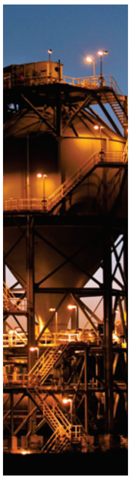
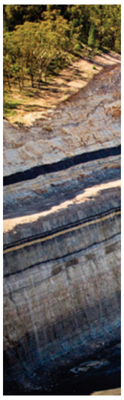
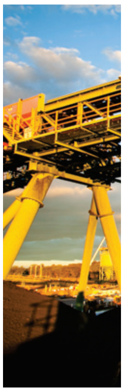






Moolarben Coal Complex
UG1 Optimisation Modification

Environmental Assessment

APPENDIX A

SUBSIDENCE ASSESSMENT

REPORT: SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

msec
mine subsidence
ENGINEERING CONSULTANTS

MOOLARBEN COAL

MOOLARBEN COAL COMPLEX:
Stage 2 of Moolarben Coal Project:
Revised Predictions of Subsidence Parameters and Revised Assessments of Subsidence Impacts resulting from the Proposed UG1 Mine Layout Optimisation Modification

© MSEC JUNE 2015 | REPORT NUMBER: MSEC731 | REVISION A

DOCUMENT REGISTER

Revision	Description	Author	Checker	Date
01	First Draft Issue	DRK		Nov 2014
02	Issued Report	DRK	JW	Dec 2014
A	Final Report	DRK	JW	June 2015

Report produced to:- Support the submission by Moolarben Coal Mines Pty Ltd to the Department of Planning and Environment (DP&E) to modify the approved mine layout plan within the UG1 Area of Stage 2 of the Moolarben Coal Project.

Previous Reports: MSEC353 Revision E, November 2011

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)

Moolarben Coal Operations (MCO) operates the Moolarben Coal Complex (MCC), which is located approximately 40 kilometres north east of Mudgee in New South Wales. 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, Open Cut 3 mine and Open Cut 4 mine), and three approved underground mines, (known as Underground Area 1 (UG1), Underground Area 2 and Underground Area 4) and the associated infrastructure.

While MCO commenced mining coal from OC1 in May 2010, no mining has commenced within the three approved underground coal mining operations within the MCC. Studies have been carried out by MCO to optimise the approved underground mine layouts by varying the positions and dimensions of the approved longwalls. A Modified Mine Layout (ModML) for the UG1 Optimisation Modification (the Modification) has been finalised, as is detailed below:

- Relocate the central main headings to the north-east of the proposed UG1 ModML longwalls so that there are now only five longwalls within the UG1 and the access to these five longwalls will be from the OC1 highwalls;
- Lengthen the longwall panels to the north-east by approximately 150 to 500 metres;
- Lengthen two of the longwall panels in the south-west by approximately 75 metres;
- Widen the longwall panel void width from 305 metres to 310.8 metres;
- Reduce the longwall chain pillar widths from 30 metres to 19.6 metres; and
- Increase the total coal seam extraction height by approximately 300 millimetres (mm) to a maximum extraction height of 3.5 metres.

The above modifications have resulted in increased subsidence predictions over these UG1 longwalls. MCO is therefore seeking approval under Section 75W of the *Environmental Planning and Assessment Act 1979* to modify the MCP (Stages 1 and 2) Project Approvals and adjust the mine layout and this report has been prepared to support that application.

The locations of the approved MCC open cut mines and underground mines, including the UG1, are shown in Drawing No. MSEC731-01, which together with all other drawings is included in Appendix E. It should be noted that the proposed UG1 longwalls will be surrounded by approved open cut areas. This regional drawing also shows the locations of the adjoining Ulan Coal Mine (UCM), the Wilpinjong Coal Mine, the Goulburn River National Park, the Munghorn Gap Nature Reserve and the Sandy Hollow Gulgong Railway Line.

MCO commissioned Mine Subsidence Engineering Consultants Pty Ltd (MSEC) in 2007 to prepare a detailed subsidence report to provide the necessary mine subsidence predictions and subsidence impact assessments for a Preferred Project Report for Stage 2 of the MCP, (see MSEC353 Revision E, dated November 2011). MSEC has been engaged to prepare this revised subsidence assessment report, MSEC731, to provide the necessary mine subsidence predictions and the subsidence impact assessments for the proposed ModML for the UG1 and to provide comparisons of the revised subsidence predictions and impact assessments for this ModML against the previously approved mine subsidence predictions and assessments for the PrefML.

The General Study Area has been defined, as a minimum, as the surface area enclosed by a 26.5 degree angle of draw line from the limit of proposed mining and by the predicted 20 mm subsidence contour resulting from the extraction of the proposed UG1 ModML longwalls. The extent of the General Study Area is shown in a solid black line in Drawing No. MSEC731-01. The extent of the UG1 Study Area has been defined as the General Study Area plus any additional areas that lie outside the General Study Area that may be subjected to valley related or far-field horizontal movements and could be sensitive to such movements. A number of natural features and items of surface infrastructure have been identified in the UG1 Study Area including critically endangered ecological communities, threatened species, cliffs and overhangs, archaeological sites, power lines, several tracks, and farm dams as is detailed in Chapter 2 of this report.

The approved underground mine plans for the PrefML were based on only extracting coal from the D Working Section (DWS) section of the Ulan Seam and the extracted seam thickness within the UG1 ranged from 2.7 metres to 3.2 metres. For the new ModML for this UG1 area, MCO now plan to extract coal from both the D Top (DTP) and the DWS of the Ulan Seam and, hence, the extracted seam thickness to be extracted within the UG1 now ranges from approximately 3.0 metres to 3.5 metres.

The maximum predicted total systematic subsidence due to the extraction of the proposed ModML for the UG1 Longwalls is 2380 mm at a location over Longwall 101 where the depth of cover is 130 metres and the proposed extracted seam thickness is 3.5 metres. This predicted maximum total subsidence represents 68% of the extracted seam thickness.

The maximum predicted total systematic subsidence for the approved PrefML was 1980 mm for a location where the depth of cover was 143 metres and the proposed extracted seam thickness was 3.2 metres, representing 62% of the proposed extracted seam thickness at that location.

The increase in the maximum predicted subsidence over UG1 for the ModML from the approved PrefML (1980 mm to 2380 mm or [20%]) is mostly a result of this increased extracted seam thickness, but, it is also influenced by the increased panel width to depth ratios, by the increased panel lengths, by the reduced pillar width to depth ratios and by adopting a more conservative prediction methodology.

The maximum predicted total systematic tilt over UG1 for the PrefML was 95 mm/m. The maximum predicted total systematic tilt over UG1 for the ModML is 115 mm/m and this value is expected near the tailgate of Longwall 102 where the depth of cover is around 50 metres.

The maximum predicted total systematic tensile and compressive strains over UG1 resulting from the extraction of the proposed longwalls in the approved PrefML and for the ModML, are both expected to be greater than 50 mm/m. The maximum predicted total systematic tensile and compressive strains are both expected to occur near the tailgate of Longwall 102.

The predicted levels of subsidence, tilt and strain that are expected to be experienced at the natural features and items of surface infrastructure, due to the proposed extraction of the longwalls of the ModML, vary across the UG1 depending on their positions in relation to the edges of the modified panel layout.

Hence there are some locations where reduced levels of subsidence, tilt and strain are now expected, but, generally slightly increased levels of predicted levels of subsidence, tilt and strain are expected after the extraction of the ModML compared to the predicted levels of subsidence, tilt and strain due to the PrefML.

This report is structured as follows:

Chapter 1	provides an introduction, outlines the Modification, presents the purpose of the report, and provides the base information on the mine layout, surface topography, seam and geological information.
Chapter 2	defines the UG1 Study Area for this report and provides a list of the natural features and items of surface infrastructure that have been identified within the UG1 Study Area.
Chapter 3	includes an overview of conventional and non-conventional subsidence movements and the methods that have been used to predict these movements resulting from the extraction of the proposed UG1 ModML longwalls.
Chapter 4	provides the maximum predicted subsidence parameters resulting from the extraction of the proposed UG1 ModML longwalls.
Chapters 5 and 6	provide the descriptions, predictions and impact assessments for each of the natural features and items of surface infrastructure that have been identified within the UG1 Study Area. Recommendations for monitoring and mitigation for each of these features are also provided.

The overall findings of the subsidence predictions and impact assessments that have been undertaken by MSEC for this report due to the proposed extraction of the ModML are that the levels of ground movements, impacts and damage to the identified natural features and built infrastructure are manageable and can be controlled by the preparation and implementation of Extraction Plans.

In accordance with Project Approvals (05_0117) and (08_0135), MCO is required to prepare an Extraction Plan to monitor and manage the effects of mine subsidence on these features. Some mitigation measures are recommended in order to mitigate or avoid the risk of serious consequences should impacts occur to some critical surface features.

Extraction Plans would be developed with the owners of infrastructure and are to be approved by relevant government agencies. It should also be noted that more detailed assessments on some natural features and items of surface infrastructure have been undertaken by other consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

CONTENTS

Tables

Tables that are presented within the body of the report are prefixed by the number of the chapter or the letter of the appendix in which they are presented.

Figures

The following figures are prefixed by the number of the chapter and section numbers or the letter of the appendix in which they are presented.

The following figures are presented in Appendix C at the end of this report.

Drawings

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

1.0 INTRODUCTION

1.1. Introduction

Moolarben Coal Operations (MCO) operates the Moolarben Coal Complex (MCC), which is located approximately 40 kilometres 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.

While MCO commenced mining coal from OC1 in May 2010, no mining has commenced within the three approved underground coal mining operations within the MCC. Studies have been carried out by MCO to optimise approved underground mine layouts by varying the positions and dimensions of the approved longwalls. A Modified Mine Layout (ModML) for the UG1 Optimisation Modification (the Modification) has been finalised. These UG1 modifications will result in changes to the predicted subsidence parameters over these longwalls and, hence, MCO will be seeking approval under Section 75W of the *Environmental Planning and Assessment Act 1979* to modify the MCP (Stages 1 and 2) Project Approvals and adjust the mine layout of UG1 and this report has been prepared to support that application.

The locations of the approved MCC open cut mines and underground mines, including the UG1, are shown in Drawing No. MSEC731-01, which together with all other drawings is included in Appendix E. It should be noted that the proposed UG1 longwalls will be surrounded by the approved open cut areas. This regional drawing also shows the locations of the adjoining Ulan Coal Mine (UCM), Wilpinjong Coal Mine, Goulburn River National Park, Munghorn Gap Nature Reserve and Sandy Hollow Gulgong Railway Line.

MCO commissioned Mine Subsidence Engineering Consultants Pty Ltd (MSEC) in 2007 to prepare a detailed subsidence report to provide the necessary mine subsidence predictions and subsidence impact assessments for a Preferred Project Report for Stage 2 of the MCP (see MSEC353 Revision E, dated November 2011). MSEC has been engaged to prepare this revised subsidence assessment report, MSEC731, to provide the necessary mine subsidence predictions and the subsidence impact assessments for the proposed ModML for the UG1 and to provide comparisons of these revised ground movement and impact assessments for this ModML against the previously approved mine subsidence predictions and assessments for the PrefML.

1.2. Proposed Modification

MCO now plan to extract coal from five longwalls within the UG1 instead of nine longwalls as shown in Drawing No. MSEC731-01 and Drawing No. MSEC731-02. MCO still plan to extract coal from the lower working sections of the Ulan seam, however, as detailed below, the panels are proposed to be lengthened, the panels widths are proposed to be increased by 5.8 metres, the pillar widths are proposed to be reduced by 10.4 metres and a slightly thicker working section within the Ulan seam is to be extracted.

The overall void widths of the nine approved UG1 longwall panels within the approved PrefML were 305 metres and the solid widths of the chain pillars were 30 metres. The lengths of the then proposed longwall panels in UG1 varied from 1695 metres to 2345 metres. The cover within UG1 varied from 47 metres to 165 metres.

The modified overall void widths of the five proposed UG1 longwall panels within the proposed ModML are to be 310.8 metres and the solid widths of the chain pillars were 19.6 metres. The lengths of the longwall panels in UG1 now vary from 2630 metres to 4561 metres. The cover within this revised UG1 still varies from 47 metres to 165 metres.

The complete Ulan Seam comprises numerous coal plies separated by partings of tuffaceous claystone and carbonaceous shale. The available seam thickness of the complete Ulan Seam ranges, within UG1, from around 6 m to 13 m. While this complete seam is amenable to full recovery within the open cut mines, the D working section (DWS), which lies in the lower half of the seam, is the most amenable to underground mining.

The approved underground mine plans for the PrefML for UG1 were based on only extracting coal from the DWS section of the Ulan Seam and the proposed seam thickness to be extracted within UG1 ranged from 2.7 metres to 3.2 metres. For the new ModML for UG1, MCO now plan to extract coal from both the D Top (DTP) and the DWS of the Ulan Seam and, hence, the revised seam thickness to be extracted within UG1 now ranges from approximately 3.0 metres to 3.5 metres. This slight increase in the extracted seam thickness of approximately 0.3 metres and the slight changes to the longwall panel widths and chain pillar widths will result in increased subsidence over UG1.

Chapter 2 of this report describes the natural features and items of surface infrastructure that have been identified in the vicinity of the proposed longwall. The proposed five longwalls and the new UG1 Study Area, which is defined in Section 2.1, have been overlaid on an orthophoto and topographic map of the area, which are shown in Fig. 1.1 and Fig. 1.2 respectively. The major natural features and items of surface infrastructure within the UG1 Study Area can be seen in these figures.

As can be seen in Drawing No. MSEC731-01 and the figures below, barriers of unmined coal have still been provided to protect various surface infrastructure and natural features from the effects of mine subsidence in a manner that is consistent with previously approved projects in this region.

A barrier has been proposed against the Gulgong to Sandy Hollow Railway and Ulan-Wollar Road, which are located to the north and east of the proposed longwall panels. Extraction Plans would be prepared to monitor and manage the effects of mine subsidence on these (and other natural and built) features.

Chapter 3 includes a brief overview of longwall mining, the development of mine subsidence and the method that has been used to predict the mine subsidence movements resulting from the extraction of the proposed UG1 ModML longwalls.

Chapter 4 provides a general overview of the maximum predicted systematic subsidence parameters resulting from the extraction of the proposed UG1 ModML longwalls.

Chapter 5 provides the site-specific predicted subsidence parameters for each natural feature and item of surface infrastructure described in Chapter 2. The impact assessments and recommendations for each of these features have been made based on the predicted subsidence parameters.

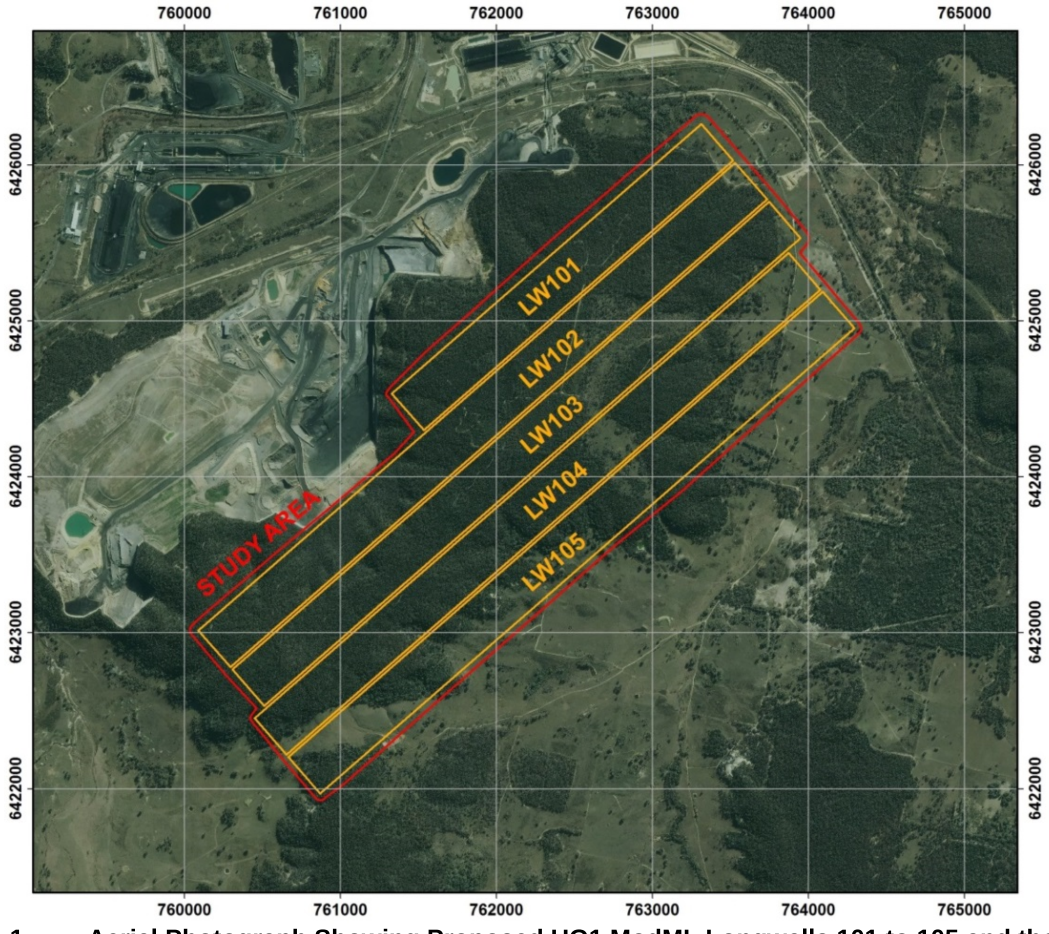


Fig. 1.1 Aerial Photograph Showing Proposed UG1 ModML Longwalls 101 to 105 and the UG1 Study Area

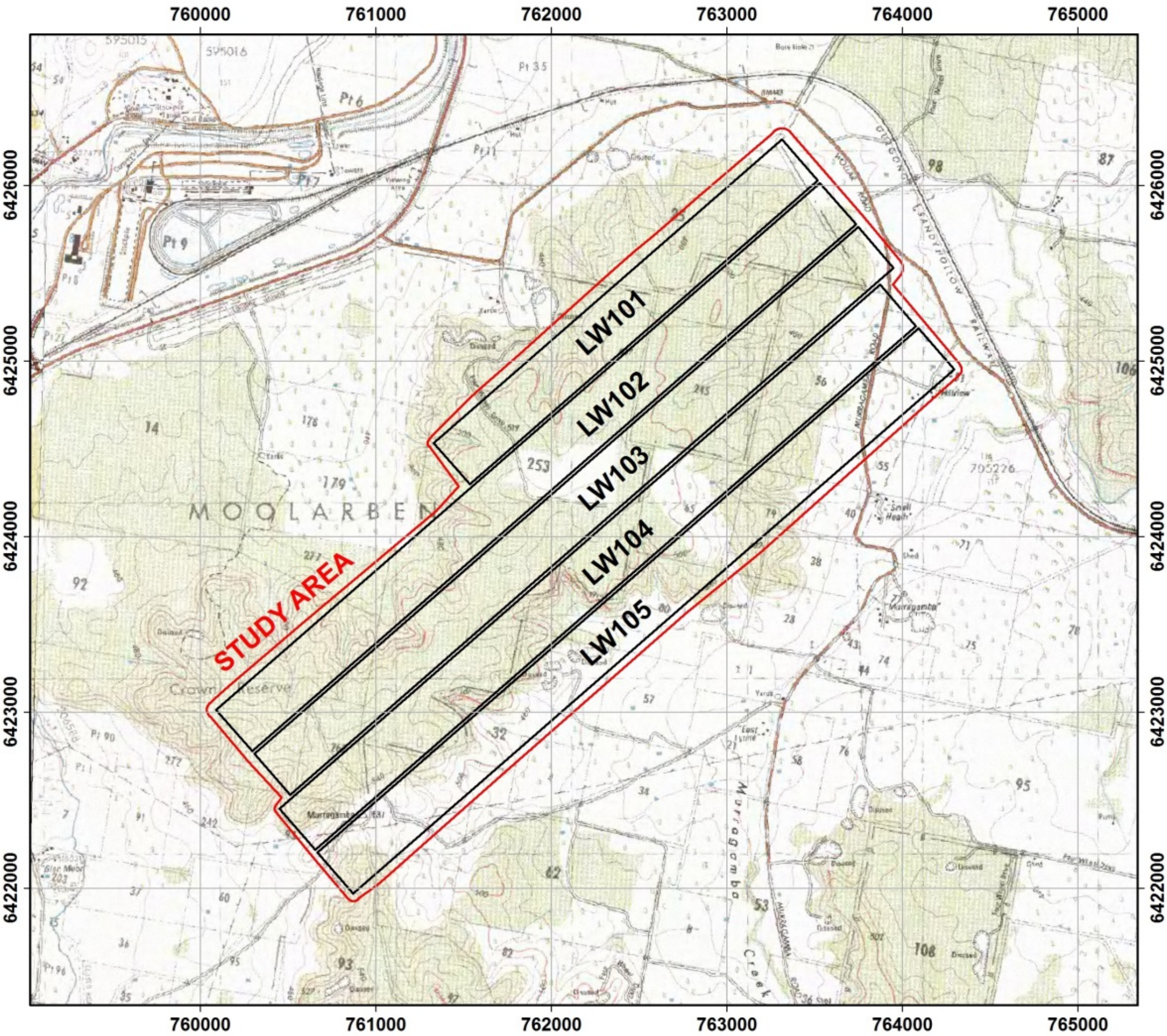


Fig. 1.2 Topographic Map Showing Proposed UG1 ModML Longwalls 101 to 105 and the UG1 Study Area

1.3. Mining Geometry

The proposed UG1 ModML of Longwalls 101 to 105 is shown in the attached Drawing No. MSEC731-01 to MSEC731-02 and a summary of the proposed longwall dimensions is provided in Table 1.1.

Table 1.1 Proposed Longwall Dimensions within the UG1 Study Area

Longwall Number	Total Void Width (m)	Width of Pillar Preceding Longwall Maingate (m)	Overall Longwall Length (m)
LW101	310.8	19.6	2630
LW102	310.8	19.6	4561
LW103	310.8	19.6	4561
LW104	310.8	19.6	4540
LW105	310.8	19.6	4540

The proposed UG1 ModML longwalls are surrounded to a large extent by the approved open cut mine areas and the entry to these longwalls will be accessed from the approved OC1 highwalls. The depth of cover to the Ulan Seam above these longwalls varies between a minimum of about 47 metres over the proposed Longwall 102, and a maximum of 165 metres over the proposed Longwall 102. The seam floor generally dips from the south-west down to the north-east over the entire mining area.

The surface level contours, DWS seam floor contours, DWS plus DTP seam thickness contours, the DTP Seam Roof and the overburden depth contours to the DTP Seam Roof are shown in Drawings Nos. MSEC731-03 to MSEC731-07. The depth of cover has also been presented on Drawings No. MSEC731-08 and MSEC731-09 in three zones, of less than 50 metres, 50 to 100 metres and greater than 100 m.

1.4. Geological Details

The surface geological features in the vicinity of the UG1 are shown in Fig 1.3.

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.

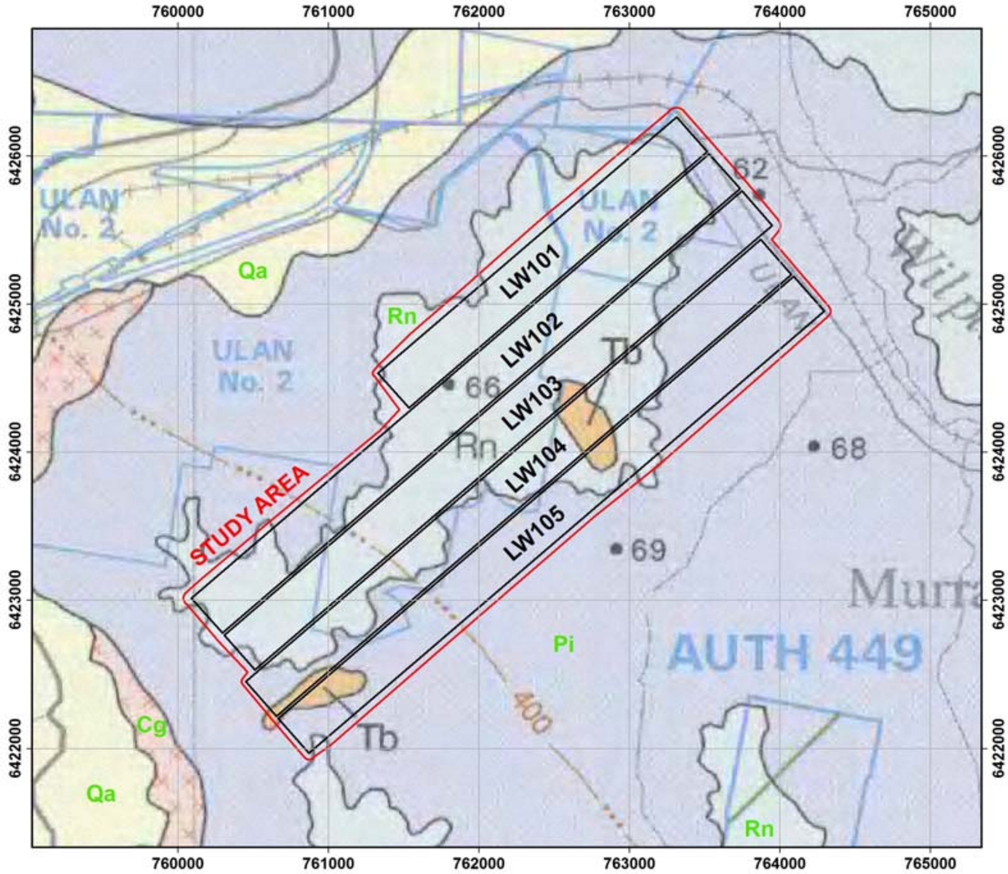


Fig. 1.3 Surface Geological Map Showing the Proposed UG1 ModML Longwalls 101 to 105 and the UG1 Study Area (Source-1:100000 Western Coalfield Map)

As can be seen in this figure the surface geology 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 geology around the longwalls are from the Illawarra Coal Measures (Pi). Other surface geological units that are shown in this figure, but are not within the General Study Area are areas of Alluvials (Qa) and Granite (Cg).

A typical stratigraphic section for the UG1 Study Area, which was provided by Minerva Geological Services Pty Ltd, is shown in Fig. 1.4. A discussion of the geological units is provided below in Section 1.4.1.

1.4.1. Lithology

The major geological units in the UG1 Study 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 UG1 Study Area, known as basalt caps, is shown on Fig. 1.3. These basalt caps provide soils that are suited to the endangered ecological community the *White Box Yellow Box Blakely's Redgum Woodland and derived Native Grasslands.* Approximate locations of these communities are shown on Drawing No. MSEC731-08.

Tertiary alluvial palaeochannel deposits, with a maximum thickness of 40-50 m, have been identified and described in HydroSimulations (2015) to the north and east of the proposed UG1 longwalls, as shown in Drawing No. MSEC731-07. 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 UG1 Study Area. Where present, the sandstones are between 14 metres and 70 metres thick with both massive and strongly cross-bedded units of individual thickness in the range of 1.5 metres to 3 metres.

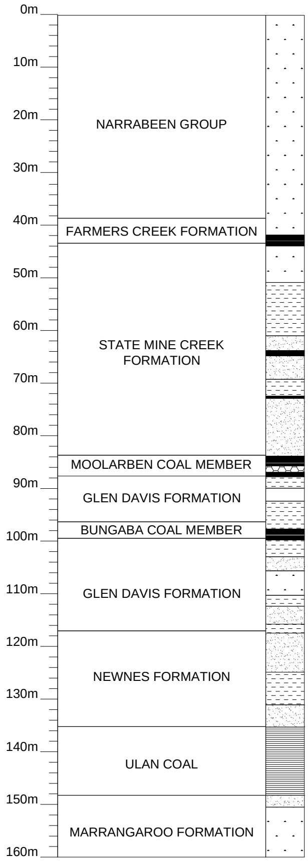


Fig. 1.4 Stratigraphic Column (based on WMLB117)

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 degrees to the northeast. A brief description of each formation, provided in Minerva Geological Services, (February 2007), is as follows;

- Farmers Creek Formation: between 6 metres to 10 metres of siltstone, sandstone, and white cherty claystone;
- State Mine Creek Formation: up to 30 metres of interbedded sandstone, siltstone and claystone. The Moolarben Coal Member occurs at the base of the State Mine Creek Formation and is between 2 metres and 4 metres 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 metres thick, consisting of stony coal and claystone;
- Cockabutta Creek Sandstone Member: up to 9 metres of predominantly medium to very coarse-grained quartzose sandstone, similar to the Marrangaroo Conglomerate;
- Newnes and Glen Davis Formations: up to 20 metres 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 metres to 15 metres 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 metres and 6 metres 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. The UG1 Study Area

The UG1 Study Areas 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 UG1 Study Area has been calculated by combining the areas bounded by the following limits:-

- The 26.5 degree angle of draw line,
- The predicted vertical limit of subsidence, taken as the 20 mm subsidence contour, and
- Features sensitive to far-field movements.

As the depth of cover above the proposed longwall varies between 35 and 165 metres, the 26.5 degree angle of draw line has been conservatively determined by drawing a line around the outer edge of the proposed longwall voids at a horizontal distance that varies between 18 and 88 metres.

The predicted limit of vertical subsidence has been taken as the predicted incremental 20 mm subsidence contour as determined using the Incremental Profile Method, which is described in further detail 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'.

A thick black line has been drawn, therefore, defining the UG1 Study Area, and it was based upon the combined 26.5 degree angle of draw line and the 20 mm subsidence contour line, whichever was furthest from the proposed UG1 ModML longwalls, and this line is shown in Drawing No. MSEC731-01. The predicted incremental 20 mm subsidence contour line resulting from the extraction of proposed UG1 ModML Longwalls 101 to 105 was found to be located entirely within the area bounded by the 26.5 degree angle of draw line.

There are additional areas that lie outside the UG1 Study Area that are expected to experience either far-field movements, or valley related upsidence and closure 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 the UG1 Study Area.

- Gulgong to Sandy Hollow Railway Line;
- Survey Control Marks; and
- Highwalls of the proposed open cut mines and the underground mine entries from these highwalls.

2.2. General Description of the Natural Features and Items of Surface Infrastructure

The major natural features and items of surface infrastructure within the UG1 Study Area can be seen in the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA), Sheet Number 8833-2-N, an extract of which is included above as Fig. 1.2. The following sections in this chapter identify and describe all of the major natural features and items of surface infrastructure that lie within the UG1 Study Area. The natural features and items of surface infrastructure, which are further defined in specific studies, are illustrated in Drawings Nos. MSEC731-08 to MSEC731-12.

Table 2.1 lists the types of natural features and surface improvements that have been identified within the UG1 Study Area and indicates the sections of this report that provide further descriptions and details of these features. This list follows the format of the list included in Appendix B of the Division of Resources and Energy's Subsidence Management Plan Guideline 2003. Further details of areas of environmental sensitivity, are provided in subsequent sections of this report.

Table 2.1 Natural Features and Surface Improvements within the UG1 Study Area

Item	Within Study Area	Environmentally Sensitive Area	Section Number Reference
NATURAL FEATURES			
Catchment Areas or Declared Special Areas			
Rivers or Creeks			
Aquifers or Known Groundwater Resources	✓		2.3.3
Springs			
Sea or Lakes			
Shorelines			
Natural Dams			
Cliffs or Pagodas	✓	✓	2.3.8
Steep Slopes	✓		2.3.9
Escarpments			
Land Prone to Flooding or Inundation			
Swamps, Wetlands or Water Related Ecosystems			
Threatened, Protected Species or Critical Habitats	✓		2.3.13
National Parks or Wilderness Areas			
State Recreational or Conservation Areas			
State Forests			
Natural Vegetation	✓		2.3.17
Areas of Significant Geological Interest			
Any Other Natural Feature Considered Significant			
PUBLIC UTILITIES			
Railways	✓		2.4.1
Roads (All Types)	✓		2.4.2
Bridges			
Tunnels			
Culverts	✓		2.4.1
Water, Gas or Sewerage Pipelines	✓		2.4.6
Liquid Fuel Pipelines			
Electricity Transmission Lines or Associated Plants	✓		2.4.7
Telecommunication Lines or Associated Plants	✓		2.4.8
Water Tanks, Water or Sewage Treatment Works			
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	Environmentally Sensitive Area	Section Number Reference
FARM LAND AND FACILITIES			
Agricultural Utilisation, Agricultural Improvements or Agricultural Suitability of Farm Land			
Farm Buildings or Sheds			
Gas or Fuel Storages			
Poultry Sheds			
Glass Houses or Green Houses			
Hydroponic Systems			
Irrigation Systems			
Fences	✓		2.6.4
Farm Dams	✓		2.6.5
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 and Associated Plants			
Buildings, Equipment or Operations that are Sensitive to Surface Movements			
Surface Mining (Open Cut) Voids and Rehabilitated Areas			
Mine Infrastructure Including Tailings Dams or Emplacement Areas	✓		2.7
Any Other Industrial, Commercial or Business Features			
AREAS OF ARCHAEOLOGICAL OR HERITAGE SIGNIFICANCE	✓		2.8 and 2.9
ITEMS OF ARCHITECTURAL SIGNIFICANCE			
PERMANENT SURVEY CONTROL MARKS	✓		2.11
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			

2.3. Natural Features

2.3.1. Drinking Water Catchment Areas or Declared Special Areas

There are no drinking water catchment areas or declared special areas within the UG1 Study Area.

2.3.2. Rivers or Creeks

There are no rivers or creeks within the UG1 Study Area.

The nearest river is the Goulburn River, which is located at least 1.5 kilometres north west of the proposed UG1 ModML longwalls. Murragamba Creek is located approximately 300 metres to the south east of proposed Longwall 5.

A number of other small drainage lines have been identified within the UG1 Study Area, as shown in Drawing No. MSEC731-08.

It should be noted that open cut areas surround a majority of the proposed UG1 and a high proportion of the surface flows from the UG1 Study Area will either be diverted around or flow into the open cut areas. The position of some of these small drainage lines may change as a result of clearing and placement of open cut fill in this area.

2.3.3. Aquifers and Known Ground Water Resources

The aquifers and groundwater resources within the vicinity of the UG1 have been investigated and are described in the report by HydroSimulations (2015). The proposed UG1 ModML longwalls do not pass beneath any water bearing palaeochannel sediments (HydroSimulations, 2015).

2.3.4. Springs

No natural springs have been identified within the UG1 Study Area.

Groundwater resources within the UG1 Study Area are described in the report by HydroSimulations (2015).

2.3.5. Seas or Lakes

There are no seas or lakes within the UG1 Study Area.

2.3.6. Shorelines

There are no shorelines within the UG1 Study Area.

2.3.7. Natural Dams

There are no natural dams within the UG1 Study Area.

2.3.8. Cliffs and Natural Rock Formations

Other mine subsidence assessment reports have adopted a minimum cliff height of 20 metres because only those cliffs could be seen above the general heights of trees within those study areas. However, there are no cliffs with heights greater than 20 metres within the UG1 Study Area.

Therefore, only for the purposes of this report, a cliff has been defined as a continuous rockface having a minimum height of 10 metres and a minimum slope of 2 to 1, i.e. having a minimum angle to the horizontal of 63°. The locations of the cliffs were determined from site inspections and from the 2 metre surface contours of the area.

The locations of cliffs identified within the UG1 Study Area are shown in Drawing No. MSEC731-09 as presented within Appendix E. The cliffs and overhangs have formed from sandstone. Details of the cliffs and overhangs are provided in Table 2.2.

Table 2.2 Details of the Cliffs identified within the UG1 Study Area

ID	Approximate Overall Length (m)	Approximate Maximum Height (m)	Approximate Maximum Overhang (m)
C1	20	10	0
C2	20	15	0
C3	20	12	4
C4	20	15	5
C5	20	15	0
C6	20	10	0

The cliffs have been defined as an area of potential environmental sensitivity for the purposes of this report.

A typical photograph of one of these small cliffs are provided in Fig. 2.1. Cliffs C2, C3 and C4 will be covered by the out-of-pit emplacement. There are also a number of overhangs and smaller cliffs, which have been called rock ledges in this report. The overhangs and rock ledges are located across the UG1 Study Area.

Fig. 2.1 Photograph of Cliff C5

2.3.9. Steep Slopes

A number of natural steep slopes have been identified within the UG1 Study Area. The reason for identifying the steep slopes is to highlight areas where existing ground slopes may be marginally unstable. For the purposes of this report, a natural steep slope has been defined as an area of land having a natural gradient between 1 in 3 (i.e. a grade of 33 %, or an angle to the horizontal of 18°) and 2 in 1 (i.e. a grade of 200 %, or an angle to the horizontal of 63°).

The maximum slope of 2 to 1 represents the threshold adopted for defining a cliff. The minimum slope of 1 to 3 represents a slope that would generally be considered stable for slopes consisting of rocky soils or loose rock fragments. These natural steep slopes were identified from the surface level contours that were generated from the two metre surface contours of the area, and the locations of these steep slopes have been shown in Drawing No. MSEC731-09. The steep slopes located directly above the UG1 typically have natural grades of up to 1 in 1, or a maximum angle to the horizontal of 45°.

The surface soils above the UG1 generally consist of soils derived from sandstone, in varying stages of weathering and fracturing. The stability of these natural slopes varies depending on their soil or rock types, and in many cases, natural slopes can be stable at much higher gradients than 1 to 3, for example talus slopes in sandstone. The majority of these existing natural slopes have been stabilised, to some extent, by trees and other natural vegetation. Some steep slopes are located within the footprint of the proposed out-of-pit emplacement area as shown on Drawing No. MSEC731-09 and these will therefore be covered before the extraction of the proposed UG1 ModML longwalls.

2.3.10. Escarpments

There are no escarpments within or near the UG1 Study Area.

2.3.11. Land Prone to Flooding or Inundation

There are no major natural flood prone areas identified within the UG1 Study Area.

2.3.12. Wetlands and Swamps

There are no swamps or wetlands within the UG1 Study Area.

2.3.13. Threatened, Protected Species or Critical Habitats

There are vegetation communities, known as White Box Yellow Box Blakely's Redgum Woodland and Derived Native Grasslands and Central Hunter Grey Box – Ironbark Woodland in the NSW North Coast and Sydney Basin Bioregions, which occur within the UG1 Study Area and these ecological communities have been listed as Critically Endangered Ecological Communities (EECs) under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The occurrence of the White Box Yellow Box Blakely's Redgum Woodland and Derived Native Grasslands EEC appears to be related to the isolated tertiary basalt deposits above UG1 as shown on Drawing No. MSEC731-08.

There is known and potential habitat for a number of threatened fauna species within the UG1 Study Area, including microbats.

A discussion on flora and fauna within the UG1 Study Area, including the two threatened bat species and the EECs, is included in a report by Ecovision Consulting and Marine Pollution Research (2008) and Ecological Australia (2015).

2.3.14. National Parks or Wilderness Areas

There are no National Parks or any land identified as wilderness under the *Wilderness Act 1987* within the UG1 Study Area.

The nearest edge of the Goulburn River National Park is more than 1000 metres from the UG1 Study Area and the nearest edge of the Munghorn Gap Nature Reserve is located more than 1000 metres from the UG1 Study Area.

2.3.15. State Recreation Areas and State Conservation Areas

There are no State Recreation Areas or State Conservation Areas within the UG1 Study Area.

2.3.16. State Forests

There are no State Forests within the UG1 Study Area.

2.3.17. Natural Vegetation

The vegetation within the UG1 Study Area generally consists of disturbed land and undisturbed native bush. A detailed survey of the natural vegetation has been undertaken and is described in a report by Ecovision Consulting and Marine Pollution Research (2008).

2.3.18. Areas of Significant Geological Interest

There are no areas of significant geological interest within the UG1 Study Area. A brief description of the geology within the UG1 Study Area is provided in Section 1.4. A detailed description of the geology within the UG1 Study Area is provided in a report by Minerva Geological Services (2007).

2.3.19. Any Other Natural Feature Considered Significant

There are no other significant natural features within the UG1 Study Area.

2.4. Public Utilities

2.4.1. Railways

There are no railways within the UG1 Study Area, however, as shown in shown in Drawing No. MSEC731-10, the Gulgong to Sandy Hollow Railway is located to the north east of the UG1 Study Area.

The nearest edge of the proposed Longwall 105 to the Railway line is approximately 255 metres.

The nearest edge of the proposed Longwall 104 to the Railway line is approximately 345 metres.

The nearest edge of the proposed Longwall 103 to the Railway line is approximately 315 metres.

The nearest edge of the proposed Longwall 102 to the Railway line is approximately 400 metres.

The nearest edge of the proposed Longwall 101 to the Railway line is approximately 365 metres.

At these locations the rail track will not be subjected to measurable systematic mine subsidence ground movements; however, it may experience small far field horizontal movements and the Gulgong to Sandy Hollow Railway has therefore been included in the assessment.

2.4.2. Roads

The locations of the roads, fire trails and four wheel drive tracks within and adjacent to the UG1 Study Area are shown in Drawing No. MSEC731-10.

There is one sealed public road located near the north west side of the UG1 Study Area, the Ulan-Wollar Road. A section of this road has already been upgraded and moved from its previous location to be immediately adjacent to the Gulgong to Sandy Hollow Railway.

There is one unsealed public road that passes through the UG1 Study Area. Murragamba Road passes over the north east part of the UG1 Study Area over proposed UG1 ModML Longwalls 104 and 105. However this road will not be used after the OC4 is developed, which is currently planned to commence before Longwalls 104 to 105 are to be extracted.

All other roads within the UG1 Study Area are unsealed access roads and are inaccessible to the public.

MCO proposes to construct a new haul road to connect the OC1 with the OC4. This haul road crosses over Longwalls 102 to 105.

2.4.3. Bridges

There are no bridges within the UG1 Study Area.

2.4.4. Tunnels

There are no tunnels within the UG1 Study Area.

2.4.5. Drainage Culverts

No drainage culverts were identified within the UG1 Study Area; however, drainage culverts are located along the Gulgong to Sandy Hollow Railway, the largest of which is at the Murragamba Creek crossing.

At this location the rail track and culverts will not be subjected to measurable systematic mine subsidence ground movements; however, they may experience small far field horizontal movements and the Gulgong to Sandy Hollow Railway and culverts have therefore been included in the assessment.

2.4.6. Water, Gas or Sewer Pipelines

There is no public water infrastructure within the UG1 Study Area.

There are no public sewage pipelines or sewage treatment works within the UG1 Study Area. However, disused septic tanks and disposal areas may be present at the locations where houses have been removed.

There are no gas or fuel pipelines within the UG1 Study Area.

2.4.7. Electrical Services

The low voltage powerlines that were within the UG1 Study Area have been decommissioned as shown in Drawing No. MSEC731-11.

There is a 66kV powerline located along the Ulan-Wollar Road with three poles just located within the UG1 Study Area, and outside the finish of Longwall 103. The nearest pole is labelled CE70548 and it is within 30 metres of the finishing end of Longwall 103, where the depth of cover to the Ulan Seam is 110 metres.

There is a new 330kV transmission line located just outside the north eastern ends of the UG1 Study Area. There is one tension tower located 550 metres to the north east of the northern corner Longwall 101. The nearest suspension tower is located approximately 300 metres to the north of the northern corner Longwall 101 and four other suspension towers are located up to 750 metres to the north east of the north eastern corner Longwall 105.

2.4.8. Telecommunications Services

The main underground copper cables within the UG1 Study Area are located along Murragamba Road. However, this cable is no longer in service.

There is an optical fibre cable located along the northern side of Ulan-Wollar Road and the closest point of the cable to the UG1 is approximately 240 metres to the north east of Longwall 105.

2.4.9. Dams, Reservoirs and Associated Works

There are no dams located within the general UG1 Study Area.

2.4.10. Any Other Public Utilities

There are no other public utilities within the UG1 Study Area.

2.5. Public Amenities

There are no public amenities within the UG1 Study Area.

2.6. Farm Land or Facilities

2.6.1. On Site Waste Water Systems

Two demolished residences on the properties within the UG1 Study Area are likely to have had on-site waste water systems.

2.6.2. Rural Building Structures

There are no rural building structures within the UG1 Study Area.

2.6.3. Tanks

There are no tanks within the UG1 Study Area.

2.6.4. Fences

There are a number of fences within the UG1 Study Area which are constructed in a variety of ways, generally using either timber or metal materials. The fences are located across the UG1 Study Area.

2.6.5. Farm Dams

There are 13 small farm dams (Structure Type D) that have been identified within the UG1 Study Area. The locations of the dams are shown in Drawings No. MSEC731-11.

2.6.6. Wells or Bores

Other than project specific bores there are no registered wells or water bores within the UG1 Study Area.

2.7. Industrial, Commercial and Business Establishments

2.7.1. Factories

There are no factories within the UG1 Study Area.

2.7.2. Workshops

There are no workshops within the UG1 Study Area.

2.7.3. Business or Commercial Establishments or Improvements

There are no businesses, commercial establishments or improvements within the UG1 Study Area.

2.7.4. Gas or Fuel Storages and Associated Plant

There are no known gas or fuel storages or associated plant within the UG1 Study Area.

2.7.5. Waste Storages and Associated Plant

There are no waste storages or associated plant within the UG1 Study Area.

2.7.6. Buildings, Equipment or Operations that are Sensitive to Surface Movements

There are no known buildings, equipment or operations that are sensitive to surface movements within the UG1 Study Area.

2.7.7. Surface Mining (Open Cut) Voids and Rehabilitated Areas

The approved open cut mining areas are located to the north, west, south and east of the proposed UG1 areas, i.e. OC1, OC2 and OC4, as shown in Drawing No. MSEC731-01.

2.7.8. Mine Infrastructure Including Tailings Dams or Emplacement Areas

Some of the overburden materials from the OC4 Pit are proposed to be stockpiled in an approved out-of-pit emplacement area that will be located above portions of proposed UG1 Longwalls 103 to 105. The location of this approved out-of-pit emplacement area is shown in Drawing No. MSEC731-01.

Other mine infrastructure above UG1 includes Stage 2 ROM coal facilities, which are located at the south western end of Longwall 105, conveyors between Stage 2 ROM coal facilities and Stage 1 ROM coal facilities and the proposed new haul road to connect the OC1 with the OC4.

2.7.9. Any Other Industrial, Commercial or Business Features

There are no other industrial, commercial or businesses within the general UG1 Study Area.

2.8. Items of Archaeological Significance

There are approximately 24 archaeological sites (identified in both Stage 1 and Stage 2 archaeological assessments and including subsequent 2014 survey) that have been identified within the UG1 Study Area which comprise isolated finds, artefact scatters or potential archaeological deposits. The locations of the archaeological sites within the UG1 Study Area are shown in Drawing No. MSEC731-12.

Detailed descriptions of the archaeological sites are provided in the report by Niche Environment and Heritage (2015).

2.9. Items of Historical or Heritage Significance

There is one item of moderate local significance located near the south-western end of the proposed 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). The location of the item is shown on Drawing No. MSEC731-12.

2.10. Items of Architectural Significance

There are no items of architectural significance within the UG1 Study Area.

2.11. Permanent Survey Control Marks

There is one survey mark, known as Murragamba Trig Station, included in the UG1 Study Area (MGA coordinates E 760942.064, N 6422386.932, i.e. near the south-western end of the proposed Longwall 105. The location of the survey control mark is shown in Drawing No. MSEC731-11.

2.12. Residential Establishments

2.12.1. Houses

There are no houses within the UG1 Study Area.

2.12.2. Swimming Pools

There are no swimming pools located within the UG1 Study Area.

2.12.3. Flats or Units

There are no flats or units within the UG1 Study Area.

2.12.4. Caravan Parks

There are no caravan parks within the UG1 Study Area.

2.12.5. Retirement or Aged Care Villages

There are no retirement or aged care villages within the UG1 Study Area.

2.12.6. Any Other Associated Structures

There are no other associated structures within the UG1 Study Area.

2.12.7. Any Other Residential Feature

There are no other major residential features within the UG1 Study Area.

2.13. Any Other Items

There are no other major items within the UG1 Study Area.

3.1. Introduction

This chapter provides a brief overview of longwall mining, the development of mine subsidence and the method that has been used to predict the mine subsidence movements resulting from the extraction of the proposed UG1 ModML longwalls. More detailed descriptions of longwall mining and the development of subsidence are provided in a document titled “Introduction to Longwall Mining and Subsidence” which can be downloaded from the MSEC website at http://www.minesubsidence.com. Detailed descriptions of methods used to predict mine subsidence movements are provided in a document titled “General Discussion of Mine Subsidence Ground Movements” which can also be downloaded from the same website.

3.2. Overview of Longwall Mining

The coal within the UG1 area will be extracted using longwall mining techniques. A cross-section along the length of a typical longwall at the coal face is shown in Fig. 3.1.

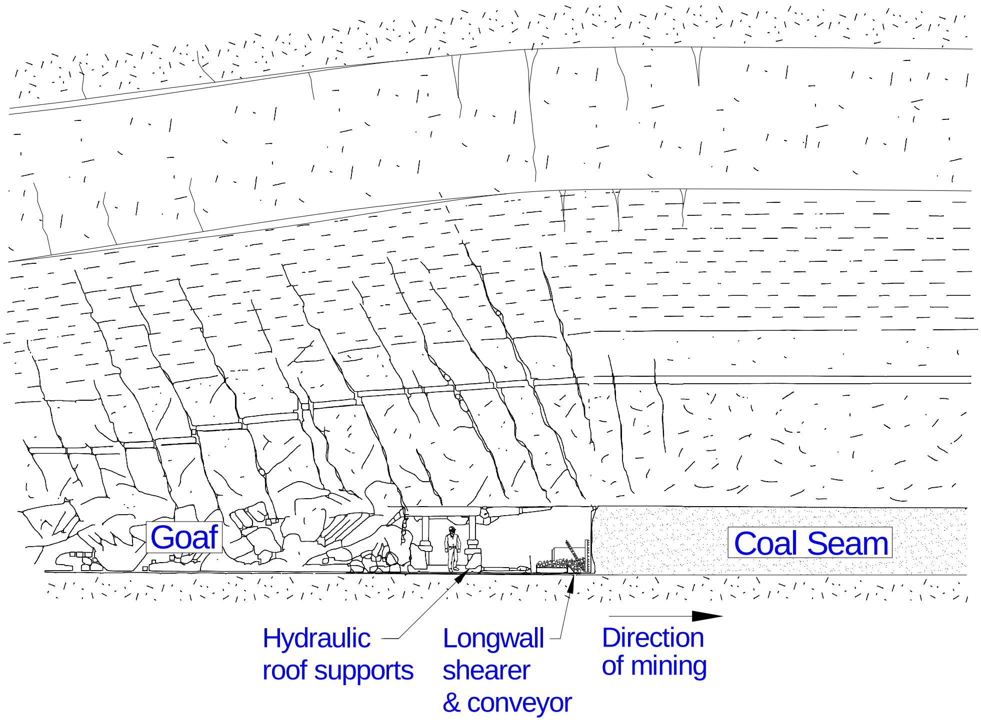


Fig. 3.1 Cross-section along the Length of a Typical Longwall at the Coal Face

The coal is removed by a shearer that cuts the coal from the coal face on each pass as it traverses the width of the longwall. The roof at the coal face is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata, and provides a working space at the coal face. The coal is then transported by a face conveyor belt which is located behind the shearer. As the coal is removed from each section of the coal face, the hydraulic supports are stepped forward, and the coal face progresses (retreats) along the length of the longwall.

The strata directly behind the hydraulic supports and immediately above the extracted coal seam, is allowed to collapse into the void that is left as the coal face retreats. The collapsed zone comprises of loose blocks and can contain large voids. Immediately above the collapsed zone, the strata remains relatively intact and bends into the void, resulting in new vertical factures, opening up of existing vertical fractures, and bed separation. The amount of strata sagging, fracturing, and bed separation reduces towards the surface.

At the surface, the ground subsides vertically and also moves horizontally towards the centre of the mined goaf area. The maximum subsidence at the surface varies depending on many factors including longwall geometry, depth of cover, extracted seam thickness, and geology. Based on observed data it is generally accepted that the maximum achievable subsidence in the Hunter and Western Coalfields is typically between 60 to 65 % of the extracted seam thickness, especially if there are no strong sandstone or conglomerate strata layers within the overburden that could limit the observed subsidence levels.

3.3. Overview of Systematic Subsidence Movements

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

- **Subsidence** usually refers to vertical movement of a point, but the generalised term "subsidence of the ground" can be meant to include both vertical and horizontal movement. Subsidence is usually defined as the vertical component of mining induced movement and is calculated as the difference in level of a point before and after mining. The vertical components of subsidence are usually greater than the horizontal movements, although, in some cases beyond the edges of the mined panel, where the subsidence is small, horizontal movements can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.
- **Horizontal Displacements,** unlike mining induced vertical subsidence, which has a magnitude only, horizontal displacements have both a magnitude and a direction, i.e. they are a vector. Early researchers generally only measured and predicted vertical subsidence and distances between ground survey pegs (to determine ground strains) but they rarely measured or predicted the absolute horizontal displacements of these points. These early researchers noticed similarities between the observed tilt and horizontal movement profiles and usually predicted maximum horizontal movements linearly from predicted tilts. Now it is recognised that other components of the observed horizontal movements are caused by various factors that are not related to tilt, i.e. by the release of in situ compressive horizontal stresses in the strata layers around the goafed areas above a mined panel and other strata mechanisms that are also not associated with tilt.
  Horizontal displacements and **far field horizontal movements** are discussed in Section 3.8. Subsidence and horizontal movements are usually expressed in units of *millimetres (mm)*.
- **Tilt** is the change in ground slope due to differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 % or 1 in 1000.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres (1/km)*, but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.
- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*.
  Tensile Strains occur where the distance between two points increases and **Compressive Strains** occur where 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. When strains are measured over longer bay lengths lower averaged values are generally observed.

  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. However, it is not possible to determine the horizontal shear strain across a monitoring line using standard 2D or 3D monitoring techniques. High deformations along monitoring lines (i.e. normal strains) are generally measured where high deformations have been measured across the monitoring line (i.e. shear deformations) and vice versa.

High resolution surveying techniques using GPS technology and satellite based differential interferometry are providing far more data and a much better basis for understanding the extent and the mechanics of the mining induced vertical and horizontal ground movements. Modern surveyors now provide the current easting, northing and reduced level of each installed peg from which three dimensional subsidence and mining induced horizontal movements and directions can be derived for each epoch. Because of these improvements in subsidence surveying our understanding of both the magnitude and direction of mining induced vertical and horizontal ground movements and the lateral extent of these mining induced ground movements has improved substantially.

Incremental subsidence, tilts, curvatures and strains are the additional movements due to the extraction of each longwall and are determined from monitored data by subtracting the movements monitored before a longwall was mined from the movements monitored after that longwall was mined.

The **total** subsidence, tilts, curvatures and strains are the accumulated parameters resulting from the extraction of a series of longwalls.

The **travelling** tilts, curvatures and strains are the transient movements as the longwall extraction face mines directly beneath a given point.

Residual subsidence is defined as the additional, time-dependent subsidence that develops after active mining has been completed or has moved sufficiently far enough away from the affected area to no longer have an immediate influence. As the amount of subsidence being measured reduces asymptotically to smaller and smaller levels, the shrinking and swelling of the soil due to changes in moisture content and the survey accuracy can form a large proportion of the measured subsidence.

A cross-section through a typical single longwall showing typical profiles of systematic subsidence, tilt, curvature and strain is provided in Fig. 3.2.

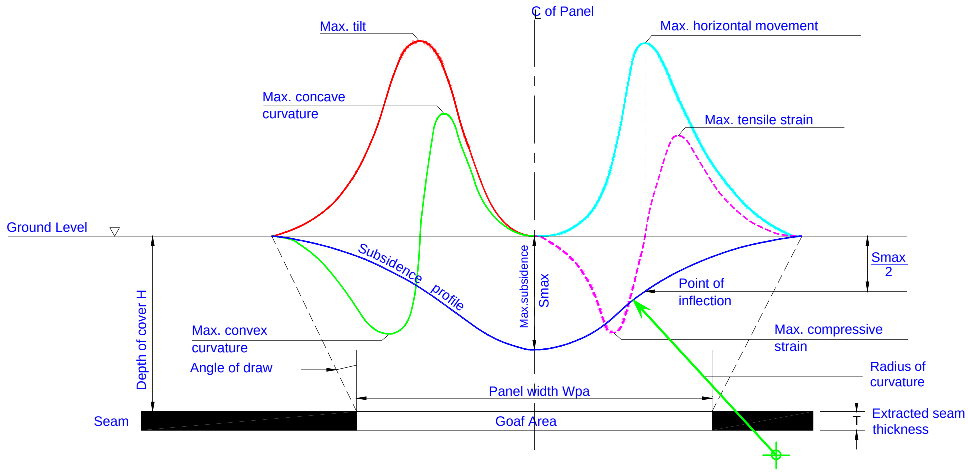


Fig. 3.2 Typical Profiles of Systematic Subsidence Parameters for a Single Longwall

Based on the above, the definitions of incremental, cumulative, total and travelling subsidence parameters are provided below:-

- **Incremental** subsidence parameters provided in this report, are the additional subsidence, tilts, curvatures, and strains which occur due to the extraction of a single longwall. Observed incremental subsidence profiles are determined by subtracting the observed subsidence profiles before from the observed subsidence profiles after the extraction of each longwall.
- **Cumulative** subsidence parameters provided in this report, are the accumulated subsidence, tilts, curvatures, and strains which occur due to the extraction of all proposed series of longwalls within a single seam.
- **Total** subsidence parameters provided in this report, are the accumulated subsidence, tilts, curvatures, and strains which occur after the extraction of all proposed series of longwalls within the current and preceding seams.
- **Travelling** subsidence parameters provided in this report, are the transient tilts, curvatures, and strains which occur as the longwall extraction faces passes directly beneath a point.

3.4. Overview of Conventional and Non-Conventional Subsidence Movements

Some subsidence terms and definitions were first published in an Independent Inquiry report entitled "*Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield*", (Southern Coalfield Inquiry Report), which was published in July 2008, (NSW DP, 2008). The terms and definitions draw a distinction between subsidence effects, subsidence impacts, environmental consequences, consequences, secondary consequences, conventional effects and non-conventional effects.

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

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near surface strata layers. Where the depth of cover is greater than 400 metres, which is not the case within the UG1 Study Area, the observed subsidence profiles along monitoring survey lines are generally smooth. Where the depth of cover is less than 100 metres, the observed subsidence profiles along monitoring lines are generally irregular. Very irregular subsidence movements are observed with much higher tilts, curvatures and strains at very shallow depths of cover where the collapsed zone above the extracted longwalls extends up to or near to the surface.

© MSEC JUNE 2015 | REPORT NUMBER MSEC731 | REVISION A

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

Non-conventional movements due to geological conditions, steep topography and valley related movements are discussed in the following sections.

3.4.1. Non-conventional Subsidence Movements due to Changes in Geological Conditions

For those sites where the depth of cover is less than 100 metres, the observed subsidence profiles along monitoring lines are generally irregular with much higher tilts, curvatures and strains principally because the collapsed zone has extended up to or near to the surface. Where the depth of cover is around 400 metres the observed subsidence profiles along monitoring survey lines are generally smooth as is typical in the Southern Coalfields. However, irregular subsidence movements can occasionally be observed even at deeper depths of cover along an otherwise smooth subsidence profile and these localised irregular subsidence movements, that are called non-conventional subsidence movements, are often associated with sudden or abrupt changes in geological conditions, steep topography, and valley related mechanisms.

Accordingly non-conventional subsidence movements may occur or could be expected within the river and creek valleys, near the major fault zones, and/or near the outcrop of the interface between sandstone and shale strata layers. It is believed that most of the unexpected irregular subsidence movements, (i.e. the non-conventional ground movements), are a result of the reaction of near surface strata to increased horizontal compressive stresses due to mining operations. Some of the geological conditions that are believed to influence these irregular subsidence movements are the blocky nature of near surface sedimentary strata layers and the possible presence of unknown faults, dykes or other geological structures, cross bedded strata, thin and brittle near surface strata layers and pre-existing natural joints. The presence of these geological features near the surface can result in bumps in an otherwise smooth subsidence profile which are usually accompanied by locally increased tilts, curvatures and strains.

Even though it may be possible to attribute a reason behind many of the 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, the analyses of non-conventional ground movements have been carried out 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. A further review of the variations in observed strains is provided in Section 4.3.1 which includes strains resulting from both conventional and non-conventional anomalous movements.

3.4.2. Non-conventional Subsidence Movements due to Valley Related Movements

The watercourses within the UG1 Study Area 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 Hunter Coalfield, which typically have much shallower depths of cover. The reason that valley related movements are less commonly observed in the Hunter Coalfield could be that the systematic 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 streams within the UG1 Study Area are unlikely to experience noticeable mining induced valley related movements, (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.

3.4.3. Non-conventional Subsidence Movements due to Steep Topography

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

Further discussions on the potential for slope instability movements for the steep slopes within the UG1 Study Area are provided in Section 5.4.

3.5. Subsidence Predictions using the Incremental Profile Method

The predicted systematic subsidence parameters for the UG1 were made using the Incremental Profile Method (IPM), which was developed by MSEC, formally known as Waddington Kay and Associates. A detailed description of the standard Incremental Profile Method is provided in the background reports that can be found on the website at http://www.minesubsidence.com. 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.

The database of detailed subsidence monitoring data from various coalfields includes data from the following Collieries or Mines: Abel, Angus Place, Appin, Ashton, Awaba, Austar, Baal Bone, Bellambi, Beltana, Berrima, Blakefield South, Bulga, Bulli, Burwood, Carborough Downs, Chain Valley, Clarence, Coalcliff, Cook, Cooranbong, Cordeaux, Corrimal, Crinum, Cumnock, Dartbrook, Delta, Dendrobium, Donaldson, Eastern Main, Ellalong, Elouera, Fernbrook, Glennies Creek, Grasstree, Gretley, Invincible, John Darling, Kenmare, Kemira, Kestrel, Lambton, Liddell, Mandalong, Metropolitan, Moranbah North, Mt. Kembla, Munmorah, Narrabri, Nardell, Newpac, Newstan, Newvale, Newvale 2, NRE Wongawilli, Oaky Creek, Ravensworth, South Bulga, South Bulli, Southern, Springvale, Stockton Borehole, Tasman, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, United, West Cliff, West Wallsend, and Wyee.

The raw survey database includes the observed incremental subsidence profiles, which are the additional subsidence profiles resulting from the extraction of each longwall within a series of longwalls. It was noted from the normalised incremental subsidence profiles within the database, that the observed shapes and magnitudes of these incremental subsidence profiles are reasonably consistent where the mining geometry and local geology are similar.

The IPM subsidence predictions use the database of observed subsidence profiles, the proposed longwall geometries, local surface and seam information and geology. The IPM model for Moolarben uses the surface level contours, seam floor contours and seam thickness contours that were provided by MCO to make predictions and these contours are shown in Drawings Nos. MSEC731-03, to MSEC731-04, respectively. Subsidence predictions have been made at points on regular grids orientated north-south and east-west across the UG1 Study Area. A grid spacing of 10 metres in each direction was adopted, which provides sufficient resolution for the generation of subsidence, tilt, and strain contours. The method has a tendency to over-predict the systematic subsidence parameters (i.e. is slightly conservative) where the proposed mining geometry and geology are within the range of the empirical database.

The maximum predicted systematic subsidence parameters resulting from the extraction of the proposed UG1 longwalls are provided in Chapter 4. The predicted systematic subsidence parameters at each of the natural features and items of surface infrastructure are provided in Chapter 5.

3.6. Calibration of Incremental Profile Method for Moolarben

Changes in overburden lithology can significantly influence the magnitude and shape of the observed subsidence profiles. The IPM model should therefore be calibrated to local geological conditions wherever subsidence monitoring information is available from nearby monitoring sites that have similar geology.

3.6.1. Influence of Lithology and Geology on the Maximum Possible Subsidence

The maximum possible subsidence over wide supercritical areas, (either over longwall panels, or, over second working pillar extraction areas with few remnant pillars), **principally** depends on the geology and the geomechanical properties of the strata. That is, the behaviour of the overlying roof strata, (i.e. how it caves or falls into the mined void and how the fallen rocks are broken and can be recompressed), affects the amount by which the higher strata beds can settle.

The more argillaceous strata types, (i.e. mudstones, siltstones, tuffs and claystones), break and cave easily and they can be compressed easily, so that, there is only a small increase in volume of the caved argillaceous rocks. However, whilst more massive beds of arenaceous strata or igneous units, (i.e. conglomerates, limestones, sandstones and basalts etc.), are more capable of spanning over wider voids, they cave at larger intervals into bigger blocks creating larger voids in between the fallen rock pieces and this results in a greater increase in volume (bulking) of the caved rock.

Additionally when thick layers of conglomerates, sandstones and basalts are present within the overburden layers that lie above the goafed and collapsed zone, far more bedding separations (voids) are observed beneath these massive strata beams than is observed when the overburden contained the weaker and thinner mudstones, siltstones and claystones.

The ultimate result of the greater bulking within the caved zone and the creation of more voids within the overburden is that less subsidence is observed when the strata has a greater arenaceous content than over strata that has a more argillaceous content.

For example Karmis et al (1987) noticed the following correlation between observed subsidence and the panel geometry for varying rock hardness ratios within the overburden from monitoring data in the USA, (HR or hard rock percentage of limestone and sandstone).

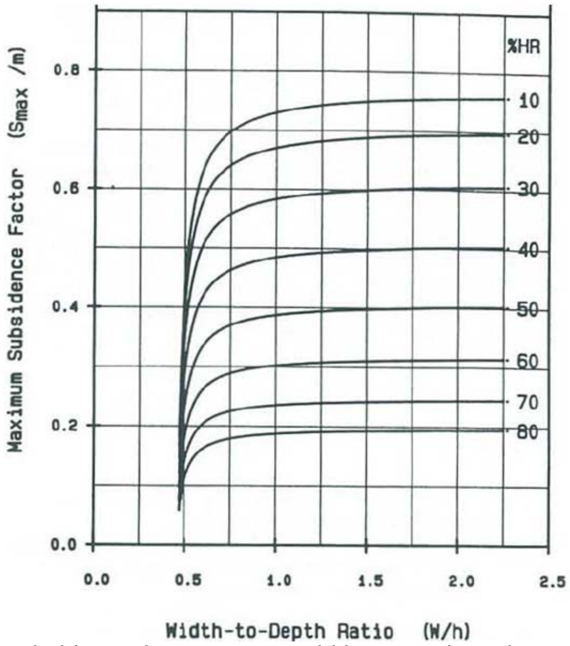


Fig. 3.3 Maximum subsidence factor versus Width to Depth Ratio curves (Karmis et al, 1987)

Similar subsidence behaviour patterns have been recognised in Australia for differing rock types, i.e. ;

- Where strong and massive conglomerate and sandstone strata units are present in the overburden, as are often observed in the Newcastle and Hunter Coalfields of NSW, the maximum observed vertical subsidence over supercritical width panels in single seam conditions is typically between 30% and 55% of the extracted seam thickness.
- Where there is a mix of sandstones, shales, siltstones and claystones strata layers within the overburden, the maximum vertical subsidence for supercritical width panels in single seam conditions is typically observed to be between 60% and 65% of the extracted seam thickness, as is typical in Southern Coalfield of NSW.
- Where there were ***no*** conglomerate or sandstone strata units and where there are ***predominantly*** thinly bedded shales, mudstones, siltstones and claystones within the overburden, the maximum subsidence, over supercritical width panels in single seam conditions, has been observed to be higher than 90 % of the extracted seam thickness. But, these conditions are rarely found in Australia with only one case known to date.

3.6.2. Influence of Depth of Cover on Maximum Possible Subsidence

Apart from the influence of lithology and geology, the depth of cover over the mined panel also influences the likely maximum possible subsidence as a proportion of the extracted seam thickness. Where the overburden is shallow then the available weight of the overburden to compact the fallen rocks within the goafed zone is reduced and where the overburden is very deep then there is a greater load to compact the fallen and broken rocks within the goaf. However this depth of cover factor appears to have a greater influence for sub critical width panels than for supercritical width panels, as is discussed further below.

The National Coal Board of the UK published (1966 and 1975) the following plot, Fig. 3.4, in 1975 to predict the maximum possible subsidence over mined panels in the UK for a particular width (W) at a particular depth (H). These UK curves have been reproduced as blue coloured lines in Fig. 3.5 and they show different subsidence prediction curves plotted against the panel width to depth ratio (W/H) for a range of specific depths of cover (H). It can be noted that for the same panel width to depth ratio, reduced subsidence levels occur for shallow depths of cover.

The early subsidence prediction curves for Australian conditions, however, that were prepared by Kapp (1973, 1976, 1978, 1982, 1984) and Holla (1985, 1987 and 1991), only presented one subsidence prediction curve for the Southern, Newcastle and Western Coalfields of NSW even though the depths of cover varies significantly within each coalfield. These curves are also shown in Fig. 3.5. MSEC reviewed the available incremental subsidence monitoring results in 1998 and published the purple coloured subsidence prediction curves that are shown in Fig. 3.5 to predict subsidence for varying depths of cover.

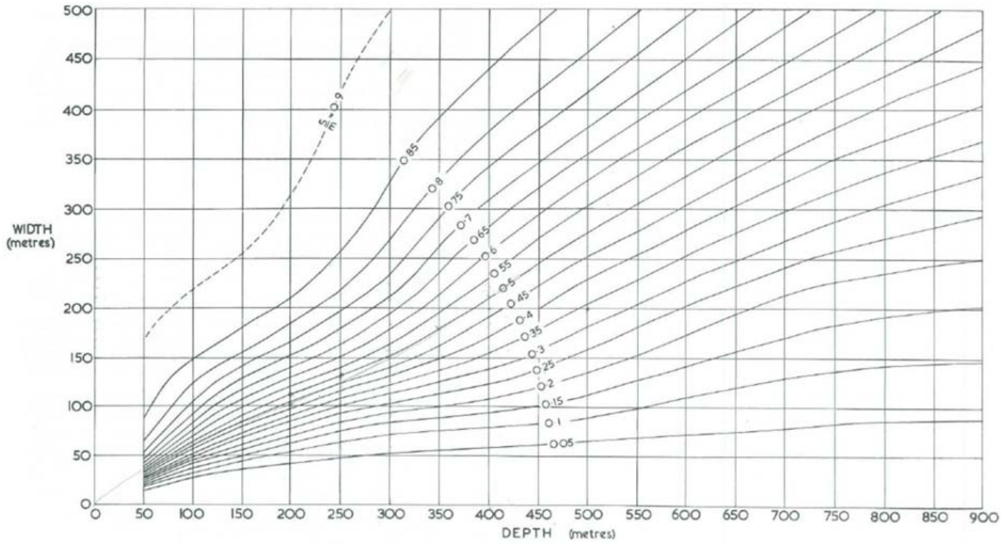


Fig. 3.4 Maximum subsidence factor prediction curves based on Width and Depth (SEH, 1966 & 1975)

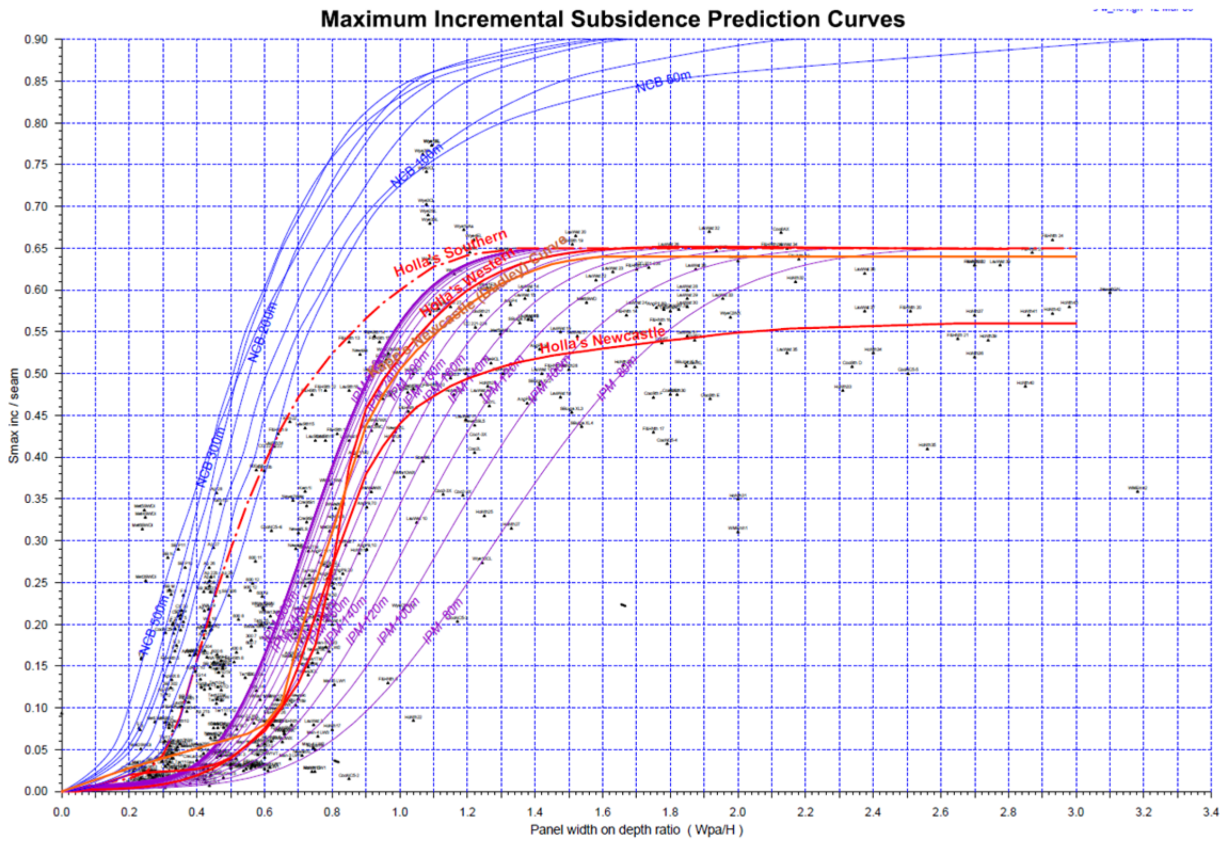


Fig. 3.5 Maximum subsidence prediction curves (Karmis et al, 1987)

The early Newcastle Subsidence Prediction Curves (Holla, 1987) were based on the then available empirical data, where the depths of cover did not exceed 220 metres and, for these cases, the magnitude of the pillar compression on either side of the mined panels was small when compared to the subsidence resulting from the sagging of the strata over the voids, (particularly for single isolated panels).

However, as the depth of mining in the Newcastle Coalfields increased, it was later realised, (particularly after the Teralba experience), that the component of the observed subsidence that results from the compression of the coal seam within the chain pillars, the immediate floor layers and the roof strata overlying the coal seam, can equal or exceed the subsidence component that results from the sagging over the voids.

For example, at depths of cover around 200 metres, calculations indicate that the compression of a 30 metre wide chain pillar and the overlying and underlying strata can account for up to 250 mm to 400 mm of the observed surface subsidence. At depths of cover around 400 metres, the compression of a 30 metre wide chain pillar can account for up to 600 mm to 1000 mm of the observed surface subsidence. Unfortunately this additional subsidence due to pillar compression was not allowed for in the early subsidence prediction curves for the Newcastle Coalfield.

Hence, it is expected that increased levels of subsidence would be experienced over the chain pillars at UCM where the overburden is around 300 metres compared to chain pillars at MCC.

3.6.3. 2009 Maximum Possible Subsidence Calibration

The IPM subsidence prediction model for standard cases in the Southern Coalfields, where the depths of cover are around 500 metres, is usually based on a maximum subsidence proportion of 65% of the extracted seam thickness for supercritical panels in single seam conditions. However, this standard IPM model is often calibrated or adjusted to lower subsidence levels for those cases that have shallower depths of cover or have specific geological conditions.

The predicted systematic subsidence parameters that were determined in previous MSEC reports for the proposed UG1 PrefML longwalls at Moolarben in 2009 were determined based on the standard IPM model for the Hunter, Newcastle and Western Coalfields, after applying some local calibrations that were determined to suite the particular geological and the overburden depth conditions at MCC. Hence, in 2009 the IPM model for the MCC was adjusted to predict a maximum subsidence factor value of 60% of the extracted seam thickness for supercritical panels in single seam conditions because of:

- the known presence of siltstones, claystones, mudstones, various small coal members and sandstones layers within the lower 100 metres of the overburden, plus,
- the influence of some thin sandstone and conglomerate strata layers that can reduce subsidence where the depth of cover increases above 120 metres, plus,
- the greatest depths of cover over the UG1 PrefML at MCC is only 165 metres.

That is, the 60% factor was chosen in 2009 as a conservative balance above the maximum observed subsidence to date at Ulan of 53% of the extracted seam thickness, and this 60% factor allowed for the relatively shallow depths of cover at MCC. Hence no modifications to the standard IPM model were made to account for the potential presence of any thick and massive strata units as are present at the adjacent UCM, because such thick or massive units are not present at Moolarben.

The maximum observed subsidence at Ulan at that time was 53% of the extracted seam thickness along the A-Line over Longwall 1, (at the shallow depth of cover of 105 metres). At this location there would have been no influence from the relatively thin Wollar Sandstone.

It should also be noted that, when the maximum ***incremental*** subsidence for each panel is limited to 60% of the extracted seam thickness, the maximum ***total*** subsidence over a series of longwall panels can still accumulate to be as high as 65% of the extracted seam thickness due to the overlapping effects from adjacent longwalls.

3.6.4. Previous Peer Review of IPM subsidence predictions (2009) for MCC

A peer review of the Stage 2 PPR Subsidence Assessment was commissioned in 2009 by the then Department of Planning, titled "*Review of Subsidence Assessment Moolarben Coal Project Stage 2 prepared for Department of Planning*" (Galvin & Associates, 2009). The main conclusion from Galvin & Associates (2009) was that the vertical displacement predictions, which were based on a maximum subsidence factor value of 60% of the extracted seam thickness, may have been overstated (i.e. conservative) because IPM model was not calibrated against the observed subsidence at the UCM. In its summary this report advised:

> *"If similar geological conditions to Ulan Coal Mine are associated with the Moolarben Stage 2 underground workings, the limited local data that is available indicates that vertical displacement is likely to have been over-predicted in the Moolarben Stage 2 EA by as much as 100%.*
>
> *"Normally, this order of accuracy would be unacceptable. Although it results in very conservative outcomes in respect of vertical displacement, it does not necessarily result in conservative predictions of other subsidence effects that derive from the rate of change of vertical displacement across the mine workings (for example, tilt and strain).*
>
> *"All subsidence prediction techniques require field data for calibration and verification purposes and, therefore, similar limitations are associated with alternative prediction techniques to the IPM technique.*
>
> *"Nevertheless, it may have been more helpful to have calibrated the IPM technique specifically to the limited data available from Ulan Coal Mine. This approach still has limitations as there are a number of parameters which can be manipulated in order to calibrate a prediction technique and, in the absence of an adequate database, uncertainty can surround the sensibility of the options adopted.*
>
> "*Although vertical displacement may have been grossly over-estimated, on this occasion it appears from the limited local subsidence data available that both tilt and strain have not been under-predicted and that the profiles (distribution patterns) of vertical displacement, tilt and strain are sensible. It is recommended, therefore, that if the project is approved, the approval conditions require:*
>
> - *"the IPM technique be recalibrated after the extraction of Longwall 2 and progressively thereafter until it can be demonstrated that it produces vertical subsidence predictions within the order of*

accuracy normally associated with reliable subsidence prediction techniques (for example, ± 15% for vertical displacement).

- *"The IPM technique to be supplemented with an alternative prediction technique, preferably one based on numerical modelling, if this order of accuracy cannot be achieved after the extraction of four longwall panels*.
- *"All predictions of subsidence impacts on specific surface features be reviewed after the completion of LW2 in light of measured versus predicted outcomes, and regularly thereafter until such times as the order of accuracy of predicted subsidence effects and impacts has been established."*

MSEC considers that the IPM subsidence prediction model that was used in 2009 for the Preferred Project Report for Stage 2 of the MCP, (MSEC353 Rev B), was appropriate for that report because the geological conditions at Ulan and Moolarben are not similar, in fact, they are very different (as detailed below) and, therefore, greater vertical subsidence is expected over the MCC than has been observed over most of the longwalls at the UCM.

Since the geological conditions at Moolarben are very different to the geological conditions at Ulan, the IPM model that was developed in 2009 for Moolarben was not calibrated against the monitoring data from Ulan.

The above generalised subsidence observations on the subsidence behaviour of the Permian and Triassic strata at Ulan have been supported by Ken Mills of Strata Control Technology in various published subsidence monitoring reports that he prepared for the UCM.

Mills (2011) published the following plot, Fig. 3.6, which shows that the observed maximum subsidence values, as a proportion of seam thickness, at Ulan, for locations where the Triassic sandstones are thick are much lower than the standard subsidence prediction curve for NSW (65%) and the observed maximum subsidence values, as a proportion of seam thickness, at Ulan, for locations where the Permian strata only, are also lower than the standard subsidence prediction curve for NSW (65%).

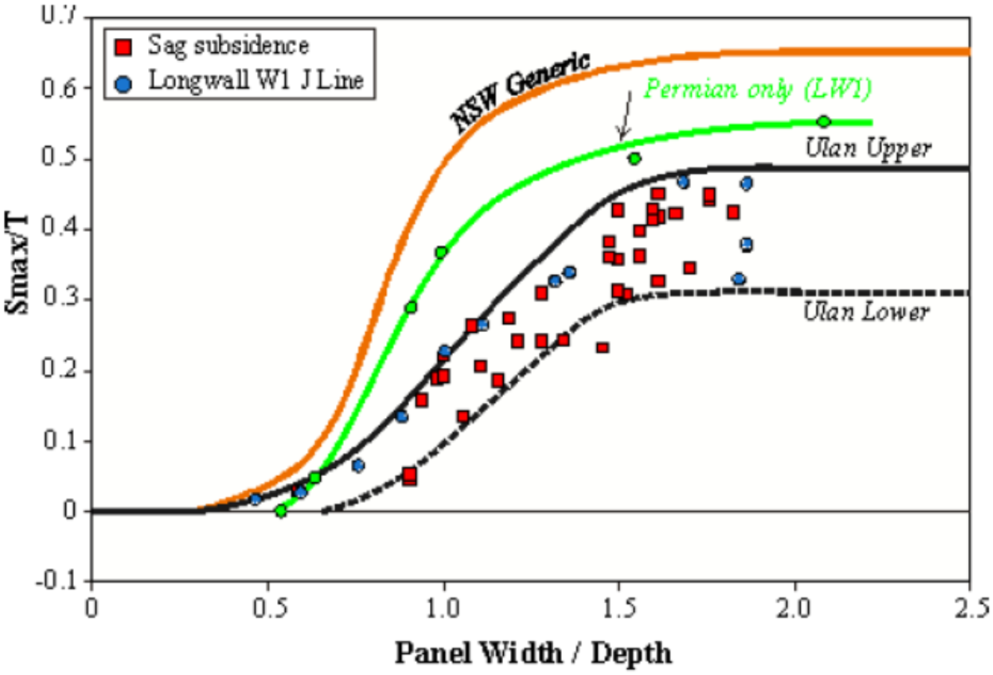


Fig. 3.6 Sag Subsidence above each panel at Ulan (Mills, 2011)

Ken Mills advised: "*the maximum subsidence is expected to be controlled by the ability of the goaf to reconsolidate under the weight of overburden strata and bulking of the Triassic sandstone. Where the overburden depth is low and the Triassic sandstone is not present near the southern end of the first few longwall panels in Ulan West, maximum subsidence of up to 55% of seam extraction thickness or 1.6m [for 2.9m mining section) is expected, but in most areas the maximum subsidence is expected to be less than 50% of seam extraction thickness and possibly as low as 30-50% of seam thickness in areas where the Triassic sandstone is present and the overburden depth is less than about 220m*."

3.6.5. 2015 Maximum Possible Subsidence Calibration of IPM model for the UG1

Since 2009, there has been more monitoring at two locations at Ulan where there would have been only a minor influence from relatively thin layers of the Wollar Sandstone. These new monitoring lines are the E-Line over Longwall E, (at the relatively shallow depth of cover of 137 metres) where the observed subsidence represented 45% of the extracted seam thickness, and, the F-Line over Longwall F, (at the shallower depth of cover of 127 metres), where the observed subsidence represented 55% of the extracted seam thickness.

From these observations it is not certain that the maximum subsidence values would be less than 60% of the extracted seam thickness for cases where there is absolutely no Wollar Sandstone. MSEC is now aware of several new monitoring cases within the Hunter Coalfield where the observed maximum subsidence as a proportion of the extracted seam thickness was greater than 60% and up to 63% for relatively shallow depth of cover conditions of less than 100 metres in locations where there were no massive or strong sandstone or conglomerate units.

Hence, for this UG1 Modification Report it has therefore been decided to apply a similar IPM model to that used to predict subsidence for Moolarben in 2009, but, it has been decided to apply an extra layer of conservatism by using a maximum subsidence of 65% as a proportion of the extracted coal seam for supercritical panels in single seam cases at MCC, because:

- The overburden overlying the Ulan Coal Seam above the longwalls at UCM and the MCC comprise two very different types of strata the;
  - Permian Illawarra Coal Measures, which are present up to a thickness of approximately 100 to 120 metres thick; and the
  - Triassic Narrabeen Group (Wollar) Sandstone, which lies immediately over the coal measures (where present);
- Within these Permian Illawarra Coal Measures there are several units that can be up to 9 metres thick, but, these occasionally thin to narrower thicknesses so that all the Permian strata layers can be thinly bedded and are predominantly argillaceous with increasing proportions of mudstones, siltstones and claystones;
- The depths of cover over the UCM longwalls ranges from 70 metres to 300 metres and, hence, the overburden at Ulan often contains a significant proportion of these strong Wollar Sandstone layers that are often not present at all over the Moolarben UG1 Longwalls, where the depths of cover only ranges from 50 metres to 165 metres;
- There are only a few cases of subsidence monitoring at Ulan where the overburden only included the Permian Illawarra Coal Measures;
- Where the overburden at Ulan only contained the Permian Illawarra Coal Measures or these coal measures plus a thin layer of the Wollar Sandstone, the observed subsidence represented 55% of the extracted seam thickness;
- Where the overburden at Ulan contained increasing proportions of the stronger Wollar Sandstone layers, then, the observed subsidence represented only 30 to 40% of the extracted seam thickness;
- Where regular and frequent monitoring was undertaken along longitudinal centrelines at Ulan, the results showed that the Wollar Sandstones were capable of spanning twice the void distances that the Permian coal measures were capable of spanning;
- Hence, greater vertical subsidence is expected over the MCC than has been observed over most of the longwalls at the UCM;
- There has been several cases of subsidence monitoring within the Hunter Coalfields at shallow depths of cover of less than 100 metres where the maximum observed subsidence was up to 65% of the extracted coal seam; and
- Where the overburden contained only thin layers of the Permian Illawarra Coal Measures with no thin layers of the Wollar Sandstone, the observed subsidence could increase higher than 53% or 55% and could be up to 65% of the extracted seam thickness;

3.7. Testing of the Incremental Profile Method

3.7.1. Testing of the Incremental Profile Method against Longwalls 12 to 19 at Ulan Coal Mine

As discussed above, an IPM model was developed in 2009 for use at both Moolarben, using a maximum incremental subsidence factor of 60% of the extracted seam thickness due to the known presence of known thinly bedded siltstones, claystones, mudstones, various small coal members and only thin sandstones layers within the lower 100 metres of the overburden, plus, as the depth of cover increases, it allows for the presence of some sandstone and conglomerate strata layers that can result in lower subsidence values.

It was accepted that this IPM model may over predict subsidence for those monitoring lines at Ulan where the overburden depth was greater than 200 metres as the strong Wollar Sandstone unit would reduce the observed subsidence levels to 30 to 50% of the extracted seam thickness. But it was expected that the IPM model would predict reasonably closely at Ulan where the depths of cover were less than 165 metres.

The predicted subsidence movements along Line D at UCM can be compared to the observed subsidence movements in Fig. 3.7 after the extraction of UCM Longwalls 12 to 19, (where there was a constant panel void width of 265 metres, an extracted seam thickness varying between 2.9 metres and 3.2 metres, the depths of cover ranged from 165 metres to 235 metres and the Wollar Sandstone unit thickness ranged from 65 metres to over 135 metres). The maximum subsidence per longwall along this monitoring line was observed to vary between 970 mm to 1300 mm and similar variations are often seen when reviewing the observed subsidence along longitudinal lines over the length of a panel; especially where the depths of cover are relatively shallow.

These observed subsidence represented 30% to 40% of the seam thickness extracted. As expected these observed subsidence values are considerably lower than the predicted subsidence profiles that were based on a constant maximum subsidence factor of 60% of the seam thickness.

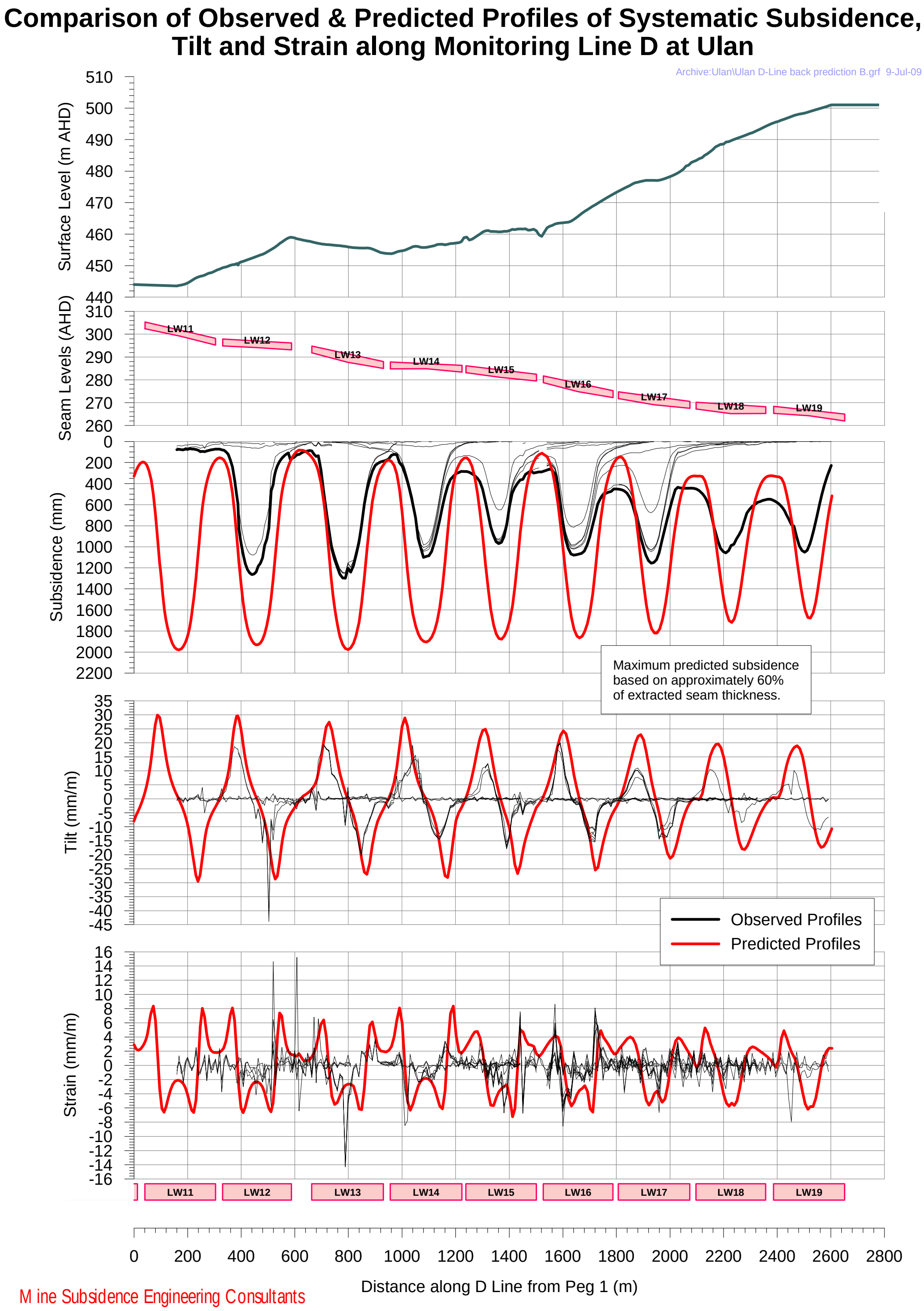


Fig. 3.7 Ulan Coal Mine Longwalls 11 to 19 Monitoring Results along Monitoring Line D in the Ulan Seam (Permian plus Strong and Massive Triassic Wollar Sandstones)

The predicted subsidence movements along the Line A at UCM can be compared to the observed subsidence movements in Fig. 3.8 after the extraction of UCM Longwall 1, (where there was a constant panel void width of 210 metres, an extracted seam thickness varying between 3.0 metres and 3.2 metres, the depths of cover ranged from 70 metres to 110 metres and, where present, the Wollar Sandstone unit thickness was not thicker than 10 metres).

The observed subsidence for this case represents 53% of the seam thickness extracted and, as expected, this observed subsidence is just lower than the predicted subsidence profiles that were based on a constant maximum subsidence factor of 60% of the seam thickness.

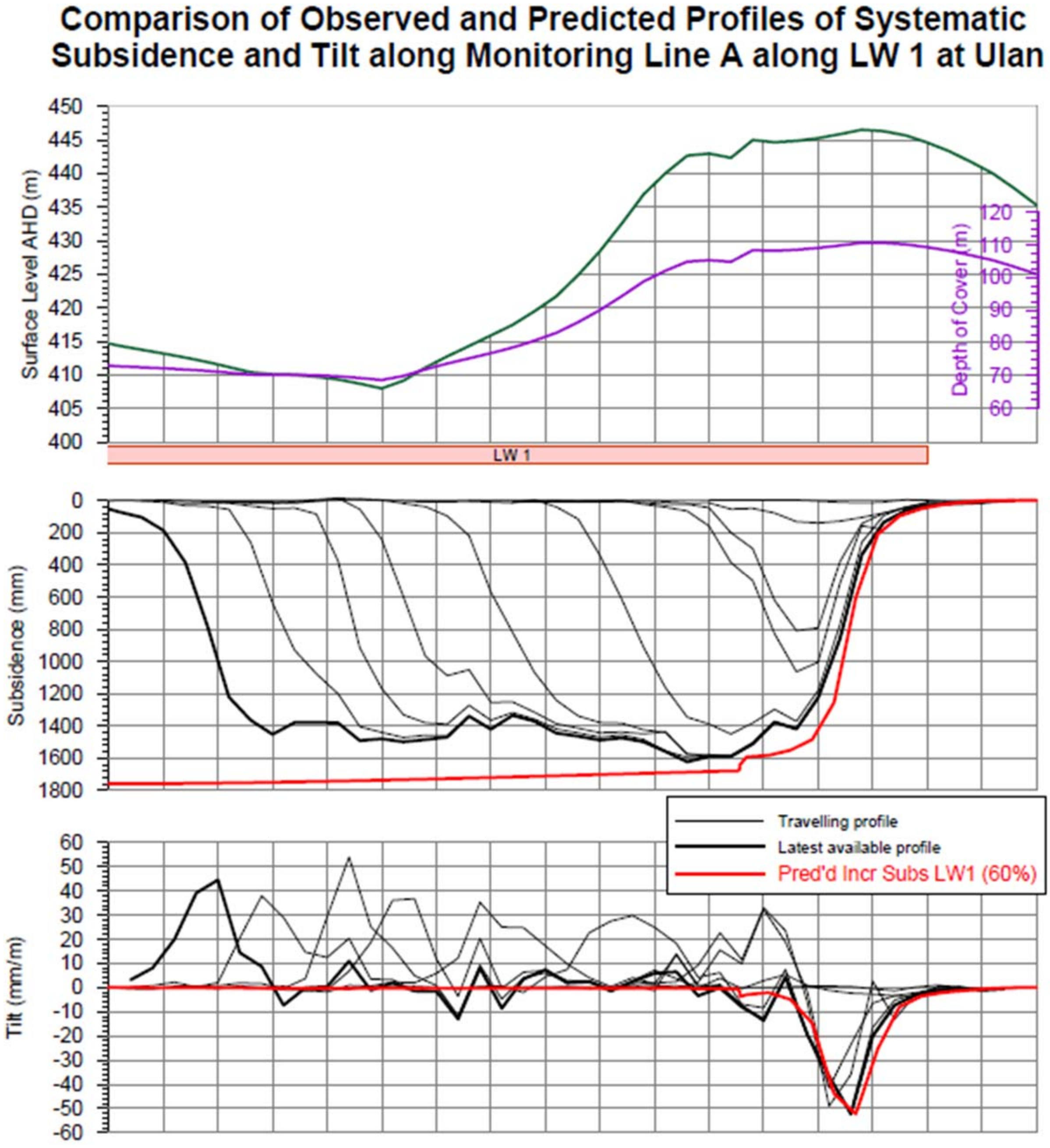


Fig. 3.8 Ulan Coal Mine Monitoring Results along Longwall 1 (Permian Only)

The Longwalls 101 to 105 at the UG1 of the MCC are proposed to be wider (305 metres) than those at Ulan Longwalls 1 and 11 to 19 and the depth of covers over the proposed Moolarben longwalls are shallower. Hence, the panel width to depth ratios for the UG1 at MCC will vary from approximately 2 to greater than 3, which is higher than the width to depth ratios for these longwalls at UCM of approximately 1 to 1.7.

3.7.2. Testing of the Incremental Profile Method against Longwall 1 at the Beltana Mine

The predicted subsidence profiles, obtained using the Incremental Profile Method, have also been compared against the measured subsidence survey results after the extraction of Longwall 1 within the Whybrow Seam in Beltana Central Mining Area, where the geology and depths of cover are similar to those at Stage 2 of the Moolarben Coal Project.

A graph comparing the predicted and measured subsidence profiles along the monitoring line at the Longwall 2 Ridge Cross Line is shown in Fig. 3.9. It can be seen that the predicted subsidence, tilts and strains were comparable to the observed subsidence, tilts and strains, however, there was a slight lateral shift between the predicted and observed results. This lateral shift is typically accounted for in the impact assessments by predicting the maximum subsidence parameters within a 20 metre radius of an isolated natural feature.

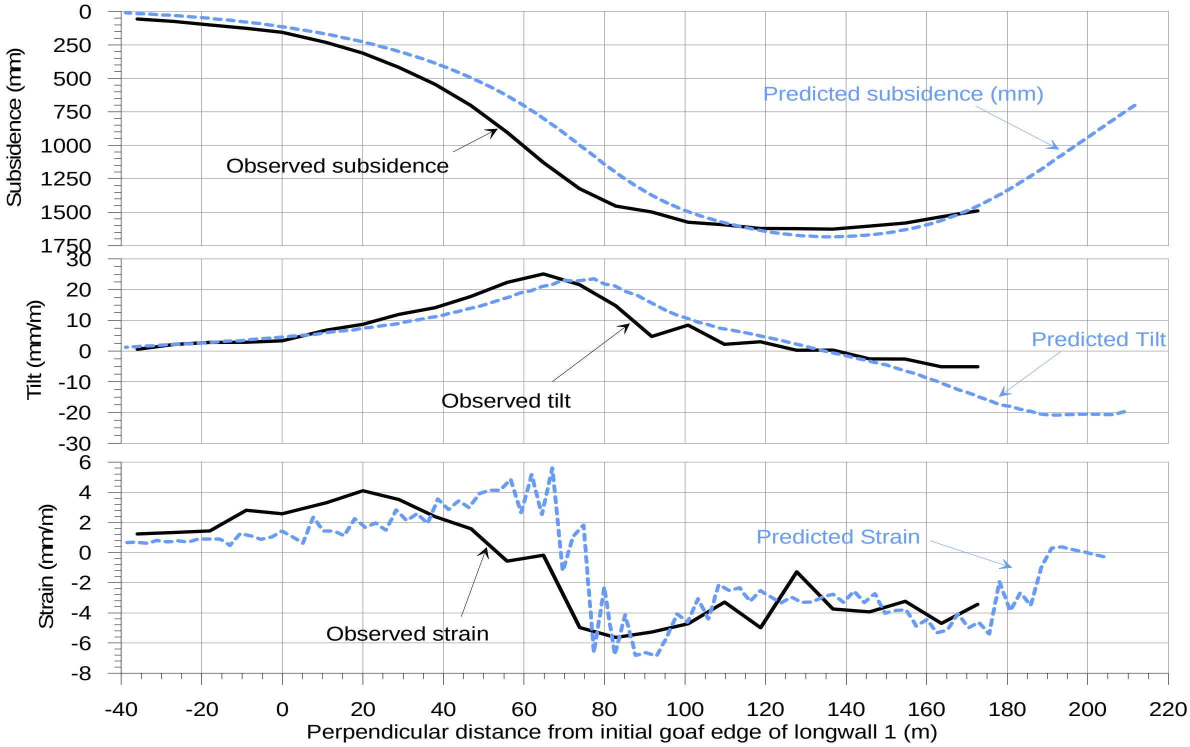


Fig. 3.9 Beltana Mine Monitoring Results after extraction of Longwall 1 in Whybrow Seam – Ridge Cross Line

Graphs comparing the predicted and measured subsidence profiles along the monitoring lines at the Optical Fibre Cross Line, West Charlton Road Cross Line and East Fence Cross Line are shown in Fig. 3.10, Fig. 3.11 and Fig. 3.12, respectively.

It can be seen that the predicted subsidence, tilts and strains closely match the observed profiles, and generally provide slightly conservative results. The slight lateral shift between the predicted and observed results has been accounted for in the impact assessments as described above.

© MSEC JUNE 2015 | REPORT NUMBER MSEC731 | REVISION A

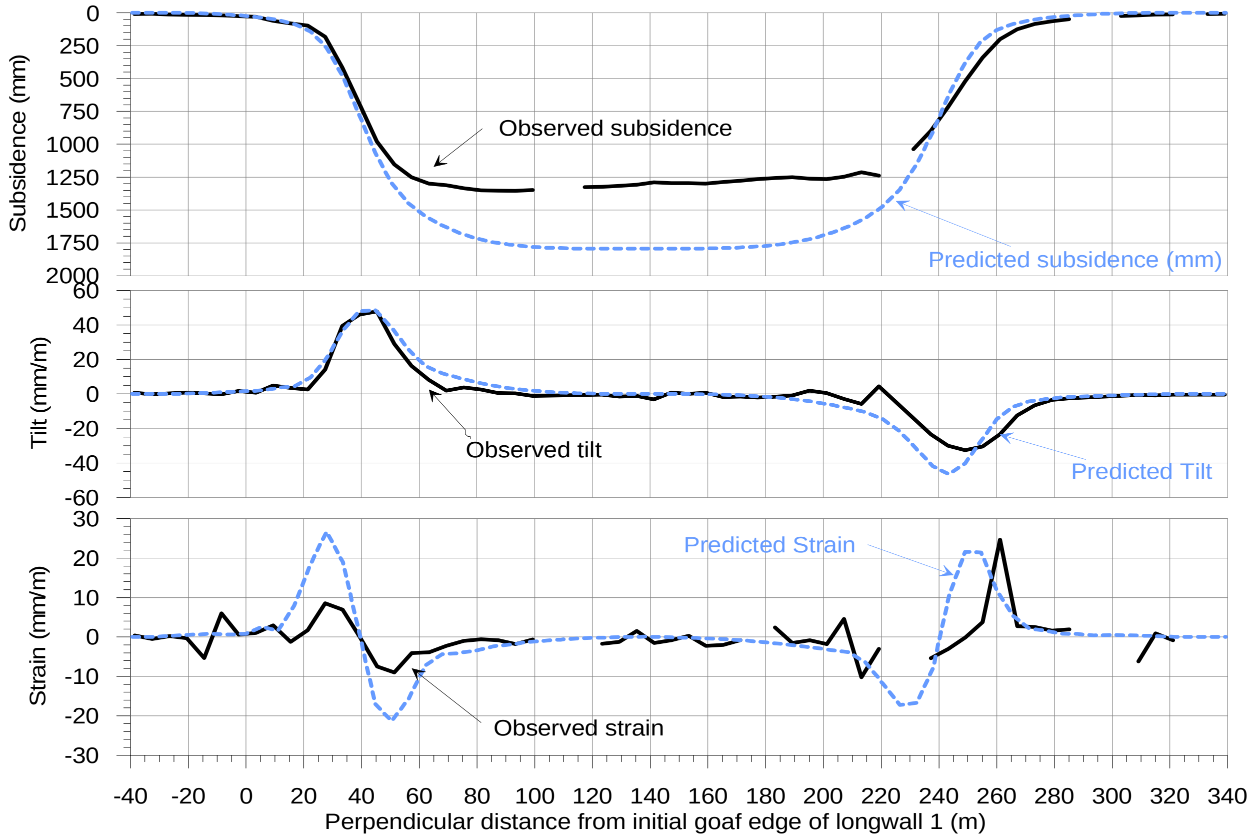


Fig. 3.10 Beltana Mine Monitoring Results after extraction of Longwall 1 in Whybrow Seam – Optical Fibre Cross Line

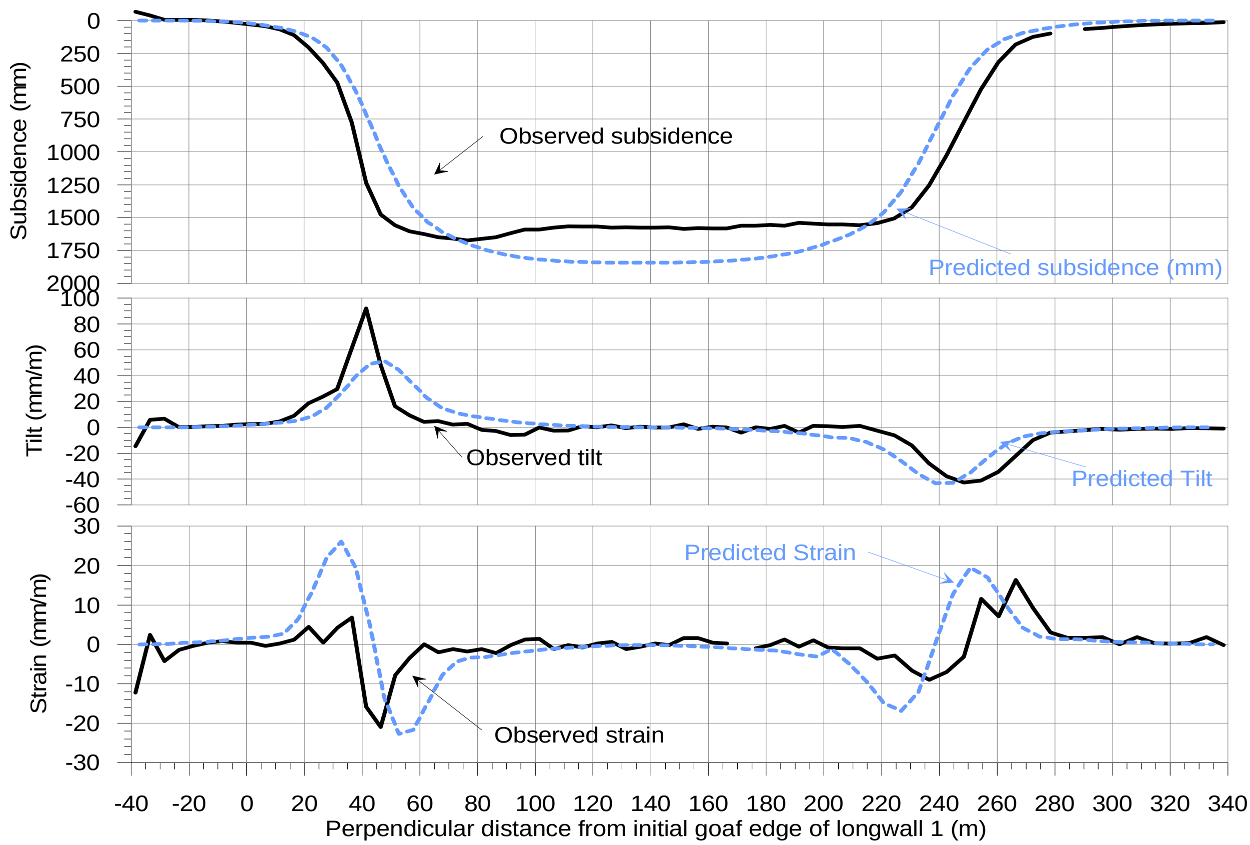


Fig. 3.11 Beltana Mine Monitoring Results after extraction of Longwall 1 in Whybrow Seam – West Charlton Road Cross Line

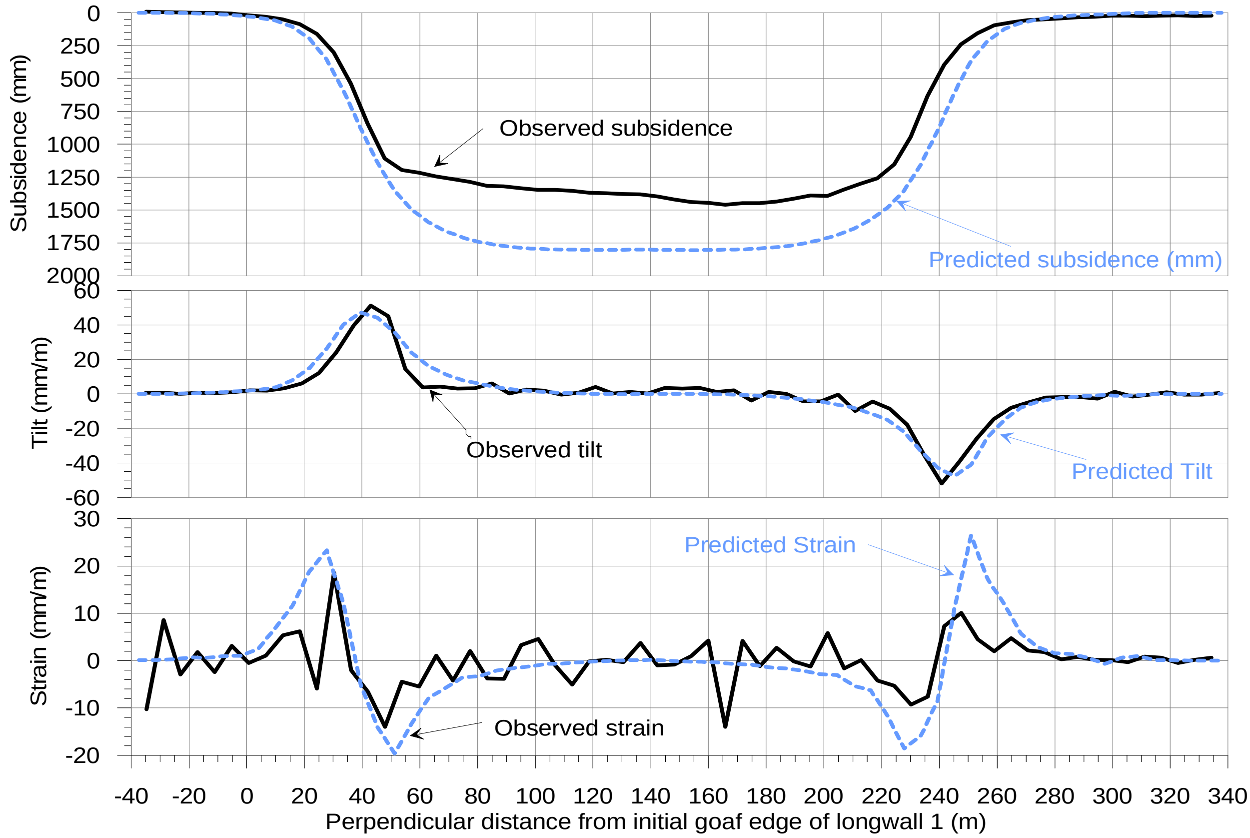


Fig. 3.12 Beltana Mine Monitoring Results after extraction of Longwall 1 in Whybrow Seam – East Fence Cross Line

3.8. Mining Induced Horizontal Movements and Far-field Movements

Early mine subsidence surveys did not measure the magnitudes or the directions of mining-induced horizontal displacements. Instead early subsidence surveys predominantly undertook the measuring of the levels of and the distances between pegs installed in the ground over and around the mined panels. The changing levels of each peg and the changing distances between these pegs were measured before, during and after mining of each panel and, from these measurements, the vertical subsidence at each peg and the slope and horizontal ground strains between the pegs were determined.

Early researchers reviewing these two dimensional monitoring results, noticed the close similarity between the observed tilt and horizontal displacement profiles and between the observed curvature and strain profiles. It was logical therefore for the early horizontal displacement prediction methods were based on linear relationships with the predicted tilt and the early strain predictions to be based on predicted curvatures. A tilt to horizontal displacement factor of 15 was commonly used to predict the maximum horizontal movements in the Southern Coalfield of NSW and a factor of 10 was used in the Northern Coalfield. A curvature to strain factor of 15 was commonly used to predict the maximum strains in the Southern Coalfield of NSW and a factor of 10 was used in the Northern Coalfield. However, it wasn't long before it was noticed that, while these correlations between tilt and horizontal movements and curvature and strain were reasonable for the maximum values that occurred over the mined panels, but, they were not as useful in other areas, particularly in locations that were beyond the edges of the mined panels.

Before year 2000, it was common to have mine subsidence monitoring survey control only extending out for a distance equal to approximately one depth of cover or a few hundred metres from the edges of longwall panels - because of the challenges associated with maintaining survey accuracy over large distances. Now an array of survey benchmarks is established around the area being subsided with far more accurate equipment and surveying techniques. Concentric networks of survey control are now routinely established remote from all sides of the mined areas.

While it took some years before GPS technology became readily available and routinely used for subsidence monitoring at a high enough resolution, the effect of their use has been profound. Fortunately improvements in high resolution surveying techniques, GPS technology and satellite based differential interferometry using synthetic aperture radar (DinSAR) three dimensional monitoring and stress change monitoring have now became available to measure the magnitude, direction, and lateral extent of mining induced horizontal ground movements more accurately.

Modern surveys now provide the current easting, northing and reduced level of each installed peg at each epoch, from which three dimensional subsidence movements and directions are determined. Usually many more pegs are now installed over a mined panel. Now pegs are not only installed in lines along or across the mined panel, but, pegs are also installed randomly at points of interest anywhere over or near the panel. Previously only strain data and occasional 2D horizontal movement data was available for analysis, but, as a result of having improved surveying equipment and more accurate monitoring techniques, the understanding of the lateral extent, the magnitude and the direction of the mining induced horizontal ground movements has improved significantly and this is providing a much better basis for understanding the mechanics of these mining induced horizontal ground movements.

By analysing these three dimensional monitoring results, it is now becoming clearer that the magnitude of mining-induced horizontal movements and the directions of these horizontal movements are affected by a complex interaction of many strata mechanisms. As more and more accurate mining induced three dimensional surveying data has become available, the following three main components have been recognised to all contribute to the observed magnitudes and directions of the mining induced horizontal movements.

- ***Conventional or systematic*** horizontal movements that occur generally toward the active longwall extraction face or the centre of a subsidence trough as a result of the vertical subsidence, curvature and sagging of the strata layers over the mined panel. The maximum conventional horizontal movements in such cases can be approximately estimated with appropriate tilt-horizontal movement factors depending on the geological conditions;
- ***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 surface strain. Initially it was thought that far field horizontal movements were only associated with survey marks that were located beyond the longwall goaf edges and over solid unmined coal areas, but, now they are seen to be the result of complex changes or perturbations to the stress field around and over mined panels.
  The observed far field horizontal movement at survey pegs that are located beyond the longwall goaf edges are often measured to be much greater than the observed vertical movements at those marks. However, the differential far field horizontal movements are very small and generally do not result in significant impacts on natural features or surface infrastructure, except where they are experienced by large structures that can be sensitive to small differential horizontal movements.
  Before mining occurs the overburden strata is in a state of compressive stress, in all directions, and are, generally, in a state of equilibrium or balance. However, when mining occurs, this equilibrium is disturbed and the stresses that used to be supported by the rocks within the goaf zone have to be redistributed around, over and below the goaf to achieve a new balance as the strata around the mined panel expands towards the goafed areas.
  Around very wide super-critical panels, where cracking occurs from the seam up to the surface, the observed far field horizontal movements are predominantly the result of the partial relief or relaxation of in situ compressive horizontal stresses of the immediate strata toward the goafed areas after slippage occurs along at least one bedding plane. These horizontal movements are, in many ways, similar to how observed horizontal movements occur around large building foundations or open cut excavations.
  Around narrow sub-critical panels, the redistributions are more complicated in that the strata layers around the panel are still relieved towards the goafed zones, but, only after slippage occurs along various horizontal bedding planes, and, only after the strata layers that overly the fractured and goafed zones experience increased compression due to the redistribution of the pre mining in situ horizontal stresses and due to the inward movements of the strata around the mined panel.
  Hence, ***far field movements*** are complex, but, they can be predicted using a combination of separate, but related, stress relief and stress redistribution models. The magnitude and extent of these far field movements are believed to be dependent on: the compressive in situ stress levels of the various strata zones between the seam and the surface; the principal stress direction; the panel widths and depths of cover; the presence and proximity of previously extracted panels; the stiffness, dip, thickness and geomechanical properties of the overburden strata layers; and many other factors.
- ***Valley related or topography related*** horizontal movements of the strata around the valleys toward the valleys, i.e. the additional bedrock movements in a down-slope direction towards the base of valleys and steep slopes that are usually a major component of the observed closures across the valley. Various mechanisms have been put forward by various researchers to explain both the increased observed movements towards valleys and to explain the observed increased horizontal compressive stresses in the strata in both the sides and the base of the valleys that seem to drive these valley closure related movements.

Hence, rather than there being one factor causing the mining induced horizontal movements or strains, it is now recognised that multiple complex factors influence these observed movements, including the:

- panel and pillar widths, depth of cover and extracted seam thickness;
- magnitude and principal direction of the in situ horizontal compressive stresses in the strata layers around the mined goaf and the surface strata layers;
- geology, geomechanical properties and thicknesses of all the overburden strata layer, the seam and the strata layers immediately under the seam;
- direction of mining in relation to the mined panel;
- steepness and direction of the seam dip;
- direction of mining in relation to the seam slope;
- steepness and direction of the surface topography;
- direction of mining in relation to the surface slope;
- presence of geological faults, joints and igneous intrusions;
- presence and proximity of previously extracted panels in the currently mined seam and in other seams; and
- other contributing factors such as; time effects depending on the travelling longwall face, the degree of surface roughness and frictional resistance along the bedding planes, the presence of groundwater flows along the bedding planes, etc.

When viewing observed incremental or total subsidence, tilt, curvature and strain profiles along monitored survey lines, there is always a much wider scatter in observed horizontal movement and strain profiles than the other parameters.

The variation in the observed horizontal movement and strain, especially when comparing strain values at a point rather than the maximum strains along a line, is usually far greater than the other parameters, not only in magnitude, but also in sign, (that is, often tensile strains have been observed where compressive strains were predicted, and vice versa). These observed variations varied the most in the mining induced hogging and sagging curvatures and tensile and compressive ground strains, for those cases where the depths of cover were below 100 metres.

At shallow depths of cover the observed values of tilt, horizontal movement, curvature and strain are all particularly sensitive to: the exact location of the survey pegs in relation to the moving longwall panel and the moving longwall face; the exact placement of the monitoring survey pegs in relation to the other pegs, (i.e. the baylengths between and the orientation of these pegs); and any variations in local geology and surface topography.

In addition to the conventional subsidence movements that have been predicted above and adjacent to the proposed UG1 ModML longwalls, it is also likely that far-field horizontal movements will be experienced during the extraction of these longwalls. 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 was a higher scatter in the orientation of the observed movements.

The observed incremental far-field horizontal movements, resulting from the extraction of single longwalls, are shown in Fig. 3.13. The observed directions of these far-field horizontal movements were generally observed to be orientated towards the extracted longwall.

This plot of far field horizontal movements includes various multi-seam mining cases and some sites where it is known that the plotted movements include components from valley closure effects. The confidence levels, based on fitted GPDs, have also been shown in this figure to illustrate the spread of the data. It should be emphasised that for example 60 % of the observed far field horizontal movements are lower than 75 mm. The magnitude of these movements decrease with distance from the mined edges' however, there have been cases where the observed far field horizontal movements beyond the edges of the mined panels have approached 400 mm. This plot of observed data points indicates that incremental far-field horizontal movements of up to 20 mm have been observed at distances of 2000 metres from extracted longwalls. The highest observed far field horizontal movements are multi seam cases that are located close to large valleys.

This data includes some of the available observed far field horizontal movements that have been measured at UCM and other observed data from other regions where the depths of cover are also relatively shallow compared to the Southern Coalfield of NSW. The available far field incremental horizontal movement data has therefore been replotted, as shown in Fig. 3.14, against the distances from the nearest edge of the incremental panel divided by the depth of cover.

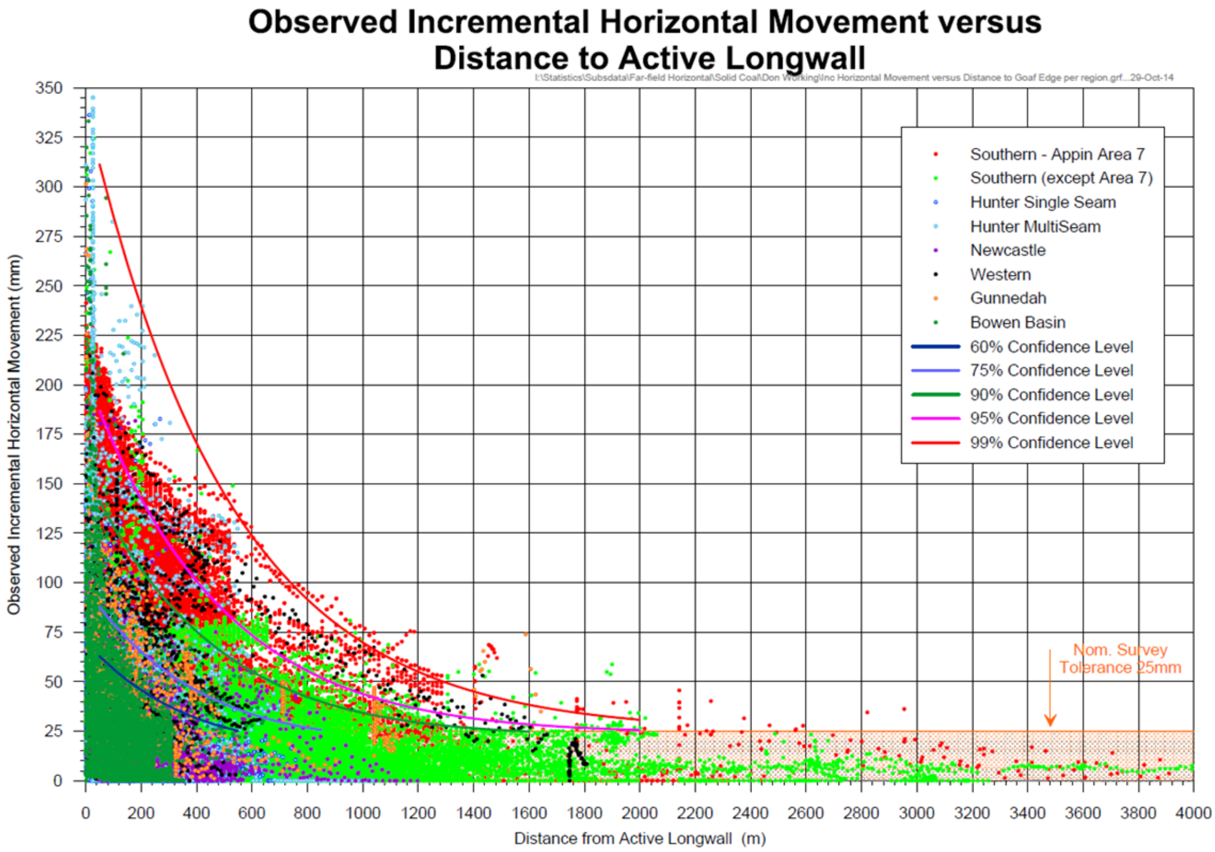


Fig. 3.13 Observed Incremental Far-Field Horizontal Movements (mm) from many regions in NSW plotted against the distance to the nearest edge of the mined panel (m)

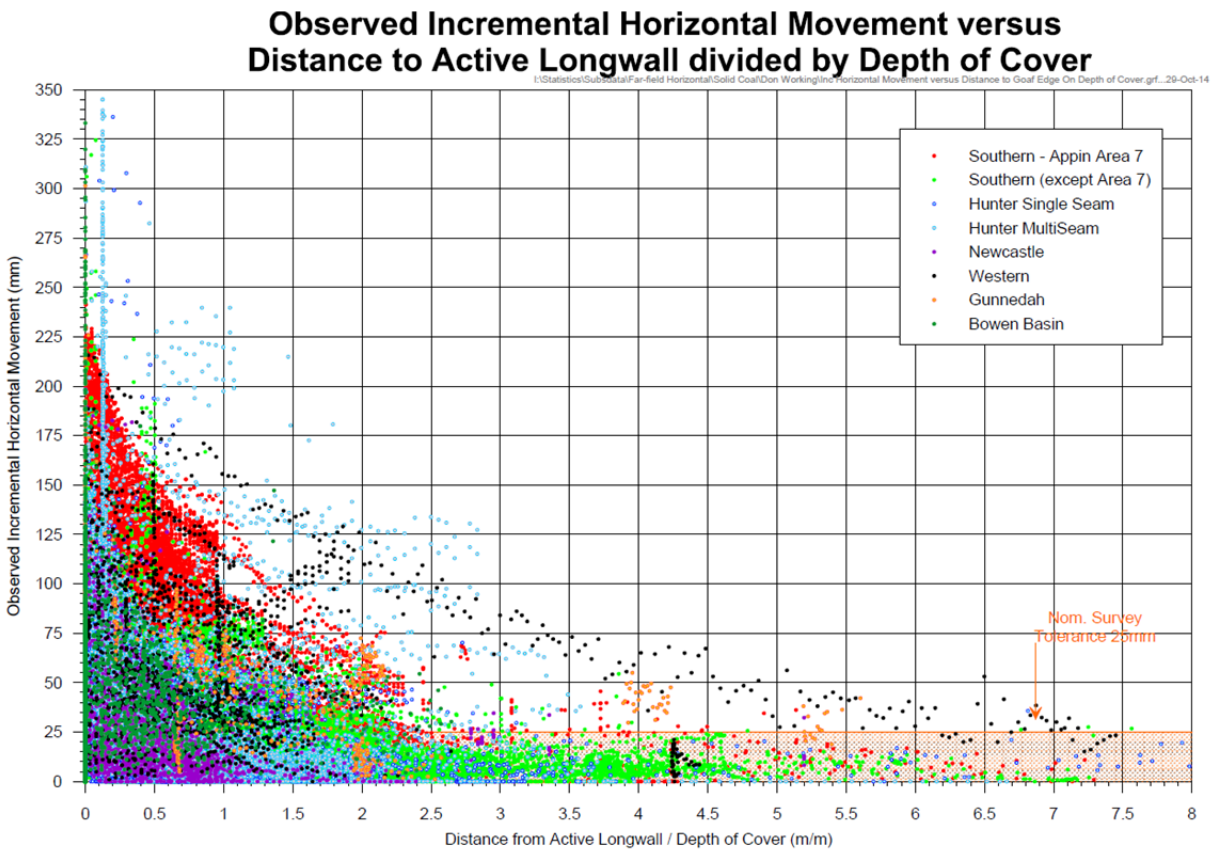


Fig. 3.14 Observed Incremental Far-Field Horizontal Movements (mm) from many regions in NSW versus the distance to the nearest edge of the mined panel divided by the depth of cover (m/m)

Fig. 3.14 therefore replots the available far field horizontal movement data that was shown in Fig. 3.13 to allow for the influence of changing depths of cover and this plot is for appropriate for use at MCC. This plot still includes those many cases where higher movements occurred because of multi-seam mining and valley closure effects.

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.

The impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the vicinity of the UG1 is 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.

3.8.1. Additional Far Field Horizontal Movement Observations from Ulan Coal Project

The above referenced far field horizontal movement database only includes a few monitoring lines over the adjacent UCM, but, further far field horizontal movement data has recently been published after monitoring at UCM, as discussed below, which supports the above prediction graph.

In a paper by Mills, (published in 2011), titled "*Developments in Understanding Subsidence with Improved Monitoring*", Mills, advised;

> *"Stress relief movements are primarily driven by the release of horizontal stress either toward the goaf or toward topographic low points. Stress relief movements are likely to occur as relatively sudden events in the first instance and then incrementally as the extracted longwall geometry changes to allow further movement.*
>
> *"Such far-field horizontal movements have been observed and reported in the past by Reid (1991) and others to distances of the order of 1.5km from active mining. It is considered likely that such movements could extend considerably further when the longwall geometries and in situ stresses are favourable."*

In a second paper titled "*Experience of Monitoring Subsidence at Ulan Coal Mine*", Mills et al (2011), advised;

> *"Ulan Coal Mines Ltd (UCML) operates a longwall mine that is adjacent to the MCP. "*
>
> *"Subsidence monitoring has been conducted throughout the life of the mine, but a recent upgrade of the survey control network has added significantly to the understanding of subsidence related ground movements at the mine. "*
>
> *"This paper presents an overview of the improved survey control network introduced for Longwall W1 at UCM using a far-field survey control network based on Global Position System (GPS) and broadly distributed survey control marks. This longwall panel was the first longwall panel mined in a new area and the panel was 410 metres wide. "*
>
> *"The characteristic that has not previously been identified at UCM is the significant distance to which the horizontal ground movements extend outside the panel and the nature of these movements as shown in (Fig. 3.15)."*
>
> *"Soon after full subsidence had developed, horizontal ground movements extended to a distance of approximately 600m from the northern goaf edge of Longwall W1 (approximately 1000m from the southern goaf edge). The ground movements vary along the line as a linear function of distance from the goaf edge."*
>
> *"By the end of the panel, a second stage of horizontal movement occurred toward the goaf but this additional movement extends to a distance of 1.6km from the northern goaf edge of Longwall W1."*
>
> *"The ground movements observed are occurring in a direction opposite to the dip of the seam and opposite to the general dip of the surface topography so they do not appear to be related to downslope movement. "*
>
> *"The ground movements that were observed indicated horizontal stress relief has occurred to a distance of approximately 1.6km from the panel causing horizontal movements of 200mm at the goaf edge decreasing to 20mm at 1.6km."*

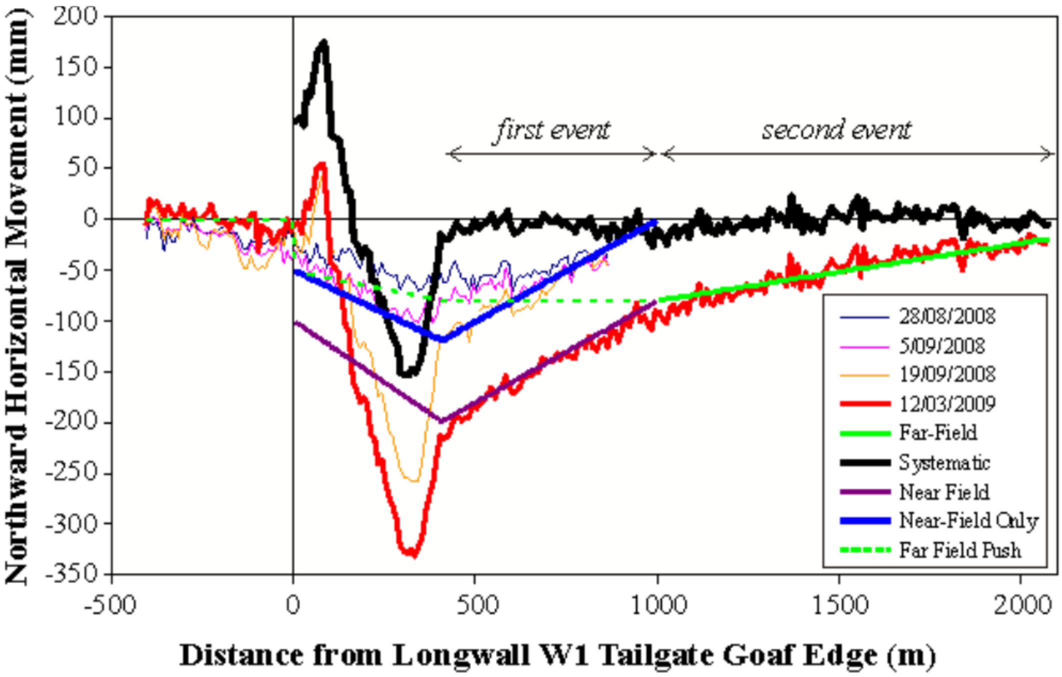


Fig. 3.15 Components of horizontal movement inferred from measured subsidence profile (Mills)

In a further paper titled "*Analysis of Subsidence Results from Longwall W2, Comparison with Predictions and Implications for Ground Deformation at Ulan*", Mills advised in 2011;

> *"Longwall W2 is the second panel on the western side of the main headings in the current mining area and has provided an opportunity to observe far field horizontal subsidence movements in a new mining area when the second long wall is mined.*
>
> *"Far field horizontal movements were measured on the northern side of Longwall W2 tapering from 280mm at the goaf edge to less than 20mm (the nominal survey tolerance) at approximately 1250m from the northern edge of Longwall W1."*
>
> *"The southward direction of movement against the dip of the strata and the general ground slope and the linear form of these movements indicate they are most likely a result of horizontal stress relief toward the longwall panel."*
>
> *"These horizontal movements are asymmetrical in that no far field horizontal movements were measured on the southern side of Longwall W1. The far field horizontal movements on the northern side of Longwall W2 appear to have relieved linearly and incrementally as the panel has retreated."*

In a further letter, dated September 2012 and titled "*Ulan Longwall 26 End Of Panel Subsidence Report*", Mills advised;

> *"Longwall 26 is 410m wide (rib to rib). Horizontal movements in a north-south direction across the panel exhibit far-field movements similar to those observed previously over the western series longwall panels (Longwall W1 and W2) and over Longwalls 23-25, although the magnitude of movement over Longwall 26 is much greater."*
>
> *"Within the boundary of Longwall 26, horizontal compression of 0.86m is observed across the panel, concentrated mainly across the topographic low point of Bobadeen Creek. Outside the panel, horizontal movements toward the Longwall 26 goaf reduce with distance from the longwall goaf edge from approximately 0.45m at the northern goaf edge of Longwall 26 to less than 0.1 m at 700m from the goaf edge, and become imperceptible (less than 0.02m, the effective resolution of the surveying) at a distance of about 2-2.5km from the goaf edge."*
>
> *"The horizontal movement appears to increase with proximity to the longwall panel goaf edge. The Figure below shows a plot of distance from the south-west corner of Longwall 26 plotted against the incremental horizontal displacement observed during mining of Longwall 26 only. Monitoring results from F Line north of Longwall 26 and H Line from both the northern and southern edges of Longwall W1 and the northern edge of Longwall W2 are also shown below."*
>
> *"These results indicate perceptible horizontal movements are observed outside the goaf edge of each longwall panel to a distance of about 2km from the goaf edge, with most of the movement occurring within about 1 km of the goaf edge. The incremental horizontal movements for each longwall panel range from about 150-380mm at the goaf edge to less than 70mm at 1 km and less than 20mm at about 2-2.5km, although there is a step change noted on F Line to about 40mm, the reasons for which are not clear. "*

The valley height where the F-Line crosses Bobadeen Creek and Longwall 26 at UCM is 55 metres, which is relatively deep. In this report Mills noted that the highest horizontal strains occurred at the base of Bobadeen Creek and he noted that the highest far field horizontal movements were observed on the side of this Bobadeen Creek where he notes the normal far field horizontal movements and valley closure movements combine. "*The surface terrain above Longwall 26 comprises a broad valley on either side of Bobadeen Creek. Horizontal compression of 0.86m is observed across this panel, concentrated mainly across the topographic low point of Bobadeen Creek. Maximum horizontal strains are generally less than 4mm/m in tension and 6mm/m in compression, however, there is a significant spike at the topographic low point at Bobadeen Creek where the horizontal compressive strains reach a peak of 13mm/m. Maximum horizontal strains were predicted to be in the range 5-10 mm/m, which for the most part they are, but the compressive strain peak at Bobadeen Creek is higher than predicted. This strain peak appears to be a result of the coincidence of far-field horizontal stress relief movements and downslope movements concentrating at the topographic low part.*"

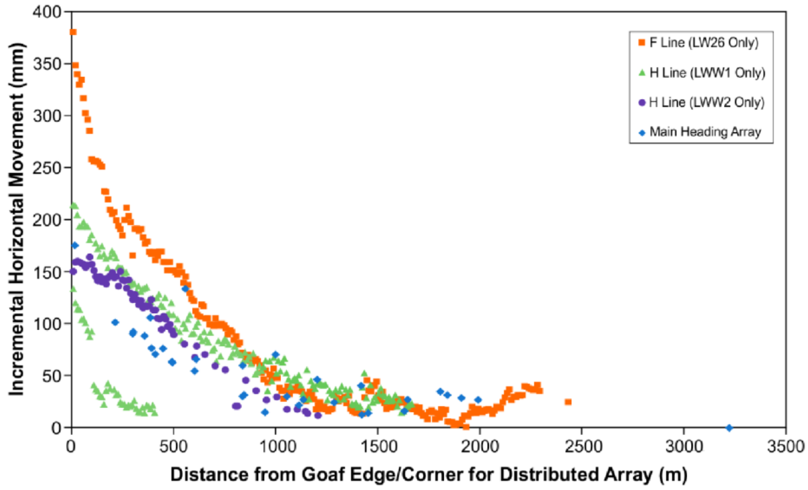


Fig. 3.16 Observed Incremental Far-Field Horizontal Movements at UCM (Mills)

The observed far field horizontal movements at UCM are therefore similar to the other far field horizontal movement plotted data in Fig. 3.13 and Fig. 3.14, (excluding the far field horizontal movements measured across this Bobadeen Creek), and those graphs can be used to predict future far field horizontal movement movements at MCC.

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

As detailed in Section 1.4.1 there are alluvial/regolith palaeochannel deposits, with a maximum thickness of 40-50 m, to the north and east of the proposed UG1 longwalls, where the depths of cover range from 90 to 130 metres, as is shown in Drawing No. MSEC731-07 and as is described in HydroSimulations (2015).

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, at other collieries, caused significant differences between the predicted and the observed levels of subsidence. Where the original strata was 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 less than was expected because these channels were capable of spanning over voids. However, where the original strata was filled in with weaker material, such as unconsolidated sediments, then, the observed subsidence under these channels can be greater than was expected because these weaker materials failed and collapsed more readily than the original strata. But, where the original strata was filled in with weak unconsolidated sediments and mining occur besides, but not under these palaeochannels, then, the observed far field horizontal movement and 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 channels, and its location with respect to the panel edges). Potential groundwater issues associated with the palaeochannel are discussed in a report by HydroSimulations (2015).

Since these palaeochannel sediments are located away from the edges of the longwalls, then, their presence should not affect the subsidence over the longwalls significantly. However, the presence of this 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.

4.1. Introduction

The following sections in this Chapter provide the maximum predicted systematic subsidence parameters resulting from the proposed extraction of Longwalls 101 to 105 within UG1 using the ModML and using the calibrated Incremental Profile Method, which was described in Chapter 3.

Comparisons are also provided between the Longwalls 101 to 105 within UG1 using the ModML and the maximum predicted systematic subsidence parameters resulting from the approved Longwalls 1 to 9 within UG1 using the PrefML.

The predicted subsidence parameters and the impact assessments for each of the natural features and items of surface infrastructure that have been identified within the UG1 Study Area, as detailed in Chapter 2, are provided in Chapter 5.

4.2. Maximum Predicted Incremental and Total Systematic Subsidence Parameters for the Proposed Longwalls

The maximum predicted subsidence parameters, which are detailed in this Chapter and the site specific predicted subsidence parameters in Chapter 5, are referred to as systematic ground movements and do not include the valley related upsidence and closure movements, or the effects of faults and other geological structures, or other non-systematic ground movements, which are discussed in Section 3.6. Such effects have been addressed separately in Chapter 5.

Typical examples of the predicted shapes of the systematic subsidence profiles over the ModML have been prepared along prediction lines called Prediction Line 1, Prediction Line 2, Prediction Line 3 and Prediction Line 4, the locations of which are shown in Drawing No. MSEC731-13.

The predicted incremental and total systematic subsidence, tilt and strain profiles along these four prediction lines over the ModML are shown in Fig. C.01, Fig. C.02, Fig. C.03, and Fig. C.04 which can be found in Appendix C. The magnitudes and the shape of these predicted subsidence profiles are very similar to the predicted profiles shown for the PrefML, however the values of the subsidence are slightly higher because of the increased seam thickness to be extracted, the slightly wider panels and narrower pillars.

When viewing observed incremental or total subsidence, tilt, curvature and strain profiles along monitored survey lines, there is always a much wider scatter in observed strain profiles than the other parameters.

The variation in the observed strain, especially when comparing strain values at a point rather than the maximum strains along a line, is usually far greater than the other parameters, not only in magnitude, but also in sign, (that is, often tensile strains have been observed where compressive strains were predicted, and vice versa). The observed strain values vary the most for those cases where the depths of cover were below 100 metres.

At these shallow depths of cover the observed values of curvatures and strain are particularly sensitive to:

- the location of the survey pegs in relation to the longwall panel edges and the moving longwall face;
- the placement of the survey pegs in relation to the other pegs, (i.e. the baylengths between and the orientation of these pegs); and
- any variations in local geology and surface topography.

Slight changes in the survey pegs positions result in large variations in curvatures and strains.

For these reasons, where the depths of cover are less than 100 metres, the predicted hogging and sagging curvatures and the predicted tensile and compressive ground strains can be very high and the actual strain or curvature value is almost meaningless. Hence the very high predicted curvatures that are presented in the following tables have been rounded to a set value of either >5 km^{-1} or <-5km^{-1} rather than presenting meaningless large numbers. Also, rather than providing predicted strains from the predicted curvatures, only the predicted curvatures are provided in these tables. The prediction of ground strains should therefore be based on a statistical approach, but, for the maximum strain cases, an approximate relationship between curvature and strain can be used, as is discussed below in Section 3.3, 3.9 and 4.4.1.

4.2.1. Maximum Predicted Incremental Subsidence Parameters

A summary of the maximum predicted incremental systematic subsidence parameters within the UG1 Study Area, due to the extraction of each of the proposed UG1 ModML longwalls, is provided in Table 4.1.

The greatest maximum incremental subsidence of 2280 mm has been predicted for Longwall 101, and the smallest maximum incremental subsidence of 2170 mm has been predicted for Longwall 105. The maximum predicted incremental subsidence of 2280 mm for Longwall 101 represents approximately 65% of the proposed extracted seam thickness at this location (3.5 metres). At this location, the depth of cover to the seam was 130 metres, the panel width to depth ratio is 310.8/130 = 2.39 and the pillar width to depth ratio is 19.6/130 = 0.15.

Table 4.1 Maximum Predicted Incremental Systematic Subsidence Parameters due to the Extraction of Longwalls 101 to 105 in the ModML

Longwall	Maximum Predicted Incremental Subsidence (mm)	Maximum Predicted Incremental Tilt (mm/m)	Maximum Predicted Incremental Hogging Curvature (km^{-1})	Maximum Predicted Incremental Sagging Curvature (km^{-1})
Due to LW101	2280	65	3.5	-3.5
Due to LW102	2220	115	>5	<-5
Due to LW103	2250	70	>5	-4
Due to LW104	2240	80	>5	-4
Due to LW105	2170	90	>5	<-5

For the approved PrefML over UG1, the maximum predicted incremental systematic subsidence was 1890 mm and this subsidence value was expected over Longwall 3 (after the extraction of Longwall 4). At this point the depth of cover was 143 metres and the proposed extracted seam thickness was 3.2 metres. This predicted total subsidence represented 62% of the proposed extracted seam thickness at that location. The panel width to depth ratio at that location for this approved PrefML was 305/143 = 2.13 and the pillar width to depth ratio was 30/143 = 0.21.

The increase in the maximum predicted incremental subsidence over UG1 from the approved Preferred Project Report (i.e. from 1890 mm to 2280 mm [20%]) is mostly due to the increased extracted seam thickness (3.2 metres to 3.5 metres [9%]), but, it is also influenced by the slightly increased panel width to depth ratios, the reduced pillar width to depth ratios and by adopting a more conservative approach for maximum incremental subsidence of 65% of the proposed extracted seam thickness.

The maximum predicted incremental systematic tilt over the UG1 due to the extraction of Longwalls 1 to 9 in the approved PrefML was 95 mm/m (i.e. 9.5 %) over Longwall 9. The maximum predicted incremental systematic tilt over the UG1 for the proposed ModML, due to the extraction of the proposed UG1 ModML Longwalls 101 to 105, is 115 mm/m, and this maximum tilt is predicted to occur near the tailgate of Longwall 102 after the extraction of Longwall 103.

The maximum predicted systematic incremental hogging and sagging curvature over the UG1 for the approved PrefML, after the extraction of the proposed Longwall 105, were provided as >5 km^{-1} and <-5 km^{-1}. The maximum predicted systematic incremental hogging and sagging curvature over the UG1 for the proposed ModML, after the extraction of the proposed Longwall 105, are provided as >5 km^{-1} and <-5 km^{-1}. As discussed in Section 4.2, these predicted incremental curvature values were rounded down to >5 km^{-1} and <-5 km^{-1} rather than presenting meaningless large numbers. (The actual unrounded curvature values were 10 km^{-1} and <-10 km^{-1} for the PrefML case and 14 km^{-1} and <-11 km^{-1} for the ModML case).

As discussed in Section 3.3 and 4.2, the maximum systematic incremental tensile and compressive strains can be predicted using the curvature to strain factor of 10. This approximate conversion provides maximum systematic incremental tensile and compressive strain values of 100mm/m for the PrefML. For the ModML case, the maximum predicted systematic incremental tensile strain is 140 mm/m and the maximum predicted systematic incremental compressive strain is 105mm/m, but, it is better to provide strain values of > 100 mm/m as these high values are not really meaningful.

4.2.2. Maximum Predicted Total Subsidence Parameters

A summary of the maximum predicted total systematic subsidence parameters within the UG1 Study Area, after the extraction of the proposed Longwall 105, is provided in Table 4.2. The predicted total systematic subsidence contours, after the extraction Longwall 105, are shown in Drawing No. MSEC731-13.

The maximum predicted total systematic subsidence after the extraction of Longwall 105 within UG1 is 2380 mm which occurs over Longwall 101 after the extraction of Longwall 102. At this location the depth of cover is 130 metres and the proposed extracted seam thickness is 3.5 metres. This predicted total subsidence of 2380 mm represents 68% of the extracted seam thickness at this location. At this location, the panel width to depth ratio is 310.8/130 = 2.39 and the pillar width to depth ratio is 19.6/130 = 0.15.

The increase in the maximum predicted total subsidence over this UG1 area from the approved PrefML (i.e. from 1980 mm to 2380 mm [20%]) is mostly due to the increased extracted seam thickness (3.2 metres to 3.5 metres [9%]), but, this increase is also influenced by the slightly increased panel width to depth ratios, the reduced pillar width to depth ratios and by adopting a more conservative approach for maximum incremental subsidence of 65% of the proposed extracted seam thickness.

The maximum predicted total systematic tilt over the UG1 due to the extraction of Longwalls 1 to 9 in the approved PrefML was 95 mm/m (i.e. 9.5 %). The maximum predicted total systematic tilt over the UG1 for the proposed ModML, due to the extraction of the proposed UG1 ModML Longwalls 101 to 105, is 115 mm/m, and this maximum tilt is predicted to occur near the tailgate of Longwall 102 after the extraction of Longwall 103.

Table 4.2 Maximum Predicted Total Systematic Subsidence Parameters within the UG1 Study Area after the Extraction of Longwall 105 in the ModML

Longwall	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
After LW101	2280	65	>3.5	<-3.5
After LW102	2380	115	>5	<-5
After LW103	2380	115	>5	<-5
After LW104	2380	115	>5	<-5
After LW105	2380	115	>5	<-5

The maximum predicted systematic hogging and sagging curvature over the UG1 for the approved PrefML, after the extraction of the proposed Longwall 10, were provided as >5 km^{-1} and <-5 km^{-1}. The maximum predicted systematic hogging and sagging curvature over the UG1 for the proposed ModML, after the extraction of the proposed Longwall 105, are also provided as >5 km^{-1} and <-5 km^{-1}. As discussed in Section 4.2, these predicted curvature values were rounded down to >5 km^{-1} and <-5 km^{-1} rather than presenting meaningless large numbers. (The actual unrounded numbers were 10 km^{-1} and <-10 km^{-1} for the PrefML case and 14 km^{-1} and <-11 km^{-1} for the ModML case).

As discussed in Section 3.3 and 4.2, the maximum predicted systematic tensile and compressive strains can be predicted over the UG1 for the approved PrefML, after the extraction of the Longwall 9, using the approximate curvature to strain factor of 10. This conversion provides tensile and compressive strain values of 100mm/m. For the ModML case, the maximum predicted systematic tensile strains is slightly greater than 140 mm/m and the maximum predicted systematic compressive strain is 105mm/m, but, it should be remembered that these high strain numbers are not really meaningful. These maximum strain values occurred near the tailgate of Longwall 102.

As discussed above, these predictions of systematic subsidence parameters do not include the valley related upsidence and closure movements, or the effects of faults and other geological structures. Such effects have been addressed separately in Chapter 5.

4.3. Review and Comparison of Predicted Subsidence Parameters using the Holla Series and Department's Handbook Methods

The maximum predicted systematic subsidence parameters over the proposed UG1 Longwalls 101 to 105 were determined using the Incremental Profile Method and then these values have been compared with the maximum predicted subsidence parameters obtained using the Holla Series Method (Holla, 1988) and the Department's Handbook Method for the Western Coalfields (Holla, 1991).

The maximum predicted systematic subsidence obtained using the Holla Series Method is determined from Figure 4 of a published paper which has been reproduced in Fig. 4.1. This figure provides the maximum predicted subsidence, as a ratio of the extracted seam thickness, for varying panel width-to-depth ratios and varying pillar width-to-depth ratios, based on critical extraction conditions.

From the figure, a prediction of 60% of the extracted seam thickness can be used for the proposed UG1 Longwalls 101 to 105 for comparative purposes. However, using the Department's Handbook Method for the Western Coalfields and based on an individual panel width-to-depth ratio of 2.59 (i.e. 310.8 metres / 120 metres) the maximum predicted subsidence per panel, obtained using Figure 7 of the Handbook, is 65% of the extracted seam thickness.

The Holla Series and the Department's Handbook Methods only allow the prediction of the maximum values of subsidence, tilt, curvature and strain, and do not precisely indicate where these maxima will occur. The comparisons were limited to, therefore, the maximum predicted values of each parameter over the proposed UG1 ModML longwalls.

The maximum predicted values of systematic subsidence, tilt and strain obtained using the Incremental Profile Method are compared to those obtained using the Holla Series and Department's Handbook Methods in Table 4.3. It can be seen from Table 4.3, that the maximum predicted systematic subsidence obtained using the Incremental Profile Method is similar to, but slightly greater than those obtained using the Holla Series and Department's Handbook Methods.

The maximum predicted systematic tilts and strains were obtained using the Department's Handbook Method after multiplying various factors by the maximum predicted subsidence in millimetres and dividing the result by the depth of cover in metres.

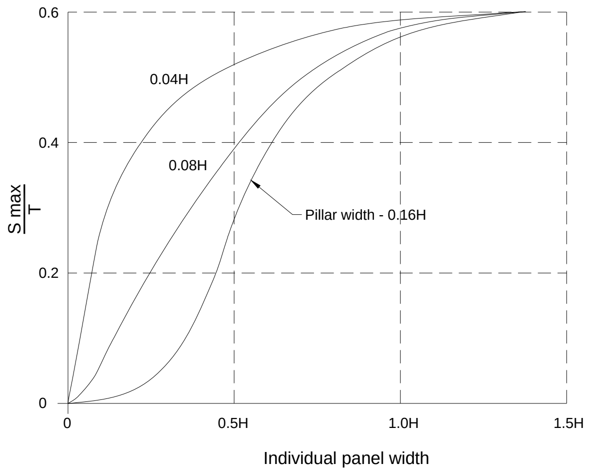


Fig. 4.1 Graph for the Prediction of Maximum Subsidence over a Series of Panels for Critical Extraction Conditions (after Holla 1988)

Table 4.3 Comparison of Maximum Predicted Parameters Obtained using Alternative Methods for the proposed UG1 Longwalls 101 to 105 in the ModML

Predicted Parameter	Incremental Profile Method	Holla Series and the Departments Handbook Methods
Vertical Subsidence (mm)	2280	2180
Tilt (mm/m)	115	110
Tensile Strain (mm/m)	>100	35
Compressive Strain (mm/m)	>100	65

4.4. Estimation of the Reliability of the Subsidence Predictions

The Incremental Profile Method should provide realistic, if not conservative predictions of the modified systematic subsidence, tilt, curvature, and strain movements over the proposed UG1 ModML longwalls. The predicted profiles obtained using this method also reflect the way in which each parameter varies over the mined area and indicate the movements that are likely to occur at any point on the surface.

Empirical methods of subsidence prediction are generally accepted as providing predictions of maximum subsidence to an accuracy of ±10 % to ±15 %. It was indicated by Dr Lax Holla, in his paper entitled, "Reliability of Subsidence Prediction Methods for use in Mining Decisions in New South Wales" (1991), that the accuracy of predictions of maximum subsidence, made using the Department's Empirical Method, generally ranged from +8 % to -11 %.

Only four of the 14 examples referred to in this paper had a maximum predicted subsidence less than the maximum observed subsidence, based on the information from seven different collieries in the Southern and Newcastle Coalfields. When the predictive graphs used in the Incremental Profile Method have been calibrated to local data, even greater accuracies have been found to be possible in predicting the maximum values of the subsidence parameters.

The prediction of subsidence parameters at a specific point is more difficult. Based upon a large number of comparative analyses, however, it has been concluded that the vertical subsidence predictions for single seam extractions, obtained using the Incremental Profile Method, should generally be conservative where the geology is consistent and the model has been calibrated to local data. Where subsidence is predicted at points beyond the goaf edge, which are likely to experience very low values of subsidence, the predictions should generally be accurate to within 50 mm of subsidence.

The systematic tilts can be predicted to a similar level of accuracy as subsidence as detailed above. It has been found, however, that variations between predicted and observed tilts at a point can occur where there is a lateral shift between the predicted and observed subsidence profiles, which can result from seam dip or variations in topography. In these situations, the lateral shift can result in the observed tilts being greater than those predicted in some locations, with the observed tilts being less than those predicted in other locations.

4.4.1. Variations in Observed Mining Induced Ground Strains

As discussed in Sections 3.3, 3.5 and 4.2, measured strains, at a point, have been found to vary considerably from the predicted systematic strain values that were based solely on a curvature to strain factor, not only in magnitude, but also in sign, (that is, the tensile strains have been observed where compressive strains were predicted, and vice versa).

These variations in measured strains suggest, reveal or indicate that:

- there are difficulties in measuring small changes in distances accurately;
- pre-existing natural joints can be influencing the measured ground movements;
- variations in the local surface geology can result in increased observed strains;
- whilst a component of the observed strains may result from the mining induced curvatures other horizontal movement components must be contributing towards the measured ground movements; and
- these other horizontal movement components that are believed to be caused by a complex interaction of many mechanisms including the:
  - magnitude of the vertical subsidence and tilt;
  - magnitude and principal direction of the in situ horizontal compressive stresses in the strata layers around the mined goaf and the surface strata layers;
  - presence and proximity of previously extracted panels in the currently mined seam and in other seams;
  - depth of cover;
  - steepness and direction of the surface topography (presence of headlands, valleys or gorges);
  - steepness and direction of the seam dip;
  - direction of mining in relation to both the surface and seam slope;
  - geology, geomechanical properties and thicknesses of all the overburden strata layers from the surface to the seam as well as the strata layers immediately under the seam;
  - presence of "headlands", valleys or gorges;
  - presence of geological faults, joints and igneous intrusions; and,
  - other contributing factors such as the degree of surface roughness and frictional resistance along the bedding planes, the changing moisture content of the surface rocks and soils, and the presence of groundwater flows along the bedding planes, etc..

Accordingly the confidence levels that we assign to subsidence, tilt and curvature predictions cannot be assigned to horizontal movement or strain predictions.

The following additional reasons also contribute to why strain predictions cannot be provided with the same degree of confidence as subsidence and tilt predictions:-

- Where a thick surface layer of soil, clay or rock exists, the underlying movements in the bedrock are often transferred to the surface at reduced levels and the measured strains are, therefore, more evenly distributed or more systematic in nature than they would be if they were measured at rockhead.
- Strain measurements can sometimes give a false impression of the state of stress in the ground. For example:
  - buckling of the near-surface strata can result in localised cracking and apparent tensile strain in areas where overall, the ground is in fact being compressed, because the actual values of the measured strains are dependent on the locations of the survey pegs.
  - where joints open up or cracks develop in the tensile phase and fail to close in the compressive phase, as they sometimes do if they are subsequently filled, the ground can appear to be in tension when it is actually in compression.
- Sometimes, survey limitations or errors can also affect the measured strain values and these can result from movement in the benchmarks, inaccurate instrument readings, or disturbed survey pegs. In these circumstances it is not surprising that the predicted systematic strain at a point does not match the measured strain. For example, it is difficult to measure variations in baylengths more accurately than ±5 mm, especially where tripods have to be set over sunken survey marks. Over a typical baylength of 20 metres, surveying error variations of ±0.25 mm/m are commonly seen in the observed strain data.
- Variations in local geology can affect the way in which the near surface rocks are displaced as subsidence occurs. In the compression zone, the surface strata can buckle upwards or can fail by shearing and sliding over their neighbours. If the surface strata layers are thinly bedded or if localised cross bedding exists, this shearing can occur at relatively low values of stress. These variations in longwall in local geology can result in fluctuations in the local strains, which can range from tensile to compressive. In the tensile zone, existing joints can be opened up and new fractures can be formed at random, leading to localised concentrations of tensile strain.
- In sandstone dominated environments, much of the earlier tensile ground movements can be concentrated at the existing natural joints, which have been found to be at an average spacing of 7 to 15 metres.

- Current systematic horizontal prediction methods are principally based on factors being applied to the predicted curvature ground movements and do not account for movements due to the far field movement mechanism or valley related movements, i.e. the release of insitu horizontal stress towards the goafed areas or valleys.
- It is also recognised that the ground movements above a longwall panel can be affected by the gradient of the coal seam, the direction of mining and the presence of faults and dykes above the panel, which can result in a lateral shift in the subsidence profile.

Predictions of strain at isolated features have been provided in this report for comparison purposes, so that the potential for impacts can be compared from place to place. As described above, it is possible that the actual strain at each feature could be greater or less than that predicted, or could be tensile where compression was predicted, or vice versa. It is expected, however, that the observed strains at the features will generally be within the range of the maximums predicted within the UG1 Study Area, which were provided in Section 4.2.

The Incremental Profile Method approach allows site specific predictions for each natural feature or item of infrastructure and hence provides a more realistic assessment of the subsidence impacts than by applying the maximum predicted strains at every point, which would be overly conservative and would yield an excessively overstated assessment of the potential subsidence impacts. However, because of the variability in observed strain values, the prediction of strain at a point obtained using the Incremental Profile Method should be considered within an appropriate confidence interval.

The comparison between predicted and observed subsidence movements can be undertaken during the extraction of the proposed UG1 ModML longwalls. The subsidence predictions made using the Incremental Profile Method can then be refined based on the monitoring data obtained during mining. Further refinement can also be made to the predictions where local monitoring data close to the UG1 Study Area becomes available.

4.5. Predicted Horizontal Movements and Tilts

As discussed above in Section 4.4.1, it is much harder to accurately predict horizontal movements and strains than it is to accurately predict subsidence and tilts. Predicted horizontal movements at particular locations over the UG1 have been calculated by applying a factor to the predicted tilt values. In the Newcastle, Hunter and Western coalfields, a uniform factor of 10 is typically adopted, being the same conversion factor that is also used to determine strains from curvatures and this conversion factor has been found to give a reasonable correlation with the measured ***maximum*** horizontal movement and strain data for single-seam conditions.

Based on available monitoring data, this factor varies and will be higher at low tilt values and lower at high tilt values. The application of this uniform factor will generally lead to over-prediction of horizontal movements where the tilts are high and under-prediction of the horizontal movements where the tilts are low, for single-seam conditions. However, it should be noted that the application of this factor of 10 does not allow for the possible additional non-systematic ground movements, such as far field movements, which is discussed below.

The maximum predicted systematic tilt in the UG1 Study Area, resulting from the extraction of the proposed UG1 ModML longwalls, is 95 mm/m. Applying a factor of 10 to this magnitude of tilt should provide a conservative prediction of the maximum horizontal movement. It is expected, therefore, that the maximum horizontal movements resulting from the extraction of the proposed UG1 ModML longwalls would be in the order of 950 mm.

Horizontal movements do not directly impact on natural features or items of infrastructure, and most impacts occur as the result of differential horizontal movements. The impacts of systematic strain on the natural features and items of infrastructure are addressed in the impact assessments for each feature in Sections 5.1 to 5.17.

In addition to the systematic or conventional subsidence movements that have been predicted above and adjacent to the proposed UG1 ModML longwalls, it is also likely that far-field horizontal movements will be experienced during the extraction of these longwalls.

4.6. Predicted Far-Field Horizontal Movements

As discussed in Section 3.5, relatively high far-field horizontal movements have been observed at UCM and such movements could occur at MCC.

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data from the NSW Coalfields. The far-field horizontal movements resulting from longwall mining were generally observed to be orientated towards the extracted longwall. At very low levels of far-field horizontal movements, however, there was a high scatter in the orientation of the observed movements, which can contain larger proportions of survey error, in addition to valley related closure movements, and movements along geological anomalies

The observed incremental far-field horizontal movements, resulting from the extraction of a single longwall, were predicted using the prediction graphs in Section 3.8 and Section 3.8.1. The data points in these plots indicate that incremental far-field horizontal movements of up to 250 mm have been observed at distances of 250 metres from extracted longwalls and up to 20 mm have been observed at distances of 2000 metres from extracted longwalls.

The predicted far-field horizontal movements resulting from the extraction of the proposed UG1 ModML longwalls are generally very small and can only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than the order of survey tolerance (i.e. less than 0.3 mm/m).

The impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the vicinity of the UG1 is not expected to be significant, except where they occur at large structures which are sensitive to small differential movements.

The expected far-field horizontal movements to the north and east of the proposed UG1 longwalls are likely to be less than normally predicted because of the presence of the unconsolidated palaeochannel sediments within the palaeochannels to the north and east of the proposed UG1 longwalls, as shown in Drawing No. MSEC731-07. Since the depth of these unconsolidated palaeochannel sediments represents a reasonable proportion of the shallow depths of cover in these locations, then, reduced subsidence and reduced far field horizontal movements are likely to be experienced along the railway line, road and transmission lines that are located beyond the edges of these panels in this area.

4.7. Likely Height of the Fractured Zones above the Proposed Longwalls

Longwall mining results in surface and sub-surface subsidence movements and it creates new fractures and opens up or widens pre-existing bedding planes and natural joints within the overburden. The location of and the impacts from these mining induced fractures depend on both the mining geometry and the overburden geology. Unfortunately, there have been mining cases, where mine subsidence ground movements have caused extensive surface cracking and overburden fracturing and captured and drained surface water and groundwater down into mine workings. Usually these mine inflow events occurred at shallow depths of cover, however, significant inflows have been recorded in some cases at depths of cover up to 300 metres. On the other hand, there have also been many cases where mining has been successfully carried out in Australia at very shallow depths of cover of less than 50 metres under surface waters, rivers, creeks, lakes and oceans with negligible water inflows into the mine. Mining has also been carried out successfully under various aquifers with negligible, minor or only small losses of water from the aquifers being recorded into the mines.

The issue of hydraulic connections between the surface water bodies, groundwater and mine workings has been the subject of several government inquiries and reports over the past few decades by the NSW State government and more recently by the federal government. The first major inquiry was commenced in 1974 by Mr Justice Reynolds for the State Government of NSW because of the fear that hydraulic connections between the stored waters of many major dams and deep mine workings in the Southern Coalfields of NSW could impact on Sydney's water supply. The Stored Waters Inquiry concluded in 1977 that under certain strict conditions mining could be permitted beneath these major water supply reservoirs. In the Stored Waters Inquiry Report, Reynolds (1977) advised that first workings coal was extensively and successfully mined under Newcastle Harbour and under the ocean off Newcastle with narrow bords and pillars at many mines taking up to 50% of the coal by plan area with no reported inundations where the depths of cover is less than 50 metres. Additionally extensive areas of first workings, panel and pillar second workings, longwall and total extraction has taken place under various lakes south of Newcastle.

Hence, the impacts of mining and subsidence on surface water and groundwater resources have been found to be extremely variable and it is important to appreciate the circumstances for each of these mining cases in order to understand when water may be lost from the surface or aquifers and when mining can be undertaken safely without noticeable impacts on groundwater or surface flows.

The height that new mining induced fractures may form above a panel has been investigated by many researchers and some researchers have found new cracks hundreds of metres above the coal seam. Some researchers advise that the height at which new fractures (HoF) can form up to 1 to 1.5 times the panel width above the coal seam. However, the creation of a new mining induced fracture does not necessarily imply that a direct hydraulic connection will exist down from that fracture to the seam. It should be recognised that the height of the highest observed fracture that was caused by mining is usually much higher than the height of the highest interconnected fracture. In order for significant volumes of surface water or groundwater to flow into the mine, the created fractures must form a connected continuous path or a conductive network towards the mined opening.

The height of the connected fracturing zone (HoCF) which is defined as the height of a zone above the seam from which mining induced connected or continuous fractures can transmit water from the overlying strata to the mined void, or, the height of a zone above the seam from which water would flow freely into the mine. The HoCF is less than the HoF, depending on many factors as is discussed below.

The extent, severity and manner of the observed impacts of coal mining on surface water resources and groundwater aquifers vary between different coal mines and coal mining regions because every situation is different. The nature and extent of mining induced ground movements around, beneath and near these surface water resources and groundwater aquifers varies considerably due to differing sizes of the mined panels, depths of cover and proximities to the water bodies. The specific geology of each case should be closely considered as the presence or absence of strong strata channels or impermeable layers in the overburden can completely change the generalised impact assessment that are commonly based on longwall widths or seam thicknesses.

A number of researchers have commented on the likely mechanics of mining induced strata deformations. A common approach to the study of these impacts has centred on classifying the overburden strata over mined panels into a number of zones with different deformation characteristics. However, the terminology used by different authors to describe these strata deformation zones above extracted longwalls varies considerably and caution should be taken when comparing the recommendations from differing authors.

Singh and Kendorski (1981) proposed the following three zones that were called the: fracture zone; aquiclude zone; and zone of surface cracking. These zones are illustrated in Fig. 4.2.

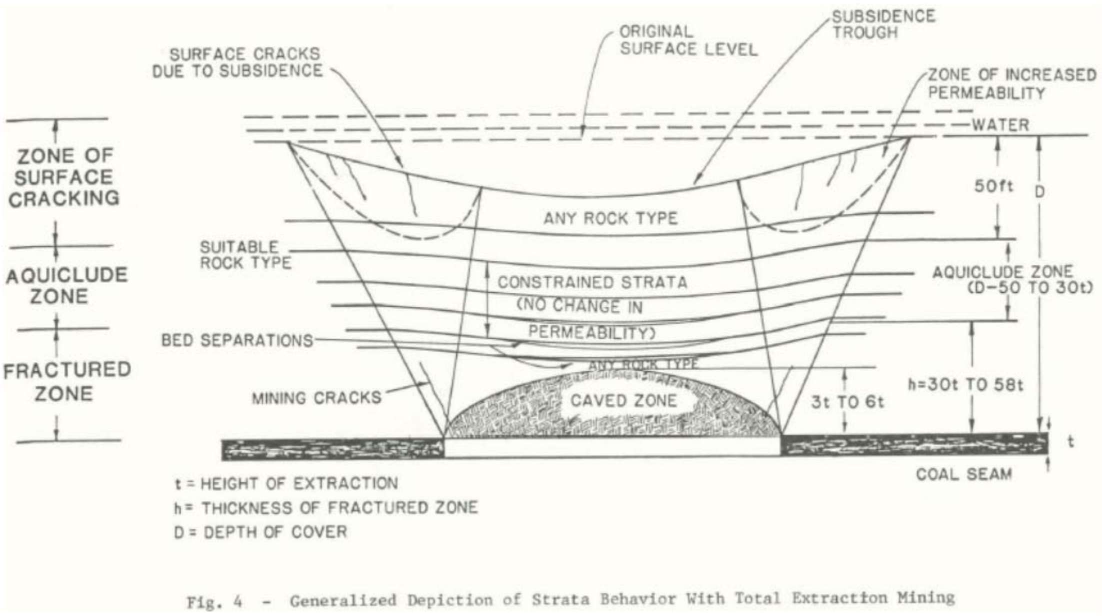


Fig. 4.2 Zones in the Overburden according to Singh and Kendorski (1981)

Kratzsch (1983) identified four zones, but named them the: immediate roof; main roof; intermediate zone; and surface zone. These zones are illustrated in Fig. 4.3.

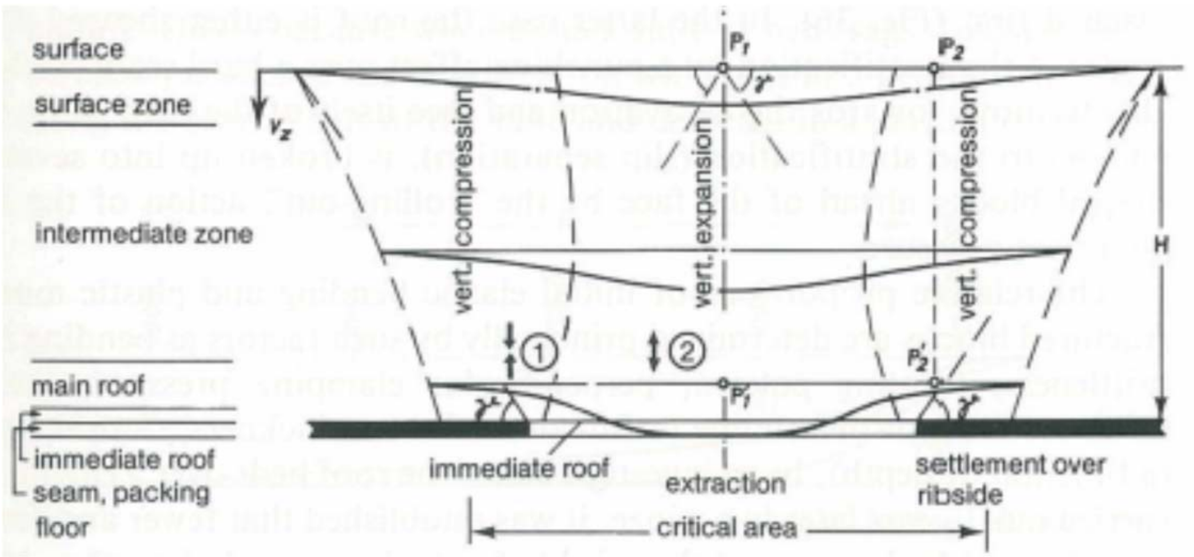


Fig. 4.3 Zones in the Overburden according to Kratzsch (1983)

Peng and Chiang (1984) recognised only three zones as reproduced in Fig. 4.4.

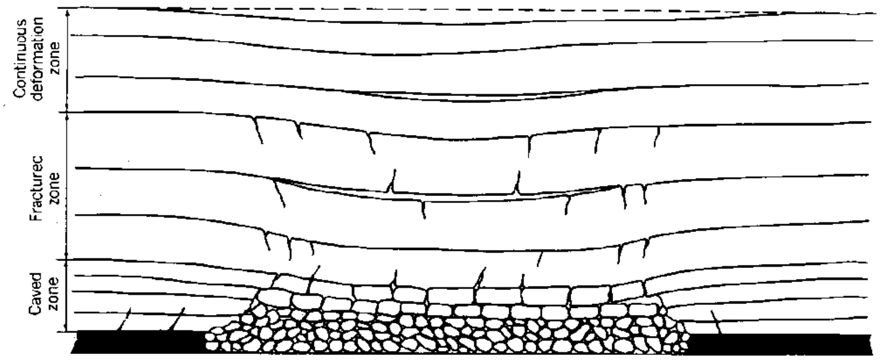


Fig. 4.4 Zones in the Overburden According to Peng and Chiang (1984)

Whittaker and Reddish (1989) used physical models built of sand, plaster and water mixes that were suitably scaled in strength and size to simulate the movement of the overburden, to illustrate the development of fracture propagation and to demonstrate the strata mechanisms. An example of the physical models is provided in Fig. 4.5.

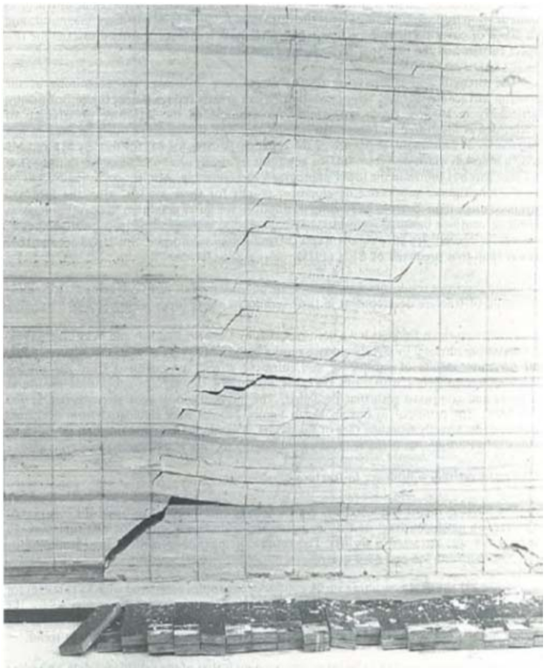


Fig. 4.5 Physical Modelling of the Overburden (Whittaker and Reddish, 1989)

Two fracturing zone were considered in these models: firstly the maximum height extended by those fractures which were judged to be interconnected with the extraction horizon, referred to as *Zone A*; and secondly the extent of any appreciable fracturing even if they did not necessarily directly connect with the extraction horizon, referred to as *Zone B*.

Zone A fracture development was interpreted as being indicative of where free flow from an overlying aquifer would readily occur, whilst Zone B could be indicative of where there might be a risk of water inflow seeping horizontally from an overlying aquifer but not necessarily flowing downwards to the mine. The interpretation of these fracture development zones as a proportion of the depth of cover based on maximum tensile stresses in the overburden was presented in Fig. 4.6 (Whittaker and Reddish, 1989).

Whittaker and Reddish (1989) also recognised that local geology and depth of mining play important roles, especially in influencing the magnitude and extent of fracture development. They stated that bands of low permeability, such as claystones, shales, siltstones, mudstones and tuffs within the overburden, can act as major factors in controlling water seeping from overlying horizons, even though stronger fractured beds may exist above and below such pliable and impervious bands. It was also noted that the existence of pliable mudstone beds within the strata sequence would tend to inhibit the magnitude and extent of fracture development above the ribside.

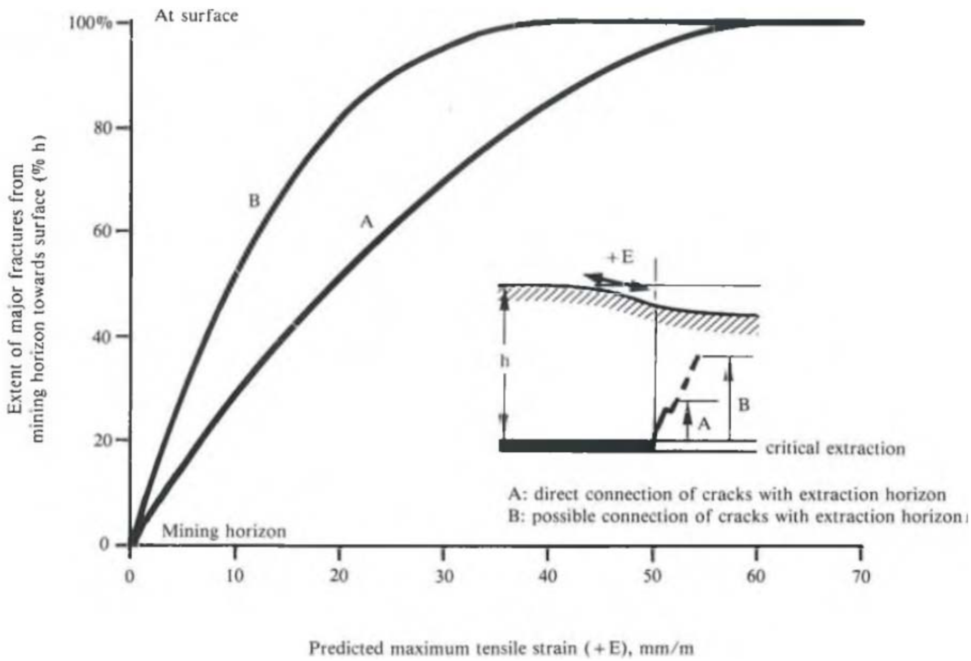


Fig. 4.6 Extent of Major Fractures from the Mining Horizon (Whittaker and Reddish, 1989)

Forster and Enever (1992) undertook a major groundwater investigation over supercritical extraction areas in the Central Coast of NSW and concluded that that overburden could be sub divided into four separate zones, as shown in Fig. 4.3, with some variations in the definitions of each zone. Forster and Enever noted that while the height of the caved zone over these total extraction areas were related principally to the extracted seam height, seam depth and the nature of the roof lithology, the extent of the overlying disturbed zone was dependent on the strength and deformation properties of the strata and to a lesser extent on the seam thickness, depth of cover and width of the panel. Forster (2014) wrote a hydrogeological assessment report for a mine in the Central Coast area of NSW in which he provided the following additional advice on the HoCF relating to the influence of the presence of layers of low permeability within the overburden; "*The exact level of the top of this zone* (HoCF) *will most likely depend on the position of the numerous tuff layers located in the upper part of the formation. Previous analyses of bore cores indicated that there are up to 100 separate tuff or tuffaceous claystone horizons ranging from 1 mm to more than 3 metres thick in the overburden. Any cracks which penetrate the entire thickness of coarse-grained material in the lower section of the formation should be sealed when they reach the tuff layers, due to plastic deformation or swelling of the reactive clays contained in them. This is even more likely if the cracking results in some groundwater movement. Any one of these tuff layers therefore could form a relatively impermeable horizon that would present a barrier to vertical groundwater movement in the overburden strata, provided that it is located higher than about 65 metres above the roof of the seam."*

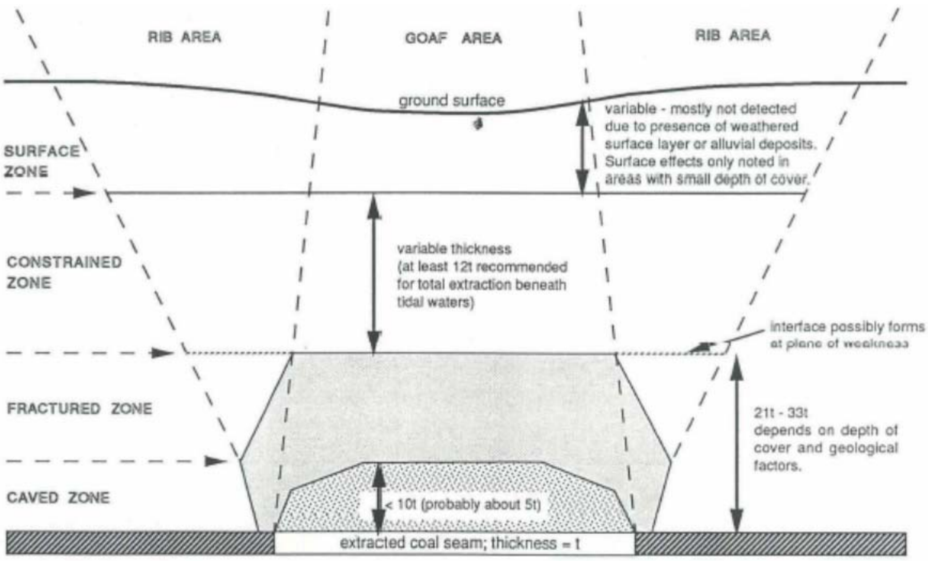


Fig. 4.7 Zones in the Overburden according to Forster and Enever (1992)

McNally et al (1996) recognised only three zones, which they referred to as the: caved zone; fractured zone; and elastic zone. These zones are illustrated in Fig. 4.8.

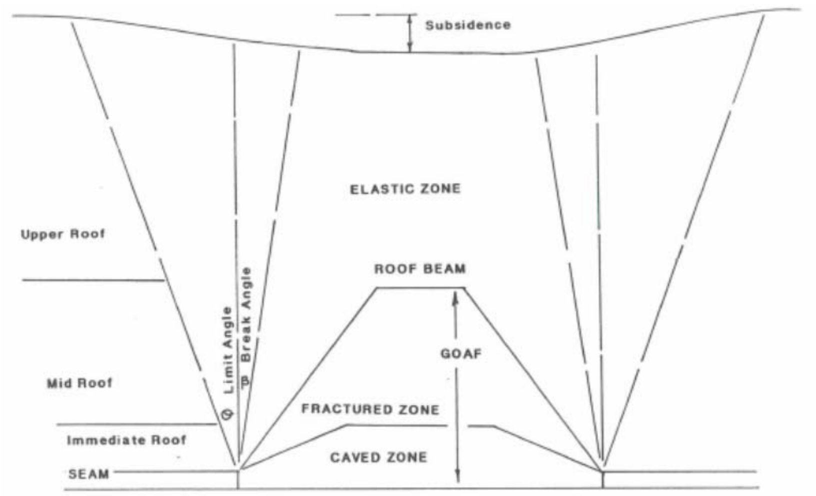


Fig. 4.8 Zones in the Overburden according to McNally et al (1996)

Ditton, Frith and Hill (ACARP Project C10023, 2003) reviewed the available borehole data within the Central Coast Region of the Newcastle Coalfield and derived regional formulas for the Height of Connected Fracturing (HoCF), referred to as Zone A, and the Height of (disconnected) Fracturing (HoF), referred to as Zone B at which the horizontal permeability increases as a result of strata de-lamination and fracturing, however, a direct connection with the workings does not occur. Ditton, Frith and Hill confirmed that their definition of HoCF refers to height from which mining induced fractures provides a direct hydraulic connection to the workings.

Ditton (2005) provided the following description of five zones in the following sketch. It can be noted that Ditton has split the constrained zoned, as described by Forster and Enever into the Dilated Zone (B) and the Confined Zone C.

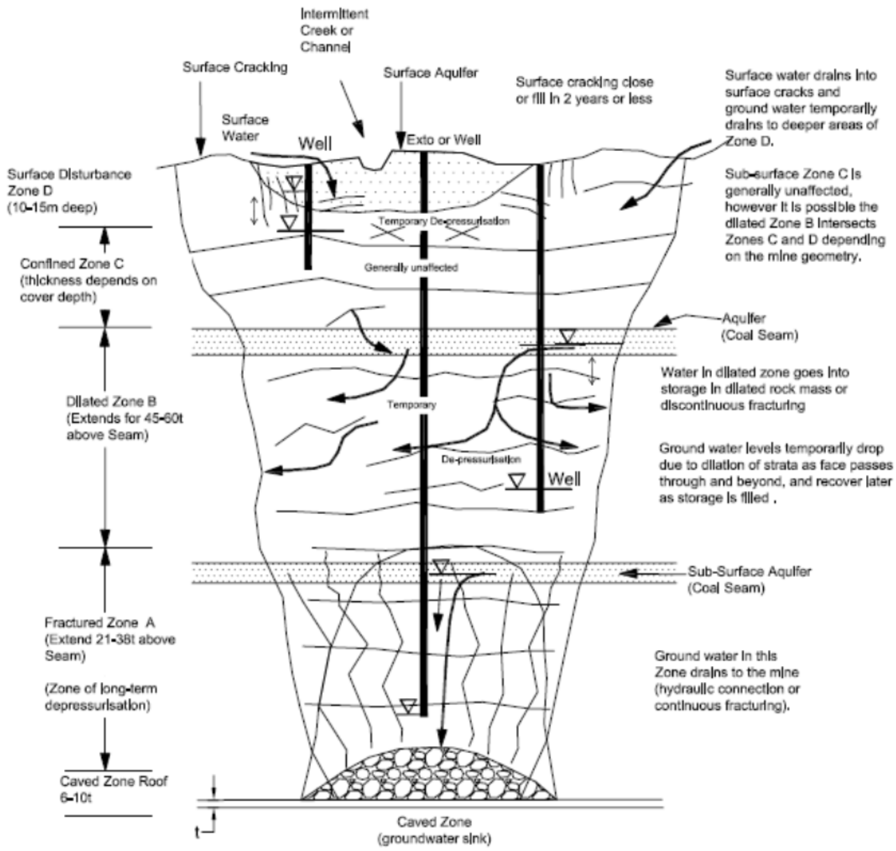


Fig. 4.9 Zones in the Overburden according to Ditton (2005)

Since then there have been several major government inquiries that have reviewed the effects of mining on surface and groundwater and the potential loss of water towards a mine and these report have included the following sketch that was prepared by Mackie (2007) to explain the nature of fracturing over a coal mine. This model has four zones as illustrated in Fig. 4.10.

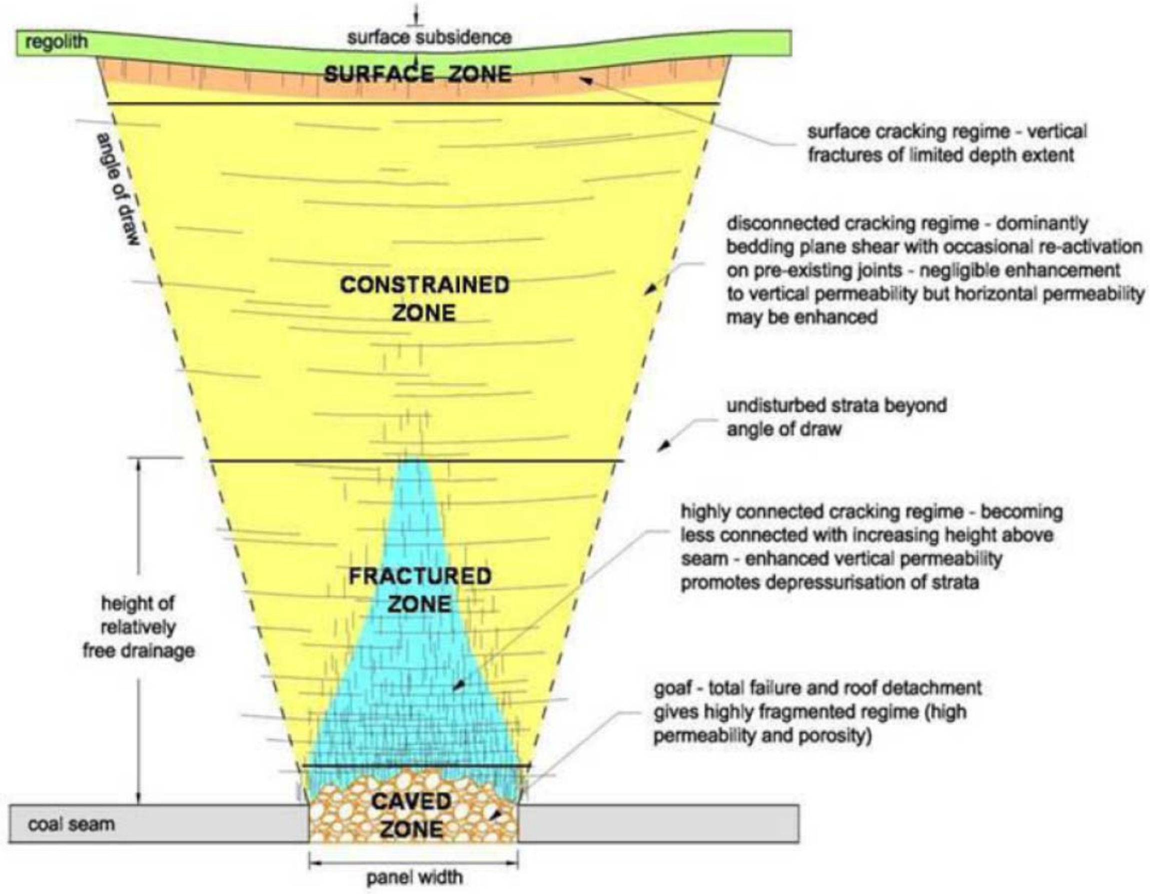


Fig. 4.10 Zones and Nature of Overburden Fracturing - Conceptual Caving Model (Mackie, 2007)

The more recent studies have highlighted that mine design recommendations should not be applied blindly based on the extracted seam thickness or longwall panel width and that careful consideration must always be given to site specific geology as host geology plays a significant or major role in determining the height of connected fracturing.

Experience in NSW, Queensland and around the world has indicated that, if the right type and thickness of the less permeable strata layers, (i.e. clays, shales, siltstones, tuffs or claystones), are present above the "fractured zone" and within a "constrained zone", then extraction may take place beneath water bodies without surface water finding its way into the workings. Where none of these less permeable materials are present in the overburden above the "fractured zone", then, much higher HoCF are observed.

For the purpose of the discussions provided in this report, the following four zones have been adopted:-

- *Caved* or *Collapsed Zone* comprises loose blocks of rock detached from the roof and occupying the cavity formed by mining. This zone can contain large voids (high porosity and high permeability). It should be noted, that some authors note primary and secondary caving zones.
- *Disturbed* or *Fractured Zone* comprises in-situ material that has undergone significant deformation and is supported by the material in the caved zone. This zone has sagged downwards and consequently suffered significant bending, fracturing, joint opening and bed separation. Enhanced horizontal and vertical permeability. It should be noted, that some authors include the secondary caving zone in this zone.
- *Constrained Zone* comprises confined rock strata above the disturbed zone which have sagged slightly but, because they are located above arching or spanning strata layers or because they are supported by the collapsed and disturbed zones, they have not experienced significant fracturing or alteration to the original physical properties. Some bed separation or slippage can be present as well as some discontinuous vertical cracks, usually on the underside of thick strong beds, but not of a degree or nature which would result in connective cracking or significant increases in vertical permeability. Some increases in horizontal permeability can be found but experience negligible increase in vertical permeability. Weak or soft beds in this zone may suffer plastic deformation. It should be noted that some authors include a dilated zone within this zone.
- *Surface Zone* comprises unconfined strata at the ground surface in which mining induced tensile and compressive strains may result in the formation of surface cracking or ground heaving.

Just as the terminology differs between the various authors, the means of determining the extents of each of these zones also varies. Sometimes the heights of each zone were based on fracture observations, or sub-surface borehole measurements only, or pore pressure and permeability monitoring.

Hence some of the misunderstanding and difficulties in establishing the heights of the various zones of disturbance above extracted longwalls stem from: the imprecise definitions of the fractured and constrained zones; the differing zone names and clarity regarding whether the fractures were continuous, connected, discontinuous or not connected; the use of different extensometer borehole testing methods, the use of differing permeability or piezometer measuring methods and differing interpretations of monitoring data. Some authors have suggested simple equations to estimate the heights of the collapsed and fractured zones based solely on the extracted seam height, whilst others have suggested equations based solely on the widths of extraction, and then others have suggested equations should have been based on the width-to-depth ratios of the extractions.

While some authors assessed the influence of geology on the height of the connected fracturing to be only associated with the ability of various massive strata layers to span over the mined void, other authors believe “the influence of geology” should include an assessment of the presence of and the effect of strata layers of low permeability, (such as claystones, shales, siltstones, mudstones and tuffs within the overburden), because these layers, if they are present, can act as a barrier to the downward flow of water into the mine.

Many engineers, surveyors, geologists and groundwater hydrologists have published reports and papers on the effects of mine subsidence on surface water and groundwater resources. Over the past decade the Australian Coal Industry’s Research Program (ACARP) sought research proposals that addressed this issue as one of their key industry problems. Several ACARP research reports have now been published that provide advice on the likely impacts of mining on surface water and aquifers. Two recent ACARP funded reports provide extensive discussions on modelling techniques to assess the heights of the various defined zones over mined panels and discuss models that can be used to determine the HoCF. These reports are:

- CSIRO, Guo, Adhikary and Gaveva (2007), “Hydrogeological Response to Longwall Mining”, ACARP Research Project No. C14033; and
- Gale (2008), “*Aquifer Inflow Prediction above Longwall Panels*”, ACARP Research Project No. C13013.

Gale (ACARP C14033, 2007) provided the following overview chart, Fig. 4.11, to provide an averaged mine inflow assessment based on averaged rock and conductivity rates, however, it should be noted that Gale emphasised that these averaged inflows change with differing geology.

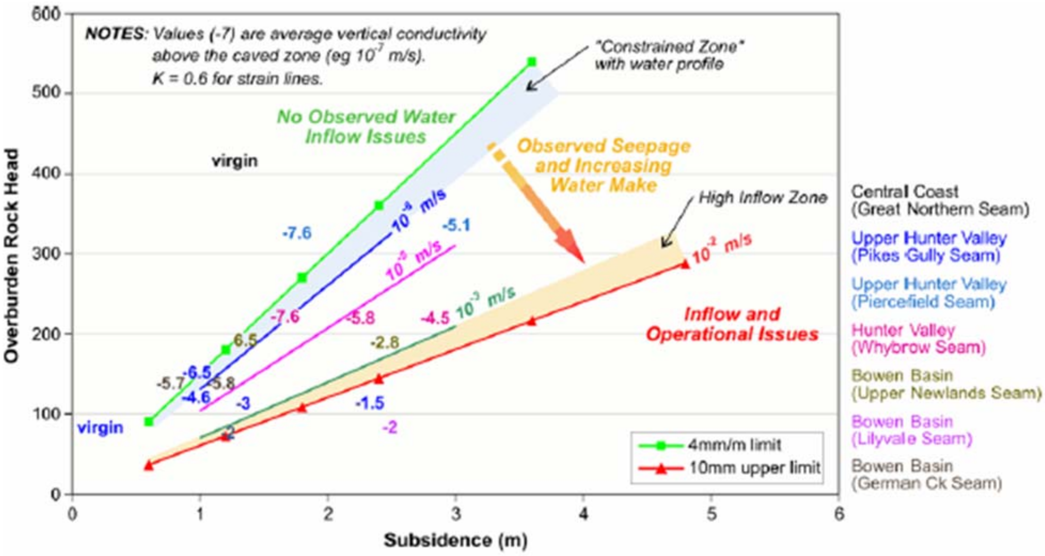


Fig. 4.11 Average Overburden Conductivity characteristics relative to subsidence and depth criteria (Gale, 2007)

Recently some further extensive studies have been published on this issue by the Australian Government Department of Environment, on the advice of the Independent Expert Scientific Committee on Coal Seam Gas and Large Scale Mining Development. This Committee was established as a statutory committee in 2012 by the Australian Government under the *Environment Protection and Biodiversity Conservation Act 1999 (Cth)* in response to community concerns about coal seam gas and coal mining.

Fortunately, some basic concepts and understandings are now developing, but, varying opinions are still being provided on: which subsidence parameter influences the observed mine flow impacts the most; how best to determine the HoF and likely impacts of mining on water resources; and the choice of which computer programmes should be utilised in these studies.

Importantly the presence of strong or massive strata layers and the presence of layers of low permeability have been observed to have a significant influence on the impact of mining on surface water, aquifers and on the rate of water inflows into mines. In conclusion, MSEC believes that a detailed model is required that combines both the geotechnical and hydrogeological factors to predict the HoCF accurately.

4.7.1. Likely Height of the Fractured Zone above the Proposed Longwalls at MCC

The proposed UG1 Longwalls for both the PrefML and the ModML at MCC have width-to-depth ratios between 2 and 3 and it is conservatively assumed that there are no competent strata layers spanning over the top of the fractured zone. In this case where the extracted seam thicknesses is 3.2 to 3.5 metres, the depths of cover are shallower than 100 metres, the panel width-to-depth ratios are greater than 2, the predicted levels of subsidence that are greater than 2 metres, and, the overburden strata has no aquitard or aquiclude units near the surface, it is expected that the HoCF will extend up from the coal seam to the ground surface, as was previously suggested for approved UG1 PrefML at MCC.

Though it is also possible that some thick units of high strength basalt may exist within the overburden at places with sufficiently high strength to prevent the HoCF from always reaching the ground surface level.

Hence, a more detailed analysis of the likely HoCF is required and further discussions on the likely heights of the fractured zones are provided in the specialist report by HydroSimulations (2015).

4.8. The Likelihood of Irregular Profiles

Wherever faults, dykes and abrupt changes in geology are present at the surface, it is possible that irregularities in the subsidence profiles could occur. Similarly, where surface rocks are thinly bedded and where cross-bedded strata exist close to the surface, it is possible for surface buckling to occur, leading to irregular movements. Many of the observed irregularities in subsidence profiles can be explained by the presence of surface incisions such as gorges, river valleys and creeks.

Irregular profiles can also occur where longwall mining is carried out beneath previous workings such as bord and pillar extractions. In such situations, the stooks left in the upper seam can collapse, when mining occurs beneath them, leading to localised subsidence and irregular subsidence profiles. However, there are no earlier workings above the proposed UG1 ModML longwalls, and this kind of irregularity will not occur in this case. Irregularities commonly occur in very shallow mining situations, where the collapsed zone, above the extracted seam, extends all the way to the surface. It is therefore possible that anomalous movements could occur as a result of the extraction of the proposed UG1 ModML longwalls.

5.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE EACH OF THE NATURAL FEATURES AND ITEMS OF SURFACE INFRASTRUCTURE LOCATED WITHIN THE UG1 STUDY AREA

5.1. Introduction

The following sections provide the descriptions, predictions and impact assessments for the natural features and items of infrastructure that were identified within the UG1 Study Area.

The predicted subsidence parameters for each of the natural features and items of surface infrastructure were determined using the calibrated Incremental Profile Method that is described in Chapter 3. The Incremental Profile Method is generally conservative, i.e. it provides predicted subsidence values that are generally higher than those actually measured after mining. Similarly the predictions of valley upsidence and closure movements using the ACARP method for predicting upsidence and closure are also generally higher than those actually measured after mining.

Accordingly the observed parameters at a specific site are more likely to be less than predicted, particularly when comparing the maximum predicted values with the maximum observed values. But, when comparing site specific predictions, the actual subsidence parameters often vary from those predicted, depending on many factors including differences in local geology, and the exact position of each feature or item within the subsidence trough. Therefore to provide additional conservatism for these site specific predictions the predicted values of subsidence, tilt, curvature and strain have been determined at the specific location and within a distance of 20 metres from the perimeter of each specific location. The maximum of these predicted values for each natural feature or item of surface infrastructure has been reported. This methodology may therefore increase the site specific predictions, especially where the predicted values are small.

As described in Section 4.4.1, the prediction of strain at a point is more difficult than the prediction of subsidence and tilt at a point. This variation is seen as a reflection, not only in the variations in the local surface geology, that pre-existing natural joints influence actual ground movements, and the difficulties in measuring small changes in distances accurately, but it also reflects the fact that strains result from both mining induced curvatures, from differential horizontal movements caused by the relief of in situ horizontal compressive stress towards the mined goafed areas and from various other strata mechanisms. It is possible, therefore, that the actual strain measured at each isolated feature could be greater or less than that predicted, or the measured strain could be tensile where compression was predicted, or vice versa.

Because of the variability in the observed strain values, the prediction of strain at a point obtained using the Incremental Profile Method should be considered within appropriate confidence intervals. Therefore, although predictions of strain at isolated features have been provided in this report, for comparison purposes, based on curvature alone, so that the potentials for impact can be compared from place to place, the actual strains at the isolated features will generally be within a range of the maximums predicted within this UG1 Study Area.

5.2. Drainage Lines

A number of small drainage lines have been identified above the longwalls and within the UG1 Study Area, as shown in Drawing No. MSEC731-08.

Some of these drainage lines flow to the north and west off the UG1 area towards the OC1 Pit. Other drainage lines currently flow off the UG1 area to the north and east towards the Murragamba Creek or Wilpinjong Creek. However, after the OC4 Pit is formed most of these drainage lines will either be diverted or flow into this Pit.

Drainage Lines 4 and 5 are located within the footprint of the approved out-of-pit emplacement and would be covered before the longwalls are to be extracted. That is, when Longwall 104 is being extracted, rather than being at the base of a valley, the current Drainage Lines 4 and 5 will be part of an out-of-pit emplacement. Hence revised subsidence predictions are not provided for these two drainage lines.

The predictions and impact assessments for the remaining drainage lines within the UG1 Study Area are provided in the following sections.

5.2.1. Predictions for the Drainage Lines

The drainage lines are located across the UG1 Study Area and are likely, therefore, to be subjected to the full range of predicted systematic subsidence and valley related movements. The predicted movements have been determined along two drainage lines, which have been called DL6 and DL7, and these drainage lines are shown in Drawing No. MSEC731-08.

The predicted profiles of systematic subsidence, tilt and strain along the alignments of DL6 and DL7 resulting from the extraction of the proposed UG1 ModML longwalls, are shown in Figs. C.05 and C.06, respectively, in Appendix C.

A summary of the maximum predicted total systematic subsidence parameters along these drainage lines, after the extraction of each proposed longwall in UG1, is provided in Table 5.1.

Table 5.1 Maximum Predicted Systematic Subsidence Parameters along the Alignments of the Drainage Lines Resulting from the Extraction of the Proposed UG1 ModML Longwalls

Location	Approved PrefML		Proposed ModML			
	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Drainage Line 6	1830	70	2215	60	>5	<-5
Drainage Line 7	1850	70	2225	60	>5	<-5

Assuming a curvature to strain conversion factor of 10, the maximum predicted systematic total ***tensile*** and ***compressive*** strains along these drainage lines due to the extraction of Longwalls 1 to 9 in the approved PrefML were greater than 50 mm/m. The maximum predicted systematic total ***tensile*** and ***compressive*** strains over the UG1 for the proposed ModML, after the extraction of the proposed UG1 ModML Longwall 105, are also greater than 50 mm/m.

The drainage lines will also be subjected to travelling tilts and strains where the extraction faces of the proposed UG1 ModML longwalls pass beneath them. It is expected that the drainage lines could be subjected to travelling tilts up to 60 mm/m (i.e. 6 %), or changes in grade up to 1 in 17, and could be subjected to travelling strains up to 40 mm/m.

It is also possible that the drainage lines could experience some valley related movements resulting from the extraction of the proposed UG1 ModML longwalls, however these movements should be small since some of the in situ stress would have been released during the excavation of the open cut pits. It is also noted that the valley shapes of the drainage lines become much flatter beyond the UG1 Study Area and hence the magnitudes of these upsidence and closure movements are expected to be much lower than the systematic movements and hence may not be significant.

5.2.2. Impact Assessments for the Drainage Lines

The drainage lines within the UG1 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. The maximum predicted systematic subsidence along drainage lines resulting from the extraction of the proposed UG1 longwalls is approximately 2225 mm and the maximum predicted systematic tilt along the alignments of the drainage lines is 60 mm/m (i.e. 6 %) and or a change in grade of 1 in 17.

The predicted changes in grade along the drainage lines are generally less than most of the natural grades, which vary from approximately 20 mm/m to 500 mm/m. Consistent with the approved PrefML, it is still expected that some ponding may occur along these drainage lines resulting from the extraction of the proposed UG1 ModML longwalls. The predicted final surface levels along the drainage lines following the completion of mining are illustrated in Figs. C.05 and C.06.

The drainage lines within the UG1 Study Area contain predominantly thin alluvial and colluvial soil deposits and consistent with the approved PrefML, it is expected that sections of beds downstream of the additional ponding areas, may erode during subsequent rain events, especially during times of high flow. It is expected over time, that the gradients along the drainage lines would approach grades similar to those which existed before mining. The extent of additional ponding along the drainage lines would, therefore, be expected to decrease with time.

The maximum predicted systematic tensile and compressive strains at the drainage lines, at any time during or after the extraction of the proposed UG1 ModML longwalls, are >50 mm/m. It is expected, at strains of these magnitudes, that fracturing and dilation of the bedrock would occur as a result of the extraction of these longwalls. The drainage lines may have relatively thin alluvial and colluvial soil deposits above the bedrock but, consistent with the approved PrefML, it is still expected that fracturing in the bedrock would be observed at the surface, especially around the locations of natural jointing in the bedrock and where the depths of soil above the bedrock are the shallowest.

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 also expected that with time the fracturing in the bedrock would be filled with alluvial and soil colluvial materials during subsequent flow events, reducing the diversion of surface water flows into subsurface flows. It may be necessary, however, that some remediation of the beds of the drainage line would be required, such as the infilling of surface cracks with materials comprising a high clay content, or by locally regrading and re-compacting the surface.

As discussed in Section 4.7, the height of the fractured zone above the proposed UG1 ModML longwalls will extend up from the Ulan Seam to the surface and this would result in increased connectivity between surface water, ground water resources and the mine workings particularly where the depths of cover are shallowest. However these areas are the closest to the open cut pits. Further discussion on the effects of fracturing on groundwater flows are provided in the report by HydroSimulations (2015).

5.2.3. Drainage management measures will be implemented to manage surface runoff from and around the out-of-pit emplacement, including management of ponding following longwall extraction, where necessary. Impact Assessments for the Drainage Lines Based on Increased Predictions

If the predicted systematic subsidence and tilts along the drainage lines were increased by a factor of 1.25 to 2 times, the extents of additional ponding and scouring would increase accordingly. It would still be expected, however, that the methods of remediation, if required, would not significantly change.

If the predicted systematic strains at the drainage lines were increased by a factor 1.25 to 2 times, the extent of fracturing and dilation in the bedrock and, hence, the extent of potential cracking in the thin alluvial and soil colluvial deposits would increase accordingly. It would still be expected, however, that the methods of remediation, if required, would not significantly change.

5.2.4. Recommendations for the Drainage Lines

There are no changes to the previous recommendations made for the approved PrefML as a result of the Modification.

It was previously recommended (MSEC, 2011) that the drainage lines are visually monitored as the longwalls mine beneath them. Consistent with the recommendations provided for the approved PrefML, it is still recommended that management strategies are developed for the drainage lines, such that the impacts can be identified and remediated, as and if they are required.

5.3. Cliffs, Overhangs and Rock Ledges

A total of 6 cliffs were identified within the UG1 Study Area as described in Section 2.3.8. The locations of the cliffs within the UG1 Study Area are shown in Drawing No. MSEC731-09. The predictions and impact assessments for the cliffs are provided below. Three of the cliffs are located within the footprint of the approved out-of-pit emplacement (C2, C3 and C4) and will therefore be covered before the underlying Longwalls 104 and 105 are proposed to be extracted. Hence revised subsidence predictions are not provided for these three cliffs.

5.3.1. Predictions for the Cliffs

A summary of the maximum predicted values of total systematic subsidence, tilt and strain at the cliffs and overhangs within the UG1 Study Area, at any time during or after the extraction of the proposed UG1 ModML longwalls, is provided in Table 5.2. The predicted values are the maximum values within a distance of 20 metres from the identified extents of the cliffs that occur during or on completion of the extraction of the proposed UG1 ModML Longwalls 101 to 105.

Table 5.2 Maximum Predicted Total Systematic Subsidence, Tilt and Strain at the Cliffs within the UG1 Study Area Resulting from the Extraction of Longwalls 101 to 105

Cliff	Approved Layout		Proposed Modified UG1 Layout			
	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total or Travelling Tilt (mm/m)	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total or Travelling Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
C1	1240	55	820	60	3.5	-2.5
C5	1790	35	2210	4	4.5	<-5
C6	1770	30	2120	1	4.5	<-5

The maximum predicted subsidence parameters that are presented above in Table 5.2 are the maximum subsidence parameters predicted anywhere over the rock outcrops and within a distance of 20 metres from the extents of the outcrops.

For the approved PrefML the predicted maximum total systematic subsidence at any cliff after all the longwalls are extracted was 1790 mm at Cliff C5. The maximum predicted total systematic tilt at any cliff after all the PrefML proposed longwalls are extracted was 55 mm/m . The maximum predicted total systematic hogging and sagging curvatures at any cliff after all the proposed PrefML longwalls are extracted were 3.5 km^{-1}, and 3 km^{-1} respectively. Assuming a curvature to strain conversion factor of 10, the maximum predicted total systematic strains after all the proposed PrefML longwalls are extracted were 35 mm/m and 30 mm/m.

For the proposed ModML the predicted maximum total systematic subsidence at any cliff after all the proposed UG1 ModML longwalls are extracted is 2210 mm at Cliff C5. The maximum predicted total systematic tilt at any cliff after the proposed UG1 ModML longwalls are extracted is 60 mm/m at Cliff C1. The maximum predicted total systematic hogging and sagging curvatures at any cliff after the proposed UG1 ModML longwalls are extracted are 4.5 km^{-1}, and <-5 km^{-1} respectively at Cliffs C5. Assuming a curvature to strain conversion factor of 10, the maximum predicted total systematic strains after the proposed UG1 ModML longwalls are extracted are greater than 45 mm/m and less than -50 mm/m and these are predicted to occur at Cliff C5.

5.3.2. Impact Assessments for the Cliffs and Overhangs

Rock falls occur naturally at locations where there is no mining and this is a reminder that cliffs and rock overhangs are landforms that are part of a naturally occurring erosion/weathering cycle and hence they can be marginally stable. This highlights that caution is required when inspecting surface areas near these natural features and when proposing any surface management plans near or around cliffs and overhangs before, during and immediately after mining.

Extensive databases of mining induced rock falls have been established that include details on the various mining and geographical parameters that are thought to effect the likelihood of rock falls, including data on the topography, the geometries of the mine and the cliff faces and the magnitudes of the observed and predicted subsidence induced ground subsidence, tilt, curvature and strain movements at cliff sites at the time of known rock falls and these provide a guide as to the likelihood or frequency of rock falls and rock instabilities.

Consistent with the approved PrefML, these predicted levels of ground movements for the proposed ModML are higher than the magnitudes of the observed and predicted subsidence induced ground subsidence, tilt, curvature and strain movements at cliff sites at the time of known rock falls and, hence, rock falls can be expected at these cliff lines.

However, it should be recognised that it is extremely difficult to assess the likelihood of mining induced cliff instabilities based upon the predicted ground movements alone. The likelihood of a particular cliff becoming unstable naturally, i.e. without the effects of mining induced ground movements, is dependent on many factors, including the existing vertical and horizontal jointing, inclusions or weaknesses within the rock mass, the height, extent of undercutting, the length and orientation of the particular cliff with respect to the valley and the water pressure and seepage flow behind the rock face.

Even where these factors can be determined, it is very difficult to assess an individual cliff's stability after being exposed to mine subsidence movements which are influenced by the magnitude of the mining-induced subsidence parameters, the location of the cliff with respect to the longwall panels, the orientation of the cliff with respect to the panels and the river valley.

Tilt can increase the overturning moments in steep or overhanging cliffs which, if they are of sufficient magnitude, could result in toppling type failures. However a review of the occurrence and location of observed cliff falls with respect to panel edges and increasing or decreasing the steepness of the slopes of the cliff faces at known mining induced cliff falls indicated that this mechanism does not result in many of the observed cliff falls in NSW.

Where the mining induced ground strains are of sufficient magnitude, sections of rock faces could fracture along existing bedding planes or existing joints and become unstable, resulting in sliding or toppling type failures along the cliffs and overhangs. Fracturing of sandstone has generally been observed where the systematic tensile and compressive strains have exceeded 0.5 mm/m and 2 mm/m, respectively. Most of the predicted systematic tensile and compressive strains at the cliffs are much greater than 0.5 mm/m and 2 mm/m and are therefore, expected to be of sufficient magnitude to result in the fracturing of sandstone.

© MSEC JUNE 2015 | REPORT NUMBER MSEC731 | REVISION A

Therefore, rather than trying to quantify the likelihood of rock falls at a particular cliff, it has been found to be more meaningful to quantify the likely proportion of a cliff line that may be affected by mining. This proportion is increased with increasing mining induced movements, with higher, longer and larger cliffs, and with shallower depths of cover. For example, when assessing the effect of mining at shallow depths of cover under high and large cliff lines researchers found it very difficult to accurately predict which particular cliff would experience rock falls. Often the most exposed or undercut cliff face, or the cliff that would experience the highest movements was not the cliff that experienced rock falls.

It has therefore been recognised that it is easier to identify what proportion of a cliff line that could be damaged than to identify which particular cliff face would be damaged. Cliff impact assessments statistics have been gathered on the effects of the various factors that influence the proportion or extent of the cliff falls per length of cliff line.

The number and the size of instabilities along cliffs as the result of mining have been recorded at a number of collieries in the NSW Coalfields. A database of observed rock falls was compiled to determine the proportion of instabilities that occurred due to mining, being the total length of instabilities divided by the total length of undermined cliffline. Data was only included from collieries where the details of all instabilities due to mining were identified and recorded. The total length of undermined cliffline, over and near the goaf edges, was also determined for each colliery.

A summary of the observed instabilities and the total length of undermined cliffs at Angus Place, Baal Bone, Invincible, Lithgow Valley and Nattai North Collieries, is provided in Table 5.3

The proportion of instabilities due to mining at each colliery was determined by dividing the total length of observed instabilities due to mining by the total length of undermined cliff above or within 0.7 times the depth of cover from the extracted longwalls.

The proposed UG1 Study Area at MCC, has similar depths of cover to the some of the collieries identified in Table 5.3, however, the depths of the valleys and heights of the cliffs that were undermined at the other collieries were much higher than the cliffs that are located over the proposed UG1 ModML longwalls.

Table 5.3 Lengths of Observed Instabilities and Lengths of Undermined Cliffs at Other Collieries within the NSW Coalfields

Colliery	Coalfield	Longwalls	Number of Recorded Instabilities due to Mining	Total Length of Recorded Instabilities due to Mining (m)	Total Length of Undermined Cliff within 0.7 times depth of cover from the Goaf (m)	Observed Proportion of Rockfalls due to Mining (%)
Angus Place	Western	LWs 1-11	58	862	6 820	12.6
Baal Bone	Western	LWs 1-9	127	1,350	14 640	9.2
Invincible	Western	LW 2	1	30	150	20.0
Lithgow Valley	Western	N/A	5	150	4 400	3.4
Nattai North	Southern	N/A	22	1,365	4 600	29.7
		TOTAL	213	3,757	30 610	12.3

It is also important to note that during extensive field monitoring for a NERDDC funded research project that was titled “Effects of Subsidence on Steep Topography and Cliff Lines" (Kay, 1991), no rock falls were noticed to occur off narrow lengths of cliff lines or escarpments where the cliff line length was less than 30 metres, i.e. no falls were observed off isolated rock features that could be moved during the subsidence wave. Eighty per cent of the observed falls at Baal Bone Colliery occurred off rock formations that were relatively continuous and had cliff line lengths that were greater than 60 metres.

That is, the observed rock falls at these other collieries occurred off long lengths of cliff lines or escarpments, whilst, the cliff lines at MCC are much shorter and are more discrete or isolated rock formations and this can result in a smaller proportion of rock falls.

A summary of assessed impacts to the cliffs identified in the UG1 Study Area is provided in Table 5.4.

Table 5.4 Summary of Assessed Cliff Impacts due to Extraction of Longwalls 101 to 105

Cliffline	Length (m)	Height (m)	Location	Predicted Impact
C1	20	10	Over LW105, 20m from tailgate	Minor impact expected
C5	20	15	Over LW103, 90m from maingate	Minor impact expected
C6	20	10	Over LW103, 80m from maingate	Minor impact expected

It has been observed that cliff instabilities typically occur after the cliff has been directly mined beneath, and almost all of the rock falls occurred when the cliff was located above the goaf and it can be noted that all 6 of the cliffs that are identified within the UG1 Study Area, are located directly over the proposed UG1 ModML longwalls. However, not one of these 6 cliffs are higher than 15 metres and all of these 6 are 20 metres or shorter in length. Cliffs C2, C3 and C4 will be covered by the out-of-pit emplacement before the extraction of the longwalls.

Based on the above information, and noting the shallow depths of cover and predicted high values of subsidence for the cliffs, it is expected that cliff instabilities could occur on up to approximately 15% of the length of the exposed cliffs that are located over the proposed UG1 ModML longwalls.

5.3.3. Impact Assessments for the Cliffs Based on Increased Predictions

If the predicted systematic subsidence, tilts and strains were increased by factors of up to 1.25 to 2 times, then the likelihood and extent of cliff instabilities would be expected to increase accordingly, as the changes in grade would still be small when compared to the existing slopes of the cliff faces.

5.3.4. Recommendations for the Cliffs

There would be no change to the recommendations made for the approved PrefML as a result of the Modification.

One of the most significant consequences associated with cliff instabilities is the potential to cause injury or death and it is paramount that access is denied whilst the longwalls pass under the cliffs even if the probability of rock falls is low. Owners of the land above the UG1 include MCO, the nearby UCM and some land is Crown land. Whilst the area is generally not available for public access, it is possible that the area will be visited during the mining period. Consistent with recommendations for the approved PrefML, it is still recommended, that persons who enter the area in the vicinity of the cliffs are made aware of the potential for rockfalls resulting from the extraction of the proposed UG1 ModML longwalls by appropriate signs and temporary fencing.

The aesthetics of the landscape could be temporarily altered by isolated rock falls, which would typically occur off pre-existing natural joints, but, they could result in the exposure of a fresh face of rock and debris scattered around the base of the cliff. As with naturally occurring instabilities, the exposed fresh rockface weathers and erodes over time to a point where it blends in with the remainder of the cliff face and vegetation below the cliff regenerates.

As there is a small possibility of rock falls, consistent with the recommendations provided for the approved PrefML, it is still recommended that appropriate management strategies are put in place to ensure the safety of people that may be within the vicinity of the cliffs during the mining period. With these measures in place, it is unlikely that there would be a significant impact associated with the cliffs resulting from the extraction of the proposed UG1 ModML longwalls.

Consistent with the recommendations provided for the approved PrefML, it is still recommended that the existing condition of cliffs C1, C5 and C6 within the UG1 Study Area should be documented and photographed prior to mining. Consistent with the recommendations provided for the approved PrefML, it is still recommended that the cliffs should be visually monitored during the mining period from a remote and safe location until such time that the mine subsidence movements have ceased. Should any cliff face appear to become unstable, management strategies should be put in place to further restrict access or to possibly make the site area safe.

5.3.5. Rock Ledges and Overhangs

As discussed in Chapter 2, there are many smaller cliffs or rock ledges with small overhangs distributed over the UG1 Study Area which are likely to be subjected to the full range of predicted systematic subsidence movements as presented in Chapter 4.

The maximum predicted total systematic subsidence due to Longwalls 101 to 105 is 2380 mm which occurs above the Longwall 101 after the extraction of Longwall 102. The maximum predicted total systematic tilt due to Longwalls 101 to 105 and within the UG1 Study Area of 115 mm/m (i.e. 11.5 %), or a change in grade of 1 in 9, occurs near the tailgate of Longwall 102 after the extraction of Longwall 102. The maximum predicted total systematic tensile and compressive strains resulting from the extraction of the proposed UG1 ModML longwalls, are both greater than 50 mm/m.

Based on the maximum predicted tilts and strains, it is likely that fracturing of sandstone will occur as a result of the extraction of the longwalls and, hence, could result in small rockfalls, particularly where the rock ledges or overhangs are marginally stable. It is noted that many of the exposed rocks are isolated from the parent rock by weathered bedding planes and joints and in such cases there would be a lower risk of fracturing of the rock and subsequent rock falls. It is expected that occasional rockfalls or fracturing would not impact more than 5% of the total face area of rock ledges and overhangs within the UG1 Study Area.

As there is a possibility of rock falls from these rock ledges and overhangs, consistent with the recommendations provided for the approved PrefML, it is still recommended that appropriate management strategies are put in place to ensure the safety of people that may be within the vicinity of these rock ledges and overhangs during the mining period.

Consistent with the recommendations provided for the approved PrefML, it is still recommended that visual inspections of the exposed rock ledges within the UG1 Study Area that are easily inspected should be undertaken during the mining period. Should any rock ledge appear to become unstable, management strategies should be put in place to prevent access, make the site safe and appropriate signs should be provided to warn of the possibility of rock falls.

5.4. Steep Slopes

The locations of the natural steep slopes within the UG1 Study Area are shown in Drawing No. MSEC371-09. The predictions and impact assessments for the natural steep slopes are provided in the following sections.

Further discussion is provided on the steep slopes on the sides of the out-of-pit emplacement area in Section 5.14.1.

5.4.1. Predictions for the Steep Slopes

The steep slopes are located across the UG1 Study Area and are likely, therefore, to be subjected to the full range of predicted systematic subsidence movements as presented in Chapter 4.

5.4.2. Impact Assessments for the Steep Slopes

The maximum predicted total systematic tilt due to Longwalls 101 to 105 and within the UG1 Study Area is 115 mm/m (i.e. 11.5 %), or a change in grade of 1 in 9. The steep slopes are more likely to be impacted by the systematic strains, rather than tilt, as the maximum predicted tilt is small when compared to the existing surface gradients of the steep slopes.

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 any large-scale slope failure, since such failures have not been observed elsewhere as the result of longwall mining.

The maximum predicted total systematic tensile and compressive strains within the UG1 Study Area resulting from the extraction of the proposed UG1 ModML Longwalls 101 to 105, are both greater than 50 mm/m. Similar to the PrefML, the maximum predicted total systematic tensile strains at the steep slopes are likely to result in surface cracking.

5.4.3. Impact Assessments for the Steep Slopes Based on Increased Predictions

If the predicted systematic tilts were increased by factors of up to 1.25 to 2 times, the potential impacts on the steep slopes would not be expected to significantly increase.

If the predicted systematic strains were increased by factors of up to 1.25 to 2 times, the extent of potential surface cracking and soil slippage would increase accordingly at the steep slopes located directly above the proposed UG1 ModML longwalls. It is expected, however, that the surface cracking could be remediated by infilling with soil or other suitable materials, or by locally regrading and compacting the surface. With these remediation measures in place, it is unlikely that there would be any significant impact on the environment.

5.4.4. Recommendations for the Steep Slopes

Consistent with the recommendations provided for the approved PrefML, it is still recommended that the steep slopes are monitored throughout the mining period. Any significant surface cracking should be remediated by infilling with soil or other suitable materials, or by locally regrading and compacting the surface. Consistent with the recommendations provided for the approved PrefML, it is still recommended that management strategies be developed, to ensure that the steep slopes are maintained throughout the mining period.

5.5. Threatened or Protected Species

An investigation of the flora and fauna within the proposed UG1 longwall panel extension areas as well as the location of the approved PrefML central mains (to be removed for the Modification) was undertaken by Ecological Australia (2015). Flora and fauna surveys within these areas were undertaken and did not identify any threatened flora species under the *Threatened Species Conservation Act, 1995*. There is known and potential habitat for a number of threatened fauna species within the UG1 Study Area as described in Ecological Australia (2015).

Therefore there is no additional subsidence impacts expected to threatened flora or fauna species as a result of the Modification.

5.6. Vegetation Communities

There are two Endangered Ecological Communities (EECs) known as *White Box Yellow Box Blakely's Redgum Woodland and Derived Native Grasslands* and *Central Hunter Grey Box – Ironbark Woodland in the NSW North Coast and Sydney Basin Bioregions*, which within the UG1 Study Area as shown on Drawing No. MSEC731-08. One EEC (EEC03) is partially located within the out-of-pit emplacement footprint and rear air intake shaft footprint.

The predictions and impact assessments for the vegetation communities that are within the UG1 Study Area are provided in the following sections. The effects of subsidence and emplacement on flora and fauna within the UG1 Study Area are considered within the report by Ecovision Consulting and Marine Pollution Research (2008) and Ecological Australia (2015).

5.6.1. Predictions for the Vegetation Communities

The provided maximum predicted tilts and strains at the EECs are the maximum values which occur at any time during, or after the extraction of each proposed longwall, whichever is the greater. The values are the maximum predicted systematic subsidence parameters within a 20 metre radius of the perimeter of each vegetation community and do not include valley related upsidence and closure movements.

The maximum predicted systematic subsidence at the vegetation communities is 2340 mm. The maximum predicted systematic tilt at the vegetation communities, at any time during or after the extraction of the proposed UG1 ModML longwalls, is 115 mm/m (i.e. 11.5 %), or a change in grade of 1 in 9. The approximate natural grade of the surface within the mapped areas of these communities varies between near level surfaces to approximately 500 mm/m (i.e. 50 %) with an estimated average of approximately 140 mm/m (i.e. 14%) or a change of grade of 1 in 7.

The maximum predicted systematic tensile and compressive strains at the EECs are both greater than 50 mm/m.

5.6.2. Impact Assessments for the Vegetation Communities

The predicted systematic tilts at the vegetation communities are likely to result in changes in surface gradients in the EECs by factors of up to about 2, which are similar to the predictions for the PrefML. The 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, such as over proposed UG1 ModML Longwalls 103, 104, and 105. The portion of EEC03 that is located in the out-of-pit emplacement footprint will be covered during the filling operations and before the proposed extraction of the longwalls.

It is expected, at strains of the magnitudes noted in Section 5.6.1, that fracturing and dilation of the bedrock would occur as a result of the extraction of the proposed UG1 ModML longwalls. 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, similar to that described for the steep slopes in Section 5.4, however, the extent of the basalt materials, is unknown.

It is expected, however, 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. The relevant approvals for such works would be obtained prior to undertaking any remediation works. With these remediation measures in place, it is unlikely that there would be any significant impact on the vegetation communities.

5.6.3. Impact Assessments for Vegetation Communities Based on Increased Predictions

If the predicted subsidence and tilts at the vegetation communities were increased by a factor of up to 1.25 to 2 times, the extents of additional ponding and scouring would increase accordingly. It would still be expected, however, that the methods of remediation, if required, would not significantly change.

If the predicted systematic strains at the vegetation communities were increased by a factor 1.25 to 2 times, the extent of fracturing and dilation in the bedrock and, hence, the extent of cracking in the surface soils would increase accordingly. It would still be expected, however, that the methods of remediation, if required, would not significantly change.

5.6.4. Recommendations for the Vegetation Communities

Consistent with the recommendations provided for the approved PrefML, it is still recommended that the EECs are visually monitored as the proposed UG1 ModML longwalls mine beneath them so that the impacts can be identified and remediated, if required. With these strategies in place, it is unlikely that there would be any significant impacts on the EECs resulting from the extraction of the proposed UG1 ModML longwalls.

5.7. Gulgong to Sandy Hollow Railway

The Gulgong to Sandy Hollow Railway Line is located to the north and east of the proposed UG1 longwalls as is discussed in Section 2.4.1 and is shown in Drawing No. MSEC731-10,

The nearest edges of the proposed UG1 ModML Longwalls 101 to 105 to the Gulgong to Sandy Hollow Railway Line varies from approximately 255 metres to 400 metres from the nearest edges of the proposed UG1 ModML Longwalls 101 to 105 (compared to 330 metres for the PrefML longwalls). At these locations the depths of cover ranges from 90 to 130 metres and, hence, these distances between the edges of the mined panels and the railway are equivalent to 2.8 to 3.5 times the depths of cover.

As detailed in Section 1.4.1, there are alluvial/regolith palaeochannel deposits, with a maximum thickness of 40-50 m, to the north and east of the proposed UG1 longwalls, where the depths of cover range from 90 to 130 metres. Section 3.9 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

5.7.1. Predictions for the Gulgong to Sandy Hollow Railway

At these distances between the panels and the railway track and based on these depths of cover, the rail track will not be subjected to measurable systematic mine subsidence ground movements; however, as indicated in Figs. 3.13, 3.14 and 3.15, the ground near the railway line may experience far field horizontal movements and possibly small valley upsidence and closure movements.

As shown in Fig. 3.13, the upper limit of previously observed absolute far field horizontal movements for sites located 255 metres from longwalls is approximately 220 mm. It should also be noted, as shown in Fig 3.16, that far field horizontal movements of over 150 mm have been measured at 255 metres from longwalls at the neighbouring UCM. Hence, as is discussed further below, these far field horizontal movements will require monitoring of the ground between the panels and the railway and may require some mitigation/maintenance along the railway track to ensure the continued safe operations of this railway line.

However it should be noted that most of the monitored NSW far field horizontal movement data were measured at sites in the Southern Coalfield, where the depths of cover are approximately 500 metres and the depths of cover at UCM where high far field horizontal movements were monitored were approximately 300 metres, which are both much deeper than at MCC near this railway line where the depth of cover ranges from 90 to 130 metres. Hence Fig. 3.14 was prepared by replotting the available far field horizontal movement data shown in Fig. 3.13 to allow for the influence of changing depths of cover, and this is a more useful plot for predicting far field horizontal movements at MCC.

Fig. 3.14 shows the upper limit of previously observed absolute far field horizontal movements at UCM for the sites located 2.8 to 3.5 times the depths of cover from longwalls, was less than 100 mm, (however this data includes the H-Line case and the F-Line case where high valley closure movements were observed). Ignoring sites with high valley closure movements and the multi seam cases, Fig. 3.14 shows the upper limit of previously observed absolute far field horizontal movements for sites located 2.8 to 3.5 times the depths of cover from longwalls, is less than 70 mm.

However, as discussed in Sections 1.4.1, 3.8, 3.8.1, 3.9 and 4.6, the likely subsidence and far field horizontal movements at the Gulgong to Sandy Hollow 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 metres thick just outside the edges of the proposed longwall panels.

These far-field horizontal movements generally do not result in impact at structures, except where they occur at large structures, such as railway lines, since these large structures can be 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.

Beyond Australia, there is a wealth of experience of mining beneath railways, particularly in the UK and continental Europe. Until recently, there was little experience in mining directly beneath Australian railways. Glencore's Tahmoor Colliery has successfully extracted four of many planned longwalls directly beneath the Main Southern Railway at Tahmoor, southwest of Sydney, while allowing trains to operate normally at full speed. The train operations were not affected. Similarly BHPB's Appin Colliery has successfully extracted three of many planned longwalls directly beneath the Main Southern Railway near Appin, southwest of Sydney, while allowing trains to operate normally at full speed. Again train operations were not affected.

The risks to these railway tracks were successfully managed by the Australian Rail Track Corporation, Glencore (formerly Xstrata Coal), BHPB and a Rail Management Group including specialists in the fields of railway engineering, geotechnical engineering, subsidence and monitoring systems. The maximum subsidence that has been measured along the railway line at Tahmoor was approximately 850 mm and at Appin the maximum subsidence was approximately 1050 mm. The techniques that were used to manage the impacts on the track were a "world first" and included the use of expansion switches, zero toe load clips, extensive real time monitoring, and on call response procedures.

Recent detailed monitoring of rail tracks whilst longwalls approached and passed underneath showed that the movements had negligible impacts until the longwall passed under the rail track. The longwalls at MCC are not passing under the railway line. The predicted levels of mine subsidence along the Gulgong to Sandy Hollow Railway are likely to be less than 20 mm and the predicted far field horizontal movements are likely to be less than 70 mm. The effects of this subsidence and the differential far field movements due to the proposed extraction of the UG1 longwalls on the Gulgong to Sandy Hollow Railway are very small and are unlikely to adversely impact on the railway line.

However detailed monitoring is recommended near the railway line for each longwall and maintenance of the track may be required to ensure the safe operations of the railway line.

5.7.2. Recommendations for Gulgong to Sandy Hollow Railway

The railway should be inspected on a regular basis as the proposed UG1 ModML Longwalls 101 to 105 are mined, to confirm that the observed ground movements are consistent with the predictions. In this way, the railway can be maintained in a safe and serviceable condition throughout the mining period.

A management plan should be established for the railway to cover the mining of Longwalls 101 to 105. Consistent with the recommendations provided for the approved PrefML, it is still recommended that the management plan be prepared in consultation with the Australian Rail Track Corporation.

5.8. Sealed and Unsealed Roads

The locations of the existing roads within the UG1 Study Area are shown in Drawing No. MSEC731-11. There are no sealed roads within the UG1 Study Area. The Ulan to Wollar Road is a sealed road that was located near the edge of the UG1 Study Area, however, it has been relocated to be adjacent to the Sandy Hollow to Gulgong Railway line and now this road is more than 200 metres from the nearest edges of the UG1.

Murragamba Road is the only public access road within the Study Area and it is located over the north east part of the Proposed UG1 ModML Longwalls 104 and 105. However Murragamba Road is currently subject to a road closure application and will not be used once the OC4 commences, (i.e. before the extraction of Longwall 104 and 105). Notwithstanding, subsidence predications are provided below. A new haul road is proposed to be constructed between the OC4 and the OC1 above Longwalls 101 to 105 as part of the OC4 South-West Modification.

5.8.1. Predictions for the Sealed and Unsealed Roads

Many tracks, unnamed roads and haul roads are located directly above the UG1 Study Area and they will therefore experience the full range of subsidence movements during the extraction of these longwalls, which are provided in Chapter 4, i.e. the maximum subsidence along these roads and haul roads can be up to 2380 mm, tilts greater than 100 mm/m and maximum predicted systematic tensile and compressive strains of greater than 60 mm/m at any time during or after the extraction of the proposed UG1 ModML longwalls. Predicted crack widths are discussed further in Section 5.18.1.

As discussed in Section 5.7 above, the relocated Ulan to Wollar Road has been located adjacent to the Sandy Hollow to Gulgong Railway line and, at this location, it should experience negligible systematic subsidence movements and small far field horizontal movements of up to 70 mm.

5.8.2. Impact Assessments for the Sealed and Unsealed Roads

The predicted subsidence levels at the tracks, unnamed roads and haul roads that are located directly above the UG1 Study Area are consistent with those predicted for the approved PrefML and it is expected, at these magnitudes of the predicted ground strains that considerable cracking, stepping and rippling of the road surfaces would occur as a result of the extraction of the proposed UG1 ModML longwalls.

Other subsided tracks, unnamed roads and haul roads may also experience ponding, however, the impacts of increased levels of ponding along these roads can be easily remediated by regrading and relevelling the roads using standard road maintenance techniques. The repairs will be progressive and, therefore, can be staged to suit the mining of each longwall in sequence. It may be necessary to introduce speed restrictions along these roads until the appropriate remediation measures have been implemented.

If the Murragamba Road is still being used when Longwalls 104 and 105 are extracted, then, increased levels of ponding could occur along the parts of this road that are located in terrain with shallow flat grades.

The effects of the predicted subsidence and the differential far field movements due to the proposed extraction of the UG1 longwalls on the Ulan to Wollar Road are unlikely to adversely impact on the road, however, this road should be inspected on a regular basis as the proposed UG1 ModML Longwalls 101 to 105 are mined, to confirm that the observed ground movements and impacts are consistent with the predictions and assessments. In this way, the road can be maintained in a safe and serviceable condition throughout the mining period.

5.8.3. Impact Assessments for the Sealed and Unsealed Roads Based on Increased Predictions

If the predicted systematic subsidence and tilts at the roads were increased by a factor of 1.25 to 2 times, the impacts of increased ponding would increase accordingly. It would still be expected, however, that any impacts could still be remediated using standard road maintenance techniques.

If the predicted systematic strains at the roads were increased by a factor 1.25 to 2 times, the likelihood and extent of cracking and rippling in the road surfaces would increase accordingly. It would still be expected, however, that these impacts could be managed by monitoring, traffic management and the implementation of remediation works using standard road maintenance techniques.

5.8.4. Recommendations for the Sealed and Unsealed Roads

Consistent with the recommendations provided for the approved PrefML, it is still recommended that any road that is still in use should be monitored regularly and frequently as the extraction faces of the proposed UG1 ModML longwalls are mined near and beneath them, such that any impacts can be identified early and remediated accordingly.

It is still recommended that management strategies be developed to maintain the sealed roads in a safe and serviceable condition throughout the proposed mining period. It may be necessary to slow traffic along the affected section of road, or in some cases, to locally divert traffic, until the required remediation works have been implemented.

MCO should monitor the proposed haul road across the UG1 during underground extraction and implement remediation measures as required.

5.9. Powerlines and 330kV Transmission Line

The existing low voltage powerline that previously provided power within the Murragamba Creek valley where the OC4 Pit will be developed has been decommissioned and, hence, no subsidence predictions are provided for this disused powerline.

The locations of the 66kV powerline and poles and the 330 kV Transmission lines and the towers are shown in Drawing No. MSEC731-11.

5.9.1. Predictions for the 66kV Powerlines

The depth of cover under the three poles of the 66kV powerline, which are located along the Ulan-Wollar Road and just within the UG1 Study Area, is 110 metres. The nearest pole is located within 30 metres of the finishing end of Longwall 103, and, as shown in the Fig. C.07 in Appendix C, this pole is predicted to experience low systematic subsidence movements of less than 20 mm and very low tilts and strains. The other poles are predicted to experience no systematic subsidence movements.

In addition to these low systematic subsidence and tilts the 66kV Powerline may also experience some far field horizontal movements of up to 200 mm towards the mined panels. However, these movements usually occur with little differential horizontal movements, i.e. strains.

As discussed in Sections 1.4.1, 3.9 and 4.6, the expected subsidence and far field horizontal movements at the 66kV Powerline are expected to be less than the normally predicted far field horizontal movements because of the presence of unconsolidated sediments in palaeochannels that are up to 50 metres thick just outside the edges of the proposed longwall panels.

5.9.2. Predictions for the 330kV Transmission Line

As the 330kV transmission line is located well outside the UG1 Study Area, no systematic subsidence parameters are provided for the 330kV transmission line. However, some of the 330kV towers may experience small far field horizontal movements of up to 120 mm.

These far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain. Hence, the differential far field movements due to the proposed extraction of the UG1 longwalls between the legs of the towers are expected to be very small and are unlikely to adversely impact on the towers.

Furthermore, as discussed in Sections 1.4.1, 3.9 and 4.6, the expected far field horizontal movements at the 330kV transmission line towers are expected to be less than normally predicted because of the presence of unconsolidated sediments in palaeochannels that are up to 50 metres thick just outside the edges of the proposed longwall panels.

5.9.3. Impact Assessments for the 66kV Powerline

At the predicted low levels of subsidence, tilt and strains no impacts are expected along the 66kV Powerline.

5.9.4. Impact Assessments for the 330kV Transmission Line

At the predicted low levels of subsidence, tilt and strains no impacts are expected along the 330kV Transmission Line Towers.

Nevertheless, consistent with the recommendations provided for the approved PrefML, it is still recommended that the movements at the base of these towers are monitored as the extraction faces of the proposed UG1 ModML longwalls are mined, such that any impacts can be identified and remediated accordingly. With the implementation of suitable management strategies, it is expected that these towers can be maintained in a safe and serviceable condition throughout the mining period.

5.9.5. Impact Assessments for the 66kV Powerline and the 330kV Transmission Line Based on Increased Predictions

If the predicted systematic tilts at the powerline were increased by a factor of 1.25 to 2 times, the likelihood of impacts would increase slightly but are still very low. It is expected that these impacts can be managed by monitoring and the implementation of suitable management strategies.

5.9.6. Recommendations for the 66kV Powerline and the 330kV Transmission Line

Consistent with the recommendations provided for the approved PrefML it is recommended that the 66 kV powerline and the 330 kV transmission line is inspected by a suitably qualified person prior to mining to determine the existing conditions and confirm that no mitigation or preventive measures are required for these low predicted subsidence, tilt and strain values.

Consistent with the recommendations provided for the approved PrefML, it is recommended that management strategies are prepared, in consultation with Essential Energy, as required, to incorporate the assessed impacts to the 66 kV powerline and the 330 kV transmission line resulting from the extraction of the proposed UG1 ModML longwalls.

With the implementation of suitable management strategies, it is expected that the 66kV powerline and these 330 kV transmission line towers can be maintained in a safe and serviceable condition throughout the mining period.

5.10. Optical Fibre Cables

There is an optical fibre cable located along the northern side of Ulan-Wollar Road. The closest point of the cable to the UG1 is approximately 100 metres from the north east end of Longwall 105. At this location the optical fibre cable will not be subjected to measurable systematic mine subsidence ground movements; however, it may experience small far field horizontal movements and possibly negligible upsidence and closure movements.

5.10.1. Predictions for the Optical Fibre Cable

Since the predicted subsidence is negligible we have not prepared specific profiles of total systematic subsidence, tilt and strain along the alignment of the optical fibre cable.

As can be seen in Fig. 3.14, the upper limit of observed absolute far field horizontal movements, for ground sites located 100 metres from longwalls at a depth of cover of 90 metres, would be approximately 150 mm.

A discussion of far field horizontal movements is presented in Section 3.5, 3.8 and 3.8.1 of this report. 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 impact, except where they occur at large structures which are very sensitive to differential horizontal movements. The differential ground horizontal movements at this distance from the longwalls are expected to be negligible.

As discussed in Sections 1.4.1, 3.9 and 4.6, the expected far field horizontal movements at the optical fibre cable are expected to be less than normally predicted because of the presence of unconsolidated sediments in palaeochannels that are up to 50 metres thick just outside the edges of the proposed longwall panels.

The effects of the predicted subsidence and the differential far field movements due to the proposed extraction of the UG1 longwalls on the optical fibre cable are unlikely to adversely impact on the cable. However, this cable should be inspected on a regular basis as the proposed UG1 ModML Longwalls 101 to 105 are mined, to confirm that the observed ground movements and impacts are consistent with the predictions and assessments. In this way, the cable can be maintained in a safe and serviceable condition throughout the mining period.

5.10.2. Recommendations for Optical Fibre Cable

Nevertheless consistent with the recommendations provided for the approved PrefML, it is still recommended that the optical fibre cable are monitored during the extraction of the proposed UG1 ModML Longwalls 101 to 105 using optical fibre sensing techniques, such as Optical Time Domain Reflector (OTDR) monitoring.

With the required management measures in place, the optical fibre cable can be maintained in a serviceable condition throughout the mining period. Management measures can be undertaken, such as excavating and exposing the cable, if a strain concentration is detected during mining.

A monitoring, management and response plan should be established for the optical fibre cable prior to mining the proposed UG1 ModML Longwalls 101 to 105, to the satisfaction of the owners of the optical fibre cable.

5.11. Copper Telecommunications Cables

The main copper telecommunications cables have been decommissioned and, hence, no subsidence predictions are provided for this disused copper cabling.

5.12. Fences

There are a number of fences within the UG1 Study Area which are constructed in a variety of ways, generally using either timber or metal materials. The fences are located across the UG1 Study Area and are likely, therefore, to be subjected to the full range of predicted systematic subsidence movements, which are summarised in Table 4.1 and Table 4.2.

Wire fences could be affected by tilting of the fence posts and changes of tension in the fence wires due to strain as mining occurs. Fence post tilts of less than 10 mm/m are barely noticeable and strains of less than 5 mm/m typically have little impact on wire tensions. However, this depends upon the existing tensions in the wires of the fences and their residual capacity to accept mining induced strains.

The maximum predicted systematic tilts and strains, resulting from the extraction of the proposed UG1 ModML longwalls, are greater than those which can be typically tolerated by fences. It is likely, therefore, that some sections of the fences would be impacted by the predicted subsidence movements and would require repair or replacement.

Impacted fences are relatively easy to rectify by re-tensioning the fencing wire, straightening the fence posts, and if necessary, replacing some sections of fencing.

5.13. Farm Dams

Thirteen farms dams have been identified within the UG1 Study Area. The locations of the farm dams are shown in Drawings Nos. MSEC731-11. Five of the farm dams are located within or adjacent to the footprint of the out-of-pit emplacement and will be covered during the filling operations, prior to extraction of the longwalls.

5.13.1. Predictions for the Farm Dams

Predictions of systematic subsidence, tilt and strain have been made at the centroid and at points located around the perimeter of each farm dam within the UG1 Study Area, as well as at points located at a distance of 20 metres from the perimeter of each farm dam. The maximum predicted systematic subsidence parameters for each farm dam have then been taken as the maximum predicted values at these points.

The maximum predicted values of systematic subsidence, tilt and strain have been determined for the farm dams within the UG1 Study Area, after the extraction of each proposed longwall, and are provided in Table D.02 in Appendix D.

5.13.2. Impact Assessments for the Farm Dams

The maximum predicted systematic tilts at the farm dams, resulting from the extraction of the proposed UG1 ModML longwalls, vary between a minimum of less than 1 mm/m (i.e. < 0.1 %) and a maximum of 35 mm/m (i.e. > 3.5 %), or changes in grade varying from less than 1 in 1000 to 1 in 29.

Mining induced tilts can affect the water levels around the perimeters of farm dams, with the freeboard increasing on one side and decreasing on the other. Large tilts can potentially reduce the storage capacity of farm dams, causing them to overflow, or affect the stability of the dam walls. The potential for overflowing dams is dependent on the freeboard at the dam wall at the time of mining and the direction of tilt relative to the dam.

The maximum predicted changes in freeboard for each farm dam has been determined by taking the maximum predicted subsidence anywhere around each dam from the minimum predicted subsidence anywhere around each dam. The maximum predicted changes in freeboard for the farm dams within the UG1 Study Area are summarised in Table D.02.

The maximum predicted change in freeboard at the farm dams, resulting from the extraction of the proposed UG1 ModML longwalls, vary between a minimum of less than 50 mm and a maximum of greater than 100 mm. Farm dams A02d03 and A03d01 are predicted to experience changes in freeboard of 100 mm and all other farm dams within the UG1 Study Area are predicted to experience changes in freeboard of less than 50 mm.

The directions of the maximum predicted tilts at Dams Refs. A02d03 and A03d01 are such that the freeboards at the dam walls could slightly decrease (i.e. water levels slightly increase) by approximately 100 mm. This change in level is not expected to have any appreciable impact on the normal functioning of the dam.

The maximum predicted systematic strains, tensile or compressive, at the farm dams, resulting from the extraction of the proposed UG1 ModML longwalls, vary between a minimum of less than 0.1 mm/m and a maximum of greater than 30 mm/m. The minimum radii of curvatures associated with the maximum predicted systematic strains vary from greater than 150 kilometres to less than 0.5 kilometres.

The farm dams within the UG1 Study Area 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. There are 6 farm dams which are predicted to experience systematic tensile strains of 3 mm/m or greater.

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.

5.13.3. Impact Assessments for the Farm Dams Based on Increased Predictions

If the predicted systematic tilts and strains at the farm dams were increased by factors of 1.25 to 2 times, the likelihood of impact on the dams would increase accordingly.

5.13.4. Recommendations for the Farm Dams

Consistent with the recommendations provided for the approved PrefML, it is still recommended that the farm dams are visually monitored as the proposed UG1 ModML longwalls mine beneath them, such that any impacts can be identified and remediated accordingly. It may be necessary for remedial work to be undertaken to maintain these dams. In this way all the farm dams within the UG1 Study Area can be maintained in a safe and serviceable condition throughout the mining period.

5.14. Mining Infrastructure

The open cut mine schedule includes a new haul road that crosses over Longwalls 102 to 105 and an out-of-pit emplacement above several of the proposed UG1 longwalls, the location of which is shown in Drawing No. MSEC731-14. The predictions and impact assessment for the new haul road is provided in Section 5.8. The predictions and impact assessments for the other mine infrastructure are provided in the following sections.

5.14.1. Out-of-pit Emplacement

The location of the approved out-of-pit emplacement area that is to be placed above Longwalls 103 to 105 in UG1 is shown in Drawing No. MSEC731-01. It should be noted that the extraction of the proposed UG1 ModML longwalls and the subsequent subsidence ground movements will result in additional subsidence of the spoil heap and possibly result in slumping of the steep slopes associated with the spoil heap.

The approved out-of-pit emplacement area over UG1 will be completed prior to the extraction of Longwalls 103 to 105. The rehabilitation works for the out-of-pit emplacement area will also be undertaken above the UG1 area during the extraction of the UG1 longwalls.

The top of the approved out-of-pit emplacement area is proposed to be relatively flat with a top surface level of approximately 530 metres to 540 metres Australian Height Datum. 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 proposed UG1 ModML longwalls at the base of the out-of-pit emplacement will be approximately 2300mm in the south western end of Longwall 104. The maximum predicted total tilts are 90 mm/m and maximum predicted total compressive and tensile strains of greater than 50mm/m and greater than 50mm/m respectively.

The predicted subsidence parameters that have been provided in this report are the predicted ground movements at the natural surface, beneath the out-of-pit emplacement.

Additionally, it is expected that additional settlement would occur at the top of the out-of-pit emplacement, as the proposed UG1 ModML 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. 5.1.

The maximum predicted subsidence (S) at the natural surface below the out-of-pit emplacement is approximately 2300 mm and the depth of cover (h) between the natural surface and the mined seam varies from approximately 70 metres to 130 metres. The ratio of subsidence (S) to depth of cover (h) at the out-of-pit emplacement varies from 0.017 to 0.033, which is beyond the maximum limit of the range of cases considered in Fig. 5.1.

Based on an extrapolation of the linear trend line, from Fig. 5.1 for S/h ratios of 0.017 to 0.033, the potential additional settlement at the surface of the out-of-pit emplacement above the extracted longwalls ranges from approximately 30 mm/m to 60 mm/m, or 3% to 6% 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 3300 mm. The maximum predicted total subsidence plus potential excess settlement therefore is approximately 5500 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.

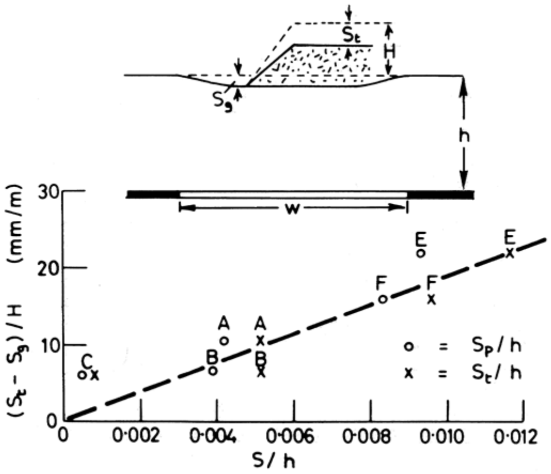


Fig. 5.1 Relationship between Excess Settlement of Mine Spoil Heap and the S/H Ratio. (From Whittaker and Reddish, 1989)

The areas of greatest concern are still 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 that are located in the south western corner of Longwall 105. 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.

Consistent with the recommendations provided for the approved PrefML, it is still recommended, therefore, that management strategies are developed for the management of the surface and the slopes of the proposed out-of-pit emplacement area as the proposed UG1 longwalls are mined beneath the out-of-pit emplacement area.

Such management should include surface crack repair and remediation of the ground surface to ensure that adequate surface water drainage is maintained. Consistent with the recommendations provided for the approved PrefML, it is still recommended that the settlement and movement of the out-of-pit emplacement be monitored as the proposed UG1 ModML longwalls are mined beneath it. As noted previously, it may be necessary to monitor the out-of-pit emplacement area from a remote location using reflectors placed on the out-of-pit emplacement, or using aerial laser scan techniques.

5.14.2. Stage 2 ROM facilities and Conveyors

The approved Stage 2 ROM facilities will be located above the south western end of Longwall 105 and conveyors between Stage 2 ROM facilities and Stage 1 ROM coal facilities will cross UG1 Longwall 101 to Longwall 105. Provision should be made for adjustments or repair of any mine infrastructure located above the UG1 to accommodate the predicted subsidence parameters and to ensure that safety and serviceability is maintained.

5.14.3. Remote Services Facilities

Remote Services Facilities are proposed at the north western end of Longwalls 101 and 102. Provision should be made for adjustments or repair of any mine infrastructure located above the proposed longwalls to accommodate the predicted subsidence parameters and to ensure that safety and serviceability is maintained.

5.14.4. The Highwall of the Open Cut Mines

The finishing ends of the longwalls, in the Ulan Seam, must be positioned by MCO to ensure that the longwalls do not affect the stability the highwalls of the open pit and to ensure that the mine accesses remain safe and serviceable throughout the mining period.

It is possible that some horizontal movement of the highwalls could occur, towards the open pit, due to relaxation of in situ stresses in the strata as they are undermined. It would, therefore, be prudent to establish survey lines along the top and bottom of the highwalls to monitor the movements as the longwalls are mined. Regular visual inspection of the faces of the highwalls and the tops of the highwalls, as mining occurs, would also be advantageous in order to ensure that any cracking in the strata is identified. In this way, preventive measures can be put in place, before the stability of the highwalls is compromised.

5.15. Archaeological Sites

There are 24 archaeological sites located within the UG1 Study Area, the locations of which are shown in Drawing No. MSEC731-12. One archaeological site is located within the out-of-pit emplacement footprint. The predictions and impact assessments for the archaeological sites are provided in the following sections.

5.15.1. Predictions for the Archaeological Sites

The maximum predicted total systematic subsidence parameters at the archaeological sites within the UG1 Study Area, resulting from the extraction of the proposed UG1 ModML longwalls, are shown in Table D.01 in Appendix D. A comparison between the maximum predicted total systematic subsidence parameters at the archaeological sites within the UG1 Study Area using the PrefML and the ModML is provided in Table D.03 in Appendix D.

A summary of the maximum predicted values of total systematic subsidence, tilt and strain at these 24 archaeological sites, after the extraction of the proposed UG1 ModML longwalls, is provided in Table 5.5.

Table 5.5 Maximum Predicted Total Systematic Subsidence, Tilt and Strain at the Archaeological Sites within the UG1 Study Area after the Extraction of Longwalls 101 to 105

Type	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total or Travelling Tilt (mm/m)	Maximum Predicted Total or Travelling Tensile Strain (mm/m)	Maximum Predicted Total or Travelling Compressive Strain (mm/m)
Archaeological Sites	2300	65	>50	>50

The values provided in the above tables are the maximum predicted parameters within a 20 metre radius of each site. The predicted tilts and strains are the maximum values which occur during, or after the extraction of each proposed longwall, whichever is the greater.

5.15.2. Impact Assessments for the Archaeological 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 archaeological sites was required after mining, these works could potentially impact on the archaeological sites. Remediation works in areas adjacent to these sites will need to be supervised by a qualified archaeologist should any works be required. A discussion on surface cracking resulting from the extraction of the proposed UG1 ModML longwalls is provided in Section 5.18.1.

Consistent with the approved PrefML, the site that is located within an overhang will be subject to similar impacts as described for the cliffs and overhangs in Section 5.3, and artefact scatters and isolated finds can potentially be affected by rock falls. Any artefacts that require protection from potential impacts would either need to be removed from the overhang or would need to be protected by minimising the risk of rock falls at the relevant overhang.

One site, Site ID S2MC231 is located within the out-of-pit emplacement footprint and will be covered during the filling operations.

Further details and discussions on the potential impacts on the archaeological sites resulting from the extraction of the proposed UG1 ModML longwalls and emplacement are provided in the report by Niche Environment and Heritage (2015).

5.16. 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). The location of the item is shown on Drawing No. MSEC731-12.

The maximum predicted subsidence at the heritage site, after the extraction of the proposed UG1 ModML longwalls is 2250 mm. The maximum predicted systematic tilt at the heritage site is 2 mm/m (i.e. 0.2 %), or a change in grade of 1 in 500. The maximum predicted systematic tensile and compressive strains at the heritage site are >50 mm/m.

At these levels of tilt and strain, the dry stone wall is likely to be subjected to significant impact resulting from the extraction of the proposed UG1 ModML longwalls. Potential impacts at this site could include cracking and loose stones that may become dislodged during mining.

Consistent with the recommendations provided for the approved PrefML, it is still 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 replaced in the correct positions following the completion of mining.

5.17. Survey Control Marks

There is one survey mark, known as Murragamba Trig Station, included in the UG1 Study Area. The location of the survey control mark is shown in Drawing No. MSEC731-11.

The trig station is located near the south-western end of the proposed Longwall 105. The predicted maximum subsidence and tilt at this location are 1150 mm and 60 mm/m respectively.

At this location the predicted maximum horizontal movement resulting from the extraction of the proposed UG1 ModML longwalls is approximately 600 mm. Further discussion on horizontal movements is provided in Section 4.5 of this report.

It is anticipated that that there would be no significant impact on the survey mark itself as a result of the proposed mining, however, it will be necessary on the completion of the proposed UG1 ModML longwalls, i.e. when the ground has stabilised, to re-establish the exact location of this survey mark. Consultation between MCO and the Department of Lands will be required throughout the mining period to ensure that the survey mark is not used for detailed surveying purposes by others and that it is reinstated at an appropriate time, as required.

5.17.1. Recommendations for the Survey Control Marks

Consistent with the recommendations provided for the approved PrefML, it is still recommended that management strategies are developed, in consultation with the Department of Lands, such that the survey control marks can be re-established, as required, at the appropriate time.

5.18. Other Potential Impacts

5.18.1. The Likelihood of Surface Cracking in Soils and Fracturing of Bedrock

As subsidence occurs, surface cracks will generally appear in the tensile zone from panel edges, i.e. within 0.1 to 0.4 times the depth of cover from the longwall perimeter and in the tensile zone around the travelling longwall face. That is, these tensile cracks will occur over the longwall panels and, since the depth of cover varies around the proposed longwall perimeter between 35 and 143 metres, these tensile surface cracks will generally appear within 3 metres to 60 metres from the edges of the panels. Most of the cracks will occur within a radius of approximately 0.1 times the depth of cover from the longwall perimeter. The cracks will generally be parallel to the longitudinal edges of the longwall and to the ends of the longwall.

At shallow depths of cover, it is also likely that smaller 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. This cracking, however, tends to be transient, since the tensile phase of the travelling wave, which causes the cracks to open up, is generally followed by a compressive phase, which closes them. It has been observed at other mines in the past, however, that surface cracks which occur during the tensile phase of the travelling wave do not fully close during the compressive phase, and tend to form compressive ridges at the surface.

At shallow depths of cover, therefore, surface cracking can potentially occur in any location above the extracted goaf areas of the proposed UG1 ModML longwalls. The larger and more permanent cracks, however, are usually located in the final tensile zones around the perimeters of the longwalls.

The incidence of surface cracking is dependent on the location relative to the extracted longwall goaf edges, the depth of cover, the extracted seam thickness, and the thickness and inherent plasticity of the soils that overlie the bedrock. The surface soils above the UG1 are generally weathered. The widths and frequencies of the cracks are also dependent upon the pre-existing jointing patterns in the bedrock. Large joint spacing can lead to concentrations of strain and possibly the development of fissures at rockhead, which are not necessarily coincident with the joints.

Consistent with the approved PrefML, the largest surface cracks within the UG1 Study Area are expected to occur as the result of soil slumping down the steep slopes, which is discussed in Section 5.4.

Where the surface is relatively flat, the relationship between surface crack width and depth of cover, based upon measured data in the NSW Coalfields and observations over mines in the United Kingdom, is discussed in Section 1.6 of the online document “General Discussion of Mine Subsidence Ground Movements”. It can be seen that the crack width increases as the depth of cover reduces and that significant crack widths can develop at lower depths of cover.

The depths of cover over the underground mining areas vary from 35 metres to 165 metres. Based on the relationship between surface crack width and depth of cover, where the depths of cover above the UG1 are less than 100 metres the predicted surface crack widths are, 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 predicted surface crack widths are smaller where the depths of cover are greater, or where the surface cracks result from the travelling wave. Where the depths of cover above the UG1 are 100 to 150 metres, the predicted surface crack widths are, typically in the order of 100 to 150 mm wide.

The surface cracks will tend to close and heal naturally, especially during rain events. If significant cracking is left untreated, however, it could form trip hazards for people and farm animals, (where relevant), or result in soil erosion on the steep slopes or in the drainage channels.

Consistent with the recommendations provided for the approved PrefML, it is still recommended that the natural surface is visually monitored during the extraction of the proposed UG1 ModML longwalls, so that any significant cracking can be remediated, where required, by infilling, regrading, recompacting, and revegetating the surface. Consistent with the recommendations provided for the approved PrefML, it is still recommended that test pits are dug in the locations of the largest surface cracks, to determine the profile of the cracks with depth, to aid in the remediation of these cracks.

5.18.2. The Likelihood of Gas Emissions at the Surface

It is known that the mining of coal causes fracturing of the strata above the coal seam and this may result in the liberation of methane and other gases. Methane, being a lighter gas, would tend to move upwards to fill the voids in the rock mass and diffuse towards the surface through any continuous cracks or fissures.

Emissions of strata gas have occurred at underground mines in the past, generally within large river valleys, although some gas emissions have also been observed in smaller drainage lines and water bores. Analyses of gas compositions indicate that the coal seam is not the direct and major source of the gas and that the most likely source is the overlying sandstones.

Gas emissions from the beds of watercourses will not have time to dissolve in any surface water which is present. In addition to this, gas emissions as the result of mining comprises mainly of methane which is not significantly soluble in water. Any gas emissions are likely, therefore, to be released into the atmosphere and are unlikely to have any significant impact on water quality.

It is possible, if substantial gas emissions occurred at the surface, that localised vegetation die back could occur. Any impacts would be expected to be temporary and limited to small areas of vegetation local to the points of emission.

A literature and data review was conducted by MCO in October 2009, which included desorpable gas testing of three boreholes in the area during 2008. The review determined that low gas content levels were to be expected across the MCC.

5.18.3. The Potential Impacts of Ground Vibration on Structures due to Mining

The settlement of the ground resulting from systematic subsidence is generally a gradual and progressive movement, the effect of which is not apparent to an observer at the surface. The major breakage and collapse of strata into the voids left by extraction of the seam occur in the layer immediately above the seam. Above that level, the breakage and collapse of the strata reduces to become a bending and sagging of the upper layers of rock with less sudden and much smaller movements occurring. In some instances, the movements can be concentrated at faults or other points of weakness in the strata with minor stepping at the surface.

Any major collapse below ground would result in some vibration in the layers of rock above it, which might be felt as a minor effect at the surface. This effect is generally only noticeable where the depth of cover is less than 100 metres, which occurs over some of the proposed UG1 ModML longwalls.

It is possible, therefore, as the longwalls are mined and the strata subsides, for some vibrations to be felt at the surface, though these are more likely to occur directly above or close to the longwalls. The levels of vibration would, however, generally be very low and would not be of sufficient amplitude to result in any significant impact on the surface features or items of infrastructure. The impact due to vibration resulting from the extraction of the proposed UG1 ModML longwalls is predicted to be insignificant.

In accordance with Project Approvals (05_0117) and (08_0135), MCO is required to prepare an Extraction Plan to the satisfaction of the Secretary of the Department of Planning and Environment.

A subsidence ground monitoring program of survey pegs at various items of surface infrastructure and along several gridlines over the UG1 is recommended and a visual subsidence impact monitoring program is recommended.

Several subsidence mitigation measures have been recommended in the previous Chapters to minimise the impacts of subsidence at various items of infrastructure and natural features and these mitigation measures are summarised in Section 6.3.

6.1. Objectives of Ground Monitoring Program

The objectives of the ground monitoring program are to:

- provide general information on the magnitude of subsidence ground movements over the longwall panels and the extent of subsidence ground movements around the longwall panels;
- compare actual ground movements with predicted ground movements;
- monitor ground movements at or near surface infrastructure and sensitive natural features;
- provide early detection of non-systematic movements within the subsidence zone, whilst allowing contingency for assessment and response in the event that predictions are exceeded;
- satisfy the objectives of the Extraction Plan;
- satisfy the objectives of agreed management plans between MCO and infrastructure owners; and
- meet the expectations of the community with regard to monitoring subsidence.

It should be noted that ground monitoring is only one portion of the overall subsidence management program. Other forms of monitoring include visual monitoring and specific monitoring related to items of infrastructure. Whilst traditional ground movement monitoring is important, these other forms of monitoring can be very effective in identifying potential subsidence impacts at early stages in their development.

6.2. Recommended Ground Movement Monitoring for the Proposed Longwalls

The monitoring of ground movements at various ground survey pegs is recommended, as subsidence occurs, so that the observed ground movements can be compared with those predicted and to allow regular reviews of the predictions and impact assessments in the light of measured data.

Consistent with the recommendations provided for the approved PrefML, it is still recommended that a survey line be established perpendicular to and across the UG1 to monitor ground movements as the longwalls are extracted. The monitoring lines should be established prior to extraction of the longwalls and these monitoring lines should be monitored on the completion of each longwall and after a period of approximately 6 months after the completion of mining.

Consistent with the recommendations provided for the approved PrefML, it is still recommended that visual monitoring, with photographic records (where relevant), of the important natural features and items of surface infrastructure is undertaken during the mining period. A baseline inspection should be carried out to establish the condition of the natural features and items of surface infrastructure prior to extraction of the proposed UG1 ModML longwalls. Inspections should then be carried out on a regular basis during the mining period and approximately 6 months after the completion of all mining or until results show that further subsidence has reduced to minimal levels.

A summary of the monitoring recommendations for the natural features and items of surface infrastructure are provided in Table 6.1. Reference should also be made to any monitoring recommendations given in the specialist reports.

There is generally a higher risk of subsidence impacts occurring to natural features and items of infrastructure where the depth of cover is less than 100 m and this should be taken into account when preparing more detailed monitoring and mitigation programs.

Table 6.1 Summary of the Monitoring Recommendations for the Natural Features and Items of Surface Infrastructure

Feature	Recommendations
Drainage Lines	• Visual monitoring as the proposed UG1 ModML longwalls mine beneath the drainage lines.
Cliffs, Overhangs and Rock Ledges	• Visual monitoring during the mining period from a remote and safe location until such time as the mine subsidence movements have ceased.
Steep Slopes	• Visual monitoring of steep slopes above the longwalls as they are mined.
Vegetation Communities	• Visual monitoring of the vegetation communities as the proposed UG1 ModML longwalls mine beneath them.
Gulgong to Sandy Hollow Railway	• Survey the track and the ground near the railway line during extraction of the longwalls and remediate the track if monitored movements result in impacts.
Roads	• Survey ground of roads during extraction of the longwalls and remediate the roads if cracking or ponding occurs.
66kV Powerlines Poles and 330kV Transmission Lines and Towers	Survey the Poles, Towers and the ground near the powerlines located near the proposed ModML longwalls during extraction of the longwalls
Optical Fibre Cables	• Monitoring during the extraction of the longwalls using optical fibre sensing techniques, such as Optical Time Domain Reflector (OTDR) monitoring.
Mining Infrastructure	• Monitor settlement of the out-of-pit emplacement as the proposed UG1 ModML longwalls are mined beneath it. It may be necessary to monitor the out-of-pit emplacement from a remote location using reflectors placed on the out-of-pit emplacement, or using aerial laser scan techniques. • Establish survey lines along the top and bottom of the highwalls to monitor the movements as the longwalls are mined. Regular visual inspection of the faces of the highwalls and the tops of the highwalls, as mining occurs. • Monitor mine infrastructure placed above the proposed UG1 ModML longwalls and adjust or repair to maintain safety and serviceability during and following extraction of the longwalls.
Archaeological Sites	• Monitor overhang sites as required in accordance with cliff line monitoring. • Visual monitoring of open archaeological sites.
Heritage Sites – Dry Stone Wall	• Photographic record of the pre mining condition and visual monitoring during extraction of Longwalls 104 and 105.
Survey Control Marks	• Murragamba Trig station should not be used during mining as it would have moved (unless corrections are made for any movements of the trig station).

6.3. Mitigation and Remediation

The detailed monitoring programs developed for the Extraction Plans should include mitigation strategies, to ensure that safety and serviceability are maintained during the mining period and to ensure that adequate remediation is carried out in a timely manner where impacts have occurred.

A summary of the recommendations for mitigation measures for the natural features and items of surface infrastructure that were discussed and recommended in the previous Chapters of this report to minimise the impacts of subsidence at various items of infrastructure and natural features are provided below in Table 6.2.

Reference should also be made to the specialist reports for more information on potential impacts and mitigation measures.

Table 6.2 Summary of the Recommendations for Mitigation Measures for the Natural Features and Items of Surface Infrastructure

Feature	Recommendations for Mitigation Measures
Drainage Lines	• Identified cracking in drainage lines should be remediated by infilling the surface cracks with materials comprising a high clay content, or by locally regrading and recompacting the surface (where appropriate).
Cliffs, Overhangs and Rock Ledges	• The existing condition of cliffs within the Study Area should be reviewed and documented prior to mining. Management strategies should include restriction of access and making the sites safe.
Steep Slopes and Vegetation Communities	• Significant surface cracking should be remediated by infilling with soil or other suitable materials, or by locally regrading and compacting the surface (where appropriate).
Gulgong to Sandy Hollow Railway	• A management plan should be established, in consultation with the Australian Rail Track Corporation, for the railway during the extraction of the longwalls.
Roads	• Management strategies should be developed, in consultation with the Local Council where necessary, to maintain the roads in a safe and serviceable condition throughout the proposed mining period.
66kV Powerlines Poles and 330kV Transmission Lines and Towers	• The powerline should be inspected by a suitably qualified person prior to mining, to determine the existing condition and whether any preventive measures are required. • Management strategies should be prepared, in consultation with Essential Energy, as required, to incorporate the assessed impacts to the powerline resulting from the extraction of the proposed UG1 ModML longwalls.
Optical Fibre Cables	• A monitoring, management and response plan should be established for the optical fibre cable prior to mining the proposed UG1 ModML longwalls, to the satisfaction of the owners of the optical fibre cable.
Mining Infrastructure	• Management strategies should be developed for the safe placement of spoil to maintain the stability of the slopes as the proposed UG1 ModML longwalls are mined beneath and in the vicinity of the out-of-pit emplacement areas. Such management strategies should include surface crack repair and remediation of the ground surface to ensure that adequate surface water drainage is maintained. • Management strategies should be developed to maintain stability of the highwalls during the underground mining period. • Management strategies should be developed for the mine infrastructure located above the UG1 to maintain safety and serviceability during extraction of the proposed UG1 ModML longwalls
Archaeological Sites	• Management of Aboriginal heritage sites in accordance with a Heritage Management Plan prepared in consultation with Aboriginal parties. • Care should be taken if any ground surface remediation is carried out to avoid disturbance of any of the archaeological sites.
Heritage Sites – Dry Stone Wall	• If any stones become dislodged during mining, they should be replaced in the correct positions following the completion of mining.
Survey Control marks	• Survey control marks should be re-established, as required, following the completion of mining.

7.0 CONCLUSIONS

The maximum predicted incremental and total conventional subsidence parameters due to the extraction of the proposed UG1 ModML Longwalls 101 to 105 have increased by approximately 20% because of the increase in the seam thickness to be extracted, the increase in the proposed longwall panel widths, the increase in the proposed longwall panel lengths and the reduced chain pillar widths.

Site specific predictions and revised impact assessments have been prepared as a result of the Modification for each natural surface feature and infrastructure item that is located within the UG1 Study Area. It has been concluded that the assessed levels of potential impact and potential damage to the identified features are generally consistent with those for the approved PrefML layout and are still manageable through the preparation and implementation of appropriate Extraction Plans. The recommended management strategies for the natural and built features are the same as those that were recommended for the approved MCC (as reported in MSEC, 2011).

Recommended management measures are consistent with the recommendations provided for the approved PrefML and generally include monitoring of ground movements and the condition of surface features. Some mitigation measures are recommended to mitigate or avoid the risk of serious consequences should impacts occur to some critical surface features.

In accordance with Project Approvals (05_0117) and (08_0135), MCO is required to prepare an Extraction Plan to monitor and manage the effects of mine subsidence on all these features. These Extraction Plans (and component management plans) would be developed in conjunction with the owners of infrastructure and are to be approved by relevant government agencies. The findings in this report should be read in conjunction with all other associated consultant reports.

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

© MSEC JUNE 2015 | REPORT NUMBER MSEC731 | REVISION A

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

© MSEC JUNE 2015 | REPORT NUMBER MSEC731 | REVISION A

Attewell, P., (1977). *Ground Movements Caused by Tunnelling in Soil.* Conference on Large Ground Movements & Structures. University of Wales, Instit. of Sci. & Techn.

Bhattacharyya, A.K. & Zhang, M., (1993). *Study of the Parameters of the Displacement Discontinuity Method for Predicting Surface and Sub-Surface Subsidence*. Applications of Computers in the Mineral Industry. University of Wollongong, NSW, October 1993.

Bowles, Joseph E., (1977). *Foundation Analysis and Design*. McGraw – Hill.

Brady, B.H.G. & Brown, E.T., (1993). *Rock Mechanics for Underground Mining*. Chapman & Hall.

Bray, I.J. and Branch, S.E.T., (1988). *Design of Buildings for Mine Subsidence*. Conference on Buildings and Structures, Institution of Engineers, Maitland, pp. 14-22.

Burland, J.B. and Wroth, C.P., (1974). *Settlement of Buildings and Associated Damage*. Conference on Settlement of Structures. British Geotechnical Society.

Burton, B., (1995). *Behaviour of Structures Subjected to Mine Subsidence*. Mine Subsidence Technological Society, 3rd Triennial Conference on Buildings and Structures subject to Mine Subsidence. Newcastle, pp. 1-8.

Department of Lands (2007). *Data CD - surface features and cadastral information.* Reference ADS_10101_d1 and ADS_10101_d2, May 2007.

Dundon Consulting, (2015), *Moolarben UG1 Optimisation Modification Groundwater Assessment.*

Ecological Australia, (2015) *Moolarben Coal Complex – UG1 Optimisation Modification Flora and Fauna Impact Assessment*.

Ferrari, C.R., (1997). *Residual Mining Subsidence – Some Facts*. The Institution of Mining Engineers, transactions Volume 79, No. 911, July 1997.

Forster, I.R., (1995). *Impact of Underground Mining on the Hydrogeological Regime, Central Coast NSW*. Engineering Geology of the Newcastle-Gosford Region. Australian Geomechanics Society. Newcastle, February 1995.

Gale, W., (2008), *Aquifer Inflow Prediction above Longwall Panels*. ACARP, September 2008

Galvin (1981). *The Mining of South African Thick Coal Seams – Rock Mechanics and Mining Considerations – Volume 1 Text*. J.M. Galvin, University of the Witwatersrand (1981), pp 300-304.

Geddes, J.D., (1962). *Structures in Areas of Mining Subsidence*. J. Inst. Struct. Eng., March.

Geddes, J.D., (1984). *Structural Design and Ground Movements*. Ground Movements and Their Effect on Structures. Edited by Attwell, P.B. and Taylor, R.K.

Geddes, J. D., (1997). *Large Ground Movements and Structures*. Pentech Press, London.

Guo, H., Adhikary, D.P. and Gaveva, D., (2007)., *Hydrogeological Response to Longwall Mining. ACARP, October 2007*

Hebblewhite, B., Waddington, A.A. and Wood, J.H. *Regional Horizontal Surface Displacements due to Mining beneath Severe Surface Topography*. 19th International Conference on Ground Control in Mining. Morgantown, West Virginia, USA., August, 2000.

Holla, L., (1987). *The response of Domestic Structures to Ground Movement caused by Mining Subsidence*. Proc. 1st National Structural Engineering Conference, August, pp 472-477.

Holla, L., (1988). *Effects of Underground Mining on Domestic Structures - Prediction versus Performance*. Fifth Australia – New Zealand Conference on Geomechanics, Sydney, August 1988.

Holla, L., (1991a). *A Report of Mine Subsidence Relating to the Proposed Mitchells Flat Coal Project for Submission to the Commission of Inquiry*, 20th May 1991.

Holla, L., (1991b). *The Experience of Mining under Public Utility Installations in NSW*. Mine Subsidence Technological Society, 2nd Triennial Conference Proceedings, August 1991.

Holla, L. and Armstrong, M., (1986). *Measurement of Sub-Surface Strata Movement by Multi-wire Borehole Instrumentation*. Proc. Australian Institute of Mining and Metallurgy, 291, pp. 65-72.

Holla, L. and Barclay, E., (2000). *Mine Subsidence in the Southern Coalfield, NSW, Australia*. Published by the Department of Mineral Resources, NSW.

Holla, L. and Buizen, M., (1990). *Strata Movement and Longwall Mining under an Old Goaf*. The Coal Journal, No. 28.

Holla, L. (1991). *Surface Subsidence Prediction in the Western Coalfield*. Published by the Department of Minerals and Energy, NSW.

Holla, L. and Buizen, M. (1991). *The Ground Movement, Strata Fracturing and Changes in Permeability Due to Deep Longwall Mining*. Int. J. Rock Mech. Min. Sci. and Geomech. Abstr. -Vol 28 No. 2/3 PP. 207 - 217.

Holla, L., (1991). *Reliability of Subsidence Prediction Methods for Use in Mining Decisions in New South Wales*. Conference on Reliability, Production and Control in Coal Mines, Wollongong.

Hornby, P., Willey, P., Ditton, S. and Li, Z.H., (1991). *Measurement, Display, Analysis and Prediction of Surface Deformations due to Mine Subsidence in Australia*. Conference on Buildings and Structures, Institution of Engineers, Maitland.

HydroSimulations, (2015), *Moolarben Underground Mine UG1 Optimisation Modification Groundwater Modelling Assessment.*

Kapp, W.A., (1985). *Mine Subsidence in the Newcastle District, New South Wales*. Civ. Eng. Trans., IEAust, pp. 331-339.

Kay, D.R., (1991). *Effects of Subsidence on Steep Topography and Clifflines*. Report Number 1446, Common. Govt. NERRDP.

Kay, D.R. and Carter, J.P. *Effects of Subsidence on Steep Topography and Cliff Lines*. 11th International Conference on Ground Control in Mining, Wollongong, July, 1992.

Kay, D.R., McNabb, K.E., Carter, J.P. *Numerical Modelling of Mine Subsidence at Angus Place Colliery*. Computer Methods and Advances in Geomechanics, Beer, Booker & Carter (eds). 1991.

Kay, D.R., Barbato, J.P., Mills, K.W. (2007). *Review of Mechanisms Resulting in Observed Upsidence and Closure Movements*. 7th Triennial Conference Proceedings on Mine Subsidence: A Community Issue. University of Wollongong, November 2007.

King, H.J., Whittaker, B.N. and Shadbolt, C. H., (1974). *Effects of Mining Subsidence on Surface Structures*. Mining and the Environment, IMM London, 617-642.

Kratzsch, H., (1983). *Mining Subsidence Engineering*. Published by Springer - Verlag Berlin Heidelberg New York.

McNally, G.H., Willey, P.L. and Creech, M., (1996). *Geological Factors influencing Longwall-Induced Subsidence*. Symposium on Geology in Longwall mining, 12-13 November 1996, Eds G.H. McNally and C.R. Ward, pp 257-267.

Minerva Geological Services Pty Ltd, February 2007. *EL6288-Stages 1 and 2 Report on Geological Investigations*

National Coal Board Mining Department, (1975). *Subsidence Engineers Handbook*.

Niche Environment and Heritage (2015) *Aboriginal Cultural Heritage Assessment Moolarben Coal Complex UG1 Optimisation Modification*.

Patton F.D. & Hendron A.J., (1972). *General Report on Mass Movements,* Proc. 2nd Intl. Congress of International Association of Engineering Geology, V-GR1-V-GR57.

Peng S.S. & Chiang H.S., (1984). *Longwall Mining,* Wiley, New York, pg 708.

Shadbolt, C.H., (1972). *Subsidence Engineering*. Univ. Nottingham Min. Dept. Mag. 24, 80-89.

Shepherd, J. and Sefton, C.E.,(2001). *Subsidence Impact on Sandstone Cliff Rock Shelters in the Southern Coalfield, New South Wales.* Mine Subsidence Technological Society, Fifth Triennial Conference – Coal Mine Subsidence 2001 – Current Practice and Issues. Maitland, August 2001.

Shorten, C.G. and Tan, C.P., (1987). *Preliminary Appraisal of Geology and Feasibility of Numerical Modelling of Subsidence at Cataract Gorge, New South Wales*. Site Investigation Report, No. 39.

Singh, M.M. & F.D. Kendorski, 1981. *Strata Disturbance Prediction for Mining Beneath Surface Water and Waste Impoundments,* Proc. First Conference on Ground Control in Mining, West Virginia University, PP 76-89.

Sefton, C.,(2000). *Overview of the monitoring of sandstone overhangs for the effects of mining subsidence Illawarra coal measures, for Illawarra Coal.* C.E. Sefton Pty Ltd. 2000

Waddington, A.A., (1995). *The Effects of Mine Subsidence*. Association of Consulting Structural Engineers, Seminar on Building Movements, Sydney. August 1995.

Waddington, A.A., (1995). *Designing for Mine Subsidence*. Joint MSTS and MSB Seminar, Designing for subsidence, Campbelltown, NSW. November 1995.

Waddington, A.A., (1996). *Designing and Detailing for Mine Subsidence*. Joint MSTS and MSB Seminar, Designing for subsidence, Toukley, NSW. November 1996.

Waddington, A.A., (1998). *Experiences with the Incremental Subsidence Prediction Method*. Workshop entitled 'Subsidence Prediction Issues', Mine Subsidence Technological Society. Newcastle, December, 1998.

Waddington, A.A. and Kay, D.R., (1995). *The Incremental Profile Method for Prediction of Subsidence, Tilt, Curvature and Strain over a series of Longwalls*. Mine Subsidence Technological Society, 3rd Triennial Conference Proceedings, February, Newcastle. pp.189-198.

Waddington, A.A. and Kay, D.R., (1998). *Recent Developments of the Incremental Profile Method of Predicting Subsidence Tilt and Strain over a Series of Longwall Panels*. International Conference on Geomechanics / Ground Control in Mining and Underground Construction, Wollongong, July 1998.

Waddington, A.A. and Kay, D.R., (1998). *The Modelling of Subsidence Movements in the Cataract River Gorge and the Cataract Tunnel*. Mine Subsidence Technological Society, 4th Triennial Conference Proceedings, July 1998.

Waddington, A.A. and Kay, D.R., (1998). *Development of the Incremental Profile Method of Predicting Subsidence and its Application in the Newcastle Coalfield*. Mine Subsidence Technological Society, 4th Triennial Conference Proceedings, July, Newcastle, pp. 53-66.

Waddington, A.A. and Kay, D.R., (2000). *Subsidence Modelling Techniques and Applications*. Presented to the 'Working Smarter' Seminar of the Australian Institute of Mine Surveyors. Newcastle, October, 2000.

Waddington, A.A. and Kay, D.R., (2001). *Research into the Impacts of Mine Subsidence on the Strata and Hydrology of River Valleys and Development of Management Guidelines for Undermining Cliffs, Gorges and River Systems*. Final Report on ACARP Research Project C8005, March 2001.

Waddington, A.A. and Kay, D.R., (2001). *Closure and Uplift in Creeks, Valleys and Gorges due to Mine Subsidence*. Mine Subsidence Technological Society, Fifth Triennial Conference – Coal Mine Subsidence 2001 – Current Practice and Issues. Maitland, August 2001.

Waddington, A.A. and Kay, D.R., (2001). *Comparisons of Predicted and Observed Mine Subsidence Profiles*. Mine Subsidence Technological Society, Fifth Triennial Conference – Coal Mine Subsidence 2001 – Current Practice and Issues. Maitland, August 2001.

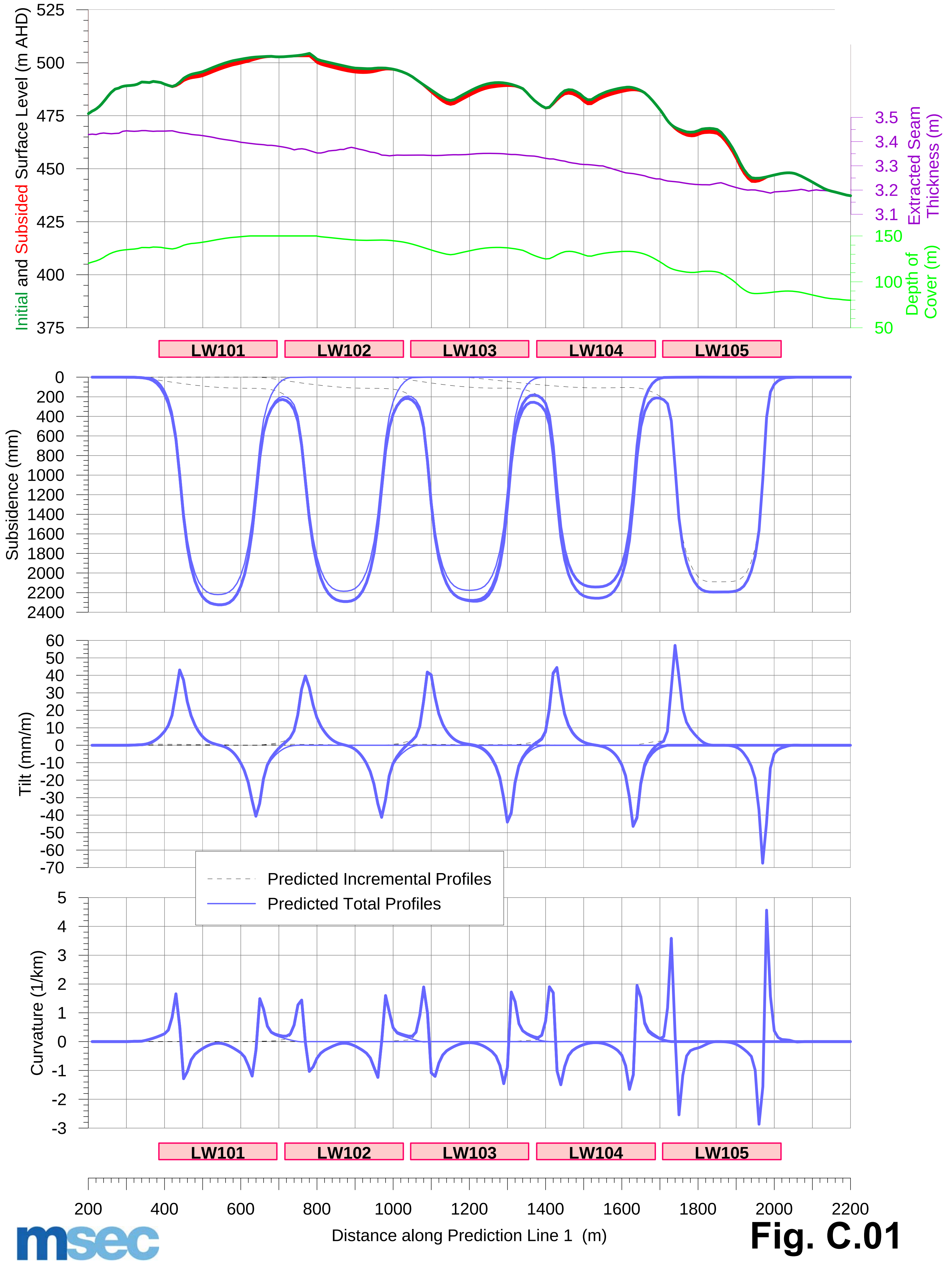
Waddington, A.A. and Kay, D.R., (2004). *Management Information Handbook on the Undermining of Cliffs, Gorges and River Systems*. ACARP Research Projects Nos. C8005 and C9067, February 2004.

Walsh, P. F., (1991). *Lessons for Mine Subsidence from Reactive Clay Design*. Mine Subsidence Technological Society. 2nd Triennial Conference on Buildings and Structures subject to Mine Subsidence. Maitland, pp.215-218.

Whittaker, B.N. and Reddish, D.J., (1989). S*ubsidence – Occurrence, Prediction and Control*. Elsevier.

APPENDIX C. FIGURES

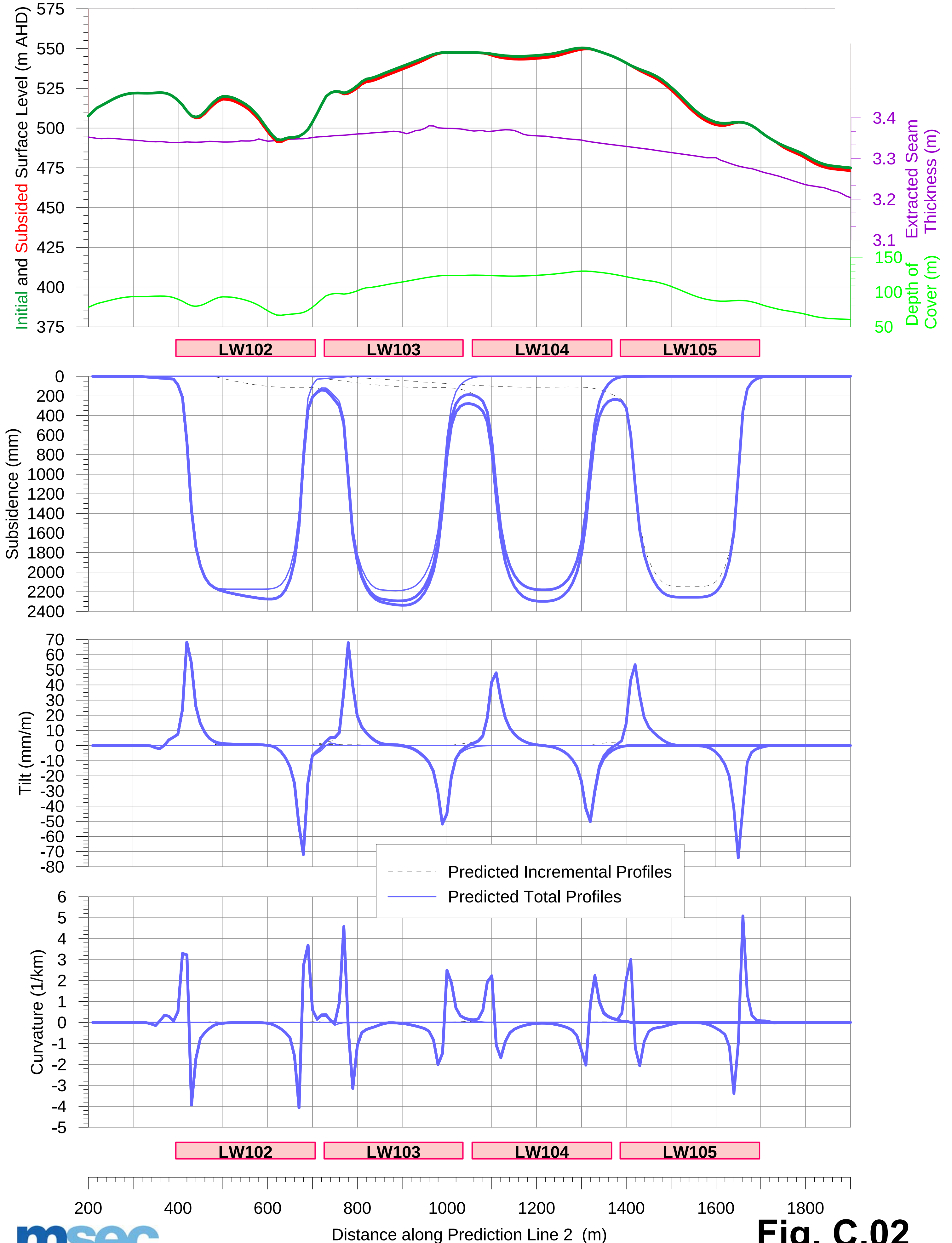
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 1 Resulting from the Extraction of Longwalls 101 to 105



msec

Fig. C.01

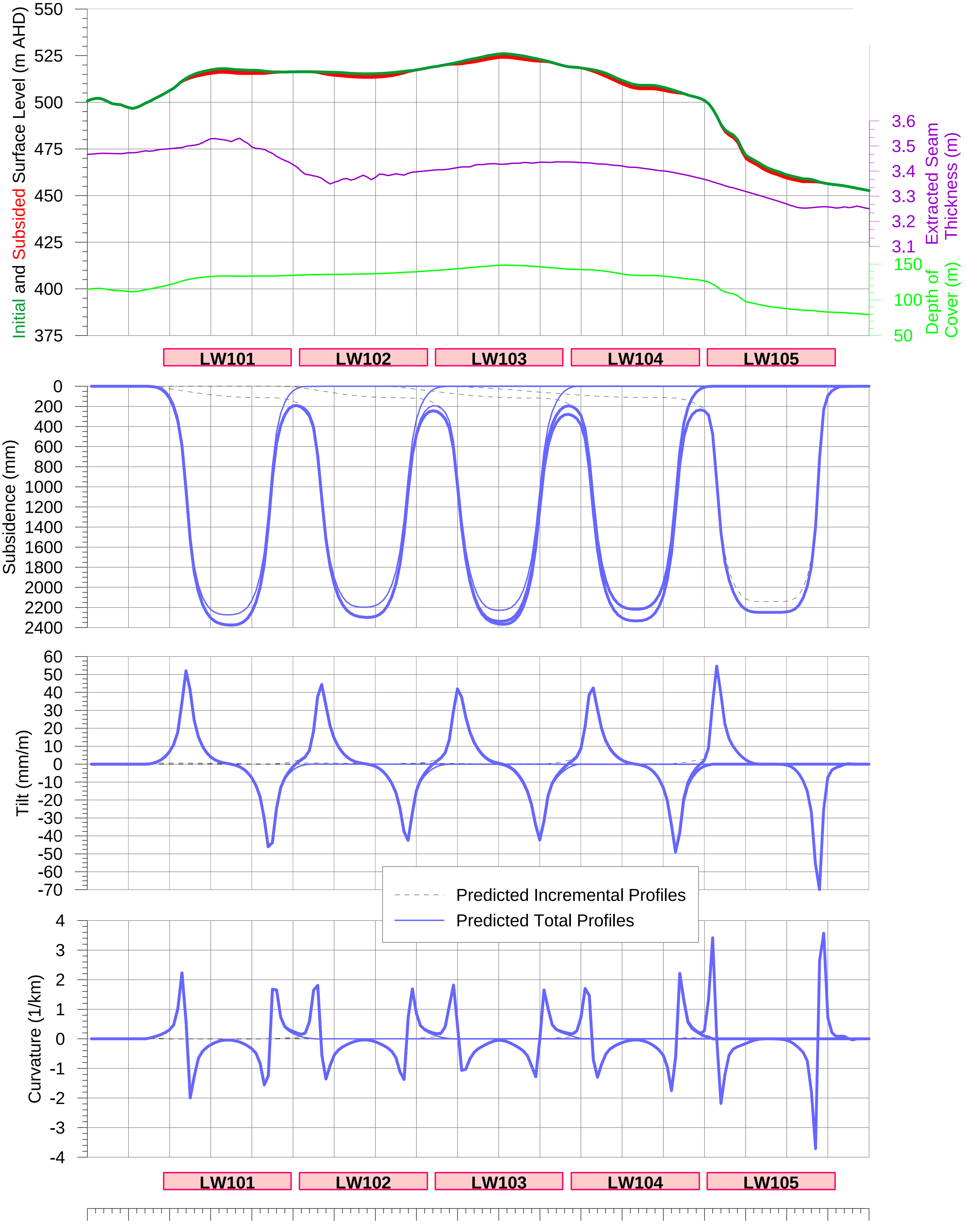
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 2 Resulting from the Extraction of Longwalls 102 to 105



msec

Fig. C.02

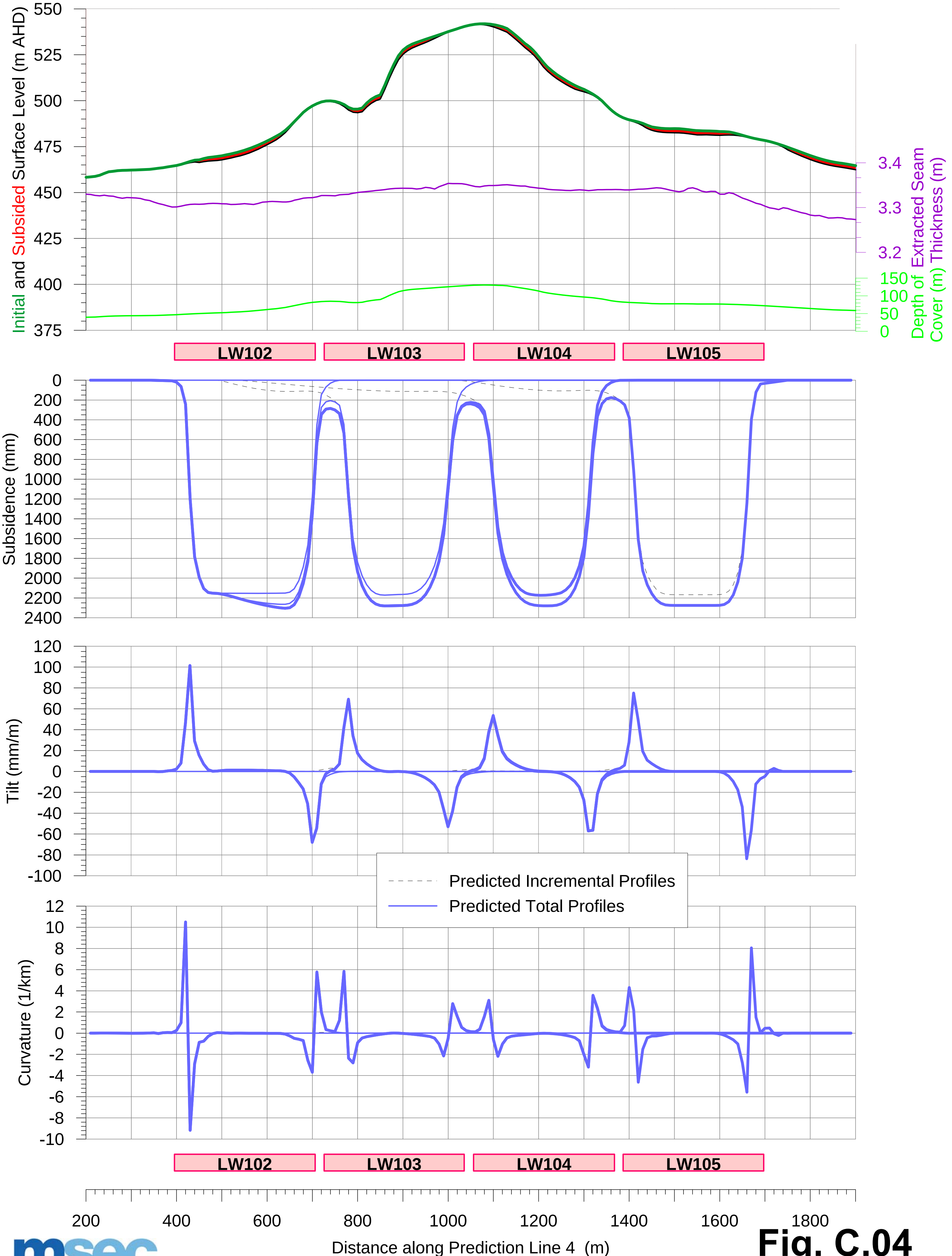
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 3 Resulting from the Extraction of Longwalls 101 to 105



msec

Fig. C.03

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 4 Resulting from the Extraction of Longwalls 101 to 105



msec

Fig. C.04

Predicted Profiles of Systematic Subsidence, Tilt Along and Tilt Across the alignment of the 66kV Powerline that is near UG1

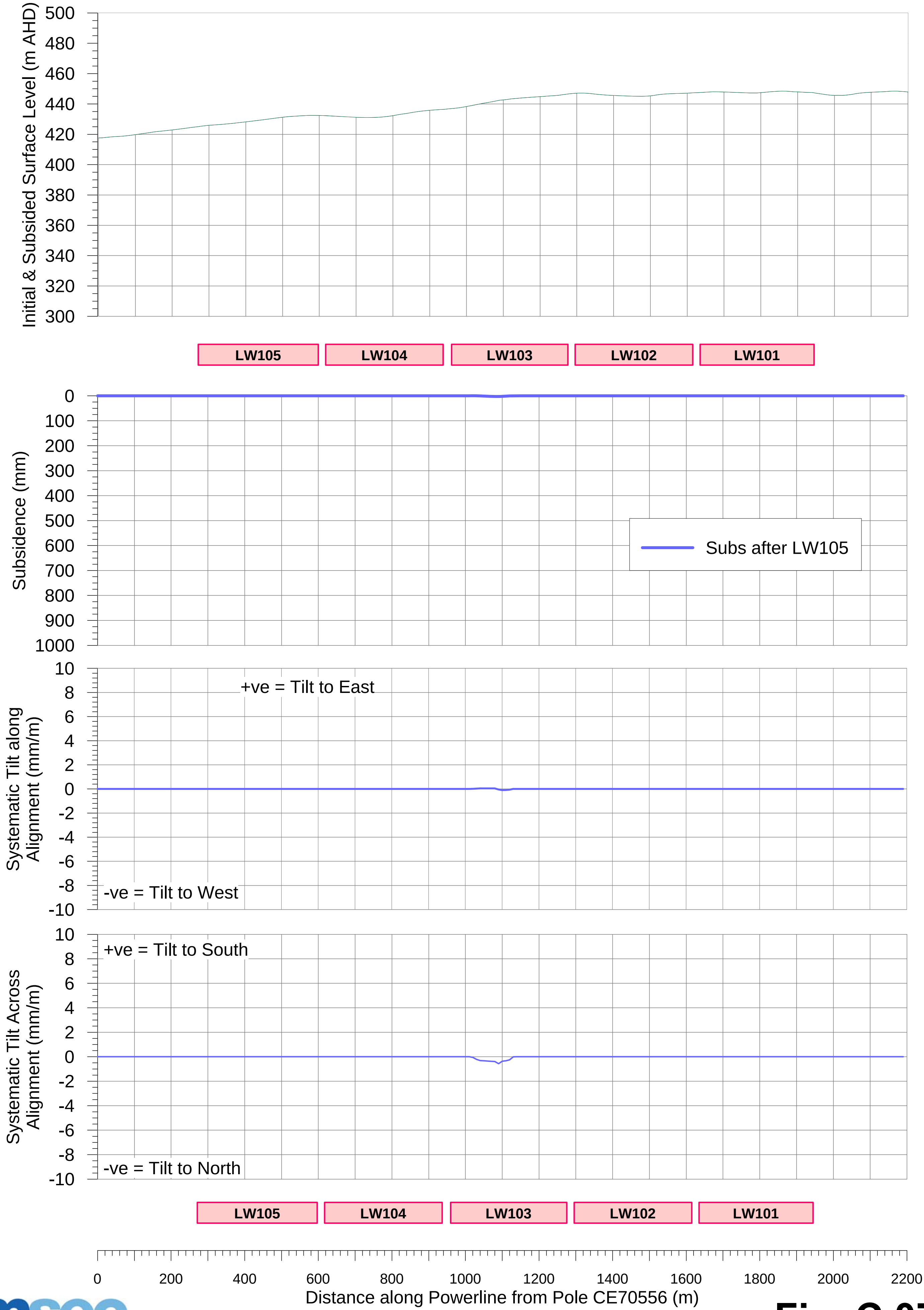
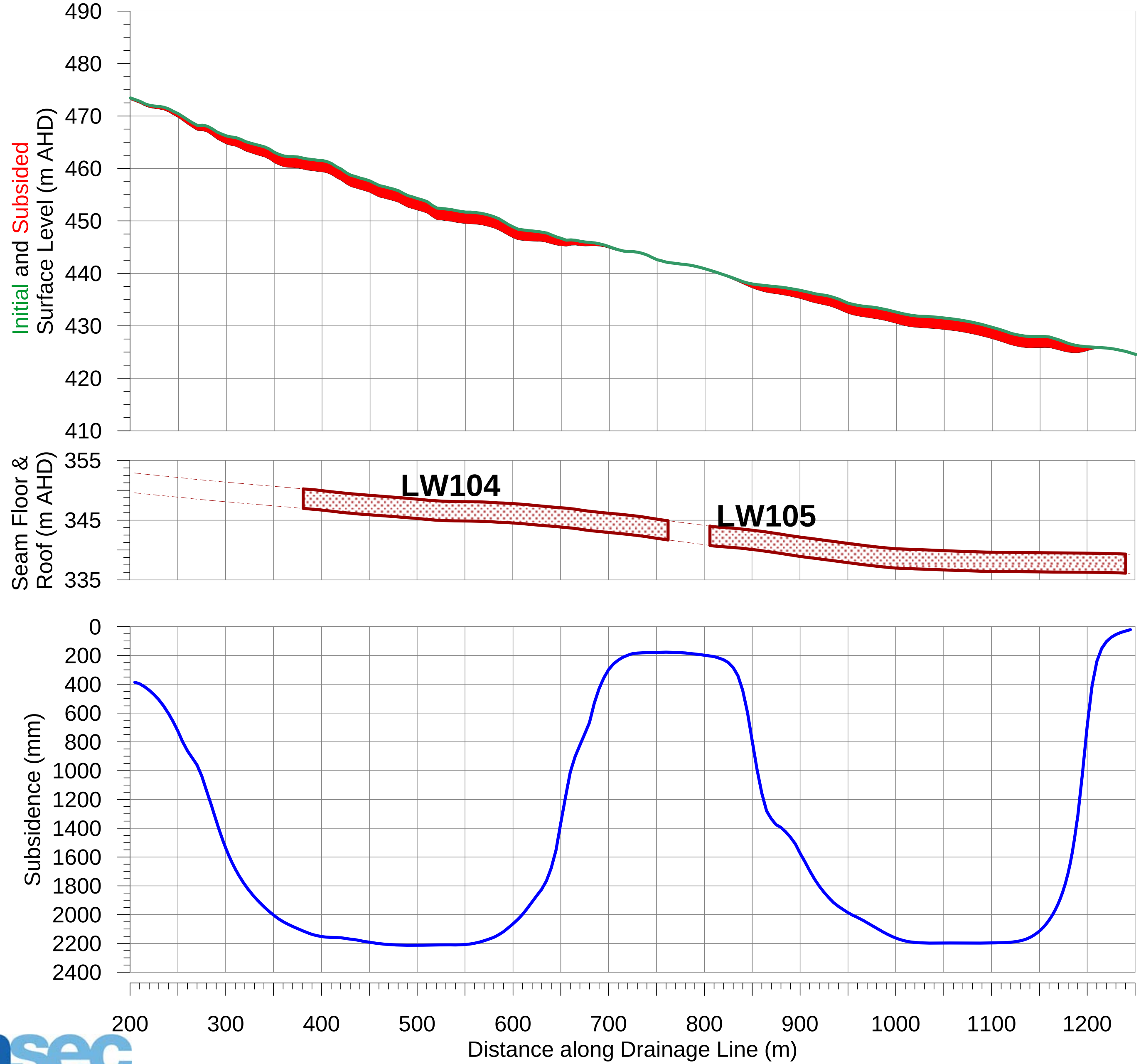
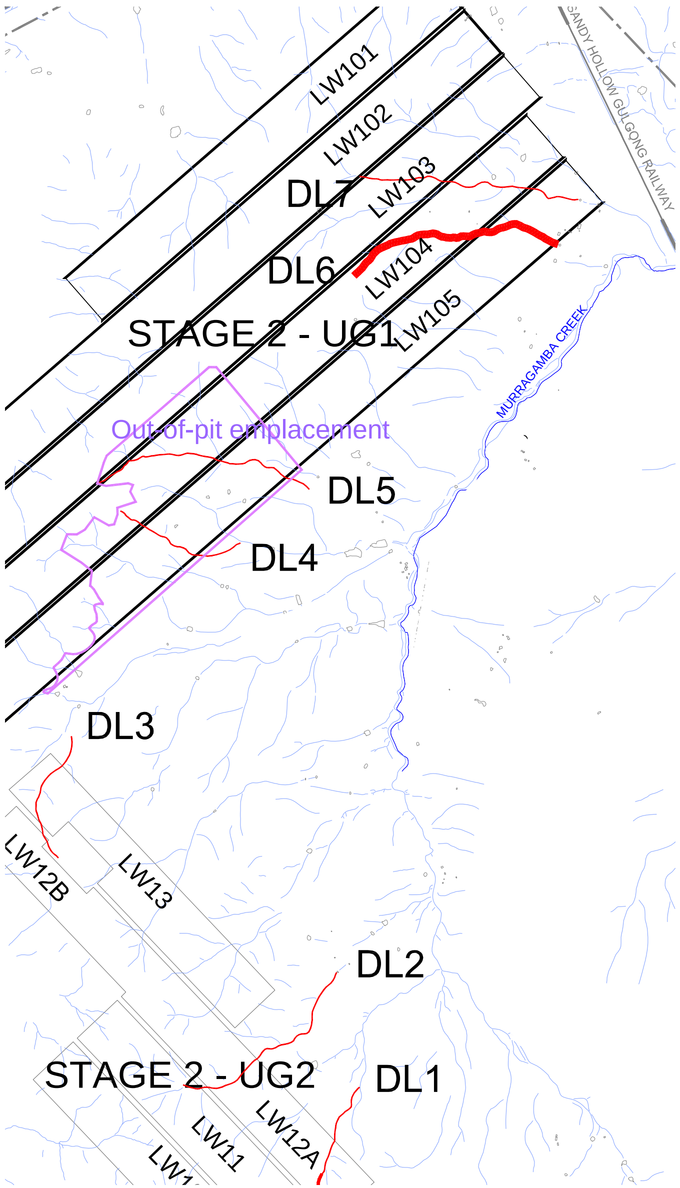


Fig. C.07

Moolarben Coal Project - Stage 2, Underground 1 - Longwalls 101 to 105
Profiles of Initial and Subsided Surface Level, and Predicted Subsidence
Drainage Line DL6

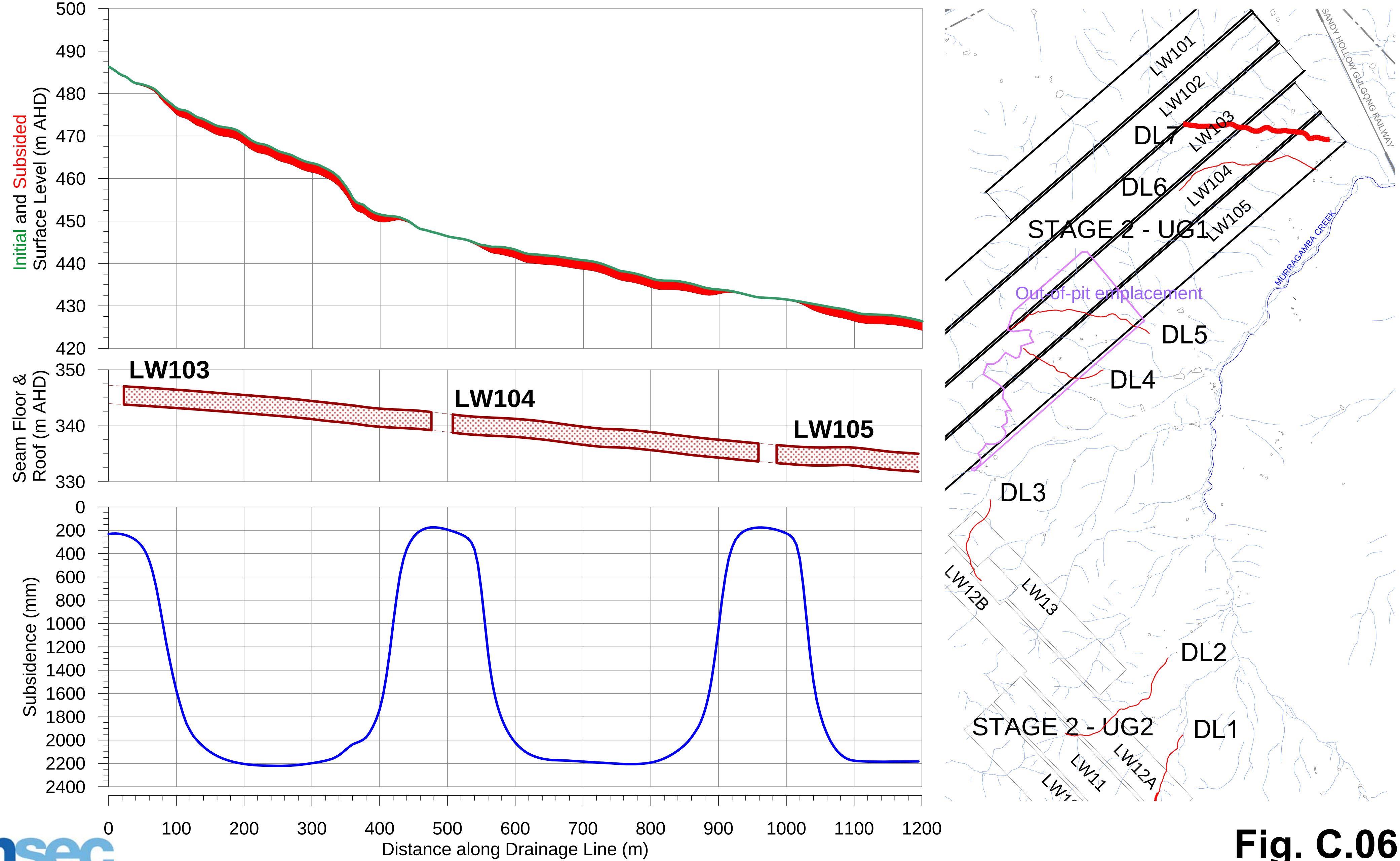




msec

Fig. C.05

Moolarben Coal Project - Stage 2, Underground 1 - Longwalls 101 to 105
Profiles of Initial and Subsided Surface Level, and Predicted Subsidence
Drainage Line DL7



msec

Fig. C.06

APPENDIX D. TABLES

© MSEC JUNE 2015 |

Table D.01 - MCC UG1 - Longwalls 101 to 105
Predicted Systematic Subsidence Parameters for the Archaeological Sites

Easting	Northing	ID	Total Subs after LW101	Total Subs after LW102	Total Subs after LW103	Total Subs after LW104	Total Subs after LW105	Total Tilt after LW101	Total Tilt after LW102	Total Tilt after LW103	Total Tilt after LW104	Total Tilt after LW105
763495	6426120	MUG1-Mod 1	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
763481	6425903	MUG1-Mod 2	0	1064	1126	1129	1129	0.0	45.8	46.3	46.3	46.3
762078	6423457	MUG1-Mod 3	0	0	0	35	190	0.0	0.0	0.0	2.5	0.5
761452	6424581	PAD 01	831	862	862	862	862	62.8	63.5	63.5	63.5	63.5
761265	6423464	PAD 02	0	0	2086	2182	2182	0.0	0.5	5.5	5.8	5.8
761265	6423392	PAD 03	0	0	2166	2278	2278	0.0	0.0	0.2	0.1	0.1
761619	6424707	S1MC029	1222	1275	1275	1275	1275	50.1	50.7	50.7	50.7	50.7
761279	6424617	S1MC038	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
761279	6424617	S1MC039	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
760964	6421902	S1MC055	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
763893	6425480	S2MC002	0	0	30	32	32	0.0	0.0	2.6	2.7	2.7
760866	6424307	S1MC004	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
763592	6424924	S2MC005	0	0	0	2085	2196	0.0	0.0	0.0	1.8	1.6
763750	6424949	S2MC006	0	0	0	208	330	0.0	0.0	0.0	19.5	18.9
763625	6425020	S2MC007	0	0	0	2103	2200	0.0	0.0	0.0	0.0	0.4
762810	6425021	S2MC008	0	396	514	516	516	0.0	18.3	17.9	17.8	17.8
762818	6424980	S2MC009	0	62	210	226	226	0.0	4.3	2.7	2.1	2.1
762899	6425019	S2MC010	0	5	206	244	244	0.0	0.9	2.1	2.7	2.7
762932	6425019	S2MC011	0	0	335	387	387	0.0	0.1	13.5	14.1	14.1
762928	6425072	S2MC012	0	50	203	234	234	0.0	3.7	2.0	1.5	1.5
762763	6423698	S2MC230	0	0	0	0	1461	0.0	0.0	0.0	0.0	46.7
762203	6423681	S2MC231	0	0	0	2006	2119	0.0	0.0	0.0	9.1	9.1
763744	6424582	S2MC269	0	0	0	0	2113	0.0	0.0	0.0	0.0	6.1
762243	6423241	S2MC270	0	0	0	0	1897	0.0	0.0	0.0	0.0	22.1
763404	6426033	S2MC277	1797	1904	1904	1904	1904	17.5	17.6	17.6	17.6	17.6

Table D.01 - MCC UG1 - Longwalls 101 to 105
Predicted Systematic Subsidence Parameters for the Archaeological Sites

		ID	Maximum Predicted Tensile Strain during or after LW101	Maximum Predicted Tensile Strain during or after LW102	Maximum Predicted Tensile Strain during or after LW103	Maximum Predicted Tensile Strain during or after LW104	Maximum Predicted Tensile Strain during or after LW105	Maximum Predicted Compressive Strain during or after LW101	Maximum Predicted Compressive Strain during or after LW102	Maximum Predicted Compressive Strain during or after LW103	Maximum Predicted Compressive Strain during or after LW104	Maximum Predicted Compressive Strain during or after LW105
763495	6426120	MUG1-Mod 1	0	0	0	0	0	0	0	0	0	0
763481	6425903	MUG1-Mod 2	0	13	13	13	13	-0	-16	-16	-16	-16
762078	6423457	MUG1-Mod 3	0	0	0	1	9	0	0	0	-1	-12
761452	6424581	PAD 01	18	18	18	18	18	-22	-22	-22	-22	-22
761265	6423464	PAD 02	0	0	37	37	37	0	-0	-44	-44	-44
761265	6423392	PAD 03	0	0	>50	>50	>50	0	0	<-50	<-50	<-50
761619	6424707	S1MC029	15	15	15	15	15	-17	-17	-17	-17	-17
761279	6424617	S1MC038	0	0	0	0	0	-0	-0	-0	-0	-0
761279	6424617	S1MC039	0	0	0	0	0	-0	-0	-0	-0	-0
760964	6421902	S1MC055	0	0	0	0	0	0	0	0	0	0
763893	6425480	S2MC002	0	0	2	2	2	0	0	-1	-1	-1
760866	6424307	S1MC004	0	0	0	0	0	0	0	0	0	0
763592	6424924	S2MC005	0	0	0	>50	>50	0	0	0	<-50	<-50
763750	6424949	S2MC006	0	0	0	24	24	0	0	0	-7	-7
763625	6425020	S2MC007	0	0	0	>50	>50	0	0	0	<-50	<-50
762810	6425021	S2MC008	0	10	10	10	10	0	-4	-4	-4	-4
762818	6424980	S2MC009	0	2	2	2	2	0	-1	-2	-2	-2
762899	6425019	S2MC010	0	1	2	2	2	0	-0	-3	-3	-3
762932	6425019	S2MC011	0	0	12	12	12	0	0	-4	-4	-4
762928	6425072	S2MC012	0	2	2	2	2	0	-0	-2	-2	-2
762763	6423698	S2MC230	0	0	0	0	25	0	0	0	0	-33
762203	6423681	S2MC231	0	0	0	39	39	0	0	0	-47	-47
763744	6424582	S2MC269	0	0	0	0	>50	0	0	0	0	<-50
762243	6423241	S2MC270	0	0	0	0	>50	0	0	0	0	<-50
763404	6426033	S2MC277	3	3	3	3	3	2	2	2	2	2

Table D.02 - MCC UG1 Longwalls 101 to 105
Predicted Systematic Subsidence Parameters for Farm Dams

Dam ID	Total Subs LW101	Total Subs LW102	Total Subs LW103	Total Subs LW104	Total Subs LW105	Total Tilt LW101	Total Tilt LW102	Total Tilt LW103	Total Tilt LW104	Total Tilt LW105
A01d01	0	0	0	0	18	0	0	0	0	2
A01d02	0	0	0	0	2125	0	0	0	0	4
A01d03	0	0	0	0	36	0	0	0	0	4
A01d04	0	0	0	0	0	0	0	0	0	1
A01d05	0	0	0	0	0	0	0	0	0	0
A01d06	0	0	0	0	0	0	0	0	0	0
A01d07	0	0	0	0	0	0	0	0	0	0
A01d08	0	0	0	0	0	0	0	0	0	0
A02d01	0	0	0	2091	2193	0	0	0	0	0
A02d02	0	0	0	2100	2194	0	0	0	0	0
A02d03	0	59	205	223	223	0	4	3	2	2
A03d01	0	0	0	1730	1846	0	0	0	16	16
A04d01	0	0	0	0	1739	0	0	0	0	36
A04d02	0	0	0	0	2261	0	0	0	0	0
A04d03	0	0	0	0	2235	0	0	0	0	0
A04d04	0	0	0	0	2143	0	0	0	0	0
A04d05	0	0	0	0	0	0	0	0	0	0
A04d06	0	0	0	0	0	0	0	0	0	0
A04d07	0	0	0	0	0	0	0	0	0	0
A05d01	0	0	0	0	0	0	0	0	0	0
A05d02	0	0	0	0	0	0	0	0	0	0
A06d01	0	0	0	0	0	0	0	0	0	0
A06d02	0	0	0	0	0	0	0	0	0	0
A06d03	0	0	0	0	0	0	0	0	0	0

Table D.02 - MCC UG1 Longwalls 101 to 105
Predicted Systematic Subsidence Parameters for Farm Dams

Dam ID	Maximum Tensile Strain during or after LW101	Maximum Tensile Strain during or after LW102	Maximum Tensile Strain during or after LW103	Maximum Tensile Strain during or after LW104	Maximum Tensile Strain during or after LW105	Maximum Compressive Strain during or after LW101	Maximum Compressive Strain during or after LW102	Maximum Compressive Strain during or after LW103	Maximum Compressive Strain during or after LW104	Maximum Compressive Strain during or after LW105
A01d01	0	0	0	0	2	0	0	0	-0	-0
A01d02	0	0	0	0	>50	0	0	0	0	<-50
A01d03	0	0	0	0	3	0	0	0	0	0
A01d04	0	0	0	0	1	0	0	0	0	-0
A01d05	0	0	0	0	0	0	0	0	0	0
A01d06	0	0	0	0	0	0	0	0	0	0
A01d07	0	0	0	0	0	0	0	0	0	0
A01d08	0	0	0	0	0	0	0	0	0	0
A02d01	0	0	0	>50	>50	0	0	0	<-50	<-50
A02d02	0	0	0	>50	>50	0	0	0	<-50	<-50
A02d03	0	2	2	2	2	0	-1	-2	-2	-2
A03d01	0	0	0	21	21	0	0	0	-23	-23
A04d01	0	0	0	0	>50	0	0	0	0	<-50
A04d02	0	0	0	0	>50	0	0	0	0	<-50
A04d03	0	0	0	0	>50	0	0	0	0	<-50
A04d04	0	0	0	0	>50	0	0	0	0	<-50
A04d05	0	0	0	0	0	0	0	0	0	0
A04d06	0	0	0	0	0	0	0	0	0	0
A04d07	0	0	0	0	0	0	0	0	0	0
A05d01	0	0	0	0	0	0	0	0	0	0
A05d02	0	0	0	0	0	0	0	0	0	0
A06d01	0	0	0	0	0	0	0	0	0	0
A06d02	0	0	0	0	0	0	0	0	0	0
A06d03	0	0	0	0	0	0	0	0	0	0

Table D.03 - MCC UG1 - Longwalls 101 to 105

Comparisons of Predicted Systematic Subsidence Parameters for the Archaeological Sites using PrefML and ModML

Easting	Northing	SiteName	SiteType	PrefML				ModML				Incremental Change	
				Total Subsidence after LW105 (mm)	Total Tilt after LW105 (mm/m)	Maximum Predicted Tensile Strain during or after LW510	Maximum Predicted Compressive Strain during or after LW105	Total Subsidence after LW105 (mm)	Maxium Tilt (mm/m)	Maximum Predicted Hogging Curvature after LW105 (km-1)	Maximum Predicted Sagging Curvature after LW105 (km-1)	Incremental Subsidence as a result of the Modification (mm)	Incremental Tilt as a result of the Modification (mm/m)
761619	6424707	S1MC029	Isolated Find	1495	34.5	15.4	-13.6	1275	51	1.5	-1.7	-220	17
761279	6424617	S1MC038	Isolated Find	-	-	-	-	0	0	0.0	0.0	N/A	N/A
761279	6424617	S1MC039	Isolated Find	-	-	-	-	0	0	0.0	0.0	N/A	N/A
761452	6424581	PAD 01	Isolated Find	-	-	-	-	862	64	1.8	-2.2	N/A	N/A
761265	6423464	PAD 02	PAD 2	-	-	-	-	2182	6	3.7	-4.4	N/A	N/A
761265	6423392	PAD 03	PAD 3	-	-	-	-	2278	0	>5	<-5	N/A	N/A
763592	6424924	S2MC005	Artefact Scatter	1816	2.9	1.4	-1.8	2196	2	>5	<-5	380	-1
763750	6424949	S2MC006	Artefact Scatter	1320	45.3	31.1	-25.0	330	19	2.4	-0.7	-990	-26
763625	6425020	S2MC007	Isolated Find	1817	1.1	1.1	-0.9	2200	0	>5	<-5	383	-1
762810	6425021	S2MC008	Isolated Find	939	34.5	11.1	0.0	516	18	1.0	-0.4	-423	-16
762818	6424980	S2MC009	Isolated Find	261	7.2	2.8	0.0	226	4	0.2	-0.2	-35	-3
762899	6425019	S2MC010	Artefact Scatter	219	4.5	2.5	0.0	244	3	0.2	-0.3	25	-2
762932	6425019	S2MC011	Isolated Find	472	24.8	16.8	0.0	387	14	1.2	-0.4	-85	-11
762928	6425072	S2MC012	Isolated Find	241	6.3	2.6	0.0	234	4	0.2	-0.2	-7	-2
762763	6423698	S2MC230	Isolated Find	1770	45.6	25.6	-24.3	1461	47	2.5	-3.3	-309	1
762203	6423681	S2MC231	Rock Shelter & Artefact Scatter	1788	81.0	71.4	-58.1	2119	9	3.9	-4.7	331	-72
763744	6424582	S2MC269	Isolated Find	-	-	-	-	2113	6	>5	<-5	N/A	N/A
763495	6426120	MUG1-Mod 1	Isolated Find	-	-	-	-	0	0	0.0	0.0	N/A	N/A
763481	6425903	MUG1-Mod 2	Isolated Find	-	-	-	-	1129	46	1.3	-1.6	N/A	N/A
762078	6423457	MUG1-Mod 3	Artefacts	-	-	-	-	190	2	0.9	-1.2	N/A	N/A
761318	6425961	CE-15-IF	Isolated Find	-	-	-	-	0	0	0.0	0.0	N/A	N/A
764185	6425290	CE-17-OS	Artefacts	-	-	-	-	0	0	0.0	0.0	N/A	N/A
763454	6426266	S2MC001	Isolated Find	-	-	-	-	0	0	0.0	0.0	N/A	N/A
763893	6425480	S2MC002	Isolated Find	-	-	-	-	32	3	0.2	-0.1	N/A	N/A
764147	6425290	S2MC003	Artefacts	-	-	-	-	0	0	0.0	0.0	N/A	N/A
763996	6425355	S2MC004	Isolated Find	-	-	-	-	0	0	0.0	0.0	N/A	N/A
762243	6423241	S2MC270	Isolated Find	-	-	-	-	1897	22	>5	<-5	N/A	N/A
763404	6426033	S2MC277	Isolated Find	-	-	-	-	1797	18	3	2	N/A	N/A
764384	6424916	S2MC271	Isolated Find	-	-	-	-	-	-	-	-	N/A	N/A
764069	6424664	S2MC272	Isolated Find	-	-	-	-	-	-	-	-	N/A	N/A