporary fencing or to temporarily relocate stock to areas outside the active subsidence zone.

  Strategies can also be developed to remediate the surface drainage, which could include regrading the drainage lines downstream of the ponding areas, or by constructing bunds adjacent to the drainage lines.

- There are farm dams, groundwater bores and fences located above the proposed mining area. These built features are owned by Malabar and they will be managed during the proposed mining.

- There are also roads and electrical infrastructure located above the proposed mining area. Management strategies for these built features should be developed as part of Built Features Management Plans in consultation with the infrastructure owners.

With the implementation of all the necessary management strategies and remediation measures, it would be expected that subsidence resulting from the proposed mining would not result in long-term impacts on the agricultural land utilisation above the proposed mining area. Further discussions on the potential impacts due to the project are provided in the Agricultural Impact Assessment.

The impact assessments provided in this report will be reviewed and refined as part of the Environmental Impact Statement process.

[2] Drainage lines where surface water only flows during and for short periods after rainfall events.

CONTENTS

1.0 INTRODUCTION 1

1.1. Background 1

1.2. Mining geometry 2

1.3. Surface and seam information 3

1.4. Geological details 5

2.0 AGRICULTURAL LAND AND UTILISATION 10

2.1. Study Area 10

2.2. Natural and built features 10

2.3. Strategic Agricultural Land 11

2.4. Agricultural utilisation 12

2.5. Natural features 12

2.6. Built features 12

3.0 OVERVIEW OF MINE SUBSIDENCE AND THE METHODS THAT HAVE BEEN USED TO PREDICT THE MINE SUBSIDENCE EFFECTS FOR THE PROPOSED PANELS AND LONGWALLS 13

3.1. Introduction 13

3.2. Overview of conventional subsidence effects 13

3.3. Far-field movements 14

3.4. Overview of non-conventional subsidence effects 14

3.4.1. Non-conventional subsidence effects due to changes in geological conditions 14

3.4.2. Non-conventional subsidence movements due to steep topography 15

3.4.3. Valley related effects 15

3.5. The Incremental Profile Method 16

3.6. Calibration of the IPM 17

3.6.1. Calibration for local single-seam mining conditions 17

3.6.2. Calibration for multi-seam mining conditions 22

3.7. Reliability of the predicted conventional subsidence parameters 25

4.0 MAXIMUM PREDICTED SUBSIDENCE PARAMETERS 27

4.1. Introduction 27

4.2. Maximum predicted subsidence, tilt and curvature 27

4.3. Predicted strains 28

4.3.1. Single-seam mining conditions 28

4.3.2. Multi-seam mining conditions 31

4.4. Predicted far-field horizontal movements 33

5.0 IMPACT ASSESSMENTS FOR THE PROPOSED MULTI-SEAM MINING 34

5.1. Introduction 34

5.2. Surface cracking and deformations 34

5.3. Predicted changes in surface water drainage 37

5.4. The Hunter River 39

5.5. Saddlers Creek 40

5.6. Drainage lines 41

5.6.1. Description of the drainage lines 41

5.6.2. Predictions for the drainage lines 42
5.6.3. Impact assessments for the drainage lines 43
5.6.4. Recommendations for the drainage lines 46
5.7. Groundwater resources 46
5.8. Agricultural land utilisation 47
5.9. Built features associated with the agricultural land utilisation 48
APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS
APPENDIX B. REFERENCES
APPENDIX C. FIGURES
APPENDIX D. DRAWINGS

LIST OF TABLES, FIGURES AND DRAWINGS

Tables

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

Table No.	*Description*	*Page*
Table 1.1	Geometry of the proposed bord and pillar panels in the Whynot Seam	2
Table 1.2	Geometry of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams	3
Table 1.3	Depths of cover, interburden thicknesses, working sections and proposed mining heights for each of the seams	4
Table 1.4	Middle Permian to Quaternary stratigraphy of the Hunter Coalfield (after Stevenson, et al., 1998)	5
Table 1.5	Stratigraphy of the Wittingham Coal Measures	6
Table 3.1	Multi-seam mining cases for longwalls mining beneath or above previous mining	23
Table 4.1	Maximum predicted additional conventional subsidence parameters	27
Table 4.2	Maximum predicted total conventional subsidence parameters	27
Table 4.3	Comparison of the mine geometry for the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams with Blakefield South Mine and the North Wambo Underground Mine	31
Table 5.1	Maximum predicted conventional subsidence, tilt and curvature for the drainage lines	42
Table 5.2	Details of the groundwater bores within the Study Area	46

Figures

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

Figure No.	*Description*	*Page*
Fig. 1.1	Locations of EL5460 and the proposed underground mining area	1
Fig. 1.2	Surface and seam levels along Section 1	4
Fig. 1.3	Surface and seam levels along Section 2	4
Fig. 1.4	Surface and seam levels along Section 3	7
Fig. 1.5	Mapped extents of the sills within the Whynot Seam	7
Fig. 1.6	Mapped extents of the sills within the Arrowfield Seam	8
Fig. 1.7	Mapped extents of the sills within the Bowfield Seam	8
Fig. 1.8	Surface, seam and sill levels along Section 4	8
Fig. 1.9	Surface lithology above the proposed mining area	9
Fig. 2.1	The Study Area and proposed mining area overlaid on CMA Map No. 9033-2	10
Fig. 2.2	The Study Area and proposed mining area overlaid on an aerial photograph	11
Fig. 3.1	Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)	15
Fig. 3.2	Measured and predicted vertical subsidence, tilt and curvature along a monitoring line in the Newcastle Coalfield with a longwall width-to-depth ratio of around 0.4	19
Fig. 3.3	Measured and predicted vertical subsidence, tilt and curvature along a monitoring line in the Hunter Coalfield with a longwall width-to-depth ratio of around 0.7	20
Fig. 3.4	Measured and predicted vertical subsidence, tilt and curvature along a monitoring line in the Hunter Coalfield with a longwall width-to-depth ratio greater than 2.0	21
Fig. 3.5	Maximum measured vertical subsidence versus longwall width-to-depth ratio for previous multi-seam mining cases	24
Fig. 4.1	Distributions of the measured tensile and compressive strains for survey bays located above supercritical longwalls at depths of cover between 100 m and 150 m	29
Fig. 4.2	Distributions of the measured tensile and compressive strains for survey bays located above longwalls with width-to-depth ratios between 0.8 and 1.2	30

Fig. 4.3	Distributions of the measured tensile and compressive strains for multi-seam longwalls in the Hunter Coalfield	32
Fig. 4.4	Observed incremental far-field horizontal movements	33
Fig. 5.1	Surface cracking above Blakefield South Mine (multi-seam conditions)	35
Fig. 5.2	Examples of surface cracking on steep slopes in the Hunter Coalfield	36
Fig. 5.3	Example of surface crack remediation in the Newcastle Coalfield (Courtesy of Donaldson Coal)	37
Fig. 5.4	Natural (top) and predicted post-mining (bottom) surface levels contours and the locations and depths of the topographical depressions	38
Fig. 5.5	Photographs of the Hunter River	39
Fig. 5.6	Section through the Hunter River and the proposed longwalls where the river is located closest to the mining area	40
Fig. 5.7	Photographs of Saddlers Creek	40
Fig. 5.8	Section through Saddlers Creek and the proposed longwalls where the creek is located closest to the mining area	41
Fig. 5.9	Photographs of typical drainage lines within the Study Area	42
Fig. 5.10	Photographs of typical drainage lines within the Study Area	42
Fig. 5.11	Natural and predicted post-mining surface levels along Drainage Line 1	43
Fig. 5.12	Natural and predicted post-mining surface levels along Drainage Line 2	44
Fig. 5.13	Natural and predicted post-mining surface levels along Drainage Line 3	44
Fig. 5.14	Natural and predicted post-mining surface levels along Drainage Line 4	45
Fig. 5.15	Typical farm dam and access track within the Study Area	48
Fig. 5.16	Land contouring within the Study Area	48
Fig. 5.17	Cattle yard and fences within the Study Area	48
Fig. 5.18	Edderton Road and aerial low voltage powerline	49
Fig. 5.19	The Golden Highway and the bridge across the Hunter River	49
Fig. C.01	Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to the extraction of the WN, WH, AF and BF Seams	App. C
Fig. C.02	Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to the extraction of the WN, WH, AF and BF Seams	App. C
Fig. C.03	Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to the extraction of the WN, WH, AF and BF Seams	App. C

Drawings

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

Drawing No.	*Description*	*Revision*
MSEC955-01	General layout	A
MSEC955-02	Layout of longwalls in Whynot Seam	A
MSEC955-03	Layout of longwalls in Woodlands Hill Seam	A
MSEC955-04	Layout of longwalls in Arrowfield Seam	A
MSEC955-05	Layout of longwalls in Bowfield Seam	A
MSEC955-06	Surface level contours	A
MSEC955-07	Depth of cover contours for the Whynot Seam	A
MSEC955-08	Depth of cover contours for the Woodlands Hill Seam	A
MSEC955-09	Depth of cover contours for the Arrowfield Seam	A
MSEC955-10	Depth of cover contours for the Bowfield Seam	A
MSEC955-11	Seam thickness contours for the Whynot Seam	A
MSEC955-12	Seam thickness contours for the Woodlands Hill Seam	A
MSEC955-13	Seam thickness contours for the Arrowfield Seam	A
MSEC955-14	Seam thickness contours for the Bowfield Seam	A
MSEC955-15	Mapped geological structures	A
MSEC955-16	Strategic agricultural land	A
MSEC955-17	Agricultural land utilisation	A
MSEC955-18	Surface drainage	A
MSEC955-19	Built features	A
MSEC955-20	Predicted total subsidence contours after the Whynot Seam	A
MSEC955-21	Predicted total subsidence contours after the Woodlands Hill Seam	A
MSEC955-22	Predicted total subsidence contours after the Arrowfield Seam	A
MSEC955-23	Predicted total subsidence contours after the Bowfield Seam	A

1.1. Background

Malabar Coal Limited (Malabar) is seeking consent to develop an underground coal mining operation within Exploration Licence (EL) 5460, referred to as the Maxwell Project (the Project). Malabar proposes to extract bord and pillar panels (with partial pillar extraction) in the Whynot Seam and longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams.

EL 5460 is located in the Hunter Coalfield of New South Wales (NSW) east-southeast of Denman and south-southwest of Muswellbrook. The locations of EL 5460 and the proposed underground mining area are shown in Fig. 1.1.

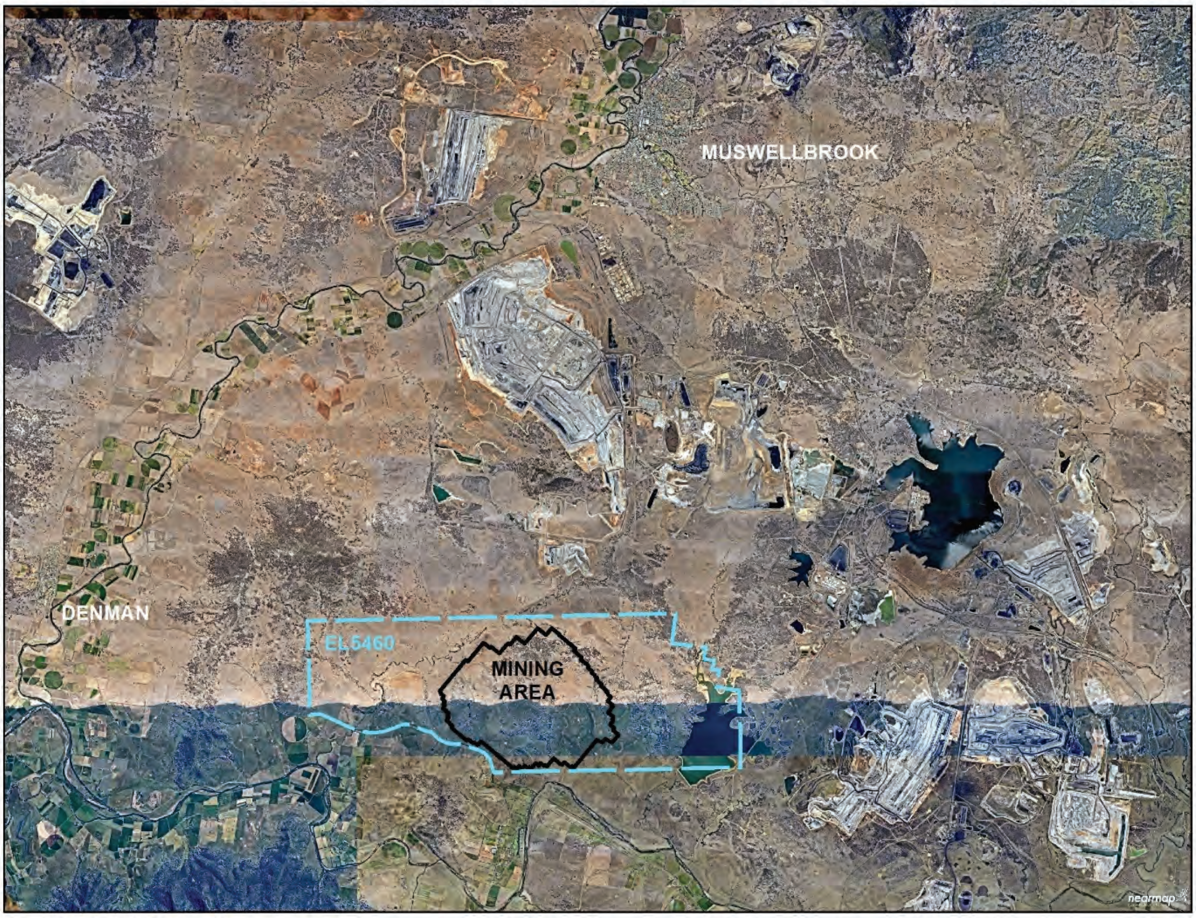


Fig. 1.1 Locations of EL5460 and the proposed underground mining area

Malabar is applying for a Gateway Certificate pursuant to clause 17F of the *NSW State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* (the Gateway Application) as the Project area is located within land mapped as Biophysical Strategic Agricultural Land (BSAL).

In determining the application for a Gateway Certificate, the Gateway Panel must consider whether the project would significantly reduce the agricultural productivity of any BSAL, based on consideration of:

- any impacts on the land through surface area disturbance or subsidence;
- any impacts on soil fertility, effective rooting depth or soil drainage;
- increases in land surface micro-relief, soil salinity, rock outcrop, slope and surface rockiness, or significant changes in pH;
- any impacts on highly productive groundwater;
- any fragmentation of agricultural land uses; and
- any reduction in the area of BSAL.

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

- review the currently proposed mining layouts in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams;
- prepare predicted subsidence contours after the extraction of the proposed panels and longwalls within each of the seams;
- identify and describe the natural and built features within the proposed mining area, with particular focus on those relevant to the Gateway Application, including:
  - strategic agricultural land;
  - agricultural land utilisation, including vineyards, horse studs and other farming activities;
  - farm facilities, including building structures and dams; and
  - built features associated with the agricultural land use, including roads and services.
- provide subsidence predictions and impact assessments for the natural and built features identified within the proposed mining area, including assessments on:
  - surface cracking and deformations;
  - changes in surface water drainage; and
  - impacts on natural and built features associated with the agricultural utilisation.
- provide recommendations for strategies to manage the potential impacts resulting from mining.

Chapter 1 of this report provides an overview of the mining geometry, seam information and the overburden geology for the project.

Chapter 2 provides a summary of the natural and built features within the proposed mining area, with particular focus on those relevant to the Gateway Application.

Chapter 3 provides an overview of conventional and non-conventional subsidence movements and the methods which have been used to predict the multi-seam mine subsidence movements for the project.

Chapter 4 provides a summary of the maximum predicted subsidence parameters resulting from the extraction of the proposed panels and longwalls in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams.

Chapter 5 provides the predictions and impact assessments for the natural and built features within the proposed mining area, based on the predicted mine subsidence movements. Recommendations of management strategies for the potential mine subsidence impacts have also been provided in this chapter.

1.2. Mining geometry

Malabar proposes to extract bord and pillar panels (with partial extraction) in the Whynot Seam and longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. The layouts of the proposed panels and longwalls are shown in Drawings Nos. MSEC955-01 to MSEC955-05.

There are 19 proposed panels in the Whynot Seam, referred to as WNP1 to WNP19. A summary of the proposed panel dimensions is provided in Table 1.1.

Table 1.1 Geometry of the proposed bord and pillar panels in the Whynot Seam

Seam	Overall void lengths including roadways (m)	Overall panel widths including first workings (m)	Solid barrier pillar widths (m)
Whynot (WN)	180 ~ 2555	185	55

The proposed panels each comprise six rows of pillars along their lengths, as shown in Drawing No. MSEC955-02. The pillars have dimensions of 25 m by 25 m and are separated by 5 m wide development roadways.

Malabar proposes to carry out partial extraction of the pillars within each of the proposed panels to achieve approximately 55 % to 70 % coal recovery based on both first and second workings. There are various partial extraction methods that could achieve this level of coal recovery.

The subsidence predictions provided in this report have been based on the extraction of the two rows of pillars adjacent to each of the barrier pillars (i.e. four rows of pillars within each panel) and leaving the two central rows of pillars unmined (i.e. central spine pillar). Small sections of the coal seam will be left as a result of the mining process, known as stooks, representing approximately 15 % of the coal for the rows of mined pillars.

This partial extraction method achieves approximately 71% coal recovery, within each of the proposed panels, based on both first and second workings. The overall coal recovery is approximately 55 % when considering both the panels and the barrier pillars.

The partial extraction within each of the proposed panels results in two voids between each of the barrier pillars and the central spine pillar. These two voids each have a width of 65 m. The overall width of the central spine pillar is 55 m, which is split by a 5 m wide roadway.

There are 14 longwalls proposed in the Woodlands Hill Seam (WHLW1 to WHLW14), 14 longwalls proposed in the Arrowfield Seam (AFLW1 to AFLW14) and 11 longwalls proposed in the Bowfield Seam (BFLW1 to BWLW11). A summary of the longwall dimensions is provided in Table 1.2.

Table 1.2 Geometry of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams

Seam	Overall void lengths including installation headings (m)	Overall void widths including first workings (m)	Overall tailgate chain pillar widths (m)
Woodlands Hill (WH)	1940 ~ 4380	305	35
Arrowfield (AF)	1300 ~ 3090	305	35
Bowfield (BF)	1470 ~ 2930	305	35

The lengths of longwall extraction excluding the installation headings are approximately 10 m less than the overall void lengths provided in Table 1.2. The longwall face widths excluding the first workings are 295 m.

The proposed longwalls within each of the seams have been staggered so that the chain pillars are not aligned. The longwalls in the Arrowfield Seam have been offset by approximately 75 m from the longwalls in the overlying Woodlands Hill Seam. The longwalls in the Bowfield Seam have been offset by approximately 100 m from the longwalls in the overlying Arrowfield Seam.

1.3. Surface and seam information

The surface level contours within the proposed mining area are shown in Drawing No. MSEC955-06. The land generally falls towards the Hunter River to the south of the mining area and towards Saddlers Creek to the north of the mining area.

The surface elevations directly above the proposed mining area vary from a low point of 110 metres above Australian Height Datum (mAHD) within a tributary to the Hunter River to a high point of 240 mAHD at the top of a hill in the eastern side of the mining area.

The depth of cover contours for the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are shown in Drawings Nos. MSEC955-07, MSEC955-08, MSEC955-09 and MSEC955-10, respectively. The seam thickness contours for the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are shown in Drawings Nos. MSEC955-11, MSEC955-12, MSEC955-13 and MSEC955-14, respectively.

A summary of the ranges of depths of cover, interburden thicknesses, working section thicknesses and mining heights is provided in Table 1.3. The values represent the ranges within the proposed mining areas for each of the seams.

Table 1.3 Depths of cover, interburden thicknesses, working sections and proposed mining heights for each of the seams

Seam	Depth of cover (m)	Interburden thickness to the overlying seam (m)	Working section thickness (m)	Mining height (m)
Whynot Seam (WN)	40* ~ 180 (100 average)	N/A (Single-seam)	1.3 ~ 2.3 (2.0 average)	1.5 ~ 2.3
Woodlands Hill (WH)	125 ~ 365 (260 average)	135 ~ 185 (165 average)	1.7 ~ 3.5 (2.7 average)	2.1 ~ 3.5
Arrowfield (AF)	170 ~ 415 (310 average)	40 ~ 70 (50 average)	2.1 ~ 3.7 (2.9 average)	2.1 ~ 3.7
Bowfield (BF)	215 ~ 425 (340 average)	10 ~ 45 (25 average)	2.2 ~ 3.3 (2.8 average)	2.4 ~ 3.3

*<u>Note</u>: * denotes that secondary extraction will only occur at depths of cover greater than 50 m.*

The surface and seam levels are illustrated along Sections 1 and 2 in Fig. 1.2 and Fig. 1.3, respectively. The locations of these sections are shown in Drawings Nos. MSEC955-06 to MSEC955-10. The Study Area is defined in Section 2.1.

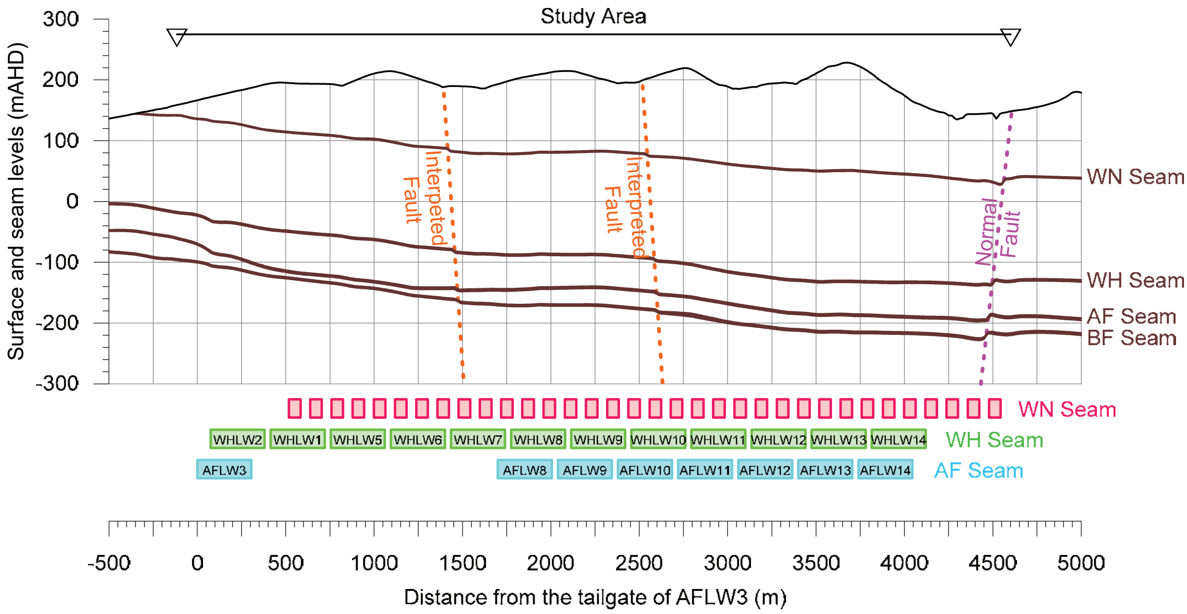


Fig. 1.2 Surface and seam levels along Section 1

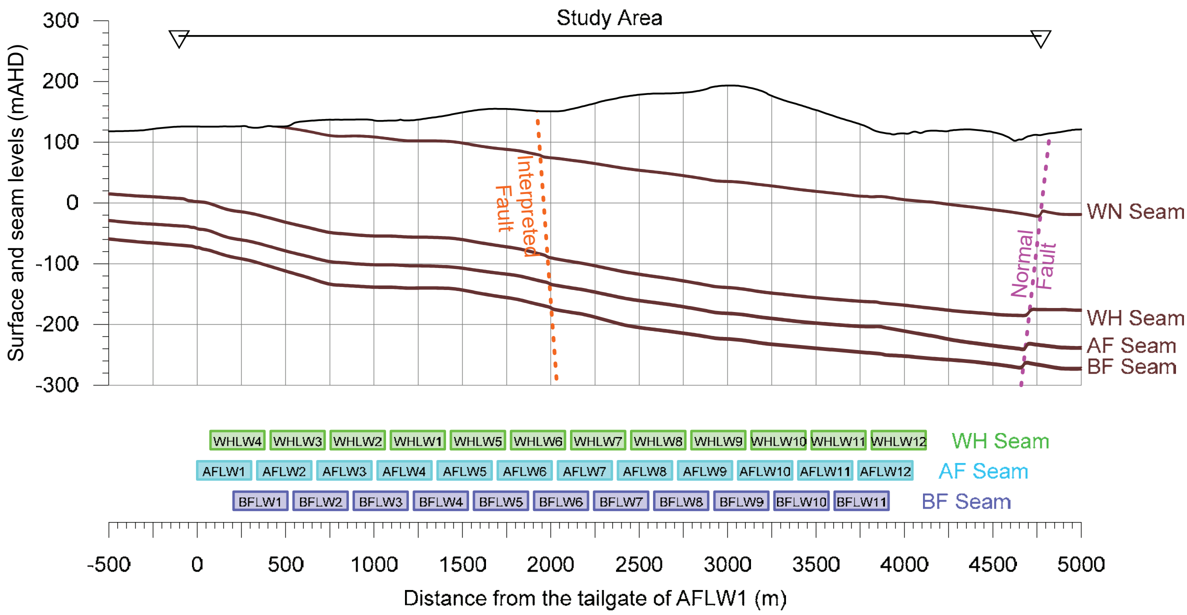


Fig. 1.3 Surface and seam levels along Section 2

The target seams generally dip from the north-north-west towards the south-south-east, with average gradients varying between 3 % and 5 % within the proposed mining area. The Whynot Seam outcrops in the northern part of EL5460.

1.4. Geological details

EL5460 lies in the Hunter Coalfield within the Northern Sydney Basin. The general stratigraphy of the Hunter Coalfield is shown in Table 1.4 (after Stevenson, et al., 1998). The target seams lie within the Jerrys Plains Subgroup of the Wittingham Coal Measures, which is shown in more detail in Table 1.5. The Newcastle Coal Measures and overlying groups are generally not present in the proposed mining area.

Table 1.4 Middle Permian to Quaternary stratigraphy of the Hunter Coalfield (after Stevenson, et al., 1998)

Period	Stratigraphy			Lithology
Quaternary				silt, sand, gravel
Tertiary				basalt
Jurassic				basalt
Triassic	Hawkesbury Sandstone			massive quartz sandstone with minor siltstone
	Narrabeen Group	Terrigal Formation		sandstone, interbedded sandstone and siltstone, mudstone, claystone
		Clifton Subgroup	Patonga Claystone Tuggerah Formation Widden Brook Conglomerate	sandstone, interbedded sandstone and siltstone, claystone
Permian	Singleton Supergroup	Newcastle Coal Measures	Glen Gallic Subgroup Doyles Creek Subgroup Horseshoe Creek Subgroup Apple Tree Flat Subgroup	coal, claystone, siltstone, shale, sandstone, conglomerate, tuffaceous sediments
			Watts Sandstone	medium to coarse sandstone
		Wittingham Coal Measures	Denman Formation Jerrys Plains Subgroup Archerfield Sandstone Vane Subgroup Saltwater Creek Formation	sandstone, siltstone, laminate coal, claystone, tuff, siltstone, sandstone, conglomerate well-sorted quartz-lithic sandstone coal, siltstone, lithic sandstone, shale, conglomerate sandstone, siltstone, minor coal

Table 1.5 Stratigraphy of the Wittingham Coal Measures

Stratigraphy			Lithology	
Wittingham Coal Measures	Denman Formation			
	Jerrys Plains Subgroup	Mount Leonard Formation Althorpe Formation	Whybrow seam	
		Malabar Formation	Redbank Creek seam	
			Wambo seam	
			Whynot seam	
		Mount Ogilvie Formation	Blakefield seam	
			Saxonvale Member	
			Glen Munro seam	
			Woodlands Hill seam	
		Millbrodale 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		
		Foy Brook Formation	Lemington seam Pikes Gully seam Arties seam Liddell seam Barrett seam Hebden seam	Wynn C. M. Edderton C. M. Clanricard C. M. Bengalla C. M. Edinglassie C. M. Ramrod Ck. C.M.
	Saltwater Creek Subgroup			

<u>Note</u>: C. M. = Coal Measure

There have been a number of drilling campaigns within EL5460 from the late 1940's through to the present. Other geological exploration includes: high-resolution ground magnetic survey, low-level aero-magnetic survey and a radiometric survey for the purposes of detecting and mapping intrusive bodies (Malabar, pers. comm., April 2018).

Geophysical logging has been generally carried out on the drillholes since 1998. The testing identified the coal seam floors, coal seam roofs, partings, igneous intrusions and tuff marker bands, lithological boundaries and structural features (Malabar, pers. comm., April 2018). Geotechnical logging to identify natural fractures has been carried out since 2008.

The mapped geological structures in EL5460 are shown in Drawing No. MSEC955-15.

The south-southeast trending Muswellbrook Anticline is located near the eastern boundary of EL5460 and well outside the proposed mining area. The strata dip steeply along this structure with gradients varying between 35 % and 85 %. On the western side of the anticline, the strata dips gently with gradients varying between 3 % and 5 % within the proposed mining area.

A complex north-northwest orientated graben structure crosses the western part of EL5460, comprising the East Graben Fault and the Randwick Park Fault, which is part of a regional graben system. The East Graben Fault is sub-vertical and has a throw of 20 m to 40 m. The Randwick Park Fault has a dip of 70° and a throw of 15 m to 20 m.

The south-western ends of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams have been set back from the graben structure. The locations of the East Graben and Randwick Park Faults relative to the proposed longwalls are shown along Section 3 in Fig. 1.4. This section has been taken where the graben structure is located closest to the proposed longwalls, as shown in Drawing No. MSEC955-15.

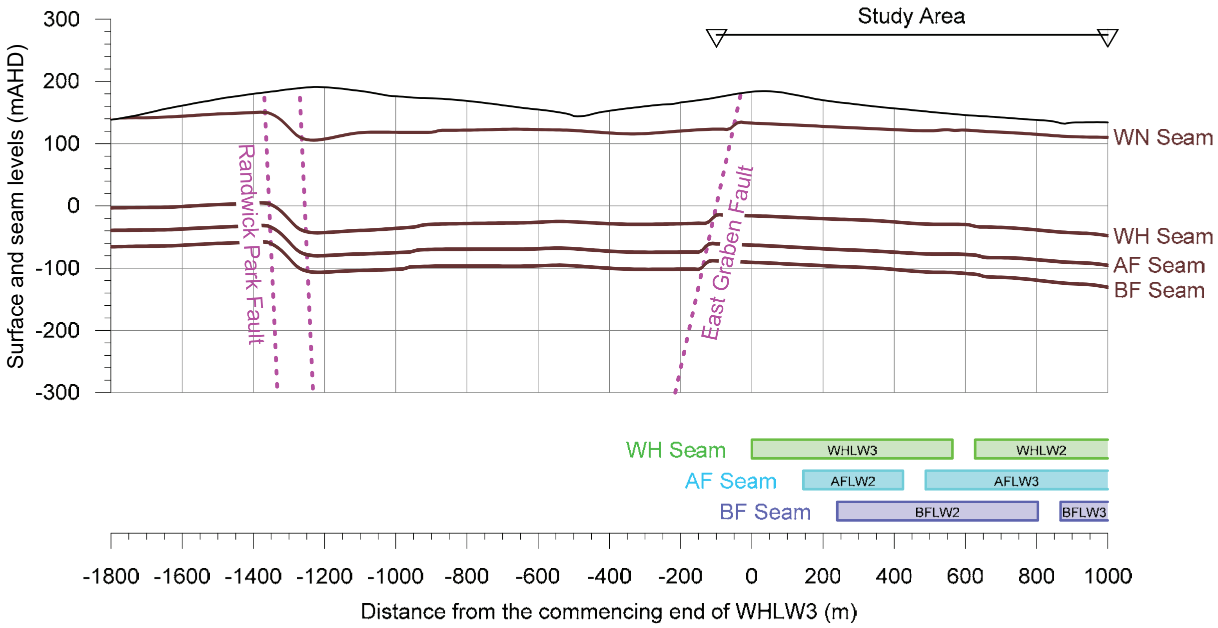


Fig. 1.4 Surface and seam levels along Section 3

The projected surface expression of the East Graben Fault is located approximately 30 m from the corner of the proposed WHLW3. Localised surface deformations could develop at the surface expression of this fault where it is located closest to the proposed longwalls. Further discussions are provided in Section 5.2.

A north-east trending fault is located on the south-eastern side of the proposed mining area. This normal fault has a dip of approximately 70° and a throw of 10 m. There are also north-west trending faults and interpreted north-east trending faults within the proposed mining area. These normal faults have dips of approximately 70° to 75° and throws of 2 m to 6 m. The north-east trending faults and interpreted faults are shown in Fig. 1.2 and Fig. 1.3.

There are two parallel north trending dykes in the northern part of the proposed mining area with widths of approximately 1.8 m. There are also two north-east trending interpreted dykes within the proposed mining area.

Sills have intruded into the Whynot, Arrowfield and Bowfield Seams within EL5460. The layouts of the proposed panels and longwalls within these seams have been designed to avoid these igneous intrusions. The mapped extents of the sills within each of these seams are illustrated in Fig. 1.5 to Fig. 1.7.

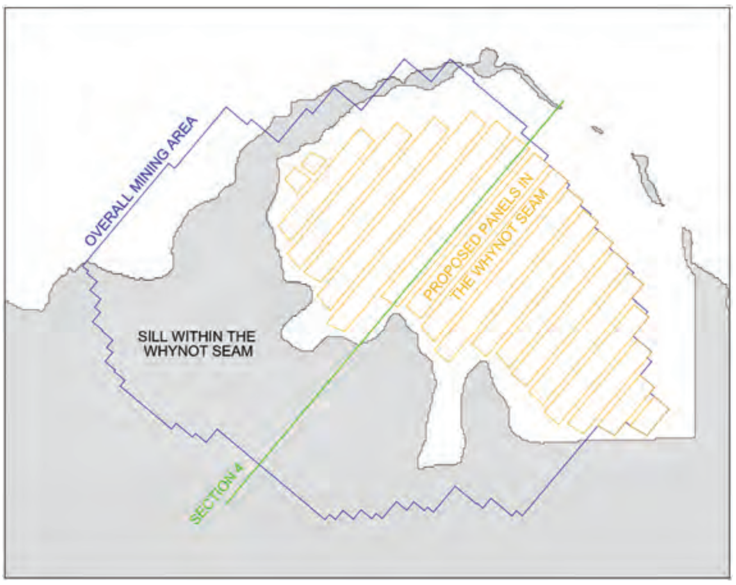


Fig. 1.5 Mapped extents of the sills within the Whynot Seam

Fig. 1.6 Mapped extents of the sills within the Arrowfield Seam

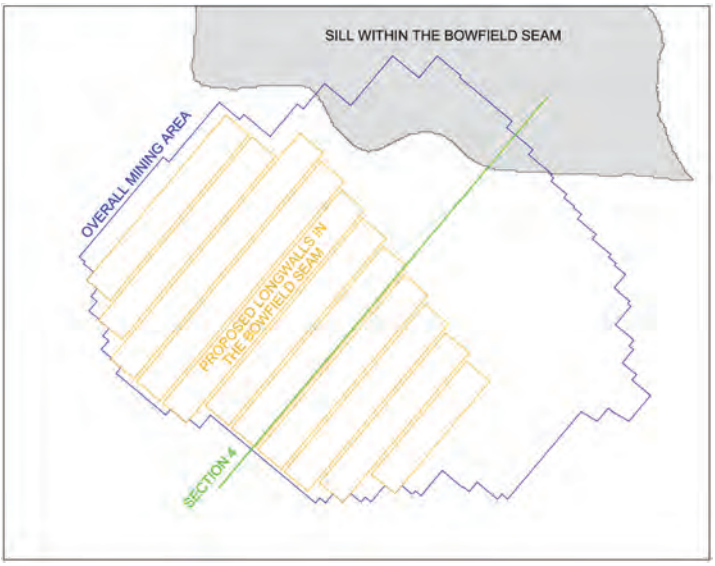


Fig. 1.7 Mapped extents of the sills within the Bowfield Seam

The levels of the Whynot, Arrowfield and Bowfield Seams and the extents of the sills are illustrated along Section 4 in Fig. 1.8. The location of this section is shown in Fig. 1.5 to Fig. 1.7.

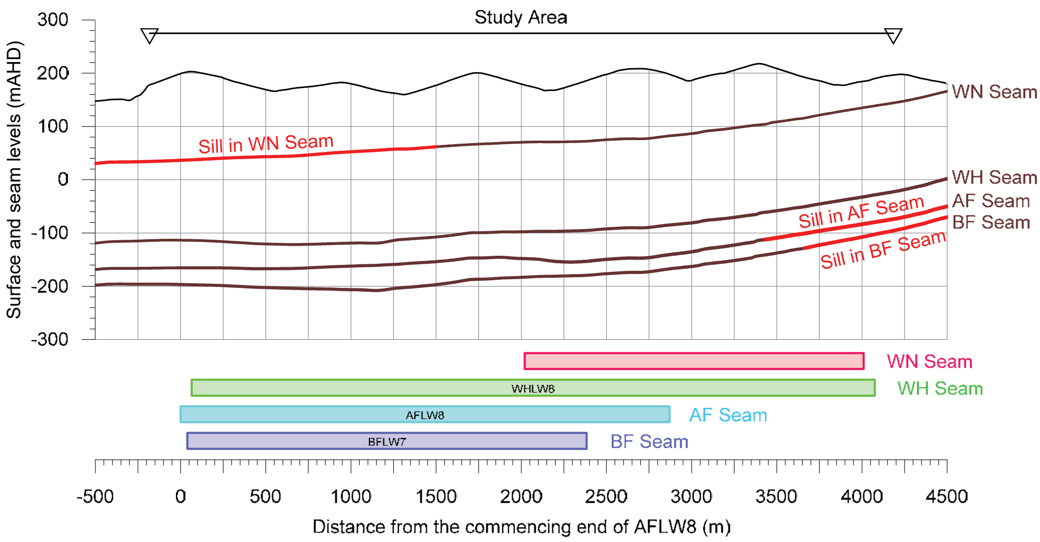


Fig. 1.8 Surface, seam and sill levels along Section 4

The south-western ends of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams will be extracted beneath the sill within the Whynot Seam. This sill is located in the upper part of the overburden and its strength and stiffness are greater than those for the sedimentary strata. The sill within the Whynot Seam, therefore, could result in reduced vertical subsidence (i.e. less than predicted) at the south-western ends of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams.

The potential for subsidence reduction for this sill is dependent on the strength and spanning capability of the material and whether it is massive (i.e. devoid of faults, inclusions and defects), which is not certain at this stage.

The sill is largely confined within the Whynot Seam and, therefore, it has a thickness of less than 3 m. It is considered, therefore, that there is low potential for subsidence reduction due to the multi-seam mining of critical to supercritical longwalls in three seams beneath this sill. The subsidence model does not consider subsidence reduction due to the sill within the Whynot Seam.

The proposed longwalls in the Bowfield Seam do not extend beneath the sill within the overlying Arrowfield Seam. The sill within the Arrowfield Seam, therefore, will not affect the subsidence that develops due to the mining in the Bowfield Seam.

Sills can potentially result in irregular surface deformations where they are located at shallow depth of cover. Localised movements can occur where the sills can partially span the corners of the extracted voids. The sill within the Whynot Seam, within the extents of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams, is located at depths of cover ranging between 40 m to 180 m. It is possible that localised surface cracking and/or stepping could develop along the boundary of this sill where the depths of cover are the shallowest. Further discussions are provided in Section 5.2.

The surface lithology above the proposed mining area is shown in Fig. 1.9. The surface soils are predominately derived from the Jerrys Plains Subgroup (Pswj) of the Wittingham Coal Measures. There are small areas that are derived from the Wollombi Coal Measures (Psl) and basalt (Jv). Quaternary material is mapped outside the proposed mining area along the alignments of the Hunter River and Saddlers Creek.

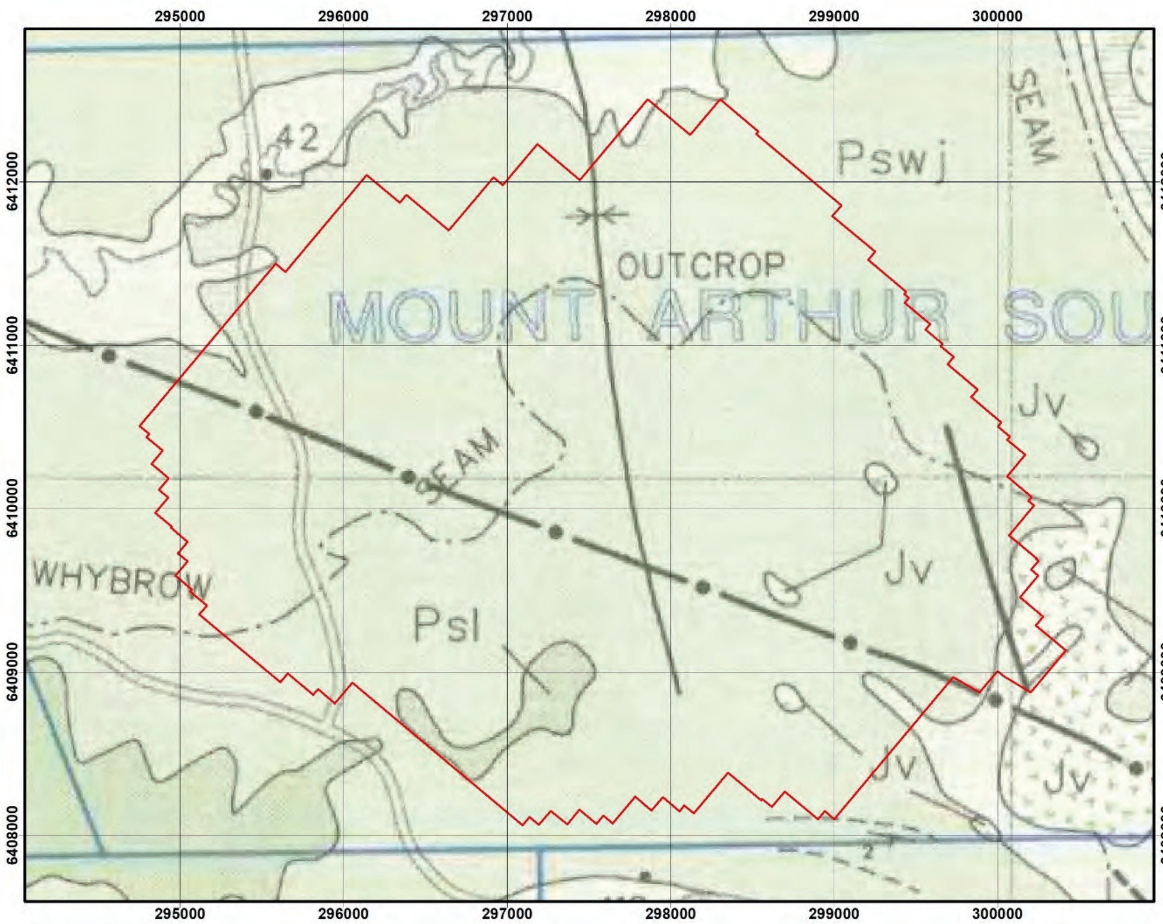


Fig. 1.9 Surface lithology above the proposed mining area

2.1. Study Area

The *Study Area* is defined as the surface area that could be affected by the mining of the proposed panels and longwalls in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:

- 26.5° angle of draw from the extents of the proposed panels and longwalls in each seam; and
- predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, resulting from the extraction of the proposed panels and longwalls in all seams.

The depths of cover contours are shown in Drawings Nos. MSEC955-07 to MSEC955-10. The depths of cover above the proposed panels in the Whynot Seam vary between 40 m and 180 m. The depths of cover above the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams vary between 125 m and 425 m. The 26.5° angle of draw, therefore, has been determined by drawing a line that is a horizontal distance varying between 20 m and 213 m around the limits of the secondary extraction areas.

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, has been determined using the Incremental Profile Method, which is described in Chapter 3. The predicted total subsidence contours after the completion of mining in all seams, including the predicted 20 mm subsidence contour, are shown in Drawing No. MSEC955-23.

The Study Area based on the greater of the 26.5° angle of draw and the predicted 20 mm total subsidence contour is shown in Drawings Nos. MSEC955-01 and MSEC955-16 to MSEC955-19. There are surface features that are located outside the Study Area that could experience either far-field horizontal movements or valley related movements. The surface features that could be sensitive to such movements have been identified and have also been included in the assessments provided in this report.

2.2. Natural and built features

The major natural and built features within the Study Area can be seen in the 1:25,000 topographic map of the area from the Central Mapping Authority (CMA) shown in Fig. 2.1. The surface topography and the larger natural and built features can also be seen in the aerial photograph of the area shown in Fig. 2.2.

Fig. 2.1 The Study Area and proposed mining area overlaid on CMA Map No. 9033-2

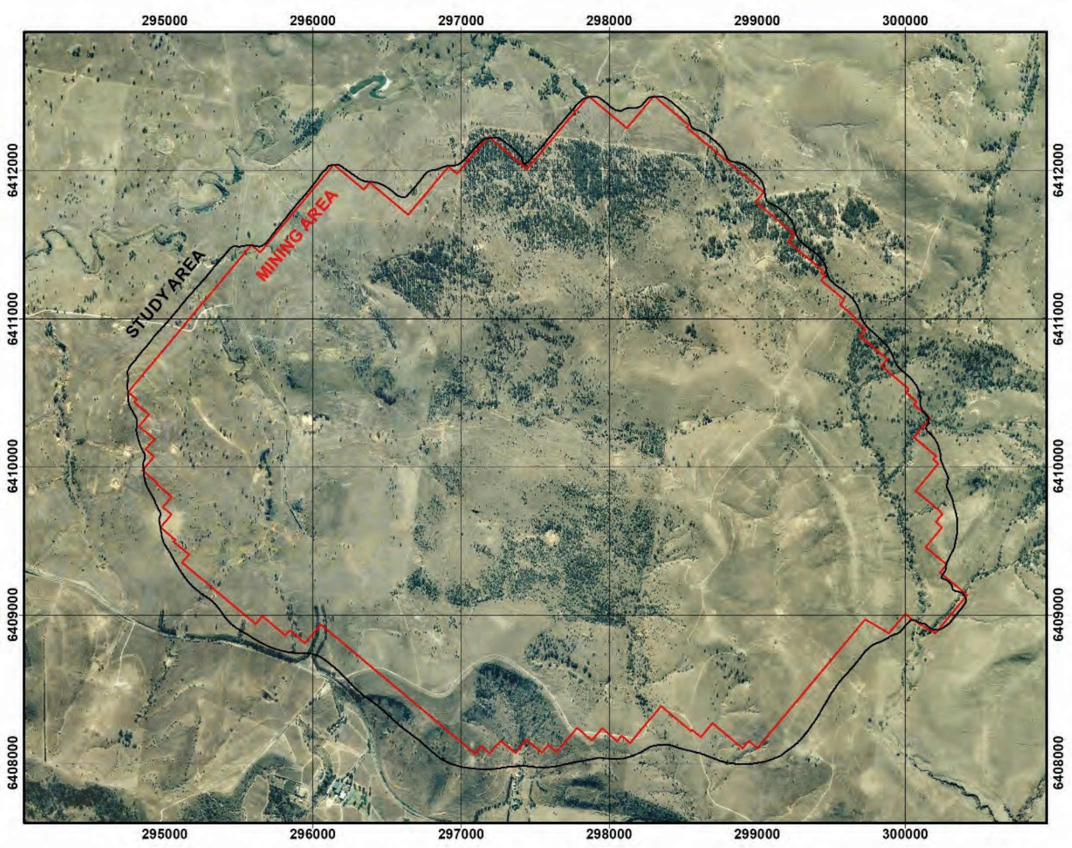


Fig. 2.2 The Study Area and proposed mining area overlaid on an aerial photograph

The following sections provide an overview of the agricultural land, agricultural utilisation and the natural and built features within the Study Area. The descriptions, predictions and impact assessments for these features are provided in Chapter 5.

2.3. Strategic Agricultural Land

The *Strategic Agricultural Land* (SAL) within the Study Area is shown in Drawing No. MSEC955-16, which is based on the mapping provided in the *State Environmental Planning Policy (Mining and Petroleum Production and Extractive Industries) 2007* and on-site verification of *BSAL*. Strategic agricultural land within the Study Area includes:

- *BSAL* – representing "*land with a rare combination of natural resources highly suitable for agriculture. These lands intrinsically have the best quality landforms, soil and water resources which are naturally capable of sustaining high levels of productivity and require minimal management practices to maintain this high quality*" (DPE, 2012).

  BSAL has been identified above the western part of the proposed mining area. The Australian Soil Classification is Eutrophic Brown Chromosol. The total surface area located directly above the mining area is 72 hectares (ha).

Strategic agricultural land located outside but in the vicinity of the Study Area includes:

- *Equine Critical Industry Cluster* – representing areas suitable for horse breading facilities and related infrastructure due to its "*combination of a temperate climate, protected aspect and varied terrain combined with a lack of tropical diseases and accessibility to Sydney. The breeders are supported by the aggregation of equine industry infrastructure and good transport routes*" (DPE, 2012).

  There are horse studs located along the Golden Highway; however, these are all located outside the Study Area. The closest is the *Coolmore Stud*, situated where the highway crosses the Hunter River, approximately 280 m south of the proposed mining area.

- *Viticulture Critical Industry Cluster* – representing the "*highly integrated concentration of vineyards and associated wineries and tourism infrastructure in a rural landscape. The region's unique terrain and climate, its heritage vines and diversity of soil types all contribute to the specific quality and characteristics of grapes produced in the area*" (DPE, 2012).

  There are no vineyards located within the Study Area. The nearest is *Hollydene Estate Wines*, situated south of the Golden Highway, to the east of the intersection with Edderton Road. The property is located approximately 340 m south of the proposed mining area, at its closest point.

2.4. Agricultural utilisation

The land above the proposed mining area is owned by Malabar. This land is used for cattle grazing. Horse studs and vineyards are located along the Golden Highway, to the south of the Study Area, as described in Section 2.3.

2.5. Natural features

The locations of the natural features within the Study Area are shown in Drawing No. MSEC955-18. The natural features which are important to the agricultural land and utilisation located within or immediately adjacent to the Study Area include:

- The Hunter River and associated alluvial aquifer – refer to Section 5.4;
- Saddlers Creek – refer to Section 5.5;
- ephemeral drainage lines – refer to Section 5.6; and
- groundwater resources – refer to Section 5.7.

Further descriptions of the surface water and groundwater resources are provided in the Agricultural Impact Assessment.

2.6. Built features

The locations of the built features are shown in Drawing No. MSEC955-19. The built features that are important to the agricultural land and utilisation that are located within or immediately adjacent to the Study Area include:

- The Golden Highway and the bridge across the Hunter River;
- Edderton Road;
- low voltage powerlines;
- copper telecommunications cables;
- farm dams;
- groundwater bores; and
- fences.

The abovementioned built features are discussed in Sections 5.7 and 5.8. The Golden Highway is located immediately adjacent to the Study Area and crosses a bridge over the Hunter River. The highway and bridge are therefore included in the discussions provided in Section 5.9.

There are no houses or other building structures currently in use that are located within the Study Area. There is a dilapidated and disused structure that was formerly used as a shearers' quarters within the Study Area. Items of potential heritage significance will be assessed as part of the Environmental Impact Statement (EIS).

3.0 OVERVIEW OF MINE SUBSIDENCE AND THE METHODS THAT HAVE BEEN USED TO PREDICT THE MINE SUBSIDENCE EFFECTS FOR THE PROPOSED PANELS AND LONGWALLS

3.1. Introduction

Overviews of longwall mining, the development of mine subsidence and the methods of predicting mine subsidence movements 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*.

The following sections provide overviews of conventional and non-conventional mine subsidence effects and the methods that have been used to predict these movements.

3.2. Overview of conventional subsidence effects

The normal ground movements resulting from the extraction of pillars or longwalls are referred to as conventional or systematic subsidence movements. These subsidence effects 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 such as 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 distance between two points increases and **Compressive Strains** occur when the distance between two points decreases. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

  Whilst mining-induced normal strains are measured along monitoring lines, ground shearing can also occur both vertically and horizontally across the directions of monitoring lines. Most of the published mine subsidence literature discusses the differential ground movements that are measured along subsidence monitoring lines, however, differential ground movements can also be measured across monitoring lines using 3D survey monitoring techniques.
- **Horizontal shear deformation** across monitoring lines can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. It is not possible, however, to determine the horizontal shear strain across a monitoring line using 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 the additional parameters which result from the extraction of each panel or longwall. The **additional** subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of a series of panels or longwalls within a single seam. The **total** subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of panels and longwalls from a number of seams.

3.3. Far-field movements

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

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

3.4. Overview of non-conventional subsidence effects

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

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near-surface strata layers. Where there is a high depth of cover, the observed subsidence profiles along monitoring survey lines are generally smooth. Where the depth of cover is less than 100 m, the observed subsidence profiles along monitoring lines are generally irregular. Very irregular subsidence movements are observed with much higher tilts and strains at very shallow depths of cover where the collapsed zone above the extracted longwalls extends up to or near to the surface.

Non-conventional ground movements are likely to occur, in this case, due to the multi-seam mining conditions where longwalls are proposed to be extracted below the previously extracted panels and longwalls. Additional subsidence, accompanied by locally elevated tilts, curvatures and strains are expected to occur, particularly in the immediate vicinity of the chain pillars in the overlying seams, where extra voids may have been formed as the overlying strata cantilevered into the overlying goafs.

Non-conventional ground movements also occur at the higher depths of cover and in single-seam mining conditions, although much less frequently than observed at very shallow depths of cover or in multi-seam mining conditions. The irregular movements appear as a localised bump in an otherwise smooth subsidence profile, accompanied by locally elevated tilts, curvatures and strains. The cause of these irregular subsidence movements can be associated with:

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

Non-conventional movements due to the above mechanisms are discussed in the following sections.

3.4.1. Non-conventional subsidence effects 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 have been considered in the statistical analyses of strain, provided in Section 4.3, which have been based on measurements for both conventional and non-conventional anomalous movements. The management strategies developed for the natural and built features should be designed to accommodate movements greater than the predicted conventional movements, so that the potential impacts resulting from non-conventional movements can be adequately managed.

3.4.2. Non-conventional subsidence movements due to steep topography

Non-conventional movements can also result from downslope movements where longwalls are extracted beneath steep slopes. In these cases, elevated tensile strains develop near the tops and along the sides of the steep slopes and elevated compressive strains develop near the bases of the steep slopes. The potential impacts resulting from down slope movements include tension cracks at the tops and on the sides of the steep slopes and compression ridges at the bottoms of the steep slopes.

3.4.3. Valley related effects

The watercourses within EL5460 may be subjected to valley related effects, 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 effects are less commonly observed in the Hunter and Newcastle 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. 3.1. The potential for these natural movements are influenced by the geomorphology of the valley.

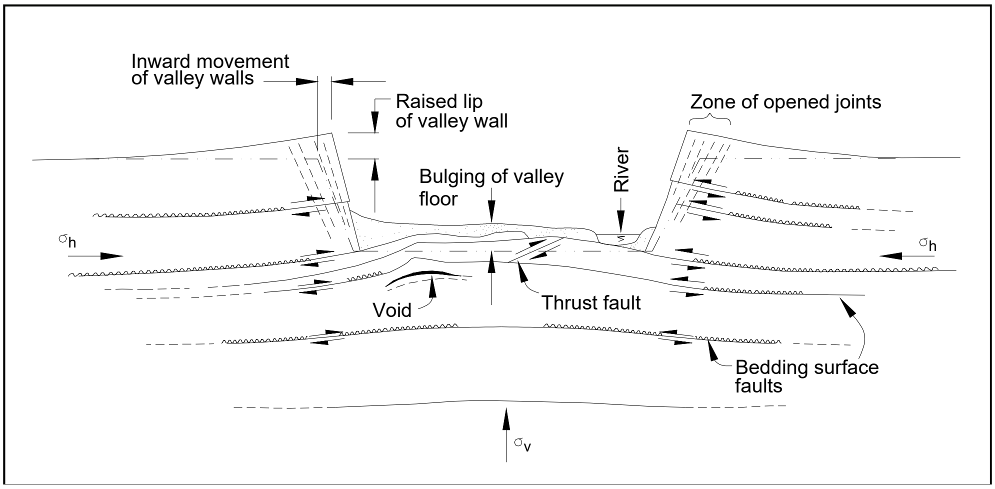


Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

Valley related effects can be caused or accelerated by mine subsidence as the result of a number of factors, including the redistribution of horizontal in situ stresses and down slope movements. Valley related effects 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; and

- **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 effects resulting from the extraction of the proposed panels and longwalls were made using the empirical method outlined in Australian Coal Association Research Program (ACARP) 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*.

3.5. The Incremental Profile Method

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

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

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

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

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

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

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

The shapes of the incremental subsidence profiles are then determined using the large empirical database of observed incremental subsidence profiles from the Hunter Coalfield. The profile shapes are derived from the normalised subsidence profiles for monitoring lines where the mining geometry and overburden geology are similar to that for the proposed longwalls.

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.

Further details on the IPM are provided in the background report entitled General Discussion on Mine Subsidence Ground Movements which can be obtained from *www.minesubsidence.com*. The following section describes the calibration of the IPM for local single-seam and multi-seam mining conditions.

3.6. Calibration of the IPM

There are no existing workings within EL5460 and, therefore, the panel extracted in the first seam will be governed by single-seam mining conditions. The calibration of IPM for local single-seam mining conditions is described in Section 3.6.1.

The longwalls in subsequent seams will then be extracted beneath the previously extracted panels and longwalls and, therefore, will be governed by multi-seam mining conditions. The calibration of the IPM for multi-seam mining conditions is described in Section 3.6.2.

3.6.1. Calibration for local single-seam mining conditions

The first seam to be extracted is the Whynot Seam. The proposed bord and pillar panels have overall widths of 185 m and barrier pillar widths of 55 m. Malabar proposes to carry out partial extraction of these panels. The subsidence predictions have been based on the extraction of two rows of pillars adjacent to each of the barrier pillars (i.e. four rows of pillars within each panel) and leaving the two central rows of pillars unmined (i.e. central spine pillar). The void widths between the barrier and spine pillars are 65 m. The overall width of the central spine pillar is 55 m, which is split by a 5 m wide roadway.

The ground monitoring data from the total extraction of bord and pillar workings in the NSW coalfields show that the measured subsidence is similar to that for longwall mining of similar mining geometries. However, the magnitude of subsidence is less due to the remnant coal that remains in the total extraction of bord and pillar workings.

Total extraction of bord and pillar workings can typically recover between 75 % and 85 % of the coal due to both the first and second workings. The total extraction of a bord and pillar panel therefore results in vertical subsidence that is around 75 % to 85 % of that for a longwall with a similar mining geometry (i.e. overall void width, barrier pillar width, depth of cover and mining height). The Maxwell Project involves the partial extraction of pillars.

The depth of cover to the Whynot Seam within the extent of the proposed mining area varies between 40 m and 180 m, with an average depth of cover of 100 m. The void width-to-depth ratios for the bord and pillar panels, therefore, vary between 0.36 and 1.6, with an average of 0.65.

The proposed panels are supercritical in width[3] at the shallowest depths of cover in the northern part of the mining area. However, the shallowest depths of cover occur near the edges of the panels and, therefore, the vertical subsidence is reduced due to the panel side and end effects. Bridging of the overburden strata within the Malabar Formation across the narrow voids (i.e. 65 m) would also reduce the vertical subsidence.

The average depth of cover to the Whynot Seam within the extents of the proposed panels is 100 m and the corresponding average void width-to-depth ratio is 0.65. The predicted vertical subsidence as a ratio of the extracted seam thickness is 25 % to 30 % of the extracted seam thickness.

The second seam to be extracted is the Woodlands Hill Seam. The longwalls in this seam extend beyond the bord and pillar panels in the overlying Whynot Seam in the southern part of the mining area. The proposed longwalls in the Woodlands Hill Seam are therefore extracted under single-seam mining conditions in the north-western and southern parts of the mining area.

The depth of cover to the Woodlands Hill Seam within the extent of the proposed longwalls and outside the extents of the overlying bord and pillar panels, varies between 130 m and 340 m, with an average depth of cover of 260 m. The width-to-depth ratios for these longwalls, therefore, vary between 0.90 and 2.3, with an average of 1.2.

[3] Supercritical width is the void width required to develop the maximum achievable vertical subsidence, which is typically for panels having void width-to-depth ratios greater than around 1.4.

The proposed longwalls are therefore critical to supercritical in width in the southern part of the mining area (i.e. single-seam conditions). The maximum achievable subsidence in the Hunter Coalfield, for single-seam supercritical conditions, is generally 60 % to 65 % of the extracted seam thickness.

The standard IPM for the Hunter Coalfield has been used to predict the mine subsidence movements at a number of nearby collieries in the same or similar coal seams, including Beltana, Blakefield South, Integra Underground, United and Wambo. Comparisons between the measured and predicted movements indicate that the standard subsidence model provides reasonable, if not slightly conservative, predictions of the mine subsidence parameters.

The comparisons between the measured and predicted profiles of vertical subsidence, tilt and curvature for monitoring lines in the Hunter and Newcastle Coalfields, where the longwall width-to-depth ratios are 0.4, 0.7 and greater than 2.0, are shown in Fig. 3.2, Fig. 3.3 and Fig. 3.4, respectively.

The measured profiles of vertical subsidence, tilt and curvature along these monitoring lines reasonably match those predicted using the standard IPM for the Hunter Coalfield. In some locations, there are small lateral shifts between the measured and predicted profiles, which could be the result of surface dip, seam dip, or variations in the overburden geology.

The magnitudes of the maximum measured vertical subsidence along the monitoring lines were similar to or less than the maxima predicted using the standard IPM. In Fig. 3.4, the longwall was supercritical and, in this case, the standard IPM adopted a maximum achievable vertical subsidence of 65 % of the extracted seam thickness, whereas the maximum observed subsidence was around 45 % of the extracted seam thickness.

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

Based on these comparisons, it has been considered that the standard IPM for the Hunter Coalfield provides reasonable predictions of vertical subsidence, tilt and curvature in these cases, where the longwall width-to-depth ratios are 0.4, 0.7 and greater than 2.0. It has not been considered necessary, therefore, to provide any specific calibration of the standard model for the proposed longwalls in the Woodlands Hill Seam based on single-seam mining conditions.

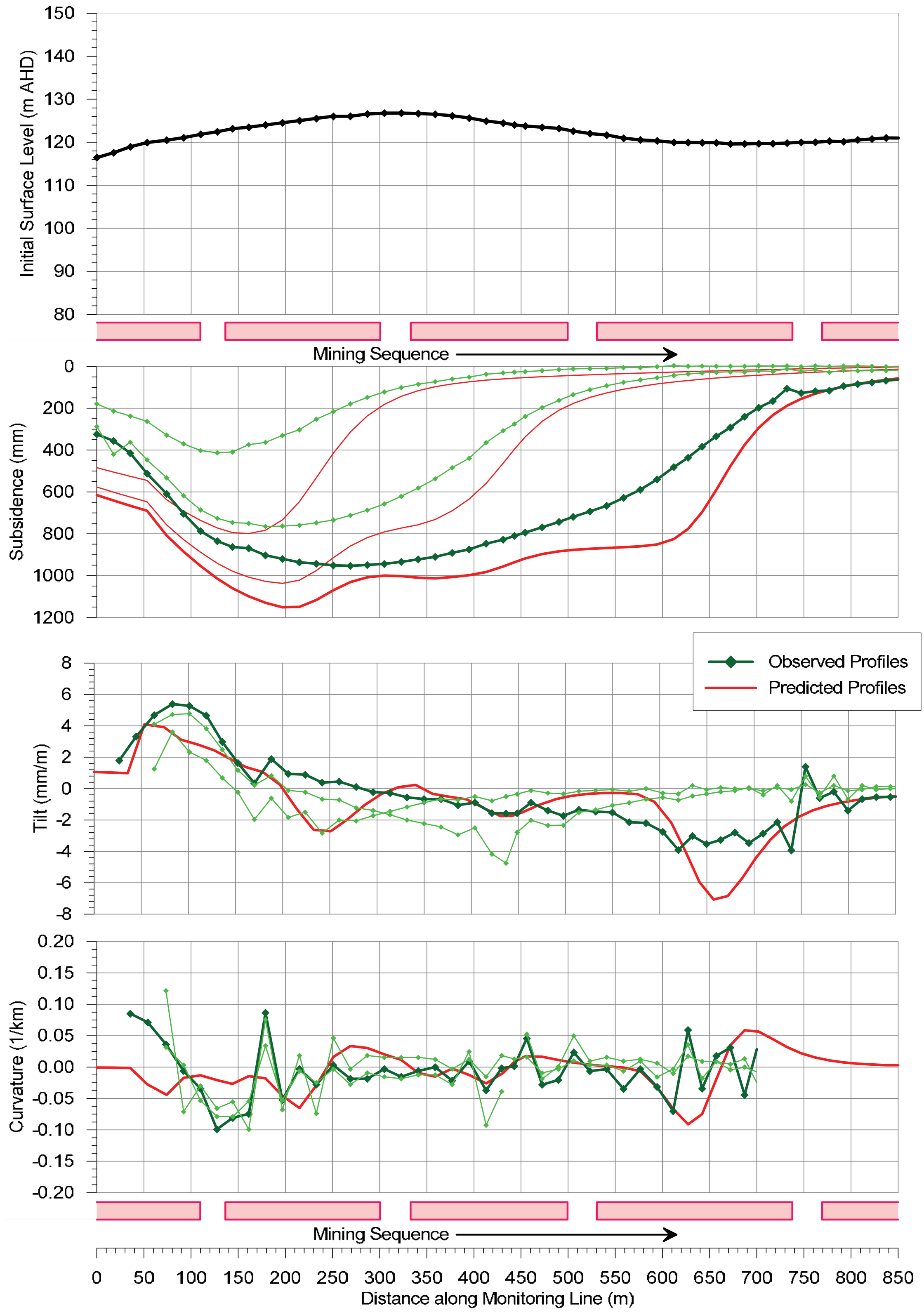


Fig. 3.2 Measured and predicted vertical subsidence, tilt and curvature along a monitoring line in the Newcastle Coalfield with a longwall width-to-depth ratio of around 0.4

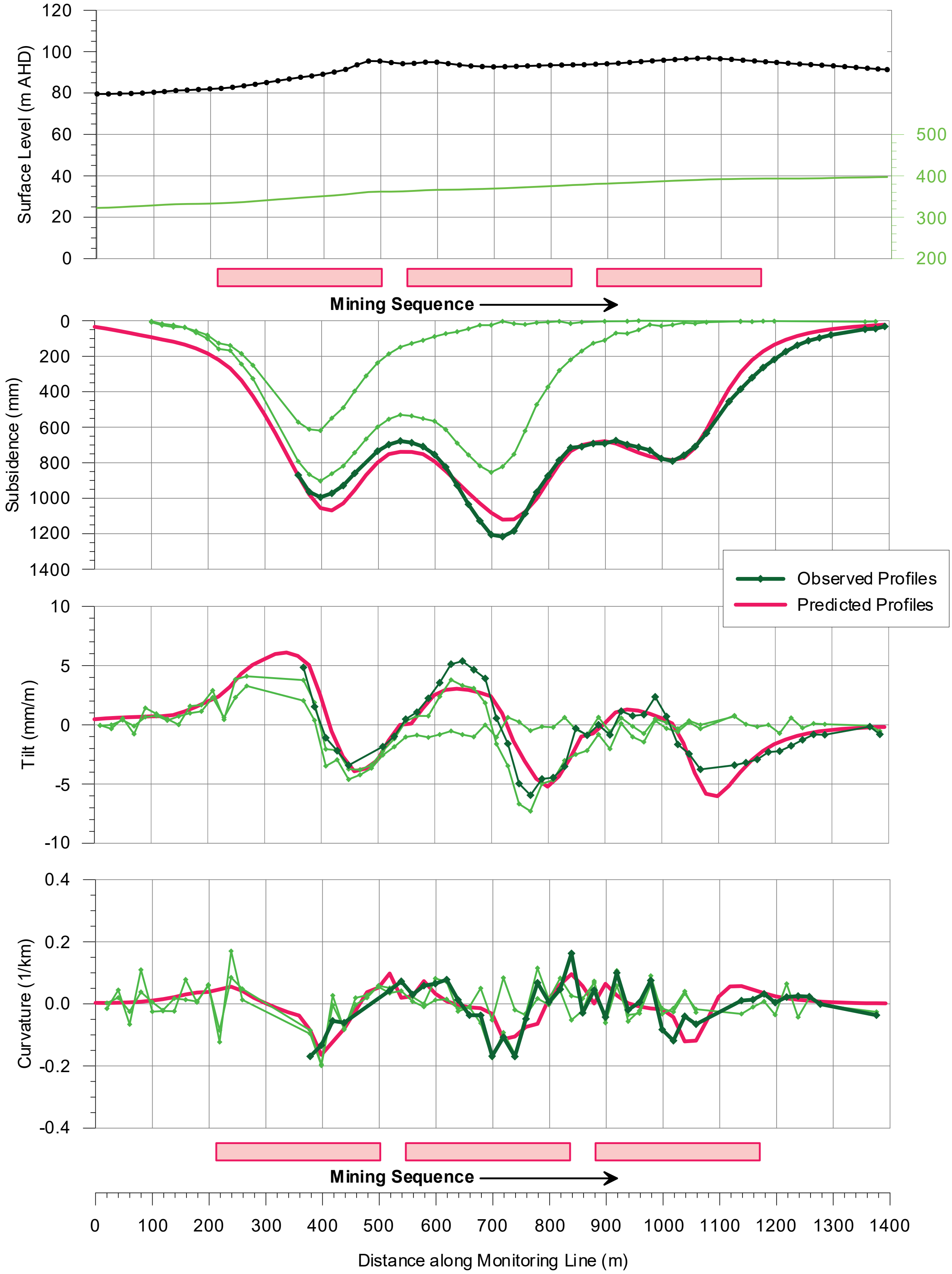


Fig. 3.3 Measured and predicted vertical subsidence, tilt and curvature along a monitoring line in the Hunter Coalfield with a longwall width-to-depth ratio of around 0.7

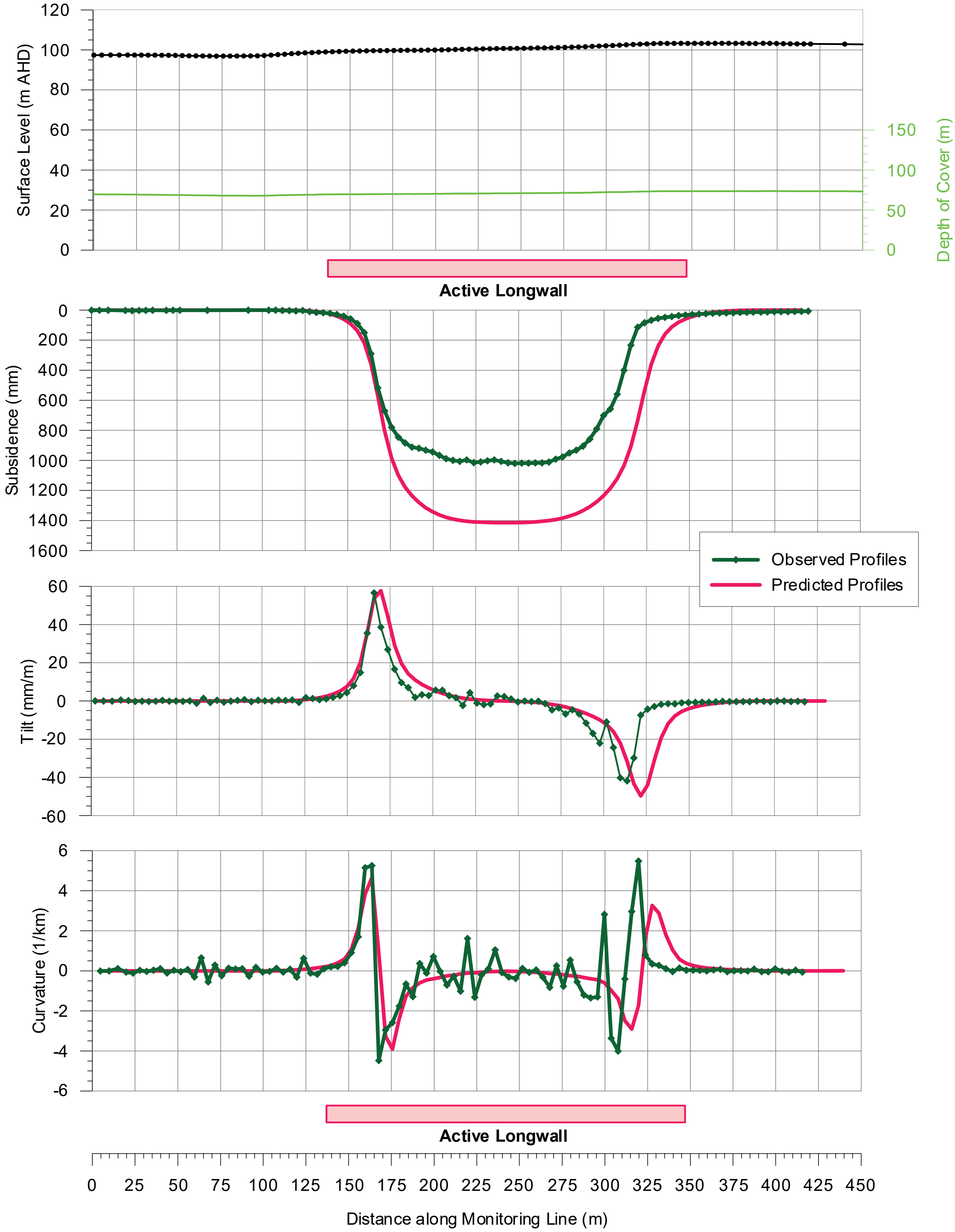


Fig. 3.4 Measured and predicted vertical subsidence, tilt and curvature along a monitoring line in the Hunter Coalfield with a longwall width-to-depth ratio greater than 2.0

3.6.2. Calibration for multi-seam mining conditions

The second seam proposed to be extracted is the Woodlands Hill Seam. The north-eastern ends of these longwalls are located beneath the bord and pillar panels in the Whynot Seam. The proposed longwalls in the Woodlands Hill Seam are therefore extracted under multi-seam mining conditions in the north-eastern part of the mining area.

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

The depth of cover to the Woodlands Hill Seam, beneath the bord and pillar panels in the overlying Whynot Seam, varies between 200 m and 360 m, with an average depth of cover of 280 m. The longwall width-to-depth ratios for these longwalls, therefore, varies between 0.85 and 1.5, with an average of 1.1. The proposed longwalls in the Woodlands Hill Seam are generally critical or supercritical in width where they are located beneath the bord and pillar panels in the overlying Whynot Seam.

The height of discontinuous fracturing for critical and supercritical longwalls is typically in the range of 1 to 1.5 times the longwall width above the seam roof. The height of discontinuous fracturing for the proposed longwalls in the Woodlands Hill Seam is in the range of 300 m to 450 m above the seam roof. The interburden thickness between the Woodlands Hill and Whynot Seams varies between 135 m and 185 m within the extents of these proposed panels and longwalls.

The discontinuous fracturing due to the extraction of the proposed longwalls in the Woodlands Hill Seam, therefore, will extend up to the previously extracted bord and pillar panels in the overlying Whynot Seam. The extraction of these longwalls will remobilise the goaf and reactivate the spine and barrier pillars in the Whynot Seam. Increased vertical subsidence due to the multi-seam mining conditions are therefore expected.

Multi-seam subsidence factors

As described in the papers by Li et al. (2007 and 2010), the maximum additional subsidence resulting from the extraction of longwalls beneath existing longwall goaf (i.e. multi-seam mining conditions) can be estimated from the following equation:

Equation 1 $S_2 = a_2 T_2$ (after Li, et al., 2007 and 2010)

where $a_2 = (a_m - a_1)\left(\frac{T_1}{T_2}\right) + a_m$

S_2 = Maximum vertical subsidence resulting from the extraction of the second seam (multi-seam conditions) as a proportion of the extracted seam thickness

a_1 = Maximum vertical subsidence resulting from the extraction of the first seam (single-seam conditions) as a proportion of the extracted seam thickness

a_m = Maximum total subsidence resulting from the extraction of the first seam (single-seam conditions) plus the extraction of the second seam (multi-seam conditions) as a proportion of total extracted seam thickness of both seams

T_1 = Extracted seam thickness in first seam

T_2 = Extracted seam thickness in second seam

The value of 'a_1' can be calculated from the predicted vertical subsidence resulting from the extraction of the existing longwalls or panels in the first seam (i.e. single-seam conditions). The value of "a_m" can be determined from the observations from previous multi-seam longwall mining cases. There is limited multi-seam monitoring data from the NSW coalfields, especially where longwalls have been extracted directly beneath or above existing longwalls or panels.

Multi-seam ground monitoring data for longwall mining beneath existing bord and pillar panels is available from John Darling, Kemira, Newstan, Teralba, Wyee and North Wambo Underground. Further multi-seam ground monitoring data for longwall mining beneath existing longwalls is also available from Blakefield South, Cumnock, Liddell, Newstan, Sigma and North Wambo Underground.

A summary of the details, measured vertical subsidence and mining heights for the multi-seam mining case studies where longwalls were mined beneath or above previously extracted longwalls or panels is provided in Table 3.1. The maximum vertical subsidence parameters (a_1, a_2 and a_m) are also provided in this table.

Table 3.1 Multi-seam mining cases for longwalls mining beneath or above previous mining

Colliery [Coalfield] (Location)	Seam	Longwall	Depth of cover (m)	Interburden thickness (m)	Vertical subsidence (m)	Seam thickness (m)	a_1 / a_2	a_m
Blakefield South [Hunter Coalfield] (BSLW1)	Whybrow	LW3 to LW6	90 ~ 140	75 ~ 80	N/A	2.2 ~ 2.5	0.65#	0.70 ~ 0.81
	Blakefield	BSLW1	165 ~ 215		2.1 ~ 2.7	2.2 ~ 3.0	0.75 ~ 0.96	
Blakefield South [Hunter Coalfield] (BSLW2)	Whybrow	LW1 to LW6	50 ~ 150	75 ~ 90	N/A	2.2 ~ 2.5	0.65#	0.64 ~ 0.82
	Blakefield	BSLW2	150 ~ 240		1.9 ~ 2.7	2.6 ~ 3.4	0.63 ~ 0.96	
Blakefield South [Hunter Coalfield] (BSLW3)	Whybrow	LW1 to LW6	75 ~ 170	70 ~ 95	N/A	2.2 ~ 2.6	0.65#	0.73 ~ 0.86
	Blakefield	BSLW3	170 ~ 270		2.0 ~ 2.8	2.8 ~ 3.1	0.81 ~ 1.04	
Blakefield South [Hunter Coalfield] (BSLW4)	Whybrow	LW1 to LW4	110 ~ 165	70 ~ 95	NA	2.2 ~ 2.6	0.65#	0.69 ~ 0.83
	Blakefield	BSLW4	200 ~ 250		2.2 ~ 2.9	2.9 ~ 3.2	0.72 ~ 0.96	
Blakefield South [Hunter Coalfield] (BSLW5)	Whybrow	LW2 to LW5	150 ~ 215	75 ~ 90	NA	2.0 ~ 2.6	0.65#	0.69 ~ 0.83
	Blakefield	BSLW5	235 ~ 305		2.8 ~ 3.0	3.1 ~ 3.4	0.87 ~ 0.93	
Cumnock Colliery [Hunter Coalfield]	Liddell	LW3	135	43	S_1 = 1.25	T_1 = 2.50	0.50	0.63
	Lower Pikes	LW17	90		S_2 = 1.72	T_2 = 2.20	0.78	
Liddell Colliery [Hunter Coalfield]	Upper Liddell	LW1 & LW2	160	40	S_1 = 1.6	T_1 = 2.72	0.59	0.67*
	Middle Liddell	LW3	200		S_2 = 2.0	T_2 = 2.65	0.76	
Newstan Colliery [Newcastle Coalfield]	Great Northern	Panel 6	55	15	S_1 = 2.03	T_1 = 3.4	0.60	0.80
	Fassifern	Panel 8	70		S_2 = 3.22	T_2 = 3.2	1.01	
Sigma Colliery [South Africa]	No. 3	LW4	135	13	S_1 = 1.1	T_1 = 2.75	0.40	0.69
	No. 2B	LW4A	150		S_2 = 2.92	T_2 = 3.05	0.96	
NWUM [Hunter Coalfield] (XL1-Line)	Woodlands Hill	LW2 to LW7	30 ~ 45	50	N/A	3.0	0.65#	0.63 ~ 0.72
	Wambo	LW2 to LW7	80 ~ 95		1.5 ~ 1.9	2.3	0.60 ~ 0.82	
NWUM [Hunter Coalfield] (XL2-Line)	Whybrow	LW10 / B&P	95 ~ 100	45 ~ 65	N/A	3.0	0.65#	0.68 ~ 0.86
	Wambo	LW1 to LW7	140 ~ 165		1.6 ~ 2.5	2.2	0.71 ~ 1.16	
NWUM [Hunter Coalfield] (XL4-Line)	Whybrow	LW10 to LW12	140 ~ 170	80	N/A	3.0	0.65#	0.70 ~ 0.76
	Wambo	LW3 to LW5	225 ~ 250		1.0 ~ 1.2	2.5	0.76 ~ 0.90	
NWUM [Hunter Coalfield] (XL5-Line)	Whybrow	LW3 / B&P	150 ~ 170	70	N/A	3.0	0.65#	0.65 ~ 0.77
	Wambo	LW6 and LW7	225 ~ 240		1.1 ~ 1.2	2.5	0.65 ~ 0.91	
NWUM [Hunter Coalfield] (SC1-Line)	Whybrow	LW10 to LW13	100 ~ 175	80 ~ 120	N/A	3.0	0.65#	0.71 ~ 0.80
	Wambo	LW2 to LW4	220 ~ 255		2.0 ~ 2.4	2.2 ~ 2.5	0.79 ~ 0.97	

*Note: * denotes that the value of "a_m" of 67 % for Liddell Colliery is based on the most recent seam extraction information provided by the colliery and, hence, is less than that provided in the paper by Li et al (2007) of 83 %. # denotes subsidence due to the extraction of the first seam has been estimated to be 65 % of the mining height based on supercritical conditions. The depths of cover have been rounded to the nearest 5 metres, therefore, calculating the interburden thicknesses by taking the difference between in the depths of covers minus the thickness of the top seam provides a slightly different result to the stated interburden thicknesses.*

NWUM = North Wambo Underground Mine

The additional vertical subsidence measured due to the extraction of the second seam varied between 60 % and 116 % of the mining height (i.e. a_2 = 0.60 ~ 1.16). In many of these cases, however, the maximum measured vertical subsidence was localised and the values elsewhere were less than the maxima provided in the table. On average, the additional subsidence observed for these available multi-seam mining cases was around 85 % of the mining height in the second seam (i.e. a_2 = 0.85).

The total vertical subsidence measured due to the extraction of both seams varied between 63 % and 86 % of the total mining height (i.e. a_m = 0.63 ~ 0.86). On average, the total vertical subsidence measured for these available multi-seam mining cases was around 75 % of the total mining height in both seams (i.e. a_m = 0.75).

Additional vertical subsidence due to the Woodlands Hill Seam

The interburden thickness for the proposed longwalls in the Woodlands Hill Seam beneath the bord and pillar panels in the Whynot Seam varies between 135 m and 185 m. The multi-seam cases provided in Table 3.1. have smaller interburden thicknesses, being less than 50 m at Cumnock, Liddell, Newstan and Sigma, between 70 m and 95 m at Blakefield South and between 45 m and 120 m at the North Wambo Underground Mine.

Whilst the interburden thickness for the proposed longwalls is greater than those for the previous multi-seam cases, these proposed longwalls are mining beneath subcritical bord and pillar panels. There is greater potential for reactivation of these workings when compared with the previous multi-seam cases, which generally comprised supercritical longwalls mining beneath supercritical longwalls and panels.

It is considered that the most relevant case studies are the XL2-Line and SC1-Line at the North Wambo Underground Mine, as well as Liddell, Cumnock and Blakefield South Mines. Based on these case studies, it appears that adopting a value for "a_m" of 75 % would provide reasonable predictions of the multi-seam subsidence for the proposed longwalls in the Woodlands Hill Seam.

The average mining height in the area of multi-seam extraction is 2.0 m for the Whynot Seam (i.e. a_1 = 2.0) and 3.0 m for the Woodlands Hill Seam (i.e. a_2 = 3.0). The additional vertical subsidence, as a proportion of the mining height, due to the extraction of the proposed longwalls in the Woodlands Hill Seam is as follows:

Equation 2 $$a_2 = (0.75 - 0.30)\left(\frac{2.0}{3.0}\right) + 0.75 = 1.05$$

The maximum predicted additional vertical subsidence due to the extraction of the proposed longwalls in the Woodlands Hill Seam, therefore, has been taken as 100 % of the mining height (i.e. a_2 = 1.0) where they are located directly beneath the bord and pillar panels in the overlying Whynot Seam. This is reasonably consistent with the observations along the monitoring lines at the North Wambo Underground Mine, as shown in Table 3.1.

The multi-seam prediction curves are illustrated as the red lines in Fig. 3.5. These have been developed by scaling up the single-seam prediction curves (i.e. grey lines) so as to achieve a maximum predicted vertical subsidence of 100 % of extracted seam thickness based on supercritical conditions. These multi-seam prediction curves provide vertical subsidence that is around 55 % greater than those obtained using the standard single-seam prediction curves.

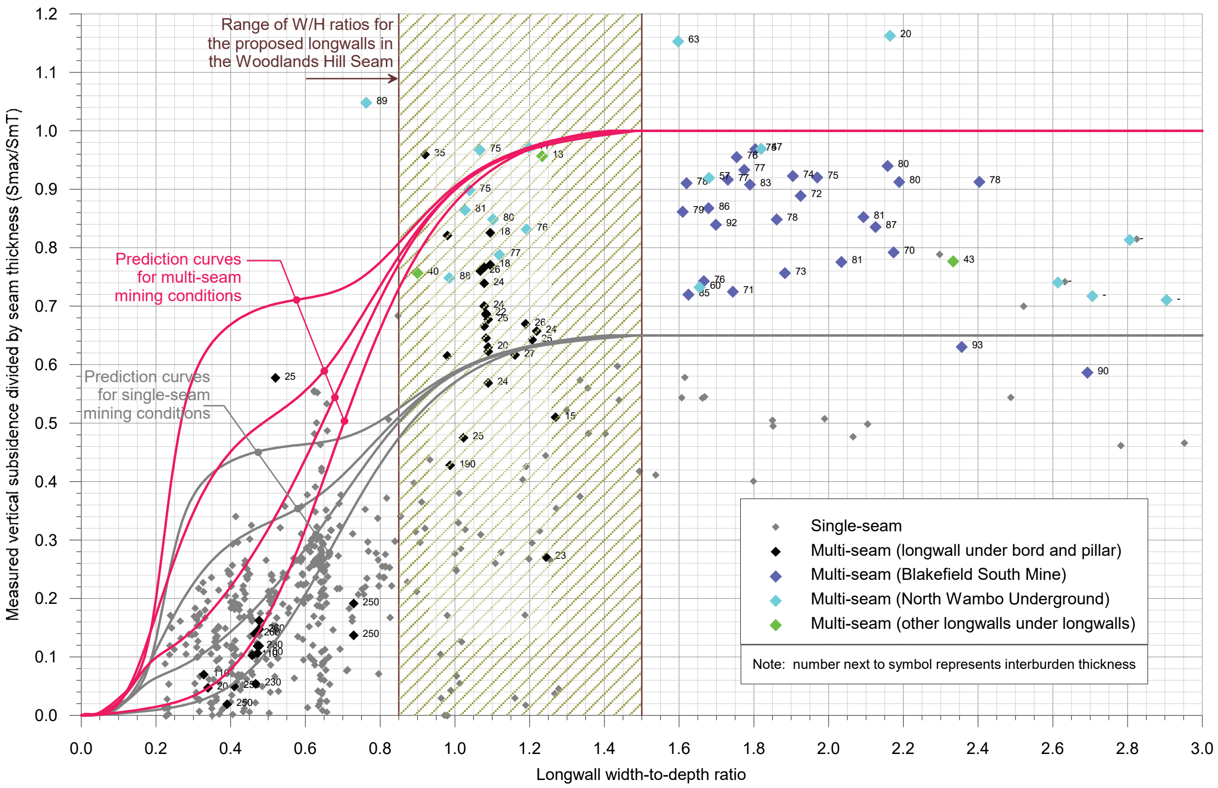


Fig. 3.5 Maximum measured vertical subsidence versus longwall width-to-depth ratio for previous multi-seam mining cases

The multi-seam mining cases beneath bord and pillar workings are shown as the black diamonds and beneath longwalls are shown as the blue, cyan and green diamonds in Fig. 3.5. The numbers adjacent to these symbols represent the interburden thicknesses. The single-seam mining cases are also shown in this figure, for comparison, as the light grey diamonds.

The multi-seam prediction curves are above the majority of the multi-seam cases based on mining beneath bord and pillar workings (i.e. black diamonds) and mining beneath longwalls (i.e. blue, cyan and green diamonds). In some cases, the maximum measured vertical subsidence exceeds the prediction curves; however, in many of these cases the maximum subsidence was localised and the subsidence elsewhere was below the prediction curves. Also, in some of these cases the upper seam was thicker than the lower seam and, therefore, there was greater potential for increased multi-seam subsidence.

The width-to-depth ratios for the proposed longwalls in the Woodlands Hill Seam vary between 0.85 and 1.5. It can be seen from Fig. 3.5, that previous longwall mining beneath bord and pillar workings (i.e. black diamonds) at similar width-to-depth ratios has resulted in vertical subsidence typically between 0.50 and 0.82 times the mining height. The previous longwall mining beneath longwalls (i.e. cyan and green diamonds) has resulted in vertical subsidence typically between 0.74 and 0.96 times the mining height.

The maximum predicted additional vertical subsidence for the proposed longwalls in the Woodlands Hill Seam, as a proportion of the mining height, varies between 0.75 (at a width-to-depth ratio of 0.85) and 1.0 (at a width-to-depth ratio of 1.5) based on the multi-seam prediction curves.

Additional vertical subsidence for the Arrowfield and Bowfield Seams

The third and fourth seams to be extracted are the Arrowfield and Bowfield Seams, respectively. The proposed longwalls in each of the seams are located beneath the previously extracted longwalls in the overlying seams. The interburden thickness between the Arrowfield and Woodlands Hill Seams varies between 40 m and 70 m. The interburden thickness between the Bowfield and Arrowfield Seams varies between 10 m and 45 m.

The discontinuous fracturing due to the extraction of the proposed longwalls in each of the Arrowfield and Bowfield Seams will extend up to the previously extracted longwalls in the overlying seams. The extraction of these longwalls will remobilise the goaf and reactivate the chain pillars in the overlying seams. Increased vertical subsidence due to the multi-seam mining conditions is therefore expected.

The maximum predicted vertical subsidence due to the extraction of the proposed longwalls in the Arrowfield and Bowfield Seams has been based on the multi-seam prediction curves shown in Fig. 3.5.

Shapes of the multi-seam subsidence profiles

It has been found from past longwall mining experience, that the shapes of multi-seam subsidence profiles depend on, amongst other factors, the depths of cover, interburden thickness, mining heights and the relative locations between the longwalls within each seam.

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

The proposed longwalls within each of the seams have been staggered so that the chain pillars are not aligned. The longwalls in the Arrowfield Seam have been offset by approximately 75 m from the longwalls in the overlying Woodlands Hill Seam. The longwalls in the Bowfield Seam have been offset by approximately 100 m from the longwalls in the overlying Arrowfield Seam.

The shapes of the multi-seam subsidence profiles were determined using the available monitoring data from Blakefield South, North Wambo Underground Mine and other available cases outlined previously. It was also observed at Blakefield South, that locally increased subsidence occurred adjacent to the chain pillars in the overlying seam, and that locally reduced subsidence occurred directly above the chain pillars and directly above the middle of the longwalls in the overlying seam.

3.7. Reliability of the predicted conventional subsidence parameters

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

In this case, the IPM was calibrated using monitoring data from elsewhere in the Hunter Coalfield. The subsidence model was also calibrated using the available multi-seam monitoring data from the NSW coalfields.

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

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

The prediction of strain at a point is even more difficult as there tends to be a large scatter in observed strain profiles. It has been found that measured strains can vary considerably from those predicted at a point, not only in magnitude, but also in sign, that is, the tensile strains have been observed where compressive strains were predicted, and vice versa. For this reason, the prediction of strain in this report has been based on a statistical approach, which is discussed in Section 4.3.

It is also likely that some localised irregularities will occur in the subsidence profiles due to near-surface geological features and multi-seam mining conditions. The irregular movements are accompanied by elevated tilts, curvatures and strains, which often exceed the conventional predictions. In most cases, it is not possible to predict the locations or magnitudes of these irregular movements. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains, including both conventional and non-conventional anomalous strains, which is discussed in Section 4.3.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed panels and longwalls in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams. The predicted subsidence parameters and the impact assessments for the natural and built features within EL5460 are provided in Chapter 5.

The predicted subsidence, tilts and curvatures have been obtained using the IPM, which has been calibrated for single-seam and multi-seam conditions, as described in Section 3.6. The predicted strains have been determined by analysing the strains measured in the NSW coalfields, where the mining geometries and overburden geologies are similar to those for the proposed panels and longwalls.

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

4.2. Maximum predicted subsidence, tilt and curvature

The predicted total subsidence contours after the extraction of the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are shown in Drawings Nos. MSEC955-20, MSEC955-21, MSEC955-22 and MSEC955-23, respectively.

A summary of the maximum predicted additional conventional subsidence parameters, due to the extraction of the proposed series of panels or longwalls in each of the seams, is provided in Table 4.1. A summary of the maximum predicted total conventional subsidence parameters, after the completion of the proposed series of panels or longwalls in each of the seams, is provided in Table 4.2. The predicted tilts are the maxima after the completion of all panels or longwalls within each of the seams. The predicted curvatures are the maxima at any time during or after the extraction of the panels or longwalls within each of the seams.

Table 4.1 Maximum predicted additional conventional subsidence parameters

Seam	Maximum predicted additional vertical subsidence (mm)	Maximum predicted additional tilt (mm/m)	Maximum predicted additional hogging curvature (km^{-1})	Maximum predicted additional sagging curvature (km^{-1})
Whynot Seam	500	20	0.5	1.0
Woodlands Hill Seam	3100	45	2.0	1.5
Arrowfield Seam	2700	25	0.5	0.5
Bowfield Seam	2500	25	0.5	0.5

Table 4.2 Maximum predicted total conventional subsidence parameters

Seam	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Whynot Seam	500	20	0.5	1.0
Woodlands Hill Seam	3200	45	2.0	1.5
Arrowfield Seam	5400	50	2.0	2.0
Bowfield Seam	5800	50	2.0	2.0

The maximum predicted additional vertical subsidence, as percentages of the mining heights, are 26 % for the Whynot Seam, 99 % for the Woodlands Hill Seam, 95 % for the Arrowfield Seam and 94 % for the Bowfield Seam.

The maximum predicted total vertical subsidence, after the extraction of the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams, is 5800 mm and it represents approximately 60 % of the total mining height of these seams. It is noted, that the percentage of the total mining height is less than the percentages of the mining heights for individual seams for multi-seam conditions, as the positions of maximum subsidence do not coincide due to the stagger of the longwalls.

The maximum predicted total conventional tilt is 50 mm/m (i.e. 5 %, or 1 in 20. The maximum predicted total conventional curvatures are 2.0 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 0.5 km.

It can be seen from Drawings Nos. MSEC955-20 to MSEC955-23, that the magnitude of the predicted subsidence varies over the mining area, due to the single-seam and multi-seam mining conditions, as well as the variations in the depths of cover and mining heights. It can also be inferred from the spacing of the contours shown in these drawings, that the magnitudes of the predicted tilts and curvatures also vary over the mining area.

To illustrate this variation, the predicted profiles of vertical subsidence, tilt and curvature have been determined along two prediction lines, the locations of which are shown in Drawings Nos. MSEC955-20 to MSEC955-23. The predicted profiles of vertical subsidence, tilt and curvature along Prediction Lines 1 and 2 are shown in Figs. C.01 and C.02, respectively, in Appendix C. The predicted profiles are shown after the completion of the Whynot Seam (red lines), Woodlands Hill Seam (green lines), Arrowfield Seam (cyan lines) and Bowfield Seam (blue lines).

4.3. Predicted strains

It is more difficult predicting strain compared to the prediction of vertical 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.

4.3.1. Single-seam mining conditions

It has been found, for single-seam mining conditions, that applying a constant factor to the predicted maximum curvatures provides a reasonable prediction for the maximum conventional or typical 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 mining conditions.

The maximum predicted conventional curvatures due to the extraction of the proposed panels in the Whynot Seam are 0.5 km^{-1} hogging and 1.0 km^{-1} sagging. Adopting a factor of 10, the maximum predicted conventional strains, due to the proposed mining in the Whynot Seam only, are 5 mm/m tensile and 10 mm/m compressive. These maximum strains occur where the depths of cover are shallowest, in the northern part of the proposed mining area.

The proposed longwalls in the Woodlands Hill Seam are located outside the extents of the overlying panels in the Whynot Seam in the north-western and southern parts of the mining area. These parts of the longwalls will be extracted under single-seam mining conditions.

The maximum predicted conventional curvatures at the south-western ends of the proposed longwalls in the Woodlands Hill Seam are 2.0 km^{-1} hogging and 1.5 km^{-1} sagging. Adopting a factor of 10, the maximum predicted conventional strains for single-seam mining conditions are 20 mm/m tensile and 15 mm/m compressive.

At a point, however, there can be considerable variation from the linear relationship, resulting from non-conventional movements or from the normal scatters which are observed in strain profiles. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strain for low magnitudes of curvature.

The range of strains above the proposed longwalls in the Woodlands Hill Seam has been determined using monitoring data from previously extracted panels in the Hunter and Newcastle Coalfields, for single-seam mining conditions, where the width-to-depth ratios and mining heights were similar to those of the proposed longwalls.

The depth of cover to the proposed longwalls in the Woodlands Hill Seam, outside of the extents of the overlying panels in the Whynot Seam, varies between 125 m in the north-western part of the mining area and 365 m in the south-eastern part of the mining area. The longwall width-to-depth ratios vary between 0.84 and 2.4, i.e. subcritical through to supercritical widths.

The strain distributions for the proposed longwalls in the Woodlands Hill Seam, for single-seam mining conditions, have therefore been determined separately in the north-western and southern parts of the mining area.

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.

Woodlands Hill Seam (north-western part of the mining area for single-seam mining conditions)

The measured ground strains have been analysed for monitoring lines from the Hunter and Newcastle Coalfields, where the longwalls have been supercritical in width and where the depths of cover are between 100 m and 150 m. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains for the proposed longwalls in the Woodlands Hill Seam, for single-seam mining conditions, in the north-western part of the mining area.

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 supercritical longwalls in the Hunter and Newcastle Coalfields at depths of cover between 100 m and 150 m, is provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

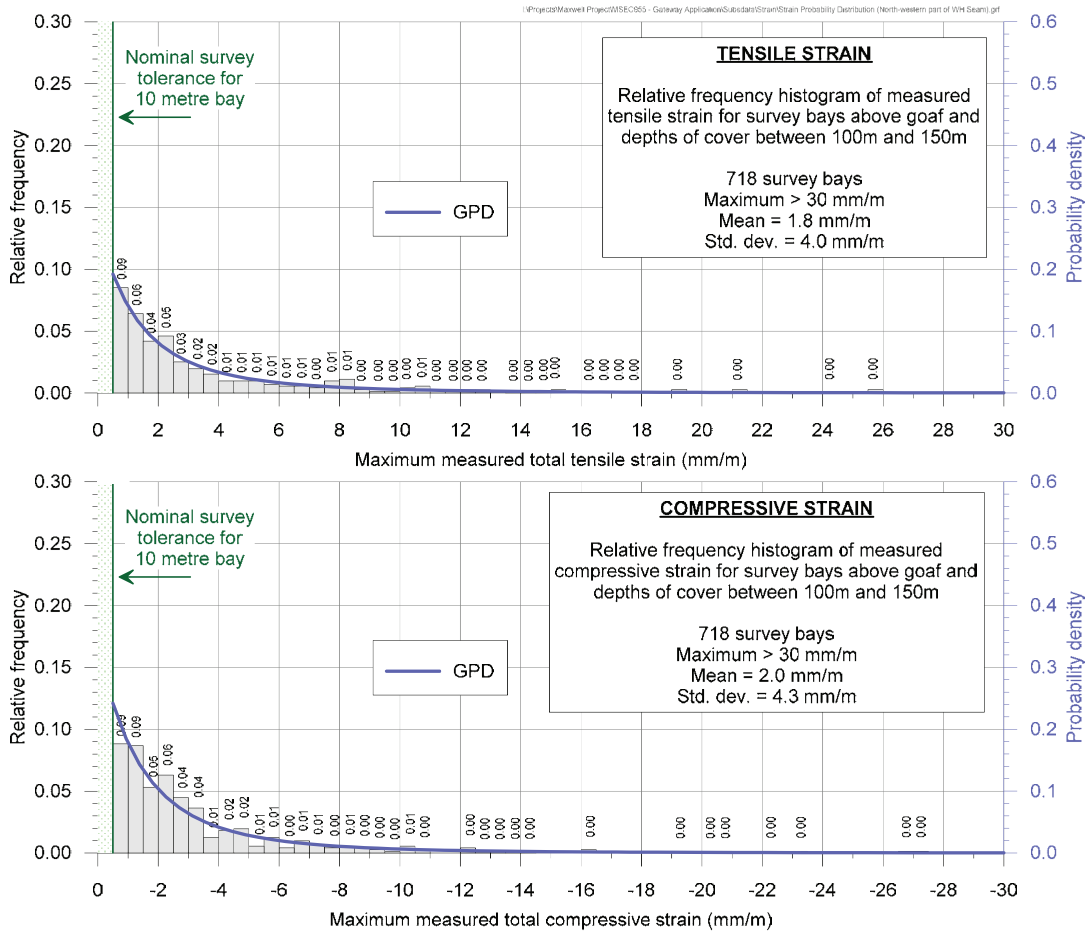


Fig. 4.1 Distributions of the measured tensile and compressive strains for survey bays located above supercritical longwalls at depths of cover between 100 m and 150 m

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

The 95 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 8 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 21 mm/m tensile and 19 mm/m compressive.

Woodlands Hill Seam (southern part of the mining area for single-seam mining conditions)

The measured ground strains have been analysed for monitoring lines from the Hunter and Newcastle Coalfields, where the longwall width-to-depth ratios are between 0.8 and 1.2. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains for the proposed longwalls in the Woodlands Hill Seam, for single-seam mining conditions, in the south-eastern part of the mining area.

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 longwalls in the Hunter and Newcastle Coalfields with width-to-depth ratios between 0.8 and 1.2, is provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

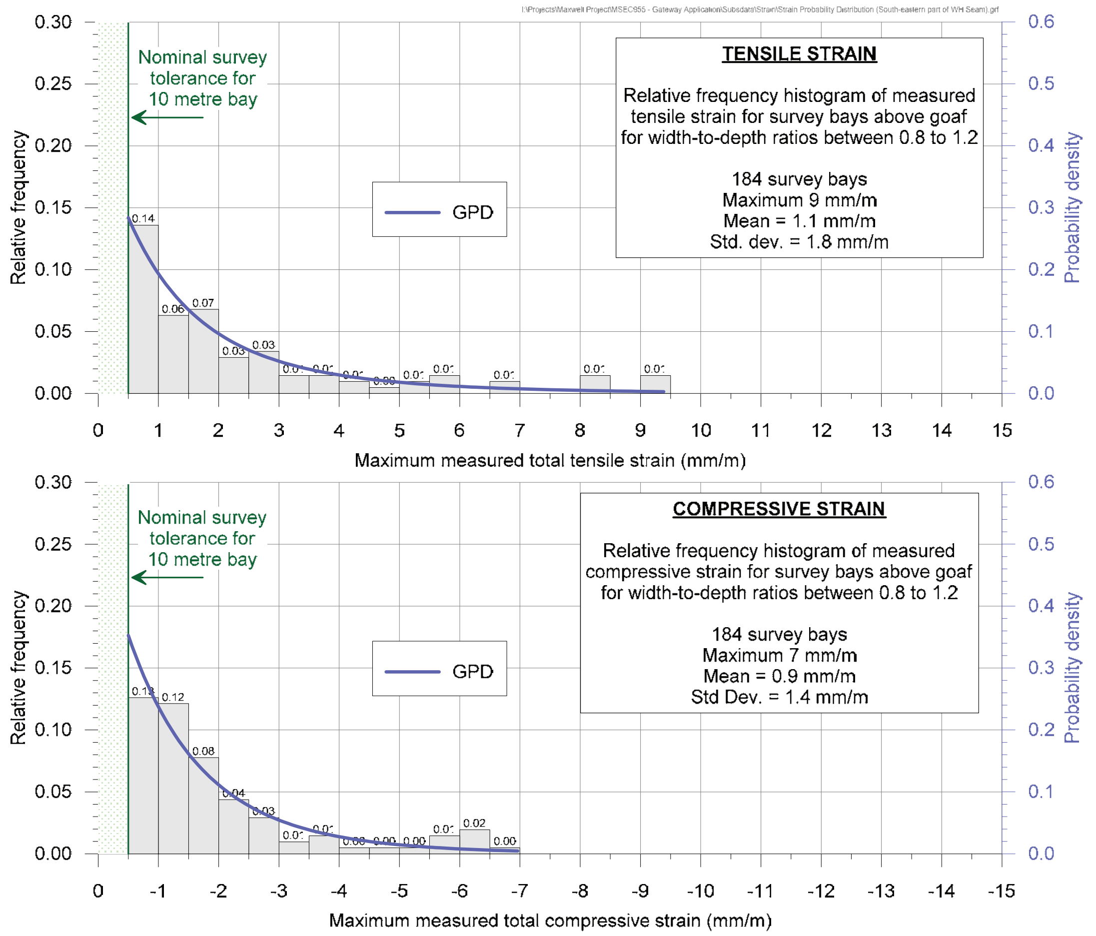


Fig. 4.2 Distributions of the measured tensile and compressive strains for survey bays located above longwalls with width-to-depth ratios between 0.8 and 1.2

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

The 95 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 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 9 mm/m tensile and 6 mm/m compressive.

4.3.2. Multi-seam mining conditions

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

The range of potential strains resulting from the extraction of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams, for multi-seam mining conditions, has been based on the observed strains for multi-seam mining in the Hunter and Newcastle Coalfields. The most extensive multi-seam strain data comes from: Blakefield South Mine where Longwalls 1 to 5 were mined beneath the South Bulga longwalls in the overlying Whybrow Seam (17 monitoring lines); and the North Wambo Underground Mine where Longwalls 1 to 10A in the Wambo Seam were extracted directly beneath the existing Homestead/Wollemi workings in the Whybrow Seam (six transverse monitoring lines).

Comparisons of the void widths, depths of cover, width-to-depth ratios, interburden thicknesses and mining heights of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams, with those at Blakefield South Mine and the North Wambo Underground Mine, are provided in Table 4.3.

Table 4.3 Comparison of the mine geometry for the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams with Blakefield South Mine and the North Wambo Underground Mine

Parameter	Proposed longwalls at the Maxwell Project			Longwalls used in the strain analysis
	Woodlands Hill Seam	Arrowfield Seam	Bowfield Seam	
Void width (m)	305	305	305	260 ~ 410 (325 ave.)
Depth of cover (m)	200 ~ 365 (260 ave.)	170 ~ 415 (310 ave.)	215 ~ 425 (340 ave.)	80 ~ 300 (190 ave.)
W/H ratio	0.84 ~ 1.5 (1.2 ave.)	0.73 ~ 1.8 (1.0 ave.)	0.72 ~ 1.4 (0.90 ave.)	0.9 ~ 3.3 (1.8 ave.)
Interburden (m)	135 ~ 185 (165 ave.)	40 ~ 70 (50 ave.)	10 ~ 45 (25 ave.)	50 ~ 120 (80 ave.)
Mining height (m)	2.1 ~ 3.5 (2.7 ave.)	2.1 ~ 3.7 (2.9 ave.)	2.4 ~ 3.3 (2.8 ave.)	2.1 ~ 3.4 (2.6 ave.)

The void width of the proposed longwalls of 305 m is similar to but slightly less than the average void width of the longwalls used in the strain analysis of 325 m. The width-to-depth ratios for the proposed longwalls of 0.72 to 1.8 are at the lower end of the range of width-to-depth ratios for the longwalls used in the strain analysis of 0.9 to 3.3.

The interburden thicknesses above the proposed longwalls in the Woodlands Hill Seam of 135 m to 185 m are greater than those for the longwalls used in the strain analysis of 50 m to 120 m. The interburden thicknesses above the proposed longwalls in the Arrowfield Seam are similar to and the interburden thicknesses above the longwalls in the Bowfield Seam are less than those for the longwalls used in the strain analysis. The average mining heights for the proposed longwalls of 2.7 m to 2.9 m are similar to but slightly greater than the average mining height of the longwalls used in the strain analysis of 2.6 m.

The strain analysis, therefore, should also provide reasonable, if not, slightly conservative indication of the range of potential strains for the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams for multi-seam mining conditions.

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. The frequency distribution of the maximum observed tensile and compressive strains measured in survey bays above goaf is provided in Fig. 4.3. The probability distribution functions, based on the fitted GPDs, are also shown in this figure.

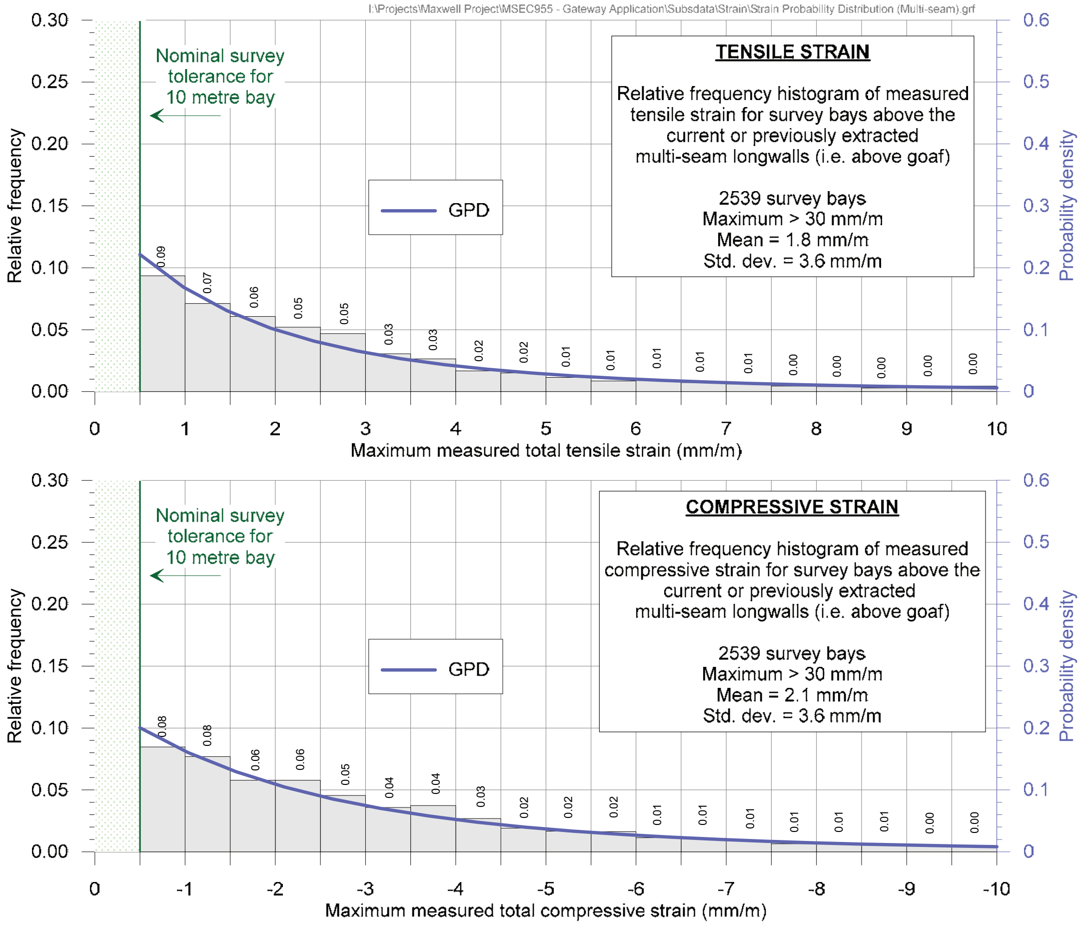


Fig. 4.3 Distributions of the measured tensile and compressive strains for multi-seam longwalls in the Hunter Coalfield

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 8 mm/m tensile and 9 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 16 mm/m tensile and compressive.

The predicted range of strains based on multi-seam conditions is similar to but slightly less than that for single-seam conditions in the north-western part of the mining area. The reason is the proposed longwalls in the Woodlands Hill Seam, in the north-western part of the mining area (i.e. single-seam conditions), are supercritical in width and have depths of cover less than 200 m. Whereas the proposed longwalls in the eastern part of the mining area (i.e. multi-seam conditions) are subcritical in width and have depths of cover greater than 200 m.

The experience from Blakefield South Mine found that the highest strains for multi-seam conditions occurred where the chain pillars in the Blakefield Seam were located directly beneath the existing chain pillars in the overlying Whybrow Seam (i.e. stacked case). The proposed longwalls within each of the Woodlands Hill, Arrowfield and Bowfield Seams have been staggered so that the chain pillars are not aligned. The predicted strains for these proposed longwalls, due to the multi-seam conditions, therefore, are expected to be less than those for single-seam conditions due to the overburden being already fractured by the extraction of the earlier seams and due to the increasing depths of cover.

4.4. Predicted far-field horizontal movements

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

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

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

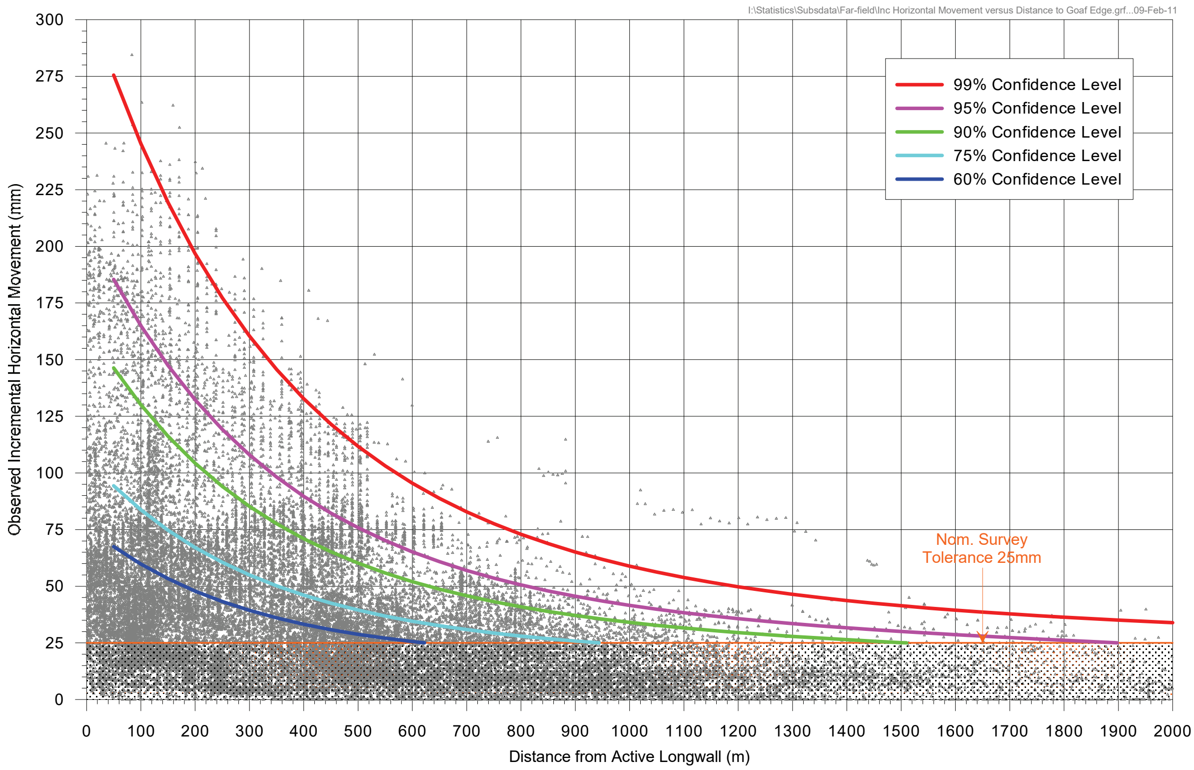


Fig. 4.4 Observed incremental far-field horizontal movements

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

The predicted far-field horizontal movements resulting from the extraction of the proposed mining 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 impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the vicinity of the proposed longwalls and panels is not expected to be significant.

5.1. Introduction

The *Strategic Agricultural Land* (SAL) within the Study Area is shown in Drawing No. MSEC955-16, which is based on the mapping provided in the *State Environmental Planning Policy (Mining and Petroleum Production and Extractive Industries) 2007* and on-site verification of *BSAL*. The agricultural land utilisation and the associated natural and built features in the area are shown in Drawings Nos. MSEC955-16 to MSEC955-19.

The land above the proposed mining area is owned by Malabar and it is used for cattle grazing.

The potential impacts on the SAL, agricultural land utilisation and associated natural and built features, resulting from the proposed mining, include the following:

- surface cracking and deformations – refer to Section 5.2;
- changes in surface water drainage – refer to Section 5.3;
- changes to surface water resources – refer to Sections 5.4 to 5.6;
- changes to the groundwater resources – refer to Section 5.7;
- impacts on the agricultural land utilisation – refer to Section 5.8; and
- impacts on built features associated with agricultural land utilisation – refer to Section 5.9.

The assessments provided in this report should be read in conjunction with the assessments provided in the Agricultural Impact Assessment and Preliminary Groundwater Assessment. The impact assessments provided in this report will be reviewed and refined as part of the EIS process.

5.2. Surface cracking and deformations

Longwall mining can result in surface cracking, heaving, buckling, humping and stepping at the surface. The extent and severity of these mining-induced ground deformations are dependent on a number of factors, including the mine geometry, depth of cover, overburden geology, locations of natural joints in the bedrock, the presence of near-surface geological structures and, in this case, multi-seam mining conditions.

Fractures and joints in bedrock occur naturally during the formation of the strata and from subsequent 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. Surface cracking normally develops behind the extraction face up to a horizontal distance equal to around half the depth of cover and, hence, the cracking in any location normally develops over a period of around two to four weeks.

At shallow depths of cover, it is also likely that additional 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. In multi-seam mining cases, surface cracking and heaving can potentially occur in any location above the extracted longwalls. The larger and more permanent cracks, however, are usually located in the final tensile zones around the perimeters of the longwalls. Open fractures and heaving, however, can also occur due to the buckling of surface beds that are subject to compressive strains.

Detailed crack mapping was undertaken above the commencing end of the Beltana No. 1 Underground Mine Longwall 1 (Beltana LW1), which was mined under single-seam conditions. The longwall had a void width of 275 m and was extracted in the Whybrow Seam at a depth of cover around 175 m. The width-to-depth ratio for Beltana LW1 was around 1.6, which is similar to but slightly greater than that for the proposed longwalls in the Woodlands Hill Seam, for multi-seam conditions, which have width-to-depth ratios varying between 0.84 and 1.5 and an average of 1.2.

The cracking observed above Beltana LW1 should, therefore, provide a reasonable indication of the extent of cracking in the relatively flat terrain above the proposed longwalls in the Woodlands Hill Seam. It was found from the detailed crack mapping, that 62 % of the cracks had widths less than 25 mm, 26 % had widths between 25 mm and 50 mm, and 12 % had widths between 50 mm and 100 mm. There were a total of 72 cracks recorded having a total length of 494 m and a total area of 17.7 m^2. The surveyed area was 112,476 m^2 and, therefore, it is estimated that less than 0.02 % of the surface was affected by cracking.

Several trial pits were excavated above Beltana LW1 to determine the nature and the depths of the cracks. It was found that the cracks up to 25 mm in width were relatively shallow, having depths less than 0.5 m below the surface. The wider cracks were found to extend more than 1 m below the surface. In all cases, the crack widths reduced as the depth below the surface increased.

Detailed crack mapping was also undertaken above the Blakefield South Mine Longwalls 1 to 5 (BSLW1 to BSLW5), which were extracted beneath the existing South Bulga longwalls in the Whybrow Seam (i.e. multi-seam conditions). The void width of BSLW1 was 330 metres and the void widths of BSLW2 to BSLW5 were 400 m. These longwalls were extracted in the Blakefield Seam at depths of cover ranging between 150 m and 305 m. The interburden thickness between the Whybrow and Blakefield Seams typically varied between 75 m and 95 m.

The cracking observed above BSLW1 to BSLW5 should provide a reasonable indication of the extent of cracking in relatively flat terrain for multi-seam conditions. It was found from the detailed crack mapping, that 79 % of the cracks had widths less than 100 mm, with the majority of these having widths less than 50 mm. The maximum observed crack width was around 500 mm.

There were more than 2390 cracks recorded above BSLW1 to BSLW5 having a total length of around 62 km. The total surface area above these longwalls was around 5.1 km^2 and it is estimated, therefore, that less than 0.09 % of this area was affected by cracking. The compression heaving and step heights observed during the extraction of BSLW1 to BSLW5 were typically less than 50 mm, but the maximum step height was around 800 mm which resulted from localised vertical ground shear.

Photographs of surface cracking resulting from the extraction of BSLW1 to BSLW5 at the Blakefield South Mine (i.e. multi-seam conditions) are provided in Fig. 5.1.

Fig. 5.1 Surface cracking above Blakefield South Mine (multi-seam conditions)

Larger surface cracking and deformations could also develop along the steep slopes. The extraction of the proposed longwalls could result in increased horizontal movements in the downslope direction, resulting in tension cracks appearing at the tops and along the sides of the steep slopes and compression ridges forming at the bottoms of the steep slopes.

Some examples of surface cracking along steep slopes in the Hunter Coalfield are provided in Fig. 5.2. Crack widths greater than 300 mm and depths greater than 3 m have been observed where longwalls have previously been extracted beneath steep slopes.

Fig. 5.2 Examples of surface cracking on steep slopes in the Hunter Coalfield

Based on the previous longwall mining experience in the NSW coalfields, the surface cracking in the flatter areas above the proposed longwalls is expected to be typically between 25 mm and 50 mm, with some isolated cracking around 100 mm or greater. The surface cracking along the steep slopes is expected to be typically in the order of 50 mm to 100 mm, with isolated cracking around 200 mm or greater.

The East Graben Fault is located approximately 150 m to the west of WHLW3, at seam level, at its closest point to the proposed longwalls. This normal fault has a dip of 70° (away from the mining area) and a throw of 15 m to 20 m, as shown in Fig. 1.4. The projected surface expression of the East Graben Fault is located approximately 30 m from the corner of the proposed WHLW3. Localised surface deformations could develop at the surface expression of this fault where it is located closest to the proposed longwalls.

The predicted vertical subsidence at the surface expression of the East Graben Fault is less than 20 mm. The ground movements could concentrate at the surface expression of the fault resulting in localised cracking with widths in the order of 20 mm.

The sill within the Whynot Seam is located above the south-western ends of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams, refer to Fig. 1.5. This sill is at a minimum depth of cover of 40 m along its northern boundary. It is possible that this sill could partially span the corners of the extracted voids resulting in localised and irregular movements where the depth of cover is shallowest.

The sill is largely confined within the Whynot Seam and, therefore, it has a thickness of less than 3 m. It is expected that localised cracking and stepping at the surface, due to the presence of this sill, would be typically less than 50 mm where the depth of cover is shallowest.

The land above the proposed mining area is owned by Malabar and it is used for cattle grazing.

The surface cracking and deformations could result in safety issues (i.e. trip hazards to people and stock), affect vehicle access (i.e. large deformations in access tracks), or result in increased erosion (especially along the drainage lines and the steeper slopes).

Management strategies and remediation measures can be developed for the surface cracking and deformations, which could include the following:

- visual monitoring of the surface in the active subsidence zone, to identify the larger surface cracking and deformations that could affect safety, access, or increase erosion;
- establish methods for surface remediation, which could include 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 vegetation in order to stabilise the steeper slopes in the longer term; and
- develop management plans incorporating the agreed methods to remediate the larger surface cracking, as required.

An example of surface crack remediation in the Newcastle Coalfield is illustrated in Fig. 5.3.

1. Excavator removes soil down to the base of cracking.

2. Trench re-filled and compacted in layers.

3. Surface area re-seeded.

4. Surface rehabilitation completed.

Fig. 5.3 Example of surface crack remediation in the Newcastle Coalfield (Courtesy of Donaldson Coal)

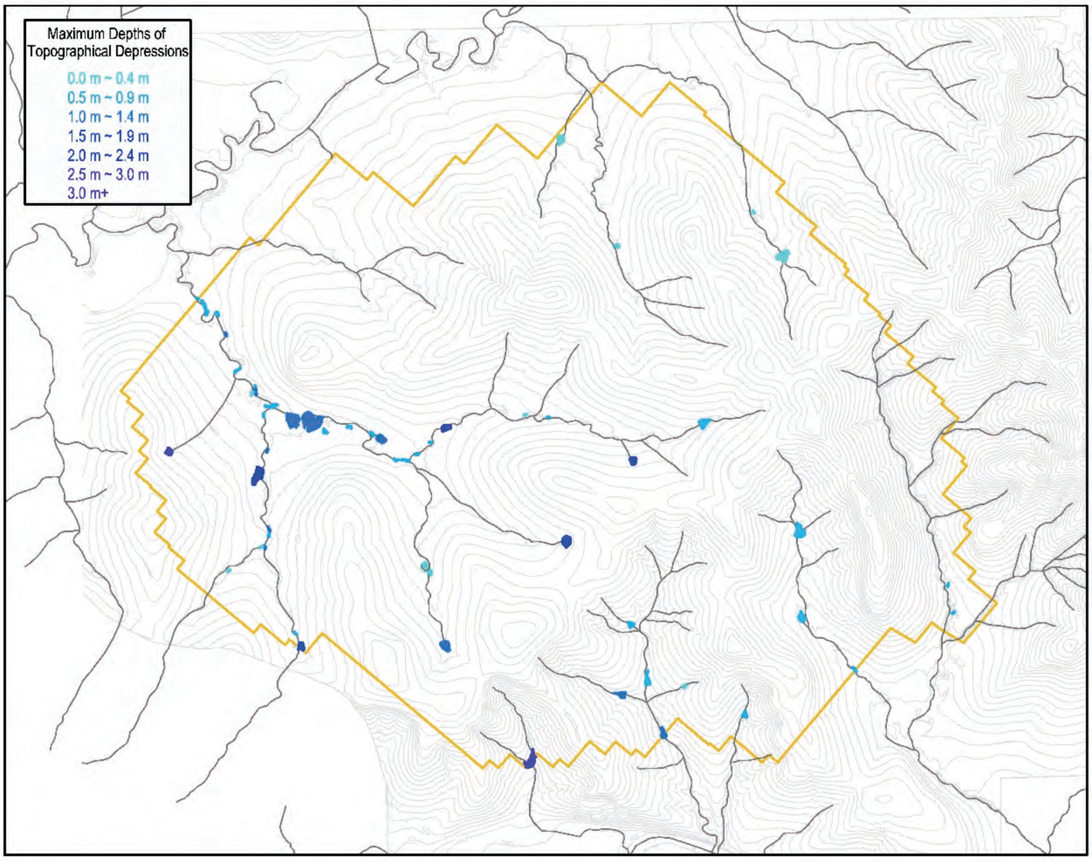
Further discussions are provided in the impact assessments in the following sections of this report.

5.3. Predicted changes in surface water drainage

The surface level contours within the proposed mining area are shown in Drawing No. MSEC955-06. The land generally falls towards the Hunter River to the south of the mining area and towards Saddlers Creek to the north of the mining area.

The drainage lines and the natural gradients within the Study Area are illustrated in Drawing No. MSEC955-18. The natural grades are typically greater than 10 % in the south-eastern part of the Study Area. The grades are typically between 5 % and 10 % in the north-western part of the mining area, with lower lying areas along some of the drainage lines having grades of less than 5 %.

The natural and the predicted post-mining surface level contours are illustrated in Fig. 5.4. The maximum extents and depths of the topographical depressions are also illustrated in this figure, which are based on the geometry of the natural and post-mining surface level contours. The potential for increased ponding in these locations is dependent on a number of other factors, including rainfall, catchment sizes, surface water runoff, permeation and evaporation and, therefore, the actual extents and depths of ponding are expected to be smaller than the topographical depressions.



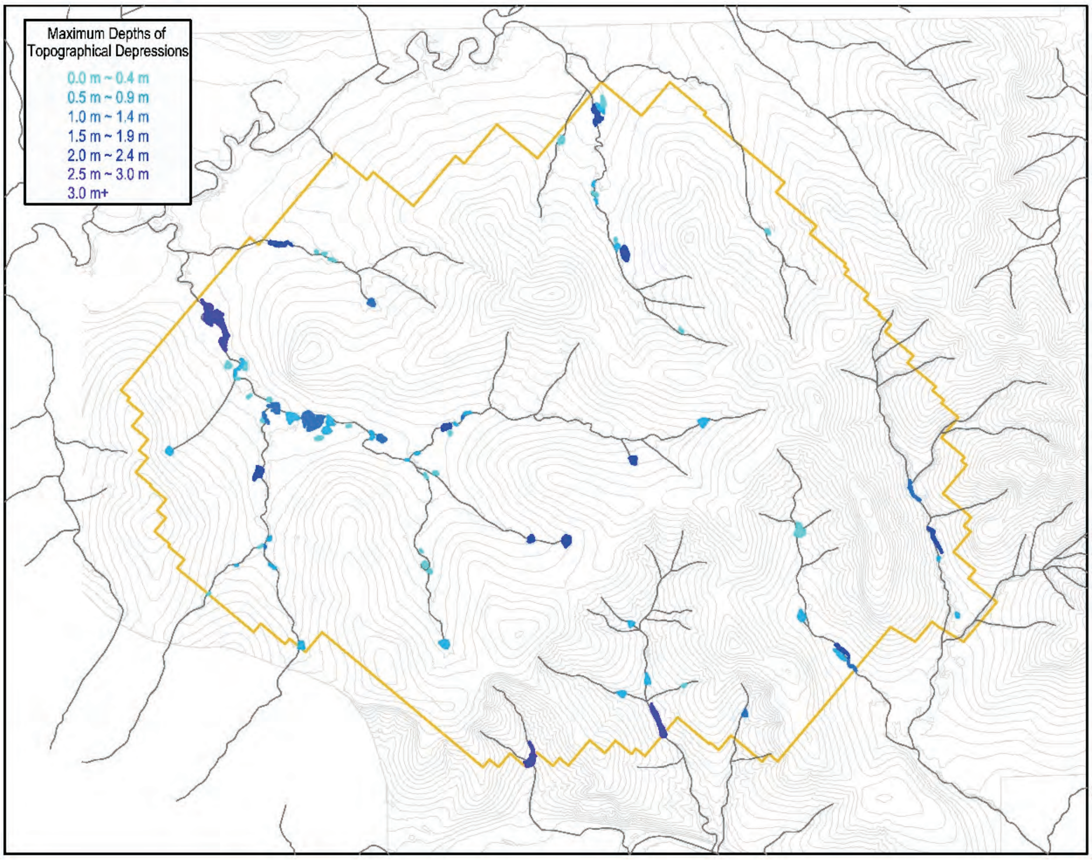


Fig. 5.4 Natural (top) and predicted post-mining (bottom) surface levels contours and the locations and depths of the topographical depressions

It can be seen at the top of Fig. 5.4, that the land is naturally draining with only localised natural topographical depressions, i.e. localised areas where ponding can naturally develop. The majority of these topographical depressions are associated with the existing farm dams or are located along the natural drainage lines.

It can be seen at the bottom of this figure, that additional topographical depressions (i.e. areas with increased potential for ponding) are expected to develop as a result of the proposed mining, primarily along the alignments of the natural drainage lines, away from the steep slopes.

The largest final topographical depression occurs in the north-western part of the proposed mining area, where the depth of cover is the shallowest, and it has a maximum depth of 3.2 m and a surface area of approximately 2 ha. The topographical depressions on the southern boundary of the proposed mining area vary up to 2.7 m deep. Elsewhere, the topographical depressions are predicted to be typically less than 2 m deep. The sizes of the topographical depressions are typically less than 1 ha in the northern part of the proposed mining area and less than 0.5 ha in the southern part of the mining area.

After the completion of mining in each seam in a particular area, surface remediation could be undertaken to re-establish the natural grades along the drainage lines, where required, so as to reduce the potential for ponding within the above the proposed mining area. Discussions on the methods of remediation for the drainage lines and, hence, the post-mining ponding are provided in Section 5.6.

The agricultural land utilisation that could be affected by the topographical depressions and, hence, may require surface remediation works include the light cattle grazing on the Malabar owned land above the proposed mining area. The topographical depressions within the BSAL are predicted to be up to 3.2 m deep and the total affected surface area is 2.5 ha.

Further discussions are also provided in the Agricultural Impact Assessment.

5.4. The Hunter River

The locations of the Hunter River and the mapped limit of alluvium in the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009* are shown in Drawing No. MSEC955-18.

The Hunter River is considered to be the most significant stream in the Hunter Coalfield. Photographs of the Hunter River are provided in Fig. 5.5 near the crossing beneath the Golden Highway (left side) and where the river is located closest to the proposed mining area (right side).

Fig. 5.5 Photographs of the Hunter River

The Hunter River is located to the south of the proposed mining area. The thalweg (i.e. centreline) of the river channel is 525 m south of the proposed WHLW12, at its closest point to the proposed mining area. A section through the Hunter River and the proposed longwalls, where the river channel is located closest to the mining area, is shown in Fig. 5.6.

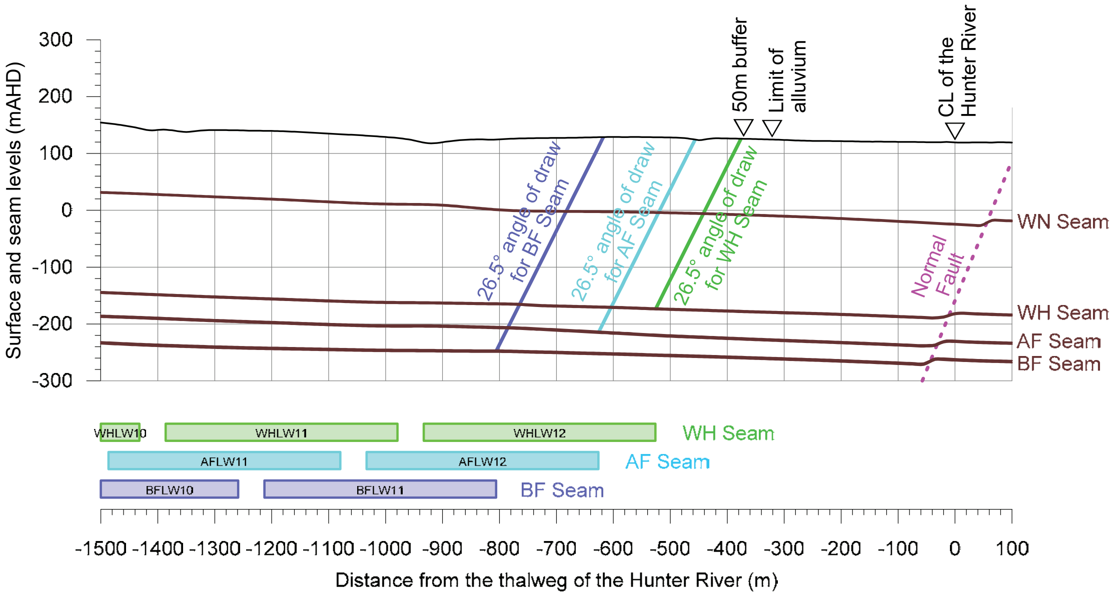


Fig. 5.6 Section through the Hunter River and the proposed longwalls where the river is located closest to the mining area

The thalweg of the Hunter River is located well outside the 26.5° angle of draw lines from the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. At this distance, the river channel itself is expected to experience negligible vertical subsidence (i.e. less than 5 mm) and, therefore, is not expected to experience measurable conventional tilts, curvatures or strains. It is unlikely, therefore, that the river channel itself would experience adverse impacts resulting from the proposed mining.

It can be seen from Drawing No. MSEC955-18 and Fig. 5.6, that the 50 m buffer to the mapped limit of alluvium for the Hunter River is also located outside the 26.5° angle of draw lines from the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. The alluvium is predicted to experience less than 20 mm vertical subsidence due to the extraction of the proposed longwalls. Whilst the alluvium could experience very low-levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains.

The potential impacts on the alluvium and associated aquifer are discussed in the Agricultural Impact Assessment.

5.5. Saddlers Creek

The locations of Saddlers Creek and the mapped limit of alluvium in the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009* are shown in Drawing No. MSEC955-18. Photographs of this creek are provided in Fig. 5.7 near the crossing with Edderton Road (left side) and further upstream (right side).

Fig. 5.7 Photographs of Saddlers Creek

Saddlers Creek is located to the north of the proposed mining area. The thalweg of the creek channel is around 240 m north of WHLW4, at its closest point to the proposed mining area. A section through Saddlers Creek and the proposed longwalls, where the creek channel is located closest to the mining area, is shown in Fig. 5.8.

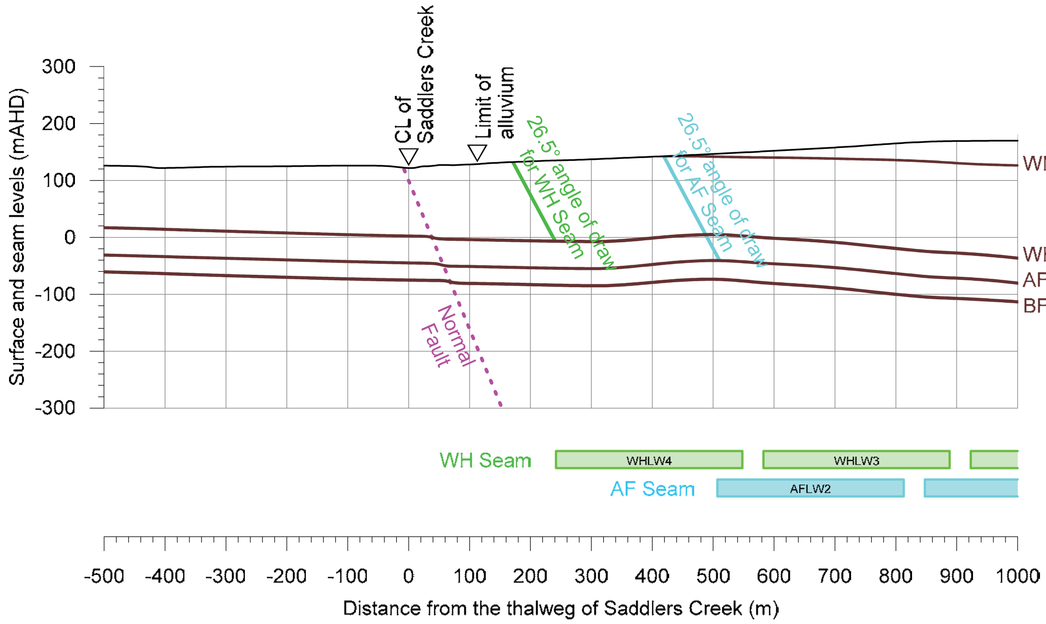


Fig. 5.8 Section through Saddlers Creek and the proposed longwalls where the creek is located closest to the mining area

The thalweg of Saddlers Creek is located well outside the 26.5° angle of draw lines from the proposed longwalls in the Woodlands Hill and Arrowfield Seams. At this distance, the creek channel itself is expected to experience negligible vertical subsidence (i.e. less than 5 mm) and, therefore, is not expected to experience measurable conventional tilts, curvatures or strains. It is unlikely, therefore, that the creek channel itself would experience adverse impacts resulting from the proposed mining.

It is possible Saddlers Creek could be coincident with the surface expression of the fault that is located outside and adjacent to the proposed mining area. This north-east trending normal fault has a throw of around 5 m. It is unlikely that localised movements would develop at the surface expression of this fault due to its distance from the proposed mining area and its small size.

The potential impacts on the alluvium and associated aquifer are discussed in the Agricultural Impact Assessment.

5.6. Drainage lines

5.6.1. Description of the drainage lines

The locations of the drainage lines within the Study Area are shown in Drawing No. MSEC955-18. It appears from the CMA Map of the area, that there are no "named" drainage lines within the area.

The drainage lines in the southern part of the Study Area are tributaries to the Hunter River and the drainage lines in the northern part of the Study Area are tributaries to Saddlers Creek. The upper reaches are first and second order streams and some parts of the lower reaches are third order streams. The drainage lines are ephemeral, where surface water only flows during and for short periods after rainfall events, although some isolated natural ponding is evident along the flatter lower reaches.

The drainage lines have shallow incisions into the natural surface soils, which are generally derived from the Jerrys Plains Subgroup of the Wittingham Coal Measures, as illustrated in Fig. 1.9. There is rock outcropping along the lower reaches of some of the drainage lines.

Photographs of the drainage lines within the Study Area are provided in Fig. 5.9 and Fig. 5.10.

Fig. 5.9 Photographs of typical drainage lines within the Study Area

Fig. 5.10 Photographs of typical drainage lines within the Study Area

The natural grades along the drainage lines typically vary between 30 mm/m and 70 mm/m (i.e. 3 % to 7 %, or 1 in 33 to 1 in 14) along the upper reaches and typically between 10 mm/m and 30 mm/m (i.e. 1 % to 3 %, or 1 in 100 to 1 in 33) along the lower reaches.

5.6.2. Predictions for the drainage lines

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

A summary of the maximum predicted vertical subsidence, tilt and curvatures for the drainage lines is provided in Table 5.1. The values are the maxima within the Study Area due to the proposed mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams.

Table 5.1 Maximum predicted conventional subsidence, tilt and curvature for the drainage lines

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Drainage lines	5800	50	2.0	2.0

The maximum predicted total conventional curvatures are 2.0 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 0.5 km. The predicted conventional strains based on applying a factor of 10 to the predicted conventional curvatures are 20 mm/m tensile and compressive. The distributions of strain above the proposed mining area are provided in Section 4.3.

The drainage lines could also experience valley related effects due to the proposed mining. The drainage lines have shallow incisions into the natural surface soils and, therefore, the predicted upsidence and closure effects are not expected to be significant when compared with the predicted conventional effects.

5.6.3. Impact assessments for the drainage lines

The impact assessments for the drainage lines are provided in the following sections.

Potential for increased levels of ponding and scouring due to the mining-induced tilts

Mining can potentially result in increased levels of ponding in the 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 scouring of the stream beds and banks in the locations where the mining-induced tilts considerably increase the natural stream gradients that exist before mining.

The maximum predicted tilt for the drainage lines is 50 mm/m (i.e. 5 %, or 1 in 20). The predicted changes in grade are similar to the natural gradients along the upper reaches and are greater than the natural gradients along the lower reaches of the drainage lines.

It is likely, therefore, that there would be areas that would experience increased ponding along the lower reaches of the drainage lines, predominately upstream of the chain pillars in the shallower seams and where the drainage lines exit the proposed mining area. It is also possible, that there could be areas which could experience increased scouring of the stream beds, predominately downstream of the chain pillars in the shallower seams.

The locations within the Study Area that are predicted to experience increased potential for ponding are illustrated in Fig. 5.4. The natural and the predicted post-mining surface levels (i.e. prior to any surface remediation) along Drainage Lines 1 to 4 are also illustrated in Fig. 5.11 to Fig. 5.14. The estimated maximum depths and extents of the topographical depressions (prior to any remediation) along these drainage lines are also indicated in these figures.

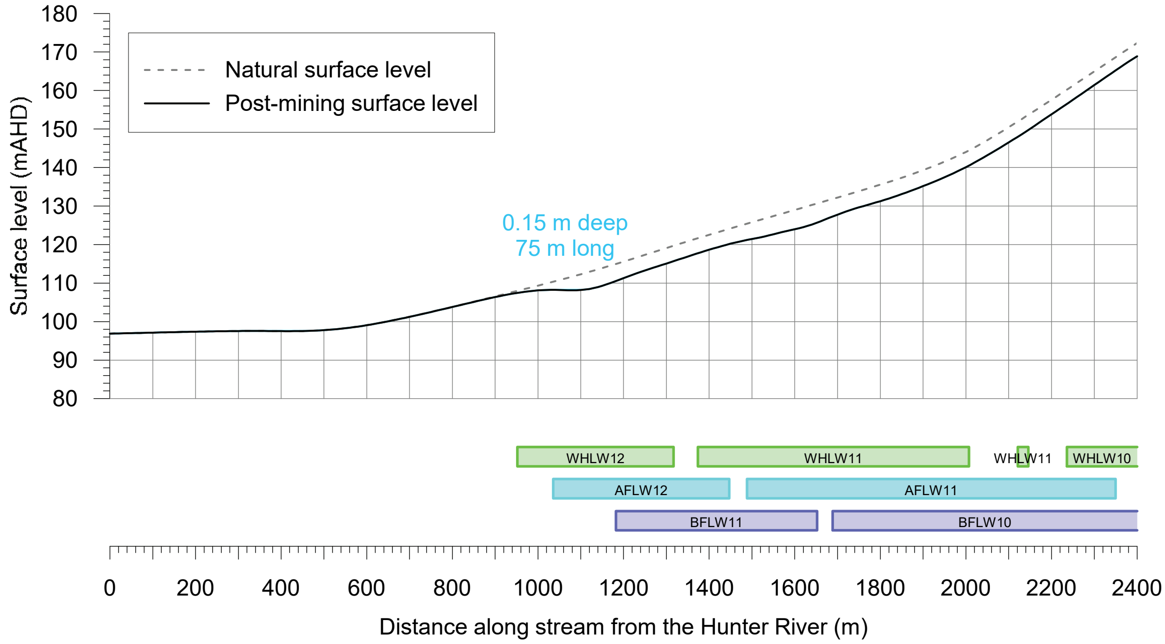


Fig. 5.11 Natural and predicted post-mining surface levels along Drainage Line 1

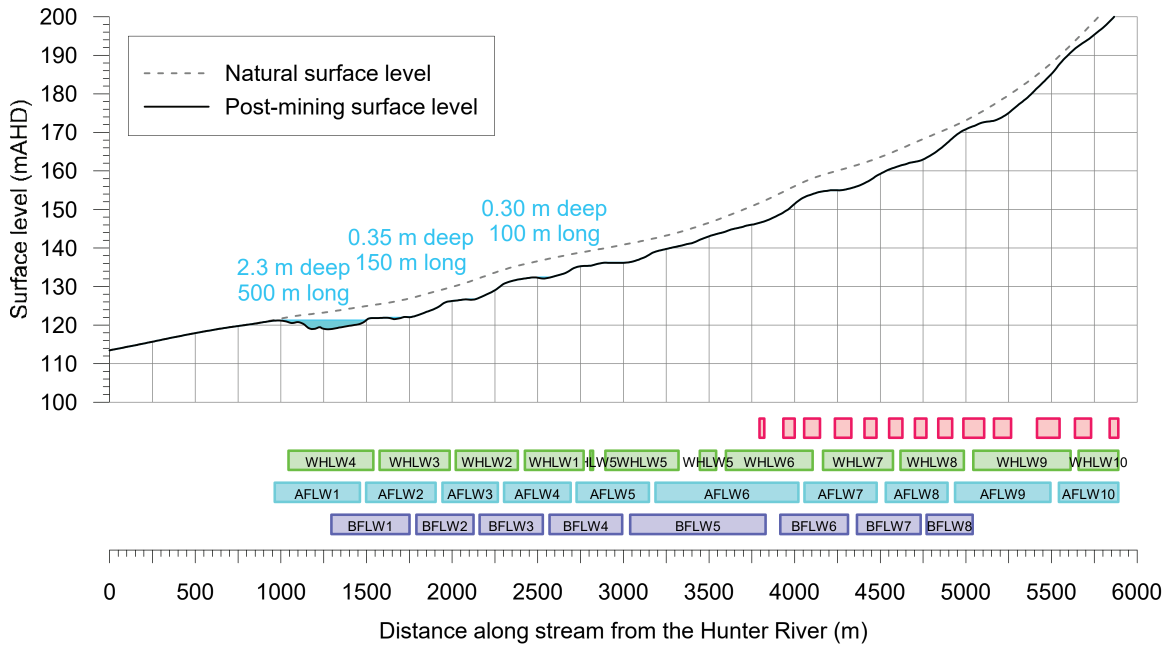


Fig. 5.12 Natural and predicted post-mining surface levels along Drainage Line 2

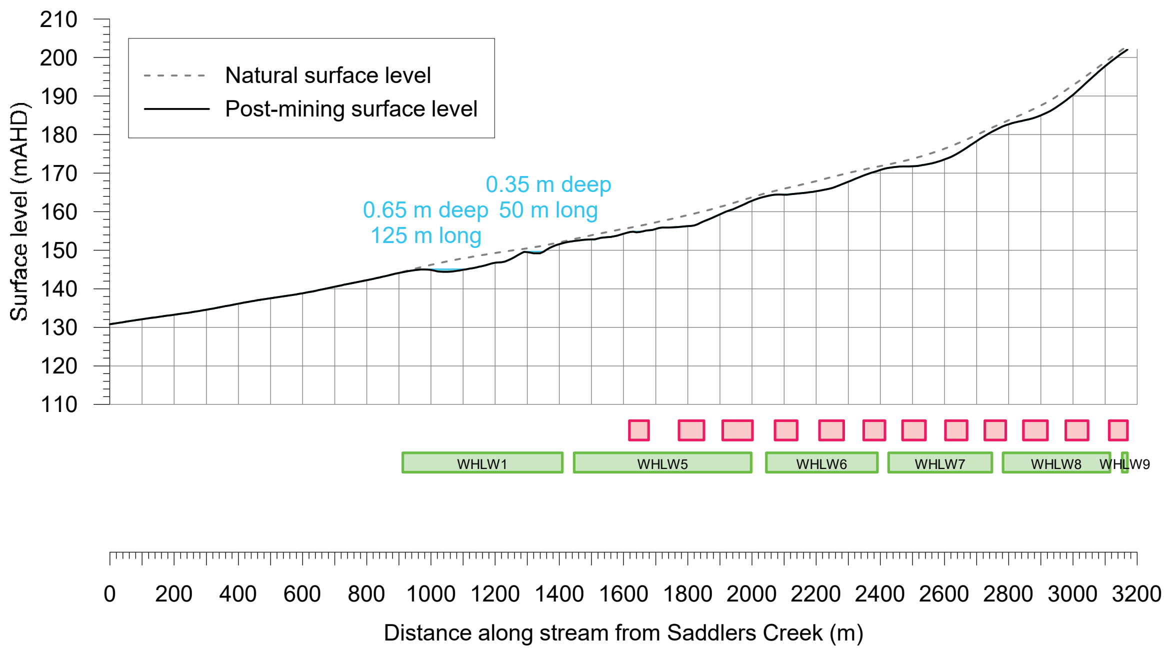


Fig. 5.13 Natural and predicted post-mining surface levels along Drainage Line 3

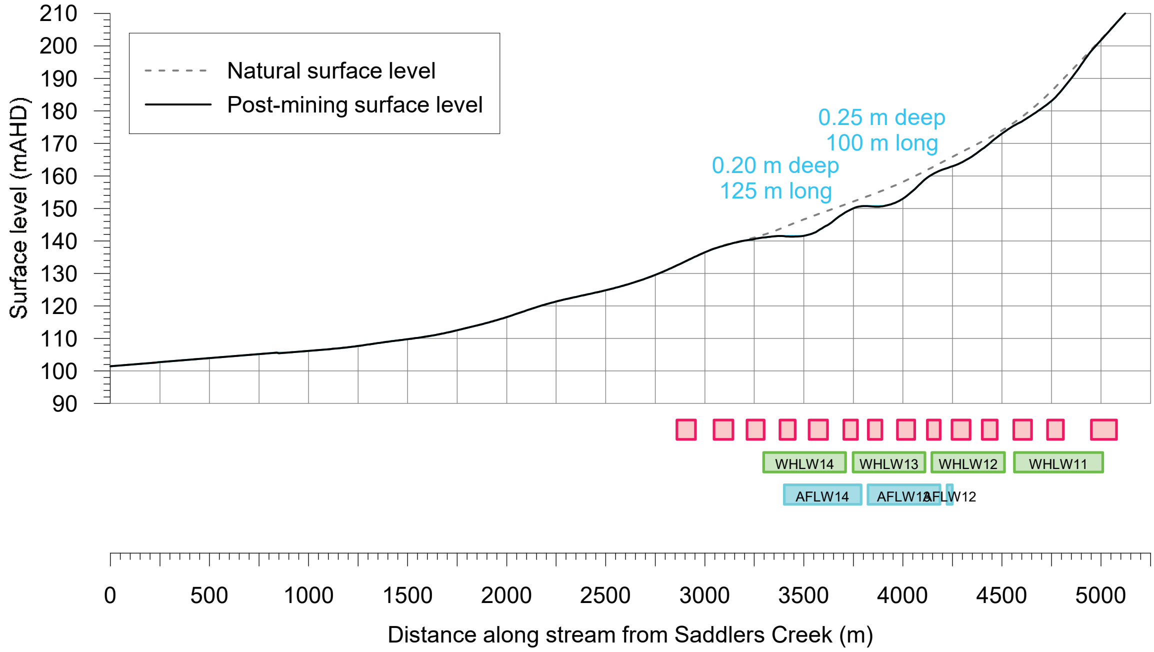


Fig. 5.14 Natural and predicted post-mining surface levels along Drainage Line 4

The largest ponding areas are predicted to occur upstream of where the drainage lines exit the proposed mining area. It is estimated, that a topographical depression up to around 2.3 m deep and up to 500 m long will develop along the drainage lines, after the completion of all the proposed longwalls. Some deeper but more localised ponding could occur in the locations of the existing farm dams.

It is noted, that the predicted ponding depths and extents are likely to be conservative, as these have been based on the predicted changes in surface levels along the original alignments of the drainage lines and, therefore, do not consider the natural grades across the alignments of the drainage lines. The proposed mining will result in some changes in the stream alignments, due to the natural cross-grades and, in consequence, the actual ponding depths are expected to be less than those predicted.

At the completion of mining in each seam, the drainage lines could be regraded in the areas of increased ponding, so as to re-establish the natural gradients. The drainage lines have shallow incisions in the natural surface soils and, therefore, it is expected that the extents of ponding could be reduced by locally excavating the drainage line channels downstream of these areas. Alternatively, if the increased surface water storage was considered desirable, additional dam walls could be constructed along the drainage lines similar to those which already exist within the Study Area.

It is possible that increased levels of bed scouring could also occur in the locations of the maximum increasing tilts, during times of high surface water flows, where the velocities of the flows exceed 1 metres per second. If significant levels of bed scouring were to occur along the drainage lines, it may be necessary to provide erosion control measures, or to locally regrade the beds of the drainage lines in these locations.

Further discussions on the potential impacts of increased ponding along the drainage lines are provided in the Agricultural Impact Assessment. A more detailed geomorphic assessment of the drainage lines will be completed as part of the EIS.

Potential for cracking in the drainage line beds and fracturing of the bedrock

Fracturing of the uppermost bedrock has been observed in the past, as a result of longwall mining, where the tensile strains have been greater than 0.5 mm/m. Buckling and dilation of the uppermost bedrock have also been observed where the compressive strains have been greater than 2 mm/m. It is likely, therefore, that fracturing, buckling and dilation would occur in the bedrock beneath the soil beds of the drainage lines based on the magnitudes of the predicted strains. Fracturing of the exposed bedrock is also expected.

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

It is likely that some remedial measures would be required at the completion of mining. Where necessary, any significant surface cracks in the drainage line beds could be remediated by infilling with the surface soil or other suitable materials, or by locally regrading and recompacting the surface.

The multi-seam mining will result in the development of a network of fractures in the overburden above the extracted panels and longwalls. The changes in hydraulic conductivity and the potential hydrogeological impacts above proposed longwalls will be further assessed as part of groundwater modelling and investigations during the Gateway Application and EIS.

Experience from mining in the Hunter and Newcastle Coalfields indicates that impacts on ephemeral streams are low where the panels are subcritical or where the depths of cover are greater than the order of 200 m. The proposed panels in the Whynot Seam are typically subcritical in width, except in the northern part of the mining area where the depths of cover are shallowest. The proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams are typically at depths of cover greater than 200 m.

For example, ephemeral drainage lines have been directly mined beneath at South Bulga and the Beltana No. 1 Underground Mine by the longwalls in the Whybrow Seam, where the depths of cover varied between 40 m and 200 m. Although surface cracking was observed across the mining area, there were no observable surface water flow diversions in the drainage lines after the remediation of the larger surface cracks had been completed. Similar experience occurred where the North Wambo Underground Mine and United Collieries extracted longwalls in the Whybrow, Wambo and Woodlands Hill Seams (i.e. multi-seam) beneath a number of ephemeral streams, including North Wambo Creek.

5.6.4. Recommendations for the drainage lines

Management strategies and remediation measures can be developed for the drainage lines, which could include the following:

- visual monitoring of the surface in the active subsidence zone, to identify the larger surface cracking and deformations that could result in the loss of surface water flows or increase erosion;
- establish methods to regrade the drainage lines in the locations where adverse impacts occur as a result of increase ponding; and
- establish methods of remediation for the surface cracking, which could include infilling 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 providing rip-rap.

These management strategies and remediation measures will be developed at the EIS stage of the project.

5.7. Groundwater resources

There are groundwater resources associated with the Hunter River alluvial aquifer and other shallow and deeper aquifers within EL5460. More detailed descriptions of these resources are provided in the Agricultural Impact Assessment.

The locations of the groundwater bores on Malabar-owned land are shown in Drawing No. MSEC955-19. A summary of the groundwater bores that are located within the Study Area is provided in Table 5.2. There are also additional groundwater bores outside the Study Area, as shown in Drawing No. MSEC955-19.

Table 5.2 Details of the groundwater bores within the Study Area

Reference	Approximate Easting (m)	Approximate Northing (m)	Depth (m)
DD1004	299800	6410925	106
DD1005	298800	6410900	139
DD1014	296800	6410875	90
DD1015	298825	6409900	163
DD1016	297800	6410875	126
DD1025	298775	6411900	45
DD1041 - Deep	296200	6409475	387
DD1041 - Shallow	296200	6409475	N/A
DD1043	295200	6409450	203
DD1052	296275	6408525	127
DD1057	295175	6410450	188
RBD1	295175	6409250	111
RD1192	296100	6409050	149
Shearers Well	296900	6410275	N/A
Shearers Well Bore	296925	6410250	N/A
WND16	298125	6408850	126
WND26	299475	6409050	152

It is likely that the groundwater bores will experience impacts as the result of the proposed mining, particularly those located directly above the proposed mining area. Impacts would include lowering of the piezometric surface, blockage of the bore due to differential horizontal displacements at different horizons within the strata and changes to groundwater quality. Such impacts on the groundwater bores can be managed and, if required, the bores can be reinstated.

The potential impacts on the bores and groundwater resources are provided in the Agricultural Impact Assessment.

5.8. Agricultural land utilisation

The land above the proposed mining area is owned by Malabar and it is used for cattle grazing. The potential impacts on the agricultural land use within the Study Area include:

- surface cracking and deformations – refer to Section 5.2;
- changes in surface water drainage – refer to Section 5.3;
- changes to surface water resources – refer to Sections 5.4 to 5.6;
- changes to the groundwater resources – refer to Section 5.7; and
- impacts to built features associated with the agricultural land use – refer to Section 5.9.

The main risk to the light cattle grazing within the Study Area is the potential for the mining-induced surface cracking and deformations to injure the cattle or workers. Management strategies can be developed for this agricultural utilisation, which could include:

- visual monitoring of the surface in the active subsidence zone, to identify any surface cracking and deformations that could potentially injure the stock or people;
- consider the installation of temporary fencing and/or the temporary relocation of stock to areas outside the active subsidence zone;
- establish methods of remediation, which could include infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface; and
- develop management plans detailing the appropriate methods to manage surface cracking and deformations within the Study Area.

Other potential impacts on the built features within the Study Area are covered in Section 5.9.

There are commercial agricultural industries and land use located just outside the Study Area, including horse studs and a vineyard. These properties will not be affected by mining-induced surface cracking and deformations, nor changes in surface water drainage and surface water resources, nor impacts on the built features. The potential impacts on the bores and groundwater resources within and outside the Study Area are provided in the Preliminary Groundwater Assessment and the Agricultural Impact Assessment.

5.9. Built features associated with the agricultural land utilisation

The locations of the built features associated with the agricultural land use within the Study Area are shown in Drawing No. MSEC955-19. The built features located directly above the proposed mining area include:

- 20 farm dams located directly above the proposed mining area – refer to Fig. 5.15;
- unsealed access tracks – refer to Fig. 5.15;
- land contouring – refer to Fig. 5.16;
- cattle yard and fencing – refer to Fig. 5.17; and
- Edderton Road and aerial low voltage powerlines – refer to Fig. 5.18.

Fig. 5.15 Typical farm dam and access track within the Study Area

Fig. 5.16 Land contouring within the Study Area

Fig. 5.17 Cattle yard and fences within the Study Area

Fig. 5.18 Edderton Road and aerial low voltage powerline

The Golden Highway is located outside of the Study Area. The highway crosses the Hunter River approximately 800 m south of the proposed mining area. The bridge could experience far-field horizontal movements due to the proposed mining and it could be sensitive to the small differential horizontal movements along its length. A photograph of the Golden Highway and the bridge across the Hunter River is provided in Fig. 5.19.

Fig. 5.19 The Golden Highway and the bridge across the Hunter River

Detailed impact assessment for the built features located within the Study Area and for the Golden Highway and bridge across the Hunter River will be undertaken during the EIS stage of the project. Management strategies for infrastructure will be incorporated into the Built Features Management Plans (BFMPs).

The preparation of BFMPs is an industry-wide practice for the management of potential subsidence impacts for privately-owned infrastructure. BFMPs generally include:

- plans showing the locations of the infrastructure in relation to the final mining layout;
- details of the predicted subsidence movements and the potential impacts to the infrastructure, including the likelihoods of these impacts occurring;
- the expected timing of mine subsidence;
- the implementation of appropriate pre-mining preventive measures to minimise the potential for impacts and to maintain safety and serviceability, where appropriate;

- details of ground monitoring to measure the development of subsidence during mining;
- development of remediation measures to maintain the infrastructure in safe and serviceable conditions during active subsidence; and
- establishment of Trigger Action Response Plans to define the necessary remediation and control procedures based on outcomes of the visual and ground monitoring.

The management strategies will need to be developed, in consultation with the owners, so that the infrastructure can be maintained in safe and serviceable conditions throughout the mining period.