Spur Hill Underground Coking Coal Project

Application for a Gateway Certificate

Appendix B
Subsidence Assessment

SPUR HILL
UNDERGROUND COKING COAL

SPUR HILL UNDERGROUND COKING COAL PROJECT:

Gateway Application – Subsidence Assessment

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

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Report produced to:- Support the Gateway Application for the Spur Hill Underground Coking 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

Spur Hill Management Pty Ltd (SHM) has been granted Exploration Licence 7429 (the EL), which is located in the Hunter Coalfield of New South Wales (NSW), east of the township of Denman. SHM proposes to extract longwalls in a number of seams within the Wittingham Coal Measures, which is referred to as the *Spur Hill Underground Coking Coal Project* (the project).

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

- review the currently proposed longwall layouts in the Whynot, Bowfield and Warkworth Seams,
- prepare predicted subsidence contours after the extraction of the proposed longwalls within each of the seams,
- identify and describe the natural and built features within the EL, 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 EL, 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 subsidence predictions provided in this report were obtained using the Incremental Profile Method, which was calibrated for multi-seam mining conditions using the available data from the NSW Coalfields. The maximum predicted subsidence parameters, resulting from the extraction of the proposed longwalls in the Whynot, Bowfield and Warkworth Seams, are as follows:-

- Vertical subsidence of 5,300 mm,
- Tilt of 40 mm/m (i.e. 4 %, or 1 in 25),
- Hogging and sagging curvatures of 1.0 km^{-1} (i.e. minimum radius of curvature of 1 kilometre), and
- Strains 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 Agricultural Impact Assessment. The main findings from this report are as follows:-

- The surface cracking in the flatter areas (i.e. away from the north-south ridgeline) above the proposed longwalls is expected to be typically between 25 mm and 50 mm, with some isolated cracking around 100 mm or greater. The surface cracking along the steeper slopes on the sides of the ridgeline are expected to be typically in the order of 50 mm to 100 mm, with isolated cracking around 200 mm or greater.

  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 EL.
- It is expected that localised topographical depressions will develop above the proposed longwalls, particularly along the alignments of the drainage lines and in the flatter areas, having depths up to around 2.5 metres. These areas have the potential for increased surface water ponding.

  After the completion of mining in each seam in a particular area, surface remediation can be undertaken to re-establish the natural grades along the drainage lines, so as to reduce the potential for increased ponding within the EL.
- The Hunter River is located to the west and to the south of the EL. The river channel is around 550 metres north-west of the EL at its closest point. At this distance, it is not expected that there would be any adverse surface impacts on the river channel resulting from the proposed mining.

  The mapped limit of alluvium for the Hunter River is located immediately adjacent to the proposed longwalls, in the north-western part of the EL. In this location, the alluvium is predicted to experience low levels of vertical subsidence, less than 100 mm, but is not expected to experience any significant conventional tilts, curvatures or strains. The potential impacts on the alluvium and associated aquifer are discussed in the Agricultural Impact Assessment.

- The ephemeral[2] drainage lines commence along the ridgeline and flow into the Hunter River on the western and southern sides of the EL. The upper reaches are 1st and 2nd order streams and some parts of the lower reaches are 3rd order streams.

  Increased potential for ponding is expected to develop along these drainage lines, which are estimated to be up to around 1 metre deep and 200 metres long, after the completion of mining. Some deeper but more localised ponding could occur in the locations of the existing farm dams. After the completion of mining in each seam in a particular area, surface remediation can be undertaken to re-establish the natural grades along the drainage lines, so as to reduce the potential for increased ponding within the EL.

  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 EL includes a vineyard, winery, cellar door, centre pivot irrigation areas and cattle grazing. The potential impacts on these features 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 vineyard trellises, 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, or by constructing bunds adjacent to the drainage lines.

- There are houses, rural building structures, farm dams, groundwater bores, roads, electrical infrastructure and telecommunications infrastructure located above the proposed mining area. Management strategies for these built features should be developed as part of Property Subsidence Management Plans (PSMPs) and Built Feature Management Plans in consultation with the owners.

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

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

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

CONTENTS

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

Spur Hill Management Pty Ltd (SHM) has been granted Exploration Licence 7429 (EL7429, or the EL), which is located in the Hunter Coalfield of New South Wales (NSW), east of the township of Denman, as shown in Fig. 1.1. SHM proposes to extract longwalls in a number of seams within the Wittingham Coal Measures, which is referred to as the *Spur Hill Underground Coking Coal Project* (the project).

Fig. 1.1 Location of the EL (JBA Planning, 2011)

SHM 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), viticulture critical industry cluster and equine critical industry cluster under the Upper Hunter Strategic Land Use Plan.

In determining the application for a Gateway Certificate, the Gateway Panel must consider:-

- Whether the project would significantly reduce the agricultural productivity of any BSAL, based on consideration of:-
    - any impacts on the land through surface area disturbance or subsidence,
    - any impacts on soil fertility, effective rooting depth or soil drainage,
    - increases in land surface micro-relief, soil salinity, rock outcrop, slope and surface rockiness, or significant changes in pH,
    - any impacts on highly productive groundwater,
    - any fragmentation of agricultural land uses, and
    - any reduction in the area of BSAL.
- Whether the project would have a significant impact on the viticulture or equine industries based on consideration of:-
    - any impacts on the land through surface area disturbance and subsidence,
    - reduced access to, or impacts on, water resources and agricultural resources,
    - reduced access to support services and infrastructure,
    - reduced access to transport routes, and
    - the loss of scenic and landscape values.

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

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

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

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

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

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

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

1.2. Mining Geometry

The layouts of the proposed longwalls in the Whynot, Bowfield and Warkworth Seams are shown in Drawings Nos. MSEC616-100 to MSEC616-103. A summary of the proposed longwall dimensions is provided in Table 1.1.

Table 1.1 Geometry of the Proposed Longwalls

Seam	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
Whynot (WN)	675 ~ 2,800	305	35
Bowfield (BF)	725 ~ 2,300	305	35
Warkworth (WW)	1,075 ~ 2,825	305	35

The Whynot Seam will be extracted first and, therefore, these proposed longwalls will be extracted in single-seam mining conditions. The Bowfield Seam and then the Warkworth Seam will be successively mined beneath the previously extracted seams and, therefore, these proposed longwalls will be extracted in multi-seam mining conditions.

1.3. Surface and Seam Information

The surface level contours within the EL are shown in Drawing No. MSEC616-110. The main topographical feature within the EL is a ridgeline, which runs approximately north-south, and has a high point of around 345 metres Australian Height Datum (mAHD) within the EL. The topographical low in the area is the Hunter River, located to the west and to the south of the EL, which is at around 110 mAHD.

The depth of cover contours for the Whynot, Bowfield and Warkworth Seams are provided in Drawing Nos. MSEC616-111, MSEC616-112 and MSEC616-113, respectively. The seam thickness contours for Whynot, Bowfield and Warkworth Seams are provided in Drawing Nos. MSEC616-121, MSEC616-122 and MSEC616-123, respectively. A summary of the seam information within the extents of the proposed mining area is provided in Table 1.2.

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

Seam	Depth of Cover (m)	Interburden Thickness to Overlying Seam (m)	Seam Thickness (m)	Extraction Height (m)
Whynot (WN)	160 ~ 340 (230 average)	-	2.5 ~ 3.5 (3.1 average)	2.5 ~ 3.5 (3.1 average)
Bowfield (BF)	350 ~ 490 (400 average)	145 ~ 175 (155 average)	1.9 ~ 3.7 (2.5 average)	1.9 ~ 3.7 (2.5 average)
Warkworth (WW)	400 ~ 570 (470 average)	40 ~ 70 (50 average)	2.4 ~ 5.0 (3.7 average)	2.4 ~ 4.5 (3.6 average)

The surface and seam levels are also illustrated along Cross-section 1 to Cross-section 3 in Fig. 1.2 to Fig. 1.4. The locations of these cross-sections are shown in Drawing Nos. MSEC616-110 to MSEC616-113. The numbers shown above or below each of the seams are the seam thicknesses.

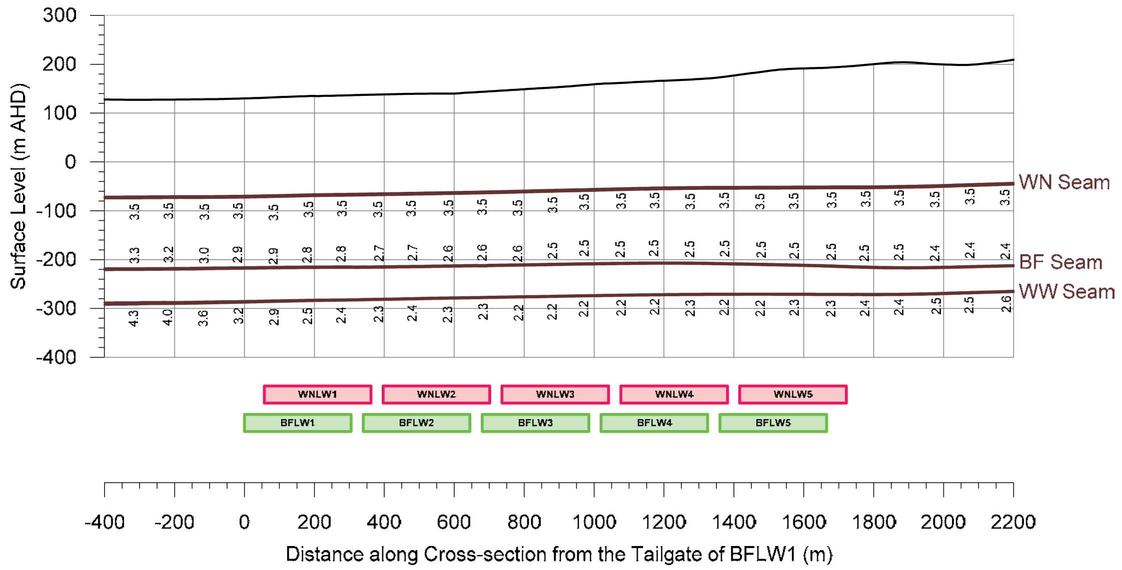

Fig. 1.2 Seam Information along Cross-section 1

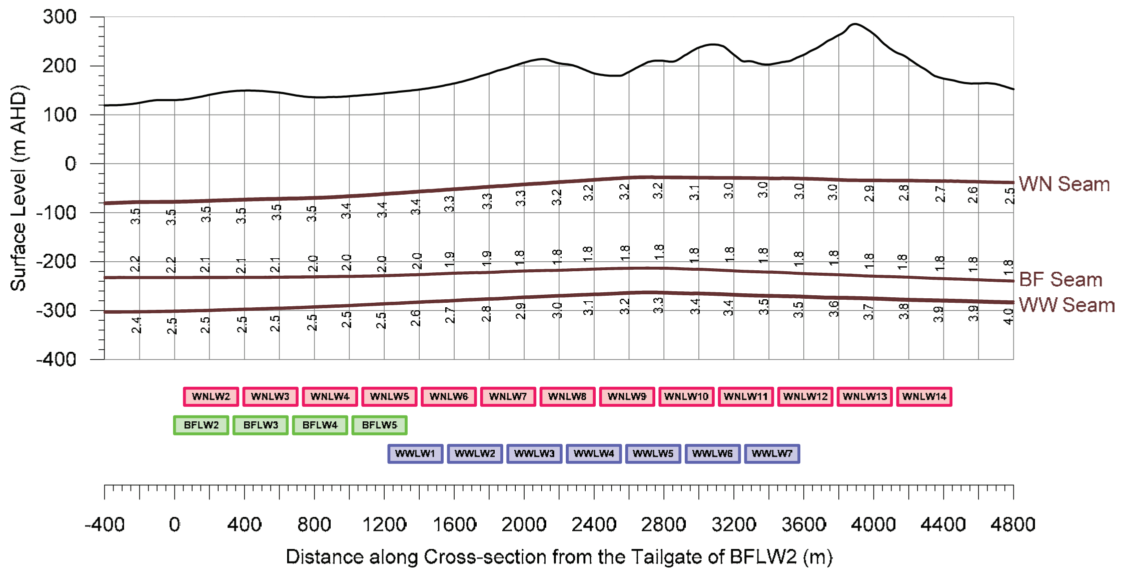

Fig. 1.3 Seam Information along Cross-section 2

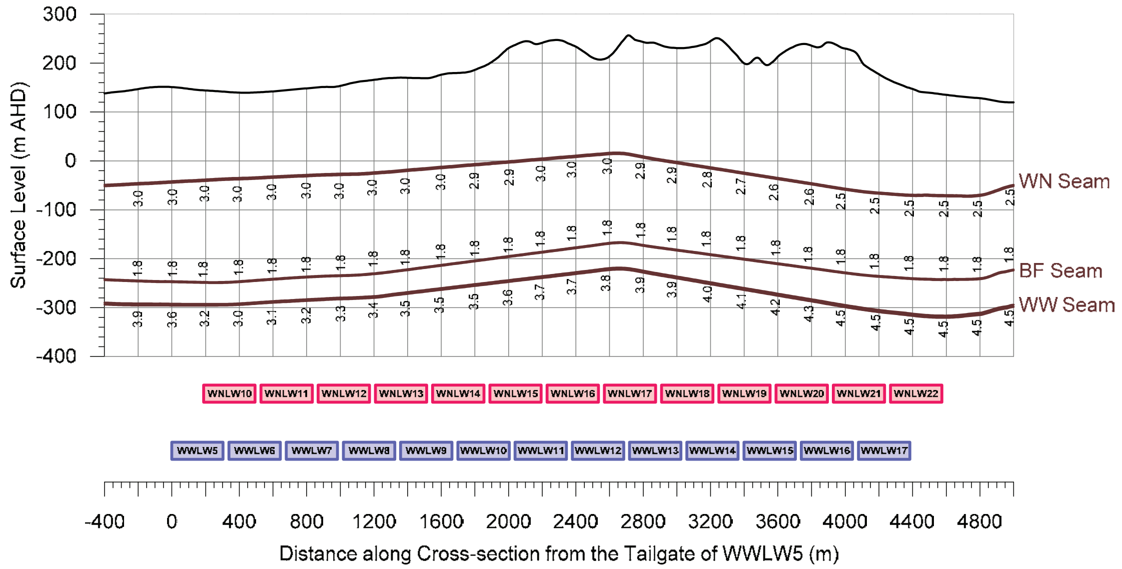

Fig. 1.4 Seam Information along Cross-section 3

The target seams in the northern part of the EL generally dip from the east down towards the west, with average gradients around 2 % to 4 % within the proposed mining area. The target seams in the southern part of the EL generally dip from the north down towards the south, with average gradients around 2 % to 3 % within the proposed mining area.

There is a monocline or major fault located to the east of the proposed longwalls. The depths of cover to the target seams, to the east of this geological feature, are in the order of 100 metres shallower when compared with those within the proposed mining area, as shown in Drawing Nos. MSEC616-111 to MSEC616-113. This geological feature will be better defined during the ongoing exploration within the EL.

1.4. Geological Details

The EL lies in the Hunter Coalfield within the Northern Sydney Basin. The general stratigraphy of the Hunter Coalfield is shown in Table 1.3 (Stevenson, et al, 1998). The strata associated with the coal seams within the EL were laid down during the Permian Period and comprise the Wittingham and Newcastle Coal Measures of the Singleton Supergroup.

The target seams lie within the Jerrys Plains Subgroup of the Wittingham Coal Measures which is shown in Table 1.4. The Denman Formation marks the top of the Wittingham Coal Measures, which is overlain by the Newcastle Coal Measures. The Newcastle Coal Measures comprise the Watts Sandstone and the Apple Tree Flat, Horseshoe Creek, Doyles Creek and Glen Gallic Subgroups.

Table 1.3 Middle Permian to Quaternary Stratigraphy of the Hunter Coalfield (Stevenson, et al, 1998)

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

Table 1.4 Stratigraphy of the Wittingham Coal Measures

<table>
<tr><th colspan="3">Stratigraphy</th><th colspan="2">Lithology</th></tr>
<tr><td rowspan="10">Wittingham Coal Measures</td><td colspan="4">Denman Formation</td></tr>
<tr><td rowspan="5">Jerrys Plains Subgroup</td><td>Mount Leonard Formation
Althorpe Formation
Malabar Formation
Mount Ogilvie Formation</td><td colspan="2">Whybrow seam
Redbank Creek seam
Wambo seam
Whynot seam
Blakefield seam
Saxonvale Member
Glen Munro seam
Woodlands Hill seam</td></tr>
<tr><td colspan="3">Millbrodale Formation</td></tr>
<tr><td>Mount Thorley Formation</td><td colspan="2">Arrowfield seam
Bowfield seam
Warkworth seam</td></tr>
<tr><td colspan="3">Fairford Formation</td></tr>
<tr><td>Burnamwood Formation</td><td colspan="2">Mount Arthur seam
Piercefield seam
Vaux seam
Broonie seam
Bayswater seam</td></tr>
<tr><td colspan="4">Archerfield Sandstone</td></tr>
<tr><td rowspan="2">Vane Subgroup</td><td colspan="3">Bulga Formation</td></tr>
<tr><td>Foy Brook Formation</td><td>Lemington seam
Pikes Gully seam
Arties seam
Liddell seam
Barrett seam
Hebden seam</td><td>Wynn C. M.
Edderton C. M.
Clanricard C. M.
Bengalla C. M.
Edinglassie C. M.
Ramrod Ck. C.M.</td></tr>
<tr><td colspan="4">Saltwater Creek Subgroup</td></tr>
</table>

The locations of the available drillholes within the EL are shown in Drawing No. MSEC616-133. A review of the graphical logs indicate that the interburden between the target seams generally comprise frequently bedded sandstone, siltstone and mudstone layers, with some thinner intermediate tuff and coal bands. There were three potentially massive units identified above the Bowfield Seam, having thicknesses between 11 metres and 16 metres (SG, 2013). Otherwise the bedding thicknesses were typically less than 10 metres.

There is a monocline or major fault located to the east of the proposed longwalls, refer to the changes in the depths of cover contours shown in Drawing Nos. MSEC616-111 to MSEC616-113. The proposed mining area is located around 400 metres west of this geological feature, at its closest point, which occurs in the southern part of the EL. At this distance, the monocline or major fault is unlikely to have a significant effect on the predicted subsidence movements above the proposed longwalls. This geological feature will be better defined during the ongoing exploration within the EL.

The surface lithology is shown in Fig. 1.5 (after Resource Strategies). The surface lithology within the EL is predominately derived from the Newcastle Coal Measures, except in the south-eastern corner of the EL (east of the monocline or major fault, which is referred to as the *Mt. Ogilvie Structure* in this figure) which is derived from the Wittingham Coal Measures. Quaternary Alluvium is also present in the north-western and south-eastern corners of the EL which is associated with the Hunter River.

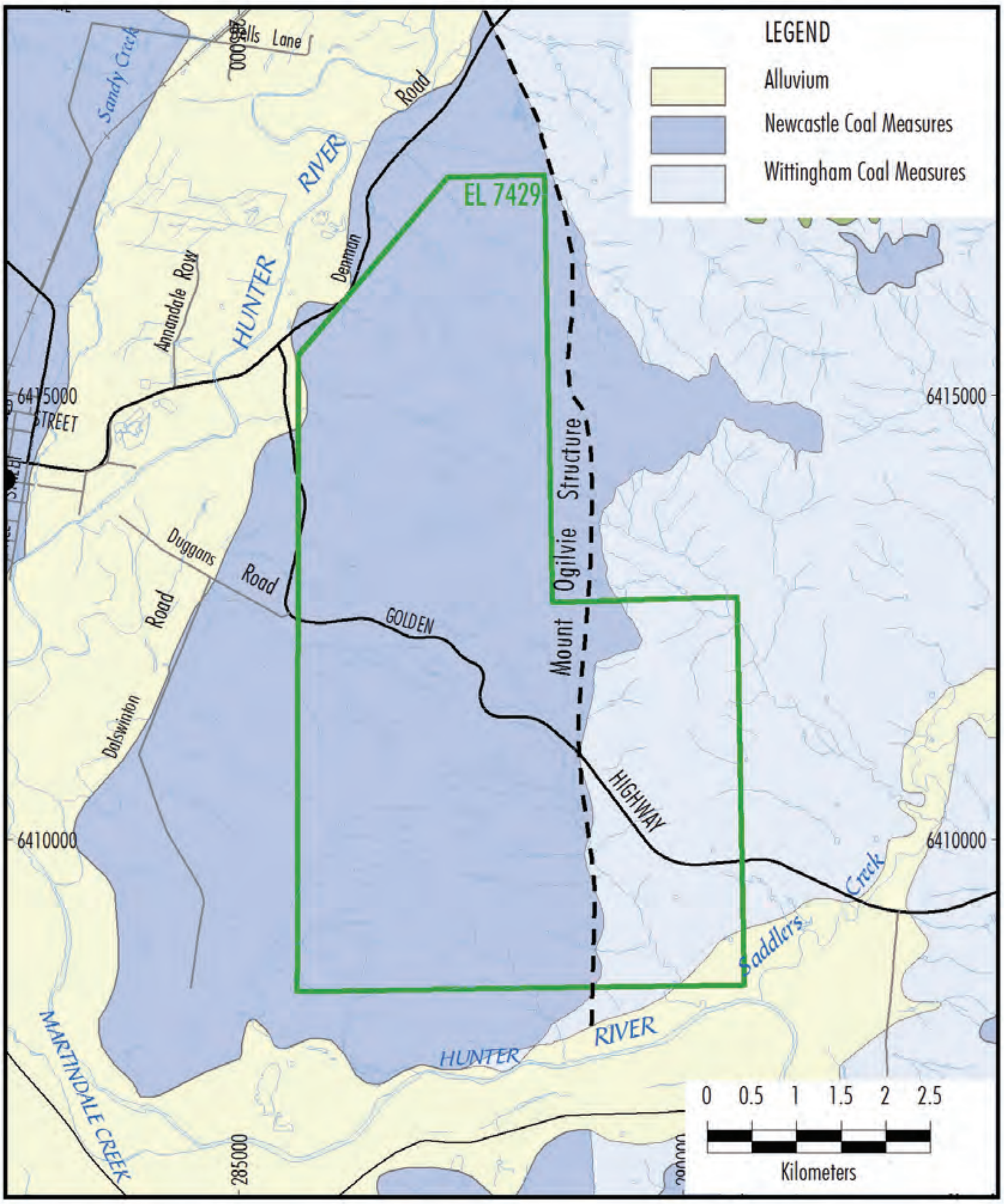

Fig. 1.5 Surface Lithology within the Spur Hill Exploration Licence (EL7429) Boundary (Source: Resource Strategies)

2.1. Introduction

The major natural and built features within the EL can be seen in the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA), numbered 9032, 9033, 9132 and 9133. The EL boundary has been overlaid on extracts of these CMA maps in Fig. 2.1. The EL boundary has also been overlaid on the aerial photograph of the area in Fig. 2.2. The surface topography and the larger natural features can also be seen in this figure.

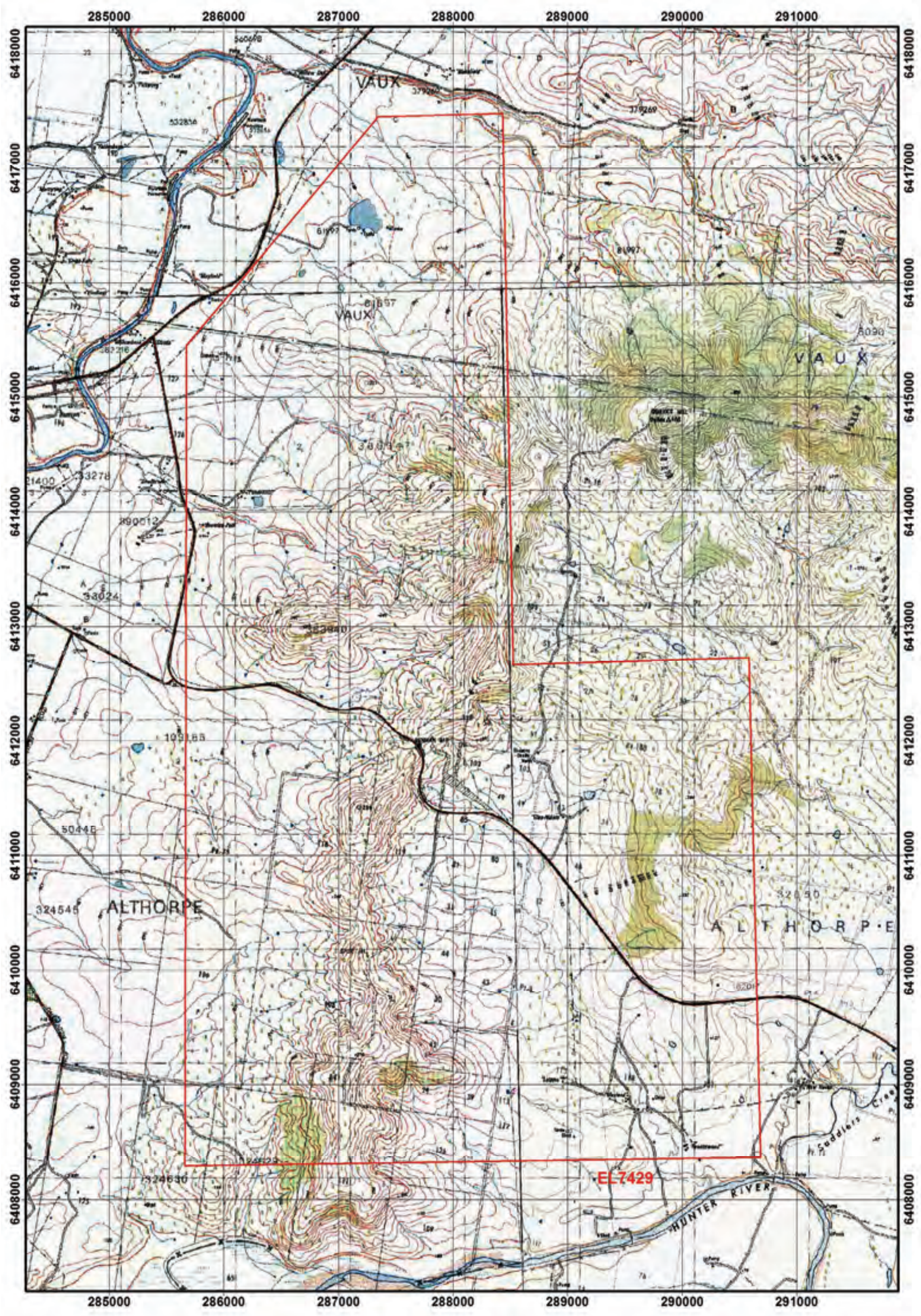

Fig. 2.1 The Spur Hill Exploration Licence (EL7429) Boundary Overlaid on CMA Map Nos. 9032, 9033, 9132 and 9133

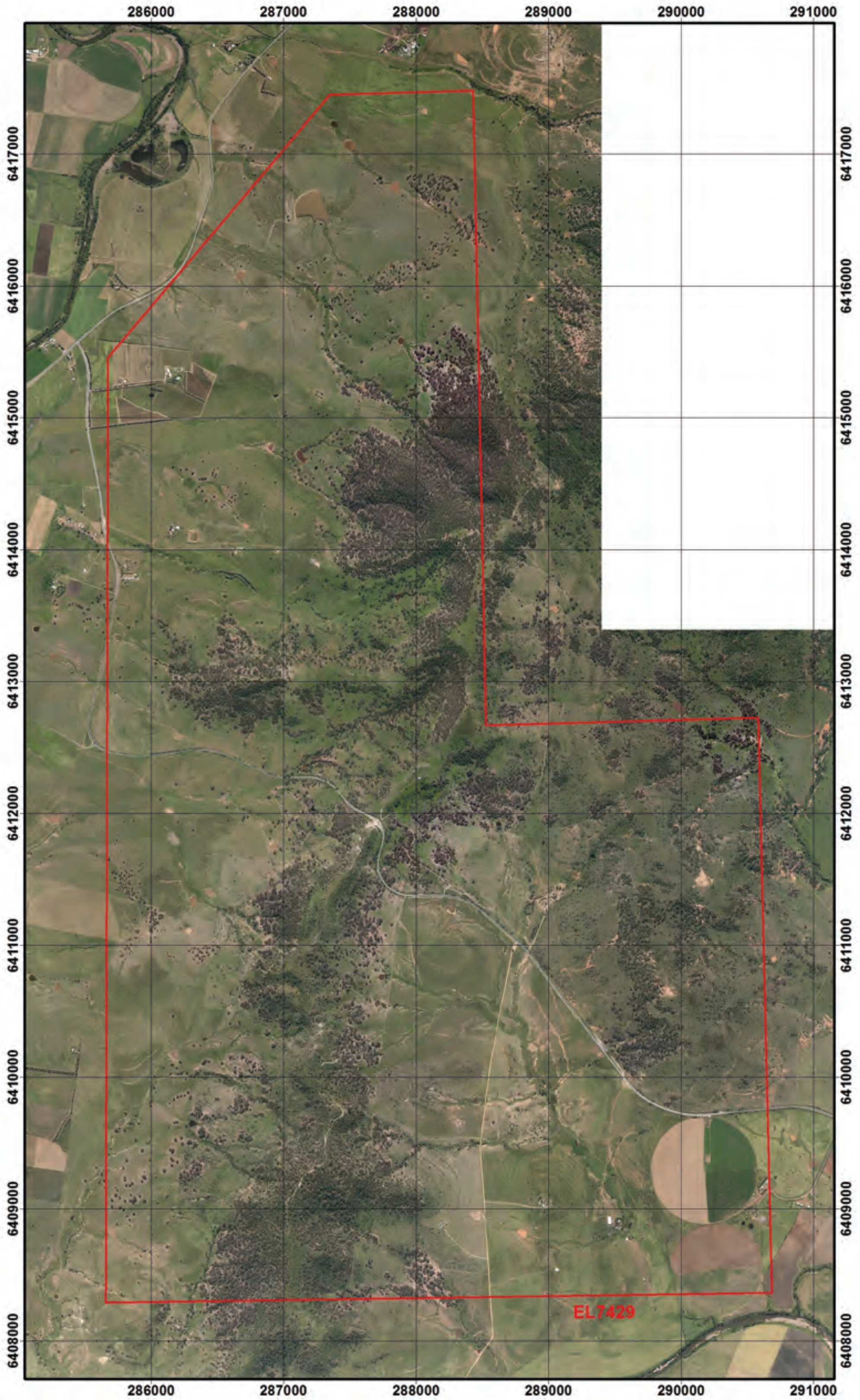

Fig. 2.2 The Spur Hill Exploration Licence (EL7429) Boundary Overlaid on the Aerial Photograph (May 2013)

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

2.2. Strategic Agricultural Land

The *Strategic Agricultural Land* (SAL) within the EL is shown in Drawing No. MSEC616-130, which is based on the mapping provided in the *Upper Hunter Strategic Land Use Plan* by the Department of Planning and Infrastructure (DoPI, 2012) and on-site verification of *BSAL*. The mapped strategic agricultural land includes the following:-

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

  The majority of the land within the EL has been identified as *Equine Critical Industry Cluster (CIC)*. It is noted, however, that there are no active horse studs operating within the EL. The NSW Government has released draft revised mapping of critical industry clusters that substantially reduces the area of *Equine CIC* within the EL.

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

  The north-western and the southern parts of the EL have been identified as *Viticulture CIC*. There is one vineyard and other farm related infrastructure in these areas, which are described in the following sections. Only the north-western corner of the EL has been mapped as *Viticulture CIC* in the draft revised mapping of critical industry clusters released by the NSW Government.

- *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 in a western portion of the EL over an area of approximately 86 hectares.

2.3. Agricultural Utilisation

The agricultural land uses within the EL are shown in Drawing No. MSEC616-131. The land within the EL is used for agricultural and light residential purposes, which includes:-

- Vineyard, winery and cellar door on Property 9 – refer to Section 5.7.1,
- Centre pivot irrigation areas – refer to Section 5.7.2, and
- Cattle grazing – refer to Section 5.7.3.

Whilst there are no horse studs within the EL, the potential impacts on any future horse studs have also been considered in Section 5.7.4.

2.4. Natural Features

The locations of the natural features within and in the vicinity of the EL are shown in Drawing No. MSEC616-132. The natural features which are important to the agricultural land and utilisation include:-

- The Hunter River and associated alluvial aquifer – 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 within and in the vicinity of the EL are shown in Drawing No. MSEC616-133. The built features which are important to the agricultural land and utilisation within the EL include:-

- Houses, rural building structures and other farm structures,
- Farm dams and groundwater bores,
- Cellar door and winery on Property 9,
- The Dalswinton Rural Fire Service building facilities,
- The Golden Highway,
- 66 kilovolt (kV) and low voltage powerlines, and
- Copper and optical fibre cable telecommunications infrastructure.

The abovementioned features are discussed in Sections 5.6 and 5.8. A cemetery and other heritage items have also been identified within the EL, but these are not directly associated with the agricultural land or utilisation. The cemetery and other heritage items are not discussed further in this report, but will be assessed as part of the Environmental Impact Statement (EIS).

3.0 OVERVIEW OF LONGWALL MINING, THE DEVELOPMENT OF SUBSIDENCE, AND THE METHOD USED TO PREDICT THE MINE SUBSIDENCE PARAMETERS FOR THE PROPOSED LONGWALLS

3.1. Introduction

Overviews of longwall mining, the development of mine subsidence and the methods of predicting mine subsidence movements are provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

The following sections provide overviews of conventional and non-conventional mine subsidence 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 1,000.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres* (km^{-1}), but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.
- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile Strains** occur where the distance between two points increases and **Compressive Strains** occur when the distance between two points decreases. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

  Whilst mining induced normal strains are measured along monitoring lines, ground shearing can also occur both vertically and horizontally across the directions of monitoring lines. Most of the published mine subsidence literature discusses the differential ground movements that are measured along subsidence monitoring lines, however, differential ground movements can also be measured across monitoring lines using 3D survey monitoring techniques.
- **Horizontal shear deformation** across monitoring lines can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. It is not possible, however, to determine the horizontal shear strain across a monitoring line using 2D or 3D monitoring techniques.

  High deformations along monitoring lines (i.e. normal strains) are generally measured where high deformations have been measured across the monitoring line (i.e. shear deformations), and vice versa.

The **incremental** subsidence, tilts, curvatures and strains are the additional parameters which result from the extraction of each longwall. The **additional** subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of a series of longwalls within a single seam. The **total** subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of longwalls from a number of seams.

3.3. Far-field Movements

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

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

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

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

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

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

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

3.4.1. Non-conventional Subsidence 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

The watercourses within the EL may be subjected to valley related movements, which are commonly observed along stream alignments in the Southern Coalfield, but less commonly observed in the Hunter and Newcastle Coalfields. The reason why valley related movements are less commonly observed in the Hunter and Newcastle Coalfields could be that the conventional subsidence movements are typically much larger than those observed in the Southern Coalfield and tend to mask any smaller valley related movements which may occur.

Valley bulging movements are a natural phenomenon, resulting from the formation and ongoing development of the valley, as illustrated in Fig. 3.1. The potential for these natural movements are influenced by the geomorphology of the valley.

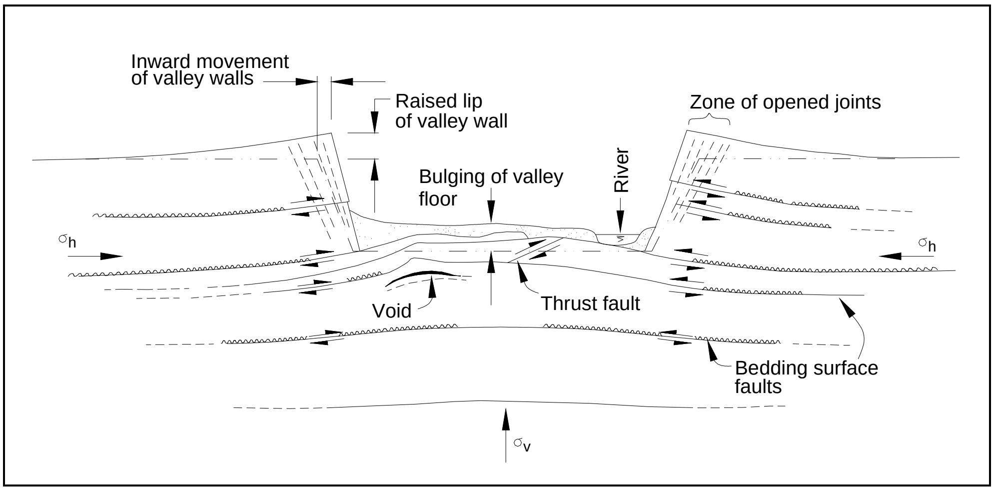

Fig. 3.1 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

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

- **Upsidence** is the reduced subsidence, or the relative uplift within a valley which results from the dilation or buckling of near surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.

- **Closure** is the reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides.

- **Compressive Strains** occur within the bases of valleys as a result of valley closure and upsidence movements. **Tensile Strains** also occur in the sides and near the tops of the valleys as a result of valley closure movements. The magnitudes of these strains, which are typically expressed in the units of *millimetres per metre (mm/m)*, are calculated as the changes in horizontal distance over a standard bay length, divided by the original bay length.

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

3.5. The Incremental Profile Method

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

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

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

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

Based on the extensive empirical data, MSEC has developed standard subsidence prediction curves for the Southern, Newcastle and Hunter Coalfields. The 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 Incremental Profile Method for local single-seam and multi-seam mining conditions are provided in Section 3.6.

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

For longwalls in the Newcastle and Hunter Coalfields, the maximum predicted incremental subsidence is initially determined, using the Incremental Profile Method 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 Incremental Profile Method subsidence prediction curves for multiple longwalls, based on the longwall 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 Hunter Coalfield. The profile shapes are derived from the normalised subsidence profiles for monitoring lines where the mining geometry and overburden geology are similar to that for the proposed longwalls.

Finally, the total subsidence profiles resulting from the series of longwalls are derived by adding the predicted incremental profiles from each of the longwalls. Comparisons of the predicted total subsidence profiles, obtained using the Incremental Profile Method, 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 Incremental Profile Method 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 Incremental Profile Method for local single-seam and multi-seam mining conditions.

3.6. Calibration of the Incremental Profile Method

There are no existing workings within EL7429 and, therefore, the longwalls extracted in the first seam will be governed by single-seam mining conditions. The calibration of the Incremental Profile Method for local single-seam mining conditions is described in Section 3.6.1.

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

3.6.1. Calibration for Local Single-seam Mining Conditions

The first seam proposed to be extracted is the Whynot Seam. The proposed longwalls in the Whynot Seam have overall void widths of 305 metres and are at depths of cover ranging between 160 metres and 340 metres.

The width-to-depth ratios for the proposed longwalls in the Whynot Seam vary between 0.9 and 1.9 and, therefore, are critical to supercritical in width[3]. The maximum achievable subsidence in the Hunter Coalfield, for single-seam super-critical conditions, is generally 60 % to 65 % of the extracted height. The predicted subsidence for the proposed longwalls in the Whynot Seam varies between 55 % and 65 % of the proposed extraction height, depending on the local depth of cover.

The standard Incremental Profile Method for the Hunter Coalfield has been used to predict the mine subsidence movements at a number of nearby collieries, 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 longwall width-to-depth ratios are 0.4, 0.7 and greater than 2.0, are shown in Fig. 3.2, Fig. 3.3 and Fig. 3.4, respectively.

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 Incremental Profile Method 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 Incremental Profile Method. In Fig. 3.4, the longwall was super-critical and, in this case, the standard Incremental Profile Method 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 Incremental Profile Method. 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 exceed those predicted in other locations. This demonstrates the difficultly in predicting tilts and curvatures at a point, especially at shallow depths of cover. It is important then to recognise that there is greater potential for variation between observed and predicted movements at a point, as the depth of cover decreases.

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

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

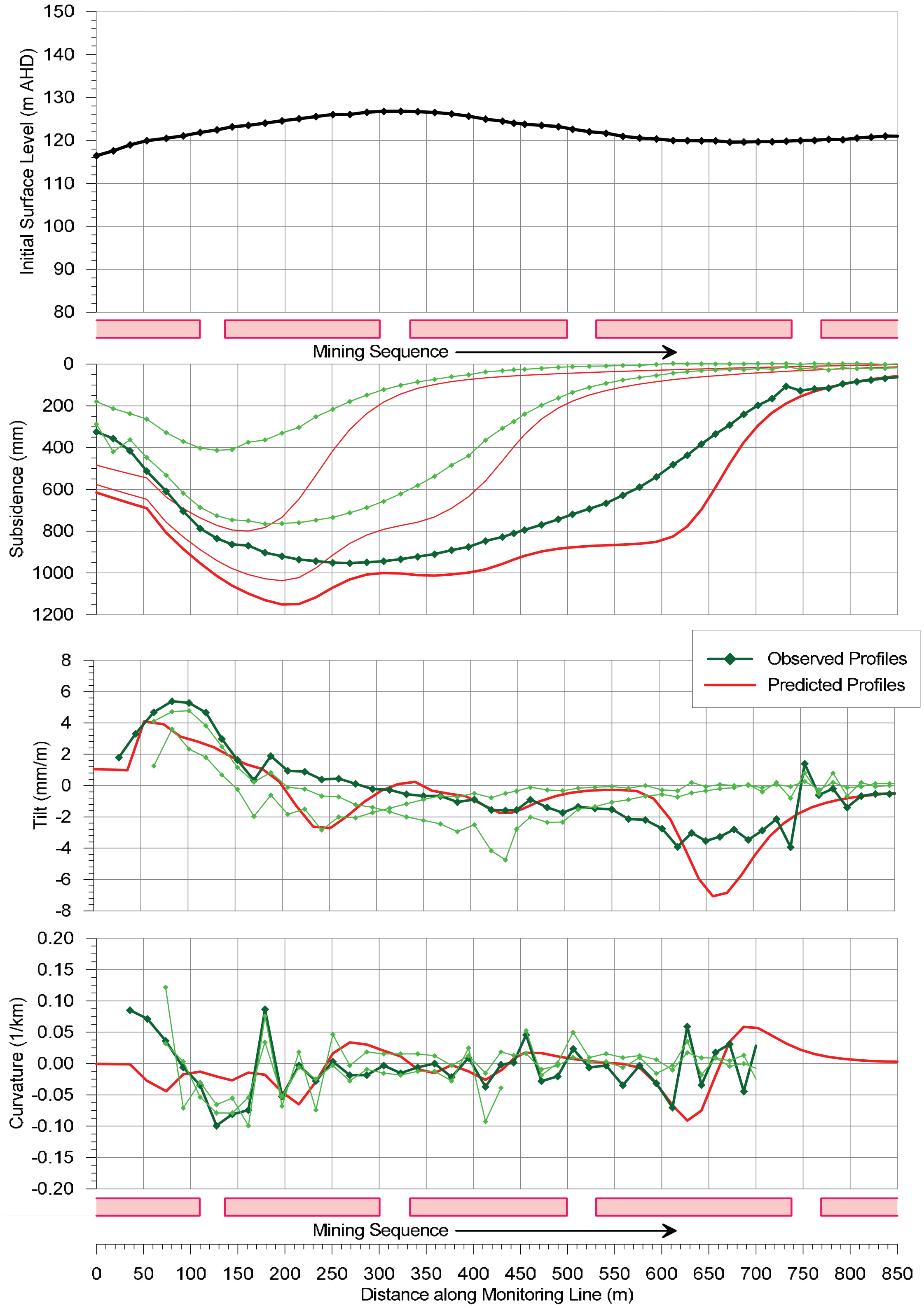

Fig. 3.2 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Newcastle Coalfield with Longwall W/H Ratio around 0.4

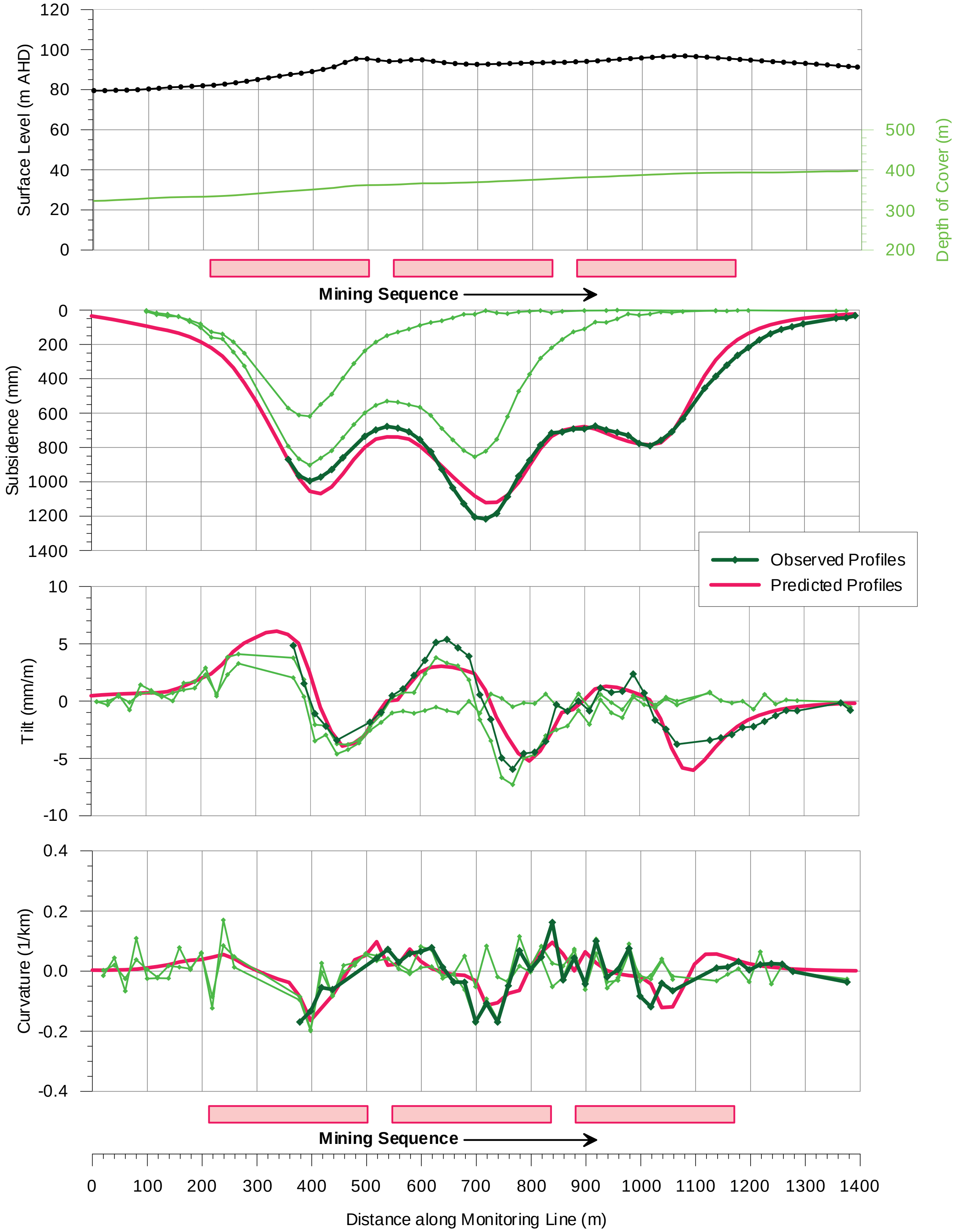

Fig. 3.3 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with Longwall W/H Ratio around 0.7

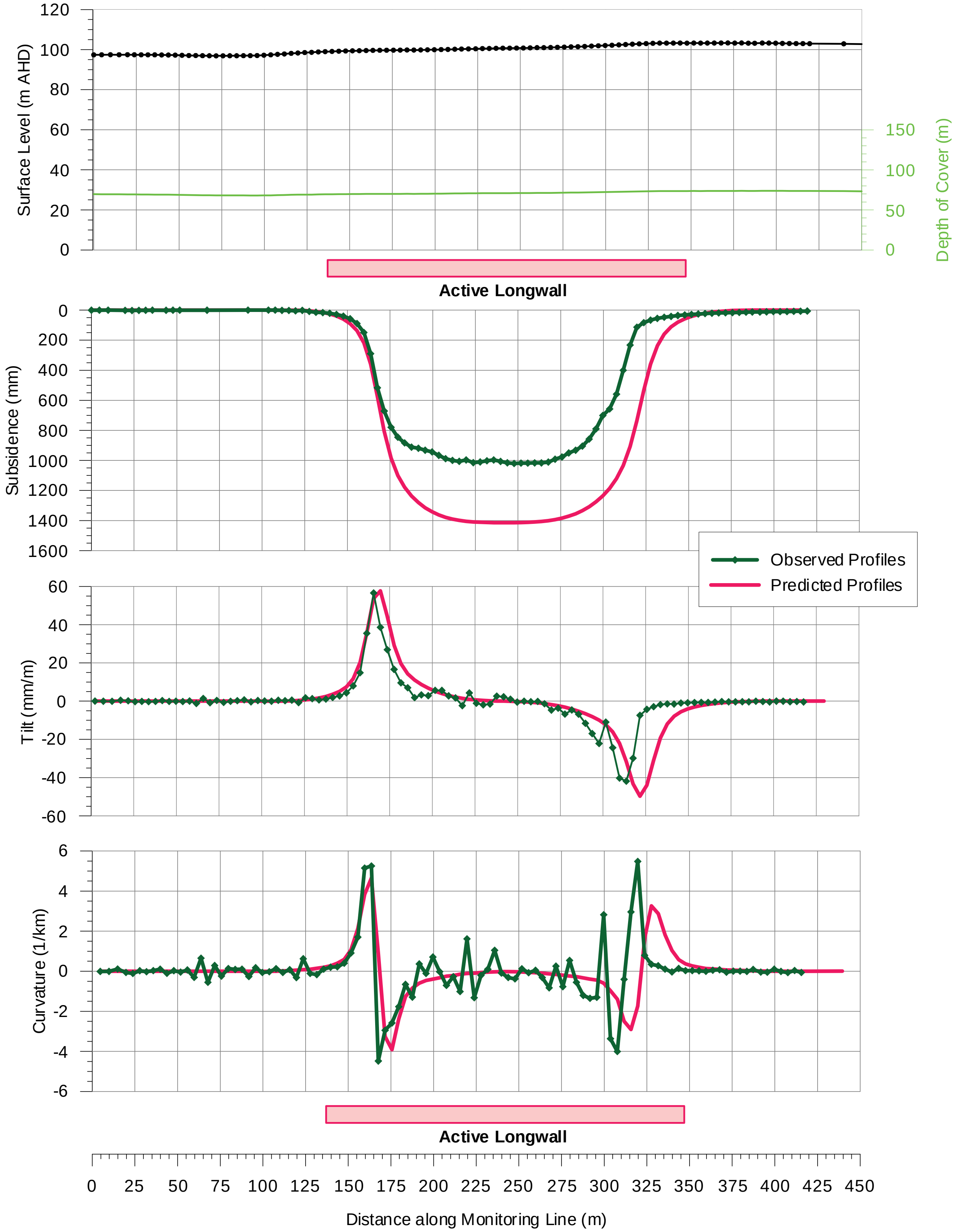

Fig. 3.4 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with Longwall W/H Ratio Greater than 2.0

3.6.2. Calibration for Multi-seam Mining Conditions

The second and third seams proposed to be extracted are the Bowfield and Warkworth Seams, respectively. The longwalls in these two seams will be extracted below the earlier extracted longwalls in the Whynot Seam and, therefore, will be governed by multi-seam conditions. Parts of the northern longwalls in the Warkworth Seam will also be extracted beneath the longwalls in the Bowfield Seam. In some cases, however, the longwalls in the Bowfield and Warkworth Seams extend beyond the extents of the previously extracted longwalls and, therefore, will also be governed by single-seam conditions in these locations.

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

As described in the paper by Li et al (2007), entitled "*A Case Study on Multi-seam Subsidence with Specific Reference to Longwall Mining under Existing Longwall Goaf*", the maximum additional subsidence resulting from the extraction of longwalls, for multi-seam mining conditions, can be estimated from the following equation:-

Equation 1 $S_2 = a_2 T_2$ (Li, et al, 2007)

where $a_2 = (a_m - a_1)(T_1 / T_2) + a_m$

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

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

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

T_1 = Extracted seam thickness in first seam

T_2 = Extracted seam thickness in second seam

The value of 'a_1' can be calculated from the predicted subsidence resulting from the extraction of the proposed longwalls in the first seam (i.e. single-seam conditions).

The value of "a_m" can be determined from the observations from previous multi-seam longwall mining cases. There is limited multi-seam monitoring data from the coalfields of New South Wales, especially where longwalls have been extracted directly beneath or above existing longwalls or panels. Historical information on multi-seam mining include the following cases:-

- Newstan Colliery Longwall 8 in the Fassifern Seam – below LW6 in the Great Northern Seam
- Newstan Colliery Longwalls 1, 2, 3 and 4 – below extracted pillar workings
- Wyee Colliery Longwalls 1, 2, 3, 4, 7 and 9 – below extracted pillar workings
- John Darling Colliery Longwall 1 – below extracted pillar workings
- Teralba Colliery Longwalls 6, 7, 8 and 9 – below extracted pillar workings
- Kemira Colliery Longwalls 1 to 6 – below extracted pillar workings
- Blakefield South Longwall 1 in the Blakefield Seam – below LW3 to LW6 in the Whybrow Seam

The observations from a number of additional multi-seam cases were also provided in the paper by Li et al (2007), which included the following:-

- Sigma Colliery, South Africa – LW4A extracted beneath LW4
- Liddell Colliery, NSW – LW3 extracted beneath LW1
- Cumnock Colliery, NSW – LW17 extracted above LW3

A summary of the details, observed subsidence and extraction heights for the multi-seam mining case studies where longwalls were mined beneath or above previous longwalls is provided in Table 3.1.

Table 3.1 Multi-seam Mining Cases for Longwalls Mining Beneath or Above Previous Longwalls

Colliery [Coalfield] (Location)	Seam	Longwall	Depth of Cover (m)	Interburden Thickness (m)	Subsidence (m)	Seam Thickness (m)	a_1 / a_2	a_m
Sigma Colliery [South Africa] (Trans Line)	No. 3 No. 2B	LW4 LW4A	135 150	13	S_1 = 1.1 S_2 = 2.92	T_1 = 2.75 T_2 = 3.05	a_1 = 0.40 a_2 = 0.96	a_m = 0.69
Liddell Colliery [Hunter Coalfield] (LW Centreline)	Upper Liddell Middle Liddell	LW1 & LW2 LW3	160 200	40	S_1 = 1.6 S_2 = 2.0	T_1 = 2.72 T_2 = 2.65	a_1 = 0.59 a_2 = 0.76	a_m = 0.67*
Cumnock Colliery [Hunter Coalfield] (LW17CLB)	Liddell Lower Pikes	LW3 LW17	135 90	43	S_1 = 1.25 S_2 = 1.72	T_1 = 2.50 T_2 = 2.20	a_1 = 0.50 a_2 = 0.78	a_m = 0.63
Newstan Colliery [Newcastle Coalfield]	Great Northern Fassifern	Panel 6 Panel 8	55 70	15	S_1 = 2.03 S_2 = 3.22	T_1 = 3.4 T_2 = 3.2	a_1 = 0.60 a_2 = 1.01	a_m = 0.80

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

Detailed ground monitoring was also undertaken during the extraction of Blakefield South Longwalls 1 and 2 (BSLW1 and BSLW2) in the Blakefield Seam, beneath the previously extracted LW1 to LW6 in the overlying Whybrow Seam. The interburden thickness between the Whybrow and Blakefield Seams typically varies between 70 metres and 90 metres.

The additional subsidence observed along the monitoring lines, resulting from the extraction of BSLW1 and BSLW2, typically varied between 70 % and 100 % of the mining height (i.e. a_2 = 0.7 ~ 1.0) and, on average, was around 85 % of the mining height (i.e. a_2 = 0.85). In some cases, the observed subsidence was greater than the mining height, but this was very localised and the observed subsidence elsewhere along the monitoring lines was less than the mining height.

Multi-seam Calibration for the Bowfield Seam

The proposed longwalls in the Bowfield Seam will be extracted directly beneath the proposed longwalls in the Whynot Seam. The interburden thickness between the Bowfield and Whynot Seams typically varies between 145 metres and 175 metres. It is considered, therefore, that the most relevant case studies are Liddell and Cumnock, which had the greater interburden thicknesses of 40 metres and 43 metres, respectively, rather than Sigma and Newstan, which had shallower interburden thicknesses of only 13 metres and 15 metres, respectively.

It is noted, that the interburden thickness between the Bowfield and Whynot Seams is greater than those for the available multi-seam case studies and, therefore, the method of calibration is likely to provide some conservatism for the multi-seam predictions. As fracturing and bedding plane separation due to the extraction of the Bowfield Seam is likely to extend up to the Whynot Seam, resulting in reactivation of the existing goaf, it is considered important to adopt this conservative approach.

Based on Liddell and Cumnock, it appears that adopting a value for "a_m" of 75 % would be appropriate for the proposed longwalls in Bowfield Seam for multi-seam conditions. It was recommended in the paper by Li et al (2007) that 80 % could be adopted for "a_m" based on the available multi-seam mining cases, however, this recommendation was based on a value of 83 % for "a_m" for Liddell Colliery, which has been shown to be 67 % based on the most recent seam information from the colliery.

The depth of cover above the proposed longwalls in the Whynot Seam (i.e. first seam to be mined) typically varies between 160 metres and 340 metres, with an average depth of cover around 230 metres. The width-to-depth ratios of these proposed longwalls vary between 0.9 and 1.9 and, therefore, the predicted maximum subsidence typically varies between 55 % (i.e. a_1 = 0.55) and 65 % (i.e. a_1 = 0.65) of the extracted seam thickness.

The extraction height within the Whynot Seam typically varies between 3.0 metres and 3.5 metres, above the proposed longwalls in the Bowfield Seam, with an average extraction height around 3.3 metres (i.e. T_1 = 3.3). The extraction height within the Bowfield Seam typically varies between 1.9 metres and 3.7 metres, with an average extraction height around 2.5 metres (i.e. T_2 = 2.5).

The maximum predicted additional subsidence resulting from the extraction of the proposed longwalls in the Bowfield Seam, as a proportion of the extracted seam thickness, therefore, has been calculated as follows:-

Equation 2 $a_2 = (0.75 - 0.55)(3.3/2.5) + 0.75 = 1.0$ *based on a_1 = 0.55*

$a_2 = (0.75 - 0.65)(3.3/2.5) + 0.75 = 0.9$ *based on a_1 = 0.65*

The maximum additional subsidence due to the extraction of the proposed longwalls in the Bowfield Seam, therefore, is predicted to be between 90 % and 100 % of the mining height. This is consistent with the recent ground monitoring data which has been collected from Blakefield South, where BSLW1 and BSLW2 extracted directly beneath the longwalls in the overlying Whybrow Seam, where the subsidence typically varied between 70 % and 100 % of the mining height.

The maximum additional subsidence due to the extraction of the proposed longwalls in the Bowfield Seam, therefore, has conservatively been taken as 100 % of the mining height (i.e. a_2 = 1.0).

Multi-seam Calibration for the Warkworth Seam

In the northern part of the EL, the proposed longwalls in the Warkworth Seam will be extracted directly beneath the proposed longwalls in both the Whynot and Bowfield Seams. In this case, the extraction of these longwalls will reactivate the existing goafs above the Bowfield Seam and, to a lesser extent, above the Whynot Seam.

There is very limited multi-seam monitoring data where longwalls have been extracted beneath two longwall goafs. For this reason, the predictions have been made based on the method proposed by Li et al (2007) assuming full reactivation of the goaf associated with Bowfield Seam and negligible reactivation of the goaf associated with the Whynot Seam. This should provide conservative predictions, as the proposed longwalls in the overlying Bowfield Seam have been assumed to be extracted in single-seam conditions and, hence, allowing for greater reactivation of the existing goaf.

The interburden thickness between the Warkworth and Bowfield Seams, in the northern part of the EL, typically varies between 50 metres and 60 metres. Adopting a value for "a_m" of 75 %, therefore, would be appropriate for the proposed longwalls in Warkworth Seam for multi-seam conditions based on the available case studies.

The depth of cover above the proposed longwalls in the Bowfield Seam (i.e. overlying seam) typically varies between 350 metres and 490 metres, with an average depth of cover around 400 metres. The width-to-depth ratios of these proposed longwalls vary between 0.6 and 0.9 and, therefore, the predicted maximum subsidence based on single-seam mining conditions typically varies between 35 % (i.e. a_1 = 0.35) and 55 % (i.e. a_1 = 0.55) of the extracted seam thickness.

The extraction height within the Bowfield Seam typically varies between 1.9 metres and 2.4 metres, above the Warkworth Seam, with an average extraction height around 2.1 metres (i.e. T_1 = 2.1). The extraction height within the Warkworth Seam typically varies between 2.4 metres and 3.0 metres, beneath the Bowfield Seam, with an average extraction height around 2.6 metres (i.e. T_2 = 2.6).

In the northern part of the EL, the maximum predicted additional subsidence resulting from the extraction of the proposed longwalls within the Warkworth Seam as a proportion of the extracted seam thickness is:-

Equation 3 $a_2 = (0.75 - 0.35)(2.1/2.6) + 0.75 = 1.07$ *based on a_1 = 0.35*

$a_2 = (0.75 - 0.55)(2.1/2.6) + 0.75 = 0.91$ *based on a_1 = 0.55*

The maximum additional subsidence due to the extraction of the proposed longwalls in the Warkworth Seam, in the northern part of the EL, therefore, has been taken as 100 % of the mining height (i.e. a_2 = 1.0). This has been considered conservative, as the above method assumes single-seam mining conditions for the overlying Bowfield Seam and, therefore, over-predicts the reactivation of the overlying goaf.

In the central and southern parts of the EL, the proposed longwalls in the Warkworth Seam will be extracted directly beneath the proposed longwalls in the Whynot Seam only. That is, the longwalls in the Bowfield Seam are only proposed to be extracted in the northern part of the EL. The interburden thickness between the Warkworth and Whynot Seams, in the central southern part of the EL, typically varies between 220 metres and 250 metres.

It is noted, that the interburden thickness between the Warkworth and Whynot Seams is greater than those for the available multi-seam case studies and, therefore, the method of calibration is likely to provide some conservatism for the multi-seam predictions. As fracturing and bedding plane separation due to the extraction of the Warkworth Seam is likely to extend up to the Whynot Seam, resulting in reactivation of the existing goaf, it is considered important to adopt this conservative approach.

The depth of cover above the proposed longwalls in the Whynot Seam (i.e. overlying seam) typically varies between 160 metres and 340 metres, in the central and southern parts of the EL, with an average depth of cover around 220 metres. The width-to-depth ratios of these proposed longwalls vary between 0.9 and 1.9 and, therefore, the predicted maximum subsidence typically varies between 55 % (i.e. a_1 = 0.55) and 65 % (i.e. a_1 = 0.65) of the extracted seam thickness.

The extraction height within the Whynot Seam typically varies between 2.5 metres and 3.5 metres, in the central and southern parts of the EL, with an average extraction height around 2.9 metres (i.e. T_1 = 2.9). The extraction height within the Warkworth Seam typically varies between 3.1 metres and 4.5 metres, in the central and southern parts of the EL, with an average extraction height around 3.8 metres (i.e. T_2 = 3.8).

In the central and southern parts of the EL, the maximum predicted additional subsidence resulting from the extraction of the proposed longwalls within the Warkworth Seam as a proportion of the extracted seam thickness is:-

Equation 4 $a_2 = (0.75 - 0.55)(2.9/3.8) + 0.75 = 0.90$ *based on a_1 = 0.55*

$a_2 = (0.75 - 0.65)(2.9/3.8) + 0.75 = 0.83$ *based on a_1 = 0.65*

The maximum additional subsidence due to the extraction of the proposed longwalls in the Warkworth Seam, in the central and southern parts of the EL, therefore, has conservatively been taken as 100 % of the mining height (i.e. a_2 = 1.0).

Shapes of the Multi-seam Subsidence Profiles

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

In the cases where the chain pillars within the lower seam are located directly beneath the chain pillars within the overlying seam, which are referred to as *Stacked Cases*, the observed subsidence profiles are steeper and more localised above the longwalls when compared with those for similar single-seam conditions. In the cases where the chain pillars within the lower seam are offset from the chain pillars within the overlying seam, which are referred to as *Staggered Cases*, the subsidence profiles are flatter and extend further when compared with those for similar single-seam conditions.

It can be seen from Figs. C.01 to C.03, in Appendix C, that the proposed longwalls in each seam have been offset from the longwalls in the overlying and underlying seams. The shapes of the multi-seam subsidence profiles for the proposed longwalls, for multi-seam conditions, have been based on profiles observed for similar *Staggered Cases*, which are illustrated in Fig. 3.5.

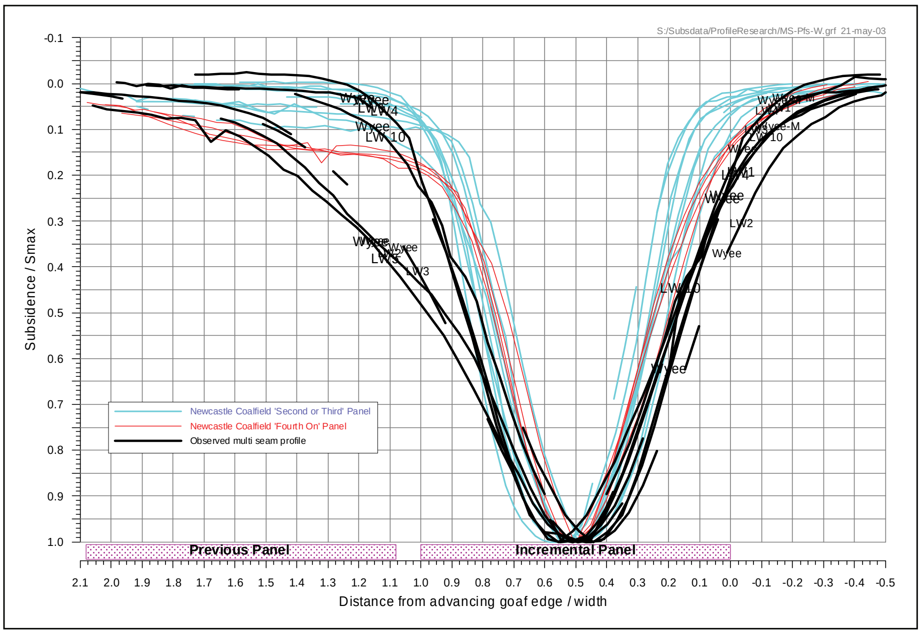

Fig. 3.5 Comparison of Observed Single Seam and Multi-seam Staggered Subsidence Profiles

The experience at Blakefield South was consistent with the profiles illustrated above, where flatter subsidence profiles were observed in the locations where the longwalls were offset (i.e. staggered). It was also observed, that locally increased subsidence occurred adjacent to the chain pillars in the overlying seam, and that locally reduced subsidence occurred directly above the chain pillars and directly above the middle of the longwalls in the overlying seam.

3.7. Reliability of the Predicted Conventional Subsidence Parameters

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

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

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

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

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

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

4.1. Introduction

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

The predicted subsidence, tilts and curvatures have been obtained using the Incremental Profile Method, which has been calibrated for single-seam and multi-seam conditions, as described in Section 3.6. The predicted strains have been determined by analysing the strains measured at other NSW Collieries, where the longwall width-to-depth ratios and extraction heights are similar to those for the proposed longwalls.

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

4.2. Maximum Predicted Subsidence, Tilt and Curvature

The predicted total subsidence contours after the extraction of the Whynot, Bowfield and Warkworth Seams are shown in Drawing Nos. MSEC616-140, MSEC616-141 and MSEC616-142, respectively.

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

Table 4.1 Maximum Predicted Additional Conventional Subsidence Parameters

Seam	Maximum Predicted Additional Conventional Subsidence (mm)	Maximum Predicted Additional Conventional Tilt (mm/m)	Maximum Predicted Additional Conventional Hogging Curvature (km^{-1})	Maximum Predicted Additional Conventional Sagging Curvature (km^{-1})
Due to Whynot Seam	2,300	30	0.7	0.7
Due to Bowfield Seam	3,100	35	0.8	0.8
Due to Warkworth Seam	4,100	25	0.6	0.6

Table 4.2 Maximum Predicted Total Conventional Subsidence Parameters

Seam	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})
After Whynot Seam	2,300	30	0.7	0.7
After Bowfield Seam	5,100	40	1.0	1.0
After Warkworth Seam	5,300	40	1.0	1.0

The maximum predicted total subsidence, after the extraction of the Whynot, Bowfield and Warkworth Seams, is 5,300 mm, which represents approximately 65 % of the total extraction height in all of these seams. It is noted, that the percentage of the total extraction height is less than the percentages of the extraction heights for individual seams for multi-seam conditions (i.e. 100 % for Bowfield and Warkworth Seams), as the positions of maximum subsidence do not coincide due to the stagger of the longwalls.

The maximum predicted total conventional tilt is 40 mm/m (i.e. 4 %), which represents a change in grade of 1 in 25. The maximum predicted total conventional curvatures are 1.0 km^{-1} hogging and sagging, which represent minimum radii of curvature of 1 kilometre.

It can be seen from Drawing Nos. MSEC616-140 to MSEC616-142, that the magnitudes of the predicted subsidence vary over the mining area, due to the varying single-seam and multi-seam mining conditions, as well as the variations in the depths of cover and proposed 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 three prediction lines, the locations of which are shown in Drawing Nos. MSEC616-140 to MSEC616-142. The predicted profiles of conventional subsidence, tilt and curvature along Prediction Lines 1, 2 and 3 are shown in Figs. C.01, C.02 and C.03, respectively, in Appendix C. The predicted profiles are shown after the completion of the longwalls in the Whynot Seam (red), Bowfield Seam (green) and Warkworth Seam (blue).

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

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. Discussions on the predicted strains are provided in the following sections.

4.3.1. Distribution of Strain for the Proposed Longwalls in the Whynot Seam for Single-seam Mining Conditions

It has been found, for single-seam mining conditions, that applying a constant factor to the predicted maximum curvatures provides a reasonable prediction for the maximum normal or conventional strains. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones. In the Hunter Coalfield, it has been found that a factor of 10 provides a reasonable relationship between the predicted maximum curvatures and the predicted maximum conventional strains, for single-seam mining conditions.

The maximum predicted conventional curvatures resulting from the extraction of the proposed longwalls in the Whynot Seam are 0.7 km^{-1} hogging and sagging. Adopting a factor of 10, the maximum predicted conventional strains, due to the proposed mining in the Whynot Seam only, are 7 mm/m tensile and compressive. Localised and elevated strains greater than the predicted conventional strains can also occur, as the 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.

The range of strains above the proposed longwalls in the Whynot Seam has been determined using monitoring data from previously extracted panels in the Hunter and Newcastle Coalfields, for single-seam conditions, where the width-to-depth ratios and extraction heights were similar to those of the proposed longwalls. Comparisons of the void widths, depths of cover, width-to-depth ratios and extraction heights for the proposed longwalls with those for the historical cases are provided in Table 4.3.

Table 4.3 Comparison of the Mine Geometry for the Proposed Longwalls in the Whynot Seam with the Longwalls in the Hunter and Newcastle Coalfields used in the Strain Analysis

Parameter	Longwalls in the Whynot Seam		Longwalls Used in Strain Analysis	
	Range	Average	Range	Average
Width (m)	305	305	135 ~ 410	205
Depth of Cover (m)	160 ~ 340	230	110 ~ 340	180
W/H Ratio	0.9 ~ 1.9	1.3	0.8 ~ 2.0	1.2
Extraction Height (m)	2.5 ~ 3.5	3.1	2.1 ~ 5.0	3.9

It can be seen from the above table, that the range of the longwall width-to-depth ratios used in the strain analysis was between 0.8 and 2.0, with an average ratio of 1.2, which is similar to the range for the proposed longwalls in the Whynot Seam. The range of extraction heights for the longwalls used in the strain analysis was between 2.1 metres and 5.0 metres, with an average of 3.9 metres, which was greater than the average extraction height for the proposed longwalls. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains for the proposed longwalls in the Whynot Seam.

The available monitoring lines have been analysed to extract the maximum tensile and compressive strains that have been measured at any time during mining, for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls. The frequency distribution of the maximum observed tensile and compressive strains measured in survey bays above goaf is provided in Fig. 4.1. The probability distribution functions, based on the fitted *Generalised Pareto Distributions* (GPDs), are also shown in this figure.

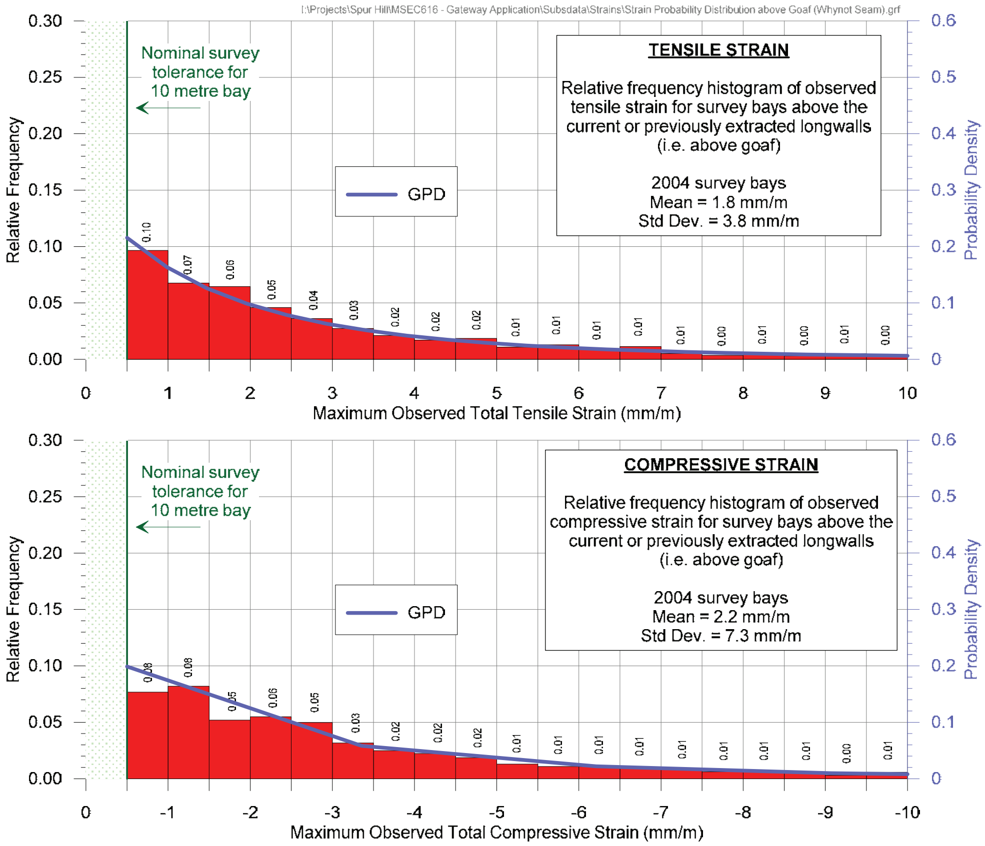

Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains in the Hunter and Newcastle Coalfields for Longwalls having W/H Ratios between 0.8 and 2.0

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).

The 95 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining were 8 mm/m tensile and 9 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining were 18 mm/m tensile and compressive. The maximum strains measured along the monitoring lines were greater than 20 mm/m tensile and compressive.

It is noted, that these strains are based on monitoring data having an average width-to-depth ratio of 1.2 and, therefore, the strains above the proposed longwalls are expected to be greater, on average, where the width-to-depth ratios are greater 1.2 (i.e. depths of cover less than 250 metres) and are expected to be less, on average, where the width-to-depth ratios are less than 1.2 (i.e. depths of cover greater than 250 metres).

4.3.2. Distribution of Predicted Strains for the Proposed Longwalls in the Bowfield and Warkworth Seams for Multi-seam Mining Conditions

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

The range of potential strains resulting from the extraction of the proposed longwalls in the Bowfield and Warkworth Seams, for multi-seam mining conditions, has been based on the observed strains for multi-seam mining in the Hunter and Newcastle Coalfields. The most extensive multi-seam strain data comes from Blakefield South Mine where Longwalls 1 and 2 (BSLW1 and BSLW2) were mined beneath the South Bulga longwalls in the overlying Whybrow Seam.

The mine subsidence movements were measured along 13 monitoring lines during the extraction of BSLW1 and BSLW2. Comparisons of the void widths, depths of cover, width-to-depth ratios, interburden thickness and extraction heights of the proposed longwalls in the Bowfield and Warkworth Seams, with those at Blakefield South, are provided in Table 4.4.

Table 4.4 Comparison of the Mine Geometry for the Proposed Longwalls in the Bowfield and Warkworth Seams with BSLW1 and BSLW2 at Blakefield South Mine

Parameter	Proposed Longwalls in the Bowfield Seam		Proposed Longwalls in the Warkworth Seam		Blakefield South BSLW1 and BSLW2	
	Range	Average	Range	Average	Range	Average
Width (m)	305	305	305	305	*330 & 400*	*365*
Depth of Cover (m)	350 ~ 490	400	400 ~ 570	470	*170 ~ 230*	*200*
W/H Ratio	0.6 ~ 0.9	0.8	0.5 ~ 0.8	0.65	*1.6 ~ 2.3*	*1.9*
Interburden Thickness (m)	145 ~ 175	155	40 ~ 70	50	*70 ~ 90*	*80*
Extraction Height (m)	1.9 ~ 3.7	2.5	2.4 ~ 4.5	3.4	*2.5 ~ 3.0*	*2.8*

The proposed longwalls in the Bowfield Seam have, on average, smaller width-to-depth ratios, larger interburden thicknesses, and similar but slightly smaller extraction heights when compared with BSLW1 and BSLW2. The strain analysis, therefore, should provide a conservative indication of the range of potential strains for the proposed longwalls in the Bowfield Seam.

The proposed longwalls in the Warkworth Seam have, on average, smaller width-to-depth ratios, smaller interburden thicknesses and similar but slightly higher extraction heights when compared with BSLW1 and BSLW2. The strain analysis, therefore, should also provide a conservative indication of the range of potential strains for the proposed longwalls in the Warkworth Seam.

The monitoring lines for BSLW1 and BSLW2 have been analysed to extract the maximum tensile and compressive strains that have been measured at any time during mining, for survey bays that were located directly above goaf. The frequency distribution of the maximum observed tensile and compressive strains measured in survey bays above goaf is provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, are also shown in this figure.

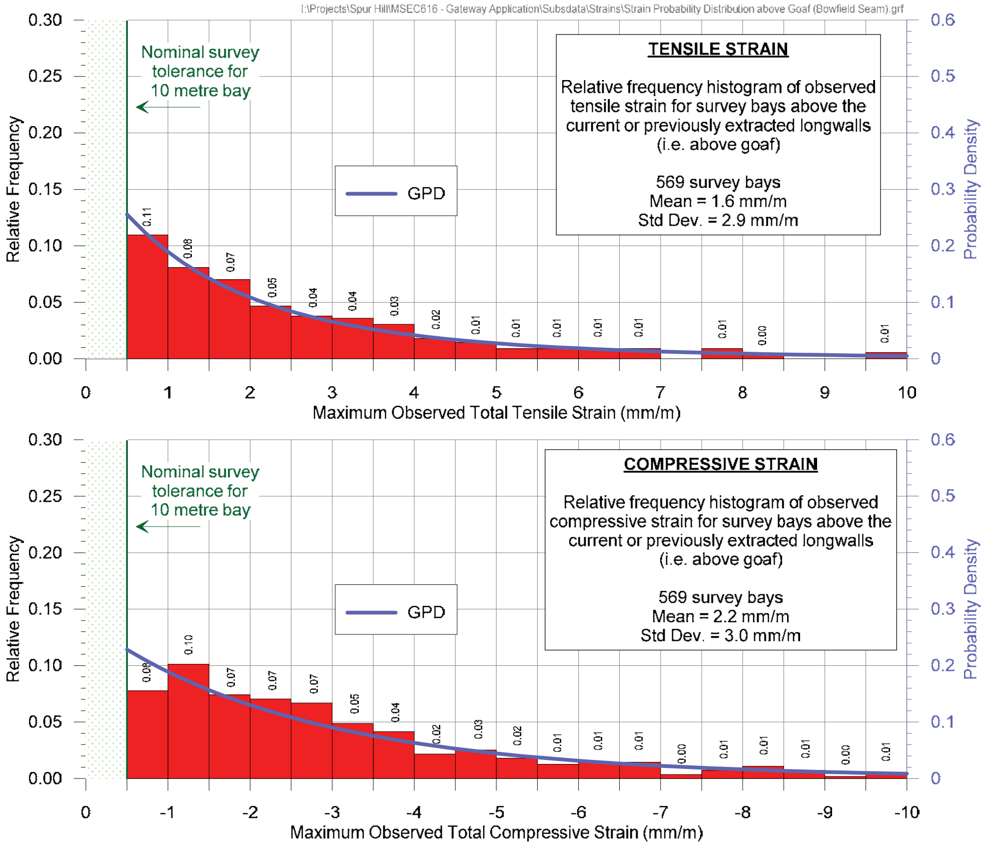

Fig. 4.2 Distributions of the Measured Maximum Tensile and Compressive Strains for the Monitoring Lines Above BSLW1 and BSLW2 at Blakefield South

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

The 95 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining were 7 mm/m tensile and 8 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining were 13 mm/m tensile and 14 mm/m compressive. The maximum strains measured along the monitoring lines were 23 mm/m tensile and 21 mm/m compressive.

It is noted, that the predicted strains for multi-seam conditions, provided above, are slightly less than those predicted based on single-seam mining conditions. It was found at Blakefield South Mine, that the highest strains for multi-seam conditions occurred where the chain pillars in the Blakefield Seam were located directly beneath the existing chain pillars in the overlying Whybrow Seam. In this case, however, the proposed longwalls are staggered (i.e. the chain pillars in adjacent seams are offset from each other) and, therefore, the strains due to multi-seam mining conditions are expected to be less than those for single-seam mining conditions, due to the overburden being already fractured by the extraction of the earlier seams and due to the increasing depths of cover.

4.4. Predicted Far-field Horizontal Movements

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

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

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

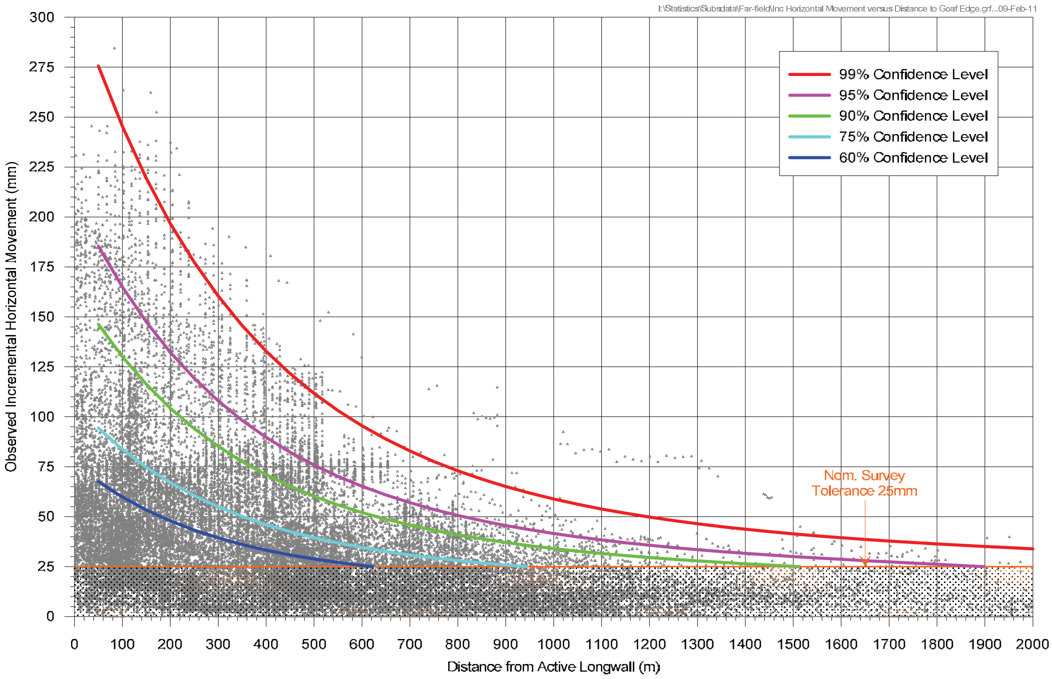

Fig. 4.3 Observed Incremental Far-Field Horizontal Movements

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

The predicted far-field horizontal movements resulting from the extraction of the proposed mining are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than the order of survey tolerance (i.e. less than 0.3 mm/m). The impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the vicinity of the proposed longwalls and panels is not expected to be significant, except where they occur at large structures which are sensitive to small differential movements.

5.1. Introduction

The *Strategic Agricultural Land* (SAL) within the EL is shown in Drawing No. MSEC616-130, which is based on the mapping provided in the *Upper Hunter Strategic Land Use Plan* (DoPI, 2012) and on-site verification of *BSAL*. The agricultural land utilisation and the associated natural and built features within the EL are shown in Drawing Nos. MSEC616-131 to MSEC616-133, in Appendix D.

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

- Surface cracking and deformations – which is discussed in Section 5.2,
- Changes in surface water drainage – which is discussed in Sections 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 built features associated with agricultural land utilisation – 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, overburden geology, locations of natural joints in the bedrock, the presence of near surface geological structures and, in this case, multi-seam mining conditions.

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

As subsidence occurs, surface cracks will generally appear in the tensile zone, i.e. within 0.1 to 0.4 times the depth of cover from the longwall perimeters. Most of the cracks will occur within a radius of approximately 0.1 times the depth of cover from the longwall perimeters. The cracks will generally be parallel to the longitudinal edges or the ends of the longwalls. Surface cracking normally develops behind the extraction face up to a horizontal distance equal to around half the depth of cover and, hence, the cracking in any location normally develops over a period of around two to four weeks.

At shallow depths of cover, it is also likely that transient surface cracks will occur above and parallel to the moving extraction face, i.e. at right angles to the longitudinal edges of the longwall, as the subsidence trough develops. In multi-seam mining cases, surface cracking and heaving can potentially occur in any location above the extracted longwalls. The larger and more permanent cracks, however, are usually located in the final tensile zones around the perimeters of the longwalls. Open fractures and heaving, however, can also occur due to the buckling of surface beds that are subject to compressive strains.

Detailed crack mapping was undertaken above the commencing end of the Beltana No. 1 Underground Mine Longwall 1 (Beltana LW1), which was mined under single-seam conditions. The longwall had a void width of 275 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 the Whynot Seam at the project, which have width-to-depth ratios varying between 0.9 and 1.9 and an average of around 1.3.

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

Several trial pits were excavated above Beltana LW1 to determine the nature and the depths of the cracks. It was found that the cracks up to 25 mm in width were relatively shallow, having depths less than 0.5 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.

Detailed crack mapping was also undertaken above the Blakefield South Mine Longwalls 1 and 2 (BSLW1 and BSLW2), which were extracted beneath the existing South Bulga longwalls in the Whybrow Seam (i.e. multi-seam conditions). The void widths of BSLW1 and BSLW2 were 330 metres and 400 metres, respectively, and were extracted in the Blakefield Seam at depths of cover ranging between 170 metres and 230 metres. The interburden thickness between the Whybrow and Blakefield Seams typically varied between 70 metres and 90 metres.

The cracking observed above BSLW1 and BSLW2 should provide a reasonable indication of the extent of cracking in the flat terrain (i.e. away from the ridgeline) for multi-seam conditions. It was found from the detailed crack mapping, that 93 % of the cracks had widths less than 100 mm, with the majority of these having widths less than 50 mm. The maximum observed crack width was around 450 mm.

There were more than 1,200 cracks recorded above BSLW1 and BSLW2 having a total length of around 27 kilometres. The total surface area above these longwalls was around 1.9 km^2 and it is estimated, therefore, that less than 0.10 % of this area was affected by cracking. The compression heaving and step heights observed during the extraction of BSLW1 and BSLW2 were typically less than 25 mm, with a maximum step height around 50 mm.

Photographs of surface cracking resulting from the extraction of BSLW1 and BSLW2 at the Blakefield South Mine (i.e. multi-seam conditions) are provided in Fig. 5.1.

Fig. 5.1 Photographs of Surface Cracking above Blakefield South Mine (Multi-seam)

Larger surface cracking and deformations could also develop along the steep slopes. The extraction of the proposed longwalls beneath the ridgeline 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 resulting from downslope movements in the Hunter Coalfield are provided in Fig. 5.2. Crack widths greater than 300 mm and depths greater than 3 metres have been observed where longwalls have previously extracted beneath steep slopes.

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

Based on the previous longwall mining experience in the NSW Coalfields, the surface cracking in the flatter areas (i.e. away from the ridgeline) above the proposed longwalls is expected to be typically between 25 mm and 50 mm, with some isolated cracking around 100 mm or greater. The surface cracking along the steeper slopes on the sides of the ridgeline are expected to be typically in the order of 50 mm to 100 mm, with isolated cracking around 200 mm or greater.

The agricultural land utilisation which could be affected by surface cracking and deformation include the:-

- Vineyards on Property 9 – refer to Section 5.7.1, and
- Cattle grazing – refer to Section 5.7.3.

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 steeper slopes).

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

- Visual monitoring of the surface in the active subsidence zone, to identify the larger surface cracking and deformations would could affect safety, access, or increase erosion,
- Establish methods for surface remediation, which could include infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of vegetation in order to stabilise the steeper slopes in the longer term, and
- Develop 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.

5.3. Predicted Changes in Surface Water Drainage

The main topographical feature within the EL is a ridgeline, which runs approximately north-south, and has a high point of around 345 mAHD within the EL. The topographical low in the area is the Hunter River, located to the west and to the south of the EL, which is at around 110 mAHD.

The drainage lines and the natural gradients within the EL are illustrated in Drawing No. MSEC616-132. It can be seen from this drawing, that the natural grades are greater than 10 % along the sides of the ridgeline, reducing to less than 5 % along the western and southern boundaries of the EL.

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

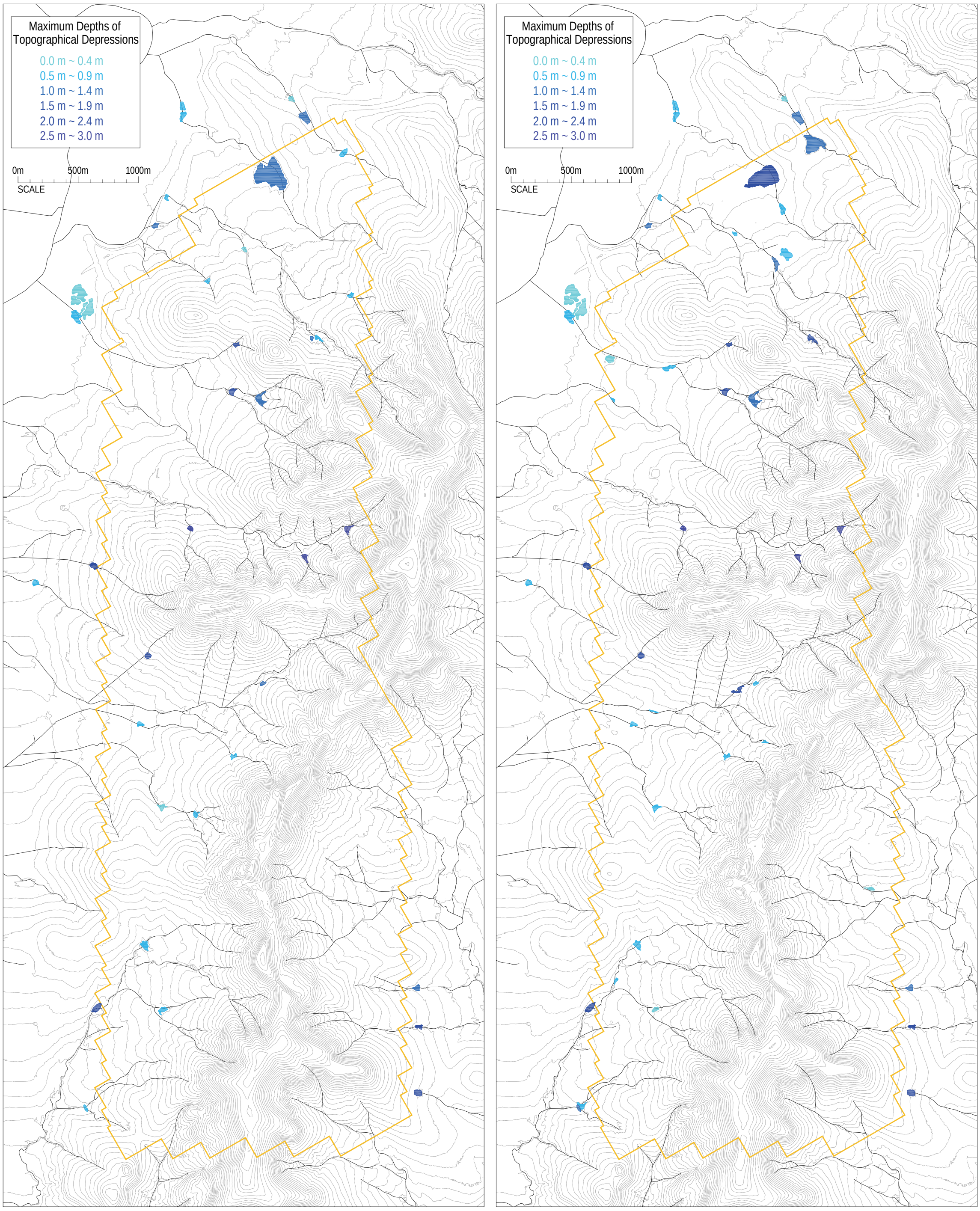

Fig. 5.4 Natural (LHS) and Predicted Post-Mining (RHS) Surface Levels Contours and the Locations and Depths of the Topographical Depressions

It can be seen on the Left Hand Side (LHS) of the above figure, that the land is naturally draining between the ridgeline and the Hunter River, with only localised natural topographical depressions (i.e. localised areas where ponding can naturally develop). The majority of these topographical depressions are associated with the existing farm dams along the natural drainage lines.

It can be seen on the Right Hand Side (RHS) of Fig. 5.4, that additional topographical depressions (i.e. areas with increased potential for ponding) are expected to develop as a result of the proposed mining, primarily along the alignments of the natural drainage lines, away from the ridgeline.

The final topographical depressions are predicted to be up to around 2.5 metres deep, with the potential ponding depths being less than this due to the various other factors previously described. The predicted post-mining surface topography and the topographical depressions (i.e. the areas with increased potential for ponding prior to the implementation of any remediation works), are also illustrated in Fig. 5.5 below.

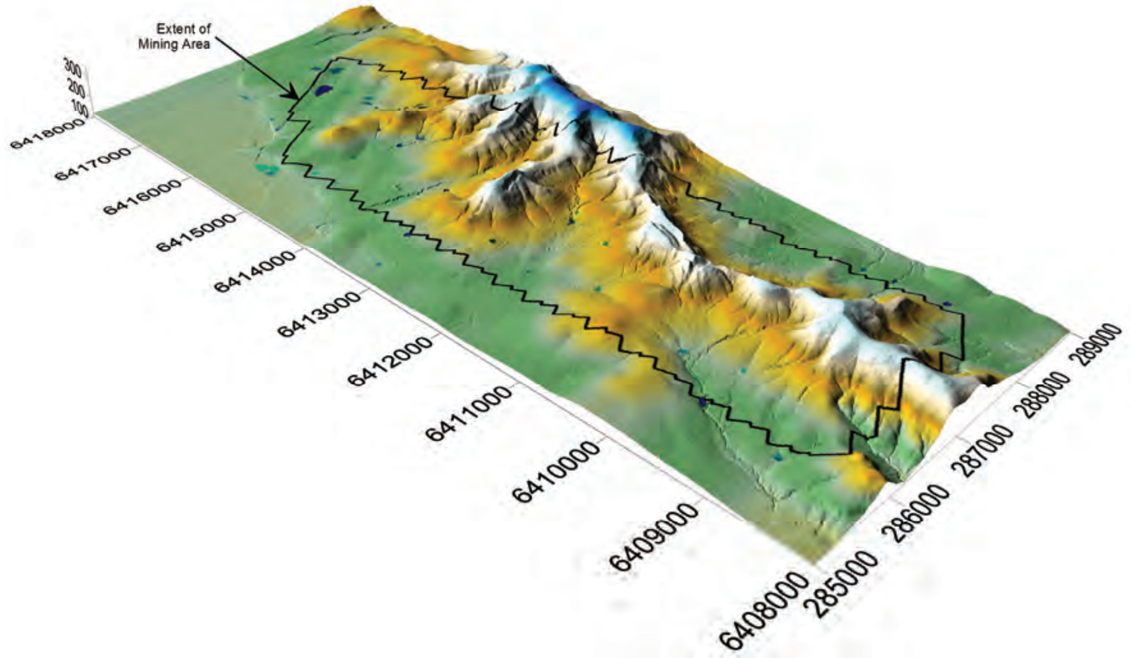

Fig. 5.5 Predicted Subsided Surface Topography and Topographical Depressions

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

The agricultural land utilisation which could be affected by the topographical depressions and, hence, may require surface remediation works include:-

- Vineyards on Property 9 – refer to Section 5.7.1, and
- Cattle grazing – refer to Section 5.7.3.

Further discussions are also provided in the Agricultural Impact Assessment.

5.4. The Hunter River

The Hunter River is located to the west and to the south of the EL. This river is considered to be the most significant stream in the Hunter Coalfield. The river channel is located around 550 metres north-west of EL, at its closest point. A cross-section through the Hunter River and the EL, where the river channel is located closest to the proposed longwalls, is shown in Fig. 5.6.

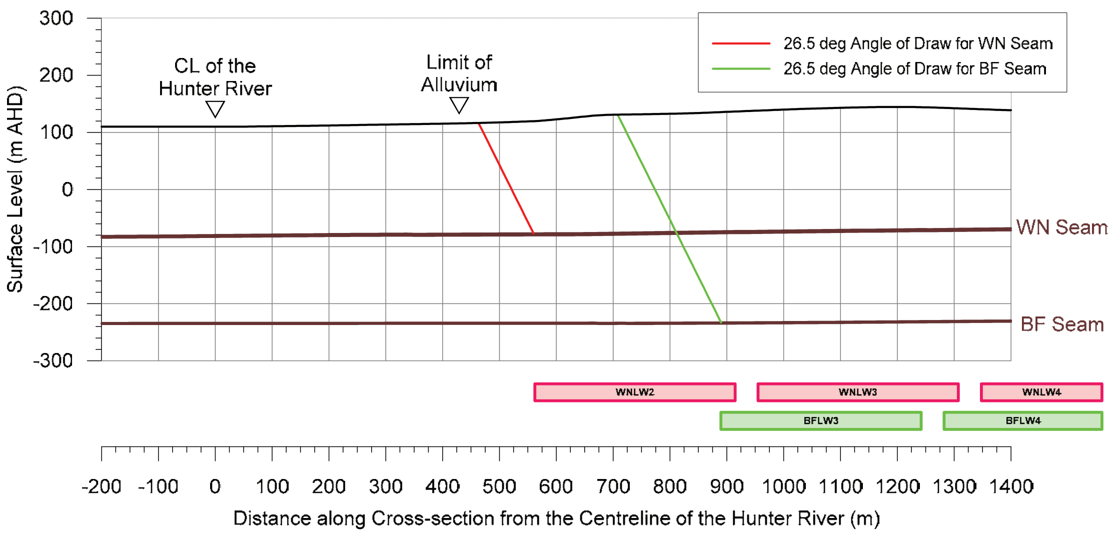

Fig. 5.6 Cross-section through the Hunter River and the EL where the River is Located Closest to the Proposed Mining

It can be seen from the above figure, that the river is located well outside the 26.5 degree Angles of Draw from the proposed longwalls. At this distance, the river channel, itself, is expected to experience negligible vertical subsidence (i.e. less than 5 mm) and, therefore, is not expected to experience any measurable conventional tilts, curvatures or strains. It is unlikely, therefore, that the river channel, itself, would experience any adverse impacts resulting from the proposed mining.

It can be seen from Drawing No. MSEC616-132, that the mapped limit of alluvium for the Hunter River is located immediately adjacent to the proposed longwalls, in the north-western part of the EL. In this location, the alluvium is predicted to experience low levels of vertical subsidence, less than 100 mm, but is not expected to experience any significant conventional tilts, curvatures or strains. The potential impacts on the alluvium and associated aquifer are discussed in the Agricultural Impact Assessment.

5.5. Drainage Lines

5.5.1. Description of the Drainage Lines

The locations of the drainage lines within the EL are shown in Drawing No. MSEC616-132. It appears from the CMA Map of the area, that there are no “named” drainage lines within the EL.

The drainage lines commence along the ridgeline and flow into the Hunter River on the western and southern sides of the EL. The upper reaches are 1st and 2nd order streams and some parts of the lower reaches are 3rd order streams. The drainage lines are ephemeral, where surface water only flows during and for short periods after rainfall events, although some isolated natural ponding is evident along the flatter lower reaches.

The drainage lines have shallow incisions into the natural surface soils, which are generally derived from the Newcastle Coal Measures, as illustrated in Fig. 1.5. There may be some isolated rock outcropping within the drainage lines, along the upper reaches, on the sides of the ridgeline.

Photographs of typical drainage lines within the EL are shown in Fig. 5.7.

Fig. 5.7 Photographs of Typical Drainage Lines within the EL

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 upper reaches (i.e. the ridgeline) and typically between 10 mm/m and 30 mm/m (i.e. 1 % to 3 %, or 1 in 100 to 1 in 33) along the lower reaches.

5.5.2. Predictions for the Drainage Lines

A summary of the maximum predicted subsidence, tilt and curvatures for the drainage lines within the EL is provided in Table 5.1. The predicted tilts are the maxima after the completion of all longwalls within each of the seams. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls within each of the seams.

Table 5.1 Maximum Predicted Conventional Subsidence, Tilt and Curvature for the Drainage Lines

Location	Seams	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})
Northern Part of the EL	WN, BF and WW	5,300	40	1.0	1.0
Southern Part of the EL	WN and WW	5,100	30	1.0	1.0

The maximum predicted conventional curvatures for the drainage lines are 1.0 km^{-1} hogging and sagging, which represent minimum radii of curvature of 1 kilometre. The predicted maximum strains for the drainage lines, based on the strain analysis provided in Section 4.3, are typically in the order of 10 mm/m to 20 mm/m tensile and compressive, with some isolated strains greater than 20 mm/m.

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

5.5.3. Impact Assessments for the Drainage Lines

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

Potential for Increased Levels of Ponding, Flooding and Scouring

Mining can potentially result in increased levels of ponding and flooding 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 40 mm/m (i.e. 4 %, or 1 in 25) in the northern part of the EL and 30 mm/m (i.e. 3 %, or 1 in 33) in the southern part of the EL. The maximum predicted changes in grade are similar to the natural grades along the drainage lines, which typically vary between 50 mm/m and 100 mm/m along the upper reaches (i.e. the ridgeline) and typically between 10 mm/m and 30 mm/m along the lower reaches.

It is expected, therefore, that there would be areas which would experience increased ponding and flooding, primarily upstream of the chain pillars in the shallower seams, or where the drainage lines exit the proposed mining area. It is also possible, that there could be areas which could experience increased scouring of the stream beds, primarily downstream of the chain pillars in the shallower seams, or where the drainage lines enter the proposed mining area. After the completion of mining in each seam in a particular area, surface remediation would be undertaken to re-establish the natural grades along the drainage lines, so as to reduce the potential for ponding within the EL.

The locations within the EL 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 two typical drainage lines, in the northern part of the EL, are also illustrated in Fig. 5.8 and Fig. 5.9. The estimated maximum depths and extents of increased ponding (prior to any remediation) along these drainage lines are also indicated in these figures.

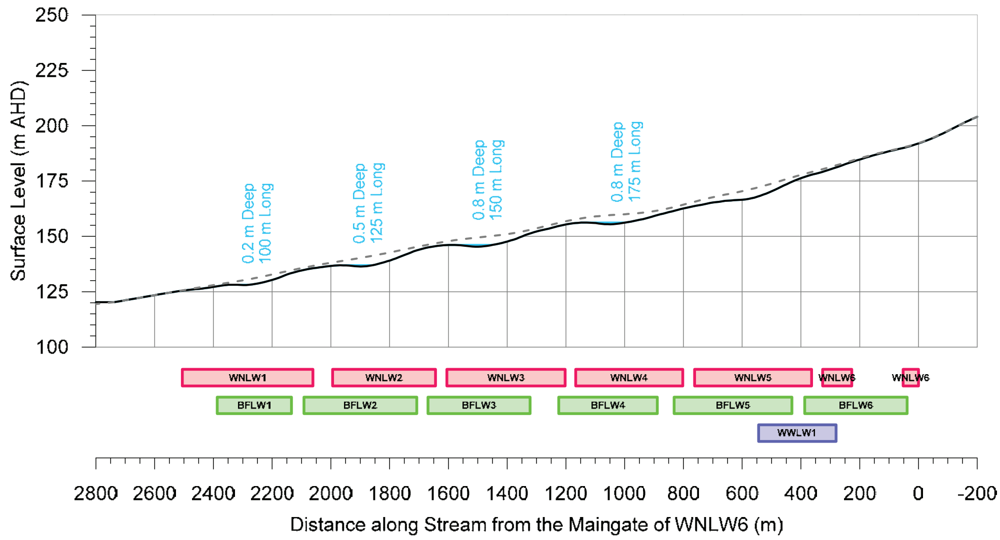

Fig. 5.8 Natural and Predicted Subsided Surface Levels along a Typical Drainage Line Located above the Proposed Longwalls in the Whynot, Bowfield and Warkworth Seams

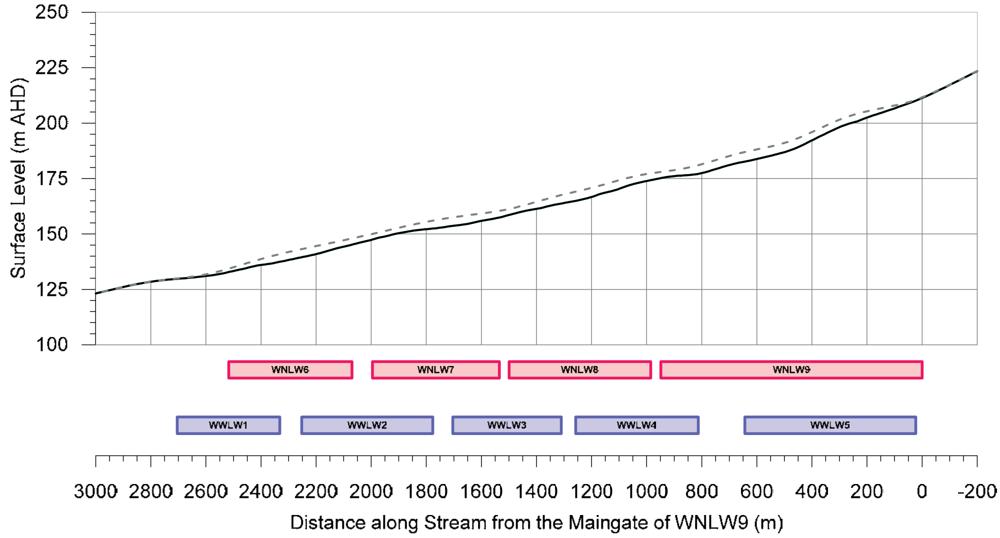

Fig. 5.9 Natural and Predicted Subsided Surface Levels along a Typical Drainage Line Located above the Proposed Longwalls in the Whynot and Warkworth Seams

It can be seen from the above figures, that the largest ponding areas are predicted to occur upstream of the chain pillars in the Whynot and Bowfield Seams. It is estimated, that increased ponding up to around 1 metre deep and up to 200 metres long will develop along the drainage lines, after the completion of all the proposed longwalls. Some deeper but more localised ponding could occur in the locations of the existing farm dams. It is noted, 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.

At the completion of mining in each seam, 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 EL.

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 m/sec. 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.

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

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 area. 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.

5.5.4. Recommendations for the Drainage Lines

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

- Visual monitoring of the surface in the active subsidence zone, to identify the larger surface cracking and deformations would could result in the loss of surface water flows or increase erosion,
- Establish methods to regrade the drainage lines in the locations where adverse impacts occur as a result to increase ponding, and
- Establish methods of remediation for the surface cracking, which could include infilling with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as providing rip-rap.

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

5.6. Groundwater Resources

There are groundwater resources associated with the Hunter River alluvial aquifer and other shallow and deeper aquifers within the EL. 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. MSEC616-133. The locations and details of these were obtained from the Department of Natural Resources using the *Natural Resource Atlas* website (NRAtlas, 2013).

A summary of the registered groundwater bores located within the EL is provided in Table 5.2 below. There are also additional groundwater bores to the north-west and south of the EL, as shown in Drawing No. MSEC616-133, adjacent to the Hunter River.

Table 5.2 Details of the Groundwater Bores within the EL

Ground Licence Number	Approximate Easting (m)	Approximate Northing (m)	Depth (m)	Authorised Use
GW029644	289050	6411225	29	Domestic / Stock
GW029650	286350	6409550	67	Stock (Not in Use)
GW029651	286375	6409825	55	Stock (Not in Use)
GW029652	286400	6410050	91	Stock (Not in Use)
GW029653	286425	6410300	49	Stock (Not in Use)
GW029656	289750	6408500	17	Stock (Not in Use)
GW029657	288500	6411325	6	Domestic / Stock
GW029659	289125	6411500	75	Domestic / Stock
GW043988	287425	6412825	9	Stock
GW050849	287400	6417275	27	Stock
GW080905	285775	6415200	10	Monitoring
GW201118	285925	6414700	19	Domestic / Stock
GW201830	287325	6413675	40	Stock
GW202523	286150	6416000	6	Monitoring

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

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

5.7. Agricultural Land Utilisation

The land within the EL is used for agricultural and rural residential purposes. The land has generally been cleared on the flatter areas within the EL, with natural vegetation remaining on the steeper slopes along the ridgeline. Photographs of the land surface within the EL are provided in Fig. 5.10.

Fig. 5.10 Photographs of the Land Surface within the EL

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 EL comprises the following:-

- A vineyard, winery and cellar door on Property 9,
- Centre pivot irrigation areas, and
- Cattle grazing on other properties.

The following sections provide the impact assessments on the agricultural utilisation for these properties. Whilst there are no active horse studs within the EL, discussions on the potential impacts and management strategies for any future horse studs have been also been provided, as the majority of the land within the EL has been classified *Equine CIC*.

5.7.1. Vineyard, Winery and Cellar Door on Property 9

A vineyard, winery and cellar door are located on Property No. 9, which is shown in Drawing No. MSEC616-133. This property is located above the proposed longwalls in the Whynot and Bowfield Seams.

The predicted changes in the surface water drainage within the EL were discussed in Section 5.3. The natural and the predicted post-mining surface level contours for Property 9 have also been illustrated in Fig. 5.11. The locations of the post-mining topographical depressions (i.e. areas with increased potential for ponding which may require surface remediation) on this property have been shown in this figure and have also been overlaid on the aerial photograph in Fig. 5.12.

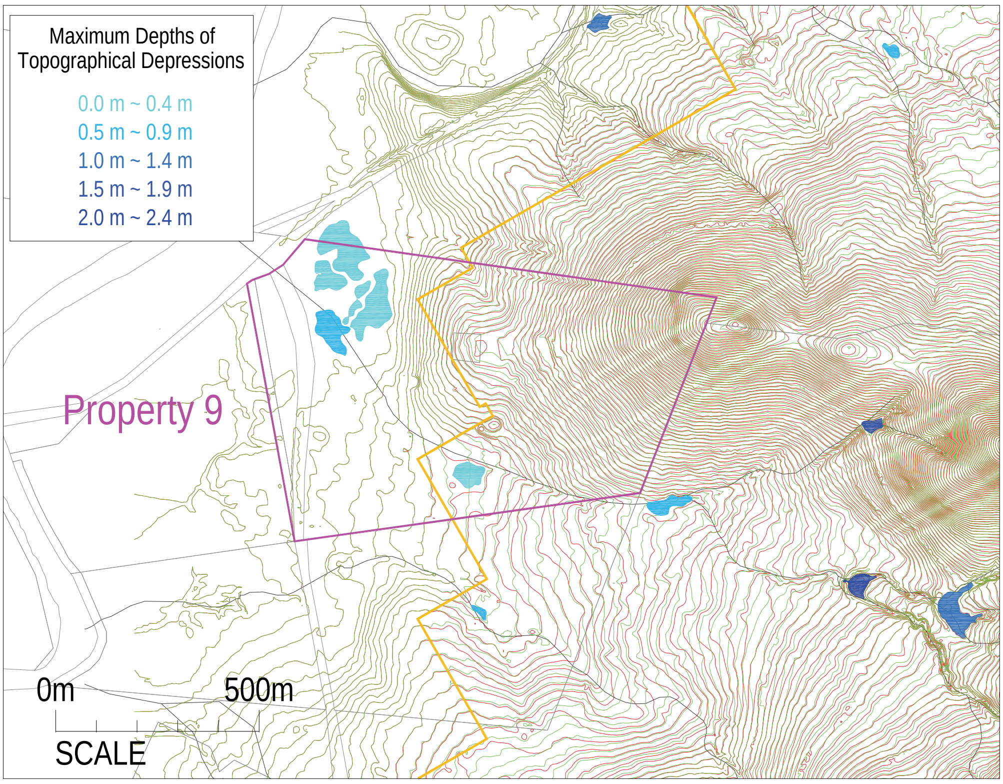

Fig. 5.11 Natural (Green) and Predicted Post-Mining (Red) Surface Levels Contours for Property 9

Fig. 5.12 Aerial Photograph and Locations of the Topographical Depressions for Property 9

It can be seen from the above figures, that there are topographical depressions in the north-western corner of Property 9, outside the extent of the proposed mining area (i.e. orange outline) and, hence, these areas indicate natural ponding due to the relatively flat natural gradients. There is only one topographical depression located directly above the proposed longwalls, near the southern boundary of Property 9, along the alignment of a natural drainage line. The maximum predicted depth of this topographical depression after the completion of all seams, based on the geometry of the post-mining surface level contours, is less than 0.5 metres.

If the potential for increased ponding were found to adversely impact on the agricultural land use (i.e. the vineyards), it may be necessary to remediate the surface drainage, which could include regrading of the drainage line downstream of the topographical depression, or by constructing bunds adjacent to the drainage line.

The vineyards could also be adversely impacted by surface cracking and deformations. As described in Section 5.2, it is expected that the surface crack widths in the flatter terrain would typically be in the order of 25 mm to 50 mm, with isolated crack widths greater than 100 mm.

A number of studies have been undertaken to assess the impacts of longwall mining on vineyards. For example, monitoring was undertaken where the Beltana No. 1 Underground Mine extracted longwalls in the Whybrow Seam beneath 119 ha of vineyards. It was found that "*Although no patterns associated with [longwall mining] are immediately apparent in the data, structure does appear within elements of the data sets*" (Thompson, et al, 2007). That is, there is currently no evidence of mining induced impacts on vineyards, however, some changes were apparent within the limits of accuracy of the study.

Management strategies can be developed for the vineyard, which could include:-

- Visual monitoring during active subsidence,
- Establish methods to adjust the trellises and irrigation systems,
- Establish methods to remediate the larger surface cracks which could adversely impact on the vines 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 on this property, including the building structure containing the winery and cellar door, are covered in Section 5.8.

5.7.2. Centre Pivot Irrigation Areas

There are centre pivot irrigation areas on the western and south-eastern boundaries of the EL, as shown in Drawing No. MSEC616-131. These are located outside the extents of the proposed mining area and, therefore, are not predicted to experience any significant subsidence movements. It is unlikely, therefore, that the centre pivot irrigation areas would be adversely impacted by the proposed mining.

5.7.3. Cattle Grazing

There is grazing of cattle on a number of the private properties within the EL. A risk to this type of agricultural land use is the potential for the mining induced surface cracking and deformations to injure the cattle 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 would 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.

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 EL, such as equine and viticultural industries, prior to the commencement or during mining. It is noted, that any future developments would require the approval by the Mine Subsidence Board.

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, 5.7.1 and 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 within the EL 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 EL are shown in Drawing No. MSEC616-133. The built features located directly above the proposed mining area include:-

- Six houses located directly above the proposed longwalls.
- 28 rural building structures located directly above the proposed longwalls, which includes sheds, garages and other non-residential building structures.
- Other farm structures, including a silo and water storage tanks.
- Cellar door and winery on Property 9.
- 39 farm dams located directly above the proposed longwalls, which have been established along the natural drainage lines.
- The Dalswinton Rural Fire Service building facilities.
- The Golden Highway (State Road 84) that provides an important link between the rural properties within the EL with the township of Denman to the west and the New England Highway to the east.
- Electrical infrastructure comprising 66 kV and low voltage powerlines supported by timber or concrete poles.
- Telecommunications infrastructure comprising direct buried copper cables and a direct buried optical fibre cable.

Detailed impact assessment for these built features will be undertaken during the EIS stage of the project.

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 likelihoods 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 EL 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 Trigger Action Response Plans (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.
Sub-critical 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.
Super-critical 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

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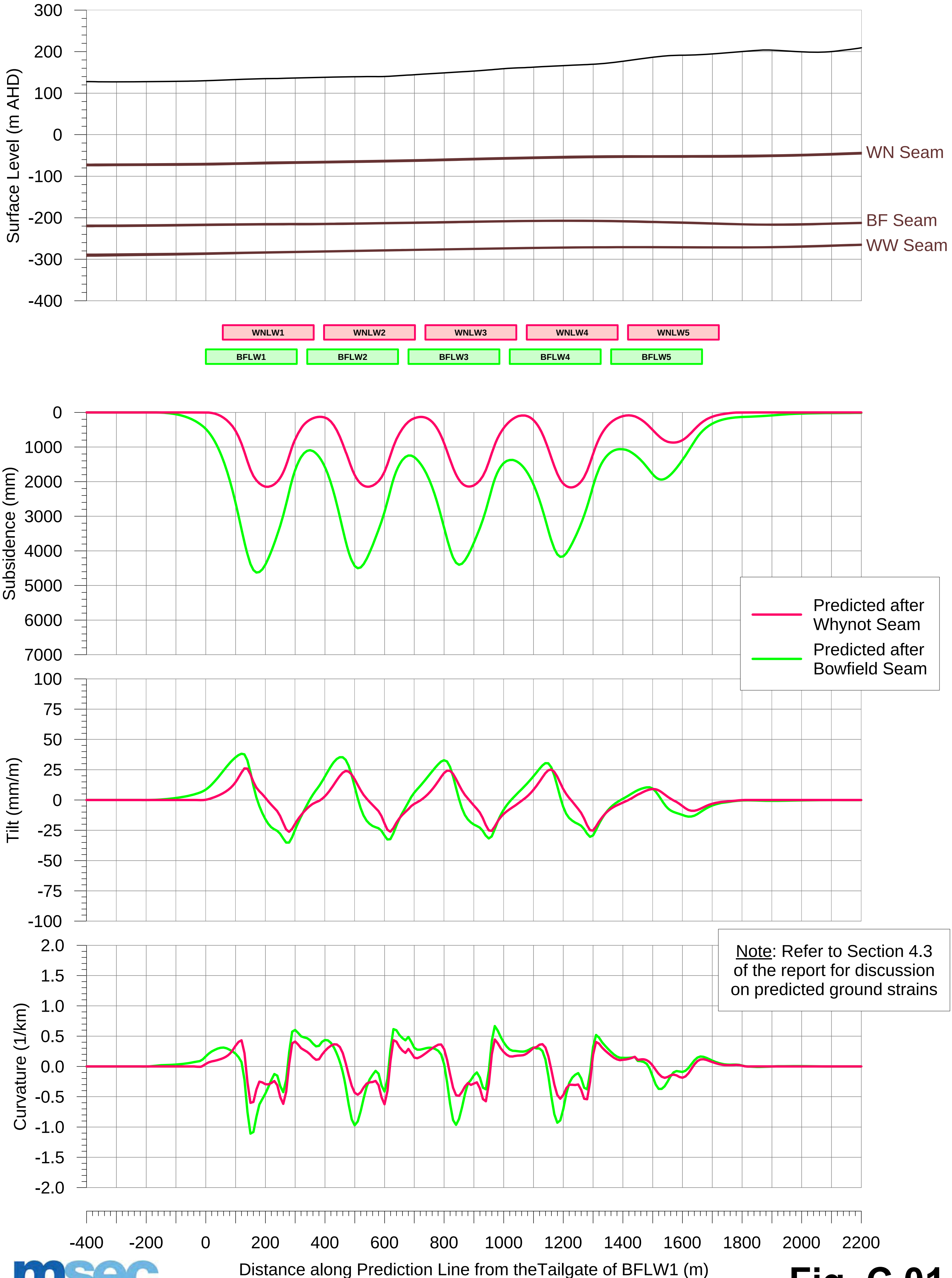
APPENDIX C. FIGURES

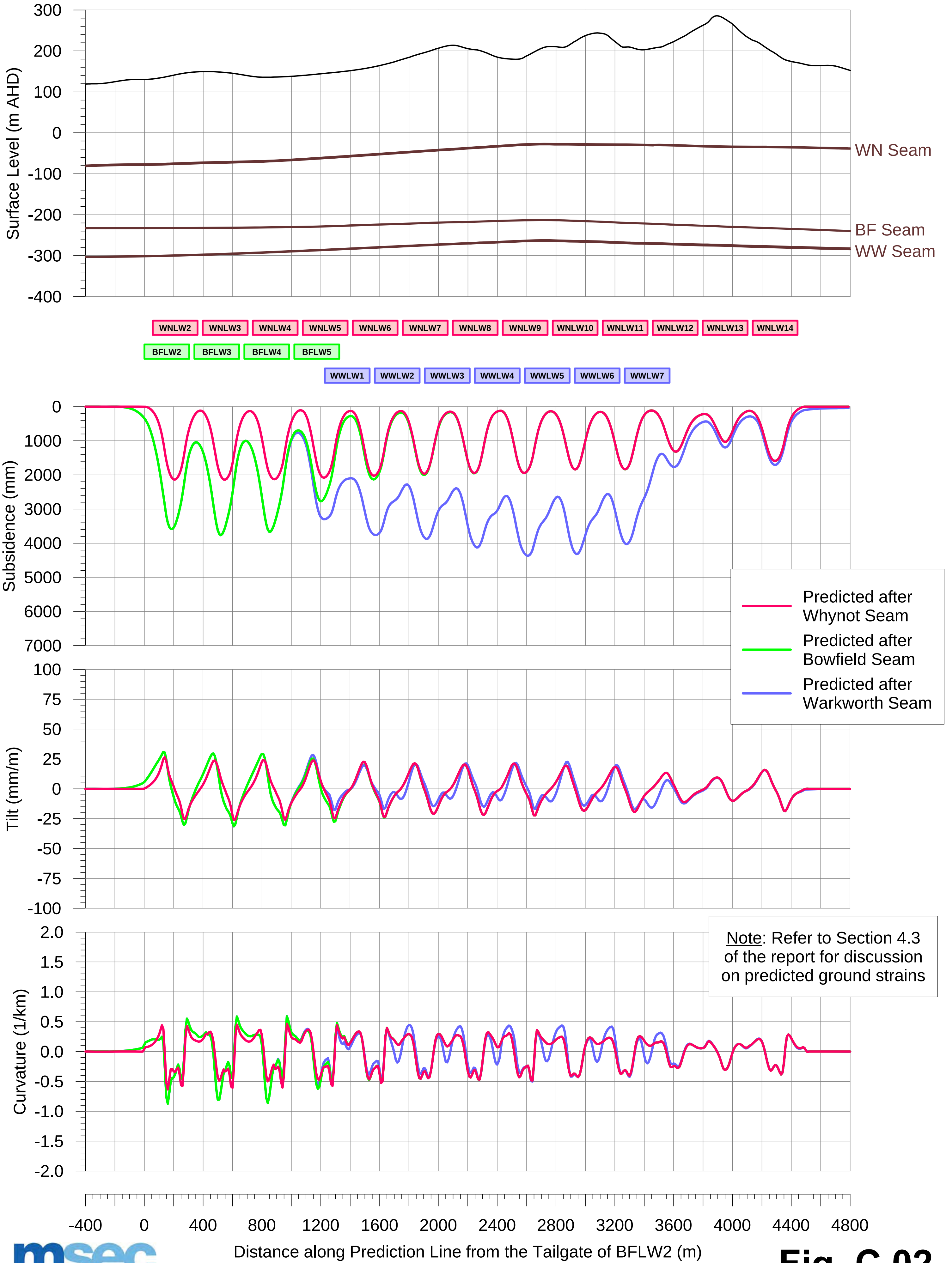
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 1 due to the Extraction of the WN and BF Seams



msec

Fig. C.01

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 2 due to the Extraction of the WN, BF and WW Seams



msec

Fig. C.02

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 3 due to the Extraction of the WN and WW Seams

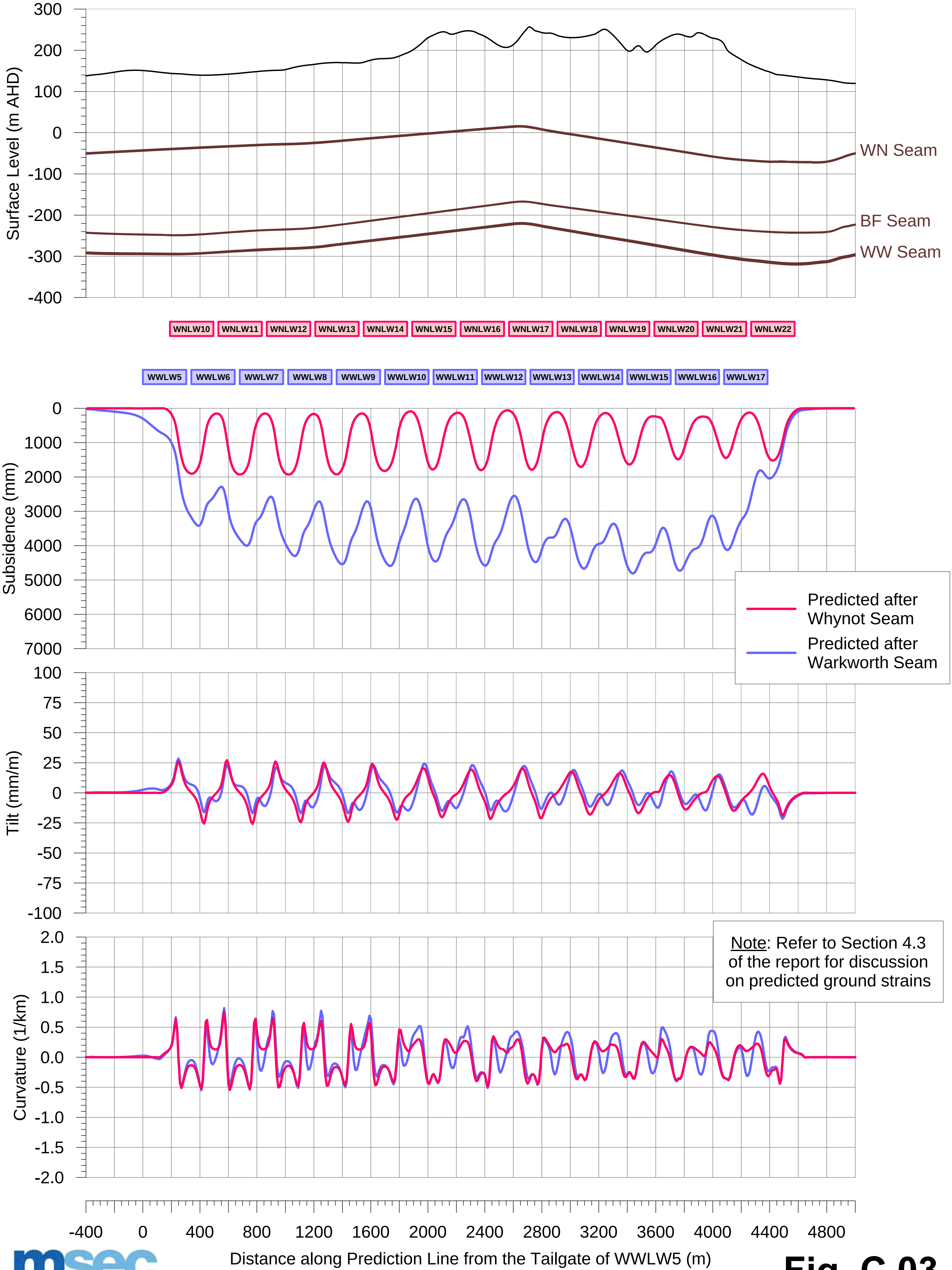


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Fig. C.03