bhpbilliton

resourcing the future

Caroona Coal Project
Application for Gateway Certificate

Appendix D
Subsidence Assessment

REPORT: SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

CAROONA COAL PROJECT:

Gateway Application – Subsidence Assessment

Subsidence Predictions and Impact Assessments for Natural and Built Features Resulting from the Proposed Longwall Mining in the Hoskissons Seam in Support of the Gateway Application

DOCUMENT REGISTER

Revision	Description	Author	Checker	Date
01	Draft Issue	JB	-	18th Dec 13
02	Minor Revisions	JB	-	15th Jan 14
03	Revised Draft	JB	-	14th Feb 14
04	Revised Draft	JB	PD	27th Feb 14
A	Final Issue	JB	PD	18th Mar 14
B	Final Issue – Minor updates	JB	PD	28th Mar 14

Report produced to:- Support the Gateway Application for the Caroona Coal 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

Coal Mines Australia Pty Limited (CMAL), a wholly owned subsidiary of BHP Billiton, was granted Exploration Licence (EL) 6505 in 2006. EL6505 is located in the Gunnedah Basin of New South Wales (NSW), approximately 14 kilometres north-west of the township of Quirindi. BHP Billiton is proposing an underground mine, referred to as the Caroona Coal Project (the Project), which will involve longwall mining in the Hoskissons Seam.

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

- review the currently proposed longwall mining in the Hoskissons Seam,
- prepare predicted subsidence contours resulting from the proposed longwall mining,
- identify and describe the natural and built features within the proposed mining areas, with particular focus on those relevant to the Gateway Application,
- provide subsidence predictions and impact assessments for the natural and built features identified within the mining areas, with particular focus on those relevant to the Gateway Application, and
- provide recommendations for strategies to manage the potential impacts resulting from mining.

This report has been issued to support the Gateway Application for the project.

The proposed longwall layout has been developed and refined through an iterative process, during the previous and current stages of the Project, based on predicted subsidence effects and assessed consequences for various mining layouts. The subsidence effects have been reduced in some locations above the proposed longwalls with the development of Subsidence Control Zones (SCZ).

The subsidence predictions provided in this report were obtained using the Incremental Profile Method, which is an empirical method based on extensive ground monitoring data from the NSW Coalfields. The maximum predicted subsidence parameters resulting from the proposed longwalls are as follows:-

Location	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Area 1	3,100	70	3.0	3.0
Area 2A	3,100	65	2.5	2.5
Area 2B	1,600	40	1.5	1.5
Area 2S	3,000	30	0.50	0.50
Area 3	2,900	25	0.40	0.45
Area 4	2,750	20	0.25	0.35
Area 5	2,400	10	0.10	0.20

The predicted strains vary across the mining areas depending on the local depth of cover. The lowest strains are expected to occur in Areas 4 and 5 (i.e. the southern portion of Doona Ridge), where the depths of cover to the targeted coal seam are the greatest, having values typically between 1 mm/m and 2 mm/m. The highest strains are expected to occur in Areas 1 and 2A, where the depths of cover are the shallowest, with values typically between 10 mm/m and 20 mm/m, with some isolated strains greater than 20 mm/m.

The assessments provided in this report should be read in conjunction with the assessments provided in the other specialist consultant reports for the Project. The main findings from this report are as follows:-

- The surface cracking and deformations will vary across the proposed mining areas depending on the local depths of cover. The largest surface cracking is expected to occur in Areas 1 and 2 having maximum widths typically between 50 mm and 100 mm, with isolated cracks greater than 300 mm. The smallest surface cracking is expected to occur within the SCZ in Areas 4 and 5 having widths typically less than 10 mm, with isolated cracks greater than 25 mm.

  The widths of surface cracking will generally be less than the maximum estimated widths provided above, especially outside the final tensile zones which occur inside the perimeters of the proposed longwalls. The surface cracking is also expected to represent a small percentage of the surface area, as has been found from detailed crack mapping at collieries in the NSW Coalfields.

  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 Property Subsidence Management Plans (PSMPs) which outline the agreed management strategies with each of the property owners within the proposed mining areas.

- It is expected that topographical depressions will develop in Area 1, primarily in the northern portion of the mining area (i.e. where the depths of cover are the shallowest), having depths between 1 metre and 2.5 metres. Topographical depressions are also predicted to develop where the longwalls in Areas 2A, 3 and 4 are located beneath the gently sloped areas, having depths typically between 0.5 metres and 1.5 metres. The more localised topographical depressions located on the ridges are associated with existing dams.

  The actual extents and depths of any increased ponding are expected to be less than the extents and depths of the predicted topographical depressions due to a number of other factors, including rainfall, catchment sizes, surface water runoff, permeation and evaporation. The potential impacts of increased ponding will be further assessed as part of the detailed Surface Water Assessment which will be undertaken during the Environmental Impact Statement (EIS) stage of the project.

  After the completion of the longwalls in each of the mining areas, surface remediation can be undertaken to re-establish the natural grades along the drainage lines, so as to reduce the potential for increased ponding and erosion.

- The Mooki River and Quirindi Creek are located at minimum distances of 250 metres and 500 metres, respectively, from the proposed longwalls. Werris and Yarraman Creeks are located more than 4 kilometres from the proposed longwalls.

  At these distances, the stream channels, themselves, are expected to experience negligible vertical subsidence and, therefore, are not expected to experience any adverse impacts resulting from the proposed mining. The potential impacts on the alluvium and associated aquifers are discussed in the Agricultural Impact Assessment.

- Ephemeral drainage lines occur on Nicholas Ridge and Doona Ridge and generally drain into the Mooki River and Quirindi Creek between the mining areas. Increased potential for ponding is expected to develop along these drainage lines, upstream of the chain pillars in Areas 1 and 2A and in the gently sloped areas above the other mining areas.

  After the completion of the longwalls in each of the mining areas, surface remediation can be undertaken to re-establish the natural grades along the drainage lines, so as to reduce the potential for increased ponding.

  It is also expected that surface cracking would occur in the soil beds of the drainage lines as a result of the proposed mining. Any significant surface cracks in the drainage line beds can be remediated by infilling with the surface soils or other suitable materials, or by locally regrading and recompacting the surface.

- The agricultural land utilisation within the proposed mining areas include cropping and cattle and sheep grazing. The potential impacts on these land uses 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 fences, irrigation systems 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 and remediation of the contour banks.

- The Caroona Feedlot is located above the northern ends of the proposed longwalls in Area 3. The property includes a number of large industrial sheds, silos, feeding yards, shade structures and other associated infrastructure.

  Management strategies will need to be developed for the Caroona Feedlot, which could include activities such as: the implementation of the necessary preventive or remediation measures; a detailed monitoring program; a Trigger Action Response Plan; and the temporary closure or relocation of infrastructure and services from the active subsidence area developed in conjunction with a suitable compensation agreement with the owner.

- There are built features including houses, rural building structures, farm dams, groundwater bores, local roads, electrical infrastructure, telecommunications infrastructure, diesel tanks and gas infrastructure located above the proposed mining areas. Impact assessments for these features will be undertaken during the EIS stage of the project and management strategies will be developed in consultation with the owners as part of PSMPs and Built Feature Management Plans.

With the implementation of all the necessary management strategies and remediation measures, it would be expected that the proposed mining would not result in long term impacts on the agricultural land use within the proposed mining areas. Further discussions on the potential impacts as a result of the proposed mining are provided in the Agricultural Impact Assessment as part of the Gateway Application.

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

CONTENTS

LIST OF TABLES, FIGURES AND DRAWINGS

Tables

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

Figures

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

Drawings

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

1.1. Background

Coal Mines Australia Pty Limited (CMAL), a wholly owned subsidiary of BHP Billiton, was granted Exploration Licence (EL) 6505 in 2006. EL6505 is located in the Gunnedah Basin of New South Wales (NSW), approximately 14 kilometres north-west of the township of Quirindi. BHP Billiton is proposing an underground mine, referred to as the Caroona Coal Project (the Project), which will involve longwall mining in the Hoskissons Seam.

Exploration activities, engineering studies and environmental baseline studies have been ongoing since 2006.

The proposed mining areas have been overlaid on the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA) numbered 89352N, in Fig. 1.1 below. Area 1 is located predominately beneath *Nicholas Ridge*, Areas 2A, 2B, 2S and 3 are partly located beneath *Doona Ridge* and the *Doona State Forest*, and Areas 4 and 5 are partly located beneath the southern portion of *Doona Ridge* (also known as *Perrys Mountain*).

Fig. 1.1 The Proposed Mining Areas Overlaid on CMA Map No. 89352N

BHP Billiton is applying for a Gateway Certificate pursuant to clause 17F of the *NSW State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* as the project area is located within land designated as Biophysical Strategic Agricultural Land (BSAL) under the *Strategic Regional Land Use Plan – New England North West* issued by the Department of Planning and Infrastructure (DoPI, 2012).

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 (within the meaning of the Aquifer Interference Policy),
- any fragmentation of agricultural land uses, and
- any reduction in the area of BSAL.

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

- review the currently proposed longwall mining in the Hoskissons Seam,
- prepare predicted subsidence contours resulting from the proposed longwalls,
- identify and describe the natural and built features within the mining areas, with particular focus on those relevant to the Gateway Application, including:-
  - BSAL,
  - agricultural land utilisation, including commercial and 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 mining areas, 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.

The contents of this report are as follows:-

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 mining areas, 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 mine subsidence movements for the project.

Chapter 4 provides a summary of the maximum predicted subsidence parameters resulting from the extraction of the proposed longwalls in the Hoskissons Seam.

Chapter 5 provides the predictions and impact assessments for the natural and built features within the mining areas, 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. Project Overview

The main components comprising the Project include:-

- an underground mining operation within EL 6505 involving a single longwall operating in the Hoskissons Seam on Doona Ridge and a second longwall operating in the Hoskissons Seam on Nicholas Ridge;
- production of approximately 260 million tonnes (Mt) of run-of-mine (ROM) coal over the life of the mine;
- production of up to approximately 10 Mtpa (million tonnes per annum) of saleable thermal coal;
- a mine life of approximately 30 years;
- development and operation of a pit top mine infrastructure area comprising administration offices, bathhouse, workshop, store, coal stockpile areas, coal handling infrastructure, bunded hydrocarbon tanks, laydown areas, car parking, electrical substation, muster area, associated linear infrastructure and access road on Doona Ridge;

- construction of mine access drifts;
- development and operation of a separate men and materials shaft on Doona Ridge;
- construction and operation of an event coal preparation plant (CPP) (up to 1 Mtpa ROM coal capacity) on Doona Ridge for washing of occasional high-ash ROM coal;
- construction and operation of a coal unloading facility on Doona Ridge to allow transportation of Nicholas Ridge ROM coal to Doona Ridge via rail for washing;
- co-disposal of fine and coarse rejects in an emplacement on Doona Ridge, with rejects to be transported within an infrastructure corridor;
- development and operation of a separate pit top mine infrastructure area comprising coal handling infrastructure, coal stockpiles, an access road, car parking, administration offices, muster area, electrical substation and associated linear infrastructure on Nicholas Ridge;
- realignment of Rossmar Park Road;
- construction and operation of separate rail loops and spurs to connect to the Binnaway-Werris Creek Railway from Doona Ridge and Nicholas Ridge;
- employment of up to approximately 400 operational personnel at peak production;
- employment of an average number of construction employees of approximately 400 and up to 600 at peak construction;
- emplacement of overburden excavated during the construction of access drifts and shafts;
- progressive development of sumps, pumps, pipelines, water storages and other water management equipment and structures (including dewatering infrastructure);
- development and operation of ventilation surface infrastructure and gas drainage infrastructure;
- development and operation of water and gas pipelines to connect the Nicholas Ridge infrastructure area to the Doona Ridge infrastructure area;
- ongoing exploration activities within EL 6505;
- ongoing surface monitoring and rehabilitation (including mine-related infrastructure areas that are no longer required) and remediation of subsidence effects; and
- other associated minor infrastructure, plant, equipment and activities.

1.3. Mining Geometry

The layouts of the proposed longwalls in the Hoskissons Seam are shown in Drawing No. MSEC635-01. A summary of the proposed longwall dimensions is provided in Table 1.1.

Table 1.1 Geometry of the Proposed Longwalls

Area	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
Area 1	1,080 ~ 3,350	410 (3 total) 305 (3 total) 265 (2 total)	40
Area 2A	1,060 ~ 4,450	410 (10 total) 320 (1 total)	30
Area 2B	1,420 ~ 3,780	210 (15 total)	30
Area 2S	1,740 ~ 2,190	410 (2 total)	30
Area 3	1,330 ~ 2,880	410 (4 total) 400 (1 total) 210 (4 total)	40
Area 4	1,280 ~ 5,680	410 (6 total) 210 (7 total)	40
Area 5	860 ~ 3,860	410 (3 total) 210 (7 total)	40

The preliminary subsidence assessment includes the adoption of subsidence control measures in both the northern and south-western portions of the Doona Ridge mine plan. In these areas, the extraction height will be decreased and/or the panel width reduced to achieve the same level of subsidence control obtained elsewhere across the mine plan. These Subsidence Control Zones (SCZs) have been included in the subsidence assessment and will be further reviewed and revised and documented in the EIS. The locations of the SCZs are shown in Drawing No. MSEC635-01.

1.4. Surface and Seam Information

The surface level contours within the mining areas are shown in Drawing No. MSEC635-02. The main topographical features within the mining areas are *Nicholas Ridge* in Area 1, *Doona Ridge* in Areas 2 and 3, *Doona Ridge (south)* (also known as *Perrys Mountain*) in Areas 4 and 5, and *Georges Island* to the west of the mining areas. The longwalls are proposed to be extracted beneath *Nicholas Ridge* and *Doona Ridge*.

The topographical highs are 485 metres Australian Height Datum (mAHD) in Area 5 (i.e. *Perrys Mountain*), 420 mAHD in Area 2 (i.e. *Doona Ridge*), and 415 mAHD in Area 1 (i.e. *Nicholas Ridge*). The topographical low in the area is the Mooki River, which is located between *Doona Ridge* and *Nicholas Ridge*, at around 290 mAHD.

The seam floor contours, seam thickness contours and depth of cover contours for the Hoskissons Seam are provided in Drawing Nos. MSEC635-03, MSEC635-04 and MSEC635-05, respectively. A summary of the seam information within the extents of the proposed mining areas is provided in Table 1.2.

Table 1.2 Seam Information within the Extents of the Proposed Mining Areas

Area	Depth of Cover (m)	Seam Thickness (m)	Extraction Height (m)
Area 1	130 ~ 360 (*250 average*)	10 ~ 16	4.8
Area 2A	180 ~ 355 (*260 average*)	8 ~ 14	4.8
Area 2B	135 ~ 275 (*200 average*)	12 ~ 13	2.5
Area 2S	330 ~ 385 (*370 average*)	9 ~ 15	4.8
Area 3	340 ~ 420 (*400 average*)	9 ~ 15	4.8 typically 2.5 in the SCZ
Area 4	395 ~ 710 (*520 average*)	10 ~ 13	
Area 5	475 ~ 620 (*570 average*)	11 ~ 12	

The proposed mining height is typically 4.8 metres with the coal extracted in the basal section of the seam. The mining height is reduced to 2.5 metres within the *Subsidence Control Zones* (SCZ) which are indicated in Drawing Nos. MSEC635-01 and MSEC635-04. These SCZ have been introduced to reduce the subsidence effects in specific areas of the Project.

The surface and seam levels are also illustrated along Cross-sections 1, 2A, 2B, 3, 4 and 5 in Fig. 1.2 to Fig. 1.7. The locations of these cross-sections are shown in Drawings Nos. MSEC635-02 to MSEC635-04. The Hoskissons Seam generally dips from the north-east towards the south-west, with the gradients typically ranging between 3 % to 5 % within the proposed mining areas.

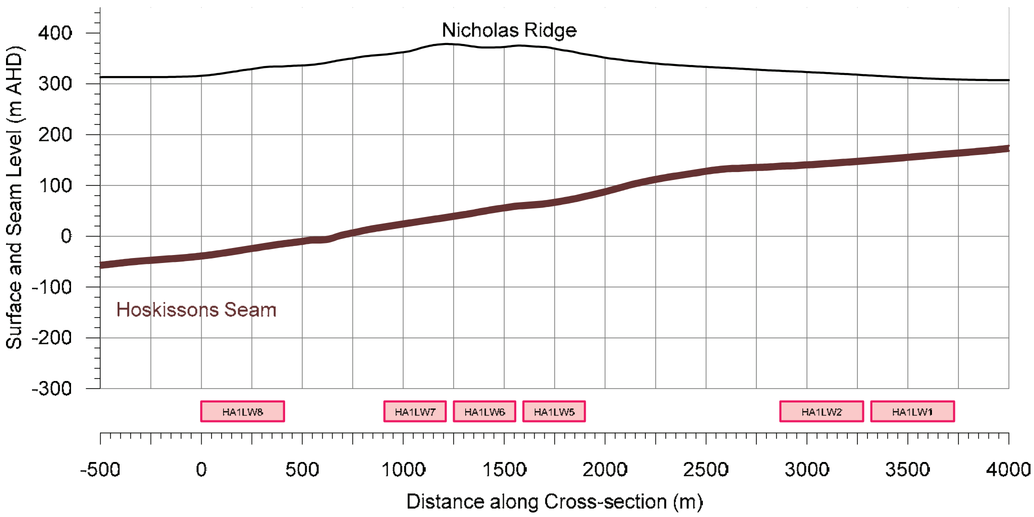


Fig. 1.2 **Seam Information along Cross-section 1 (i.e. Area 1)**

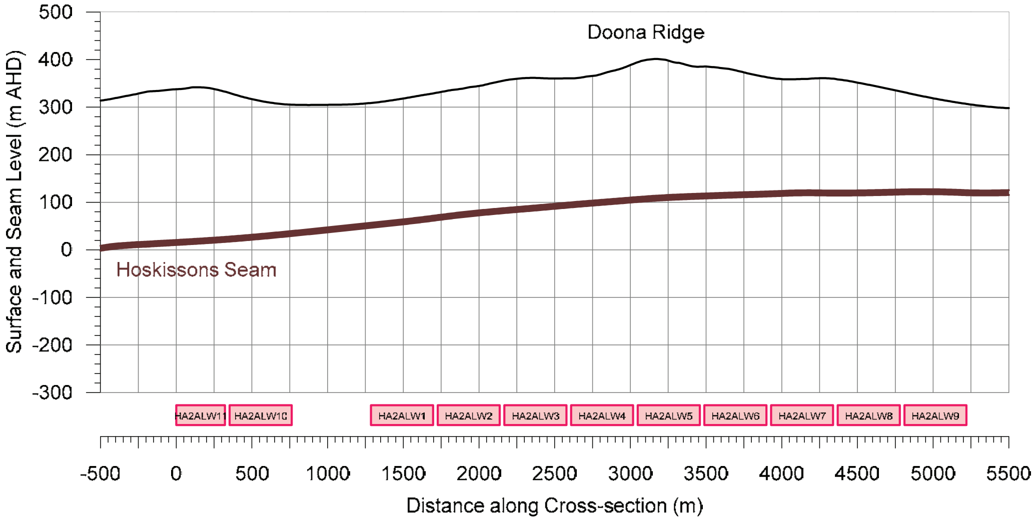


Fig. 1.3 **Seam Information along Cross-section 2A (i.e. Area 2A)**

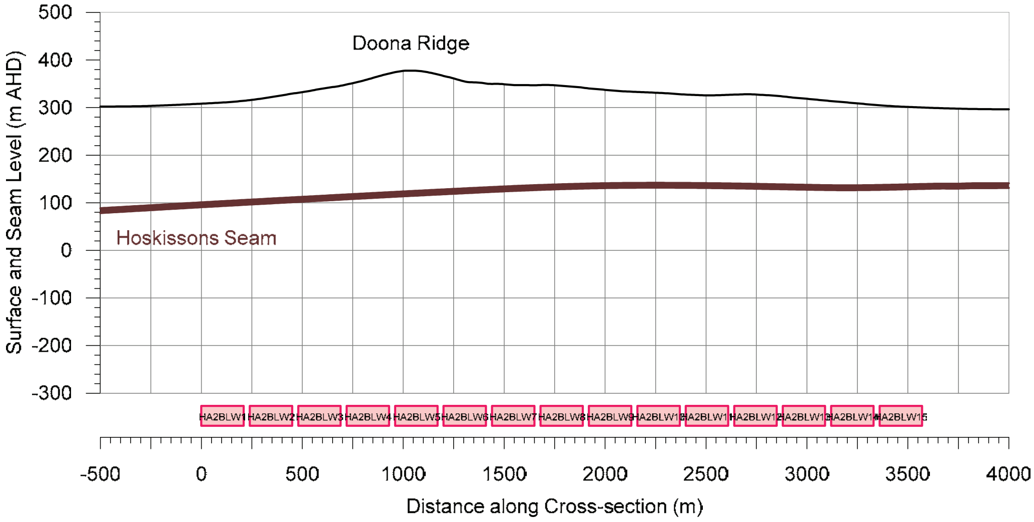


Fig. 1.4 **Seam Information along Cross-section 2B (i.e. Area 2B)**

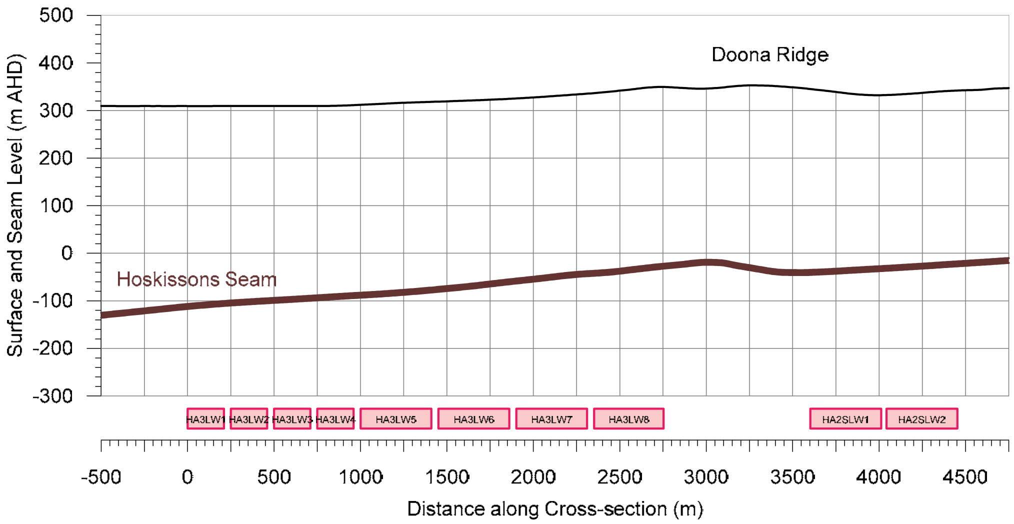


Fig. 1.5 Seam Information along Cross-section 3 (i.e. Areas 2A, 2S and 3)

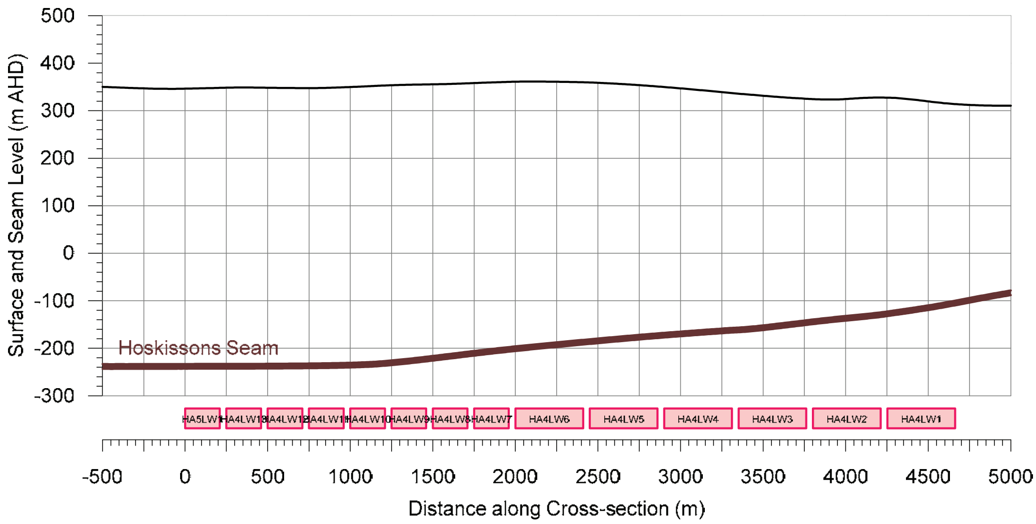


Fig. 1.6 Seam Information along Cross-section 4 (i.e. Area 4 and Part Area 5)

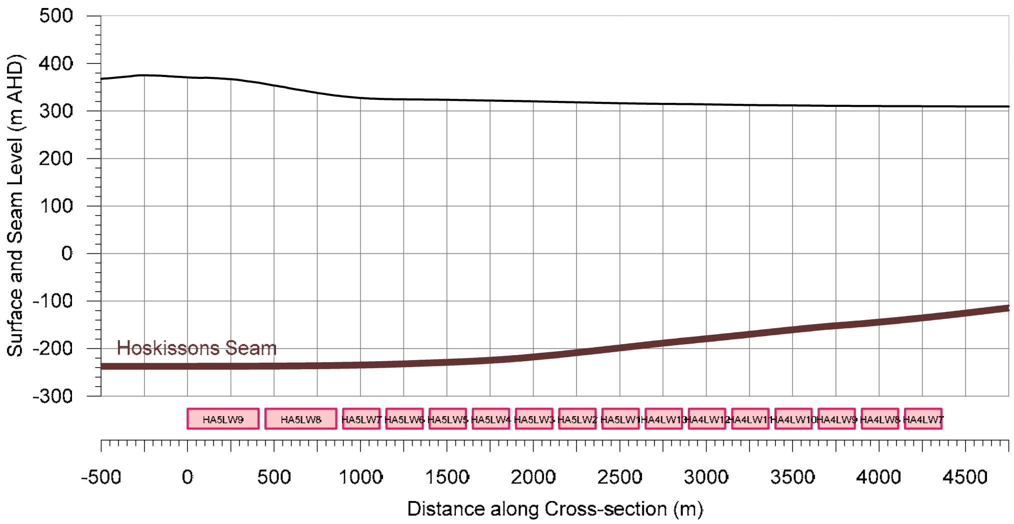
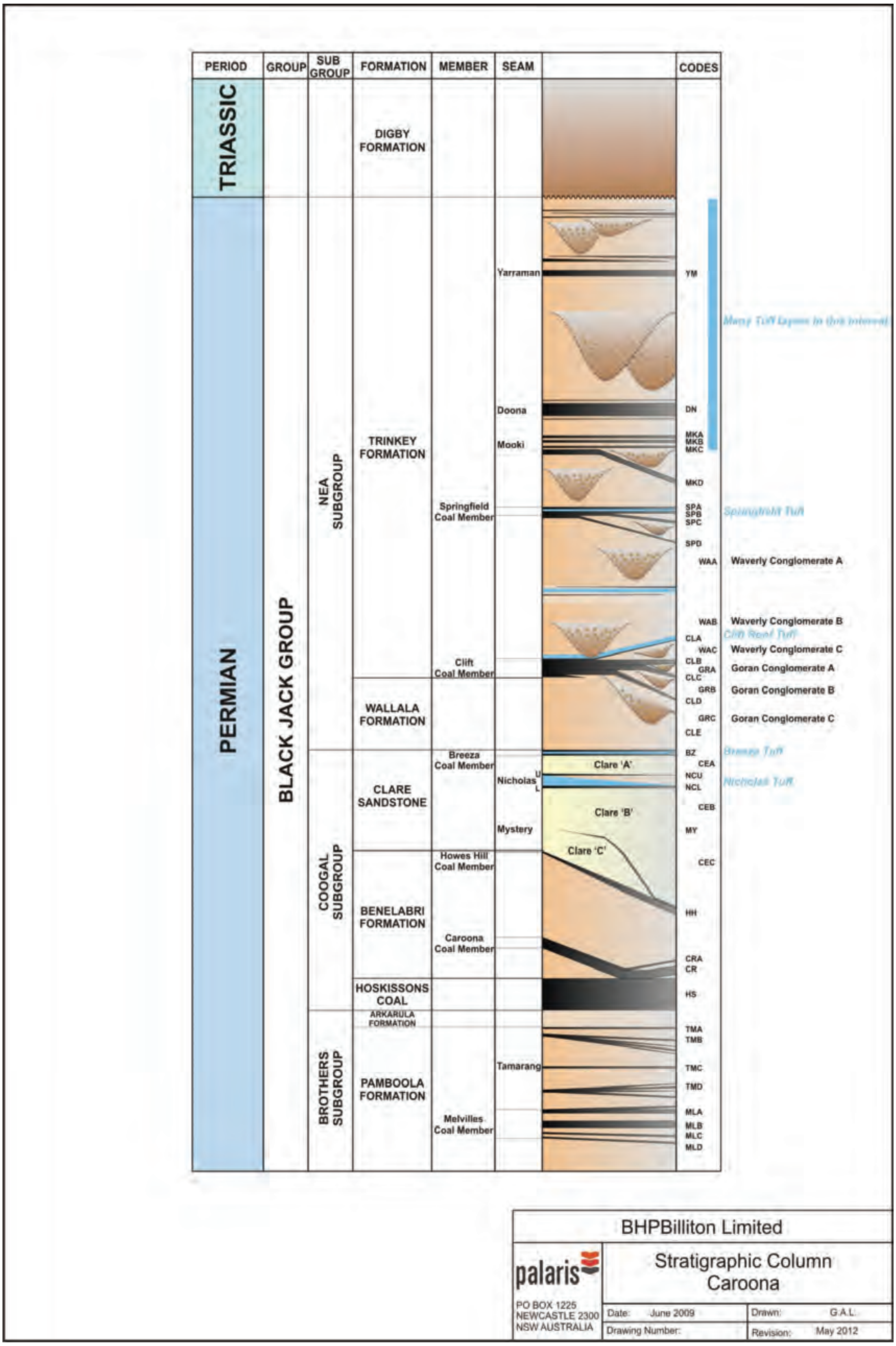


Fig. 1.7 Seam Information along Cross-section 5 (i.e. Part Area 4 and Area 5)

1.5. Geological Details

The Project lies in the southern part of the Gunnedah Basin. A stratigraphic section for the Project is shown in Fig. 1.8 (after Palaris). The Hoskissons Seam and the overlying formations were laid down during the Permian Period and the topmost formation was laid down during the Triassic Period.



Source: Palaris

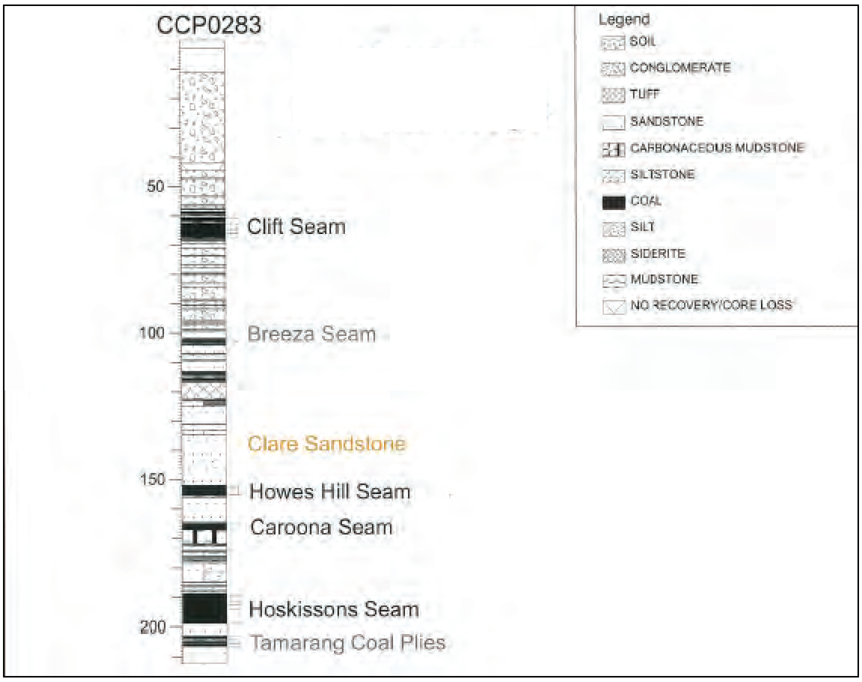
Fig. 1.8 Stratigraphic Section for the Caroona Coal Project

The formations expressed at the surface within the mining areas include Quaternary Alluvial Deposits (Qx) in the western part of the project, Jurasic Formations Pilliga Sandstone (JPS), Purlawaugh (Jpx) and Garrawilla Volcanics (Jgv) in the southern part of the project, Middle Triassic Napperby Formation (Rns), and Early Triassic Digby Formation (Rdc). The Digby Formation overlies the Late Permean Black Jack Group. The Hoskissons Seam is located within the Coogal Sub Group and is the target seam for the Caroona Coal Project.

The lithology of the overlying formations include basalt within the Garrawilla Volcanics and claystone, siltstone, sandstone, tuff, conglomerate and coal seams within the other formations. There are a number of minor coal seams in the overburden to the Hoskissons Seam, including the Caroona, Howes Hill, Breeza, Clift, Springfields and Mooki Seams.

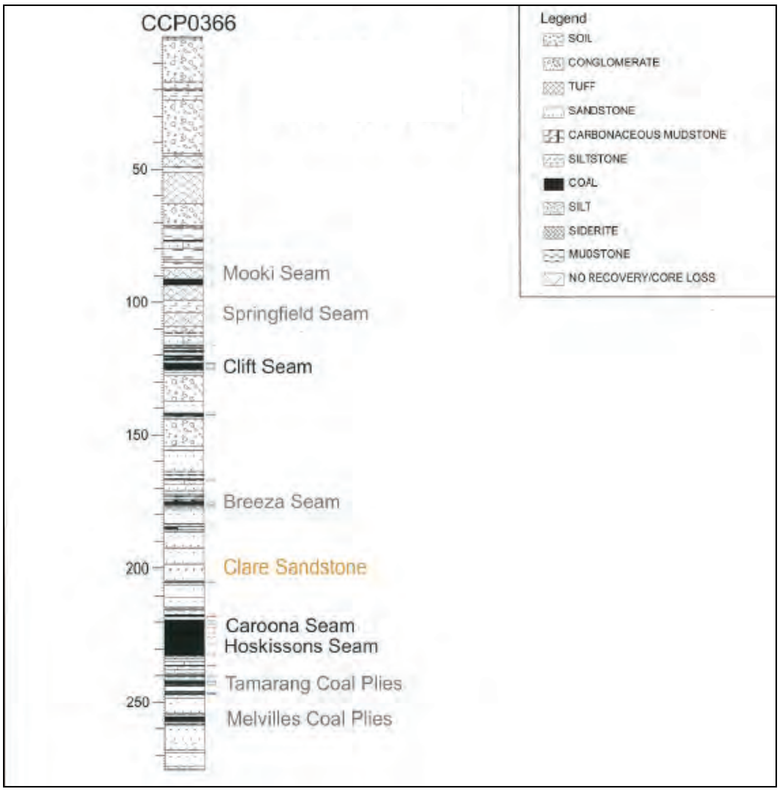
Graphical logs for Boreholes CCP0283 (Nicholas Ridge), CCP0366 (Doona Ridge) and CCP0169 (Perrys Mountain) are provided in Fig. 1.9, Fig. 1.10 and Fig. 1.11, respectively. The graphical logs indicate that the significant formations overlying the Hoskissons Seam include the Digby Formation Conglomerate and the Clare Sandstone.

The larger formations could potentially reduce the magnitude of subsidence. At this stage, no subsidence reduction factors have been used in the prediction model for any massive strata units. As further geological data is gathered, during the course of the Project, consideration will be given to the application of subsidence reduction factors based on the available information.



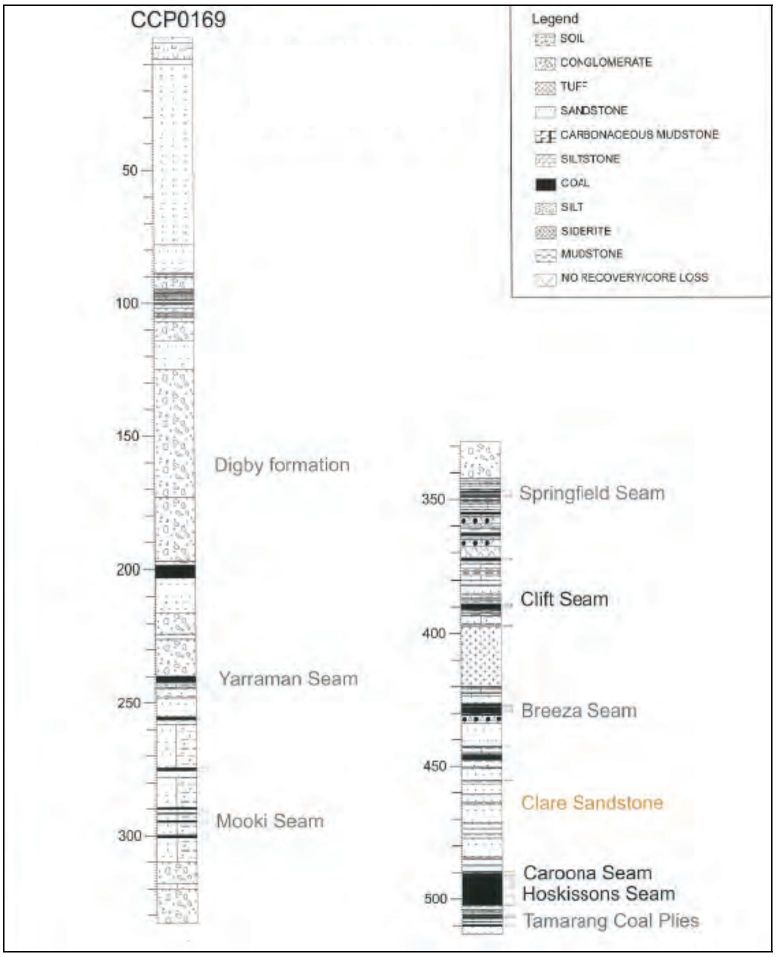
Source: Palaris

Fig. 1.9 Graphical Log of Borehole CCP0283 (Nicholas Ridge)



Source: Palaris

Fig. 1.10 Graphical Log of Borehole CCP0366 (Doona Ridge)



Source: Palaris

Fig. 1.11 Graphical Log of Borehole CCP0169 (Perrys Mountain)

2.1. Introduction

The major natural and built features within the proposed mining areas can be seen in the 1:25,000 Topographic Map of the area, which was provided in Fig. 1.1. The proposed longwalls have also been overlaid on the aerial photograph of the area in Fig. 2.1 below.

Fig. 2.1 The Proposed Longwalls Overlaid on the Aerial Photograph

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

2.2. Biophysical Strategic Agricultural Land

The BSAL within the proposed mining areas is shown in Drawing No. MSEC635-06, which is based on the mapping undertaken by McKenzie Soil Management (2014). The strategic agricultural land comprises the following:-

- *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*" (DoPI, 2012).

  BSAL has been verified by McKenzie Soil Management (2014) mainly above the proposed longwalls in Areas 4 and 5. The area of verified BSAL that would be subsided by the Project is 2,103 hectares.

There are no Critical Industry Clusters identified above or in the vicinity of the proposed longwalls.

2.3. Agricultural Utilisation

The Land and Soil Capability classifications above and in the vicinity of the proposed mining areas were mapped by McKenzie Soil Management (2014) and are shown in Drawing No. MSEC635-07. It can be seen from this drawing, that there are four main Land and Soil Capability types which are:-

- Class 2 – Very high capability land with slight limitations and is capable of most land uses and land management practices, including intensive cropping with cultivation.
- Class 3 – High capability land with moderate limitations and is capable of sustaining high-impact land uses, such as cropping with cultivation.
- Class 4 – Moderate capability land with moderate to high limitations for high-impact land uses.
- Class 5 – Moderate to low capability land with high limitations for high-impact land uses

The proposed longwalls in Area 2A, 2B, 2S and 3 are partially located beneath the *Doona State Forest*, which comprises remnant native woodland. Much of the remaining land elsewhere above the proposed longwalls has been cleared and is used for agricultural and rural residential purposes. The agricultural utilisation above and in the vicinity of the proposed longwalls includes:-

- Existing cropping areas located primarily above the proposed longwalls in Areas 4 and 5, with smaller cropping areas located above the proposed longwalls in other mining areas – refer to Section 5.7.1
- The Caroona Feedlot – refer to Section 5.7.2, and
- Cattle and sheep grazing – refer to Section 5.7.3.

2.4. Natural Features

The locations of the natural features located above and in the vicinity of the proposed mining areas are shown in Drawing No. MSEC635-08. The natural features which are relevant to the agricultural land and utilisation include:-

- The Doona State Forest – refer to Section 5.7,
- The Mooki River and Quirindi Creek – refer to Section 5.4,
- Ephemeral drainage lines – refer to Section 5.5, and
- Other groundwater resources – refer to Section 5.6.

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

2.5. Built Features

The locations of the built features located above and in the vicinity of the proposed mining areas are shown in Drawing No. MSEC635-09. The built features which are relevant to the agricultural land and utilisation within the mining areas include:-

- Houses, rural building structures, silos and other farm structures,
- Farm dams, contour banks, groundwater bores and irrigation infrastructure,
- The commercial structures and infrastructure (including a low pressure gas pipeline) associated with the Caroona Feedlot,
- The Binnaway-Werris Creek Railway,
- The local roads,
- 66 kilovolt (kV), 11 kV and low voltage powerlines,
- Copper and optical fibre cable telecommunications infrastructure, and
- The Central Ranges natural gas pipeline.

The abovementioned features are discussed in Sections 5.6 to 5.8.

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 parameters and the methods that have been used to predict these movements.

3.2. Overview of Conventional Subsidence Parameters

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

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small 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 two-dimensional or three-dimensional 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 longwall. The **total** subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of a series of longwalls. The **travelling** tilts, curvatures and strains are the transient movements as the longwall extraction face mines directly beneath a given point.

3.3. Far-field Movements

The measured horizontal movements at survey marks which are located beyond the mined area 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 Movements

Conventional subsidence profiles are typically smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata spanning the extracted void. 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 metres, 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 can develop above extracted longwalls, more often at shallower depths of cover or multi-seam conditions, but can also occur at higher depths of cover and single-seam 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 Movements due to Changes in Geological Conditions

It is believed that most non-conventional ground movements are a result of the reaction of near surface strata to increased horizontal compressive stresses due to mining operations. Some of the geological conditions that are believed to influence these irregular subsidence movements are the blocky nature of near surface sedimentary strata layers and the possible presence of unknown faults, dykes or other geological structures, cross bedded strata, thin and brittle near surface strata layers and pre-existing natural joints. The presence of these geological features near the surface can result in a bump in an otherwise smooth subsidence profile and these bumps are usually accompanied by locally increased tilts and strains.

Even though it may be possible to attribute a reason behind most observed non-conventional ground movements, there remain some observed irregular ground movements that still cannot be explained with the available geological information. The term "*anomaly*" is therefore reserved for those non-conventional ground movement cases that were not expected to occur and cannot be explained by any of the above possible causes.

It is not possible to predict the locations and magnitudes of non-conventional anomalous movements. In some cases, approximate predictions for the non-conventional ground movements can be made where the underlying geological or topographic conditions are known in advance. It is expected that these methods will improve as further knowledge is gained through ongoing research and investigation.

In this report, non-conventional ground movements 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 Movements

Localised ground movements are often observed along incised streams located above or in the vicinity of longwalls in the Southern Coalfield, which are referred to as valley related movements. These movements are often small when compared with the conventional movements for shallow streams in other coalfields where the depths of cover are shallower.

The streams located above and in the vicinity of the proposed longwalls at the Project have shallow incisions into the natural surface soils. The valley related movements resulting from the extraction of the proposed longwalls are expected to be negligible.

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 of NSW and the Bowen Basin in Queensland.

Extensive ground monitoring data has been gathered and incorporated into the empirical database including from: 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, Narrabri North, 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.

Reviews of the detailed ground monitoring data show that whilst the final subsidence profiles measured over a series of longwalls are irregular, the observed incremental subsidence profiles due to the extraction of individual longwalls are 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.

Based on the extensive empirical data, MSEC has developed standard subsidence prediction curves for the Southern, Newcastle, Hunter and Western Coalfields. The predictions curves can then be further refined, for the local geology and local conditions, based on the available monitoring data from the area. Discussions on the calibration of the IPM for local conditions in the Gunnedah Coalfield 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 northern coalfields, the maximum predicted incremental subsidence is initially determined, using the IPM subsidence prediction curves for a single isolated longwall, 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 longwalls, based on the longwall position in the series, longwall width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H). In this way, the influence of the longwall void width (W), depth of cover (H), as well as longwall 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 NSW Coalfields. The profile shapes are derived from the normalised subsidence profiles for monitoring lines where the mining geometry and overburden geology are similar to those of 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 conditions in the Gunnedah Coalfield.

3.6. Calibration of the Incremental Profile Method

There is limited ground monitoring data available for longwall mining in the Gunnedah Coalfield. At the time of this report, the only data available was from the extraction of Longwall 101 in the Hoskissons Seam at the Narrabri Coal Mine. For this reason, the predicted mine subsidence movements for the proposed longwalls at Caroona have been obtained using the IPM based on the standard model for the Hunter Coalfield. This model has been used to predict the subsidence for previously extracted longwalls in the Upper Hunter Coalfield as well as the Bowen Basin in Queensland and, in most cases, has been found to provide reliable predictions of subsidence, tilt and curvature.

The standard IPM has been reviewed using the available ground monitoring data from Longwall 101 at the Narrabri Coal Mine, which includes Line-A, Line-B and Line 101. Longwall 101 had a void width of 305 metres and was extracted within the Hoskissons Seam at a depth of cover ranging between approximately 160 metres and 190 metres. The extraction height was 4.2 metres.

The comparisons between the observed and predicted subsidence, tilt and curvature along Line-A due to the extraction of Longwall 101 are illustrated in Fig. 3.1. Similar reviews of observed versus predicted movements were also undertaken for Line-B and Line 101.

Based on these comparisons, it would appear that the IPM based on the standard profiles for the Hunter Coalfield provides reasonable predictions of subsidence, tilt and curvature for the available ground monitoring lines at the Narrabri Coal Mine.

The standard IPM has been used to predict the mine subsidence movements at a number of collieries in the Hunter Coalfield, including United, Wambo, South Bulga, Beltana, Blakefield South and Glennies Creek. Comparisons between the observed and predicted movements indicate that the standard prediction model provides reasonable, if not slightly conservative, predictions of the mine subsidence parameters.

The comparisons between the observed and predicted profiles of subsidence, tilt and curvature for monitoring lines in the Hunter and Newcastle Coalfields, where the panel 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.

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

The magnitudes of the maximum observed subsidence along the 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 subsidence of 65 % of extracted seam thickness, whereas the maximum observed subsidence was around 45 % of the extracted seam thickness.

The magnitudes of the observed tilts and curvatures along the monitoring lines were also reasonably similar to those predicted using the standard IPM. It can be seen, however, that the observed tilts and curvatures were less than those predicted, in some locations, whilst the observed tilts and curvatures exceeded those predicted in other locations. This demonstrates the 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 observed and predicted movements at a point, as the depth of cover decreases.

Based on these comparisons, it would appear that the standard IPM provides reasonable predictions of subsidence, tilt and curvature in these cases, where the panel 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 Hoskissons Seam.

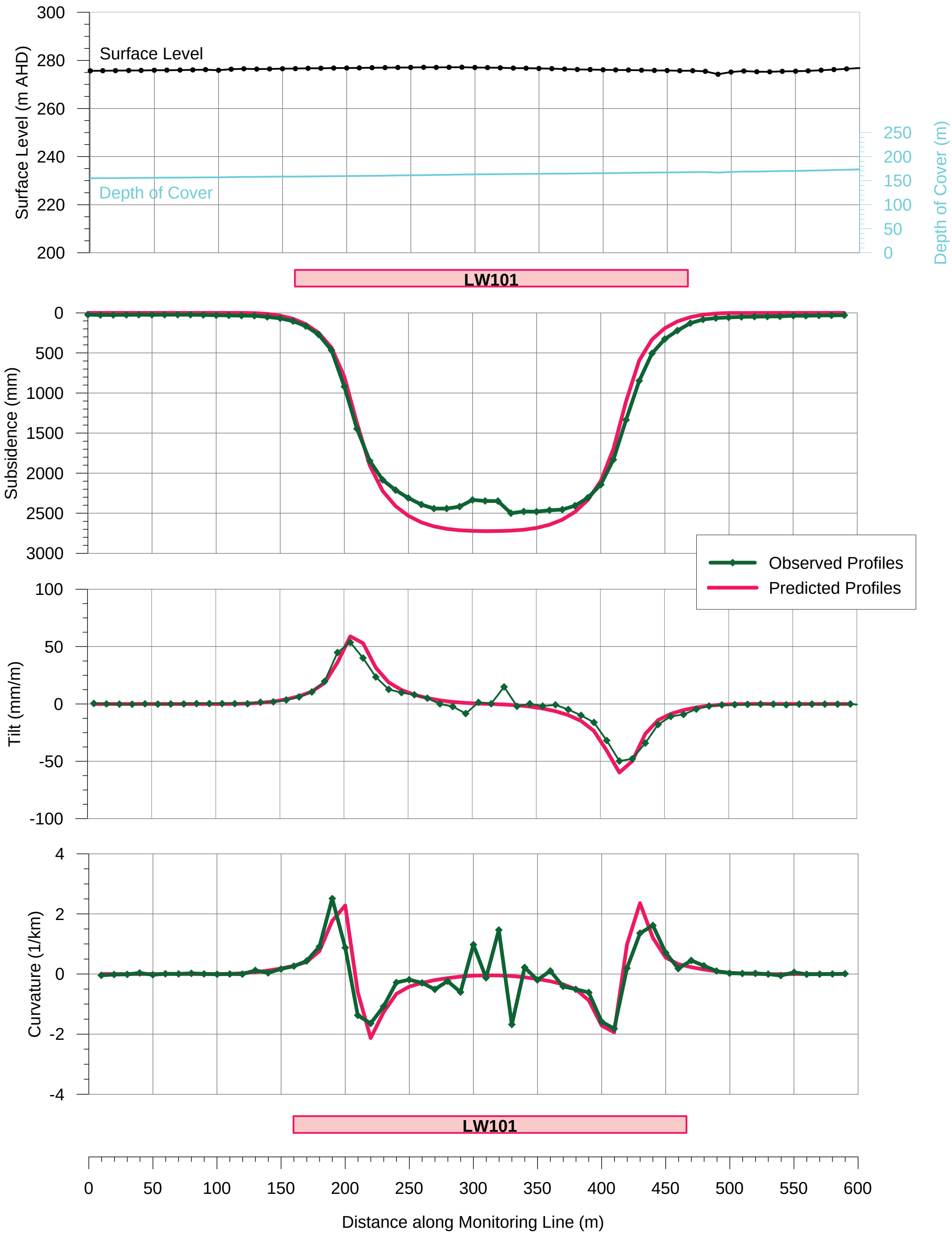


Fig. 3.1 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along Line-A above LW101 at Narrabri North

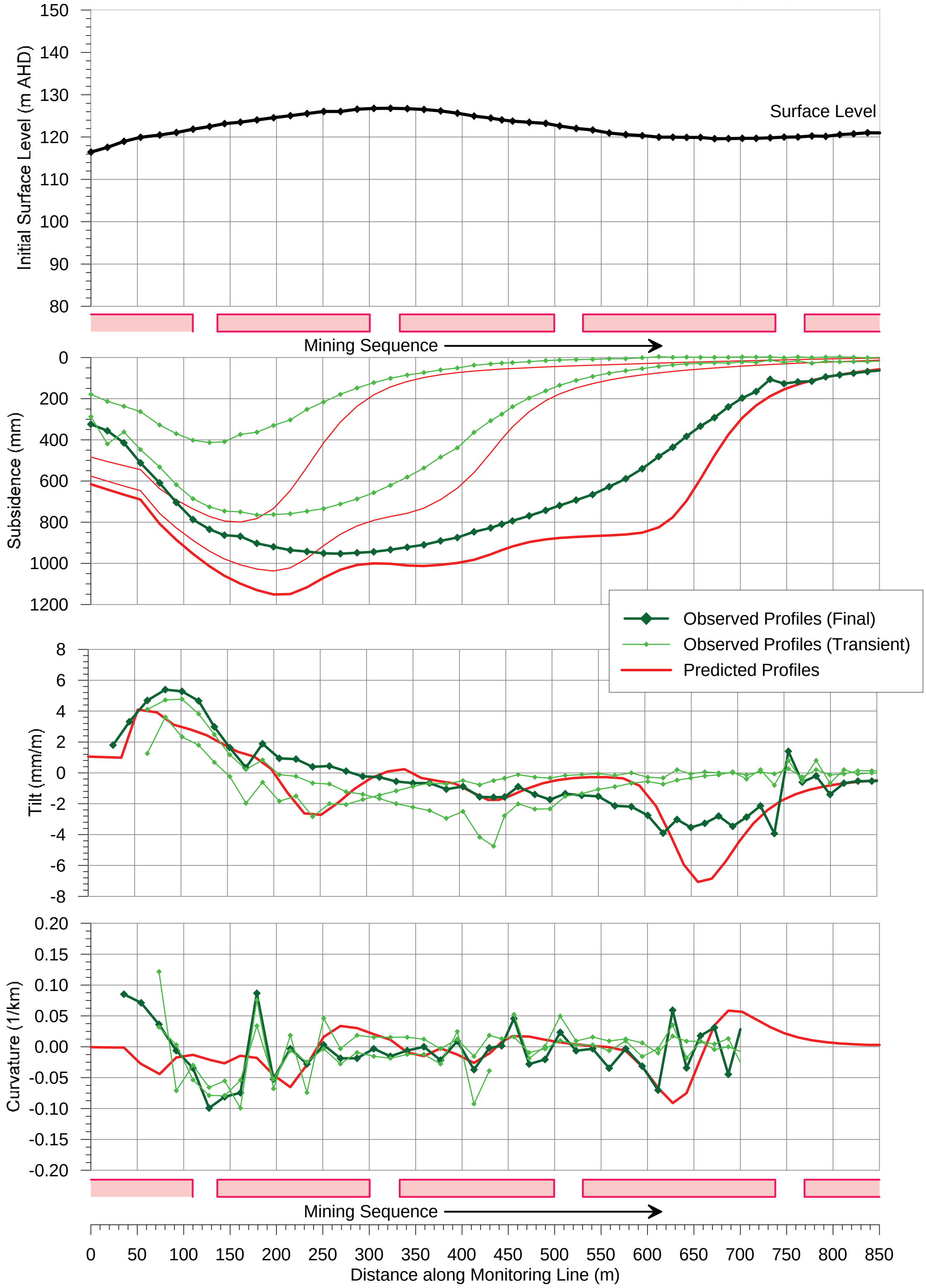


Fig. 3.2 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Newcastle Coalfield with Panel W/H Ratio around 0.4

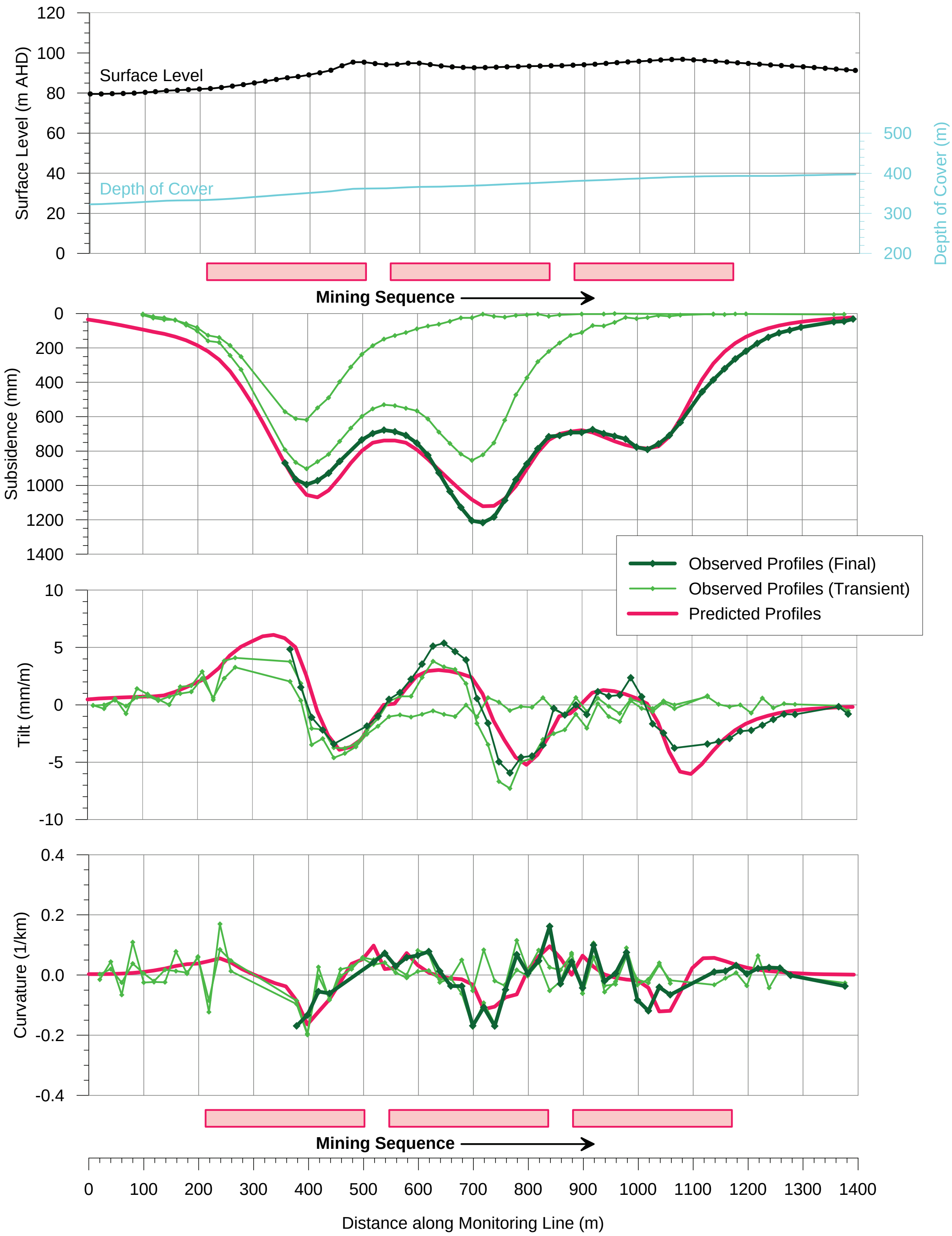


Fig. 3.3 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with Panel W/H Ratio around 0.7

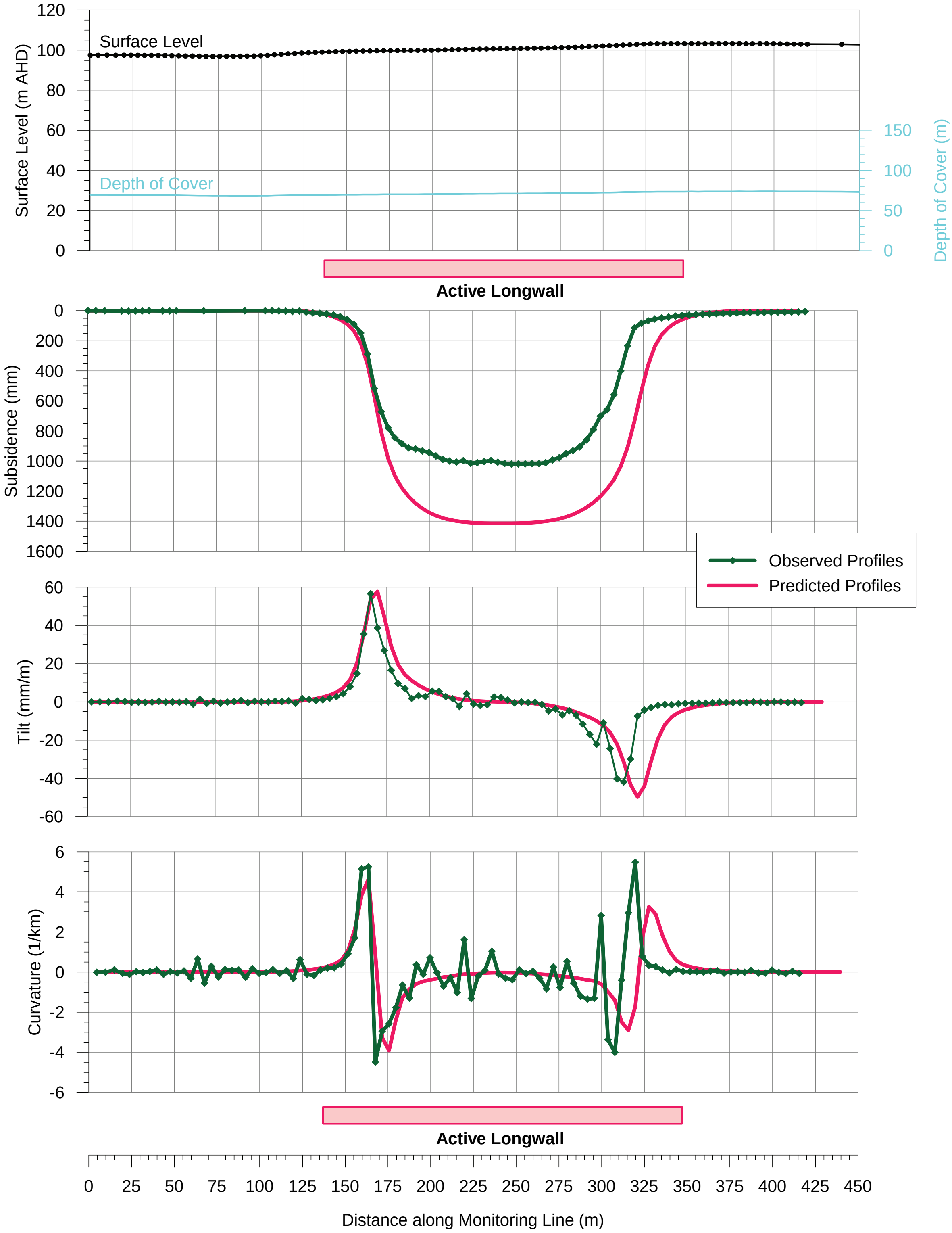


Fig. 3.4 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with Panel W/H Ratio Greater than 2.0

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 and generally slightly conservative predictions of maximum subsidence, tilt and curvature. The predicted profiles obtained using this method also reflect the way in which each parameter varies over the mined area and indicate the movements that are likely to occur at any point on the surface.

The 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. 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 longwalls in the Hoskissons Seam. The predicted subsidence parameters and the impact assessments for the natural and built features within the mining areas are provided in Chapter 5.

The predicted subsidence, tilts and curvatures have been obtained using the IPM which is described in Section 3.6. The predicted strains have been determined by analysing the strains measured at other NSW Collieries, where the width-to-depth ratios and extraction heights 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 irregular ground movements, nor the effects of faults and other geological structures. Such effects have been addressed separately in the impact assessments for each feature, which are provided in Chapter 5, and will be considered further in the Environmental Impact Statement (EIS) stage of the Project.

4.2. Maximum Predicted Subsidence, Tilt and Curvature

The predicted total subsidence contours resulting from the extraction of the proposed longwalls are shown in Drawing No. MSEC635-10. A summary of the maximum predicted total conventional subsidence parameters for each of the mining areas is provided in Table 4.1. The predicted tilts are the maxima after the completion of all longwalls within each of the mining areas. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls within each of the mining areas.

Table 4.1 Maximum Predicted Total Conventional Subsidence Parameters

Location	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Area 1	3,100	70	3.0	3.0
Area 2A	3,100	65	2.5	2.5
Area 2B	1,600	40	1.5	1.5
Area 2S	3,000	30	0.50	0.50
Area 3	2,900	25	0.40	0.45
Area 4	2,750	20	0.25	0.35
Area 5	2,400	10	0.10	0.20

The maximum predicted total subsidence for the proposed longwalls is 3,100 mm within Areas 1 and 2A, which represents 65 % of the proposed mining height of 4.8 metres. The maximum predicted total subsidence within the SCZ is 1,600 mm within Area 2B, which represents 65 % of the proposed mining height of 2.5 metres.

The maximum predicted total conventional tilt is 70 mm/m (i.e. 7 %), which represents a change in grade of 1 in 14. The maximum predicted total conventional curvatures are 3 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 0.3 kilometres. The maximum predicted tilt and curvatures occur in Area 1 where the depth of cover is the shallowest.

It can be seen from Drawing No. MSEC635-10, that the magnitudes of the predicted subsidence vary over the mining areas, due to the varying depths of cover and extraction 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 conventional subsidence, tilt and curvature have been determined along six prediction lines, the locations of which are shown in Drawing No. MSEC635-10. The predicted profiles of conventional subsidence, tilt and curvature along Prediction Lines 1, 2A, 2B, 3, 4 and 5 are shown in Figs. C.01 to C.06, respectively, in Appendix C.

4.3. Predicted Strains

The prediction of strain is more difficult than the predictions of subsidence, tilt and curvature. The reason for this is that strain is affected by many factors, including ground curvature and horizontal movement, as well as local variations in the near surface geology, the locations of pre-existing natural joints at bedrock, and the depth to 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.

In previous MSEC subsidence reports, predictions of conventional strain were provided based on the best estimate of the average relationship between curvature and strain. Similar relationships have been proposed by other authors. The reduced reliability of the strain predictions was highlighted in these reports, where it was stated that measured strains can vary considerably from the predicted conventional values.

Adopting a linear relationship between curvature and strain provides a reasonable prediction for the maximum conventional tensile and compressive strains for single-seam mining conditions. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and the locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones. In the Northern (i.e. Newcastle, Hunter and Gunnedah) Coalfields of NSW, 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.

Adopting a factor of 10, the maximum predicted conventional strains vary between 1.5 mm/m tensile and 2.5 mm/m compressive in Area 5, through to 30 mm/m tensile and compressive in Areas 1 and 2B. Localised and elevated strains greater than the predicted conventional strains could also occur, as a result of non-conventional movements, which was discussed in Section 3.4.

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. For this reason, the predicted strains provided in this report have been based on statistical analyses of strains measured in the NSW Coalfields to account for this variability.

The ranges of potential strains above the proposed longwalls have been determined using monitoring data from previously extracted longwalls in the Hunter and Newcastle Coalfields, where the width-to-depth ratios and extraction heights were reasonably similar to those of the proposed longwalls. The near surface lithology for these historic cases comprised interbedded sandstones and siltstones and shales, which is reasonably similar to the lithology above the proposed longwalls.

A summary of the overall void widths, depths of cover, width-to-depth ratios and extraction heights for the proposed longwalls in each of the mining areas is provided in Table 4.2.

Table 4.2 Mine Geometry for the Proposed Longwalls

Location	Overall Void Widths (m)	Depths of Cover (m)	Longwall Width-to-Depth Ratios	Extraction Heights (m)
Areas 1 and 2A	410	130 ~ 360 (250 average)	0.9 ~ 2.9 (1.5 average)	4.8
Area 2B	210	135 ~ 275 (200 average)	0.8 ~ 1.5 (1.1 average)	2.5
Area 2S and 3	410	330 ~ 420 (390 average)	0.5 ~ 1.2 (0.9 average)	4.8 typical (2.5 in SCZ)
Areas 4 and 5 (Outside the SCZ)	410	395 ~ 710 (570 average)	0.6 ~ 1.0 (0.7 average)	4.8
Areas 4 and 5 (Inside the SCZ)	210	425 ~ 570 (520 average)	0.3 ~ 0.5 (0.4 average)	2.5

It can be seen from the above table, that the width-to-depth ratios for the proposed longwalls vary between a minimum of 0.3 in Area 5 and a maximum of 2.9 in Areas 1 and 2A, with the averages for each mining area varying between a minimum of 0.4 in Area 5 and a maximum of 1.5 in Areas 1 and 2A. The proposed extraction height for these longwalls is typically 4.8 metres, reducing to 2.5 metres within the SCZ.

The proposed longwalls in Areas 1 and 2A are supercritical in width, having width-to-depth ratios typically greater than 1.4. There is limited ground monitoring data from the NSW Coalfields for supercritical longwalls having extraction heights greater than 4 metres. It is not possible, therefore, to undertake a detailed strain analysis of historic longwalls having similar mining geometry as the proposed longwalls in Areas 1 and 2A. Notwithstanding, some discussions on the expected strains for these areas are provided below based on the experience of longwall mining in the Newcastle and Hunter Coalfields.

A review of the available ground monitoring data for supercritical longwalls in the NSW Coalfields indicates that very localised and irregular strains develop, with maximum observed strains greater than 20 mm/m. It is noted, that the magnitudes of these high strains become less meaningful, as they are dependent on the positions of the survey marks relative to the strain concentrations and the spacing of the survey marks.

The strain analyses for the proposed longwalls in the remaining mining areas have adopted monitoring data from previously extracted longwalls in the Hunter and Newcastle Coalfields where the width-to-depth ratios were between 0.5 and 1.5. A total of 53 ground monitoring lines were included in the strain analysis. A summary of the void widths, depths of cover, width-to-depth ratios and extraction heights for the previously extracted longwalls is provided in Table 4.3.

Table 4.3 Mine Geometry for Previously Extracted Longwalls in the Newcastle and Hunter Coalfields used in the Strain Analysis

Location	Void Width (m)	Depth of Cover (m)	W/H Ratio	Mining Height (m)
Newcastle and Hunter Coalfields	135 ~ 225	130 ~ 420	0.5 ~ 1.5 (*1.1 average*)	3.0 ~ 4.8 (4.2 average)

The width-to-depth ratios for the proposed longwalls in Areas 2B, 2S, 3, 4 and 5 are typically within the range of the ratios for the previously extracted longwalls used in the strain analysis which varies between 0.5 and 1.5. The typical extraction height for the proposed longwalls, of 4.8 metres, is slightly greater than the average extraction height for the previously extracted longwalls used in the strain analysis, of 4.2 metres.

It is expected, therefore, that the strain analysis should provide a reasonable indication of the ranges of potential strains resulting from the extraction of the proposed longwalls outside the SCZ. The range of potential strains for the proposed longwalls within the SCZ have been determined by multiplying the results from the strain analysis by the ratio of the proposed extraction height of 2.5 metres divided by the average extraction height used in the analysis of 4.2 metres.

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 the goaf or the chain pillars that are located between the extracted longwalls. A number of probability distribution functions were fitted to the empirical data and, it was found, that a *Generalised Pareto Distribution* (GPD) provided good fits to the raw strain data.

The distributions of the maximum observed tensile and compressive strains versus the void width-to-depth ratio, for the available monitoring lines from the Newcastle and Hunter Coalfields and for single-seam mining conditions, is provided in Fig. 4.1.

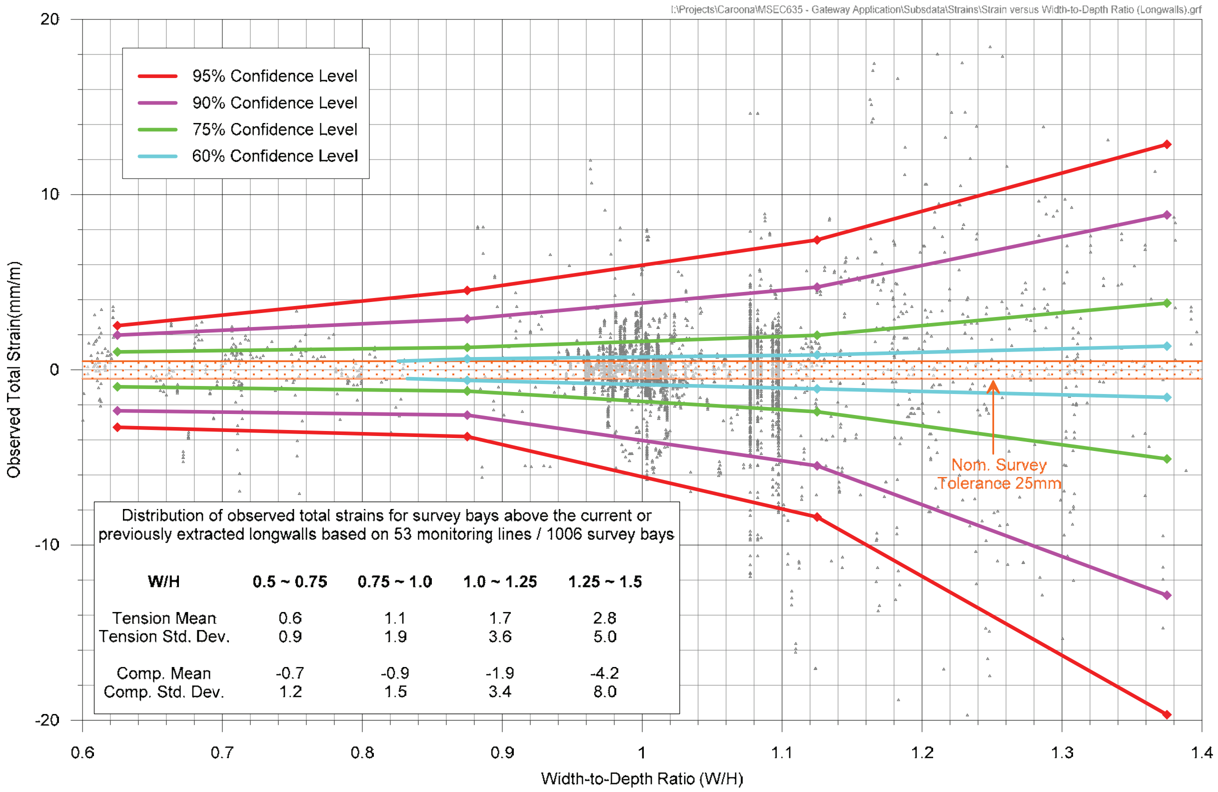


Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains during the Extraction of Previous Longwalls in the Newcastle and Hunter Coalfields

The 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 a 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).

A summary of the expected ranges of total strains for the proposed longwalls in Areas 2S, 3, 4 and 5, based on the 95 % confidence levels derived from the strain analysis, is provided in Table 4.4.

Table 4.4 Maximum Strains for the Proposed Longwalls based on the 95 % Confidence Levels

Location	Longwall Width-to-Depth Ratios	Extraction Heights (m)	Tension (mm/m)	Compression (mm/m)
Area 2B	0.8 ~ 1.5 (1.1 average)	2.5	4 ~ 14 (*7 average*)	4 ~ 20 (*8 average*)
Area 2S and 3	0.5 ~ 1.2 (0.9 average)	4.8 typical (2.5 in SCZ)	2 ~ 9 (*5 average*)	3 ~ 12 (*5 average*)
Areas 4 and 5 (Outside the SCZ)	0.6 ~ 1.0 (0.7 average)	4.8	2 ~ 6 (*3 average*)	3 ~ 6 (*4 average*)
Areas 4 and 5 (Inside the SCZ)	0.3 ~ 0.5 (0.4 average)	2.5	0.5 ~ 1.5 (*1 average*)	1.5 ~ 2.5 (*2 average*)

The strains at the lower ends of the ranges are predicted to occur where the depths of cover are the greatest in each mining area and, conversely, the strains at the higher ends of the ranges are predicted occur where the depths of cover are the shallowest.

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 and panels, 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. 4.2. The confidence levels, based on fitted GPDs, have also been shown in this figure to illustrate the spread of the data.

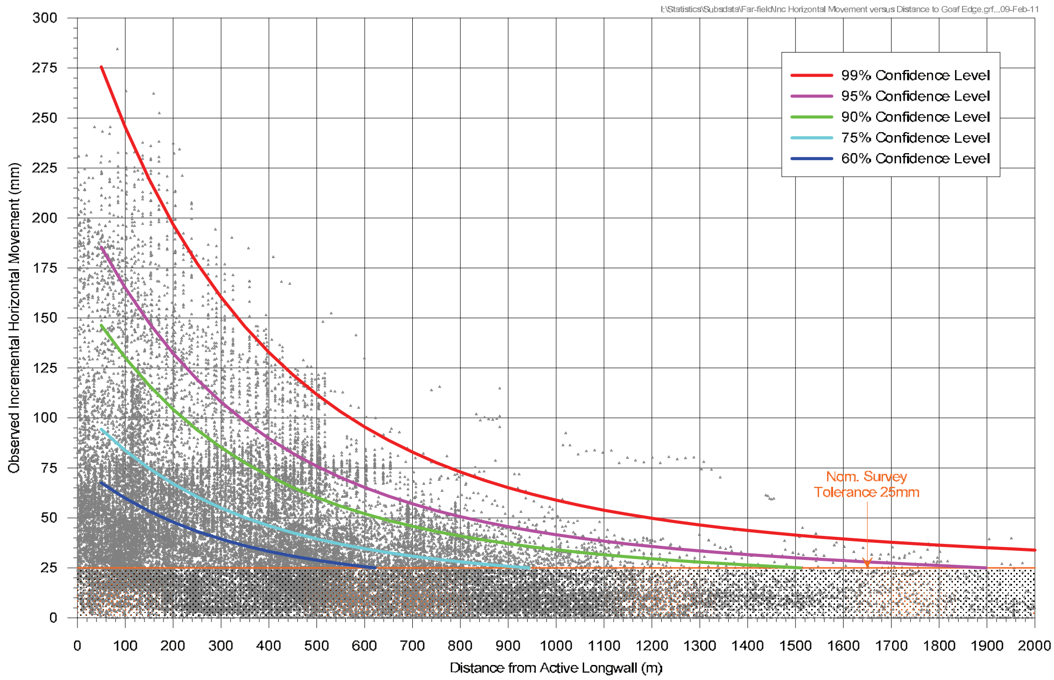


Fig. 4.2 Observed Incremental Far-Field Horizontal Movements

As successive longwalls or panels within a series 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 or panels, 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 or panels.

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 and built features within the vicinity of the proposed longwalls are expected to be negligible, as there are no large structures in the vicinity of the Project which could be sensitive to small differential movements.

5.1. Introduction

The BSAL located above and in the vicinity of the proposed mining areas is shown in Drawing No. MSEC635-06, which is based on the mapping undertaken by McKenzie Soil Management (2014). The agricultural land classification and the associated natural and built features located above of in the vicinity of the proposed mining areas are shown in Drawings Nos. MSEC635-07 to MSEC635-09, in Appendix D.

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

- Surface cracking and deformations – which is discussed in Section 5.2,
- Changes in surface water drainage – which is discussed in Section 5.3,
- Changes to surface water resources – which are discussed in Sections 5.4 and 5.5,
- Changes to the groundwater resources – which is discussed in Section 5.6,
- Impacts on the agricultural land utilisation – which is discussed in Section 5.7, and
- Impacts on the associated built features – which is discussed in Section 5.8.

The assessments provided in this report should be read in conjunction with the assessments provided in the Agricultural Impact 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, extracted seam thickness, overburden geology, locations of natural joints in the bedrock and the presence of near surface geological structures.

Fractures and joints in bedrock occur naturally during the formation of the strata and from subsequent 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 shallower depths of cover, it is also likely that transient surface cracks will occur above and parallel to the moving extraction face (i.e. arcuate fractures) as the subsidence trough develops. The larger cracks that require remediation, 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. An example of crack patterns that develop in shallow depths of cover is shown in Fig. 5.1 below.

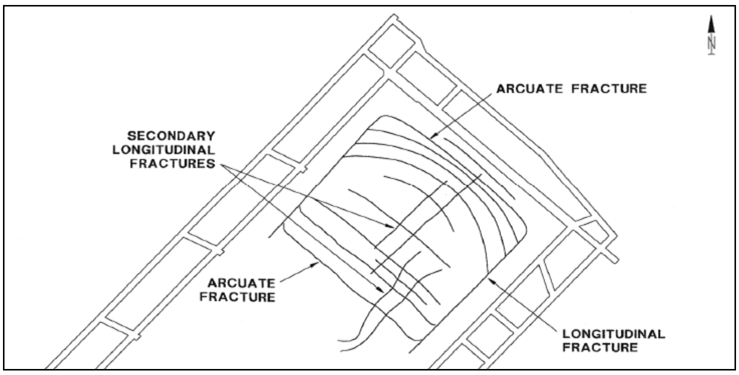


Fig. 5.1 Survey of Major Fracture Pattern at Approximately 110 metres Cover (Source: Klenowski, ACARP C5016, 2000)

Larger but isolated surface cracking and deformations could also develop along the steep slopes. The locations of the steep slopes are shown in Drawing No. MSEC635-08. The extraction of the proposed longwalls beneath the ridgelines could result in downslope movements of the surface soils, 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.

Fig. 5.2 Examples of Surface Cracking on Steep Slopes in the Hunter Coalfield

A summary of the estimated maximum crack widths within each of the mining areas is provided in Table 5.1. The estimated crack widths are based on the observations above previously extracted longwalls in the NSW Coalfields where the width-to-depth ratios and extraction heights were similar to the proposed longwalls.

Table 5.1 Estimated Maximum Surface Crack Widths within Each of the Mining Areas

Mining Area	Depths of Cover (m)	Longwall Width-to-Depth Ratios	Extraction Heights (m)	Typical Maximum Crack Widths
Areas 1 and 2A	130 ~ 360 (250 average)	0.9 ~ 2.9 (1.5 average)	4.8	Typically between 50 and 100 mm, with isolated cracks greater than 300 mm
Area 2B	135 ~ 275 (200 average)	0.8 ~ 1.5 (1.1 average)	2.5	Typically between 25 and 50 mm, with isolated cracks greater than 200 mm
Areas 2S and 3	330 ~ 420 (390 average)	0.5 ~ 1.2 (0.9 average)	4.8 typical (2.5 in SCZ)	Typically between 25 and 75 mm, with isolated cracks greater than 200 mm
Areas 4 and 5 (Outside the SCZ)	395 ~ 710 (570 average)	0.6 ~ 1.0 (0.7 average)	4.8	Typically between 10 and 25 mm, with isolated cracks greater than 100 mm.
Areas 4 and 5 (Inside the SCZ)	425 ~ 570 (520 average)	0.3 ~ 0.5 (0.4 average)	2.5	Typically less than 10 mm, with isolated cracks greater than 25 mm.

The widths of surface cracking will generally be less than the maximum estimated widths provided in the above table, especially outside the final tensile zones. The surface cracking is also expected to represent a small percentage of the surface area above the proposed longwalls, as has been found from detailed crack mapping at collieries in the NSW Coalfields.

For example, detailed crack mapping was undertaken above the commencing end of the Beltana No. 1 Underground Mine Longwall 1 (Beltana LW1). The longwall had a void width of 275 metres and was extracted in the Whybrow Seam at a depth of cover around 175 metres. The width-to-depth ratio for Beltana LW1 was around 1.6, which is similar to the proposed longwalls in Areas 1 and 2A and greater than those for the proposed longwalls in Area 2S, 3, 4 and 5.

The cracking observed above Beltana LW1 should, therefore, provide a reasonable indication of the extent of cracking in the gently sloped terrain (i.e. on the margins of the ridgelines) in Areas 1 and 2. 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 was a total of 72 cracks recorded having a total length of 494 metres and a total area of 17.7 square metres (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 metres below the surface. The wider cracks were found to extend more than 1 metre below the surface. In all cases, the crack widths reduced as the depth below the surface increased.

The surface cracking and deformation could also 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 steep 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,
- Refinement of the existing SCZ, and
- Develop Property Subsidence Management Plans (PSMPs) incorporating the agreed methods to manage surface cracking and deformations with each of the property owners.

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)

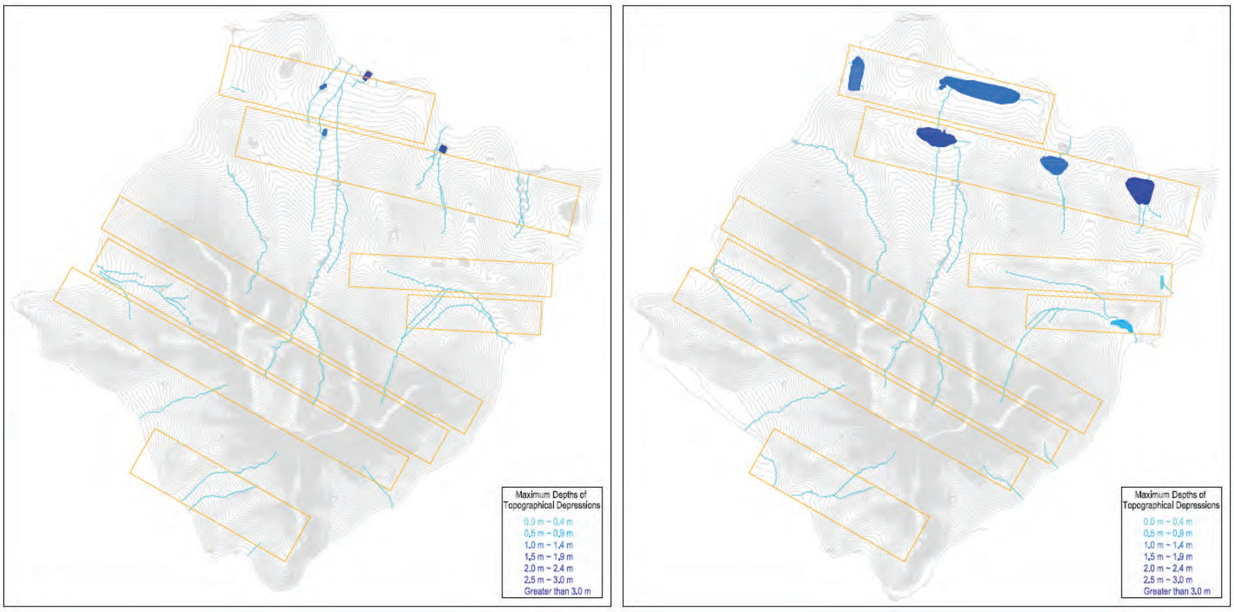
Further discussions are provided in the impact assessments in the following sections of this report and will also be included in the EIS.

5.3. Predicted Changes in Surface Water Drainage

The main topographical features within the mining areas are *Nicholas Ridge* in Area 1, *Doona Ridge* in Areas 2 and 3, *Doona Ridge (south)* (also known as *Perrys Mountain*) in Areas 4 and 5, and *Georges Island* to the west of the proposed mining areas. The topographical highs are 485 mAHD in Area 5 (i.e. *Perrys Mountain*), 420 mAHD in Area 2 (i.e. *Doona Ridge*), and 415 mAHD in Area 1 (i.e. *Nicholas Ridge*). The topographical low in the area is the Mooki River, which is located between *Doona Ridge* and *Nicholas Ridge*, at around 290 mAHD

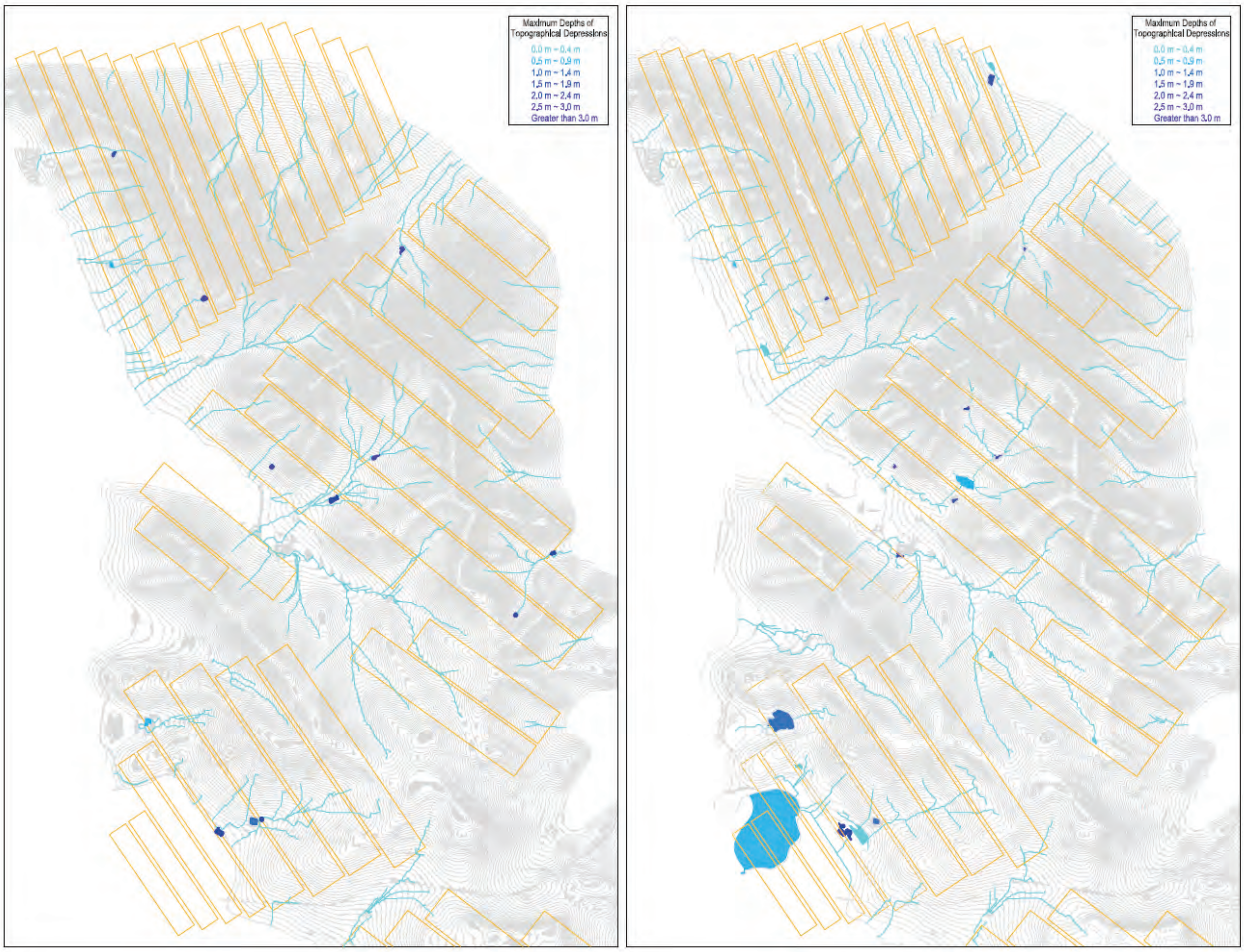
The drainage lines and the natural gradients within the mining areas are illustrated in Drawing No. MSEC635-08. It can be seen from this drawing, that the natural grades are typically between 5 % and 10 % on the lower parts of Nicholas Ridge, Doona Ridge and Perrys Mountain, increasing above 10 % on the upper reaches of these features. Away from Nicholas Ridge, Doona Ridge and Perrys Mountain, the natural grades are typically less than 5 % in the vicinity of the proposed mining areas.

The natural and the predicted post-mining surface level contours are illustrated in Fig. 5.4 for Area 1, Fig. 5.5 for Areas 2 and 3 and in Fig. 5.6 for Areas 4 and 5. The maximum extents and depths of the topographical depressions are also illustrated in these figures, which are based on the geometry of the natural and the post-mining surface level contours. The actual extents and depths of any increased ponding in these locations are dependent on a number of other factors, including rainfall, catchment sizes, surface water runoff, infiltration and evaporation and, therefore, are expected to be smaller than the topographical depressions.



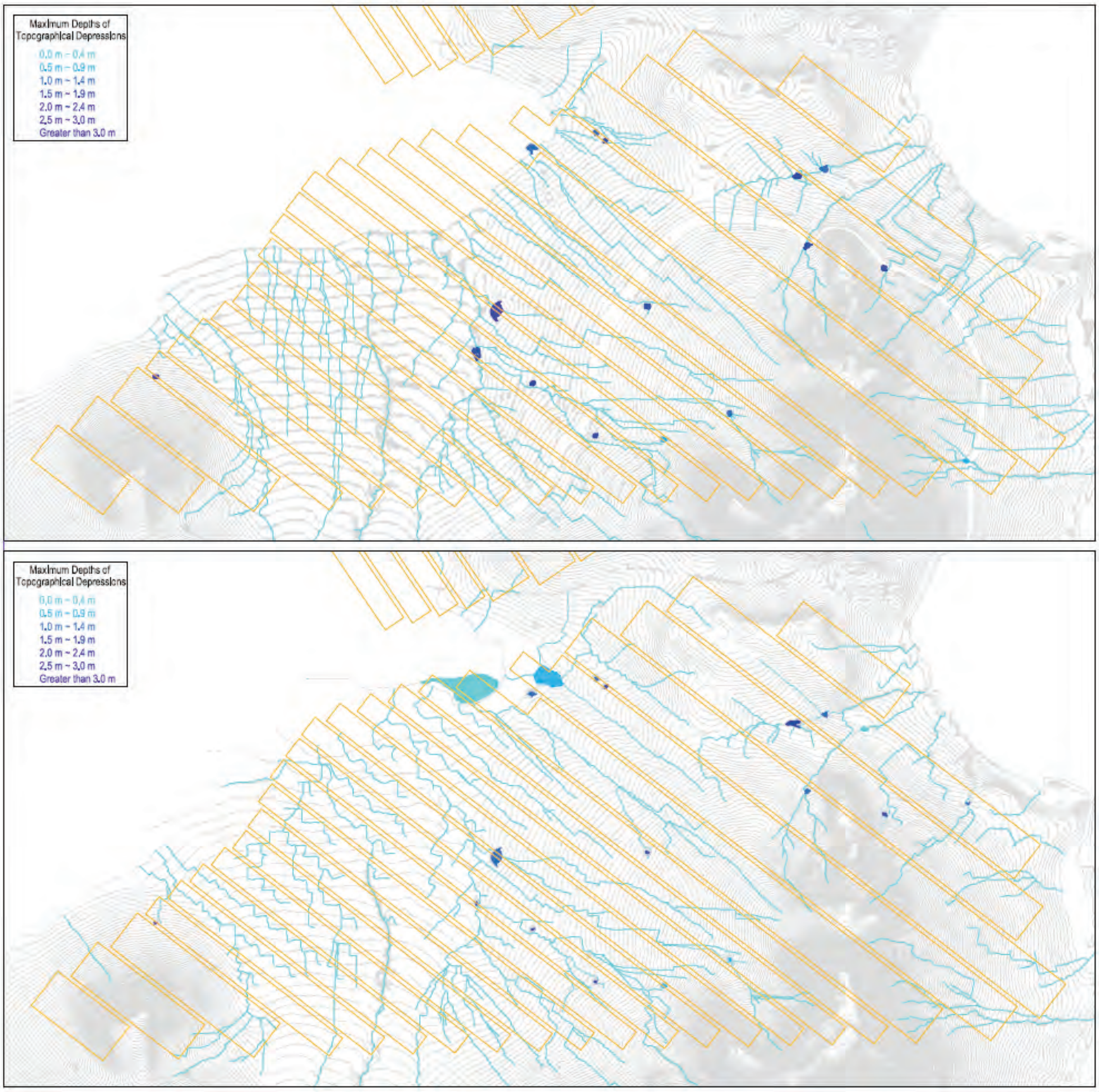
Note: Surface level contours not shown outside the mining areas for presentation purposes.

Fig. 5.4 Natural (Left Side) and Predicted Post-Mining (Right Side) Surface Levels Contours and the Locations and Depths of the Topographical Depressions for Area 1



Note: Surface level contours not shown outside the mining areas for presentation purposes.

Fig. 5.5 Natural (Left Side) and Predicted Post-Mining (Right Side) Surface Levels Contours and the Locations and Depths of the Topographical Depressions for Areas 2 and 3



Note: Surface level contours not shown outside the mining areas for presentation purposes.

Fig. 5.6 Natural (Top) and Predicted Post-Mining (Bottom) Surface Levels Contours and the Locations and Depths of the Topographical Depressions for Areas 4 and 5

It can be seen from Fig. 5.4, that topographical depressions are predicted to develop in Area 1, primarily beneath the northern portion (i.e. where the depths of cover are the shallowest), having depths between 1 metres and 2.5 metres. More localised topographical depressions are also predicted to develop elsewhere in the mining area, having depths less than 1 metre, which are associated with existing dams.

It can also be seen from Fig. 5.6, that topographical depressions are predicted to develop where the longwalls in Areas 2A, 3 and 4 are located in the gently sloped areas outside of Doona Ridge, having depths typically between 0.5 metres and 1.5 metres. The more localised but deeper topographical depressions located on the ridge are associated with existing dams.

The actual extents and depths of any increased ponding are expected to be less than the predicted topographical depressions due to the various other factors, including rainfall, catchment sizes, surface water runoff, infiltration and evaporation. The potential impacts of increased ponding will be further assessed as part of the detailed Surface Water Assessment which will be undertaken during the EIS stage of the project.

After the completion of the longwalls in each of the mining areas, surface remediation would be undertaken to re-establish the natural grades along the drainage lines and contour banks, where required, so as to reduce the potential for ponding within the mining areas. Discussions on the methods of remediation for the drainage lines and contour banks and, hence, the post-mining ponding are provided in Section 5.5.

Further discussions are also provided in the Agricultural Impact Assessment.

5.4. The Mooki River and Quirindi Creek

The locations of the Mooki River and Quirindi Creek are shown in Drawing No. MSEC635-08. Mining is not proposed directly beneath these streams. The minimum distances of the Mooki River from the proposed longwalls are 250 metres east of Area 2A, 1 kilometre east of Area 2B, 300 metres east of Area 4 and more than 2 kilometres from the remaining mining areas. The minimum distances of Quirindi Creek from the proposed longwalls are 500 metres south of Area 1, 1.2 kilometres east of Area 2A and more than 2 kilometres from the remaining mining areas. Werris and Yarraman Creeks are located more than 4 kilometres from the proposed longwalls.

The Mooki River and Quirindi Creek are ephemeral streams. The channels have shallow incisions into the Quaternary Alluvial Deposits (Qx) as illustrated in Fig. 1.8 which shows the surface lithology. These streams are part of the Water Sharing Plan for the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources gazetted on the 14th February 2003 and as amended by order gazetted on the 1st July 2004.

Photographs of the Mooki River and Quirindi Creek are provided in Fig. 5.7 and Fig. 5.8, respectively.

Fig. 5.7 Photographs of the Mooki River

Fig. 5.8 Photographs of Quirindi Creek

Cross-sections through the Mooki River and Quirindi Creek, where these streams are located closest to the proposed longwalls, are provided in Fig. 5.9 and Fig. 5.10, respectively. The 26.5 degree angles of draw from the extents of the proposed mining are also shown in these figures.

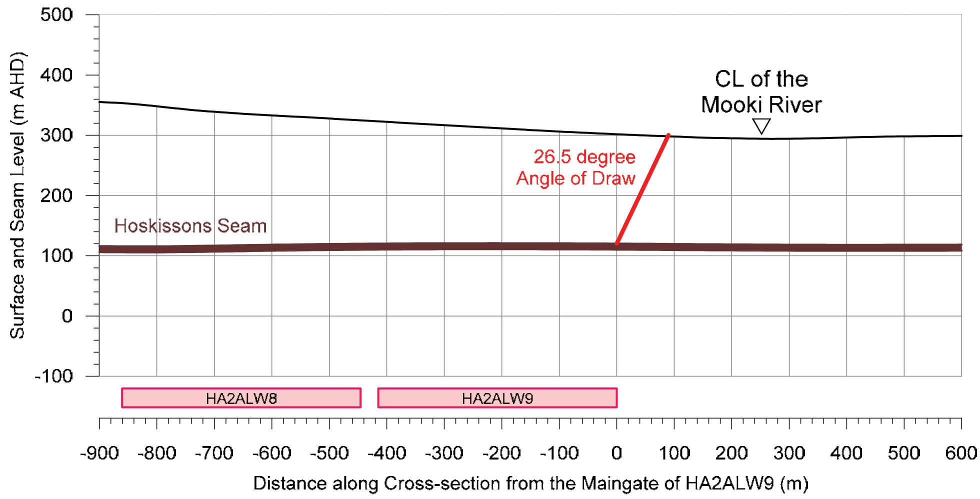


Fig. 5.9 Cross-section through the Mooki River and the Proposed Longwalls in Area 2A

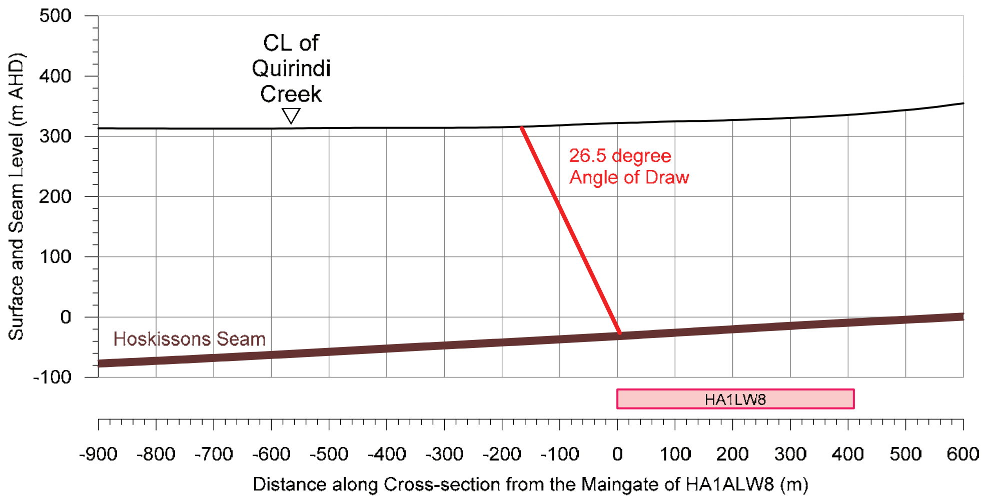


Fig. 5.10 Cross-section through the Quirindi Creek and the Proposed Longwalls in Area 1

It can be seen from the above figures, that the Mooki River and Quirindi Creek are located well outside the 26.5 degree Angles of Draw from the proposed longwalls. At these distances, the stream channels, themselves, are expected to experience negligible vertical subsidence (i.e. less than 5 mm) and, therefore, are not expected to experience any measurable conventional tilts, curvatures or strains. Similarly, no measurable subsidence movements are expected at Werris and Yarraman Creeks. It is unlikely, therefore, that the stream channels, themselves, would experience any adverse impacts resulting from the proposed mining.

The stream channels have shallow incisions into alluvium and, therefore, no significant valley related movements are anticipated to occur. The potential impacts on the alluvium and associated aquifers are discussed in the Agricultural Impact Assessment.

5.5. Drainage Lines

The locations of the drainage lines are shown in Drawing No. MSEC635-08. The drainage lines commence along Nicholas Ridge, Doona Ridge and Perrys Mountain and generally drain into the Mooki River and Quirindi Creek between the mining areas. It appears from the CMA Map of the area, that there are no "named" drainage lines located above the proposed mining areas.

The drainage lines are first or second order ephemeral streams with shallow incisions in the natural surface soils. Isolated rock outcropping occurs in some locations along the steeper sections of the streams. Photographs of typical drainage lines are provided in Fig. 5.11 and Fig. 5.12.

Fig. 5.11 Photographs of Typical Drainage Lines

Fig. 5.12 Photographs of Isolated Rock Outcropping along the Drainage Lines

The natural grades along the drainage lines typically vary between 50 mm/m and 100 mm/m (i.e. 5 % to 10 %, or 1 in 20 to 1 in 10) along the lower reaches of the ridges and more than 100 mm/m (i.e. 10 %, or 1 in 10) along the upper reaches of the ridges. The drainage lines along the alluvial flats have natural grades less than 10 mm/m (i.e. 1 % or 1 in 100).

The drainage lines are located directly above the proposed longwalls and, therefore, are expected to experience the maximum predicted subsidence parameters which were summarised in Chapter 4. The drainage lines have shallow incisions into the natural surface soils and, therefore, the predicted upsidence and closure movements are expected to be negligible when compared with the predicted conventional movements.

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

Potential for Increased Levels of Ponding and Scouring

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 tilts for the drainage lines are around 70 mm/m (i.e. 7 %, or 1 in 14) in Areas 1 and 2A, 40 mm/m (i.e. 4 %, or 1 in 25) in Area 2B, between 20 mm/m (i.e. 2 %, or 1 in 50) to 30 mm/m (i.e. 3 %, or 1 in 33) in Areas 2S, 3 and 4 and 10 mm/m (i.e. 1 %, or 1 in 100) in Area 5.

It is expected, therefore, that there would be areas which would experience increased ponding, primarily upstream of the chain pillars or where the drainage lines exit the proposed mining areas, in Areas 1, 2A, 2B and, to lesser extents in Areas 2S and 3. It is also possible, that there could be areas which could experience increased scouring of the stream beds, primarily downstream of the chain pillars where the depths of cover are the shallowest. After the completion of the longwalls in each of the mining areas, it may be necessary to undertake surface remediation to re-establish the natural grades along the gently sloped sections of the drainage lines, so as to reduce the potential for ponding within the mining areas.

The locations which are predicted to experience increased potential for ponding were illustrated in Fig. 5.4. The natural and the predicted post-mining surface levels (i.e. prior to any surface remediation) along typical drainage lines are shown in Fig. 5.13 (in Area 1), Fig. 5.14 (in Area 2A), Fig. 5.15 (in Area 2B), Fig. 5.16 (in Area 3), Fig. 5.17 (in Area 4) and Fig. 5.18 (in Area 5). The estimated maximum depths and extents of increased ponding (prior to any remediation) along these drainage lines are also indicated in these figures.

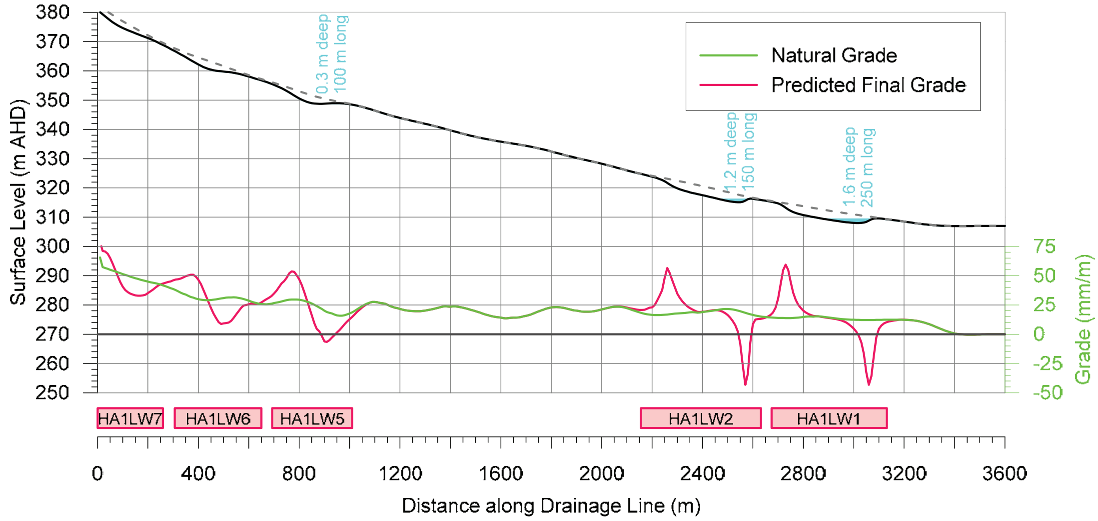


Fig. 5.13 Natural and Predicted Subsided Surface Levels for a Typical Drainage Line in Area 1

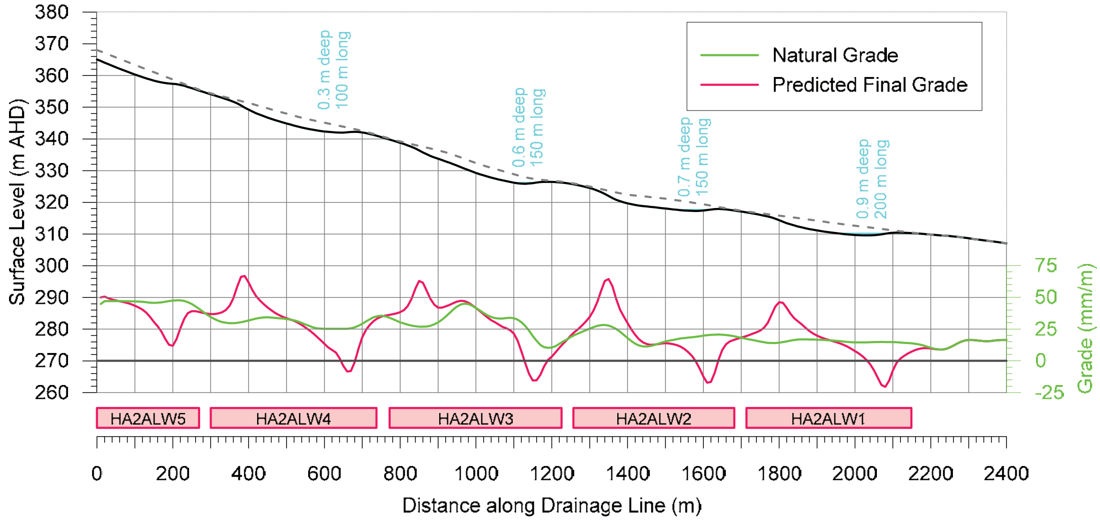


Fig. 5.14 Natural and Predicted Subsided Surface Levels for a Typical Drainage Line in Area 2A

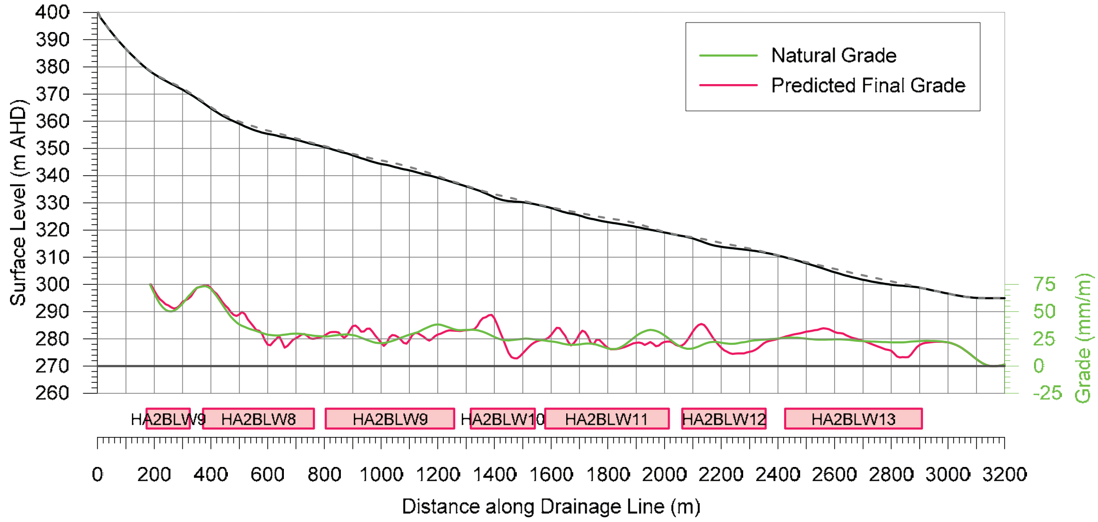


Fig. 5.15 Natural and Predicted Subsided Surface Levels for a Typical Drainage Line in Area 2B

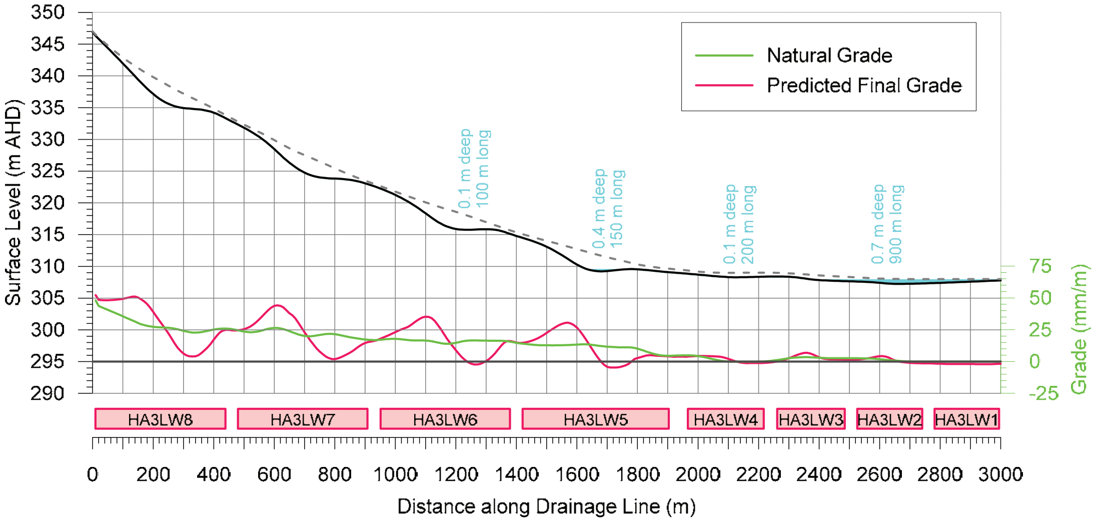


Fig. 5.16 Natural and Predicted Subsided Surface Levels for a Typical Drainage Line in Area 3

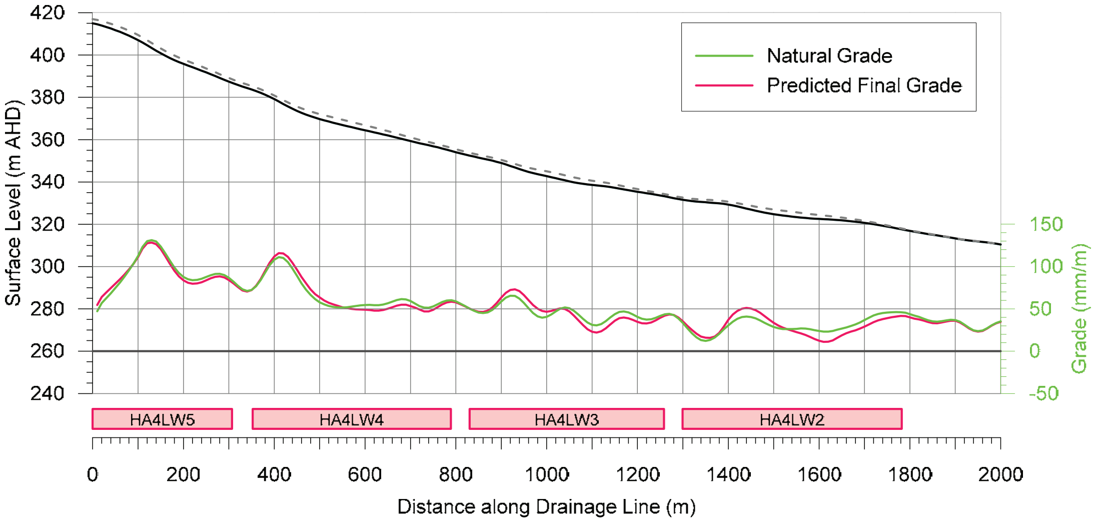


Fig. 5.17 Natural and Predicted Subsided Surface Levels for a Typical Drainage Line in Area 4

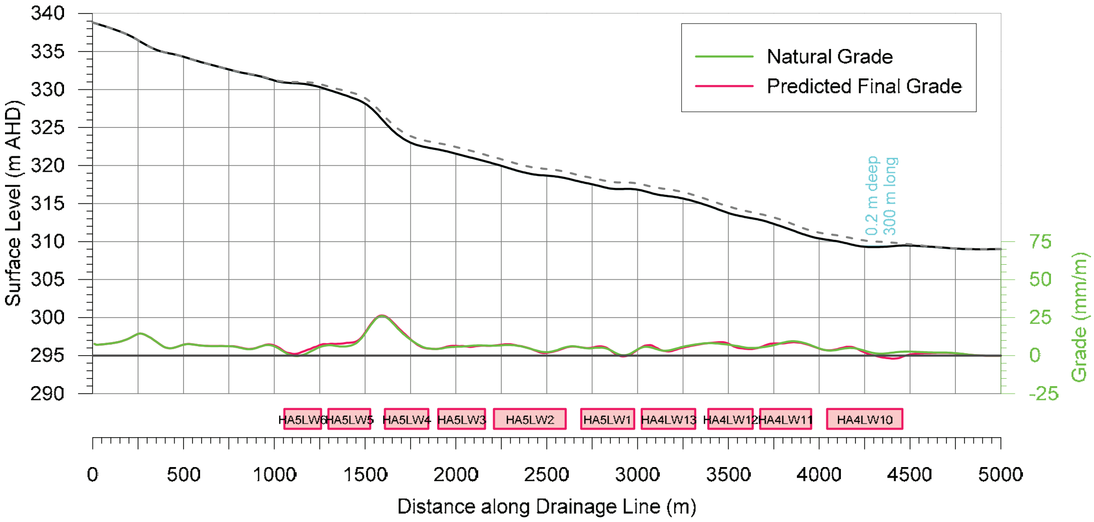


Fig. 5.18 Natural and Predicted Subsided Surface Levels for a Typical Drainage Line in Area 5

It can be seen from the above figures, that the largest ponding areas are predicted to occur upstream of the chain pillars in Areas 1 and 2A and in the gently sloped areas above the other mining areas. The planar extents of the areas predicted to experience an increased potential for ponding were illustrated in Fig. 5.4 and Fig. 5.6. It is noted, however, that surface remediation would be undertaken along these drainage lines following mining in each seam.

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. For example, the predicted ponding area at the downstream end of the drainage line in Area 5, as shown in Fig. 5.18, has a cross-gradient which would allow the surface water to flow out of this area and, hence, the actual ponding depth would be less than that indicated.

At the completion of the longwalls in each of the mining areas, the drainage lines would 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 by the local farmers, additional dam walls could be constructed along the drainage lines similar to those which already exist within the mining areas.

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 metre 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.

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 uppermost bedrock beneath the soil beds of the drainage lines based on the magnitudes of the predicted strains.

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

Experience from mining in the Hunter and Newcastle Coalfields indicates that impacts on ephemeral streams are low where the depths of cover are greater than the order of 200 metres, which is the case over a large portion of the proposed mining areas. For example, the drainage lines at South Bulga and the Beltana No. 1 Underground Mine were previously mined beneath by the longwalls in the Whybrow Seam, where the depths of cover varied between 40 metres and 200 metres. Although surface cracking was observed across the mining area, there were no observable surface water flow diversions in the drainage lines, resulting from the extraction of these longwalls, after the remediation of the larger surface cracks had been completed. 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.

Management strategies and remediation measures would 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 which could result in the loss of surface water flows or increased 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.

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

5.6. Groundwater Resources

There are groundwater resources associated with the Mooki River and Quirindi Creek alluvial aquifers and other shallow and deeper aquifers within the proposed mining areas. More detailed descriptions of these resources are provided in the Agricultural Impact Assessment.

The locations of the registered groundwater bores are shown in Drawing No. MSEC635-09, which were obtained from the NSW Office of Water using the *Natural Resource Atlas* website (NRAtlas, 2014). As part of the Gateway Assessment, a number of bores were inspected to confirm their location, hydrogeological characteristics and usage (i.e. a bore census). BHP Billiton will conduct a second stage of the bore census in consultation with relevant landholders to confirm the status, location and details of the bores not yet inspected in order to inform further impact assessment work planned for the EIS.

It is likely that the groundwater bores will experience impacts as a result of the proposed mining, particularly those located directly above the proposed longwalls. Impacts would include lowering of the piezometric surface and blockage of the bore due to differential horizontal displacements at different horizons within the strata. Such impacts on the groundwater bores can be managed and, if required, the bores can be reinstated. Repairs to property improvements, such as groundwater bores, would be facilitated by BHP Billiton and completed by the Mine Subsidence Board.

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

5.7. Agricultural Land Utilisation

The proposed longwalls in Area 2A, 2B, 2S and 3 are partially located beneath the *Doona State Forest*, and photographs in these areas are provided in Fig. 5.19. Much of the remaining land elsewhere above the proposed longwalls has been cleared and is used for agricultural and rural residential purposes, and photographs of these areas are provided in Fig. 5.20.

Fig. 5.19 Photographs of the Land Surface within the Doona State Forest

Fig. 5.20 Photographs of the Land Surface on the Margins of the Ridges

The potential impacts on the agricultural land use include:-

- Surface cracking and deformations – which was discussed in Section 5.2,
- Changes in surface water drainage – which was discussed in Sections 5.3,
- Changes to surface water resources – which was discussed in Sections 5.4 and 5.5,
- Changes to the groundwater resources – which was discussed in Section 5.6, and
- Impacts to built features associated with the properties – which is discussed in Section 5.8.

The current agricultural land utilisation within the proposed mining areas comprises the following:-

- Cropping areas,
- The Caroona Feedlot, and
- Cattle and sheep grazing.

The following sections provide the impact assessments on these agricultural land utilisations. Further discussions are provided in the Agricultural Impact Assessment.

5.7.1. Cropping Areas

The existing seasonal cropping areas are located primarily above the proposed longwalls in Areas 4 and 5, with smaller cropping areas located above the proposed longwalls in other mining areas. The potential impacts on the cropping areas include surface cracking and deformations (refer to Section 5.2) and changes in surface water drainage (refer to Section 5.3).

Topographical depressions have been predicted to develop in the more gently sloped parts of Areas 1, 2A, 2B, 3 and 4, and beneath the northern part of Nicholas Ridge where the depths of cover are the shallowest. Elsewhere, the more localised topographical depressions located above these mining areas are associated with existing dams. The natural and the predicted post mining topographical depressions have been overlaid on the aerial photograph in Fig. 5.21 to Fig. 5.23.

Fig. 5.21 Locations of the Natural (Left Side) and Predicted Post Mining (Right Side) Topographical Depressions overlaid on the Aerial Photograph for Area 1

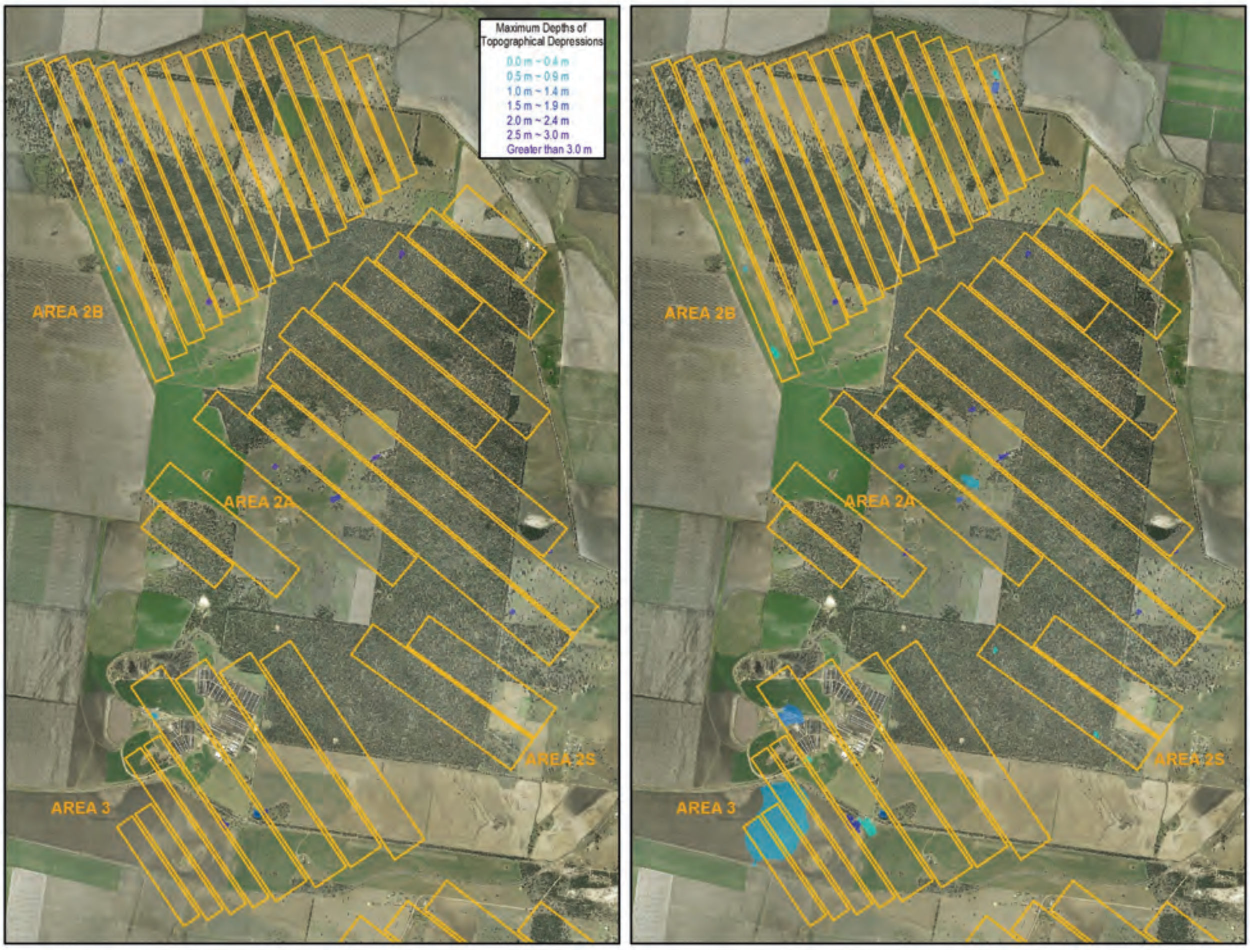


Fig. 5.22 Locations of the Natural (Left Side) and Predicted Post Mining (Right Side) Topographical Depressions overlaid on the Aerial Photograph for Areas 2 and 3

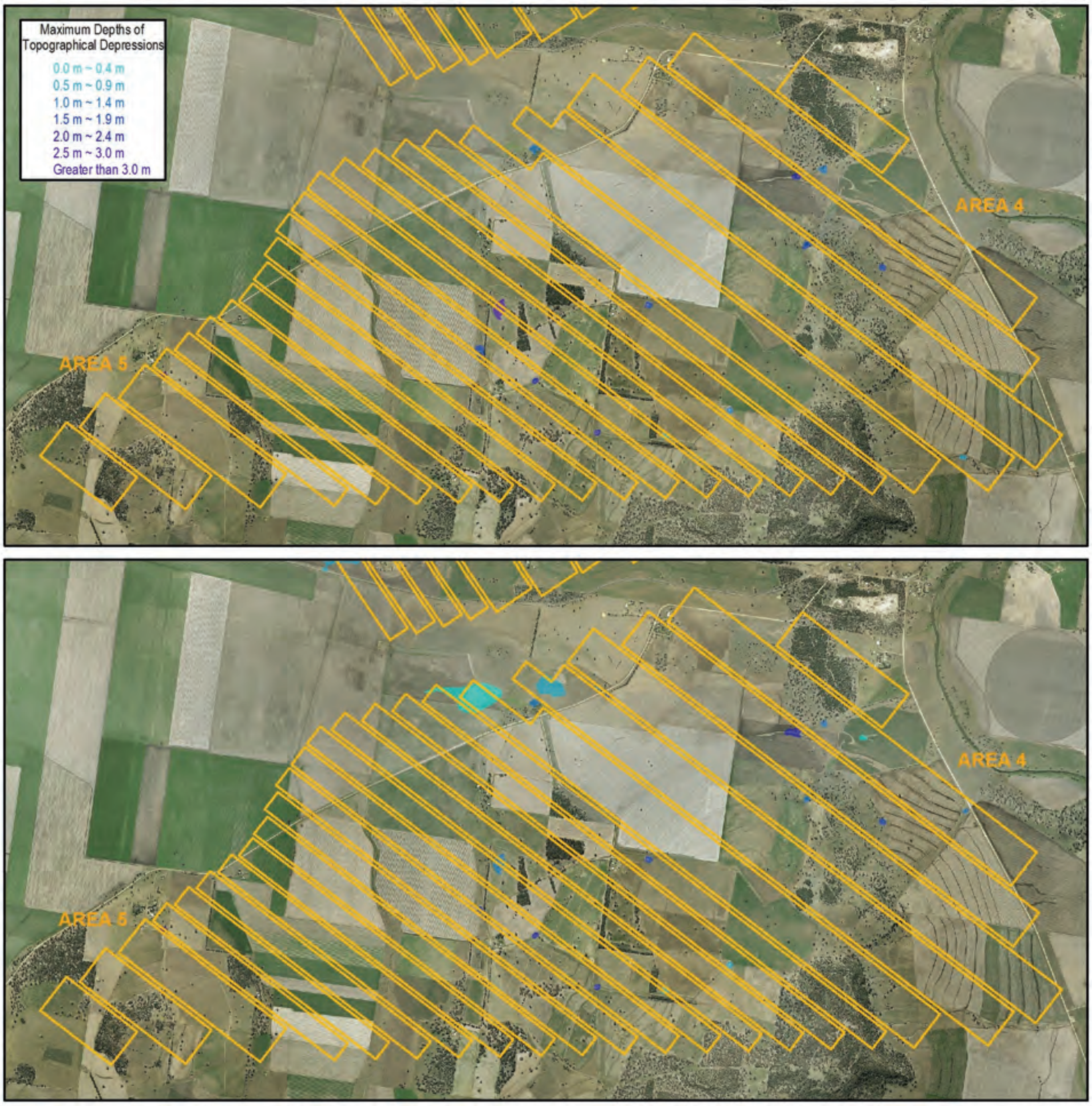


Fig. 5.23 Locations of the Natural (Top) and Predicted Post Mining (Bottom) Topographical Depressions overlaid on the Aerial Photograph for Areas 4 and 5

If the potential for increased ponding were found to adversely impact on the agricultural land use, it may be necessary to remediate the surface drainage, which could include regrading of the drainage line downstream of the topographical depressions and remediation of the contour banks.

The cropping areas could also be adversely impacted by surface cracking and deformations. The predicted ranges of surface cracking were described in Section 5.2. Management strategies can be developed for the cropping areas, to manage the potential impacts resulting from surface cracking, which could include:-

- Visual monitoring during active subsidence,
- Establish methods to adjust the fences and irrigation systems,
- Establish methods to remediate the larger surface cracks which could adversely impact on the crops or associated infrastructure, and
- Develop a Property Subsidence Management Plan (PSMP) incorporating the agreed methods to manage surface cracking and deformations with the property owner.

Other potential impacts on the built features are covered in Section 5.8.

5.7.2. The Caroona Feedlot

The *Caroona Feedlot* is located above the northern ends of the proposed longwalls in Area 3. The property includes a number of large industrial sheds, silos, feeding yards and other associated infrastructure. A detailed inspection of the property has not been undertaken at this stage of the project.

It is likely that, without the implementation of detailed management strategies and monitoring programs, the large building structures and associated infrastructure on the property could be adversely impacted by the proposed mining.

The management strategies for the *Caroona Feedlot* would be developed following an inspection of the site by suitably qualified persons, which may include the feedlot operational personnel, a structural engineer, mechanical engineer and a subsidence engineer. The options to manage the potential subsidence impacts would be developed through consultation with the owners and a detailed assessment of the potential risks and could include:-

- The implementation of preventive measures for the building structures and infrastructure assessed to be adversely impacted by the proposed mining.
- The development of strategies to manage and remediate the potential impacts during active subsidence, which would include detailed monitoring program (visual and ground), a Trigger Action Response Plan (TARP) and the development of methods to repair any impacts.
- The temporary closure or relocation of infrastructure and services from the active subsidence area. These strategies would need to be developed in agreement with the owner.

The necessary strategies would be developed such that the building structures and infrastructure on the property can be maintained in safe, serviceable and repairable conditions at all times, or as otherwise agreed with the feedlot owners.

5.7.3. Cattle and Sheep Grazing

There is grazing of cattle and sheep on some of the private properties located within the proposed mining areas. A risk to this type of agricultural land use is the potential for the mining induced surface cracking and deformations to injure the cattle, sheep or workers on these properties. Management strategies can be developed for the grazing properties, which could include the following:-

- Visual monitoring of the surface in the active subsidence zone, to identify any surface cracking and deformations which 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 PSMPs incorporating the agreed methods to manage surface cracking and deformations with the property owners.

In the locations of shallow depths of cover, where larger surface cracking is anticipated (i.e. Areas 1 and 2A), it may be necessary to install temporary fencing or to temporarily relocate stock to areas outside the active subsidence zone.

Other potential impacts on the built features on these properties are covered in Section 5.8.

5.7.4. Future Land Use

It is possible that additional agricultural land uses could be developed within the proposed mining areas prior to the commencement or during mining. PSMPs would need to be developed for these industries, prior to active subsidence, incorporating agreed management strategies with the property owners, similar to those discussed in Sections 5.5, 5.6 and 5.7.1 to 5.7.3.

It is noted that the majority of the subsidence develops as each longwall mines directly beneath or adjacent to each property, with only small long term residual subsidence developing after this time. The built features constructed above the longwalls after the completion of mining, therefore, would not experience any long term subsidence impacts.

5.8. Built Features Associated with the Agricultural Land Utilisation

The locations of the built features associated with the agricultural land use within the mining areas are shown in Drawing No. MSEC635-09. The built features located directly above the proposed longwalls include:-

- 23 houses located directly above the proposed longwalls.
- Approximately 100 rural building structures located directly above the proposed longwalls, which includes sheds, garages and other non-residential building structures.
- 52 farm dams located directly above the proposed longwalls, which have been established along the natural drainage lines.
- The *Caroona Feedlot* which is located above the proposed longwalls in Area 3. The property includes a number of large industrial sheds, silos, feeding yards and other associated infrastructure.
- The Binnaway-Werris Creek Railway which is located above the southern ends of the proposed longwalls in Area 3.
- Local roads including sections of Woodlands Road, Rossmar Park Road, Coonabarabran Road, 4D Road and Mooki Road. There are also a number of unsealed tracks within the Doona State Forest.
- Electrical infrastructure comprising aerial 33 kV, 11 kV and low voltage powerlines supported by timber poles. A zone substation is also located south of the proposed longwalls in Area 4.
- An optical fibre cable which follows the alignment of the railway which is located above the proposed longwalls in Area 3. A second optical fibre cable is also located in the vicinity of Areas 2S and 3. Copper telecommunications cables are located across each of the mining areas which service the rural properties. A telecommunications station is also located south of the proposed longwalls in Area 4.
- A water pipeline which follows the alignment of Coonabarabran Road above the proposed longwalls in Area 3. The pipeline provides potable water to the township of Caroona.
- A Central Ranges natural gas pipeline.

Detailed impact assessment for these built features will be undertaken during the EIS stage of the project. Where adverse impacts to built features are identified, management strategies will be developed to manage these potential impacts, which could included the implementation of preventive measures, development of remedial measures and further refinement of the longwall layout. The final longwall layout will be developed throughout the course of the Project such that all built features are maintained in safe and serviceable conditions at all times.

Longwalls in the NSW Coalfields have been successfully extracted beneath building structures, railway lines, roads, powerlines, water pipelines and gas pipelines with the development and implementation of the necessary management strategies, including by BHP Billiton at its Illawarra Coal operations.

Management strategies for the privately owned built features will be incorporated into the individual PSMPs prepared in consultation with the owners. Management strategies for infrastructure will be incorporated into the Built Features Management Plans.

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

- An easy-to-read plan of the property in relation to the final mining layout,
- Details of the predicted subsidence movements and the potential impacts to the property, including the likelihood of these impacts occurring,
- The expected timing of mine subsidence,
- A specific subsidence monitoring plan to identify any subsidence impacts which develop during and after mining, including visual inspections and structural surveys,
- The implementation of the appropriate pre-mining preventive measures to minimise the potential for impacts and to maintain safety and serviceability, where appropriate,
- The process for identifying and rectifying any impacts to structures that may occur as a result of mining, and
- Development of appropriate remedial measures for any subsidence impacts, including a commitment to mitigate, repair, replace or compensate any impacts in a timely manner.

Where it is not possible to maintain serviceability of the built feature during the active subsidence period, the landholder should be compensated and provided with a suitable alternative such that there is no loss of agricultural productivity due to the subsidence impact. For example, the provision of temporary alternative water supplies during the repair of farm dams.

The Built Features Management Plans would provide information for the infrastructure within the mining areas similar to that described above, but could also include:-

- 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 TARPs 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.

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

Glossary of Terms and Definitions

Some of the more common mining terms used in the report are defined below:-

Angle of draw	The angle of inclination from the vertical of the line connecting the goaf edge of the workings and the limit of subsidence (which is usually taken as 20 mm of subsidence).
Chain pillar	A block of coal left unmined between the longwall extraction panels.
Cover depth (H)	The depth from the surface to the top of the seam. Cover depth is normally provided as an average over the area of the panel.
Closure	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. It should be noted that the observed closure movement across a valley is the total movement resulting from various mechanisms, including conventional mining induced movements, valley closure movements, far-field effects, downhill movements and other possible strata mechanisms.
Critical area	The area of extraction at which the maximum possible subsidence of one point on the surface occurs.
Curvature	The change in tilt between two adjacent sections of the tilt profile divided by the average horizontal length of those sections, i.e. curvature is the second derivative of subsidence. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres* (km^{-1}), but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*. Curvature can be either **hogging** (i.e. convex) or **sagging** (i.e. concave).
Extracted seam	The thickness of coal that is extracted. The extracted seam thickness is thickness normally given as an average over the area of the panel.
Effective extracted seam thickness (T)	The extracted seam thickness modified to account for the percentage of coal left as pillars within the panel.
Face length	The width of the coalface measured across the longwall panel.
Far-field movements	The measured horizontal movements at pegs that are located beyond the longwall panel edges and over solid unmined coal areas. Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain.
Goaf	The void created by the extraction of the coal into which the immediate roof layers collapse.
Goaf end factor	A factor applied to reduce the predicted incremental subsidence at points lying close to the commencing or finishing ribs of a panel.
Horizontal displacement	The horizontal movement of a point on the surface of the ground as it settles above an extracted panel.
Inflection point	The point on the subsidence profile where the profile changes from a convex curvature to a concave curvature. At this point the strain changes sign and subsidence is approximately one half of S max.
Incremental subsidence	The difference between the subsidence at a point before and after a panel is mined. It is therefore the additional subsidence at a point resulting from the excavation of a panel.
Panel	The plan area of coal extraction.
Panel length (L)	The longitudinal distance along a panel measured in the direction of (mining from the commencing rib to the finishing rib.
Panel width (Wv)	The transverse distance across a panel, usually equal to the face length plus the widths of the roadways on each side.
Panel centre line	An imaginary line drawn down the middle of the panel.
Pillar	A block of coal left unmined.
Pillar width (Wpi)	The shortest dimension of a pillar measured from the vertical edges of the coal pillar, i.e. from rib to rib.

Shear deformations	The horizontal displacements that are measured across monitoring lines and these can be described by various parameters including; horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.
Strain	The change in the horizontal distance between two points divided by the original horizontal distance between the points, i.e. strain is the relative differential displacement of the ground along or across a subsidence monitoring line. Strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation. **Tensile Strains** are measured where the distance between two points or survey pegs increases and **Compressive Strains** where the distance between two points decreases. Whilst mining induced **strains** are measured **along** monitoring lines, ground **shearing** can occur both vertically, and horizontally **across** the directions of the monitoring lines.
Subcritical area	An area of panel smaller than the critical area.
Subsidence	The vertical movement of a point on the surface of the ground as it settles above an extracted panel, but, 'subsidence of the ground' in some references can include both a vertical and horizontal movement component. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of *millimetres (mm)*. Sometimes the horizontal component of a peg's movement is not measured, but in these cases, the horizontal distances between a particular peg and the adjacent pegs are measured.
Subsidence Effects	The deformations of the ground mass surrounding a mine, sometimes referred to as 'components' or 'parameters' of mine subsidence induced ground movements, including vertical and horizontal displacements, tilts, curvatures, strains, upsidence and closure.
Subsidence Impacts	The physical changes or damage to the fabric or structure of the ground, its surface and natural features, or built structures that are caused by the subsidence effects. These impacts considerations can include tensile and shear cracking of the rock mass, localised buckling of strata, bed separation, rock falls, collapse of overhangs, failure of pillars, failure of pillar floors, dilation, slumping and also include subsidence depressions or troughs.
Subsidence Consequences	The knock-on results of subsidence impacts, i.e. any change in the amenity or function of a natural feature or built structure that arises from subsidence impacts. Consequence considerations include public safety, loss of flows, reduction in water quality, damage to artwork, flooding, draining of aquifers, the environment, community, land use, loss of profits, surface improvements and infrastructure. Consequences related to natural features are referred to as environmental consequences.
Supercritical area	An area of panel greater than the critical area.
Tilt	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 horizontal 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.
Uplift	An increase in the level of a point relative to its original position.
Upsidence	Upsidence results from the dilation or buckling of near surface strata at or near the base of the valley. The term uplift is used for the cases where the ground level is raised above the pre-mining level, i.e. when the upsidence is greater than the subsidence. 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.

APPENDIX B. REFERENCES

References

DoPI (2012). *Strategic Regional Land Use Plan – New England North West*. The New South Wales Department of Planning and Infrastructure, September 2012.

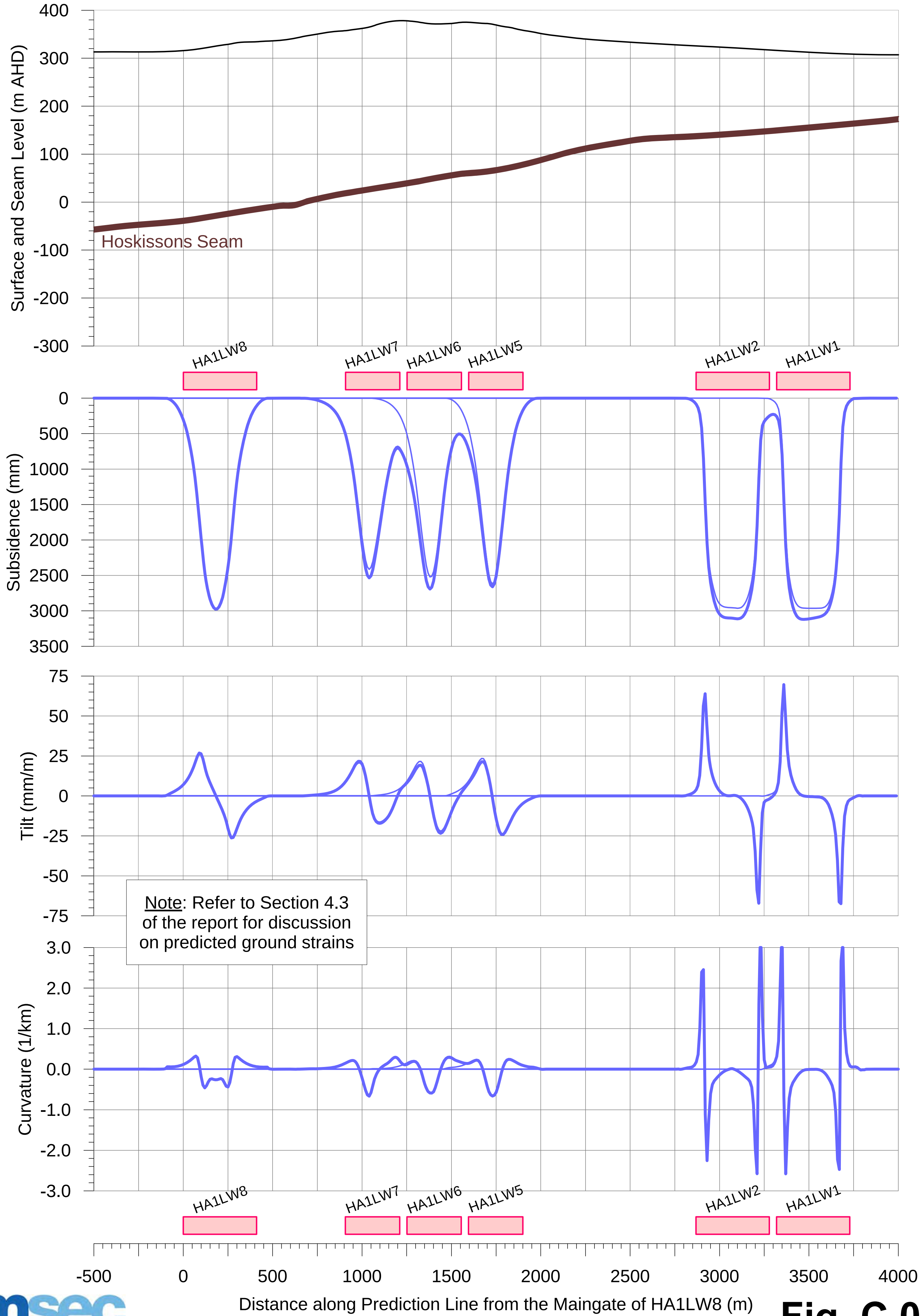
Klenowski (2000). *The Influence of Subsidence Cracking on Longwall Extraction*. Australian Coal Association Research Project No. C5016. August, 2000.

McKenzie Soil Management (2014). *Agricultural Resource Assessment: Caroona Coal Project Caroona, NSW.*

NRAtlas, (2014). *Natural Resource Atlas* website, viewed in February 2014. The Department of Natural Resources. http://nratlas.nsw.gov.au/

APPENDIX C. FIGURES

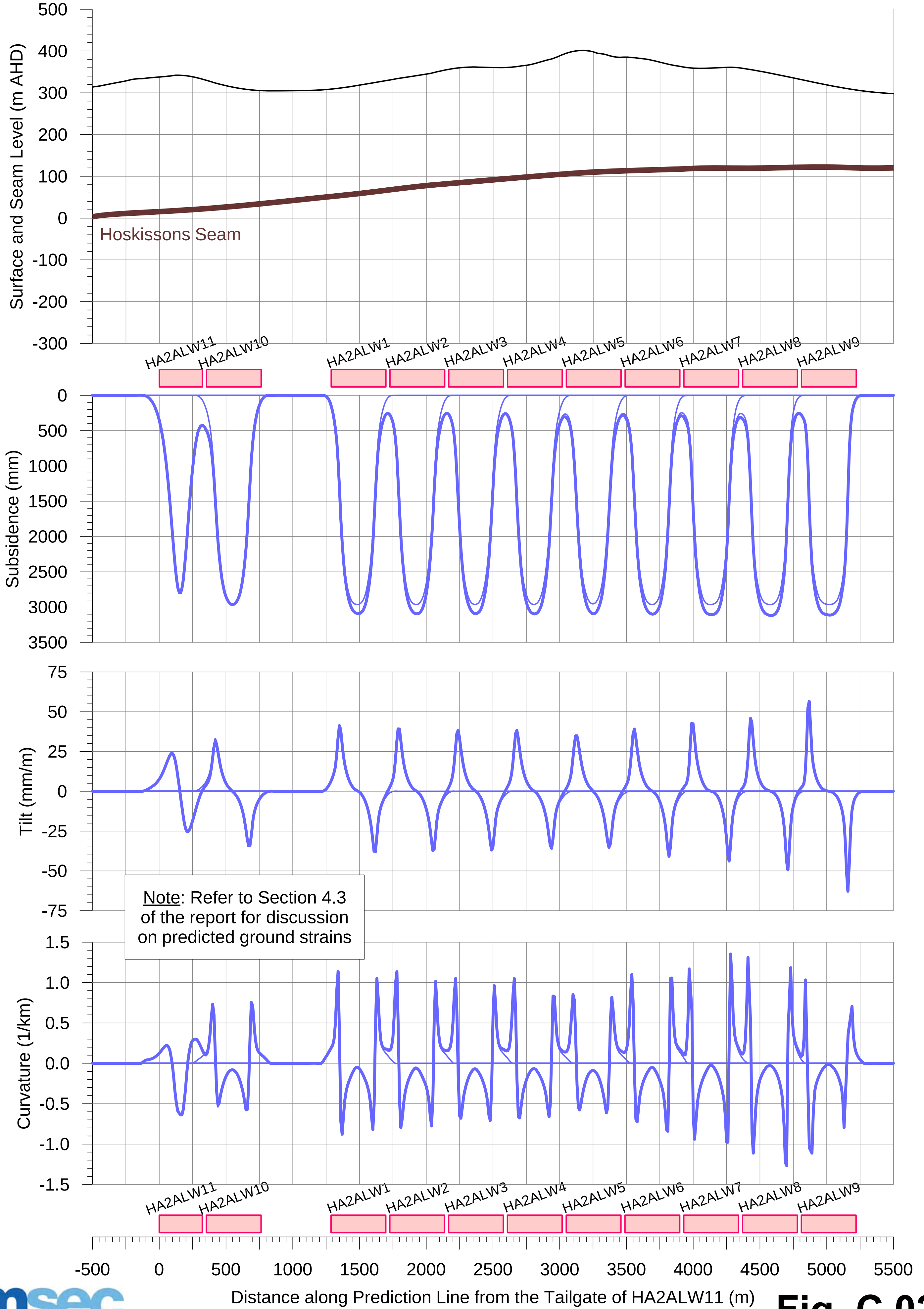
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 1 due to the Proposed Longwall Mining in Area 1



msec

Fig. C.01

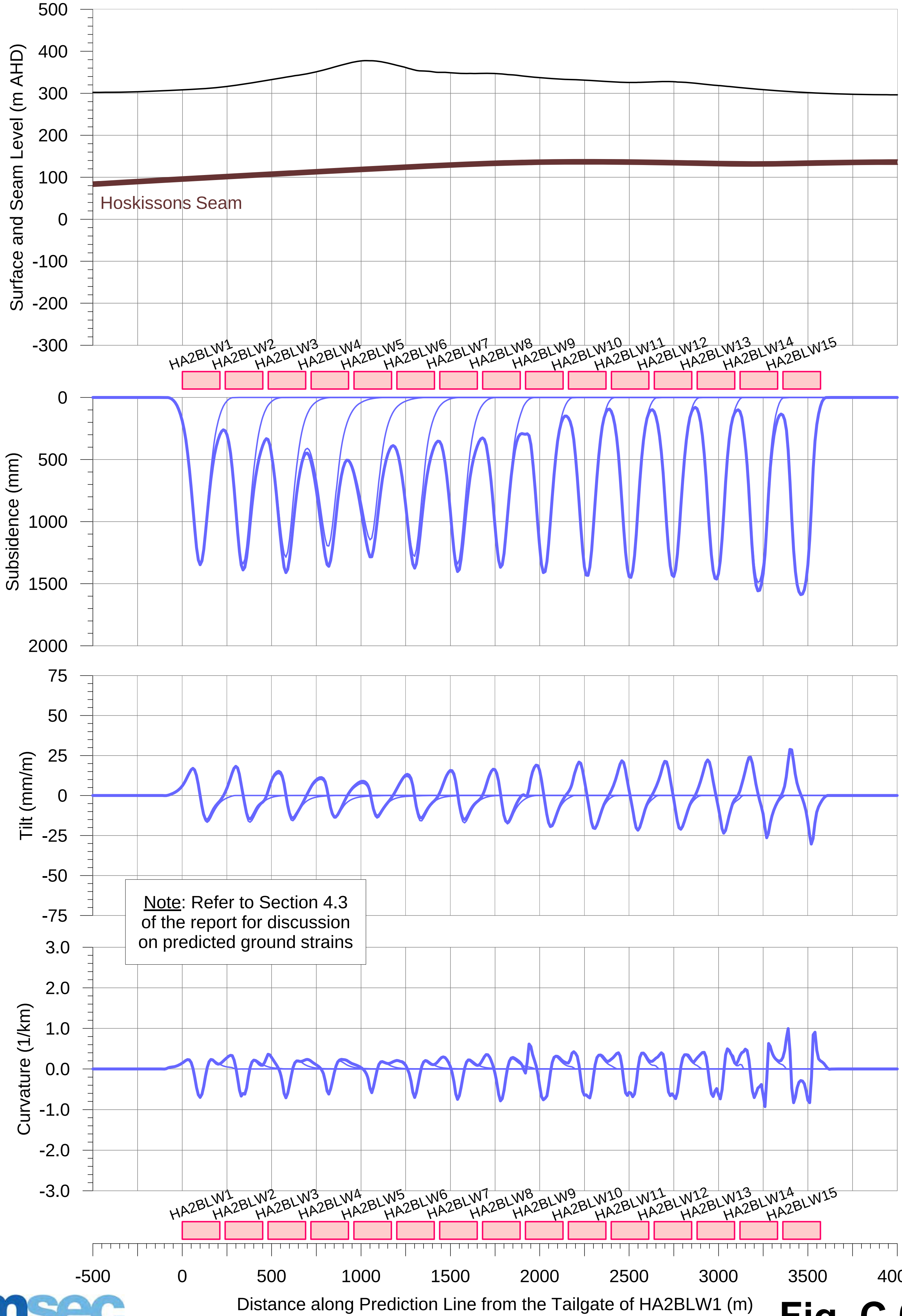
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 2A due to the Proposed Longwall Mining in Area 2A



msec

Fig. C.02

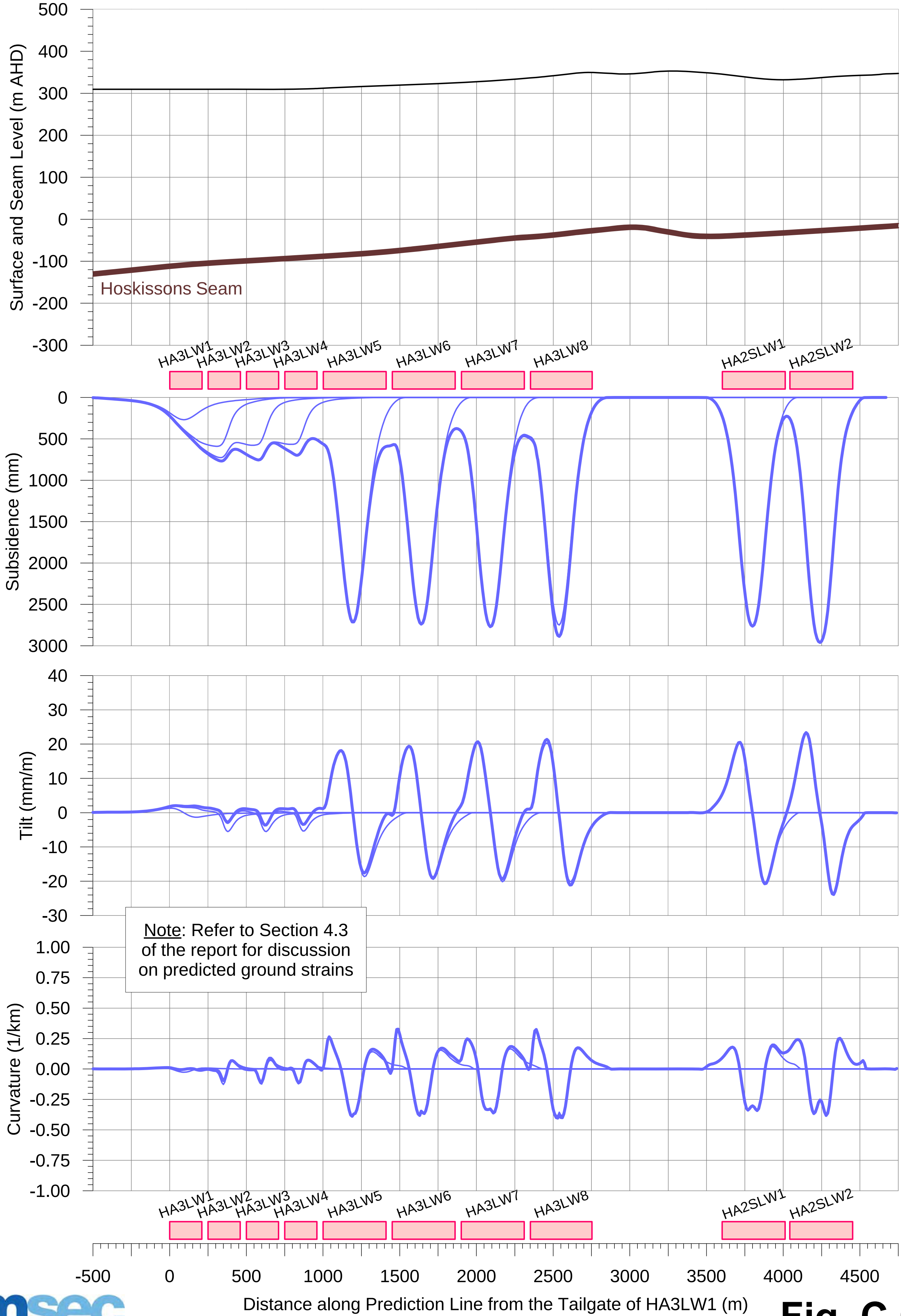
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 2B due to the Proposed Longwall Mining in Area 2B



msec

Fig. C.03

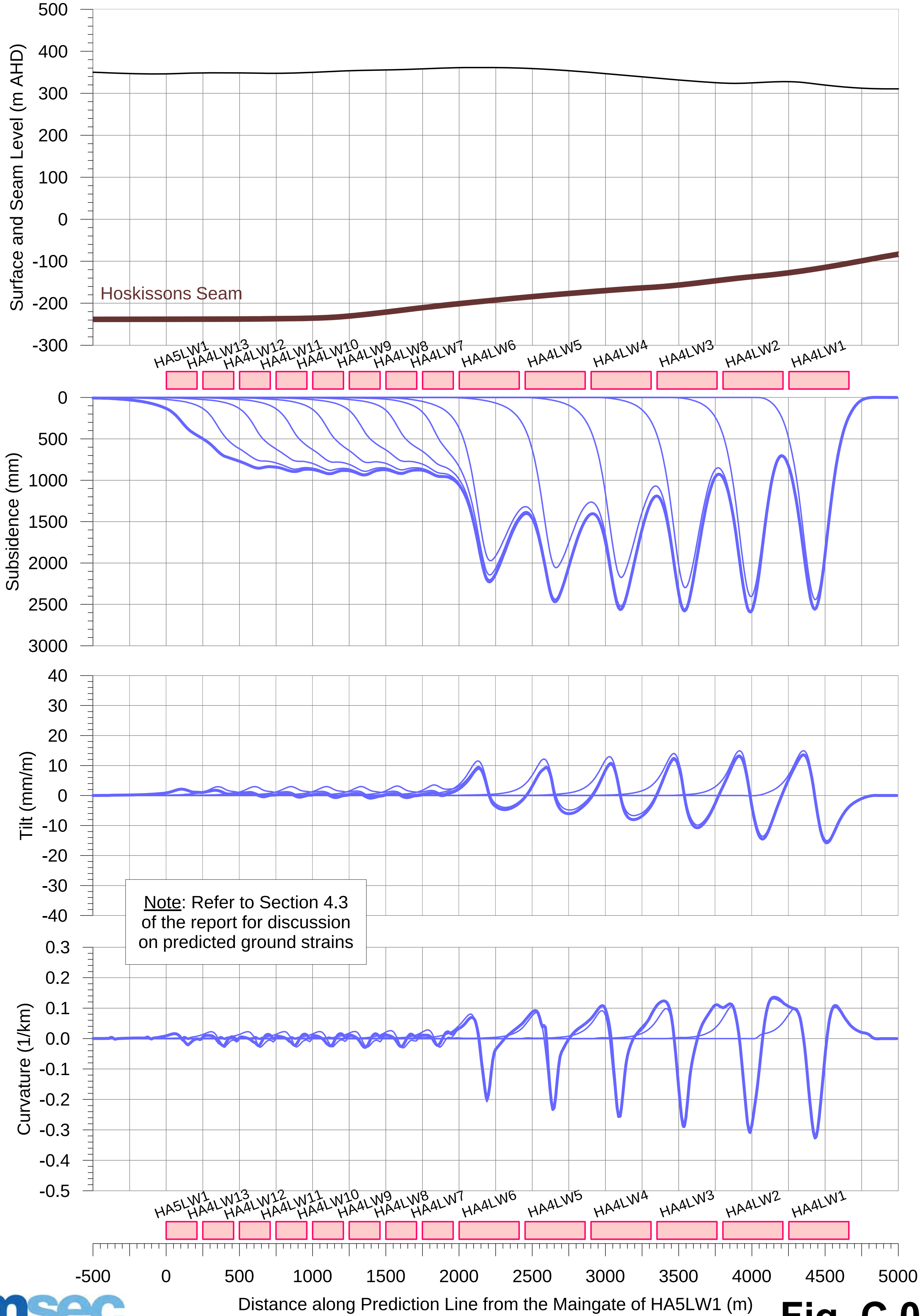
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 3 due to the Proposed Longwall Mining in Areas 2S and 3



msec

Fig. C.04

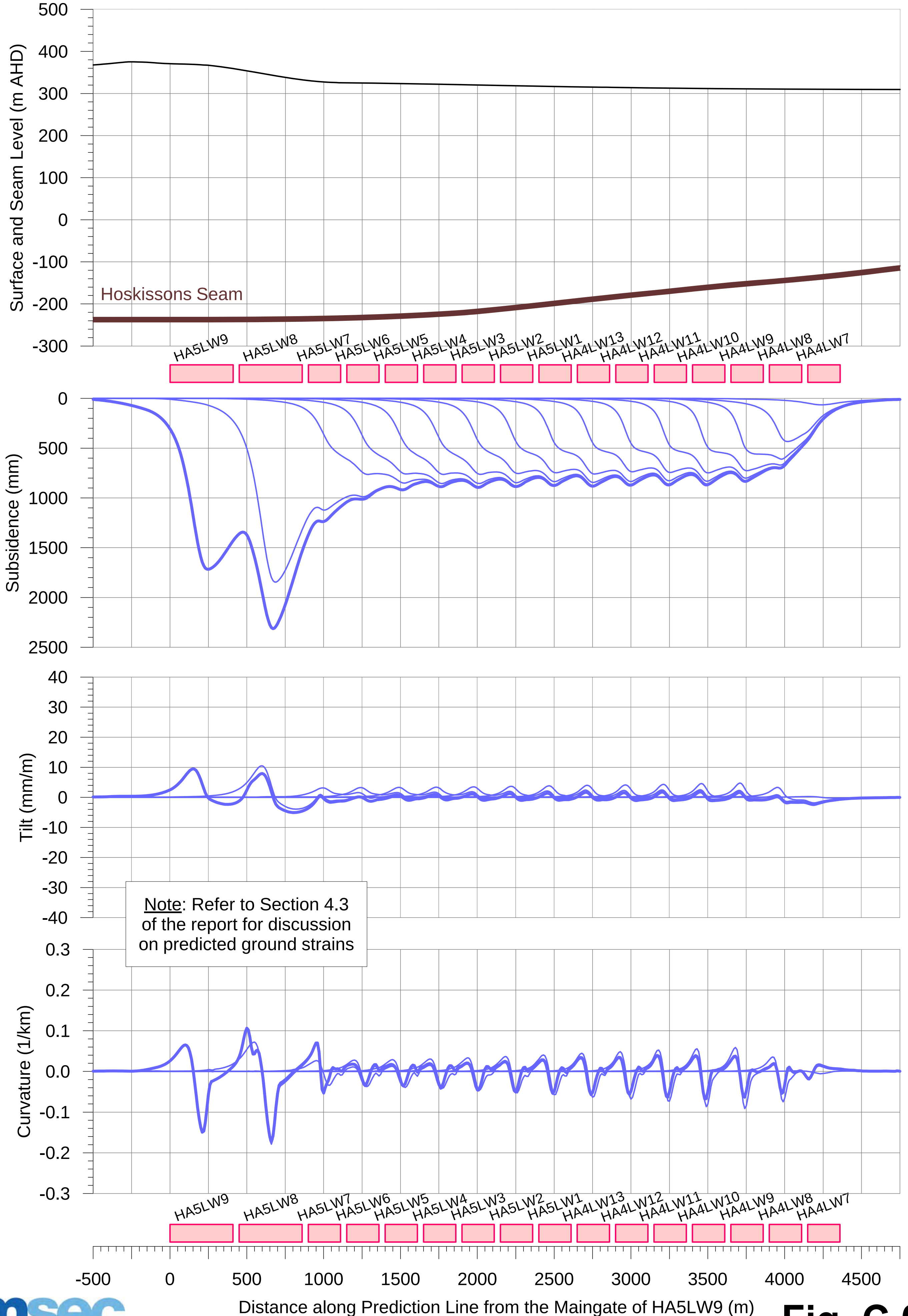
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 4 due to the Proposed Longwall Mining in Areas 4 and 5



msec

Fig. C.05

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 5 due to the Proposed Longwall Mining in Areas 4 and 5



msec

Fig. C.06