Appendix I

Subsidence Predictions and Impact Assessments for Natural and Built Features in Support of the Gateway Application

Bylong Coal Project

Gateway Certificate Application
Supporting Document

COCKATOO COAL LIMITED:

Bylong Coal Project - Gateway Application

Subsidence Predictions and Impact Assessments for Natural and Built Features in Support of the Gateway Application

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Report produced to:- Provide subsidence predictions and impact assessments for the natural and built features in support the Gateway Application for the Bylong 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

EXECUTIVE SUMMARY

Cockatoo Coal Limited (Cockatoo Coal) act on behalf of KEPCO (Bylong) Australia Pty Ltd (KEPCO), which holds Authorisation A287 and A342 over an area of approximately 10,300 ha at Bylong, NSW. Cockatoo Coal plans to develop a new thermal coal mine, called the Bylong Coal Project, which is to consist of both open cut and underground operations.

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

- Review the currently proposed longwall layouts in the Coggan Seam,
- Prepare predicted subsidence contours after the extraction of the proposed longwalls,
- Identify and describe the natural and built features that will be affected by the proposed mining, with particular focus on those relevant to the Gateway Application,
- Provide subsidence predictions and impact assessments for the natural and built features identified within Authorisation A287 and A342, including assessments on:-
  - surface cracking and deformations,
  - changes in surface water drainage, and
  - impacts on natural and built features associated with agricultural utilisation.
- 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 using the available data from the NSW Coalfields. The maximum predicted subsidence parameters, resulting from the extraction of the proposed longwalls are as follows:-

- Vertical subsidence of up to 3,400 mm, which represents approximately 65 % of the total extraction height,
- Tilt of 66 mm/m (i.e. 6.6 %, or 1 in 15),
- Hogging curvature of 3.6 km^{-1} (i.e. minimum radius of curvature of 275 metres), and Sagging curvature of 3.3 km^{-1} (i.e. minimum radius of curvature of 300 metres),
- 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 Gateway Application. The main findings from this report are as follows:-

- The surface cracking in the flatter areas above the proposed longwalls is expected to be typically between 25 mm and 50 mm, with some isolated cracking around 100 mm or greater. The surface cracking along the steeper slopes 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 property owners.
- The ephemeral drainage lines drainage lines above the proposed longwalls flow into Dry Creek which flows into Bylong River approximately 2 km north west of the proposed longwalls.

  Increased potential for ponding is expected to develop along the lower reaches of Dry Creek, which are estimated to be less than around 1 metre deep and 50 metres to 100 metres long, after the completion of mining. It is expected that localised areas of ponding will develop along other drainage lines, particularly in the areas with shallow grades. After the completion of mining, surface remediation can be undertaken to re-establish the natural grades along the drainage lines, so as to reduce the potential for increased ponding.

  It is also expected that surface cracking would occur in the soil beds of the drainage lines as a result of the proposed mining. Any significant surface cracks in the drainage line beds can be remediated by infilling with the surface soils or other suitable materials, or by locally regrading and compacting the surface.
- The agricultural land utilisation above the proposed longwalls includes cattle grazing and a small area preliminarily mapped as Revised Draft CIC (Equine) (which has since been verified to not be equine CIC). 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. 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 rural building structures, farm dams, groundwater bores, roads, and electrical infrastructure located above the proposed mining area and management strategies for these built features should be developed as part of PSMPs and Built Feature Management Plans in consultation with stakeholders. Bylong Valley Way is a tourist route and will experience significant subsidence movements as a result of the proposed mining. It will be possible to maintain the safety and serviceability of the road during mining.

With the implementation of effective management strategies and remediation measures, it would be expected that the proposed mining would not prevent the continued utilisation of agricultural land.

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

CONTENTS

LIST OF TABLES, FIGURES AND DRAWINGS

Tables

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

Figures

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

Drawings

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

1.1. Background

Cockatoo Coal Limited (Cockatoo Coal) act on behalf of KEPCO (Bylong) Australia Pty Ltd (KEPCO), who holds Authorisation A287 and A342 over an area of approximately 10,300 ha at Bylong, NSW. Cockatoo Coal plan to develop a new thermal coal mine, called the Bylong Coal Project, which is to consist of both open cut and underground operations.

Mine Subsidence Engineering Consultants (MSEC) prepared a subsidence constraints study, report number MSEC546 dated March 2012, for Cockatoo Coal to assess what constraints might be imposed on underground mining due to mine subsidence related issues in relation to the Bylong Coal Project, and what measures could be undertaken to manage these constraints at the mine planning stage.

KEPCO 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), and equine critical industry cluster (CIC) under the Upper Hunter Strategic Regional Land Use Plan.

In determining the application for a Gateway Certificate, the Gateway Panel must consider and determine whether the Project will 'significantly' affect BSAL and/or CIC. The following criteria have been defined for each BSAL and CIC:-

- 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 biophysical strategic agricultural land.
- 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.

MSEC has been commissioned by Cockatoo Coal to:-

- Review the currently proposed longwall layouts in the Coggan Seam,
- Prepare predicted subsidence contours after the extraction of the proposed longwalls,
- Identify and describe the natural and built features that will be affected by the proposed mining, with particular focus on those relevant to the underground mining and Gateway Application, including:-
  - strategic agricultural land,
  - agricultural land utilisation,
  - 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 Authorisation A287 and A342, including assessments on:-
  - surface cracking and deformations,
  - changes in surface water drainage, and
  - impacts on natural and built features associated with 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 that will be affected by the proposed mining, with particular focus on those relevant to the underground mining and Gateway Application.

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

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

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

1.2. Mining Geometry

The layout of the proposed longwalls is shown in Drawings Nos. MSEC660-01. A summary of the proposed longwall dimensions is provided in Table 1.1. It is noted that the longwall numbering presented in this report does not represent the proposed extraction sequence for the longwalls.

A Subsidence Study Area, which is based on a 26.5 degree angle of draw line, is presented in Drawings Nos. MSEC660-01 to 09. The Subsidence Study Area defines the area that is likely to be affected by the proposed mining of the Longwalls 1 to 18.

Table 1.1 Geometry of the Proposed Longwalls

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
LW1	4,014	260	-
LW2	4,014	260	30
LW3	3,714	260	30
LW4	3,364	260	30
LW5	3,014	260	30
LW6	3,014	260	30
LW7	3,264	260	30
LW8	3,464	260	30
LW9	3,314	260	220*
LW10	2,964	260	30
LW11	2,964	260	30
LW12	3,114	260	30
LW13	2,539	260	30
LW14	2,089	260	30
LW15	1,939	260	30
LW16	1,739	260	30
LW17	1,814	260	30
LW18	1,814	260	30

* Total distance between longwall panel voids, including chain pillars and barrier pillar.

1.3. Surface and Seam Information

The surface level contours within the vicinity of the proposed longwalls are shown in Drawing No. MSEC660-02, which were generated from an airborne laser scan of the area by AAM. The surface levels above the proposed longwalls vary from approximately 275 metres along Dry Creek above the middle of Longwall 1 to 530 metres at the finishing end of Longwall 15.

The depth of cover contours are provided in Drawing No. MSEC660-03 and vary from approximately 105 metres above Longwall 1 to 320 metres above Longwalls 15 to 17. The seam thickness contours are provided in Drawing No. MSEC660-04 and vary from approximately 3.4 metres at the finishing end of

Longwall 1 to 5.1 metres for Longwall 18. The Coggan Seam generally dips from the south east down towards the north west.

1.4. Geological Details

Tamplin Resources (2010) provides a description of the general geology of the project area.

The Bylong Project Boundary (incorporating A287 and A342) is located in the Western Coalfield in the Permo-Triassic Sydney Basin, within which the main coal bearing sequence is the Illawarra Coal Measures, of Late Permian age. The Illawarra Coal Measures within the Bylong Project Area contain several seams; the Farmers Creek Seam, Goulburn Seam, Ulan seam and the Coggan Seam. The lowermost seam, the Coggan Seam has been targeted for underground extraction.

A typical stratigraphic section for the Bylong Project Area has been provided by Tamplin Resources (2010) and this has been reproduced in Fig. 1.1.

The Blackmans Flat Conglomerate forms the roof of the Coggan Seam. Based on the typical stratigraphic section, the conglomerate roof appears to be less than 5 metres in thickness.

The Triassic Narrabeen Group consists predominantly of sandstone and conglomerate and forms the ridges and cliff lines within the project area.

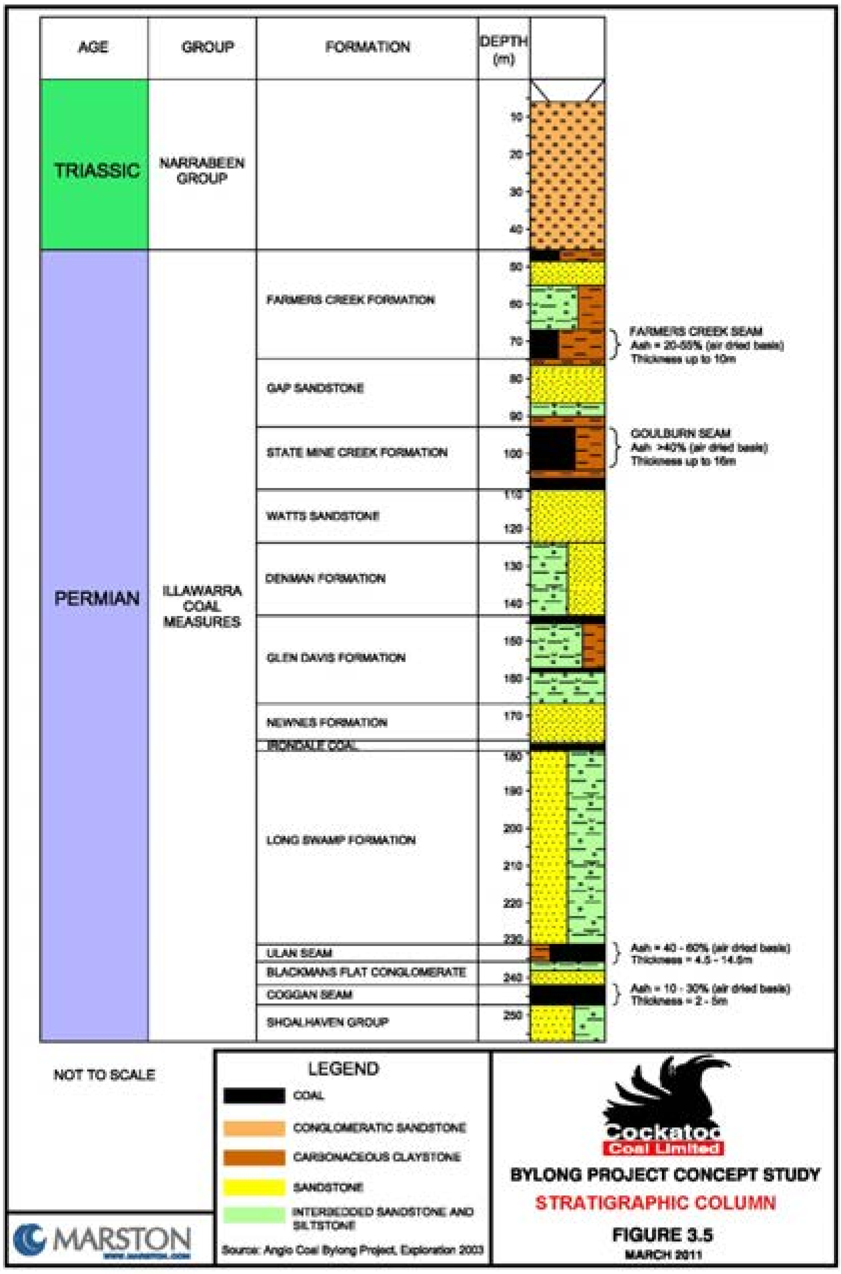

Fig. 1.1 Stratigraphy of Bylong Project Area (Tamplin Resources, 2010)

The surface geology within the vicinity of the proposed longwalls is shown in Fig. 1.2, which is based on Geological Series Sheet including part of 8832, 8833, 8834, 8932, 8933 and 8934, Edition 1 1998, published by the now Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS).

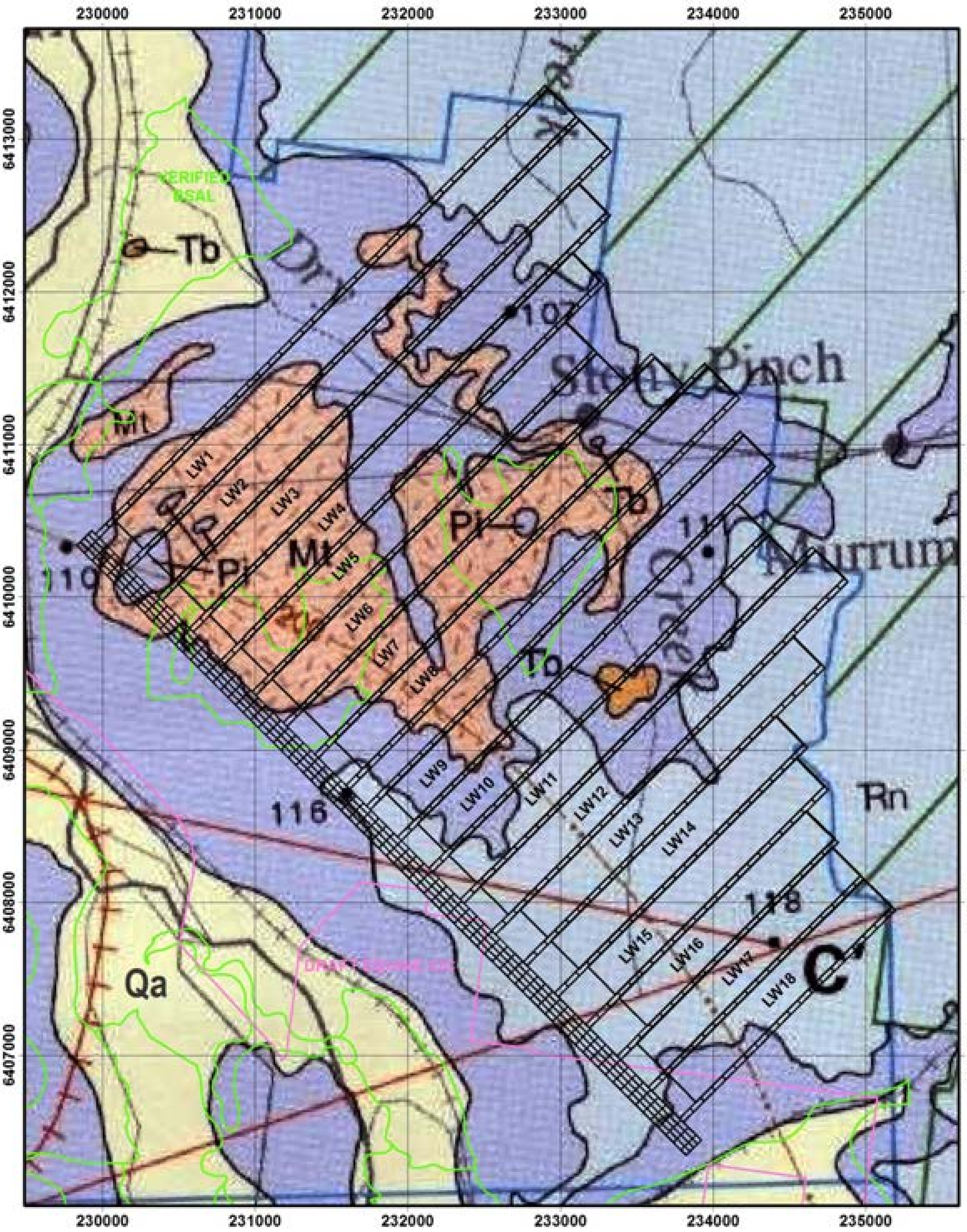

Fig. 1.2 Surface Geology within Bylong Coal Project Authorisation A287 and A342 Geological Series Sheet including part of 8832, 8833, 8834, 8932, 8933 and 8934 (DTIRIS)

It can be seen from the above figure, that the surface geology above the proposed longwalls includes intrusive material comprising Triassic Period Teschenite (Mt), Tertiary Period Basalt (Tb), Illawarra Coal Measures (Pi), and Narrabeen Group sandstone/conglomerate (Rn).

2.1. Introduction

The major natural and built features within the vicinity of the proposed longwalls can be seen in the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA), number 89333S. The proposed longwalls have been overlaid on an extract of this CMA map in Fig. 2.1. The proposed longwalls have also been overlaid on the aerial photograph of the area in Fig. 2.2. The surface topography, land usage and the larger natural features can also be seen in this figure.

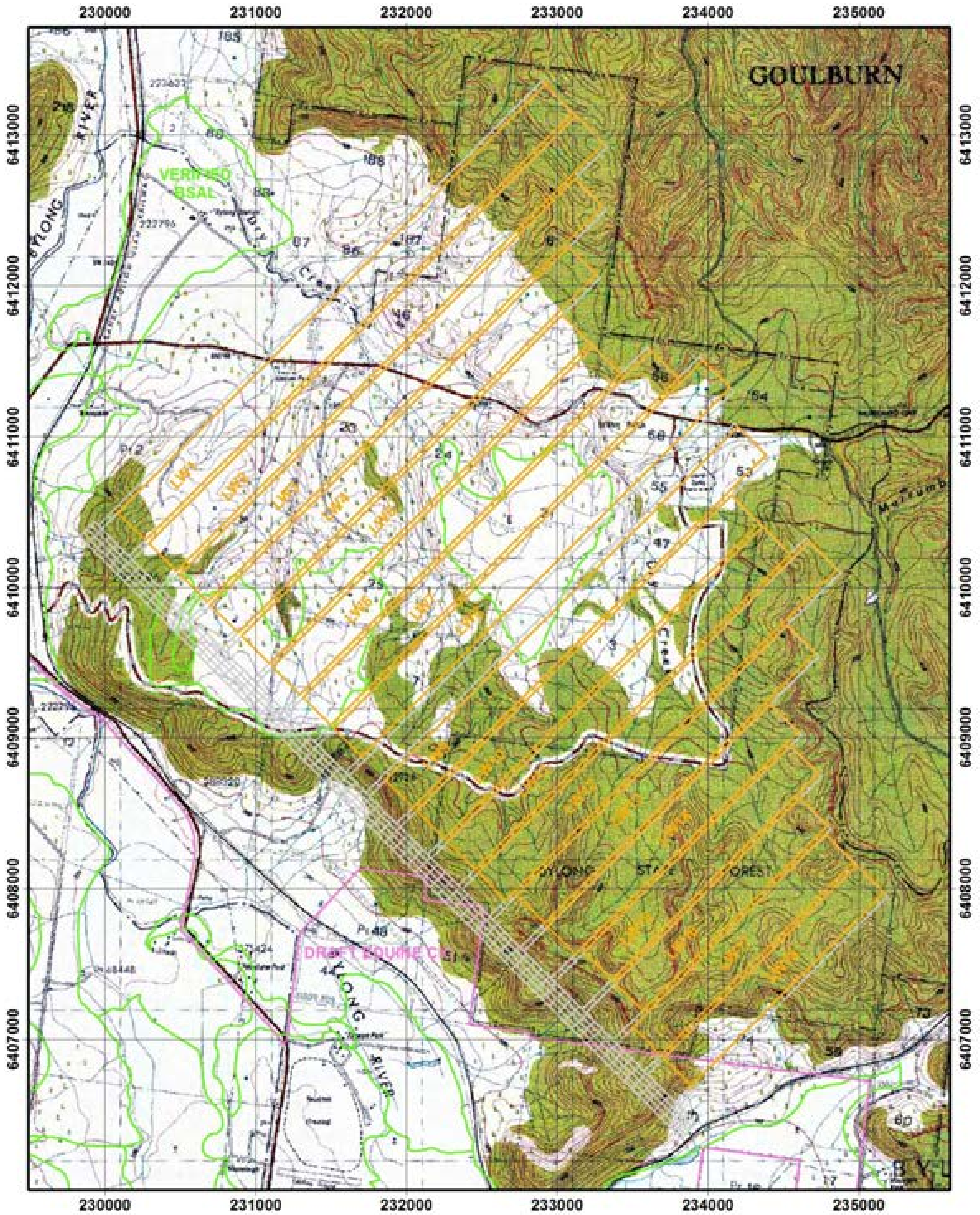

Fig. 2.1 Bylong Coal Project Proposed Longwalls Overlaid on CMA Map No. 89333S

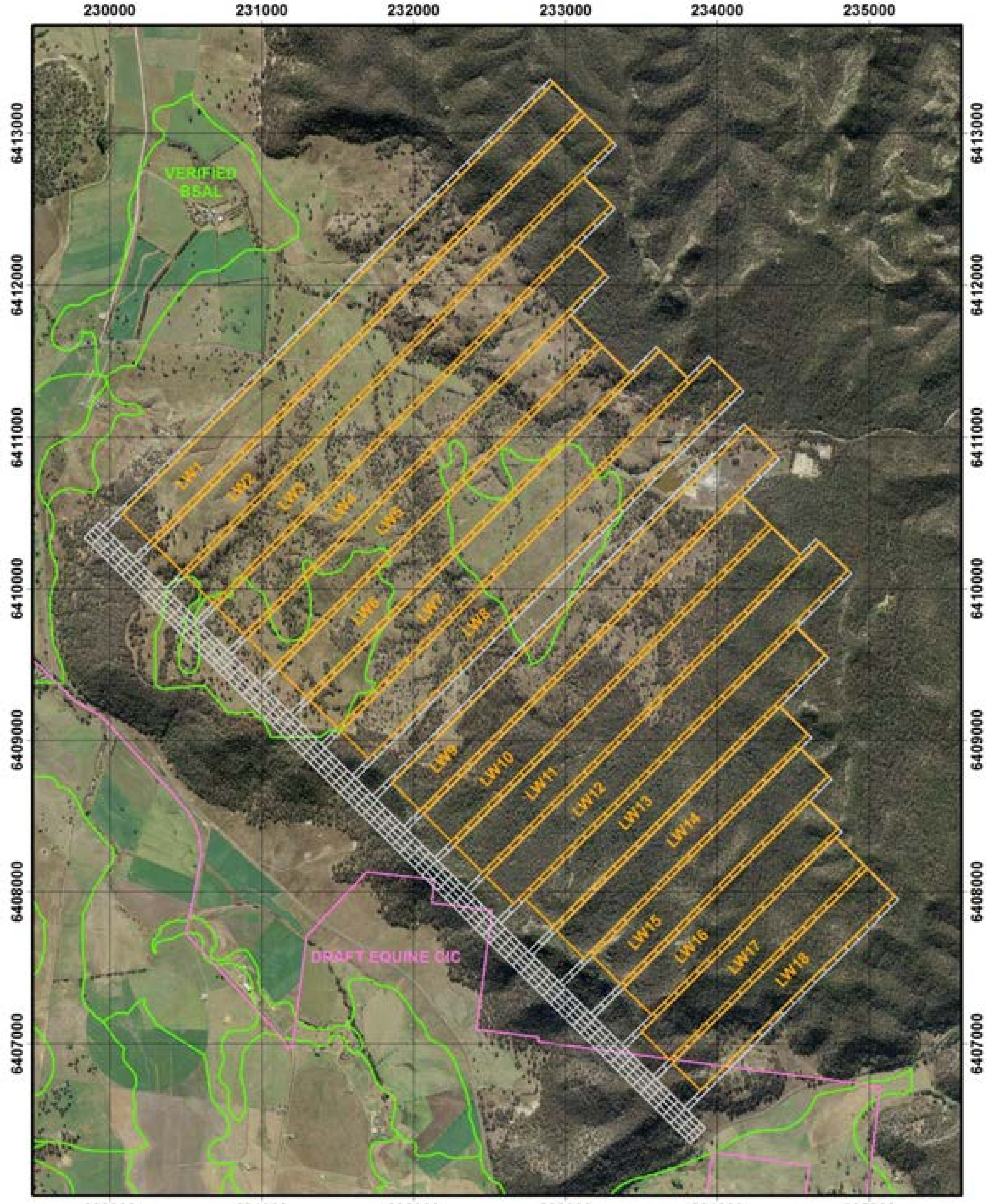

Fig. 2.2 Bylong Coal Project proposed Longwalls Overlaid on the Aerial Photograph

The following sections provide an overview of the agricultural land, agricultural utilisation and the natural and built features within the vicinity of the proposed Longwalls. Further details are provided in the report by Barnett & Associates, 2013. 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 footprint of the proposed longwalls is shown in Drawing No. MSEC660-05, which was provided by Cockatoo Coal and is based on the mapping provided in the *Upper Hunter Strategic Land Use Plan* (DoPI, 2012) and on-site verification of *Biophysical SAL* (SLR, 2013). The mapped strategic agricultural land includes the following:-

- Revised Draft CIC (Equine) Mapping 2013– representing areas potentially suitable for horse breeding facilities and related infrastructure.

  The land in Authorisation A287 and A342 that has been identified as *Revised Draft CIC (Equine)* is located predominantly to the south west of the proposed longwalls and a small portion overlies the finishing end of Longwall 18. It is noted, however, that there are no active horse studs operating within Authorisation A287 and A342.

- *Biophysical SAL* – representing land with a rare combination of natural resources highly suitable for agriculture.

  Biophysical SAL has been verified in the central area of Longwalls 5 to 9 and the finishing ends of Longwalls 3 to 7 (see Fig. 2.2).
  The agricultural land within the footprint of the proposed longwalls is used primarily for cattle grazing.

2.3. Natural Features

The locations of the natural features within and in the vicinity of the proposed longwalls are shown in Drawing No. MSEC660-07. The natural features present above the proposed longwalls which are important to the agricultural land and utilisation include surface and groundwater resources. The main watercourse over the proposed longwalls is Dry Creek. Several small ephemeral unnamed streams flow down from the ridge tops. There are no known alluvial aquifers within the footprint of the proposed longwalls.

Further descriptions of the surface water and groundwater resources are provided in the reports by WRM (2013) and AGE (2013).

2.4. Built Features

The locations of the built features within and in the vicinity of the proposed longwalls are shown in Drawing No. MSEC660-08. The built features which are important to agricultural land and utilisation above the proposed longwalls include:-

- Rural building structures and other farm structures,
- Farm dams and groundwater bores, and
- Bylong Valley Way.

The abovementioned features are discussed in Section 5.7. A quarry has also been identified within the footprint of the proposed longwalls, but is not directly associated with the agricultural land or utilisation. The quarry will be assessed as part of the Environmental Impact Statement.

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.

The presence of the intrusive materials above the proposed longwalls may result in non-conventional ground movements such as locally elevated tilts, curvatures and strains. These will be influenced by the thickness and strength of the igneous materials present and whether the properties of the surrounding sedimentary materials have been altered by the intrusion.

Non-conventional ground movements also occur at the higher depths of cover and in single-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 above the proposed longwalls within 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.

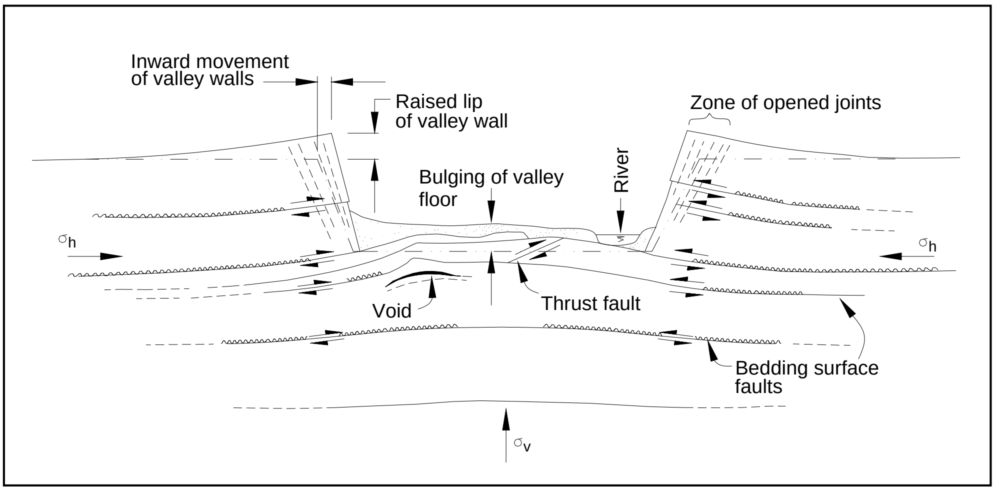

Fig. 3.1 Valley Formation in Flat-Lying **Sedimentary** Rocks (after Patton and Hendren, 1972)

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 *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 *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 ACARP Research Project No. C9067 (Waddington and Kay, 2002).

Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

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, 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, Hunter and Western 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, Hunter and Western Coalfields. The predictions curves can then be further refined, for the local geology and local conditions, based on the available monitoring data from the area. Discussions on the calibration of the 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, Hunter and Western Coalfields, the maximum predicted incremental subsidence is initially determined, using the IPM subsidence prediction curves for a single isolated panel, based on the longwall void width (W) and the depth of cover (H). The incremental subsidence is then increased, using the IPM subsidence prediction curves for multiple panels, based on the longwall series, panel width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H). In this way, the influence of the panel width (W), depth of cover (H), as well as panel width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H) are each taken into account.

The shapes of the incremental subsidence profiles are then determined using the large empirical database of observed incremental subsidence profiles. 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

The Bylong Coal Project is a Greenfield site. There is therefore no monitoring data available from this site or from nearby collieries for calibration of the Incremental Profile Method model.

The proposed longwalls have overall void widths of 260 metres and are at depths of cover ranging between 105 metres and 320 metres. The width-to-depth ratios for the proposed longwalls therefore vary between 0.8 and 2.5 and, therefore, are subcritical to supercritical in width[2]. The maximum achievable subsidence in the Western Coalfield, for single-seam super-critical conditions, is generally 60 % to 65 % of the effective extracted thickness.

The standard Incremental Profile Method for the Western Coalfield has been used to predict the mine subsidence movements at Ulan Mine which is located approximately 40km to the north west of the Bylong Coal Project. The comparisons between the observed and predicted profiles of subsidence, tilt and strain for monitoring lines at the Ulan Mine where the panel width-to-depth ratios are 1.0 to 1.7 are shown in Fig. 3.2.

It can be seen from Fig. 3.2, that the observed profiles of subsidence, tilt and strain along these monitoring lines reasonably match those predicted using the standard Incremental Profile Method. 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 line was less than the maxima predicted using the standard Incremental Profile Method. The observed subsidence results represent 30% to 40% of the 3.2 metre seam thickness extracted. This observed subsidence is considerably lower than the predicted subsidence profiles which predict up to 60% to 65% of the extracted seam thickness.

Comparisons between the observed and predicted profiles of subsidence, tilt and curvature were also made 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. 3.3, Fig. 3.4 and Fig. 3.5, respectively. The Hunter and Newcastle Coalfields are located to the east of the Bylong Coal Project with the nearest mine approximately 65km to the east.

It can be seen from Fig. 3.3, Fig. 3.4 and Fig. 3.5, that the observed profiles of subsidence, tilt and curvature along these monitoring lines reasonably match those predicted using the standard Incremental Profile Method. 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. 3.5, 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.

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[2] 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.

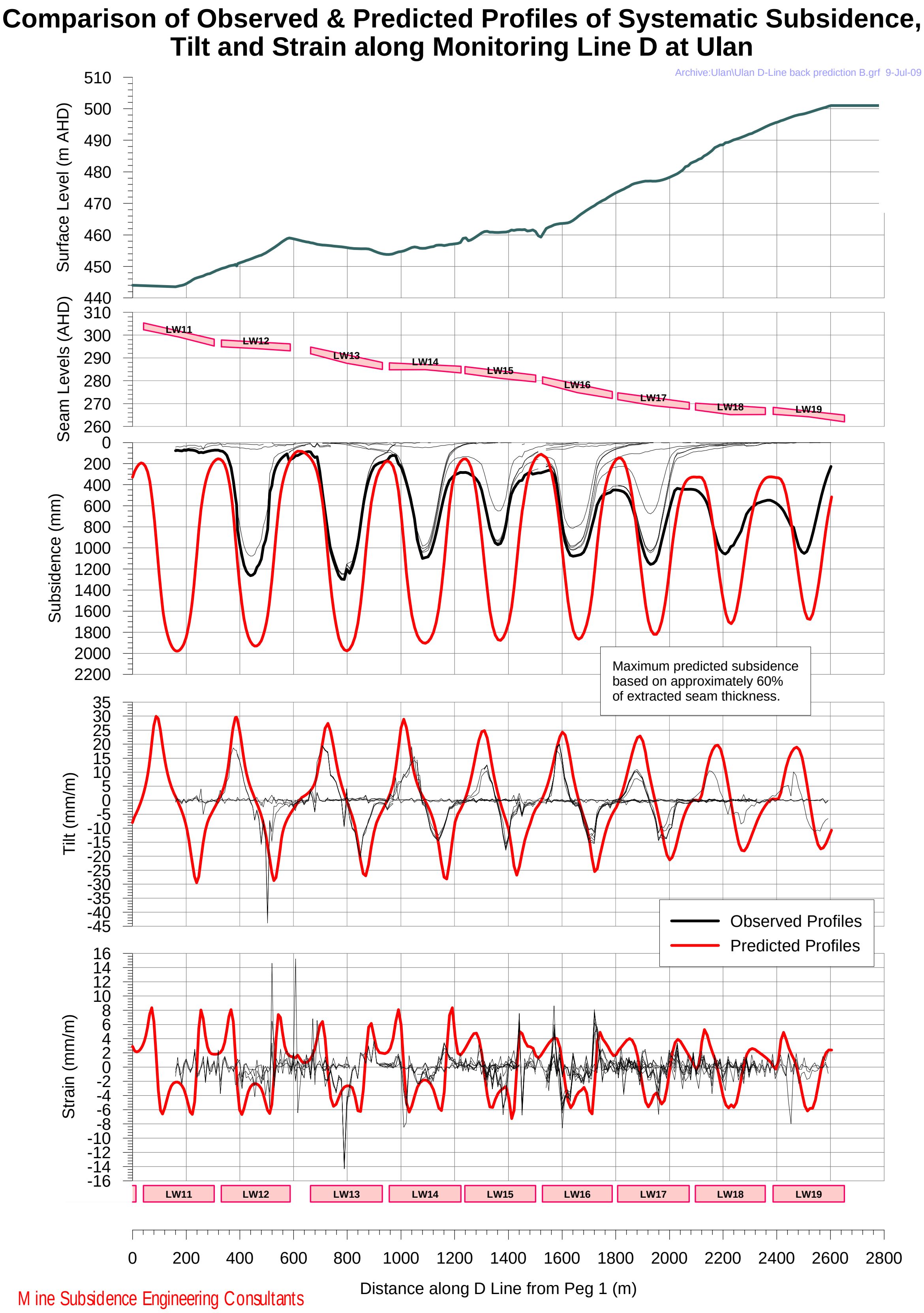

Fig. 3.2 Ulan Mine Longwalls 11 to 19 Monitoring Results along Monitoring Line D in the Ulan Seam

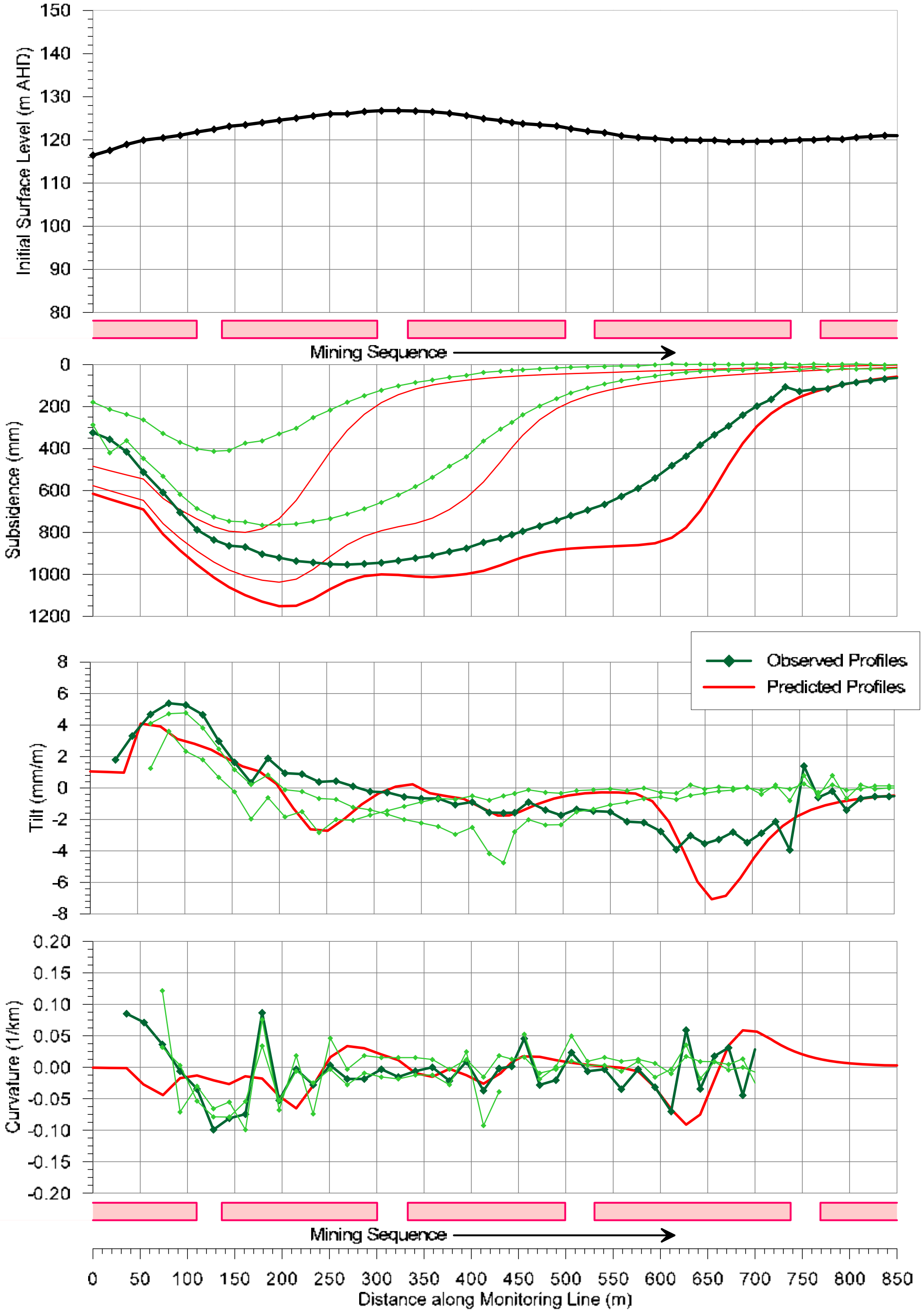

Fig. 3.3 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Newcastle Coalfield with Longwall W/H Ratio around 0.4

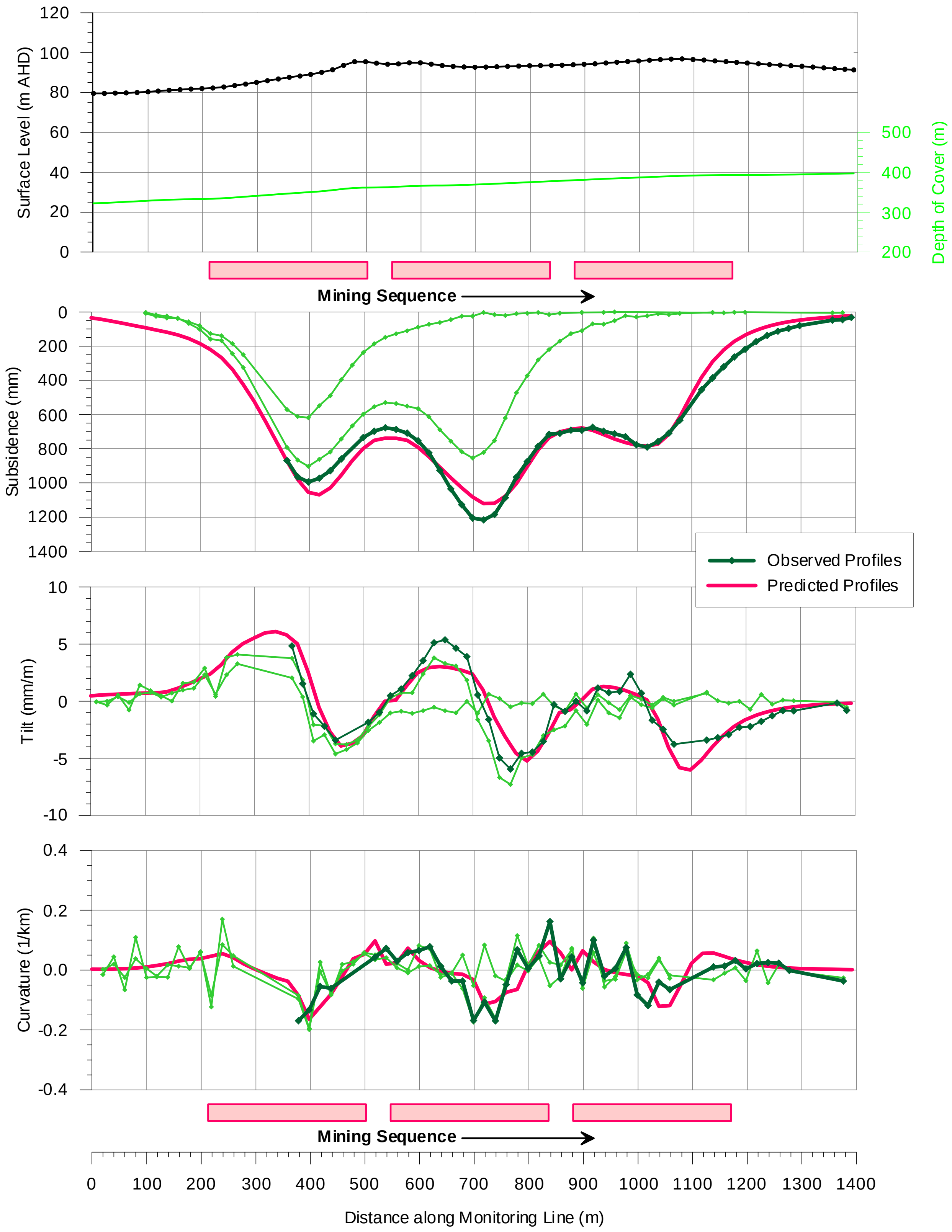

Fig. 3.4 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with Longwall W/H Ratio around 0.7

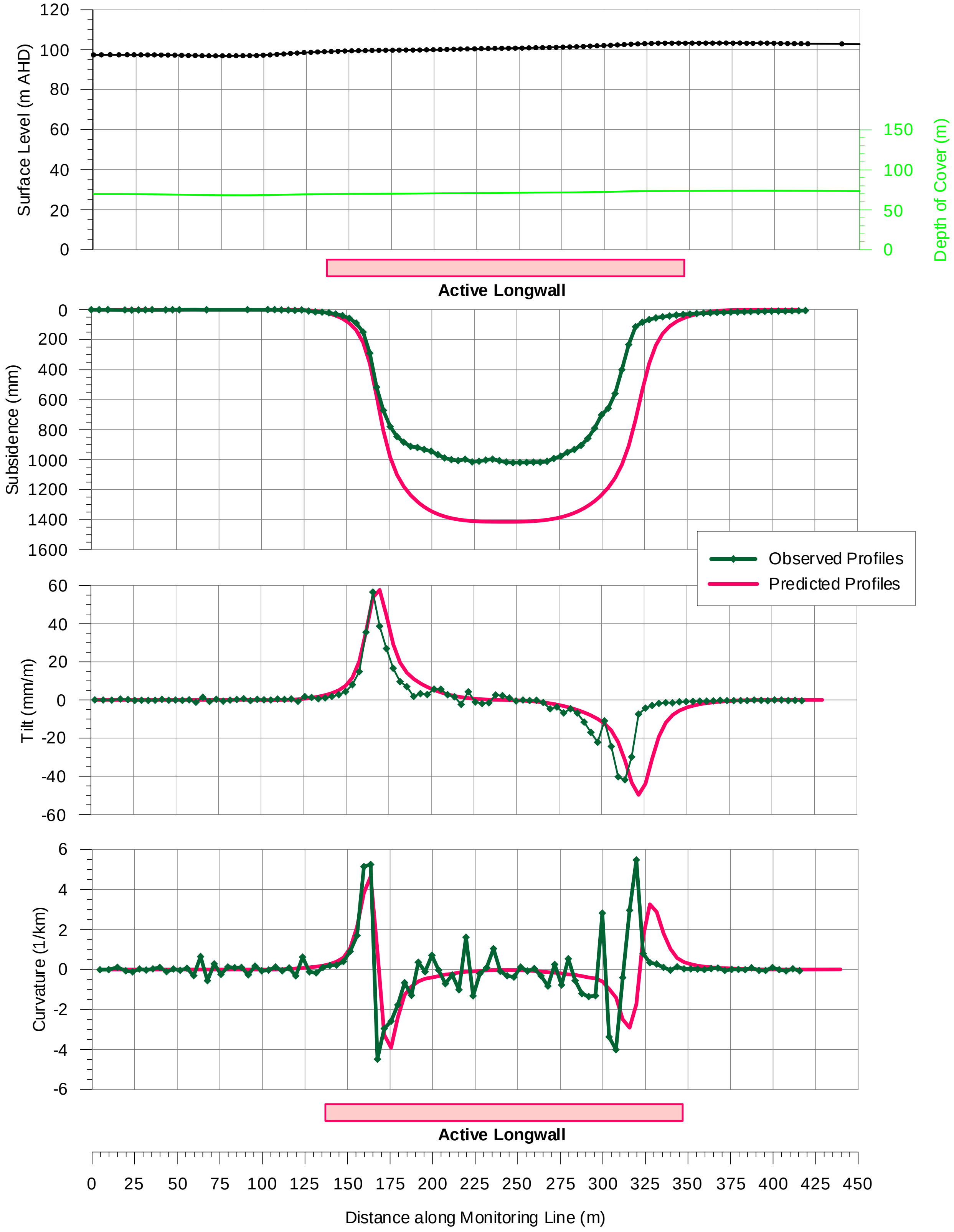

Fig. 3.5 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along a Monitoring Line in the Hunter Coalfield with Longwall W/H Ratio Greater than 2.0

3.7. 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.

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. 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. The predicted subsidence parameters and the impact assessments for the natural and built features 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 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 proposed longwalls are shown in Drawing No. MSEC660-09.

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

Table 4.1 Maximum Predicted Incremental Conventional Subsidence Parameters

Longwall	Maximum Predicted Incremental Conventional Subsidence (mm)	Maximum Predicted Incremental Conventional Tilt (mm/m)	Maximum Predicted Incremental Conventional Hogging Curvature (km^{-1})	Maximum Predicted Incremental Conventional Sagging Curvature (km^{-1})
LW1	2650	64	3.4	-2.8
LW2	2900	59	3.5	-2.4
LW3	2950	64	3.6	-3.2
LW4	3000	59	3.5	-2.4
LW5	2900	55	2.5	-2.3
LW6	2900	54	2.1	-2.3
LW7	2800	52	2.0	-1.9
LW8	2750	45	1.7	-1.4
LW9	2800	42	1.1	-1.1
LW10	2900	40	0.9	-1.1
LW11	2900	38	0.9	-1.1
LW12	2900	37	1.0	-1.0
LW13	2900	35	0.8	-1.0
LW14	2900	35	0.8	-1.1
LW15	2900	34	0.8	-1.0
LW16	2900	32	0.8	-1.0
LW17	3000	41	0.8	-1.1
LW18	3250	60	2.1	-1.6

Table 4.2 Maximum Predicted Total Conventional Subsidence Parameters

Longwall	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})
LW1 to LW18	3400	66	3.6	-3.3

The maximum predicted total subsidence, is 3,400 mm, which represents approximately 65 % of the total extraction height. The maximum predicted total conventional tilt is 66 mm/m (i.e. 6.5 %), which represents a change in grade of 1 in 15. The maximum predicted total conventional curvatures are 3.6 km^{-1} hogging and 3.3 km^{-1} sagging, which represent minimum radii of curvature of 275 metres and 300 metres respectively.

It can be seen from Drawing No. MSEC660-09, that the magnitude of the predicted subsidence varies over the mining area, due to the variations in the depths of cover and extraction heights. To illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along one prediction line, the location of which is shown in Drawing No. MSEC660-09. The predicted profiles of conventional subsidence, tilt and curvature along Prediction Line 1 are shown in Fig. C.01, in Appendix C.

4.3. Predicted Strains

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

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 and Western Coalfields, 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 are 3.6 km^{-1} hogging and 3.3 km^{-1} sagging. Adopting a factor of 10, the maximum predicted conventional strains, due to the proposed mining are 36 mm/m tensile and 33 mm/m 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 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 with Longwalls in the Hunter and Newcastle Coalfields used in the Strain Analysis

Parameter	Proposed Longwalls		Longwalls Used in Strain Analysis	
	Range	Average	Range	Average
Width	260	260	135 ~ 410	205
Depth of Cover	105 ~ 320	200	110 ~ 340	180
W/H Ratio	0.8 ~ 2.5	1.3	0.8 ~ 2.0	1.2
Extraction Height	3.4 ~ 5.1	4.0	2.1 ~ 5.0	3.9

It can be seen from the above table that the range of the panel 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. 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 is similar to 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.

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.

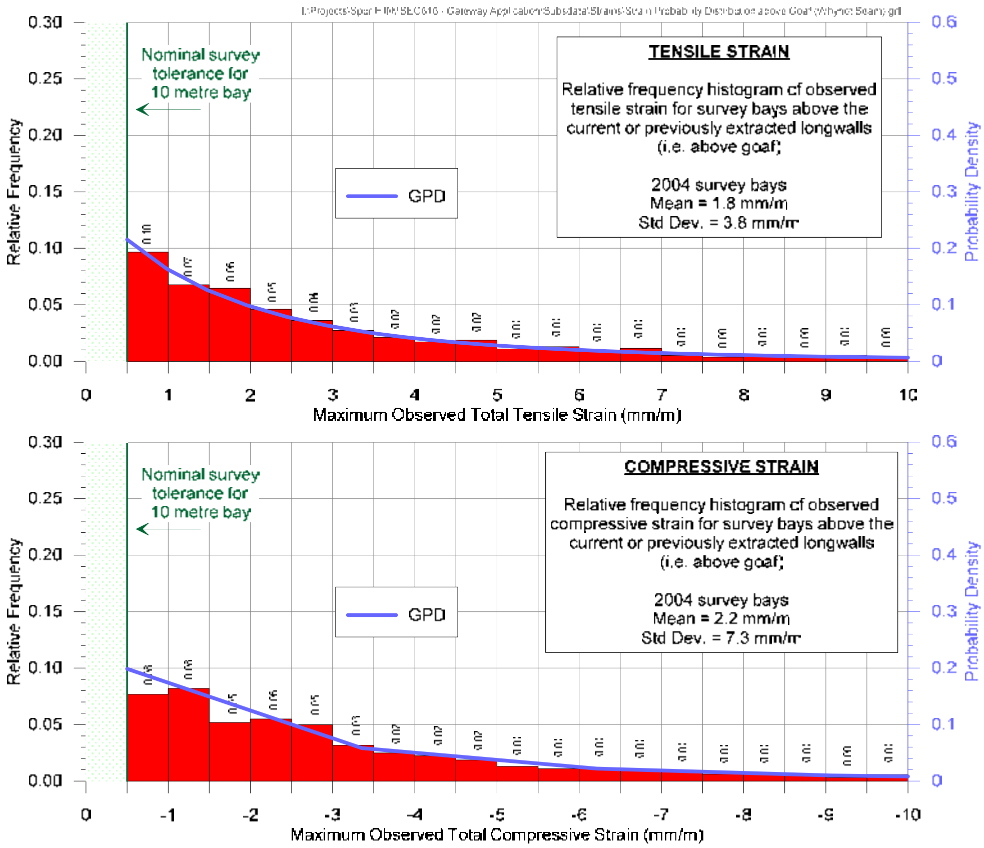

Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains in the Hunter and Newcastle Coalfields for Longwalls having W/H Ratios between 0.8 and 2.0

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 220 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 220 metres).

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

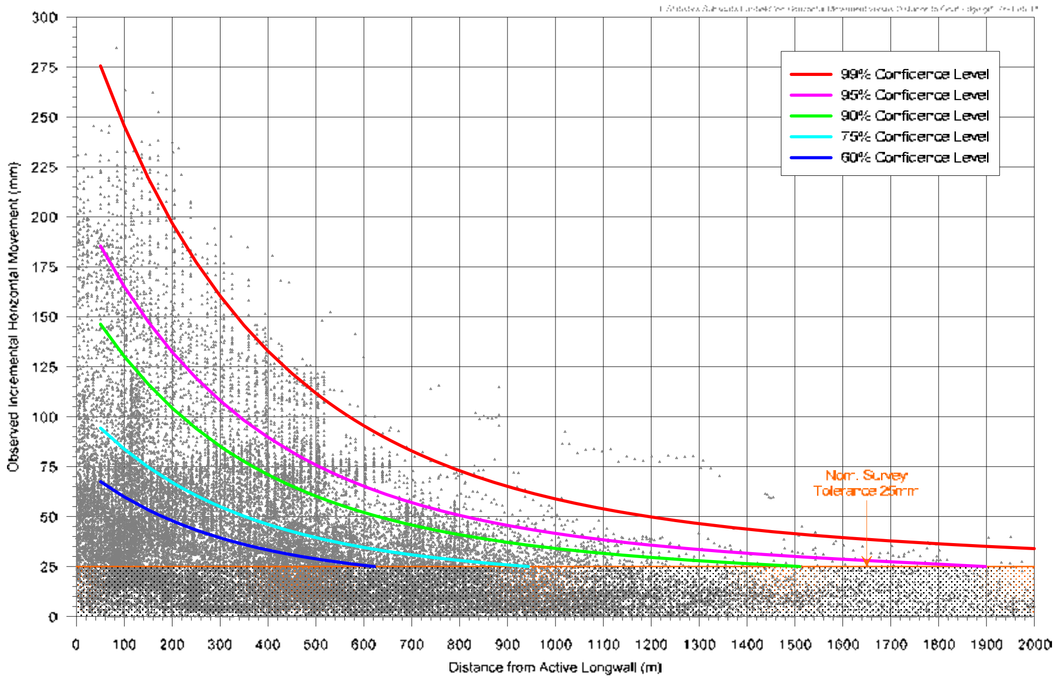

Fig. 4.2 Observed Incremental Far-Field Horizontal Movements

As successive longwalls 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) above and in the vicinity of the proposed longwalls is shown in Drawing No. MSEC660-05, which is based on the mapping provided in the *Upper Hunter Strategic Land Use Plan* (DoPI, 2012) and on-site verification of *Biophysical SAL* (SLR, 2013). The agricultural land utilisation and the associated natural and built features within Authorisation A287 and A342 are shown in Drawing No. MSEC660-06.

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 and 5.4,
- Changes to the groundwater resources – which is discussed in Section 5.5,
- Impacts on the agricultural land utilisation – which is discussed in Section 5.6, and
- Impacts on the associated built features – which is discussed in Section 5.7.

The assessments provided in this report should be read in conjunction with the assessments provided in the Agricultural Impact Statement (Barnett & Associates, 2013). 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 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. 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. An example of crack patterns that develop in shallow depths of cover is shown in Fig. 5.1 below.

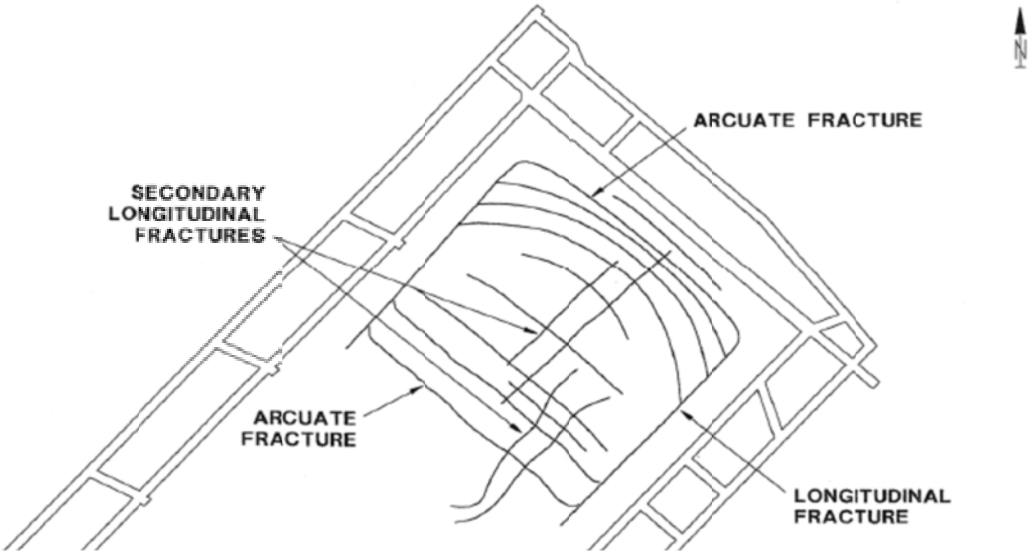

Fig. 5.1 Survey of Major Fracture Pattern at Approx. 110m Cover (Source: Klenowski, ACARP C5016, 2000)

Over previously mined longwalls, typical surface crack widths up to the order of 100 mm and step heights in the order of 100 mm have been commonly observed at shallow depths of cover, say less than 200 metres. Larger crack widths have been observed with shallow depths of cover where thicker seams are extracted, near steep terrain or where thick massive strata beams are present. These larger tensile cracks tend to be isolated and located around the perimeters of the longwalls and along the tops of steep slopes, due to down slope movements resulting from the extraction of the proposed longwalls. The typical surface cracks and these larger isolated cracks can normally be easily identified and remediated to prevent loss of surface water – Klenowski (ACARP C5016, 2000).

Experience in NSW has found that the severity and frequency of surface cracking reduces as the depth of cover to the extraction increases. Most of the mining-induced surface cracking that is observed in NSW occurs where the depths of cover are less than 200 metres. Mining at depths of cover greater than about 400 metres in NSW results in few surface cracks being observed, however significant isolated cracking can still occur. The following photographic records provide examples of surface cracking resulting from NSW longwall mining operations.

Fig. 5.2 Photographs of Surface Cracking above multi-seam longwall extraction in the Hunter Coalfield around 200m cover

The agricultural land utilisation will be affected by surface cracking and deformation. The depth of cover in the area of BSAL shown on Drawing No. MSEC660-06 varies from approximately 140 metres to 200 metres.

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

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

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

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

5.3. Predicted Changes in Surface Water Drainage

The surface RLs above the proposed longwalls vary from approximately 275 metres to 530 metres as discussed in Section 1.3 and the main drainage line over the longwalls is Dry Creek.

The drainage lines and the natural gradients above and in the vicinity of the proposed longwalls are illustrated in Drawing No. MSEC660-06. It can be seen from this drawing, that the majority of the area above the proposed longwalls has natural grades greater than 5% and approximately greater than half of the area has natural grades greater than 10%.

The natural and the predicted post-mining surface level contours based on a 5 metre contour spacing are illustrated in Fig. 5.3. An assessment was made of the geometry of the natural and post-mining surface level contours at a contour spacing of 2 metres and did not indicate the formation of post-mining topographical depressions. There is the potential for increased ponding in small isolated locations which are dependent on a number of other factors, including rainfall, catchment sizes, surface water runoff, permeation and evaporation. The areas of BSAL and Revised Draft CIC (Equine) above the proposed longwalls shown in Fig. 5.3 are presented on a larger scale in Fig. 5.4, Fig. 5.5, and Fig. 5.6.

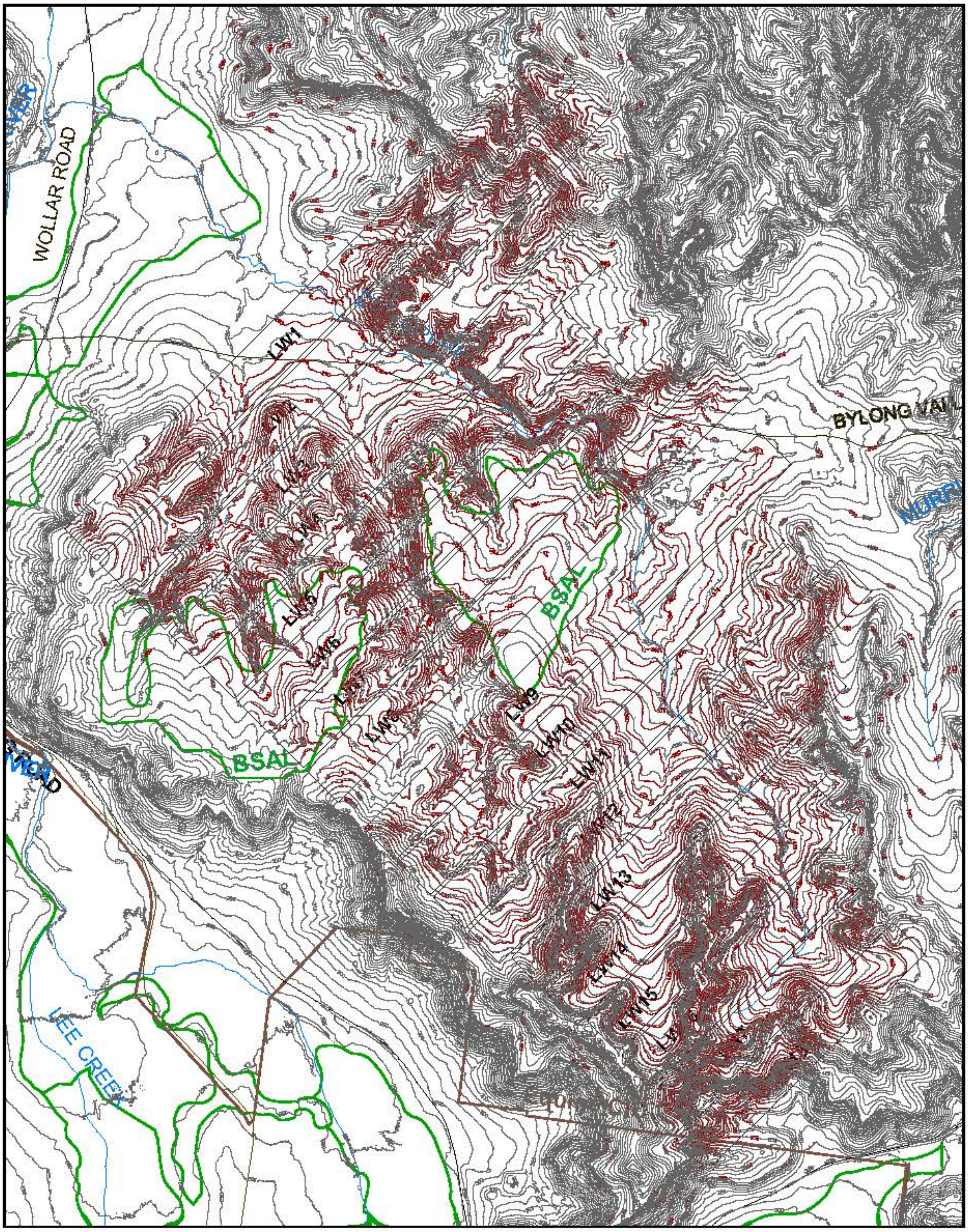

Fig. 5.3 Natural (Grey) and Predicted Post-Mining (Red) Surface Levels Contours

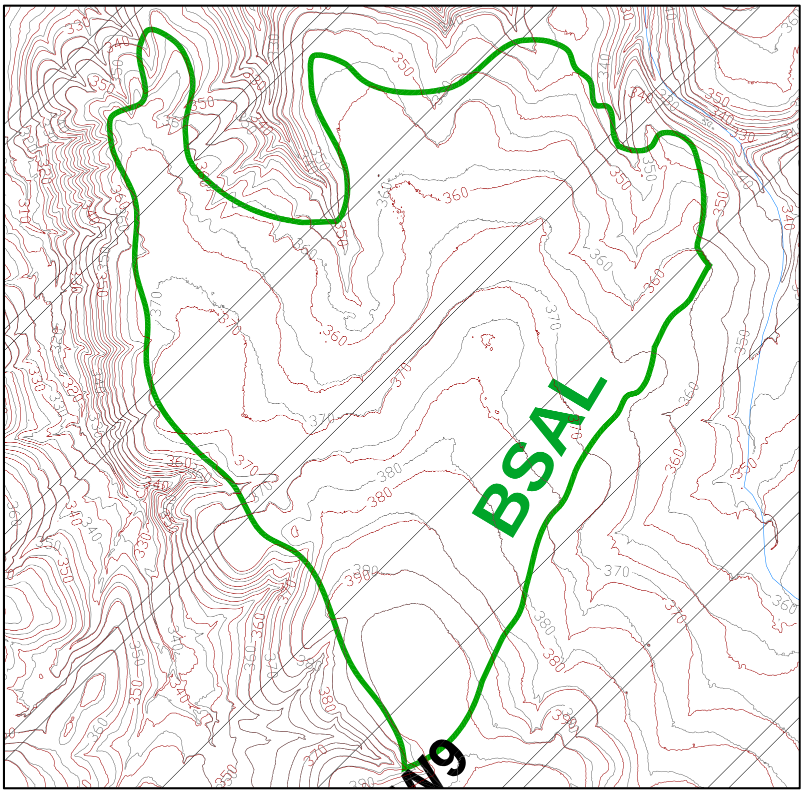

Fig. 5.4 Natural (Grey) and Predicted Post-Mining (Red) Surface Levels Contours at the location of BSAL above LW5 to LW9

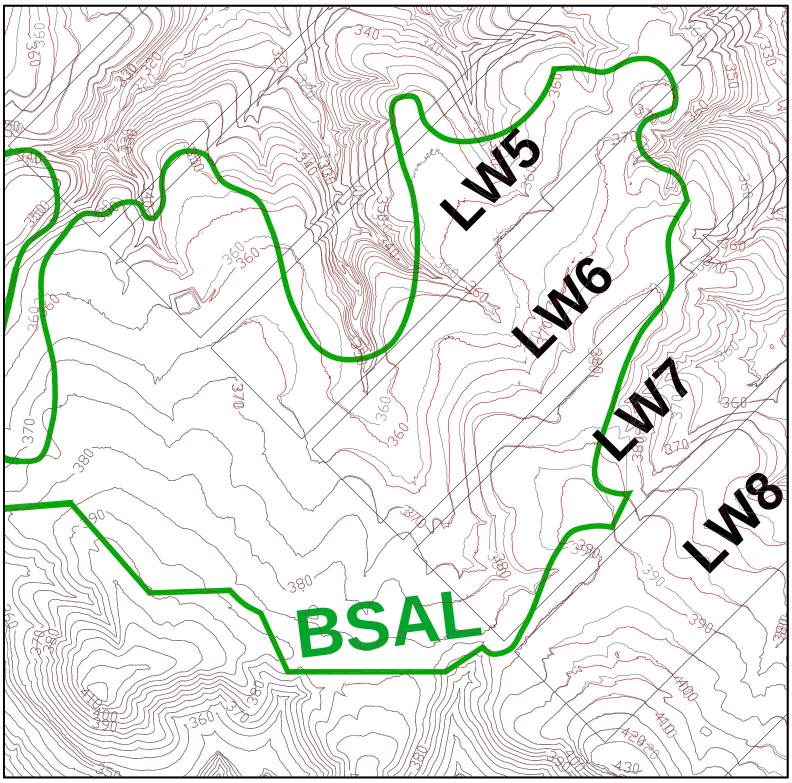

Fig. 5.5 Natural (Grey) and Predicted Post-Mining (Red) Surface Levels Contours at the location of BSAL above LW3 to LW7

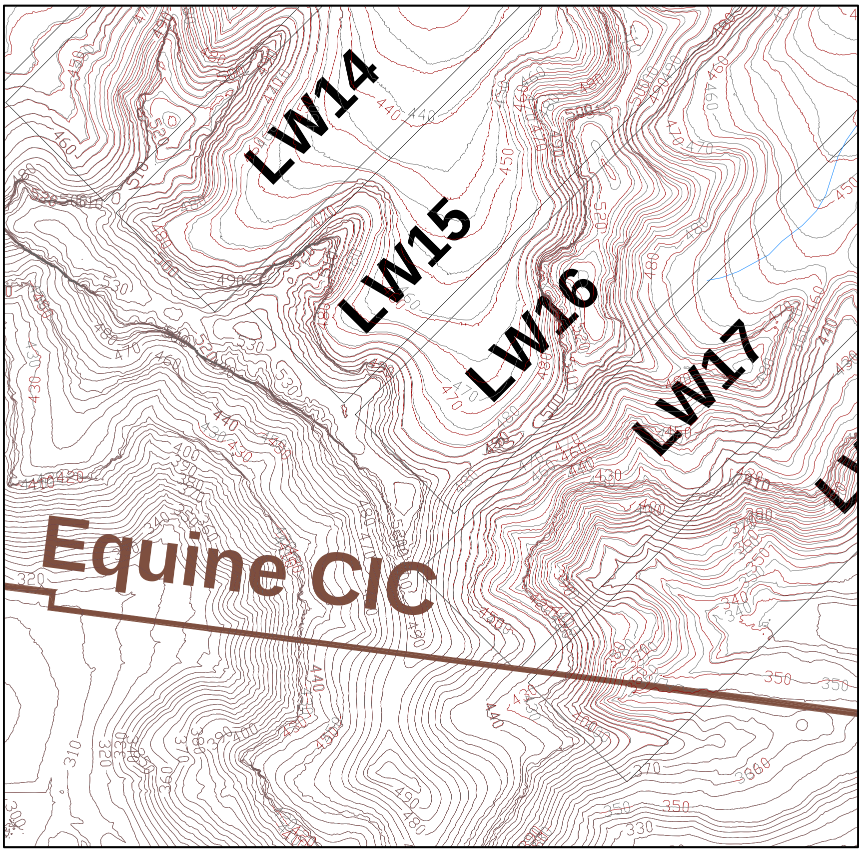

Fig. 5.6 Natural (Grey) and Predicted Post-Mining (Red) Surface Levels Contours at the location of Revised Draft CIC (Equine)

The formation of topographical depressions generally occurs in areas of shallow natural gradient, where the change in gradient due to longwall extraction can exceed the natural gradient. There are existing small localised natural topographical depressions above the proposed longwalls which change in elevation due to the extraction of the proposed longwalls but do not generally increase in area as they are located in terrain where the natural gradients are significantly greater than the resulting change due to mining.

The final topographical depressions are predicted to be isolated and less than approximately 1 metre deep, with the potential ponding depths being less than this due to the various other factors previously described. The predicted post-mining surface topography will result in a potential change in alignment along some drainage lines and this is discussed in Section 5.4.

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. Discussions on the methods of remediation for the drainage lines and, hence, the post-mining ponding are provided in Section 5.4.

The agricultural land utilisation, could be affected by the topographical depressions and, hence, may require surface remediation works.

5.4. Drainage Lines

5.4.1. Description of the Drainage Lines

The locations of the drainage lines above and in the vicinity of the proposed longwalls are shown in Drawing No. MSEC660-06. The only named drainage line above the proposed longwalls is Dry Creek and this creek does not flow through the identified BSAL or Revised Draft CIC (Equine) areas.

The drainage lines above the proposed longwalls flow into Dry Creek which flows into Bylong River approximately 2 km north west of the proposed longwalls. 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 outcropping materials shown in Fig. 1.2. A photograph of Dry Creek is shown in Fig. 5.7.

Fig. 5.7 Dry Creek, looking downstream from Bylong Valley Way crossing

The natural grades along Dry Creek vary from approximately 60 mm/m (6%) along the upper reaches to less than 20 mm/m (1%), with an average of approximately 40 mm/m (4%).

5.4.2. Predictions for the Drainage Lines

The predicted profiles of subsidence tilt and curvature along Dry Creek are shown in Fig. 03 in Appendix C. The predicted profiles of subsidence, upsidence and closure along Dry Creek are shown in Fig. 04 in Appendix C. The drainage lines have relatively shallow incisions into the natural surface soils and the impacts to the drainage lines resulting from valley related upsidence and closure movements are not expected to be significant when compared with the predicted conventional movements.

The maximum predicted total conventional curvatures for Dry Creek are 2.4 km^{-1} hogging and 1.5 km^{-1} sagging, which represent minimum radii of curvature of 420 metres and 660 metres respectively. The predicted maximum strains for the drainage lines, based on the strain analysis provided in Section 4.3, are typically in the order of 25 mm/m tensile and 15 mm/m compressive.

The other drainage lines are distributed over the proposed longwalls and will experience the range of predicted conventional movements presented in Section 4.2.

5.4.3. Impact Assessments for the Drainage Lines

The impact assessments for the drainage lines are provided in the following sections. The verified BSAL areas above the proposed longwalls have some minor drainages lines within their boundaries that flow towards Dry Creek, as shown in Fig. 5.4 and Fig. 5.5.

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 tilt for Dry Creek is 60 mm/m (i.e. 6 %) towards the western end of the creek and 40 mm/m (i.e. 4 %) in the eastern part of the creek. The maximum predicted changes in grade are generally greater than the natural grades along the western part of the creek and less than the natural grades in the eastern part of the creek.

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 grades at the western end of the creek. 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 grades. After the completion of mining 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. The areas of ponding along Dry Creek are indicated in Fig. 5.3, which are predicted to be of the order of 50 metres to 100 metres in length and less than approximately 1 metre depth. The areas of ponding are located above LW1 to LW3, and are outside the verified BSAL areas. The majority of the other drainage lines have gradients typically greater than the predicted tilts, however it is expected that localised areas of ponding will develop, particularly in the areas of drainage lines with shallow grades.

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, 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.

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 rip-rap, or to locally regrade the beds of the drainage lines in these locations.

Potential for Changes in Alignment of the Drainage Lines

The potential for changes in stream alignment of the drainage lines can occur due to changes in topography resulting from mining-induced conventional movements or valley related movements. As discussed in section 5.3, the majority of the area above the proposed longwalls has natural grades greater than 5% and approximately greater than half of the area has natural grades greater than 10%. The predicted conventional tilts resulting longwall mining vary from approximately 30 mm/m to 65 mm/m (i.e. 3% to 6%). Based on these results, the alignment of drainage lines in topographical areas above the longwalls with steeper grades are unlikely to be significantly affected by changes in topography resulting from extraction of the proposed longwalls and the alignment of drainage lines in topographical areas with shallow grades are more likely to be affected by changes in topography resulting from extraction of the proposed longwalls.

An comparison of drainage lines based on the pre and post mining surface level contours are shown in Fig. 5.8

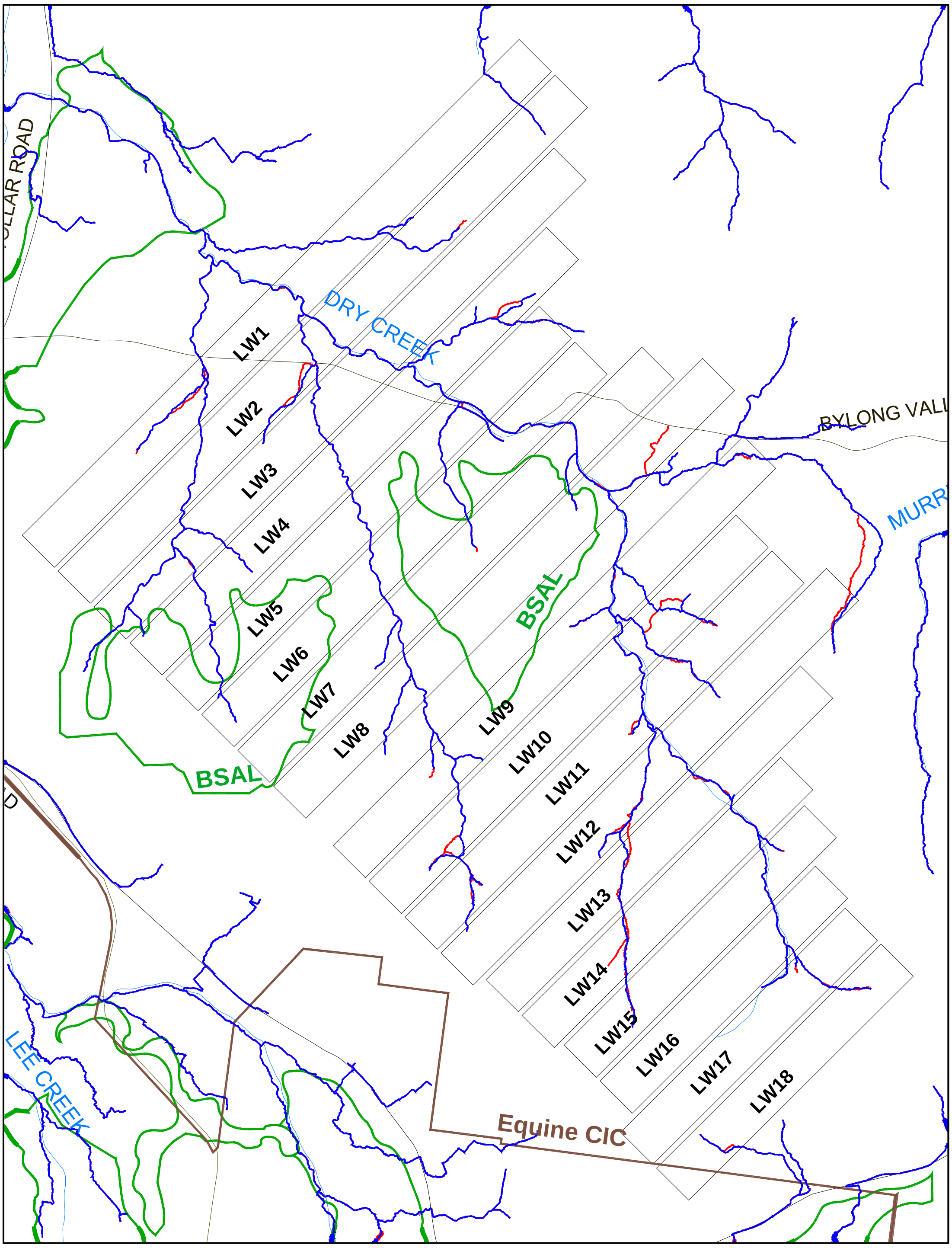

Fig. 5.8 Comparison of Pre-mining (Blue) and Post-mining (Red) Drainage Lines

It can be seen from the above figure that the majority of the drainage lines alignments remain unchanged with only minor localised changes in alignment in areas with shallow grades. There are no changes in alignment of the drainage lines within the BSAL areas. One noted change in alignment occurs above proposed Longwall 2 (outside BSAL or CIC areas) where a drainage line crosses Bylong Valley Way and could impact the flow of water through the road drainage culverts depending on the elevation of the road embankment, in which case regrading, or remediation measures may be required to restore adequate flow through the area.

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 compacting the surface.

The extraction of supercritical longwalls is expected to result in fracturing from the seam up to the surface. At the magnitudes of the predicted subsidence, the overburden is expected to have undergone large blocky movements, resulting in a network of fractures which is likely to increase the hydraulic conductivity between the surface and the seam at the areas of shallowest cover, with reducing potential for connectivity as depth of cover increases. It is likely, therefore, that some of the surface water flows in the ephemeral streams would be lost into the mine workings during high rainfall events. It may be necessary, in some locations, to remediate and reinstate the drainage line beds with highly cohesive soils, or to locally grout the bedrock along the streams, especially where the depths of cover are the shallowest.

Experience from mining in the Hunter, Newcastle and Western 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 approximately half of the proposed mining area.

Further discussion on the potential impacts from hydraulic connectivity between the surface and seam are provided in the report by AGE (2013)..

5.4.4. 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 compacting the surface. In some cases, erosion protection measures may be needed.

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

5.5. Groundwater Resources

There are groundwater resources associated with the Bylong River alluvial aquifer and other shallow and deeper aquifers within Authorisation A287 and A342. More detailed descriptions of these resources are provided in the report by AGE (2013). There are no groundwater resources utilised above the proposed longwalls. The registered groundwater bores above the proposed longwalls are used for monitoring and are discussed below.

The Bylong River is located to the west and south of the proposed longwalls. This river is considered to be the most significant stream within Authorisation A287 and A342. The river channel is located around 600 metres to the south of Longwall 18, at its closest point. The river is located well outside the Subsidence Study Area as shown in Drawing No. MSEC660-06. At this distance, the river channel, itself, is expected to experience negligible vertical subsidence 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.

Details concerning the nature and extent of alluvial aquifers are currently being investigated. As a general guide, the limit of alluvium delineated in Drawing No. MSEC660-06 provides a reasonable approximation of the extent of alluvial aquifers. Further discussion is provided in the report by AGE (2013). . It can be seen from this drawing, that the mapped limit of alluvium for the Bylong River is located outside the Subsidence

Study Area and is approximately 200 metres to the north west of Longwall 1 at its nearest point. At this distance, the alluvium is expected to experience negligible vertical subsidence and, is not expected to experience any measurable conventional tilts, curvatures or strains. It is unlikely, therefore, that the alluvial aquifer associated with Bylong River, would experience any adverse impacts resulting from the proposed longwall mining. The limit of alluvium extends from Bylong River up Dry Creek with a small portion located within the Longwall 1 footprint. Alluvial aquifers associated within this limit of alluvium above Longwall 1 are likely to be impacted by the proposed mining, which is discussed in Section 5.4.3. Longwall configuration may be changed to avoid mining beneath alluvial aquifers, subject to further studies to confirm the nature and extent of the aquifers.

The locations of the registered groundwater bores are shown in Drawing No. MSEC660-08. 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 above the proposed longwalls (all of which are located on land owned by KEPCO) is provided in Table 5.1 below. There are also additional groundwater bores to the south and west of the proposed longwalls, as shown in Drawing No. MSEC660-08.

Table 5.1 Details of the Groundwater Bore above the Proposed Longwalls

Ref.	Approximate Easting (m)	Approximate Northing (m)	Depth (m)	Authorised Use
GW201536	233577	6411225	195	Monitoring
GW201539	230443	6410218	170	Monitoring
GW201541	231893	6412110	142	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.

As discussed in Section 5.4, the extraction of supercritical longwalls is expected to result in fracturing from the seam up to the surface and result in a network of fractures which is likely to increase the hydraulic conductivity between the surface and the seam at the areas of shallowest cover, with reducing potential for connectivity as depth of cover increases.

Further discussions on the potential impacts on the groundwater resources are provided in the report by AGE (2013).

5.6. Agricultural Land Utilisation

With the exception of the Bylong State Forest, the land above the proposed longwalls is currently used for cattle grazing and has generally been cleared, with natural vegetation remaining on the steeper slopes. A small section of land above the finishing end of Longwall 18 is identified as Revised Draft CIC (Equine), however this area has steep slopes and is not cleared of natural vegetation.

The potential impacts on the agricultural land use include:-

- Surface cracking and deformations – which was discussed in Section 5.2,
- Changes in surface water and drainage – which was discussed in Sections 5.3 and 5.4,
- Changes to the groundwater resources – which was discussed in Section 5.5, and
- Impacts to built features – which is discussed in Section 5.7.

The following sections provide the impact assessments on the agricultural utilisation.

5.6.1. Cattle Grazing

There is grazing of cattle on the land above the proposed longwalls. A risk to this type of agricultural land use is the potential for the mining induced surface cracking and deformations to injury 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 compacting the surface, and
- Develop Property Subsidence Management Plans (PSMPs) incorporating the agreed methods to manage surface cracking and deformations with the property owners.

5.6.2. Equine Use

There is a small portion of privately owned land overlying Longwall 18 that is identified as CIC equine.. A Property Subsidence Management Plans (PSMP) would need to be developed for this property, prior to active subsidence, incorporating agreed management strategies with the property owners.

5.7. Built Features Associated with the Agricultural Land Utilisation

The locations of the built features associated with the agricultural land use above the proposed longwalls are shown in Drawing No. MSEC660-08. The built features located directly above the proposed longwall mining area include:-

- Rural building structures located directly above the proposed longwalls, which includes sheds and other non-residential building structures,
- 6 farm dams located directly above the proposed longwalls, which have been established along the natural drainage lines. 1 dam is located with a BSAL area,
- Fencing,
- Bylong Valley Way that provides a link between the Township of Bylong and Denman to the east, and
- A quarry.

The rural structures are not located within the BSAL and Revised Draft CIC (Equine) areas. Rural structures are typically lightweight structures and likely able to tolerate the predicted movements. Any impacts can be readily repaired.

Bylong Valley Way is a tourist route and will experience significant subsidence movements as a result of the proposed mining. The traffic volumes are, however, relatively light and it will be possible to maintain the safety and serviceability of the road during mining. This has been successfully achieved by other coal mines at similar depths of cover in the Hunter Valley.