REPORT: SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

MOOLARBEN COAL COMPLEX:

Moolarben Project Stage 2 – Longwalls 104 to 105

Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan

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Background reports available at *www.minesubsidence.com*:-

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)

EXECUTIVE SUMMARY

Moolarben Coal Operations Pty Ltd (MCO) operates the Moolarben Coal Complex (MCC), which is located approximately 40 km north east of Mudgee in New South Wales (NSW). MCO has been granted approval to develop Stages 1 and 2 of the Moolarben Coal Project (MCP) under the *Environmental Planning and Assessment Act 1979*. Approval for Stage 1 of the MCP (05_0117) was granted by the Minister for Planning on 6 September 2007. Approval for Stage 2 of the MCP (08_0135) was granted for the Preferred Project Mine Layout (PrefML) on 30 January 2015.

The MCC includes four approved open cut mines, (known as Open Cut 1 mine (OC1), Open Cut 2 mine (OC2), Open Cut 3 mine (OC3) and Open Cut 4 mine (OC4)), and three approved underground mines, (known as Underground Area 1 (UG1), Underground Area 2 (UG2) and Underground Area 4 (UG4)) and the associated infrastructure. MCO commenced mining coal from the open cut mine OC1 in May 2010. A Modified Mine Layout for the UG1 Optimisation Modification (Stage 2 Modification 2) was approved in April 2016 (Approved Layout).

MCO was granted approval for the Longwalls 101 to 103 Extraction Plan within UG1 in September 2017. During the preparation of the Longwall 101 to 103 Extraction Plan, MCO introduced a barrier pillar with a total length of 140 m containing an igneous intrusion within LW102 ,and reduced the length of Longwalls 101 to 103 by approximately 69 m. Mine Subsidence Engineering Consultants (MSEC) prepared Report No. MSEC867 (Rev. A) which supported the Extraction Plan Application for these longwalls.

The commencing end of Longwall 103 has since been shortened by 660 m due to an igneous plug and associated dykes encountered near the commencing end of this longwall. MSEC prepared Report No. MSEC1032 in support of the Longwall 103 modified commencing end. The modification of the commencing end included extraction of first workings within the 660 m reduced length, referred to as 103A workings. The first workings were designed to provide a long-term stable pillar environment, with subsidence limited to less than 20 mm.

Longwalls 101 and 102 have been extracted. Underground mining operations are scheduled to complete Longwall 103 in June 2020. Moolarben Coal will seek approval to amend the UG1 extraction plan to include the remaining Longwall panels 104 and 105. The commencing end of Longwall 104 has been reduced by 70 m. The Extraction Plan Layout referred to in this report includes the approved layout of Longwalls 101 to 103 and the addition of Longwalls 104 and 105, including the reduced Longwall 104 commencing end.

MSEC has prepared this subsidence report to support the application to amend the current approved Longwalls 101 to 103 Extraction Plan to include Longwalls 104 and 105. The predictions and impact assessments provided in this report are based on the Extraction Plan Layout. The Report focuses on the Additional Assessment Area associated with Longwalls 104 and 105.

The locations of the approved MCC open cut mines and underground mines, including UG1, are shown in Drawing No. MSEC1084-01, which together with all other drawings, is included in Appendix E.

The introduction of the barrier pillar within LW102 resulted in a decrease in subsidence predictions above and in the vicinity of the barrier pillar. The reduced longwall lengths resulted in a reduction in the predicted limit of vertical subsidence in these areas and increased the distance between the end of the longwalls and public infrastructure to the north and east of UG1. With the exception of these changes, the longwall panel dimensions and layout of Longwalls 101 to 105 do not change for the Extraction Plan Layout. As a result, the overall impact assessments for the natural and built features based on the Extraction Plan Layout are unchanged, or reduce compared to those based on the Approved Layout.

Monitoring and management strategies have been developed and implemented for the following built features as part of the Extraction Plan process for Longwalls 101 to 105 based, on consideration of the results of additional assessments and consultation with the infrastructure owners:

- Australian Rail Track Corporation (ARTC) – Sandy Hollow – Gulgong Railway;
- Mid Western Regional Council (MWRC) – local roads (including Ulan-Wollar Road) and associated infrastructure;
- Telstra – telecommunications cables;
- Essential Energy – 66kV powerline and proposed substation;
- TransGrid – 330 kV electricity transmission line and towers; and
- Spatial Services NSW – survey control marks.

Monitoring and management strategies have also been developed for the identified natural features as part of the Extraction Plan process for Longwalls 101 to 105 based on the Extraction Plan Layout. MCO is seeking approval to amend the current approved Extraction Plan for LW101 to 103 to include Longwalls 104 and 105.

The monitoring and management strategies for built features would aim to achieve the performance measure of safe, serviceable and repairable.

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Drawings

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

Drawing No.	*Description*	*Revision*
MSEC1084-01	Location Plan	A
MSEC1084-02	General Layout	A
MSEC1084-03	Surface Level Contours	A
MSEC1084-04	DWS Seam Floor Contours	A
MSEC1084-05	DTP Seam Roof Contours	A
MSEC1084-06	DWS & DTP Seam Thickness Contours	A
MSEC1084-07	Depth of Cover Contours at DTP seam	A
MSEC1084-08	Natural Features	A
MSEC1084-09	Surface Infrastructure	A
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1.1. Background

Moolarben Coal Operations Pty Ltd (MCO) operates the Moolarben Coal Complex (MCC), which is located approximately 40 km north east of Mudgee in New South Wales (NSW). MCO has been granted approval to develop Stages 1 and 2 of the Moolarben Coal Project (MCP) under the *Environmental Planning and Assessment Act 1979*. Approval for Stage 1 of the MCP (05_0117) was granted by the Minister for Planning on 6 September 2007. Approval for Stage 2 of the MCP (08_0135) was granted for the Preferred Project Mine Layout (PrefML) on 30 January 2015.

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Longwalls 101 and 102 have been extracted. Underground mining operations are scheduled to complete Longwall 103 in June 2020. Moolarben Coal will seek approval to amend the UG1 extraction plan to include the remaining Longwall panels 104 and 105. The commencing end of Longwall 104 has been reduced by 70 m. The Extraction Plan Layout referred to in this report includes the approved layout of Longwalls 101 to 103 and the addition of Longwalls 104 and 105, including the reduced Longwall 104 commencing end.

The locations of the approved MCC open cut mines and underground mines, including UG1, are shown in Drawing No. MSEC1084-01, which together with all other drawings, is included in Appendix E.

MSEC has prepared this subsidence report to support the application to amend the current approved Extraction Plan for Longwalls 101 to 103 to include Longwalls Longwalls 104 and 105. The predictions and impact assessments provided in this report are based on the Extraction Plan Layout, shown in Drawing No. MSEC1084-02 and focuses on the Additional Assessment Area (Longwalls 104 and 105).

Chapter 2 defines the Additional Assessment Area and Study Area and provides a summary of the natural and built features within the Additional Assessment Area.

Chapter 3 includes overviews of the mine subsidence parameters and the methods that have been used to predict the mine subsidence movements resulting from the extraction of the longwalls.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of Longwalls 101 to 105 based on the Extraction Plan Layout. Comparisons of these predictions with the maxima based on the Approved Layout are also provided in this chapter.

Chapters 5 to 11 provide the descriptions, predictions and impact assessments for each of the natural and built features within the Additional Assessment Area based on the Extraction Plan Layout. Comparisons of the predictions for each of these features with those based on the Approved Layout are provided in these chapters. The impact assessments and recommendations have also been provided based on the Extraction Plan Layout.

1.2. Mining Geometry

The layout of Longwalls 101 to 105 is shown in Drawing No. MSEC1084-01 in Appendix E. A summary of the longwall dimensions is provided in Table 1.1.

Table 1.1 Geometry of Longwalls 101 to 105 based on the Extraction Plan Layout

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
LW101	2,561	311	-
LW102A	3,292	311	20
LW102B	1,060	311	20
LW103	3,829	311	20
LW104	4,469	311	20
LW105	4,544	311	20

With the exception of the changes to the longwall lengths noted previously, geometry for the Extraction Plan Layout is the same as that for the Approved Layout.

1.3. Surface Topography and Seam Information

The UG1 longwalls are surrounded to a large extent by the approved open cut mine areas and the entry to these longwalls is via the approved OC1 highwalls. The depth of cover to the Ulan Seam above these longwalls varies between a minimum of about 50 m over Longwall 102A, and a maximum of 165 m over Longwall 102B. The seam floor generally dips from the south-west down to the north-east over the entire mining area. The DWS and DTP plies of the Ulan Seam are being extracted.

The surface level contours, DWS seam floor contours, the DTP seam roof contours, DWS plus DTP seam thickness contours and the overburden depth contours to the DTP seam roof are shown in Drawings Nos. MSEC1084-03 to MSEC1084-07. The depth of cover in the Additional Assessment Area has also been presented on Drawing No. MSEC1084-08 in three zones, of less than 50 m, 50 m to 100 m and greater than 100 m.

The variations in the surface and seam levels across the mining area are illustrated along Cross sections 1, 2 and 3 in Fig. 1.1, Fig. 1.2 and Fig. 1.3, respectively. The locations of these sections are at the prediction lines shown in Drawing No. MSEC1084-11.

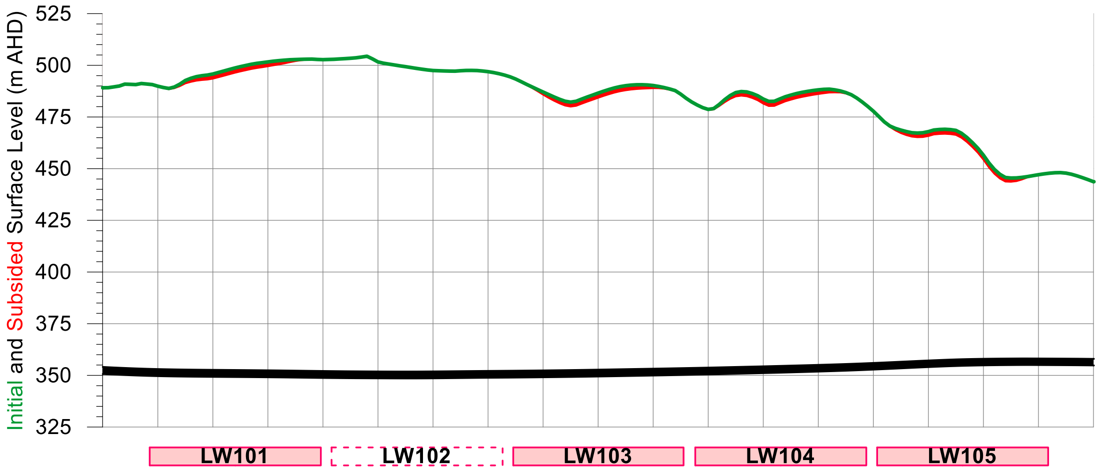

Fig. 1.1 Surface and Seam Levels along Cross-section 1

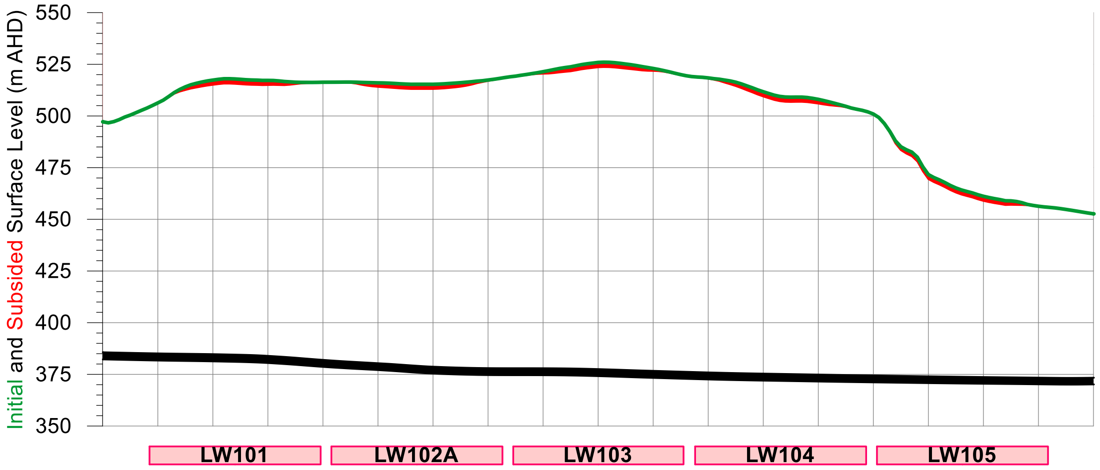

Fig. 1.2 Surface and Seam Levels along Cross-section 2

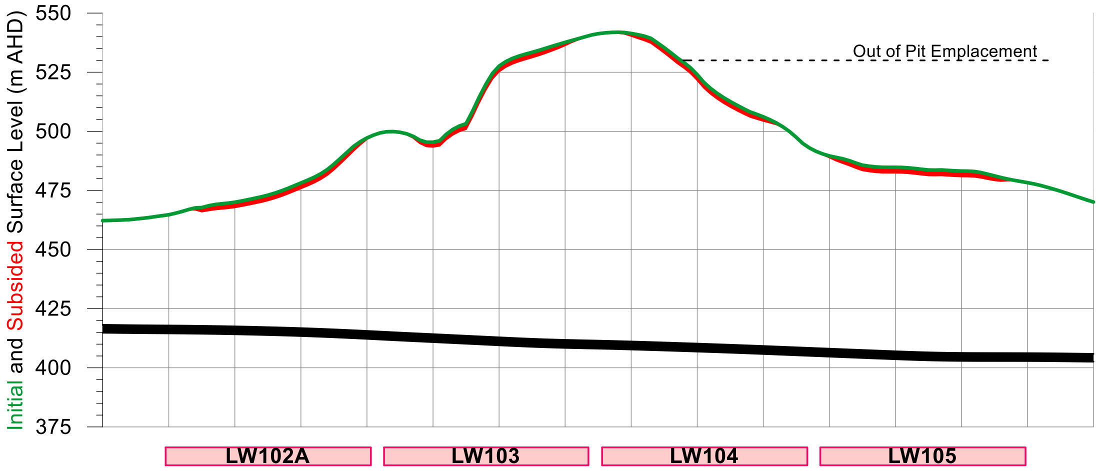

Fig. 1.3 Surface and Seam Levels along Cross-section 3

1.4. Geological Details

The surface lithology in the vicinity of the UG1 longwalls are shown in Fig. 1.4.

This figure was produced from a geological coalfield map that was downloaded from the Geological Survey of the Department of Primary Industries' website called Western Coalfield Regional Geology (Northern Part) Geological Sheet 1 1998 -1:100000 Western Coalfield Map.

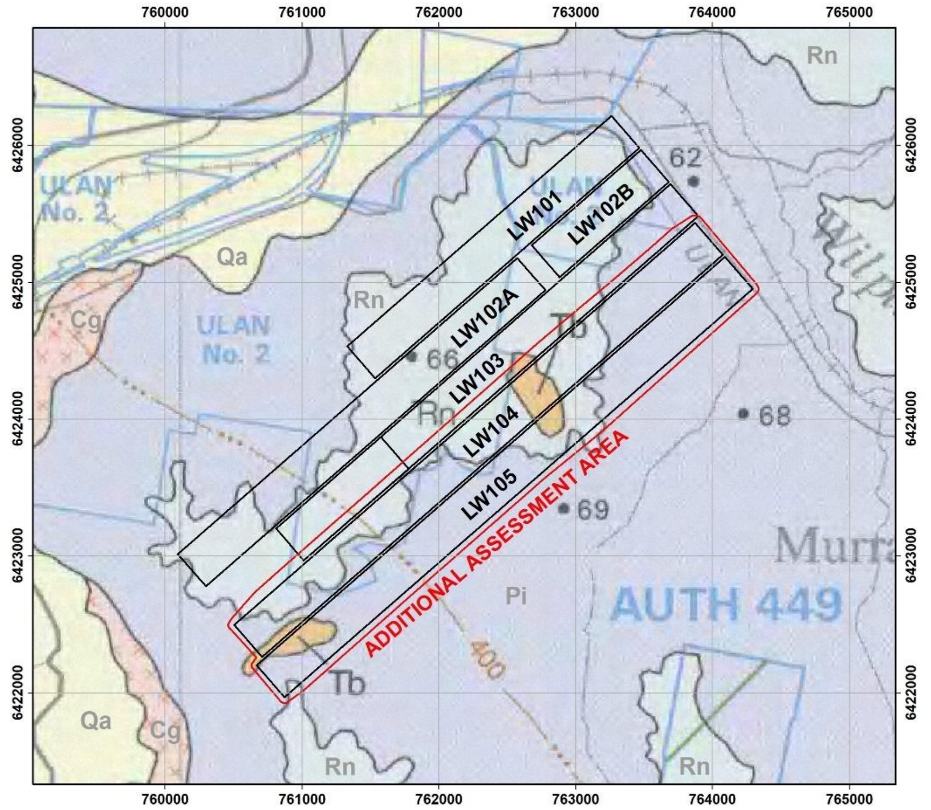

Fig. 1.4 **Surface Geological Map Showing Longwalls 101 to 105 and the Additional Assessment Area**
(Source-1:100000 Western Coalfield Map)

As can be seen in this figure, the surface lithology of most of the areas over the UG1 is predominantly units from the Narrabeen Group Sandstones and Conglomerates, (Rn), which are coloured in a light blue hatching, as well as areas of Basalt, (Tb). These units overlie areas, which are hatched in a violet colour, that indicates the surface lithology around the longwalls are from the Illawarra Coal Measures (Pi). Other surface lithology units that are shown in this figure, but are not within the Study Area, are areas of Quaternary Alluvials (Qa) and Granite (Cg).

A typical stratigraphic section for the Study Area, which was provided by Minerva Geological Services Pty Ltd, is shown in Fig. 1.5. A discussion of the geological units is provided below in Section 1.4.1.

1.4.1. Lithology

The major geological units in the Additional Assessment Area are, from the youngest to oldest:-

- Tertiary aged basalt intrusions and palaeochannel deposits;
- Triassic aged sandstones and conglomerates of the Narrabeen Group;
- Permian aged Illawarra Coal Measures, including the Ulan Seam; and
- Carboniferous aged Ulan Granite.

The tertiary intrusions consist mainly of small plugs and remnant basalt flows of Tertiary age. The approximate surface location of the tertiary basalt within the Additional Assessment Area, known as basalt caps, are shown on Fig. 1.4. These basalt caps provide soils that are suited to the endangered ecological communities *White Box, Yellow Box, Blakely's Redgum Woodland, and derived Native Grasslands.* Approximate locations of these communities are also shown on Drawing No. MSEC1084-08.

Tertiary alluvial palaeochannel deposits, with a thickness of up to 40-50 m, have been identified and described by SLR (2020) to the north and east of the proposed UG1 longwalls, as shown in Drawing No. MSEC1084-07. The Palaeochannels are remnants of inactive river or stream channels that have been later filled in or buried by younger sediment. The infill sediments consist of poorly-sorted semi-consolidated quartzose sands and gravels in a clayey matrix.

The Triassic sandstone, known as Wollar Sandstone, is part of the Narrabeen Group and this sandstone unit is the main outcropping rock formation over the Study Area. Where present, the sandstones are between 14 m and 70 m thick with both massive and strongly cross-bedded units of individual thickness in the range of 1.5 m to 3 m.

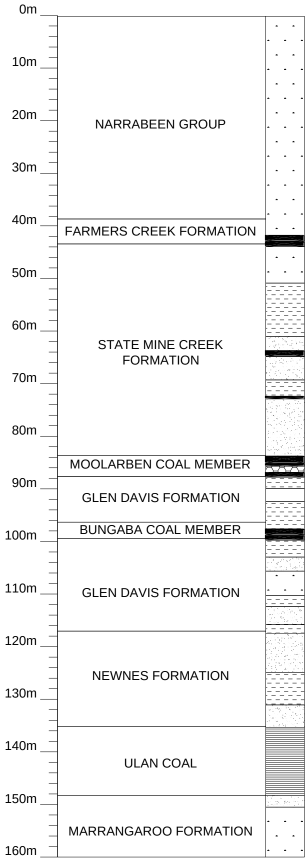

Fig. 1.5 Stratigraphic Column (based on WMLB117)

Permian Illawarra Coal Measures consist of up to six formations that include conglomerate, claystone, mudstone, siltstone, tuff, sandstone and coal with a general northwest strike direction and dip of 1 to 2° to the northeast. A brief description of each formation, provided in Minerva Geological Services, (February 2007), is as follows:

- Farmers Creek Formation: between 6 m to 10 m of siltstone, sandstone, and white cherty claystone;
- State Mine Creek Formation: up to 30 m of interbedded sandstone, siltstone and claystone. The Moolarben Coal Member occurs at the base of the State Mine Creek Formation and is between 2 m and 4 m thick, consisting of tuffaceous mudstone and claystone. The Middle River Coal Member occurs at the top of the State Mine Creek Formation and is generally less than 2 m thick, consisting of stony coal and claystone;
- Cockabutta Creek Sandstone Member: up to 9 m of predominantly medium to very coarse-grained quartzose sandstone, similar to the Marrangaroo Conglomerate;
- Newnes and Glen Davis Formations: up to 20 m thickness of laminated mudstones, siltstones and find-grained sandstones;
- Ulan Coal: the major coal development in the licence area. The seam thickness varies from approximately 6 m to 15 m and is divided into 2 units – Upper (comprising, from top down, ULA, UB1, UB2, UC1, UC2) and Lower (comprising from top down, UCL, DTP, DWS, ETP, EBT and ELR). CMK defines the boundary between upper and lower units; and
- Marrangaroo Conglomerate: generally between 2 m and 6 m thick. The conglomerate is quartzose, commonly porous, and has a “gritty” sucrosic texture.

The Carboniferous Ulan Granite forms the basement below the Illawarra Coal Measures. There are four regional structural features, none of which intersect the proposed underground mining areas. The four regional structural features are the Spring Gully Fault Zone, Curra and Greenhill’s Fault, Flat Dip Domain, and Ulan Hinge Line. A detailed description of the surface and subsurface geological features in the lease area is contained in a report by Minerva Geological Services (February 2007).

2.1. Definition of the Study Area and Additional Assessment Area

The Study Area is defined as the surface area that is likely to be affected by the proposed mining of Longwalls 101 to 105 in the Ulan Seam by MCO.

The extent of the Study Area has been calculated by combining the areas bounded by the following limits:-

- The 26.5° angle of draw line; and
- The predicted vertical limit of subsidence, taken as the 20 mm subsidence contour.

The predicted limit of vertical subsidence has been taken as the predicted total 20 mm subsidence contour as determined using the Incremental Profile Method, which is described in Section 3.5. A detailed discussion of the Incremental Profile Method can also be found at http://www.minesubsidence.com in Background Reports in the report titled 'General Discussion of Mine Subsidence Ground Movements'.

The Additional Assessment Area is a subset of the Study Area and is the surface area within the 26.5° angle of draw line from Longwalls 104 and 105.

This report focuses on the Additional Assessment Area in support of the amendment of the current approved Extraction Plan to incorporate Longwalls 104 and 105. The extraction of Longwalls 104 and 105 will result in minor additional subsidence, up to approximately 150mm, above the previously extracted Longwalls 102 and 103. The additional subsidence is minor compared to the magnitude of subsidence above the longwalls as they are extracted. This additional subsidence does not change the impact assessments for the features above Longwalls 101 to 103, which are provided in report MSEC867.

The line defining the Study Area, based on the further extent of the 26.5° angle of draw and the predicted 20 mm subsidence contour is shown in Drawing No. MSEC1084-01. The predicted total 20 mm subsidence contour line resulting from the extraction of Longwalls 101 to 105 is located entirely within the area bounded by the 26.5° angle of draw line. The extent of the Additional Assessment Area from the additional Longwalls 104 and 105 is also shown in Drawing No. MSEC1084-01.

The Study Area and Additional Assessment Area is located wholly within the UG1 Optimisation Modification Study Area which covered mining of Longwalls 101 to 105 as described in report MSEC731.

There are additional features that lie outside the Additional Assessment Area that are expected to experience far-field movements. The surface features which may be sensitive to such movements have been identified in this report and, hence, these features, which are listed below, have been included as part of this study.

- Sandy Hollow – Gulgong Railway Line;
- Electrical Transmission Lines;
- Optical Fibre and Copper Cables;
- Roads;
- Survey Control Marks; and
- Highwalls of the proposed open cut mines and the underground mine entries from these highwalls.

2.2. Natural and Built Features within the Additional Assessment Area

Many natural and built features within the Additional Assessment Area can be seen in the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA), numbered Wollar 88332N. The longwalls have been overlaid on an extract of this CMA map in Fig. 2.1.

There are no private landowners within the Study Area. All land is owned by either MCO, NSW Crown Land or the Mid-Western Regional Council.

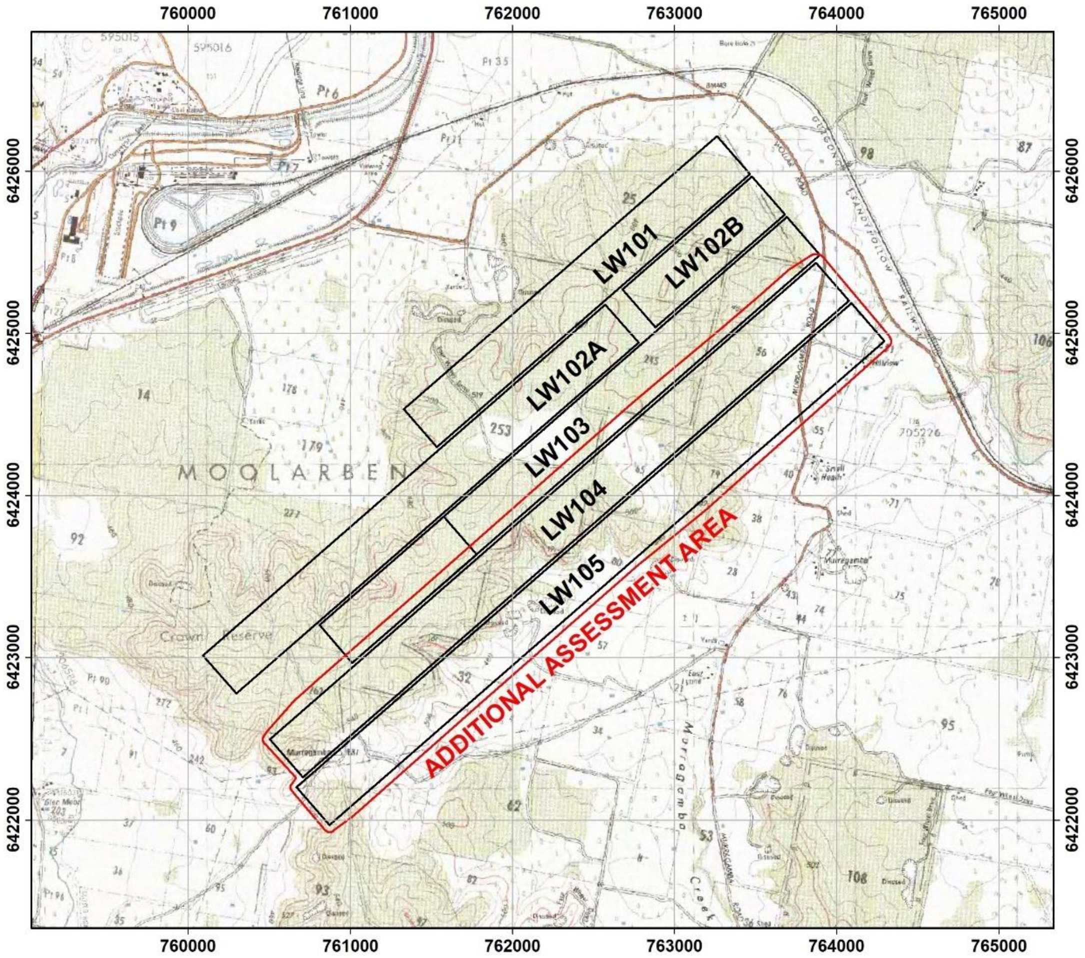

Fig. 2.1 Topographic Map Showing Longwalls 101 to 105 and the Additional Assessment Area (source: CMA Map No. Wollar 88332N)

A summary of the natural and built features within the Additional Assessment Area, or relevant to this report with respect to potential far-field movements, is provided in Table 2.1. The locations of these features are shown in Drawings Nos. MSEC1084-08 to MSEC1084-10, in Appendix E.

The descriptions, predictions and impact assessments for the natural and built features are provided in Chapters 5 through to 11. The section number references are provided in Table 2.1.

Table 2.1 Natural and Built Features

Item	Within Study Area	Section Number Reference
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	×	
Rivers or Creeks	×	
Aquifers or Known Groundwater Resources	✓	5.2
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	×	
Steep Slopes	✓	5.5
Escarpments	×	
Land Prone to Flooding or Inundation	×	
Swamps, Wetlands or Water Related Ecosystems	×	
Threatened or Protected Species	✓	5.6 & 5.7
National Parks	×	
State Forests	×	
State Conservation Areas	×	
Natural Vegetation	✓	5.8
Areas of Significant Geological Interest	✓	5.9
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	✓	6.1
Roads (All Types)	✓	6.2 to 6.3
Bridges	×	
Tunnels	×	
Culverts	✓	6.4
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	✓	6.5
Telecommunication Lines or Associated Plants	✓	6.6
Water Tanks, Water or Sewage Treatment Works	✓	9.1
Dams, Reservoirs or Associated Works	×	
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	×	
Shopping Centres	×	
Community Centres	×	
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

Item	Within Study Area	Section Number Reference
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	×	
Farm Buildings or Sheds	×	
Tanks	×	
Gas or Fuel Storages	×	
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	✓	8.1
Farm Dams	✓	8.2
Wells or Bores	×	
Any Other Farm Features	×	
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Factories	×	
Workshops	×	
Business or Commercial Establishments or Improvements	×	
Gas or Fuel Storages or Associated Plants	×	
Waste Storages or Associated Plants	×	
Buildings, Equipment or Operations that are Sensitive to Surface Movements	×	
Surface Mining (Open Cut) Voids or Rehabilitated Areas	✓	9.1
Mine Infrastructure Including Tailings Dams or Emplacement Areas	✓	9.1
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL OR HERITAGE SIGNIFICANCE	✓	10.1 & 10.2
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	10.4
RESIDENTIAL ESTABLISHMENTS		
Houses	×	
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

3.0 OVERVIEW OF MINE SUBSIDENCE PARAMETERS AND THE METHOD USED TO PREDICT THE MINE SUBSIDENCE MOVEMENTS FOR THE LONGWALLS

3.1. Introduction

This chapter provides overviews of mine subsidence parameters and the methods that have been used to predict the mine subsidence movements resulting from the extraction of the longwalls. Further details on longwall mining, the development of subsidence and the methods used to predict 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*.

3.2. Overview of Conventional Subsidence Parameters

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

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.
- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/km* (km^{-1}), but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *km (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). Conversely, high deformations across monitoring lines are also generally measured where high normal strains have been measured along the monitoring line.

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

3.3. Far-field Movements

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

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

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

Far-field horizontal movements and the method used to predict such movements are described in detail in the MSEC731 report.

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 the depth of cover is greater than say 400 m, the observed subsidence profiles along monitoring survey lines are generally smooth. Where the depth of cover is less than say 100 m, such as the case within the Study Area, 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.

Irregular subsidence movements are occasionally observed at the deeper depths of cover along an otherwise smooth subsidence profile. The cause of these irregular subsidence movements can be associated with:

- issues related to the timing and the method of the installation of monitoring lines;
- sudden or abrupt changes in geological conditions;
- steep topography; and
- valley related mechanisms.

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

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

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

In this report, non-conventional ground movements are being included statistically in the predictions and impact assessments, by basing these on the frequency of past occurrence of both the conventional and non-conventional ground movements and impacts. The analysis of strains provided in Section 4.4 includes those resulting from both conventional and non-conventional anomalous movements. The impact assessments for the natural and built features, which are provided in Chapters 5 through to 11, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

3.4.2. Non-conventional Subsidence Movements due to Steep Topography

Non-conventional movements can also result from increased horizontal movements in the downslope direction 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 the increased horizontal movements in the downslope direction include the development of tension cracks at the tops and sides of the steep slopes and compression ridges at the bottoms of the steep slopes.

Further discussions on the potential for down slope movements for the steep slopes within the Additional Assessment Area are provided in Section 5.5.

3.4.3. Valley Related Movements

Watercourses may be subjected to valley related movements, which are commonly observed along river and creek alignments in the Southern Coalfield but are less commonly observed in the Western Coalfield, which typically have shallower depths of cover. The reason that valley related movements are less commonly observed in the Western Coalfield could be that the conventional subsidence movements are typically much larger than those observed in the Southern Coalfield, which tend to mask any smaller valley related movements which may occur.

The drainage lines within the UG1 Study Area are less likely to experience noticeable mining induced valley related movements, (i.e. valley closure movements and upsidence in the floors of valleys), because of the relatively shallow depths of cover over these longwalls and the nearby presence of the deep open cut pits that would have reduced the in situ compressive horizontal stresses of the overburden strata between these open cut pits.

3.5. The Incremental Profile Method

The predicted conventional subsidence parameters for the longwalls were determined using the Incremental Profile Method, which was developed by MSEC, formally known as Waddington Kay and Associates. The method is an empirical model based on a large database of observed monitoring data from previous mining within the Southern, Newcastle, Hunter and Western Coalfields of New South Wales and from mining in the Bowen Basin in Queensland.

The database consists of detailed subsidence monitoring data from many mines and collieries in NSW including: Angus Place, Appin, Baal Bone, Bellambi, Beltana, Blakefield South, Bulli, Carborough Downs, Chain Valley, Clarence, Coalcliff, Cook, Cooranbong, Cordeaux, Corrimal, Cumnock, Dartbrook, Delta, Dendrobium, Eastern Main, Ellalong, Fernbrook, Glennies Creek, Grasstree, Gretley, Invincible, John Darling, Kemira, Kestrel, Lambton, Liddell, Mandalong, Metropolitan, Mt. Kembla, Moranbah, Munmorah, Nardell, Newpac, Newstan, Newvale, Newvale 2, South Bulga, South Bulli, Springvale, Stockton Borehole, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, United, West Cliff, West Wallsend, and Wyee.

The database consists of the observed incremental subsidence profiles, which are the additional subsidence profiles resulting from the extraction of each longwall within a series of longwalls. It can be seen from the normalised incremental subsidence profiles within the database, that the observed shapes and magnitudes are reasonably consistent where the mining geometry and local geology are similar.

Subsidence predictions made using the Incremental Profile Method use the database of observed incremental subsidence profiles, the longwall geometries, local surface and seam information and geology. The method has a tendency to over-predict the conventional subsidence parameters (i.e. is slightly conservative) where the mining geometry and geology are within the range of the empirical database. The predictions can be further tailored to local conditions where observed monitoring data is available close to the mining area.

Further details on the Incremental Profile Method can be obtained from *www.minesubsidence.com*.

The Incremental Profile Method model developed for the UG1 Optimisation Modification has been used and updated for subsidence predictions for this study. It is noted that, as per the UG1 Optimisation Modification, maximum subsidence of 65% as a proportion of the extracted seam has been conservatively predicted.

3.6. Calibration and Testing of the Incremental Profile Method

The standard Incremental Profile Method was calibrated using nearby monitoring sites that have similar geology. The calibration and testing of the Incremental Profile Method is outlined in detail in the MSEC731 report.

Since the commencement of longwall mining operations, three annual reviews have been completed (2017, 2018 and 2019) to assess the observed monitoring data. The ground movements measured during the annual review were similar to or less than those predicted in Report No. MSEC867, which supported the Extraction Plan for Longwalls 101 to 103 and it was therefore not considered necessary to re-calibrate the prediction method.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of Longwalls 101 to 105. The predicted subsidence parameters and the impact assessments for the natural and built features due to the extraction of Longwalls 104 and 105 are provided in Chapters 5 to 11.

It should be noted that the predicted conventional subsidence parameters were obtained using the Incremental Profile Method, which was calibrated to local conditions based on the available monitoring data from nearby collieries. The adequacy of the prediction model was confirmed in three annual subsidence monitoring reviews.

The maximum predicted subsidence parameters and the predicted subsidence contours provided in this report describe and show the conventional movements and do not include the valley related upsidence and closure movements, nor the effects of faults and other geological structures. Such effects have been addressed separately in the impact assessments for each feature provided in Chapters 5 to 11.

The maximum predicted subsidence parameters represent the maximum predicted movements resulting from the extraction of the longwalls. Surface features will experience a travelling component of subsidence movements as the longwall extraction face passes beneath the feature. Depending on the location of the surface feature, the predicted subsidence parameter (such as tilt) after the completion of a longwall may be lower than the travelling component. Predictions of curvature and strain for surface features typically include the travelling component and are reported as the maximum during or after the extraction of the longwalls.

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

The maximum predicted conventional subsidence parameters resulting from the extraction of Longwalls 101 to 105 were determined using the calibrated Incremental Profile Method. The predicted subsidence contours are irregular due to the shallow depths of cover. The maximum predicted tilts and curvatures are very localised and therefore do not necessarily represent the overall (i.e. macro) ground movements. The magnitudes of the localised tilts greater than 100 mm/m and the localised curvatures greater than 3.0 km^{-1} become less meaningful and, therefore, the specific values have not been presented. Revised standards for reporting adopted by MSEC may result in slight differences in reported values compared with previous reports.

A summary of the maximum predicted values of incremental conventional subsidence, tilt and curvature, due to the extraction of each of the longwalls based on the Extraction Plan Layout, is provided in Table 4.1.

Table 4.1 Maximum Predicted Incremental Conventional Subsidence, Tilt and Curvature Resulting from the Extraction of Each of the Longwalls 101 to 105

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})
Due to LW101	2250	65	> 3	> 3
Due to LW102A	2200	> 100	> 3	> 3
Due to LW102B	2150	45	2.1	1.5
Due to LW103	2250	75	> 3	> 3
Due to LW104	2250	90	> 3	> 3
Due to LW105	2150	85	> 3	> 3

The predicted total conventional subsidence contours, resulting from the extraction of Longwalls 101 to 105 are shown in Drawing No. MSEC1084-11. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature, after the extraction of each of the longwalls based on the Extraction Plan Layout, is provided in Table 4.2.

Table 4.2 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature after the Extraction of Each of the Longwalls 101 to 105

Longwalls	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 LW101	2250	65	> 3	> 3
After LW102A	2400	> 100	> 3	> 3
After LW102B	2400	> 100	> 3	> 3
After LW103	2400	> 100	> 3	> 3
Due to LW104	2400	> 100	> 3	> 3
Due to LW105	2400	> 100	> 3	> 3

The maximum predicted total conventional tilt is greater than 100 mm/m (i.e. > 10 %), which represents a change in grade greater than 1 in 10. The maximum predicted total conventional curvatures are greater than 3 km^{-1} hogging and sagging, which represent minimum radii of curvature of less than 0.33 km.

The predicted conventional subsidence parameters vary across the Study Area as the result of, amongst other factors, 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 Prediction Lines 1, 2 and 3, the locations of which are shown in Drawing No. MSEC1084-11.

The predicted profiles of vertical subsidence, tilt and curvature along Prediction Lines 1, 2 and 3, resulting from the extraction of Longwalls 101 to 105, are shown in Figs. C.01 to C.03, in Appendix C. The predicted incremental profiles along the prediction lines, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles along the prediction lines, after the extraction of each of the longwalls based on the Extraction Plan Layout, are shown as solid blue lines. The predicted total profiles based on the Approved Layout are shown as red lines for comparison.

4.3. Comparison of Maximum Predicted Conventional Subsidence, Tilt and Curvature

The comparison of the maximum predicted subsidence parameters resulting from the extraction of Longwalls 101 to 105, based on the Extraction Plan Layout, with those based on the Approved Layout is provided in Table 4.3. The values are the maxima anywhere above the longwall layouts.

Table 4.3 Comparison of Maximum Predicted Conventional Subsidence Parameters based on the Approved Layout and the Extraction Plan Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (LW101-105) (Report No. MSEC731)	2400	> 100	> 3	> 3
Extraction Plan Layout (Report No. MSEC1084)	2400	> 100	> 3	> 3

It can be seen from the above table, that the maximum predicted total subsidence parameters based on the Approved Layout are the same as those for the Extraction Plan Layout for Longwalls 101 to 105. Whilst the specific values of the maximum tilt and curvatures are not shown, due to these representing the localised irregular movements rather than the macro (i.e. overall) movements, these parameters do not change.

4.4. Predicted Strains

The prediction of strain is more difficult than the predictions of subsidence, tilt and curvature. The reason for this is that strain is affected by many factors, including ground curvature and horizontal movement, as well as local variations in the near surface geology, the locations of pre-existing natural joints at bedrock, and the depth of bedrock. Survey tolerance can also represent a substantial portion of the measured strain, in cases where the strains are of a low order of magnitude. The profiles of observed strain, therefore, can be irregular even when the profiles of observed subsidence, tilt and curvature are relatively smooth.

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 Newcastle, 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 longwalls are greater than 3 km^{-1} hogging and sagging. Adopting a factor of 10, the maximum predicted conventional strains, due to the proposed mining are greater than 30 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 potential strains above the longwalls has been assessed using monitoring data from previously extracted panels in the Hunter, Newcastle and Western Coalfields, for single-seam conditions, where the longwall width-to-depth ratios and extraction heights were similar to those of the longwalls. Comparisons of the void widths, depths of cover, width-to-depth ratios and extraction heights for the longwalls with those for the historical cases are provided in Table 4.4.

Table 4.4 Comparison of the Mine Geometry for the Longwalls 101 to 105 with Longwalls in the Hunter, Newcastle and Western Coalfields used in the Strain Analysis

Parameter	Longwalls 101 to 105		Longwalls Used in Strain Analysis	
	Range	Average	Range	Average
Width	311	311	210 ~ 410	285
Depth of Cover	47 ~ 165	120	40 ~ 239	130
W/H Ratio	1.9 ~ 6.6	2.6	1.7 ~ 6.4	2.5
Extraction Height	3.2 ~ 3.5	3.3	2.2 ~ 4.2	3.0

It can be seen from the above table that the range of the panel width-to-depth ratios used in the strain analysis are between 1.7 and 6.4, with an average ratio of 2.5, which is similar to the range for Longwalls 101 to 105. The range of extraction heights for the longwalls used in the strain analysis are between 2.2 m and 4.2 m, with an average of 3.0 m, which is slightly less than the average extraction height for Longwalls 101 to 105. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains for the longwalls.

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

A number of probability distribution functions were fitted to the empirical monitored strain data. It was found that a *Generalised Pareto Distribution (GPD)* provided a good fit to the raw strain data. 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).

4.4.1. Analysis of Strains Measured in Survey Bays

For features that are in discrete locations, such as building structures, farm dams and archaeological sites, it is appropriate to assess the frequency of the observed maximum strains for individual survey bays.

Predictions of Strain Above Goaf

The survey database has 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 GPDs, are also shown in this figure.

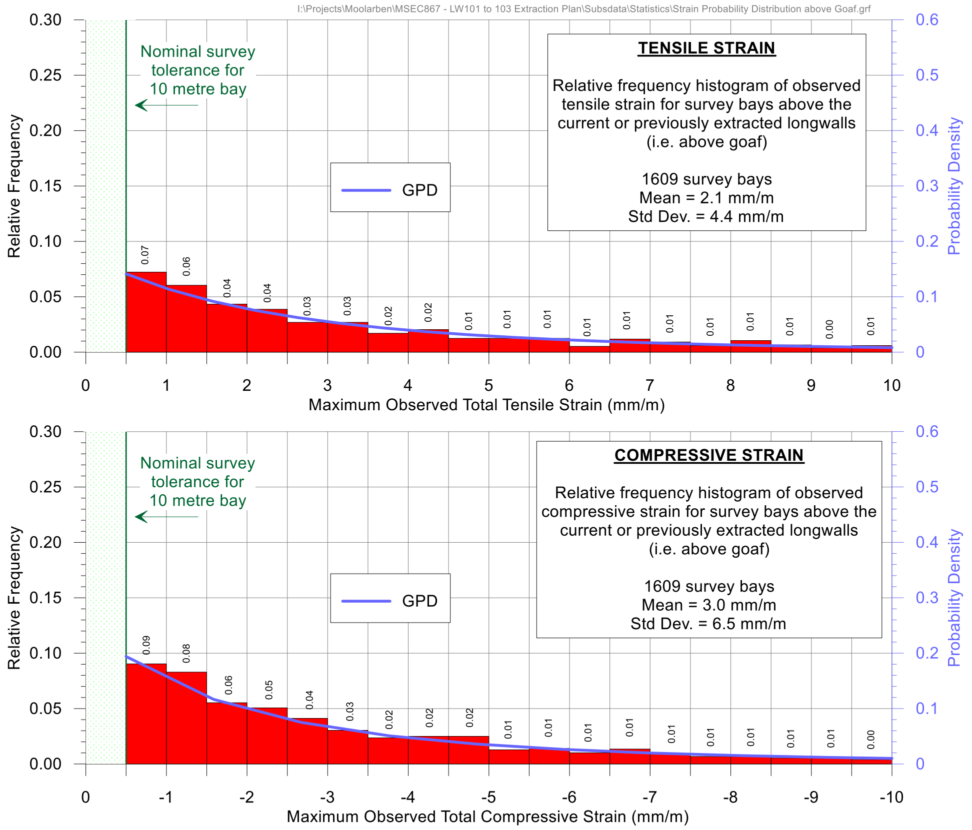

Fig. 4.1 **Distributions of the Measured Maximum Tensile and Compressive Strains in the Hunter, Newcastle and Western Coalfields for Longwalls having W/H Ratios between 1.7 and 6.4**

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 are 10 mm/m tensile and 13 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining were 22 mm/m tensile and 31 mm/m compressive. The maximum strains measured along the monitoring lines were greater than 50 mm/m tensile and 100 mm/m compressive. These maximum strains represent very localised movements in the locations of large surface deformations.

The predicted conventional strains are greater than the predicted 95 and 99 % confidence levels for the strains that include non-conventional movements, as the irregular strains are isolated and extreme events. This is demonstrated by the maximum observed strains that are considerably greater than the predicted confidence levels and the conventional strains.

It is noted, that these strains are based on monitoring data having an average width-to-depth ratio of 2.5 and, therefore, the strains above the longwalls are expected to be greater, on average, where the width-to-depth ratios are greater than 2.5 (i.e. depths of cover less than 125 m) and are expected to be less, on average, where the width-to-depth ratios are less than 2.5 (i.e. depths of cover greater than 125 m).

Predictions of Strain Above Solid Coal

The survey database has also 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 beyond the goaf edges of the mined panels and positioned on unmined areas of coal, i.e. outside the longwall panels, but within 200 m of the nearest longwall goaf edge.

The histogram of the maximum observed tensile and compressive strains measured in survey bays above solid coal is provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

The 95 % confidence levels for the maximum total strains that the individual survey bays *above solid coal* experienced at any time during mining are 3.3 mm/m tensile and 3.0 mm/m compressive. The 99 %

confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 9.2 mm/m tensile and 14.4 mm/m compressive.

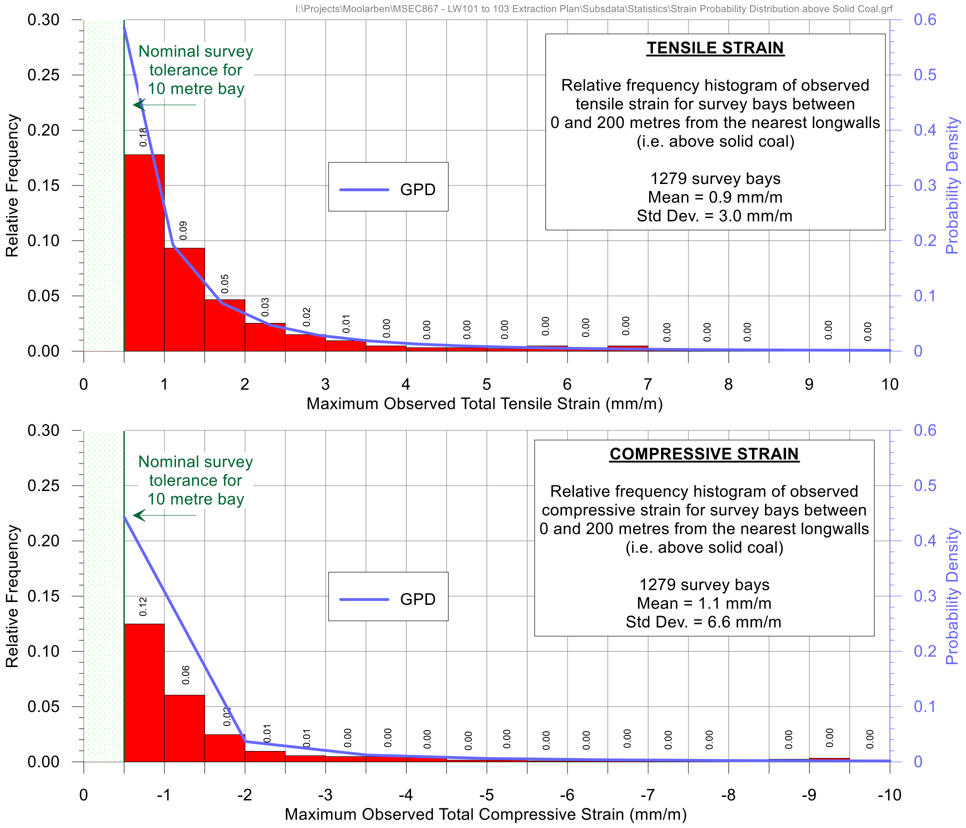

Fig. 4.2 Distributions of the Measured Maximum Tensile and Compressive Strains in the Hunter, Newcastle and Western Coalfields for Survey Bays located above Solid Coal within 200 m of the nearest longwall

Some surface features discussed in this report are located greater than 200 m from Longwalls 101 to 105, including the railway line, transmission line and fibre optic cable. The survey database has 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 beyond the goaf edges of the mined panels and positioned on unmined areas of coal between 200 m and 600 m of the nearest longwall goaf edge.

The histogram of the maximum observed tensile and compressive strains measured in survey bays above solid coal is provided in Fig. 4.3. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

The 95 % confidence levels for the maximum total strains that the individual survey bays *above solid coal* (beyond 200 m) experienced at any time during mining are 1.6 mm/m tensile and 1.5 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above solid coal (beyond 200 m) experienced at any time during mining are 2.9 mm/m tensile and 3.0 mm/m compressive. It is noted that these measured strains also include components of survey tolerance.

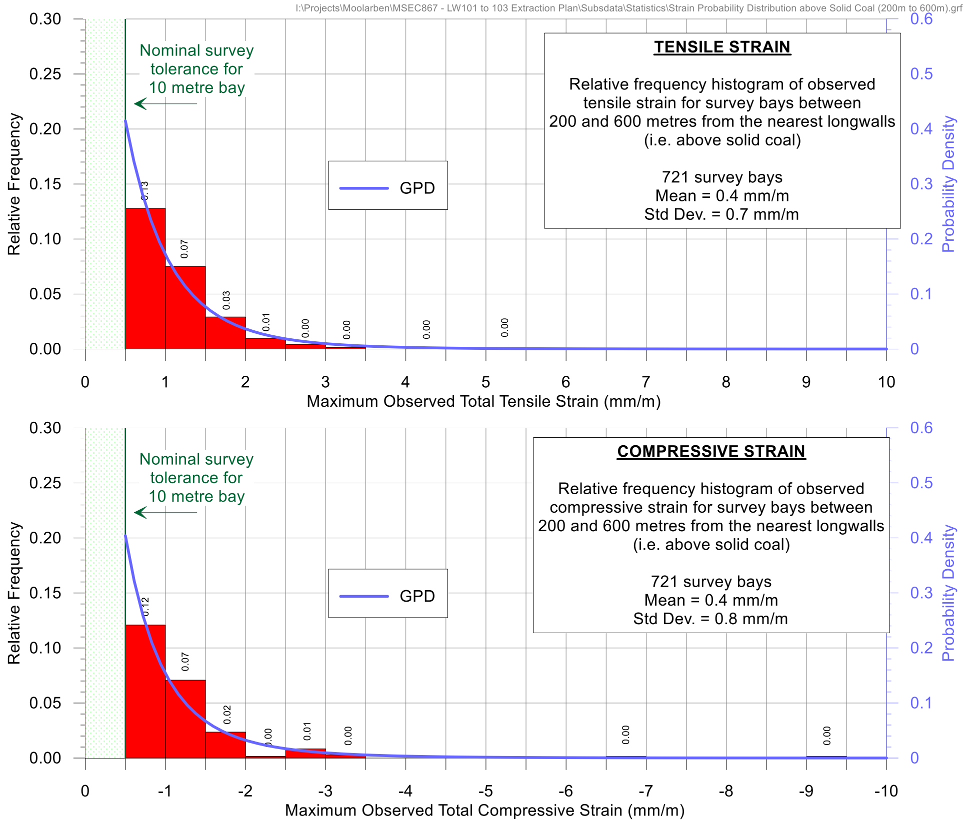

Fig. 4.3 Distributions of the Measured Maximum Tensile and Compressive Strains in the Hunter, Newcastle and Western Coalfields for Survey Bays located above Solid Coal between 200 m and 600 m of the nearest longwall

4.4.2. Analysis of Strains Measured Along Whole Monitoring Lines

For linear features such as roads, cables and pipelines, it is more appropriate to assess the frequency of the maximum observed strains along whole monitoring lines, rather than for individual survey bays. That is, an analysis of the maximum strains measured anywhere along the monitoring lines, regardless of where the strain actually occurs.

The histogram of maximum observed total tensile and compressive strains measured anywhere along the monitoring lines, at any time during or after mining, is provided in Fig. 4.4.

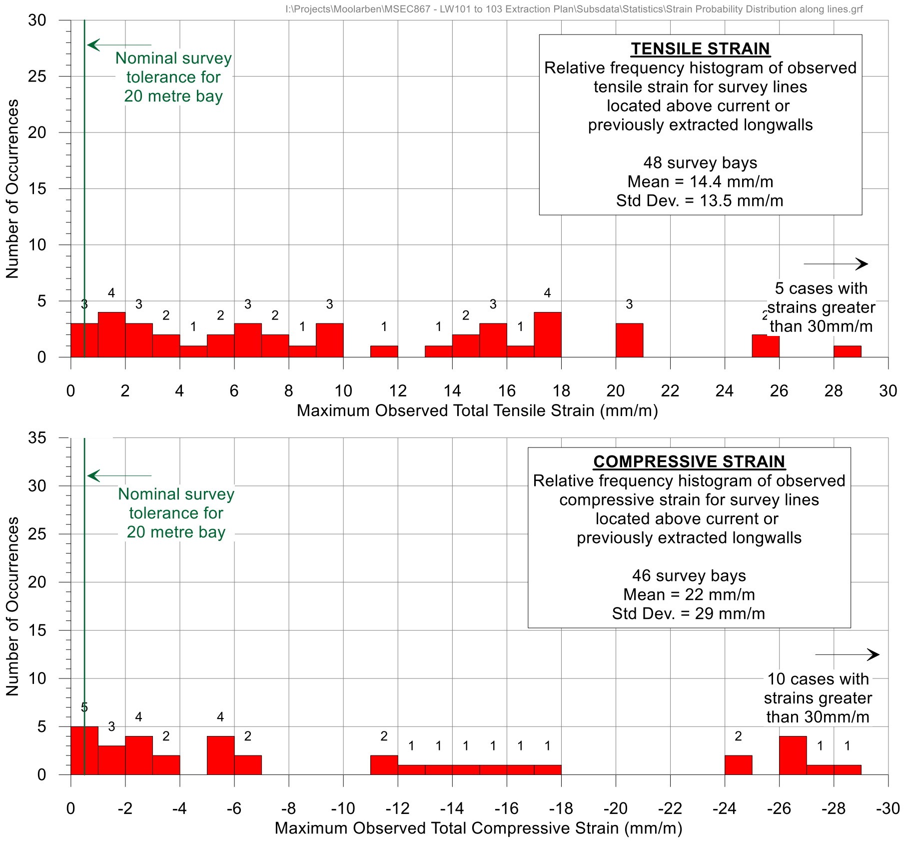

Fig. 4.4 Distributions of Measured Maximum Tensile and Compressive Strains Anywhere along the Monitoring Lines in the Hunter, Newcastle and Western Coalfields

It can be seen from the above figure, that 24 of the 48 monitoring lines (i.e. 50 %) have recorded maximum total tensile strains of 10 mm/m, or less, and that 36 monitoring lines (i.e. 75 %) have recorded maximum total tensile strains of 20 mm/m, or less. Also, 20 of the 46 monitoring lines (i.e. 43 %) have recorded maximum compressive strains of 10 mm/m, or less, and that 28 of the monitoring lines (i.e. 60 %) have recorded maximum compressive strains of 20 mm/m, or less.

4.5. Horizontal Movements

The predicted conventional horizontal movements over the longwalls are calculated by applying a factor to the predicted conventional tilt values. A factor of 10 is generally adopted for the Western Coalfield, being the same factor as that used to determine conventional strains from curvatures, and this has been found to give a reasonable correlation with measured data. This factor will in fact vary and will be higher at low tilt values and lower at high tilt values. The application of this factor will therefore lead to over-prediction of horizontal movements where the tilts are high and under-prediction of the movements where the tilts are low.

The maximum predicted total conventional tilt within the Study Area, at any time during or after the extraction of the longwalls, is greater than 100 mm/m. The application of the factor of 10 is likely to be conservative at this high magnitude of predicted tilt. The maximum predicted conventional horizontal movement is, therefore, greater than 1000 mm, i.e. 100 mm/m multiplied by a factor of 10. This prediction is considered to be conservative, with the actual horizontal movements expected to be generally less than 500 mm.

Conventional horizontal movements do not directly impact on natural or built features, rather impacts occur as a result of differential horizontal movements. Strain is the rate of change of horizontal movement. The impacts of strain on the natural and built features are addressed in the impact assessments for each feature, which are provided in Chapters 5 to 11.

4.6. Predicted Far-field Horizontal Movements

In addition to the conventional subsidence movements that have been predicted above and adjacent to Longwalls 101 to 105, it is also likely that far-field horizontal movements will be experienced during the extraction of the longwalls. A detailed discussion of far-field horizontal movements and the method used to predict such movements is provided in the MSEC731 report.

An empirical database of observed incremental far-field horizontal movements has been compiled using available monitoring data from the NSW Coalfields, but this database predominately includes measurements from the Southern Coalfield. The far-field horizontal movements are generally observed to be orientated towards the extracted longwall. At very low levels of far-field horizontal movements, however, there is a higher scatter in the orientation of the observed movements.

This database includes some of the available observed far-field horizontal movements that have been measured at Ulan Coal Mine and observed data from other regions where the depths of cover are also relatively shallow compared to the Southern Coalfield of NSW. The observed far-field horizontal movements in the database represent large variations in depth of cover from less than 50 m to greater than 600 m. In order to utilise the observed far-field horizontal data at the Moolarben Coal Complex where depth of cover is relatively shallow, the data has been plotted, as shown in Fig. 4.5, against the distances from the nearest edge of the incremental panel divided by the depth of cover. This plot excludes those cases where higher movements occurred because of multi-seam mining and valley closure effects.

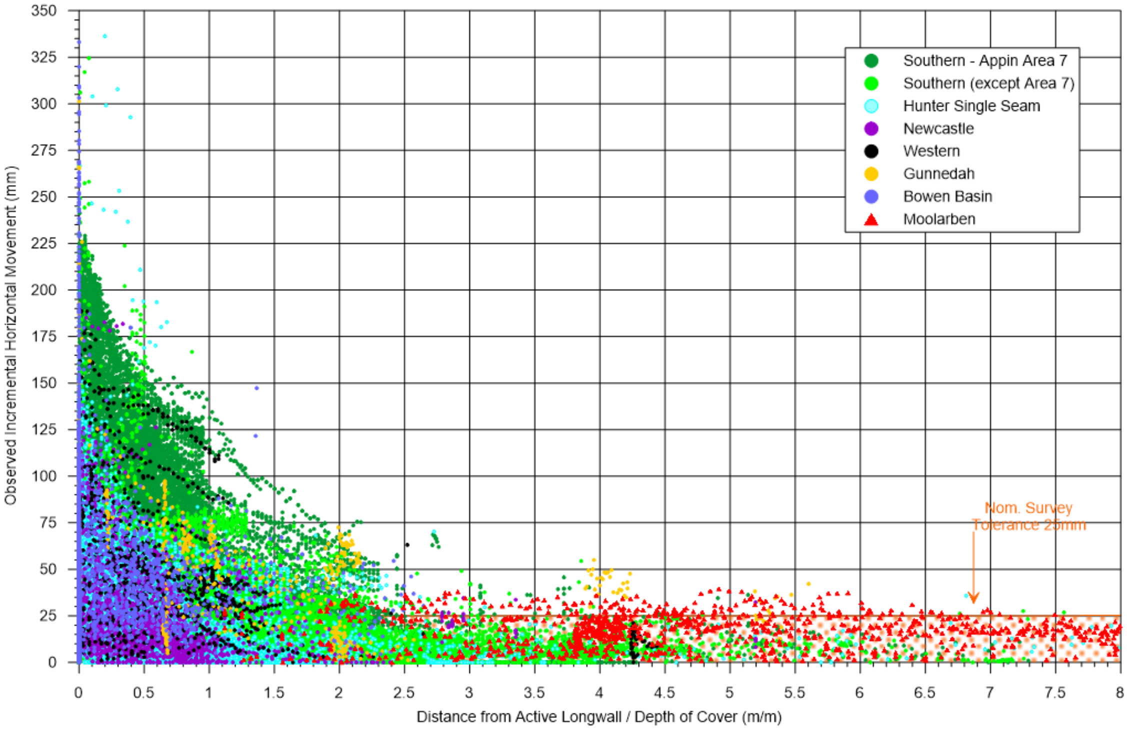

Fig. 4.5 Observed Incremental Far-Field Horizontal Movements (mm) from many regions in NSW versus the distance to the nearest edge of the mined panel divided by the depth of cover (m/m)

As successive longwalls within a series of longwall panels 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 in the strata within the collapsed zones above the first few extracted longwalls has been redistributed, 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.

Monitoring lines located at surface features to the north east of Longwalls 101 to 103 at MCC have been surveyed since the commencement of Longwall 101. The observed far-field horizontal movements for Moolarben have been plotted on Fig. 4.5. It can be seen from Fig. 4.5 that the majority of the observed far-field horizontal movements at MCC are less than 25 mm. The maximum observed far-field horizontal movement is 40 mm.

The impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the vicinity of the Extraction Plan Layout are expected to be insignificant, except where they occur at large structures, such as railway lines and roads, which may be sensitive to small differential movements and may require monitoring and maintenance to remain in a safe and serviceable condition.

4.6.1. Influence of Palaeochannel near UG1 on Horizontal Far-field Movements

As detailed in Section 1.4.1 there are Tertiary aged palaeochannel deposits, with a thickness of up to 40-50 m, located to the north and east of the UG1 longwalls and partially above Longwalls 104 and 105, where the depths of cover range from 90 to 130 m, as shown in Drawing No. MSEC1084-08. The deposits are described by SLR (2020).

These palaeochannels are remnants of inactive river or stream channels that have been later filled in or buried by younger sediment that can be stronger or weaker than the original strata. Palaeochannels have caused significant differences between the predicted and the observed levels of subsidence at other collieries. Where the original strata were eroded away to form a river channel and then the channel was filled in with stronger materials that formed massive conglomerate channels, then, the observed subsidence near these channels was found to be less than was expected because these channels were capable of spanning over voids.

However, where the original strata were filled in with weaker material, such as unconsolidated sediments, then, the observed subsidence under these channels can be greater than expected because these weaker materials failed and subsided more readily than the original strata. Where the original strata were filled in with weak unconsolidated sediments and mining occurs beside these palaeochannels, then, the observed far-field horizontal movements and vertical subsidence beyond these channels can be less than was expected beyond the palaeochannels.

At MCC the palaeochannels to the north and east of the proposed UG1 longwalls were formed when Permian strata layers were replaced with infill sediments consisting of poorly-sorted semi-consolidated quartzose sands and gravels in a clayey matrix, i.e. unconsolidated sediments, unsaturated alluvium and low permeability clays. The presence of these palaeochannel materials can modify the subsidence ground movements beyond the end of the longwalls (depending on the depth of the channel, and its location with respect to the panel edges). Groundwater associated with the palaeochannel is discussed in a report by SLR (2020).

The presence of the palaeochannel sediments should result in less subsidence within these alluvial and unconsolidated sediment areas and reduced far-field movements within and beyond these channels.

4.6.2. Influence of the Open Cut on Horizontal Far-field Movements

An open cut mining area (OC1) which recently ceased operation is located to the north west of the longwalls as shown in Drawing No. MSEC1084-02. Access to the UG1 longwalls is via the OC1 pit. Active open cut mining areas are also located to the south west (OC2) and south east (OC4).

The open cut pits extract the overburden material and the target coal seam. i.e. down to the seam floor level of the longwalls. The effect of the removal of this material is to relieve or redistribute much of the in situ stress in the overburden strata adjacent to the pit. With the removal of the overburden material, the potential for far-field effects to develop in the vicinity of the pit are significantly reduced.

With rehabilitated open cut mine areas, the overburden material has been replaced (OC1, OC2 and OC4), typically with other stripped material which is compacted by vehicle tracking during the emplacement process. Potential for far-field movements where the open cut pit has been fully rehabilitated between the longwalls and the outer natural overburden is expected to be significantly reduced, similar to the open cut pit, as the emplaced material is unlikely to support any significant stress redistribution.

4.7. Non-Conventional Ground Movements

It is likely non-conventional ground movements will occur within the Study Area, due to near surface geological conditions and steep topography, which were discussed in Section 3.4. These non-conventional movements are often accompanied by elevated tilts and curvatures which are likely to exceed the conventional predictions.

The potential for non-conventional movements associated with steep topography is discussed in the impact assessments for the steep slopes provided in Section 5.5.

In most cases, it is not possible to predict the exact locations or magnitudes of the non-conventional anomalous movements due to near surface geological conditions. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains, including both conventional and non-conventional anomalous strains, which is discussed in Section 4.4. In addition to this, the impact assessments for the natural and built features, which are provided in Chapters 5 to 11, include historical impacts resulting from previous longwall mining which have occurred as a result of both conventional and non-conventional subsidence movements.

4.8. General Discussion on Mining Induced Ground Deformations

Longwall mining can result in surface cracking, heaving, buckling, humping and stepping at the surface. The extent and severity of these mining induced ground deformations are dependent on a number of factors, including the mine geometry, depth of cover, overburden geology, locations of natural joints in the bedrock, 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. 4.6 below.

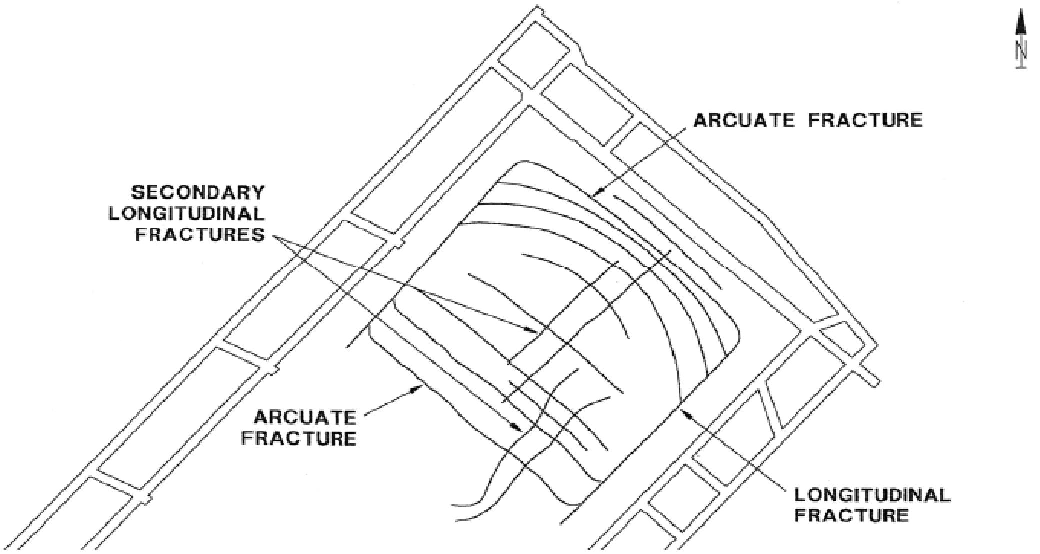

Fig. 4.6 Survey of Major Fracture Pattern at Approx. 110m Cover (Source: Klenowski, ACARP C5016, 2000)

Over previously mined longwalls, typical surface crack widths in 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 m. Larger crack widths have been observed with shallow depths of cover where thicker seams are extracted, where mining occurs near or beneath steep terrain, where thick massive strata beams are present, or where multiple cracks join to form a broader surface deformation.

Localised cracking and stepping greater than 500 mm have been observed at other collieries with similar depths of cover in the NSW Coalfields. These larger tensile cracks tend to be isolated and located above and around the perimeters of the longwalls and along the tops of steep slopes, due to down slope movements resulting from the extraction of the 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. The following photographic records provide examples of surface cracking resulting from NSW longwall mining operations.

Fig. 4.7 Isolated Surface Cracking above multi-seam longwall extraction at Blakefield South Mine in the Hunter Coalfield around 200m cover

Fig. 4.8 Surface Step 0.5m high, above Longwall C at Ulan Coal Mine. 260m void width, 1.27m maximum observed subsidence, approximately 180m cover. (Ulan Longwall C End of Panel Subsidence Report)

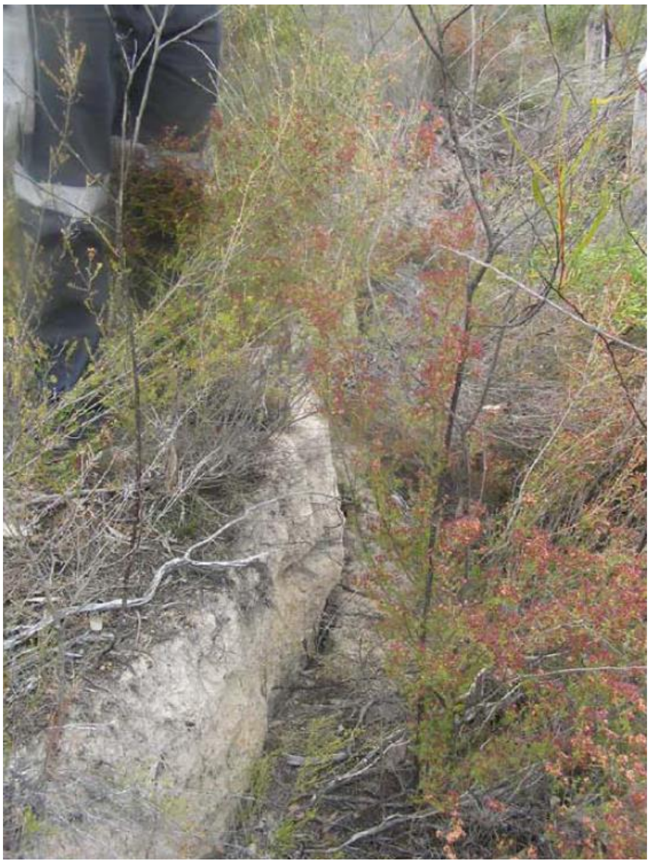

Fig. 4.9 Isolated Surface Step 0.8m high, above Longwall E at Ulan Coal Mine, 260m void width, 1.31m maximum observed subsidence, 130 to 145m cover. (Ulan Longwall E End of Panel Subsidence Report)

Fig. 4.10 Isolated Surface Cracking parallel to longwall tailgate above Longwall 26 at Ulan Coal Mine, 410m void width, 1.38m maximum observed subsidence, 240m cover (Ulan Longwall 26 End of Panel Subsidence Report)

The depths of cover over the underground mining areas vary from 47 m to 165 m. Where the depths of cover above Longwalls 101 to 105 are less than 100 m, surface cracking is expected to be typically in the order of 150 to 200 mm wide, but could be as large as 500 mm wide where the depths of cover are the shallowest. The surface crack widths are likely to be smaller where the depths of cover are greater, or where the surface cracks result from the travelling wave. Where the depths of cover above Longwalls 101 to 105 are 100 to 150 m, the surface crack widths are expected to be typically in the order of 100 to 150 mm wide.

Where the open cut highwalls are located in close proximity to the longwalls, there is a greater potential for larger cracking and surface deformation to develop due to reduced lateral confinement and strata continuity.

Surface cracking and deformation could result in safety issues (i.e. trip hazards), 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 should 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 which could affect safety, access, or increase erosion; and
- 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.

Monitoring of surface cracks to date has indicated crack widths and crack patterns consistent with the expected cracking. Anomalous movements developed at two impact sites above Longwall 102A, with cracking greater than 500 mm and vertical displacement up to 3m to 5m representing less than 0.5% of the surface area above Longwall 102A.

5.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE NATURAL FEATURES WITHIN THE ADDITIONAL ASSESSMENT AREA

The following sections provide the descriptions, predictions of subsidence movements and impact assessments for the natural features located within the Additional Assessment Area for Longwalls 104 and 105. The predicted parameters for each of the natural features have been compared to the predicted parameters based on the Approved Layout. Supporting impact assessments for the natural features have also been undertaken by other specialist consultants for the Extraction Plan Layout.

5.1. Natural Features

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

- catchment areas or declared special areas;
- rivers or creeks;
- springs;
- seas or lakes;
- shorelines;
- natural dams;
- cliffs;
- escarpments;
- land prone to flooding or inundation;
- swamps, wetlands or water related ecosystems;
- national parks;
- state forests;
- state conservation areas; and
- other significant natural features.

It is noted that previously identified cliffs located above and in the vicinity of Longwalls 104 and 105 are located within the out of pit emplacement area and conveyor alignment and have been filled over. These features are not discussed further in this report.

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

5.2. Aquifers and Known Groundwater Resources

The aquifers and groundwater resources within the vicinity of UG1 have been investigated and are described in the reports by HydroSimulations (2017), and SLR (2020). Three aquifers are identified in the vicinity of UG1, being quaternary alluvial, tertiary palaeochannel and porous rock.

The quaternary alluvial deposits are associated with Wilpinjong Creek Alluvial. There is no ‘highly productive’ groundwater, as defined under the Aquifer Interference Policy (AIP) (NSW Government, 2012), mapped in the vicinity of the Moolarben Coal Complex.

The Tertiary palaeochannel deposits are associated with the Wilpinjong and Murragamba Creek valley. Investigation of the palaeochannel has been undertaken as described in the report by SLR (2020). Field investigations in 2019 suggest that the saturated Tertiary palaeochannel extends southwards to a position where the base of Tertiary material reaches about 413 mAHD. Towards the edge of the palaeochannel, the sediments are likely to be dominated by colluvium derived from Triassic sandstone and would have progressively lower permeability as the edge is approached. The investigations have shown the deterioration in water quality (as electrical conductivity) southwards from the approved Longwall 105 take-off line. Higher permeability coupled with higher salinity, as observed at MCR855, could indicate pockets of isolated Tertiary alluvium.

The porous rock groundwater systems include the Narrabeen Group sandstones and the Illawarra Coal Measures, consisting of coal seams, conglomerate, mudstones and siltstones. This groundwater system is not a significant aquifer for groundwater abstraction. The most permeable units are the Ulan Seam and Marrangaroo Conglomerate, while the sandstones of the Narrabeen Group are of lower permeability and are elevated above the Moolarben Coal Complex.

The groundwater model was revised to incorporate the revised palaeochannel extent and properties with the hydraulic conductivities increased conservatively in the model to the highest value found in the area.

The revised groundwater model was used to assess the effects on mine inflows to UG1, as well as alluvial takes. The findings are:

- Negligible changes to UG1 mine inflow.
- Negligible differences for the alluvial takes during UG1 mining.

5.3. Drainage Lines

5.3.1. Description of the Drainage Lines

A number of small drainage lines have been identified above the longwalls and within the Additional Assessment Area as shown in Drawing No. MSEC1084-08. The larger drainage lines have been numbered as Drainage Lines 6 and 7 as shown in Drawing No. MSEC1084-08. Previously identified drainage lines 4 and 5, located above and in the vicinity of Longwalls 104 and 105, are located within the out of pit emplacement area and have been filled over. These drainage lines are therefore are not discussed in this report.

Some of these small drainage lines flow to the north and west off the UG1 area towards the OC1 Pit. Other drainage lines flow off the UG1 area to the north and east towards Murragamba Creek or Wilpinjong Creek. To the south east, the drainage lines flow into OC4 Pit.

5.3.2. Predictions for the Drainage Lines

Unnumbered drainage lines exist across the Additional Assessment Area and are likely, therefore, to be subjected to the full range of predicted conventional subsidence movements which are provided in Section 4.0 .

The predicted profiles of vertical subsidence, tilt and curvature along the alignment of Drainage Lines 6 and 7, based on the Extraction Plan Layout, are shown in Fig. C.04 and Fig. C.05 respectively in Appendix C. The predicted incremental profiles along the drainage line, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles along the drainage line, after the extraction of each of the longwalls, are shown as solid blue lines. The predicted total profiles based on the Approved Layout are shown as solid red lines for comparison.

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for Drainage Lines 6 and 7, after the extraction of Longwalls 104 and 105, is provided in Table 5.1. The values are the predicted maxima within the Study Area.

Table 5.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for Drainage Lines 6 and 7 after the Extraction of Longwalls 104 and 105

Drainage Line	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})
Drainage Line 6	2200	65	> 3.0	> 3.0
Drainage Line 7	2200	60	> 3.0	> 3.0

The maximum predicted conventional tilt for the drainage lines is 65 mm/m (i.e. 6.5 %, or 1 in 15). The maximum predicted conventional curvatures are greater than 3.0 km^{-1} hogging and sagging, which equate to minimum radii of curvature of 0.33 km. The predicted conventional strains based on 10 times the curvature are greater than 33 mm/m tensile and compressive.

The drainage lines could also experience higher strains due to non-conventional ground movements. The distribution of strain along linear features shown in Fig. 4.4 includes those resulting from both conventional and non-conventional anomalous movements.

It is also possible that the drainage lines could experience some valley related movements resulting from the extraction of Longwalls 101 to 105, however these movements should be small due to reduced ground stresses resulting from the presence of adjoining open cut pits. It is also noted that the magnitudes of these upsidence and closure movements are expected to be much lower than the conventional movements and hence may not be significant.

5.3.3. Comparison of the Predictions for Drainage Lines 6 and 7

A comparison of the maximum predicted subsidence parameters for Drainage Lines 6 and 7, after the extraction of Longwalls 104 and 105, with those based on the Approved Layout is provided in Table 5.2.

The values are the maxima along the section of the drainage line located within the Additional Assessment Area.

Table 5.2 Comparison of Maximum Predicted Conventional Subsidence Parameters for Drainage Lines 6 and 7 based on the Approved Layout and the Extraction Plan Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (101-105) (Report No. MSEC731)	2200	65	> 3.0	> 3.0
Extraction Plan Layout (Report No. MSEC1084)	2200	65	> 3.0	> 3.0

The maximum predicted total subsidence parameters for the drainage lines based on the Approved Layout are the same as those for the Extraction Plan Layout after the extraction of Longwall 105. The maximum predicted total subsidence parameters for the other drainage lines based on the Approved Layout are also the same as those for the Extraction Plan Layout after the extraction of Longwall 105 as discussed in Section 4.3.

5.3.4. Impact Assessments and Recommendations for the Drainage Lines

The maximum predicted total subsidence parameters for the drainage lines based on the Approved Layout are the same as those for the Extraction Plan Layout for Longwalls 104 and 105. The potential impacts for the drainage lines, based on the Extraction Plan Layout, therefore, are the same as those assessed based on the Approved Layout. The following summary outlines the potential impacts to the drainage lines provided in the report MSEC731:

- The drainage lines within the Study Area are ephemeral as water only flows during and for short periods after each rain event. Ponding naturally develops along some sections of the drainage lines, for short periods of time, after major rain events. Additional ponding may occur along the drainage lines resulting from the extraction of Longwalls 104 and 105.
- Sections of beds downstream of the additional ponding areas may erode during subsequent rain events, especially during times of high flow. It is expected that, over time, the gradients along the drainage lines would approach grades similar to those that existed before mining. The extent of additional ponding along the drainage lines would, therefore, be expected to decrease with time.
- Fracturing and dilation of the bedrock would occur as a result of the extraction of these longwalls.
- In times of heavy rainfall, the majority of the surface water runoff would be expected to flow over the surface cracking in the beds and only a small proportion of the flow would be diverted into the fractured and dilated strata below. In times of low flow, however, a larger proportion of the surface water flow could be diverted into the strata below the beds and this could affect the quality and quantity of this water flowing through the cracked strata beds. Nevertheless, during high flow or low flow times, this small quantity is expected to have little impact on the overall quality of water flowing out of the drainage lines.

It is recommended that the drainage lines are visually monitored in accordance with the approved Subsidence Monitoring Program. Management strategies developed for the extraction of Longwalls 101 to 103 should be updated to include Longwalls 104 and 105.

5.4. Rock Ledges

There are rock ledges, also called rock outcrops and minor cliffs, located across the Additional Assessment Area.

The rock ledges are likely to experience the full range of predicted subsidence movements, as summarised in Table 4.1 and Table 4.2. The maximum predicted subsidence parameters for the rock ledges, based on the Extraction Plan Layout, therefore, are similar to the maxima based on the Approved Layout, as summarised in Table 4.3.

The potential impacts on the rock ledges, based on the Extraction Plan Layout, therefore, are the same as those assessed based on the Approved Layout, specifically, the potential for fracturing of sandstone and subsequent rockfalls, particularly where the rocks ledges are marginally stable. It is expected that occasional rockfalls or fracturing would not impact more than 5% of the total face area of rock ledges and overhangs in the Study Area.

No public access is available to the Additional Assessment Area. Access to the rock ledges by MCO personnel or contractors is only permitted in accordance with internal Subsidence Monitoring Procedures. Visual monitoring of representative exposed rock ledges within the Additional Assessment Area should be undertaken following completion of Longwall 105 in accordance with the approved Subsidence Monitoring Program.

5.5. Steep Slopes

The locations of steep slopes are shown on Drawing No. MSEC1084-08. The steep slopes within the Additional Assessment Area could experience the full range of predicted subsidence movements, as summarised in Table 4.1 and Table 4.2. The maximum predicted subsidence parameters for the steep slopes, based on the Extraction Plan Layout, therefore, are similar to the maxima based on the Approved Layout, as summarised in Table 4.3.

The potential impacts on the steep slopes, based on the Extraction Plan Layout, therefore, are the same as those assessed based on the Approved Layout. The potential for ground surface cracking is discussed in Section 4.8.

It has been observed that down slope movements occur on slopes that are located over or near extracted longwalls. Sometimes these movements are observed to be directed down the hill slope rather than towards the extracted goaf area. Where such movements occur on steep slopes, there is a higher likelihood that surface tension cracking can occur near the tops of the slopes. It is unlikely that mine subsidence would result in large-scale slope failure, since such failures have not been observed elsewhere as the result of longwall mining. It is expected that with careful management of remediation activities, the total impact of surface tension cracking and remediation should not be more than 5% of the total face area of steep slopes in the Additional Assessment Area.

It is recommended that representative steep slopes are monitored throughout the mining period and following the completion of LW105 extraction in accordance with the approved Subsidence Monitoring Program. Any significant surface cracking should be remediated in accordance with the approved Land Management Plan management measures.

5.6. Threatened, Protected Species or Critical Habitats

An investigation of the flora and fauna within the Additional Assessment Area was undertaken by Eco Logical Australia (2020). Flora and fauna surveys within these areas were undertaken and identified one threatened flora species under the *Biodiversity Conservation Act, 2016*. There is known and potential habitat for a number of threatened fauna species within the Study Area as described in Eco Logical Australia (2020).

There is no change in expected subsidence impacts to threatened flora or fauna species based on the Extraction Plan Layout.

The effects of subsidence on flora and fauna within the Additional Assessment Area are considered by Eco Logical Australia (2020).

Endangered Ecological Communities (EEC) are located within the Additional Assessment Area and are discussed below in Section 5.7.

5.7. Endangered Ecological Communities

5.7.1. Descriptions of the EECs

A vegetation validation exercise was undertaken by Eco Logical in 2020 within the Additional Assessment Area (Eco Logical, 2020). The purpose of the survey was to revise existing vegetation mapping to confirm the extent of previously recorded vegetation communities, specifically targeting any endangered ecological communities present.

The vegetation validation exercise confirmed the presence of the two previously identified endangered ecological communities known as *White Box, Yellow Box, Blakely's Redgum Grassy Woodland, and Derived Native Grasslands* and *Central Hunter Grey Box – Ironbark Woodland in the NSW North Coast and Sydney Basin Bioregions* located within the Additional Assessment Area as shown on Drawing No. MSEC1084-08. In addition to the above, Eco Logical (2020) also identified *Central Hunter Valley Eucalypt Forest and Woodland*, listed as a CEEC under the EPBC Act. This CEEC was listed in May 2015 and does not apply to the approved Stage 1 and Stage 2 mining operations pursuant to section 158A of the EPBC Act.

The effects of subsidence on flora and fauna within the Additional Assessment Area are considered by Ecological Australia (2020).

5.7.2. Predictions for the EECs

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the EECs within the Additional Assessment Area, resulting from the extraction of Longwalls 104 to 105 for the Extraction Plan Layout, is provided in Table 5.3. The values are the maximum predicted parameters within 20 m of the perimeter of the EECs. The predicted tilts provided in this table are the maxima after the completion of all the longwalls. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 5.3 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the EECs within the Additional Assessment Area Resulting from the Extraction of Longwalls 104 to 105

ID	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})
EEC01	2350	60	> 3	> 3
EEC03	2250	> 100	> 3	> 3
EEC05	2200	> 100	> 3	> 3
EEC09	50	< 0.5	0.06	0.06
EEC11	2250	> 100	> 3	> 3
EEC12	1100	55	2.7	2.0
EEC13	65	3	0.26	0.11
EEC14	1300	100	> 3	> 3

The predicted strains for the EECs are provided in Table 5.4. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis provided in Section 4.4).

Table 5.4 Predicted Strains for the EECs based on Conventional and Non-Conventional Anomalous Movements

Type	Conventional based on 10 times Curvature	Non-conventional based on the 95 % Confidence Level	Non-conventional based on the 99 % Confidence Level
Tension	> 30	10	22
Compression	> 30	13	31

It is noted that the predicted conventional strains are greater than the predicted 95 and 99 % confidence levels for the strains that include non-conventional movements, as the irregular strains are isolated and extreme events.

5.7.3. Comparison of the Predictions for the EECs

A comparison of the maximum predicted subsidence parameters for the EECs within the Additional Assessment Area, resulting from the extraction of Longwalls 104 to 105, with those based on the Approved Layout, is provided in Table 5.5.

Table 5.5 Comparison of Maximum Predicted Conventional Subsidence Parameters for the EECs based on the Extraction Plan Layout and the Approved Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (LW101-105) (Report No. MSEC731)	2350	> 100	> 3	> 3
Extraction Plan Layout (Report No. MSEC1084)	2350	>100	> 3	> 3

It can be seen from Table 5.5, that the maximum predicted conventional subsidence, tilt and curvature for the EECs, based on the Extraction Plan Layout, are the same as the maxima based on the Approved Layout.

5.7.4. Impact Assessments and Recommendations for the EECs

The maximum predicted total subsidence parameters for the EECs within the Additional Assessment Area based on the Extraction Plan Layout are the same as or lower than those for the Approved Layout for Longwalls 101 to 105. The potential impacts for the EECs, based on the Extraction Plan Layout, therefore, are the same as or lower than those assessed based on the Approved Layout.The following summary outlines the potential impacts to the EECs provided in the report MSEC731:

- The likely changes in gradients will result in reduced grades and increased grades depending on the position of the EECs in the subsidence bowl. These changes in grade may result in ponding of surface water runoff where existing natural grades are relatively shallow.
- It is expected that fracturing and dilation of the bedrock would occur as a result of the extraction of Longwalls 101 to 105. It is possible that below some of the EECs, massive basalt layers could be present that could resist the deformation and cracking that occurs in the sandstone layers. Fracturing and dilation of the bedrock could result in surface cracking, as described in Section 4.9.
- It is expected, that the surface cracking could be easily and quickly remediated, if it is required, by infilling with soil or other suitable materials, or by locally regrading and compacting the surface.

It is recommended that management strategies developed for the EECs for Longwalls 101 to 103 are updated to include Longwalls 104 and 105. The EECs should be visually monitored after the proposed UG1 longwalls mine beneath them so that impacts can be identified and remediated, if required. With remediation measures in place, potential impacts to EECs are predicted to be negligible (Ecological, 2020).

5.8. Natural Vegetation

Natural vegetation covers the majority of the Additional Assessment Area. The natural vegetation could, therefore, experience the full range of predicted subsidence movements, as summarised in Table 4.1 and Table 4.2. The maximum predicted subsidence parameters for the natural vegetation, based on the Extraction Plan Layout, therefore, are the same as the maxima based on the Approved Layout, as summarised in Table 4.3.

The potential impacts on the natural vegetation, based on the Extraction Plan Layout, therefore, are the same as those assessed based on the Approved Layout.

5.9. Areas of Significant Geological Interest

A brief description of the geology within the Additional Assessment Area is provided in Section 1.4. A discussion of alluvial/regolith palaeochannel deposits to the north east of the Study Area is provided in Section 4.6.1.

6.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE PUBLIC UTILITIES

The following sections provide the descriptions, predictions of subsidence movements and impact assessments for the public utilities located within the Additional Assessment Area for Longwalls 104 to 105. The predicted parameters for each of the built features have been compared to the predicted parameters based on the Approved Layout.

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

- Tunnels;
- Liquid Fuel Pipelines;
- Gas pipelines;
- Liquid fuel pipelines;
- Water and sewage treatment works;
- Dams, Reservoirs or Associated works; and
- Air strips.

6.1. Railways

The Sandy Hollow – Gulgong Railway Line is located to the north and east of Longwalls 101 to 105 as shown in Drawing No. MSEC1084-10.

The nearest edge of Longwalls 104 and 105 to the Sandy Hollow – Gulgong Railway Line is approximately 255 m from Longwall 105. At this location the depth of cover is approximately 90 m and, hence, the distances between the edges of the mined panels and the railway are equivalent to 2.8 or more times the depths of cover, which is much greater than 0.5 times the depth of cover used as a guide to the extent of the area likely to be affected by mining. A drainage culvert is located at Murragamba Creek approximately 550 m from Longwall 105, which is equivalent to approximately 6 times the depth of cover from Longwall 105. At this distance, the culvert is not expected to be impacted by the extraction of Longwalls 104 and 105.

The distances to the railway line based on the Extraction Plan layout are slightly greater than those for the Approved Layout. Therefore, the predictions and impact assessments based on the Extraction Plan Layout are the similar to or less than those for the Approved Layout. A discussion of the predicted subsidence movements and impact assessments from MSEC731 is provided below.

As detailed in Section 1.4.1, there are palaeochannel deposits, with a thickness of up to 40-50 m, to the north and east of the UG1 longwalls, where the depths of cover range from 90 to 130 m. Section 4.6.1 notes that the presence of a palaeochannel should result in less subsidence within these alluvial and unconsolidated sediment areas and reduced far-field movements beyond these channels at the railway track and transmission towers. It is also reported by SLR (2020) that only minor drawdown of the water table is predicted beyond the extracted longwalls, therefore significant settlement due to dewatering of alluvial sediments is considered unlikely to occur at the location of the railway line.

6.1.1. Predictions for the Sandy Hollow – Gulgong Railway Line

At distances of 255 m or greater between the longwalls and the railway track and based on these depths of cover, the rail track will not be subjected to measurable tilts, curvatures or strains; however, the railway line may experience far-field horizontal movements which are discussed in Section 3.3 and 4.6.

Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located 2.8 to 3 times the depths of cover from longwalls, was less than 70 mm.

As discussed above, the likely subsidence and far-field horizontal movements at the Sandy Hollow – Gulgong Railway are expected to be less than the normally predicted subsidence and far-field horizontal movements because of the presence of unconsolidated sediments in palaeochannels that are up to 50 m thick just outside the edges of the proposed longwall panels.

These far-field horizontal movements generally do not result in impacts at structures unless they are very sensitive to differential horizontal movements. The predicted far-field horizontal movements of less than 70 mm at the railway track are expected to be bodily movements that are directed across the track towards the extracted goaf area and should be accompanied by very low levels of strain.

The range of potential strains associated with non-conventional movements has been assessed using monitoring data from previously extracted panels in the NSW Coalfields, for single-seam conditions, where the width-to-depth ratios and extraction heights were similar to those of Longwalls 101 to 105.

The 95 % confidence levels for the maximum total strains that the individual survey bays *above solid coal* experienced at any time during mining are 1.6 mm/m tensile and 1.5 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 2.9 mm/m tensile and 3.0 mm/m compressive. The 75 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 0.5 mm/m both tensile and compressive, which is the typical limit of accuracy of strain measurement by conventional survey methods. It is noted that these results comprise a component of survey tolerance and have also been affected by disturbed survey marks and survey errors.

6.1.2. Impact Assessment and Recommendations for the Sandy Hollow – Gulgong Railway Line

The Sandy Hollow – Gulgong Railway Line is located more than 255 m from Longwalls 104 to 105. The railway line is not expected to be subject to measurable conventional vertical subsidence, tilt, curvature or conventional strain. However, the railway may experience low level far-field horizontal movements. The upper limit of previously observed absolute far-field horizontal movements for sites located 2.8 to 3 times the depths of cover from longwalls, is in the order of 70 mm. The presence of unconsolidated sediments should result in reduced far-field movements at the railway line.

The predicted far-field horizontal movements of less than 70 mm at the railway track are expected to be bodily movements that are directed across the track towards the extracted goaf area and should be accompanied by very low levels of strain that are in the order of survey tolerance.

Longwalls 101 and 102B have been extracted and measured subsidence, tilt and strain are within the limits of survey accuracy and have been consistent with predictions. Far-field horizontal movements have measured up to 40mm of horizontal movement which is less than the 70 mm discussed above. With the extraction of Longwalls 101 and 102B, the likelihood of far-field horizontal movements developing to the north east of Longwalls 104 and 105 is further reduced.

It is recommended that monitoring and management strategies developed for the extraction of Longwalls 101 to 103 are updated to include Longwalls 104 and 105. It is expected that the potential impacts on the ARTC infrastructure can be managed with the implementation of the necessary monitoring and management strategies.

6.2. Roads

6.2.1. Descriptions of the Roads

The locations of the roads owned by Mid Western Regional Council (MWRC) are shown in Drawing No. MSEC1084-09. The roads in the vicinity of Longwalls 104 to 105 include:

- Ulan-Wollar Road; and
- other roads closed to the public (on land owned by MWRC) including Murragamba Road and Carrs Gap Road.

MWRC also own infrastructure associated with these roads, such as the road pavement, embankments and culverts.

The current route of Ulan-Wollar Road from the intersection with Ulan Road and around the northern end of Longwalls 101 to 105 is shown in Drawing No. MSEC1084-09. Other closed roads include the decommissioned portion of Ulan-Wollar Road, and unsealed roads Murragamba Road and Carrs Gap Road as shown in Drawing No. MSEC1084-09 which are located on MWRC owned land.

The nearest publicly accessible sections of Ulan-Wollar Road to the longwalls are approximately 250 m from Longwall 101 and 225 m from Longwall 105. At these locations the depths of cover range from 130 m to 90 m and at these distances equate to 1.9 to 2.5 times the depths of cover from the longwalls.

The nearest closed sections of Ulan-Wollar Road are approximately 100 m from Longwall 105. Additionally, sections of the other closed roads, Murragamba Road and Carrs Gap Road, directly overlie Longwalls 104 to 105. As these roads are closed to the public, detailed subsidence predictions have not been provided.

Ulan-Wollar Road is a sealed bitumen pavement with no kerb and gutter. The nearest drainage culvert is located approximately 550 m to the south east at Murragamba Creek.

6.2.2. Predictions for the Roads

At distances of 225 m or more between the longwalls and the publicly accessible sections of Ulan-Wollar Road and based on depths of cover of 90 m to 130 m, Ulan-Wollar Road will not be subjected to measurable conventional mine subsidence ground movements (i.e. less than limits of survey accuracy); however, the road may experience far-field horizontal movements which are discussed below.

Previously observed absolute far-field horizontal movements from Fig. 4.5 show the upper limit for the sites located 1.9 times the depths of cover from longwalls is 75 mm.

Ulan-Wollar Road, therefore, is predicted to experience incremental far-field horizontal movements in the order of 75 mm due to the extraction of each of Longwalls 104 to 105. These low level horizontal movements are not expected to be associated with measurable tilts, curvatures or strains. The estimated far-field horizontal movements may be conservative due to the presence of the palaeochannel as discussed in Section 4.6.1.

The maximum observed strains from Section 4.4.1 at distances between 200 m and 600 m from the nearest longwall goaf edge are 1.6 mm/m tensile and 1.5 mm/m compressive based on the 95 % confidence level and 2.9 mm/m tensile and 3.0 mm/m compressive based on the 99 % confidence level. The 75 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 0.5 mm/m both tensile and compressive, which is the typical limit of accuracy of strain measurement by conventional survey methods. It is noted that these results comprise a component of survey tolerance and have also been affected by disturbed survey marks and survey errors.

6.2.3. Impact Assessments and Recommendations for the Roads

The Ulan-Wollar Road culvert at Murragamba Creek is located about six times the depth of cover from the longwalls and far-field horizontal movements would not be expected at this distance. Adverse impacts to this features resulting from the extraction of Longwalls 104 to 105 is considered to be unlikely to occur.

The predicted far-field horizontal movements of less than 75 mm at the road are expected to be bodily movements that are directed across the general alignment of the road towards the extracted goaf area and should be accompanied by very low levels of strain that are in the order of survey tolerance.

There is the potential for measurable ground strains to occur resulting from non-conventional movements. The statistical analysis of observed strain data between 200 m and 600 m from extracted longwalls shows a 25% probability of exceedance of 0.5 mm/m tensile and compressive, and a 5% probability of exceedance of approximately 1.5 mm/m tensile and compressive.

With the publicly accessible sections of Ulan-Wollar Road located 250 m or more from Longwalls 104 to 105 and the low probability of significant strains developing based on statistical analysis, the development of adverse impacts to the road due to the extraction of Longwalls 104 to 105 is considered to be unlikely to occur.

The observed subsidence, tilt and strain during the extraction of Longwalls 101 to 102B, and part extraction of Longwall 103, have been within the limits of survey accuracy, and are consistent with predictions. Far-field horizontal movements have measured up to 40mm of horizontal movement which is less than the 75 mm discussed above. The horizontal movements in the most recent survey are less than 10 mm. Non-conventional subsidence movements have not been identified from the monitoring data to date.

It is recommended that monitoring and management strategies developed for Longwalls 101 to 103 are updated to include Longwalls 104 and 105.

It is expected that the potential impacts on the MWRC infrastructure can be managed with the continuation of existing monitoring and management strategies.

6.3. Four Wheel Drive Tracks

There are a number of four wheel drive tracks through the Additional Assessment Area, one of which is shown on Drawing No. MSEC1084-09 above the south western end of Longwalls 104 and 105. These tracks are not publicly accessible.

The tracks could experience the full range of predicted subsidence movements, as summarised in Table 4.1 and Table 4.2. The maximum predicted subsidence parameters for these tracks, based on the Extraction Plan Layout, therefore, are the same as the maxima based on the Approved Layout, as summarised in Table 4.3.

The potential impacts on the tracks within the Additional Assessment Area are the same as those assessed based on the Approved Layout. Impacts are expected to include cracking, stepping and rippling of the road surfaces. The tracks may also experience ponding, however, the impacts of increased levels of ponding along these roads can be remediated by regrading and relevelling the roads using standard road maintenance techniques, if required.

6.4. Road Drainage Culverts

No drainage culverts were identified within the Additional Assessment Area; however, drainage culverts are located along Ulan-Wollar Road and the Sandy Hollow – Gulgong Railway, the nearest of which are at the Murragamba Creek crossings, over 550 m from Longwall 105.

At this distance the culverts would not be subjected to measurable conventional mine subsidence ground movements. The culverts are located over six times the depth of cover from the longwalls and far-field horizontal movements would not be expected at this distance. Adverse impacts to these culverts resulting from the extraction of Longwalls 104 to 105 are considered to be unlikely to occur. Should impacts occur, they are expected to be isolated and of a minor nature and readily repairable if required.

6.5. Electrical Infrastructure

6.5.1. Descriptions of the Electrical Infrastructure

The locations of the electrical infrastructure within the vicinity of Longwalls 104 to 105 are shown in Drawing No. MSEC1084-09.

A 66kV powerline owned by Essential Energy is located along the general alignment of Ulan-Wollar Road and Sandy Hollow – Gulgong Railway. At changes in the alignment of the 66kV powerline, the timber poles have guy wires for additional lateral restraint. A substation is located to the north east of Longwall 101 and is approximately 1km from Longwall 104.

The nearest sections of the 66kV powerline to the longwalls are approximately 60 m from the finishing (northern) end of Longwall 105 (pole 70454) and 90 m from Longwall 103 (pole 70458). Longwalls 101 and 102B have been extracted to within 140 m of the powerline. The substation is approximately 1 km to the north west of Longwall 104. At these locations the depths of cover range from 90 m to 130 m and at the minimum distance of 60 m the powerline is 0.7 times the depth of cover from the longwall. The substation is located over 9 times the depth of cover from Longwall104 and at this distance is unlikely to experience impact due to the extraction of Longwalls 104 and 105.

A 330kV electricity transmission line owned by TransGrid is located to the north east of the Additional Assessment Area. The transmission tower locations and reference numbers are shown in Drawing No. MSEC1084-09. There are five towers that are located within 1 km of Longwalls 104 and 105. The distances of these towers from the nearest longwall are summarised in Table 6.1. A photograph of the suspension towers is shown in Fig. 6.1. Depths of cover at the nearest longwalls vary from about 90 m to 110 m.

Table 6.1 Distances of the 330kV Transmission Towers from Longwalls 104 to 105

Tower Number	Nearest Longwall	Tower Type	Distance of the Transmission Towers Centrelines from the Nearest Longwall (m)	Distance divided by depth of cover
101	105	Suspension	888	9.9
102	105	Suspension	735	8.2
103	104	Suspension	702	6.4
104	104	Suspension	725	6.6
105	104	Suspension	900	8.2

Fig. 6.1 330 kV Suspension Tower

6.5.2. Predictions for the 66kV Powerline

At distances of 60 m or more from the longwalls, the 66kV powerline is outside the predicted 20 mm subsidence contour. The predicted subsidence movements at the 66kV powerline are therefore less than typical limits of measurable conventional mine subsidence ground movements (i.e. less than limits of survey accuracy); however, the 66kV powerline may experience far-field horizontal movements.

The far-field horizontal movements from Fig. 4.5 show the upper limit of previously observed absolute far-field horizontal movements for the sites located 0.7 times the depths of cover from longwalls, was less than 200 mm. This value is governed by a small number of data points from a Hunter Coalfield single seam case that was adjacent to an open cut pit and can be excluded for assessment of the horizontal movements to the north east of Longwalls 104 to 105. The resulting upper limit of previously observed absolute far-field horizontal movements is 160 mm.

The 66kV powerline, therefore, is predicted to experience maximum incremental far-field horizontal movements in the order of 160 mm due to the extraction of each of Longwalls 104 to 105. These horizontal movements are not expected to be associated with measurable tilts, curvatures or strains.

The estimated far-field horizontal movements may be conservative due to the presence of the palaeochannel as discussed in Section 4.6.1.

The maximum observed strains from Section 4.4.1 at distances within 200 m of the nearest longwall goaf edge are 3.3 mm/m tensile and 3.0 mm/m compressive based on the 95 % confidence level and 9.2 mm/m tensile and 14.4 mm/m compressive based on the 99 % confidence level. The 75 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 0.9 mm/m tensile and 0.5 mm/m compressive. It is noted that these results comprise a component of survey tolerance and have also been affected by disturbed survey marks and survey errors.

6.5.3. Predictions for the 330kV Electricity Transmission Line

The 330kV transmission towers are located 700 m or more from Longwalls 104 and 105. At these distances and based on depths of cover of 90 m to 110 m, the towers will not be subjected to measurable conventional mine subsidence ground movements (i.e. less than limits of survey accuracy); however, the towers may experience far-field horizontal movements.

The tower distances of 700 m or more from Longwalls 104 and 105 equate to over 6 times the depth of cover from the longwalls. Fig. 4.5 shows the observed absolute far-field horizontal movements for the sites located over 6 times the depths of cover are predominantly in the order of survey accuracy.

The transmission line, therefore, is not expected to experience measurable far-field horizontal movements due to the extraction of Longwalls 104 and 105. The presence of the palaeochannel as discussed in Section 4.6.1 further reduces the likelihood of measurable far-field horizontal movements for the towers.

6.5.4. Impact Assessments and Recommendations for the Electrical Infrastructure

The maximum predicted total subsidence parameters for the electrical infrastructure within the Additional Assessment Area are the same as or less than those for the Approved Layout for Longwalls 101 to 105. The potential impacts for the electrical infrastructure, based on the Extraction Plan Layout, therefore, are the same as or lower than those assessed based on the Approved Layout.

66kV Powerline

The predicted subsidence movements at the 66kV powerline are expected to be less than typical measurable limits for conventional vertical subsidence, tilt, curvature or strain. However, the 66kV powerline may experience far-field horizontal movements. The upper limit of previously observed absolute far-field horizontal movements for sites located 0.7 times the depths of cover from longwalls, is in the order of 160 mm. The presence of unconsolidated sediments should result in reduced far-field movements at the 66kV powerline.

The predicted far-field horizontal movements at the 66kV powerline are expected to be bodily movements that are directed across the general alignment of the 66kV powerline towards the extracted goaf area and should be accompanied by very low levels of strain that are in the order of survey tolerance. Relative movement between poles is expected to be less than 50 mm. Adverse impacts to the 66kV powerline resulting from these potential far-field horizontal movements are considered to be unlikely to occur.

There is the potential for measurable ground strains to occur resulting from non-conventional movements. The statistical analysis of observed strain data within 200 m of extracted longwalls shows a 25 % probability of exceedance of 0.8 mm/m tensile and 0.5 mm/m compressive, and a 5% probability of exceedance of 3.3 mm/m tensile and 3.0 mm/m compressive.

With the location of the 66kV powerline outside the longwall footprint and the low probability of significant observed strains developing based on statistical analysis, the development of adverse impacts to the 66kV powerline due to the extraction of Longwalls 104 to 105 is considered to be unlikely to occur.

It is recommended that monitoring and management strategies developed for Longwalls 101 to 103 are updated to include Longwalls 104 and 105, in consultation with Essential Energy, to manage the powerline for potential irregular ground movements. It is expected that the powerline can be maintained in a safe and serviceable condition with the implementation of the appropriate monitoring and management strategies.

330kV Electricity Transmission Line

The 330kV transmission towers are located over 700 m or over 6 times the depth of cover from Longwalls 104 and 105. At these distances the towers will not be subjected to measurable conventional mine subsidence ground movements and are unlikely to experience measurable far-field horizontal movements. The potential for non-conventional movements in the locations of the towers is very low, due to their distances from the longwalls. Unless greater than predicted, or anomalous movements are observed at monitoring sites for other features located to the north east of Longwalls 104 and 105, it is considered reasonable to relax or discontinue monitoring of the 330kV transmission line for the extraction of Longwalls 104 and 105.

6.6. Telecommunications Infrastructure

6.6.1. Descriptions of the Telecommunications Infrastructure

The locations of the telecommunications infrastructure are shown in Drawing No. MSEC1084-09.

The telecommunications infrastructure in the vicinity of Longwalls 104 to 105 comprises Telstra owned optical fibre and copper cables that roughly follow the alignment of Ulan Wollar Road and the Sandy Hollow – Gulgong Railway Line. There are no active telecommunication cables above Longwalls 104 to 105.

The telecommunication cables are located approximately 160 m to the north east of Longwall 105 at their nearest point. To the west of Longwall 101, the cable distance from the longwall increases from 240 m to greater than 1 km. At these locations the depths of cover range from 90 m to 130 m and at the minimum distance of 160 m the cables are 1.8 times the depths of cover from the longwalls. The optical fibre cable is direct buried.

6.6.2. Predictions for the Telecommunications Infrastructure

At distances of 160 m or more between the longwalls and the telecommunications cables and based on depths of cover of 90 m to 130 m, the cables will not be subjected to measurable conventional mine subsidence ground movements (i.e. less than limits of survey accuracy); however, the cables may experience far-field horizontal movements.

Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located 1.8 times the depths of cover, or greater, from longwalls, is less than 80 mm.

The telecommunication cables, therefore, are predicted to experience maximum incremental far-field horizontal movements in the order of 80 mm due to the extraction of each of Longwalls 104 to 105. These low level horizontal movements are not expected to be associated with measurable tilts, curvatures or strains. The estimated far-field horizontal movements may be conservative due to the presence of the palaeochannel as discussed in Section 4.6.1.

The maximum observed strains from Section 4.4.1 at distances within 200 m of the nearest longwall goaf edge are 3.3 mm/m tensile and 3.0 mm/m compressive based on the 95 % confidence level and 9.2 mm/m tensile and 14.4 mm/m compressive based on the 99 % confidence level. The 75 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 0.9 mm/m tensile and 0.5 mm/m compressive. It is noted that these results comprise a component of survey tolerance and have also been affected by disturbed survey marks and survey errors.

6.6.3. Impact Assessment and Recommendations for Telecommunications Cables

The optical fibre and copper cables are located 160 m or more from Longwalls 104 to 105. The cables are not expected to be subjected to measurable conventional vertical subsidence, tilt, curvature or strain. However, the cables may experience low level far-field horizontal movements. The upper limit of previously observed absolute far-field horizontal movements for sites located 1.8 times the depths of cover from longwalls, is in the order of 80 mm. The presence of unconsolidated sediments should result in reduced far-field movements at the cables.

The predicted far-field horizontal movements of less than 80 mm at the cables are expected to be bodily movements that are directed across the general alignment of the cable towards the extracted goaf area and should be accompanied by very low levels of strain that are in the order of survey tolerance.

Copper telecommunications cables have been mined beneath extensively in NSW and are known to tolerate significant subsidence related movements without impact. The copper cables are located over 1.8 times the depth of cover from Longwalls 104 to 105 and at this distance the development of adverse impacts to the copper cable due to the extraction of Longwalls 104 to 105 is considered to be unlikely to occur.

The optical fibre cable is direct buried and, therefore, will not be impacted by the tilts resulting from the extraction of Longwalls 104 to 105. The cables may experience measurable ground strains resulting from non-conventional movements. The statistical analysis of observed strain data within 200 m from extracted longwalls shows a 25 % probability of exceedance of 0.9 mm/m tensile and 0.5 mm/m compressive, and a 5% probability of exceedance of approximately 3.3 mm/m tensile and 3.0 mm/m compressive.

Tensile strains in the optical fibre cables can develop where the cables connect to the support structures, which may act as anchor points, preventing any differential movements that may have been allowed to occur within the ground. Tree roots have also been known to anchor cables to the ground. The extent to which the anchor points affect the ability of the cable to tolerate the mine subsidence movements depends on the cable size, type, age, installation method and ground conditions.

In addition to this, optical fibre cables contain additional fibre lengths over the sheath lengths, where the individual fibres are loosely contained within tubes. Compression of the sheaths can transfer to the loose tubes and fibres and result in ‘micro-bending’ of the fibres constrained within the tubes, leading to higher attenuation of the transmitted signal.

With the location of the optical fibre cable at 160 m or more from Longwalls 104 to 105 and the low probability of significant strains developing based on statistical analysis, the development of adverse impacts to the optical fibre cable due to the extraction of Longwalls 104 to 105 is considered to be unlikely to occur.

The potential transfer of ground strain into the Telstra optical fibre cables can be monitored using a Remote Fibre Monitoring System (RFMS). The ground movements can also be monitored using traditional survey lines and visual inspections. These monitoring methods can be used to identify the development of irregular ground movements. If non-conventional movements or signal attenuation are detected during active subsidence, then the cable can be relieved by locally exposing and then reburying the affected section of cable.

It is recommended that monitoring and management strategies developed for Longwalls 101 to 103 are updated and continued to include Longwalls 104 and 105, in consultation with Telstra, to manage the optical fibre cable for potential irregular ground movements. It is expected that the cable can be maintained in serviceable condition with the implementation of the appropriate monitoring and management strategies.

7.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE PUBLIC AMENITIES

As listed in Table 2.1, the following public amenities were not identified within the Additional Assessment nor in the immediate surrounds:

- Hospitals;
- Places of worship;
- Schools;
- Shopping centres;
- Community centres;
- Office buildings;
- Swimming pools;
- Bowling greens;
- Ovals or cricket grounds;
- Racecourses;
- Golf courses; and
- Tennis courts.

8.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE FARM LAND AND FARM FACILITIES

The following sections provide the descriptions, predictions of subsidence movements and impact assessments for the farm land and facilities located within the Additional Assessment Area for Longwalls 104 to 105.

As listed in Table 2.1, the following farm land facilities were not identified within the Additional Assessment Area nor in the immediate surrounds:

- Agricultural utilisation or agricultural suitability of farm land;
- Farm buildings or sheds;
- Tanks;
- Gas or fuel storages;
- Poultry sheds;
- Glass houses;
- Hydroponic systems;
- Irrigation systems; and
- Wells or Bores.

8.1. Fences

Fences are located within the Additional Assessment Area and are constructed in a variety of ways, generally using either timber or metal materials.

The fences could experience the full range of predicted subsidence movements, as summarised in Table 4.1 and Table 4.2. The maximum predicted subsidence parameters for the fences within the Additional Assessment Area are the same as the maxima based on the Approved Layout, as summarised in Table 4.3.

Fences can be affected by tilting of the fence posts and by changes of tension in the fence wires due to strain as mining occurs. Fences are generally flexible in construction and can usually tolerate significant tilts and strains.

Any impacts on the fences are likely to be of a minor nature and relatively easy to remediate by re-tensioning fencing wire, straightening fence posts, and if necessary, replacing some sections of fencing.

It is recommended that management plans developed for Longwalls 101 to 103 are updated to include Longwalls 104 and 105.

8.2. Farm Dams

8.2.1. Descriptions of the Farm Dams

The locations of the identified farm dams are shown in Drawing No. MSEC1084-10. There are seven farm dams within the Additional Assessment Area and four dams located within the out of pit emplacement area that have been infilled. The farm dams are located on land owned by MCO.

8.2.2. Predictions for the Farm Dams

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the farm dams, resulting from the extraction of Longwalls 104 to 105 is provided in Table 8.1. The predicted tilts provided in this table are the maxima after the completion of all the longwalls. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 8.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Farm Dams within the Study Area after the Extraction of Longwall 105

ID	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})
A03d01	1850	17	> 3.0	> 3.0
A01d01	20	2.0	0.15	0.06
A01d02	2150	4.5	> 3.0	> 3.0
A01d03	30	4.0	0.28	0.11
A01d04	<20	< 0.5	0.08	<0.01
A02d01	2200	< 0.5	> 3.0	> 3.0
A02d02	2200	< 0.5	> 3.0	> 3.0

The predicted strains for the farm dams are provided in Table 8.2. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis provided in Section 4.4).

Table 8.2 Predicted Strains for the Farm Dams based on Conventional and Non-Conventional Anomalous Movements

Type	Conventional based on 10 times Curvature	Non-conventional based on the 95 % Confidence Level	Non-conventional based on the 99 % Confidence Level
Tension	> 30	3.3	9.2
Compression	> 30	3.0	14.4

8.2.3. Comparison of the Predictions for the Farm Dams

The comparison of the maximum predicted subsidence parameters for the farm dams within the Additional Assessment Area, resulting from the extraction of Longwalls 104 to 105, with those based on the Approved Layout is provided in Table 8.3.

Table 8.3 Comparison of Maximum Predicted Conventional Subsidence Parameters for the Farm Dams based on the Extraction Plan Layout and the Approved Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (LW101-105) (Report No. MSEC731)	2200	17.0	> 3.0	> 3.0
Extraction Plan Layout (Report No. MSEC1084)	2200	17.0	> 3.0	> 3.0

It can be seen from Table 8.3, that the maximum predicted conventional subsidence parameters based on the Extraction Plan Layout the same as those for the Approved Layout.

8.2.4. Impact Assessments and Recommendations for the Farm Dams

The maximum predicted total subsidence parameters for the farm dams within the Additional Assessment Area are similar to or less than the parameters for the Approved Layout for Longwalls 101 to 105 and do not change the impact assessments for the farm dams. The following summary outlines the potential impacts to the farm dams provided in the report MSEC731:

- The predicted change in freeboard at the farm dams varies from approximately 50 mm to 100 mm. This change in level is not expected to have any appreciable impact on the normal functioning of the dam.
- Farm dams are typically constructed of cohesive soils with reasonably high clay contents, and are likely to be capable of withstanding tensile ground strains up to 3 mm/m without impact. The predicted strains based on the Extraction Plan Layout are greater than 3 mm/m based on the statistical assessment of observed data.
- It is expected, therefore, that cracking and leakage of water could occur in the farm dams which are subjected to the greater strains, though, any cracking or leakages can be easily identified and repaired. Any loss of water from the farm dams would flow into the drainage line in which the dam was formed.

It is recommended that monitoring and management strategies developed for Longwalls 101 to 103 are updated to include Longwalls 104 and 105 and incorporate consideration of dewatering and/or decommissioning of farm dams prior to secondary extraction. In this way the farm dams within the Additional Assessment Area can be maintained in a safe and serviceable condition throughout the mining period.

9.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE INDUSTRIAL, COMMERICAL AND BUSINESS ESTABLISHMENTS

The following sections provide the descriptions, predictions of subsidence movements and impact assessments for the industrial, commercial and business establishments located within the Additional Assessment Area for Longwalls 104 to 105. The predicted parameters for each of the built features have been compared to the predicted parameters based on the Approved Layout.

As listed in Table 2.1, the following Industrial, Commercial and Business Establishments were not identified within the Study Area nor in the immediate surrounds:

- Factories;
- Workshops;
- Business or commercial establishments or improvements;
- Gas or fuel storages and associated plant;
- Waste storages and associated plant;
- Buildings, equipment or operations that are sensitive to surface movements; and

The only industrial/commercial infrastructure within the Additional Assessment Area is owned and controlled by MCO.

9.1. Mine Infrastructure Including Tailings Dams or Emplacement Areas

The open cut mine operations include a haul road (OC4 South-west Haul Road) that crosses over Longwalls 101 to 105, ROM facilities and conveyor and associated powerline, the open cut highwalls, communications tower, settlement ponds, water tanks, and an out-of-pit emplacement, the locations of which are shown in Drawing No. MSEC1084-09. The predictions and impact assessments for the mine infrastructure are provided in the following sections.

9.1.1. Communications Tower

The communications tower is located above Longwall 104, approximately 1.6 km from the commencing end, and within the northern end of the out of pit emplacement area. The communications tower comprises a triangular steel lattice structure approximately 50 m in height on a raft slab. The structure has been designed as self supporting. A fibre optic cable extends from the tower to the ROM facilities area as shown in Drawing No. MSEC1084-09.

A summary of the maximum predicted values of total subsidence, tilt and curvature for the communications tower, resulting from the extraction of Longwalls 101 to 105, is provided in Table 9.1. The predicted tilt and curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 9.1 Predicted Total Subsidence, Tilt and Curvature for the Communications Tower from the Extraction of Longwalls 104 to 105

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})
2250	70	> 3.0	2.5

The maximum predicted conventional tilt for the communications tower is 70 mm/m (i.e. 7.0 %, or 4°, or 1 in 14). The maximum predicted conventional curvatures are greater than 3 km^{-1} hogging and 2.5 km^{-1} sagging, which equate to minimum radii of curvature of 0.33 km and 0.4 km respectively. The majority of the maximum predicted total conventional tilt and ground curvature occur as transient movement during the extraction of Longwall 104 when the longwall face passes beneath the tower location. Minor ground movements are expected to occur due to the extraction of Longwall 105 and are included in the abovementioned parameters.

The predicted ground strains for the communications tower are provided in Table 9.2. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis provided in Section 4.4).

Table 9.2 Predicted Strains for the Section of the Conveyor Located directly above Longwalls 101 to 105 based on Conventional and Non-Conventional Anomalous Movements

Type	Conventional based on 10 times Curvature (mm/m)	Non-conventional based on the 95 % Confidence Level (mm/m)	Non-conventional based on the 99 % Confidence Level (mm/m)
Tension	> 30	10	22
Compression	25	13	31

It is understood that the communications tower has been designed for the above predicted subsidence parameters and a design review will be conducted prior to the extraction of Longwall 104.

With mine subsidence movements accounted for in the communications tower design, it is expected that the communications tower could be maintained in a safe and serviceable condition during the mining period.

It is recommended that the communications tower should be monitored as the extraction faces of the Longwalls 104 and 105 are mined near and beneath the tower, such that any irregular movements or impacts can be identified early and remediated accordingly.

The optic fibre cable extends above Longwalls 103 to 105 and will experience similar magnitudes of subsidence parameters as outlined above. The cable has been mined beneath by Longwall 103 with no impacts being identified. It is recommended that the cable signal is monitored during active subsidence for Longwalls 104 and 105. Consideration could be given to temporarily locating the cable above ground or providing an alternative communication cable during the extraction of Longwall 104 and 105.

It is recommended that management strategies be developed to maintain the communications tower and optical fibre cable throughout the mining period.

9.1.2. Stage 2 ROM facilities and Conveyor

The Stage 2 ROM facilities and conveyor have been constructed. The location of the conveyor is shown in Drawing No. MSEC1084-09. The conveyor crosses diagonally over Longwall 104 to 105 and includes an access road adjacent to the conveyor. The Stage 2 ROM facilities are located adjacent to the maingate of Longwall 105. The Stage 2 ROM facilities are located outside the 26.5° angle of draw from Longwall 105. The majority of the features of the Stage 2 ROM facility are located approximately 100 m or more from the Longwall 105 maingate which equates to approximately 1.0 times the depth of cover. The main feature of the ROM facilities considered sensitive to movements is the reinforced earth wall (RE wall), which is located outside the 26.5° angle of draw, approximately 65 m to 120 m from the nearest edge of the Longwall 105 void.

Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located 1.0 times the depths of cover, or greater, from longwalls, is less than 140 mm. With the extraction of OC4 prior to the extraction of Longwall 105 adjacent to this area, the predicted horizontal movements may be significantly lower. These horizontal movements are not expected to be associated with measurable tilts, curvatures or strains.

The predicted profiles of vertical subsidence, tilt and curvature along the alignment of the conveyor, resulting from the extraction of Longwalls 101 to 105, are shown in Fig. C.06 in Appendix C. The predicted incremental profiles for the conveyor, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles after the extraction of each of the longwalls, are shown as solid blue lines. The predicted total profiles based on the Approved Layout are shown as red lines for comparison.

A summary of the maximum predicted values of total subsidence, tilt and curvature for the conveyor, resulting from the extraction of Longwalls 104 to 105, is provided in Table 9.3. The values are the maxima anywhere along the section of the conveyor within the Additional Assessment Area. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 9.3 Predicted Total Subsidence, Tilt and Curvature for the Conveyor from the Extraction of Longwalls 104 to 105

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})
2350	50	> 3.0	> 3.0

The maximum predicted conventional tilt for the conveyor is 50 mm/m (i.e. 5.0 %, or 1 in 20). The maximum predicted conventional curvatures are greater than 3 km^{-1} hogging and sagging, which equate to minimum radii of curvature of 0.33 km.

The predicted strains for the conveyor are provided in Table 9.4. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis provided in Section 4.4).

Table 9.4 Predicted Strains for the Section of the Conveyor Located directly above Longwalls 104 to 105 based on Conventional and Non-Conventional Anomalous Movements

Type	Conventional based on 10 times Curvature (mm/m)	Non-conventional based on the 95 % Confidence Level (mm/m)	Non-conventional based on the 99 % Confidence Level (mm/m)
Tension	> 30	10	22
Compression	10	13	31

A comparison of the maximum predicted subsidence parameters for the conveyor with those based on the Approved Layout is provided in Table 9.5. The values are the maxima anywhere along the section of the conveyor located within the Additional Assessment Area.

Table 9.5 Comparison of Maximum Predicted Conventional Subsidence Parameters for the Conveyor based on the Extraction Plan Layout and the Approved Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (LW101-105) (Report No. MSEC731)	2350	50	> 3.0	> 3.0
Extraction Plan Layout (Report No. MSEC1084)	2350	50	> 3.0	> 3.0

It can be seen from Table 9.5 that the maximum predicted conventional subsidence, tilt and hogging curvature for the conveyor, based on the Extraction Plan Layout, are the same as the maxima based on the Approved Layout. The potential impacts for the conveyor, based on the Extraction Plan Layout, therefore, are the same as those assessed based on the Approved Layout. The predicted subsidence parameters will result in significant movement in the conveyor. It is understood that provision has been made for mine subsidence movements in the design of the conveyor. The potential impacts to the access road include cracking, stepping, rippling and ponding of the road surface.

With mine subsidence movements accounted for in the conveyor design, it is expected that the conveyor could be maintained in a safe and serviceable condition during the mining period.

It is expected that the impacts to the access road could be remediated by standard road maintenance techniques. If required, the repairs would be progressive and, therefore, could be staged to suit the mining of each longwall in sequence.

Longwalls 101 and 102A have been successfully extracted beneath the conveyor. It is recommended that the conveyor and access road should be monitored as the extraction faces of the remaining Longwalls 104 to 105 are mined near and beneath them, such that any impacts can be identified early and remediated accordingly.

The south eastern end of the conveyor has been constructed on emplaced material to raise the natural ground surface level. The profile of the natural ground surface level is shown in Fig. C.06. It can be seen that the natural surface slopes down significantly above Longwall 104 and 105. It is estimated up to about 15 m of fill may be present beneath the conveyor in this area. Extraction of Longwalls 104 and 105 are likely to result in additional settlement of the fill as discussed below in Section 9.1.4. It is recommended that a geotechnical assessment be conducted on the fill supporting the conveyor above Longwalls 104 and 105 to assess the potential for additional settlement and slope stability.

The design of the Stage 2 ROM facilities accounted for potential subsidence movements up to the extraction of Longwall 105. Given the close proximity of the ROM facilities and sensitivity of the RE wall to movements, it is recommended that a review is undertaken to confirm the parameters and assumptions for the design of the ROM facility.

It is recommended that management strategies developed for the extraction of Longwalls 101 to 103 are updated to include Longwalls 104 and 105 to maintain the conveyor and access road throughout the mining period.

9.1.3. OC4 South-West Haul Road and Digger Walk Road

A haul road (OC4 South-West Haul Road) is located above Longwalls 104 to 105. The Digger Walk Road is located above the commencing end of Longwall 105. The locations of these roads are shown in Drawing No. MSEC1084-09

The predicted profiles of vertical subsidence, tilt and curvature along the alignment of the roads, resulting from the extraction of Longwalls 104 to 105, are shown in C.07 and C.08, in Appendix C. The predicted incremental profiles due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles after the extraction of each of the longwalls, are shown as solid blue lines. The predicted total profiles based on the Approved Layout are shown as red lines for comparison. The predicted profiles represent the movements at the natural ground surface. Additional settlement of the out of pit emplacement will occur during the extraction of Longwalls 104 and 105 as outlined in Section. 9.1.4.

A summary of the maximum predicted values of total subsidence, tilt and curvature for the roads, resulting from the extraction of Longwalls 104 to 105, is provided in Table 9.6. The values are the maxima anywhere along the sections of the roads located within the Additional Assessment Area.

Table 9.6 Predicted Total Subsidence, Tilt and Curvature for the OC4 South-West Haul Road and Digger Walk Road from the Extraction of Longwalls 104 to 105

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})
2300	85	> 3	> 3
2250	> 100	> 3	> 3

The maximum predicted conventional tilt for the haul road is 85 mm/m (i.e. > 8.5 %, or 1 in 12). The maximum predicted conventional tilt for the Digger Walk Road road is > 100 mm/m (i.e. > 10 %, or 1 in 10). The maximum predicted conventional curvatures are greater than 3 km^{-1} hogging and sagging, which equate to minimum radii of curvature of greater than 0.33 km.

The predicted strains for the sections of the roads above the longwalls are provided in Table 9.7. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis provided in Section 4.4).

Table 9.7 Predicted Strains for the Section of the Haul Roads Located directly above Longwalls 104 to 105 based on Conventional and Non-Conventional Anomalous Movements

Type	Conventional based on 10 times Curvature (mm/m)	Non-conventional based on the 95 % Confidence Level (mm/m)	Non-conventional based on the 99 % Confidence Level (mm/m)
Tension	> 30	10	22
Compression	> 30	13	31

A comparison of the maximum predicted subsidence parameters for the haul road with those based on the Approved Layout is provided in Table 9.8. The values are the maxima anywhere along the section of the haul road located within the Additional Assessment Area.

Table 9.8 Comparison of Maximum Predicted Conventional Subsidence Parameters for the Haul Road based on the Extraction Plan Layout and the Approved Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (LW101-105) (Report No. MSEC731)	2300	> 100	> 3	> 3
Extraction Plan Layout (Report No. MSEC1084)	2300	> 100	> 3	> 3

It can be seen from Table 9.8 that the maximum predicted conventional subsidence, tilt and hogging curvature for the roads, based on the Extraction Plan Layout, are the same as the maxima based on the Approved Layout. The potential impacts for the haul road and Digger Walk Road, based on the Extraction Plan Layout, therefore, are the same as those assessed for unsealed roads based on the Approved Layout. The potential impacts to the roads provided in the report MSEC731 include cracking, stepping, rippling and ponding of the road surfaces.

It is expected that the impacts to the haul road and Digger Walk Road could be remediated by standard road maintenance techniques, if required. The repairs would be progressive and, therefore, could be staged to suit the mining of each longwall in sequence. It may be necessary to introduce speed restrictions along the roads until the appropriate remediation measures have been implemented.

Longwalls 102A and part of Longwall 103 have been successfully extracted beneath the haul road. It is recommended that the roads and adjacent batters should be monitored as the extraction faces of the remaining Longwalls 104 and 105 are mined near and beneath them, such that any impacts can be identified early and remediated accordingly.

It is recommended that management strategies developed for the extraction of Longwalls 101 to 103 are updated to include Longwalls 104 and 105 to maintain the roads and adjacent batters throughout the mining period.

9.1.4. Out-of-pit Emplacement

The out-of-pit emplacement area is partially located within the Additional Assessment Area, above the maingate side of Longwall 103 and above Longwalls 104 and 105. Longwall 103 has been partially extracted beneath the out-of-pit emplacement.

The top of the approved out-of-pit emplacement area is proposed to be relatively flat with a top surface level of approximately 530 m to 540 m Australian Height Datum (AHD). The slopes of the batters formed at the sides of the emplacement area are proposed to vary from grades of approximately 1 in 4 to 1 in 6. The maximum batter height near or above UG1 is approximately 85 metres.

The maximum predicted total subsidence due to the extraction of the Extraction Plan Layout at the base of the out-of-pit emplacement is 2150mm at the north western edge of the out-of-pit emplacement. The maximum predicted total tilts are 80 mm/m and maximum predicted total hogging and sagging curvature are greater than 3.0 km^{-1}.

The maximum predicted total subsidence parameters for the out-of-pit emplacement based on the Approved Layout are the same as those for the Extraction Plan Layout for Longwalls 104 to 105. The impact assessments for the out-of-pit emplacement, based on the Extraction Plan Layout, therefore, are the same as those assessed based on the Approved Layout.

It is expected that additional settlement would occur at the top of the out-of-pit emplacement, as the longwalls mine beneath it, due to the consolidation and lateral shifting of the out-of-pit emplacement. Research reports on the response of UK out-of-pit emplacements to mine subsidence movements indicate that this extra settlement can initiate downhill slumping of out-of-pit emplacements.

A detailed discussion on the additional settlement of unconsolidated out-of-pit emplacements is provided in the background report entitled *General Discussion of Mine Subsidence Ground Movements (Revision A)* which can be obtained from *www.minesubsidence.com*. An empirical relationship for the additional settlement of unconsolidated out-of-pit emplacements which are directly mined beneath is provided in Fig. 9.1.

The maximum predicted subsidence (S) at the natural surface below the out-of-pit emplacement is 2150 mm and the depth of cover (h) between the natural surface and the mined seam varies from approximately 110 m to 130 m. The ratio of subsidence (S) to depth of cover (h) at the out-of-pit emplacement varies from 0.017 to 0.019, which is beyond the maximum limit of the range of cases considered in Fig. 9.1.

Based on an extrapolation of the linear trend line, from Fig. 9.1 for S/h ratios of 0.014 to 0.017, the potential additional settlement at the surface of the out-of-pit emplacement above the extracted longwalls ranges from approximately 30 mm/m to 35 mm/m, or 3% to 3.5% of the height of the out-of-pit emplacement. This results in a potential additional settlement of the out-of-pit emplacement area above the UG1 longwalls of up to 450 mm. This value may be a conservative estimate as the natural ground slope beneath the out-of-pit emplacement results in fill thickness increasing as the predicted subsidence reduces, i.e. location of maximum predicted subsidence is at the location of minimum fill thickness and vice versa. The maximum predicted total subsidence plus potential excess settlement therefore is approximately 2600 mm.

As discussed above, the predicted subsidence at the natural ground surface and additional settlement of the emplacement area can initiate downhill slumping of the soils in the out-of-pit emplacement area. Other factors such as the presence of natural steep ground slopes, and surface water ingress may increase the risk of downhill slumping of the sides of the emplacement area. Longwall extraction will create depressions in the flat areas of the emplacement and surface cracks, which will increase the risk of water ingress into the emplacement soils during rain periods.

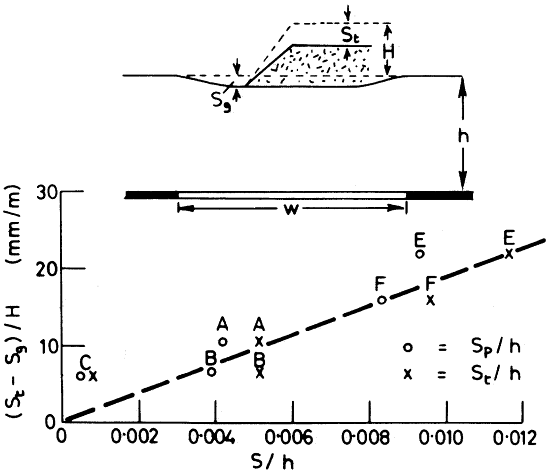

Fig. 9.1 Relationship between Excess Settlement of Mine Spoil Heap and the S/H Ratio. (From Whittaker and Reddish, 1989)

The areas of greatest concern are the possible failure of out-of-pit emplacement slopes above and close to the proposed work areas of the haul roads, the conveyors and the Stage 2 ROM facilities. Consideration could be given to restricting access to areas near the steep slopes, particularly during the active subsidence period, until subsidence movements cease or the risk of slope failure is determined to be very low.

It is recommended, that management strategies developed for Longwalls 101 to 103 for the management of the surface and the slopes of the proposed out-of-pit emplacement are updated to include Longwalls 104 and 105. Such management measures should include surface crack repair and remediation of the ground surface to ensure that adequate surface water drainage is maintained. Settlement and movement of the out-of-pit emplacement should also be monitored as the longwalls are mined beneath it.

9.1.5. The Highwall of the Open Cut Mine

The longwall geometry and distances to the open cut highwalls based on the Extraction Plan layout are the same as those for the Approved Layout. Therefore, the predictions and impact assessments based on the Extraction Plan Layout are the same as those for the Approved Layout.

Extraction in OC4 will not be in close proximity to Longwall 105 during extraction. It is recommended that a geotechnical assessment of the highwalls near extracted longwalls and future longwalls is undertaken to assess the potential for instability to develop in the highwalls. Longwall extraction near the open cut highwalls also increases the potential for larger surface cracking and surface deformation above the longwalls as discussed in Section 4.8. It is recommended that the high walls are monitored and, if cracking, deformation, or other indications of potential instability are observed, then access is restricted adjacent to the highwall.

9.1.6. Water Tanks and Mine Dam

There are three corrugated iron water tanks and one earth dam located at the end of the conveyor above Longwall 105. The dam and water tanks will experience significant movements due to the extraction of Longwall 105.

The dam will experience similar magnitudes of subsidence parameters as the farm dams outlined in Section 8.2. Similar monitoring and management strategies developed for the farm dams are recommended for the MCO dam, including consideration of dewatering and/or decommissioning of the dam prior to secondary extraction.

A summary of the maximum predicted values of total subsidence, tilt and curvature for the water tanks, after the extraction of Longwall 105, is provided in Table 9.9. The predicted tilt and curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 9.9 Predicted Total Subsidence, Tilt and Curvature for the Water Tanks after the Extraction of Longwall 105

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})
2250	70	> 3.0	> 3.0

The maximum predicted conventional tilt for the tanks during or after longwall extraction is 70 mm/m (i.e. 7.0 %, or 1 in 14). The maximum predicted conventional curvatures are greater than 3 km^{-1} hogging and sagging, which equate to minimum radii of curvature of 0.33 km. The majority of the maximum predicted total conventional tilt and ground curvature occur as transient movement during the extraction of Longwall 105 when the longwall face passes beneath the tanks.

The predicted ground strains for the tanks are provided in Table 9.2. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis provided in Section 4.4).

Table 9.10 Predicted Strains for the Section of the Conveyor Located directly above Longwalls 101 to 105 based on Conventional and Non-Conventional Anomalous Movements

Type	Conventional based on 10 times Curvature (mm/m)	Non-conventional based on the 95 % Confidence Level (mm/m)	Non-conventional based on the 99 % Confidence Level (mm/m)
Tension	> 30	10	22
Compression	> 30	13	31

It is understood that the tanks are corrugated iron with flexible liners and are used as a fire-fighting water supply. It is recommended that the structural design of the tanks is verified for the predicted subsidence parameters above. An alternative approach to management of the tanks could be to temporarily or permanently relocate the tanks to a suitable location during the extraction of Longwall 105.

It is recommended that management strategies be developed to manage the tanks during active subsidence.

10.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR AREAS OF ARCHAEOLOGICAL AND HERITAGE SIGNIFICANCE

The following sections provide the descriptions, predictions of subsidence movements and impact assessments for the archaeological and heritage sites located within the Additional Assessment Area for Longwalls 104 to 105. The predicted parameters for each of the features have been compared to the predicted parameters based on the Approved Layout.

10.1. Aboriginal Heritage Sites

10.1.1. Descriptions of the Aboriginal Heritage Sites

There are eight Aboriginal heritage sites identified within the Additional Assessment Area which comprise rock shelters with potential archaeological deposits (PAD) or artefacts, isolated finds or artefact scatters. The locations of the Aboriginal heritage sites within the Additional Assessment Area are shown in Drawing No. MSEC1084-10.

A survey was conducted by Niche Environment and Heritage in December 2020. Three new sites were recorded including one rock shelter with PADs and two rock shelters with artefacts (Niche Environment and Heritage,2020).

Several sites within the Additional Assessment Area have been salvaged since the Subsidence Assessment for the UG1 Optimisation Modification was completed (MSEC, 2015). Revised subsidence predictions and impact assessment have been provided for unsalvaged and new sites.

Detailed descriptions of the Aboriginal heritage sites and the survey conducted in December 2019 are provided in the report by Niche Environment and Heritage (2020).

10.1.2. Predictions for the Aboriginal Heritage Sites

The maximum predicted subsidence parameters for each of the Aboriginal heritage sites located within the Additional Assessment Area is provided in Table D.01, in Appendix D. The predictions have been provided based on the Extraction Plan Layout, as well as for the Approved Layout for comparison.

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the Aboriginal heritage sites within the Additional Assessment Area, for the Extraction Plan Layout, is provided in Table 10.1. The predicted tilts provided in this table are the maxima after the completion of all the longwalls. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 10.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Aboriginal Heritage Sites within the Additional Assessment Area after the Extraction of Longwall 105

Site Type	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})
Rock shelter with Artefacts or PAD	2200	8	> 3	> 3
Isolated Find	2200	55	> 3	> 3
Artefact Scatter	2200	6	> 3	> 3

The maximum predicted conventional tilt for the Aboriginal heritage sites is 55 mm/m (i.e. 5.5 %, or 1 in 18). The maximum predicted conventional curvatures for these sites are greater than 3 km^{-1} hogging and sagging, which represent minimum radii of curvature of less than 0.33 km.

The predicted strains for the Aboriginal heritage sites are provided in Table 10.2. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis above solid coal provided in Section 4.4).

Table 10.2 Predicted Strains for the Aboriginal Heritage Sites based on Conventional and Non-Conventional Anomalous Movements

Type	Conventional based on 10 times Curvature (mm/m)	Non-conventional based on the 95 % Confidence Level (mm/m)	Non-conventional based on the 99 % Confidence Level (mm/m)
Tension	> 30	10	22
Compression	> 30	13	31

10.1.3. Comparisons of the Predictions for the Aboriginal Heritage Sites

Comparisons of the maximum predicted conventional subsidence parameters for the Aboriginal heritage sites within the Additional Assessment Area, after the extraction of Longwall 105, with those based on the Approved Layout are provided in Table 10.3. A comparison of the maximum predicted subsidence parameters for each of the Aboriginal heritage sites located within the Additional Assessment Area is also provided in Table D.01, in Appendix D.

Table 10.3 Comparison of Maximum Predicted Conventional Subsidence Parameters for the Aboriginal Heritage Sites based on the Approved Layout and the Extraction Plan Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (101-105) (Report No. MSEC731)	2200	55	> 3	> 3
Extraction Plan Layout (Report No. MSEC1084)	2200	55	> 3	> 3

The maximum predicted subsidence parameters for the Aboriginal heritage sites, based on the Extraction Plan Layout, are the same as those based on the Approved Layout. The potential impacts for the Aboriginal heritage sites based on the Extraction Plan Layout, therefore, are similar to those assessed based on the Approved Layout.

10.1.4. Impact Assessments and Recommendations for the Aboriginal Heritage Sites

Open sites containing artefact scatters and isolated finds can potentially be affected by cracking of the surface soils as a result of mine subsidence movements. It is unlikely that the scattered artefacts or isolated finds themselves would be impacted by surface cracking.

Whilst it is unlikely that the scattered artefacts or isolated finds themselves would be impacted by mine subsidence, it is possible that, if remediation works to the surface areas around the Aboriginal heritage sites was required after mining, these works could potentially impact on the Aboriginal heritage sites. A discussion on surface cracking resulting from the extraction of Longwalls 104 to 105 is provided in Section 4.8.

Rock shelters in the Additional Assessment Area are predicted to be subject to similar impacts as described for rock ledges in Section 5.5 (i.e. potential for fracturing of sandstone and subsequent rockfalls).

Artefact scatters, isolated finds and/or PADs associated with these rock shelters could potentially be affected by rock falls. If impacts are considered likely based on monitoring, salvage activities should be considered based on site significance.

Further details and discussions on the potential impacts on the archaeological sites resulting from the extraction of Longwalls 104 to 105 are provided in the report by Niche Environment and Heritage (2020). Management of Aboriginal heritage sites will be outlined in the Heritage Management Plan.

10.2. European Heritage Site

There is one item of moderate local significance located near the south-western end of Longwall 105. The item is a dry stone wall that formed part of the Mudgee to Wollar road that ran via Moolarben. The item is known as Heritage Site No. 18 and is described in detail in a report by Heritas (2008) and has been subject to historical research archival recording. The location of the item is shown on Drawing No. MSEC1084-10.

The maximum predicted subsidence at the heritage site, after the extraction of Longwalls 104 to 105 for the Extraction Plan Layout is 2250 mm. The maximum predicted total tilt at the heritage site is 20 mm/m (i.e. 2 %), or a change in grade of 1 in 50. The maximum predicted conventional curvatures are greater than 3 km^{-1} hogging and sagging, which equate to minimum radii of curvature of 0.33 km.

At these magnitudes of tilt and curvature, the dry stone wall may experience impact resulting from the extraction of Longwall 105. Potential impacts at this site could include cracking and loose stones that may become dislodged during mining.

It is recommended that a detailed photographic record of the pre mining condition of the dry stone wall be prepared so that if cracking and any stones become dislodged during mining, they can be identified and remediated following the completion of mining. Impacts to the heritage site will be managed in accordance with the Moolarben Coal Complex Heritage Management Plan.

10.3. Items of Architectural Significance

There are no items of architectural significance within the Additional Assessment Area.

10.4. Survey Control Marks

There are two survey control marks (PM 86146 and Murragamba Trig Station) identified within the Additional Assessment Area. The locations of survey marks are shown in Drawing No. MSEC1084-10. Other survey marks are predominantly located along the Ulan-Wollar Road and Sandy Hollow – Gulgong Railway. The Murragamba Trig Station overlies Longwall 105.

10.4.1. Predictions for the Survey Marks

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the survey marks, resulting from the extraction of Longwalls 104 to 105 for the Extraction Plan Layout, is provided in Table 10.4. The predicted tilts provided in this table are the maxima after the completion of all the longwalls. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 10.4 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Survey Marks within the Study Area due to the Extraction of Longwalls 104 to 105

Site Type	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})
Murragamba Trig Station	1850	65	> 3	> 3
PM86146	1950	100	> 3	> 3

The maximum predicted conventional tilt for the survey marks is 100 mm/m (i.e. 10 %, or 1 in 10). The maximum predicted conventional curvatures for these sites are greater than 3 km^{-1} hogging and sagging, which represent minimum radii of curvature of less than 330 m.

The predicted strains for the survey marks ARE provided in Table 10.5. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis above solid coal provided in Section 4.4).

Table 10.5 Predicted Strains for the Survey marks based on Conventional and Non-Conventional Anomalous Movements

Type	Conventional based on 10 times Curvature (mm/m)	Non-conventional based on the 95 % Confidence Level (mm/m)	Non-conventional based on the 99 % Confidence Level (mm/m)
Tension	> 30	10	22
Compression	> 30	13	31

The survey marks will experience horizontal movements, which are discussed in Section 4.5. The survey marks located outside the Additional Assessment Area will also experience far-field horizontal movements which are discussed in Section 4.6.

10.4.2. Comparisons of the Predictions for the Survey Marks

Comparisons of the maximum predicted conventional subsidence parameters for the survey marks within the Additional Assessment Area, resulting from the extraction of Longwalls 104 to 105, with those based on the Approved Layout (LW101-105) are provided in Table 10.6.

Table 10.6 Comparison of Maximum Predicted Conventional Subsidence Parameters for the Survey Marks based on the Approved Layout and the Extraction Plan Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (101-105) (Report No. MSEC731)	1950	100	> 3	> 3
Extraction Plan Layout (Report No. MSEC1084)	1950	100	> 3	> 3

The maximum predicted subsidence parameters for the Survey marks, based on the Extraction Plan Layout, are the same as the maxima predicted based on the Approved Layout. The potential impacts for the survey marks based on the Extraction Plan Layout, therefore, are the same as those assessed based on the Approved Layout.

10.4.3. Impact Assessments and Recommendations for the Survey marks

The survey marks will experience changes to vertical and horizontal position as the longwalls are extracted. survey marks located outside the Additional Assessment Area will experience far-field horizontal movements.

It may be necessary on the completion of the longwalls, i.e. when the ground has stabilised, to re-establish the location of the survey marks. Consultation between MCO and Spatial Services NSW will be required throughout the mining period to ensure that the survey marks are not used for detailed surveying purposes by others and if required they are removed or reinstated at an appropriate time.

It is recommended that management strategies developed for the extraction of Longwalls 101 to 103 are updated to include Longwalls 104 and 105, in consultation with Spatial Services NSW, as required by the *Surveyor General's Directions No.11 Preservation of Survey Infrastructure*."

11.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE RESIDENTIAL BUILDING STRUCTURES

As listed in Table 2.1, the following residential features were not identified within the Additional Assessment Area nor in the immediate surrounds:

- Houses;
- Flats or Units;
- Caravan Parks;
- Retirement or aged care villages;
- Associated structures such as workshops, garages, water or gas tanks, tennis courts, and swimming pools.

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/km (km-1)*, but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *km (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.
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 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

APPENDIX D. TABLES

APPENDIX E. DRAWINGS