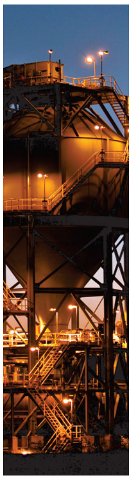
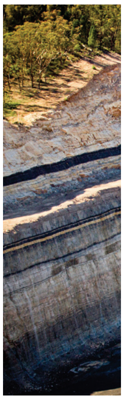
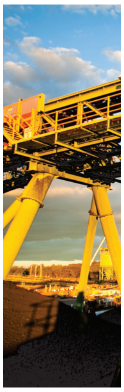
YANCOAL
兖煤澳大利亚有限公司
MOOLARBEN COAL

Moolarben Coal Complex
UG2 Modification





APPENDIX A

SUBSIDENCE ASSESSMENT

MOOLARBEN COAL COMPLEX:

Moolarben Coal Complex Stage 2 – UG2 Modification

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

DOCUMENT REGISTER

Revision	Description	Author	Checker	Date
01	Draft Issue	PD	-	May 21
02	Draft Issue	PD	BM	Jun 21
03	Draft Issue	PD	-	Sep 21
04	Draft Issue	PD	-	Oct 21
A	Final Issue	PD	-	2 Nov 2021

Report produced to:- Support the Modification for submission to the Department of Planning, Infrastructure and Environment (DPIE).

Associated reports:- MSEC353 (Revision E, November 2011) – Moolarben Coal Project Stage 2 – The Prediction of Subsidence Parameters and the Assessment of Mine Subsidence Impacts on Natural Features and Surface Infrastructure Resulting from the Proposed Extraction of Longwalls 1 to 13 in support of a Part 3A Application.

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

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

EXECUTIVE SUMMARY

Moolarben Coal Operations Pty Ltd (MCO) operates the Moolarben Coal Complex (MCC), which is located approximately 40 kilometres north east of Mudgee in New South Wales (NSW).

The MCC comprises four approved open cut mining areas (OC1 to OC4), three approved underground mining areas (UG1, UG2 and UG4) and other mining related infrastructure (including coal processing and transport facilities).

MCO has extracted Longwalls (LW) 101 to 104 within UG1 and are currently extracting LW 105. Following the completion of longwall mining within UG1 (LW 105), MCO propose to extract longwalls within UG4, followed by extraction of longwalls within UG2.

The locations of the approved MCC open cut mines and underground mines, including UG2, are shown in Drawing No. MSEC1167-01 which, together with all other drawings, is included in Appendix E.

MSEC has prepared this subsidence report to support a proposal to modify the approved UG mine layout (the UG2 Modification). The proposed modifications to the Approved Longwall layout include changes to commencing and finishing ends, longwall widths and longwall lengths as detailed in Section 1.2. The proposed extraction height has also been increased from 3.0 metres (m) for the Approved Layout to 3.5 m for the increased extraction height for the Modified Layout.

A Study Area has been identified around the Modified Layout based on the further limit of the 26.5° angle of draw line and predicted vertical limit of subsidence. The Study Area has been further divided into sub-areas including: Approved Mining Area based on the approved mining area component inside the Study Area; and Extended Mining Area based on the LW 201 and 202A extension area.

A number of features have been identified within or in the vicinity of the Study Area including: ephemeral drainage lines; cliffs; steep slopes; unsealed tracks and trails; mine infrastructure; archaeological sites; and survey control marks. There are few built features located within the Study Area.

While there is an increase in the predicted vertical subsidence for the surface features due to the increased extraction height, the maximum predicted tilt and curvatures within the Approved Mining Area based on the Modified Layout are similar to the maxima based on the Approved Layout and generally do not change the impact assessments.

As a result of changes in the longwall layouts, some locations will experience a reduction in observed impacts and some locations will experience an increase in observed impacts. The main reductions in impacts will be observed between LW 201 and 204, and between LW 202A and 202B. The main increases in impacts within the Approved Mining Area will be observed to the north west of LW 204.

The predicted vertical subsidence, maximum predicted tilt and curvatures in the Extended Mining Area based on the Modified Layout are similar to those predicted for the Approved Mining Area and therefore the potential impacts to features in the Extended Mining Area would be similar to the Approved Mining Area.

The Stage 2 Project Approval (08_0135) lists Subsidence Impact Performance Measures of negligible subsidence impact or environmental consequences for three cliffs (C7, C9 and C10) and negligible subsidence impacts or environmental consequences for Aboriginal Heritage Site S2MC236. Cliff C10 is located outside the Study Area and is not expected to experience impacts from extraction of the longwalls. Cliff C9 is located outside 0.5 times the depth of cover from the longwalls and is not expected to experience impacts from extraction of the longwalls.

Aboriginal Heritage Site S2MC236 is located at Cliff C7 and includes a rock shelter, artwork and artefact scatter. This site and Cliff C7 are protected by a sterilised coal pillar based on 0.5 times the depth of cover from the Cliff.

A survey monitoring program is recommended to enable an adaptive management approach to satisfy the performance measures for Cliffs C7 and C9, and Aboriginal Heritage Site S2MC236.

In conclusion, no changes to Subsidence Impact Performance Measures outlined in the Stage 2 Project Approval (08_0135) would be required for the Modification.

CONTENTS

LIST OF TABLES, FIGURES AND DRAWINGS

Tables

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

Figures

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

Drawings

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

1.1. Background

The Moolarben Coal Complex (MCC) is located approximately 40 kilometres (km) north of Mudgee in the Western Coalfields of New South Wales (NSW).

Moolarben Coal Operations Pty Ltd (MCO) is the operator of the MCC on behalf of the Moolarben Joint Venture (Moolarben Coal Mines Pty Ltd [MCM] and Yancoal Moolarben Pty Ltd [YM]). MCO, MCM and YM are wholly owned subsidiaries of Yancoal Australia Limited (Yancoal).

The MCC comprises four approved open cut mining areas (OC1 to OC4), three approved underground mining areas (UG1, UG2 and UG4) and other mining related infrastructure (including coal processing and transport facilities).

Mining operations at the MCC are currently approved until 31 December 2038 in accordance with Project Approval (05_0117) (Moolarben Coal Project Stage 1) (as modified) and Project Approval (08_0135) (Moolarben Coal Project Stage 2) (as modified).

MCO has extracted Longwalls (LW) 101 to 104 within UG1 and are currently extracting LW 105. Following the completion of longwall mining within UG1 (LW105), MCO propose to extract longwalls within UG4, followed by extraction of longwalls within UG2.

The locations of the approved MCC underground mines are shown in Drawing No. MSEC1167-01 which, together with all other drawings, is included in Appendix E.

MCO proposes a modification to the Stage 2 Project Approval (08_0135), which would be sought under section 4.55(2) of the NSW *Environmental Planning and Assessment Act 1979*.

The Modification would comprise the following changes to the approved MCC (Fig. 1.1):

- optimisation of the approved UG2 layout (including the extension of two approved longwall panels);
- increased UG2 extraction height from 3.0 metres (m) to 3.5 m;
- revised UG2 mining sequence;
- increased UG2 ROM coal production from 9.4 million tonnes (Mt) to 13.9 Mt;
- construction and operation of a remote services infrastructure area (including two UG2 service boreholes) within the approved OC4 disturbance footprint to support UG2 operations;
- development of an additional non-subsiding gate road along the southern boundary of the UG1 mining area to assist with ventilation in UG2; and
- small reduction in the approved OC4 extent to accommodate the optimised UG2 layout.

MSEC has prepared this subsidence report to support the Modification. The approved UG2 longwalls, LW 10 to 13[1], are referred to as the Approved Layout in this report. The proposed modifications to the longwall layouts include changes to commencing and finishing ends, longwall widths and longwall lengths as detailed in Section 1.2. The modified UG2 longwalls, LW 201 to LW 205 are referred to as the Modified Layout in this report.

A Study Area has been identified around the Modified Layout based on the 26.5° angle of draw line and predicted vertical limit of subsidence. The Study Area has been further divided into sub-areas including: Approved Mining Area based on the approved mining area component inside the Study Area; and Extended Mining Area based on the LW 201 and 202A extension area.

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

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

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of Longwalls 201 to 205 based on the Modified Layout. Comparisons of these predictions with the maxima based on the Approved Layout are also provided in this chapter.

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

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[1] LW 10 is now LW 203; LW 11 is now LW 202B; LW 12 is now LW 201 (south-eastern end) and LW 204 (north-western end); and LW 13 is now LW 205. LW 202A is an extension of LW 202B.

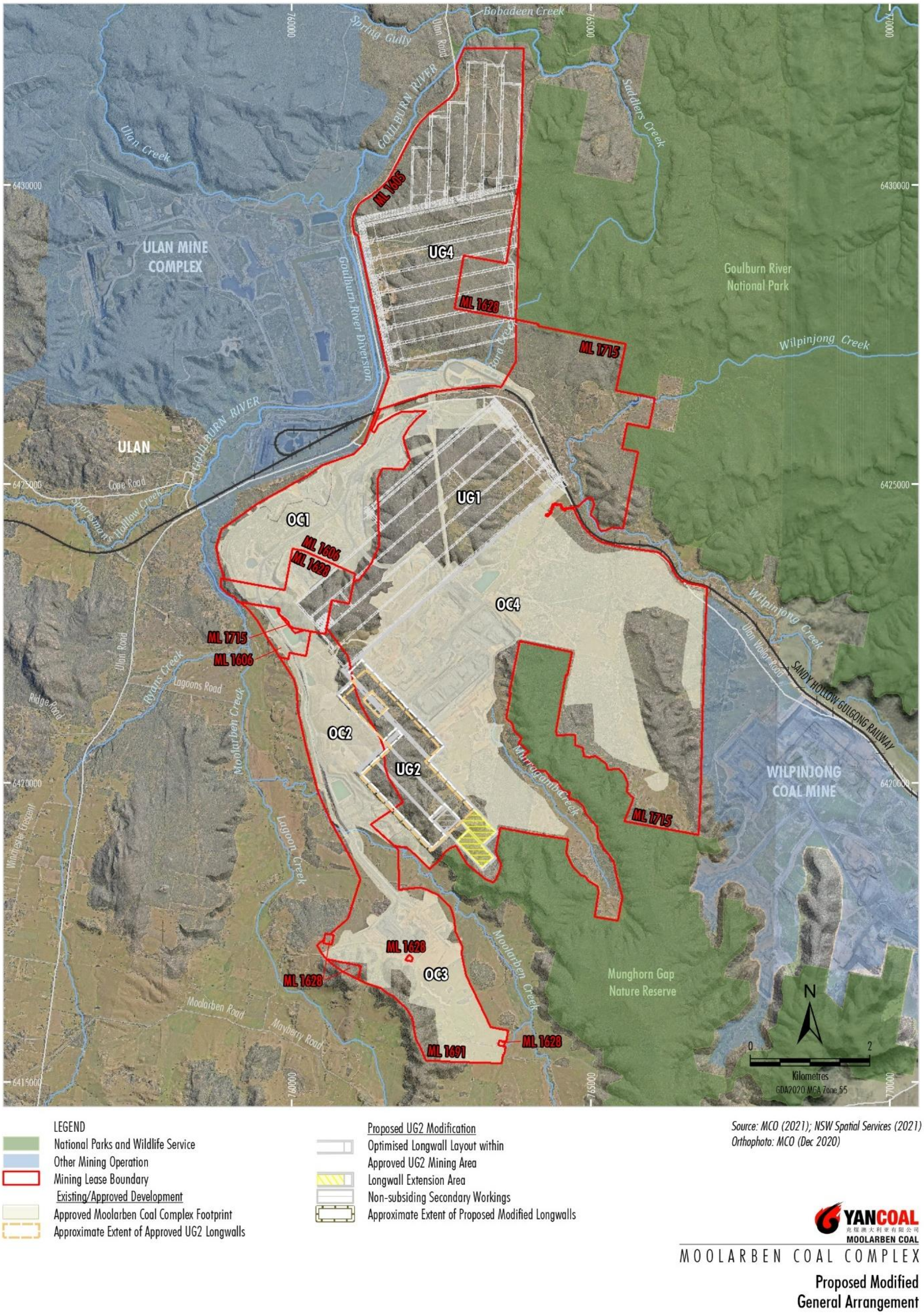

Fig. 1.1 Proposed Modified General Arrangement

1.2. Mining Geometry

The layout of LW 201 to 205 for the Modified Layout is shown in Drawing No. MSEC1167-01 in Appendix E. The Approved Layout is also shown in Drawing No. MSEC1167-01. A summary of the longwall dimensions based on the Approved Layout and Modified Layout is provided in Table 1.1.

Table 1.1 Geometry of Longwalls 201 to 205 based on the Approved Layout and Modified Layout

Layout	Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
Approved Layout	LW 10	1706	305	-
	LW 11	1706	305	30
	LW 12A	1706	270	30
	LW 12B	1163	305	30
	LW 13	1806	305	30
Modified Layout	LW 201 (LW 12A^)	2263	311	-
	LW 202A (new)	630	262	20
	LW 202B (LW 11^)	1337	311	20
	LW 203 (LW 10^)	1727	311	20
	LW 204 (LW 12B^)	1079	311/234*	-
	LW 205 (LW 13^)	1994	311/257*	45/99*

* Sterilised coal pillar beneath Cliff C7 and Aboriginal Heritage Site S2MC236 (AHIMS Numbers 36-3-0016 and 36-3-0134)
^ Previous naming convention.

1.3. Surface Topography and Seam Information

The UG2 longwalls are surrounded to a large extent by the approved open cut mine areas. The entry to these longwalls is via UG1. The depth of cover to the Ulan Seam above these longwalls varies between a minimum of about 40 m over LW 203, and a maximum of 155 m over LW 202B. The seam floor generally dips from the south-west down to the north-east over the entire mining area. The D working section (DWS) and D top (DTP) plies of the Ulan Seam would be extracted at a fixed height of 3.5 m for the Modified Layout. The proposed extraction height of 3.5 m is increased from 3.0 m for the Approved Layout.

The surface level contours, seam floor contours, seam thickness contours and the overburden depth contours are shown in Drawings Nos. MSEC1167-03 to MSEC1167-05. The depth of cover in the Study Area has also been presented on Drawing No. MSEC1167-06.

The variations in the surface and seam levels across the mining area are illustrated along Cross sections 1, 2 and 3 in Fig. 1.2, Fig. 1.3 and Fig. 1.4, respectively. The locations of these sections are at the prediction lines shown in Drawings Nos. MSEC1167-09 and 10.

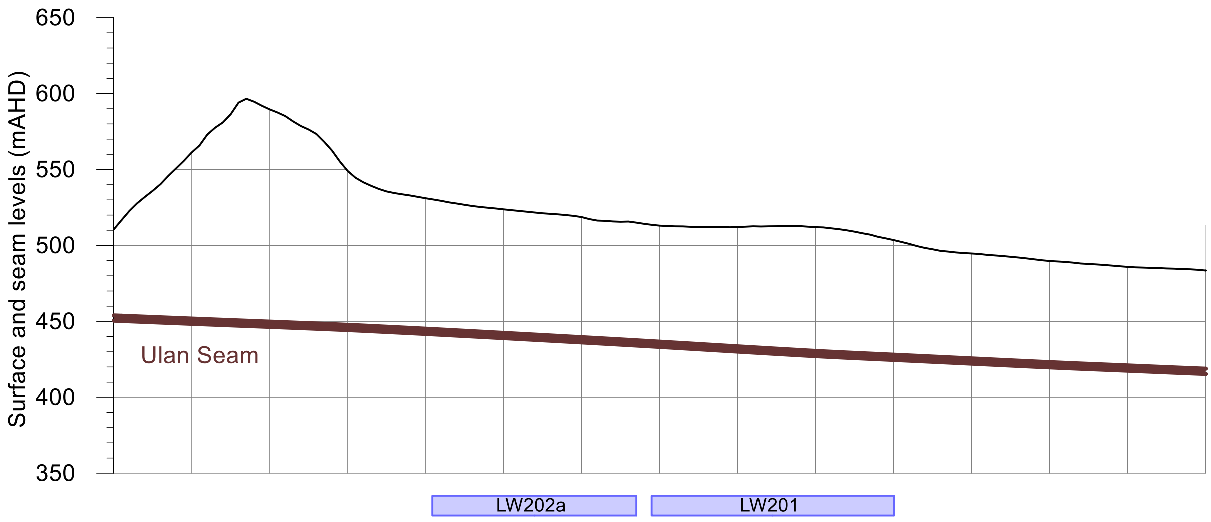

Fig. 1.2 Surface and Seam Levels along Cross-section 1

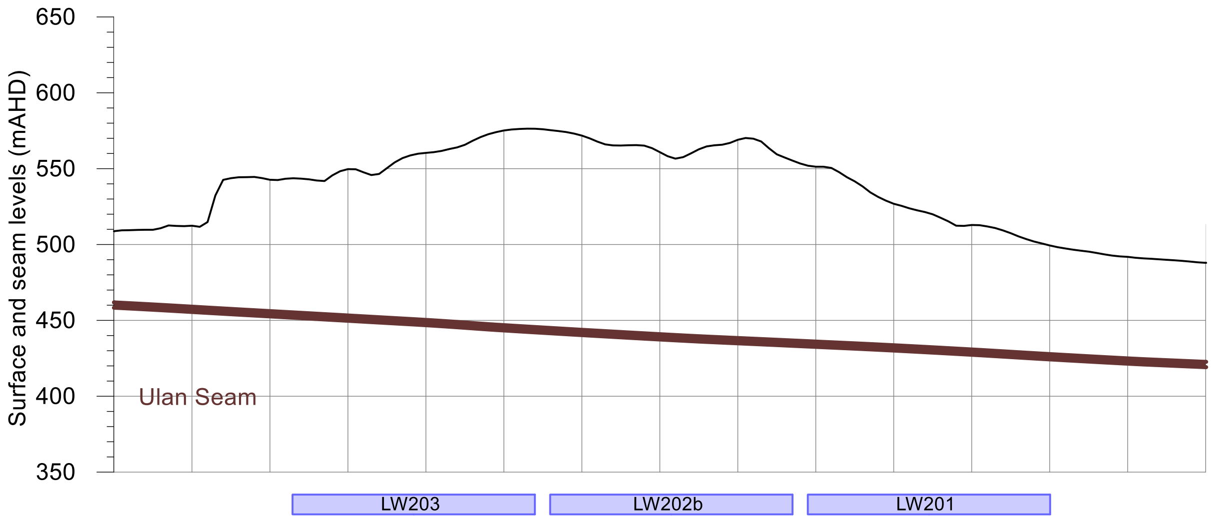

Fig. 1.3 Surface and Seam Levels along Cross-section 2

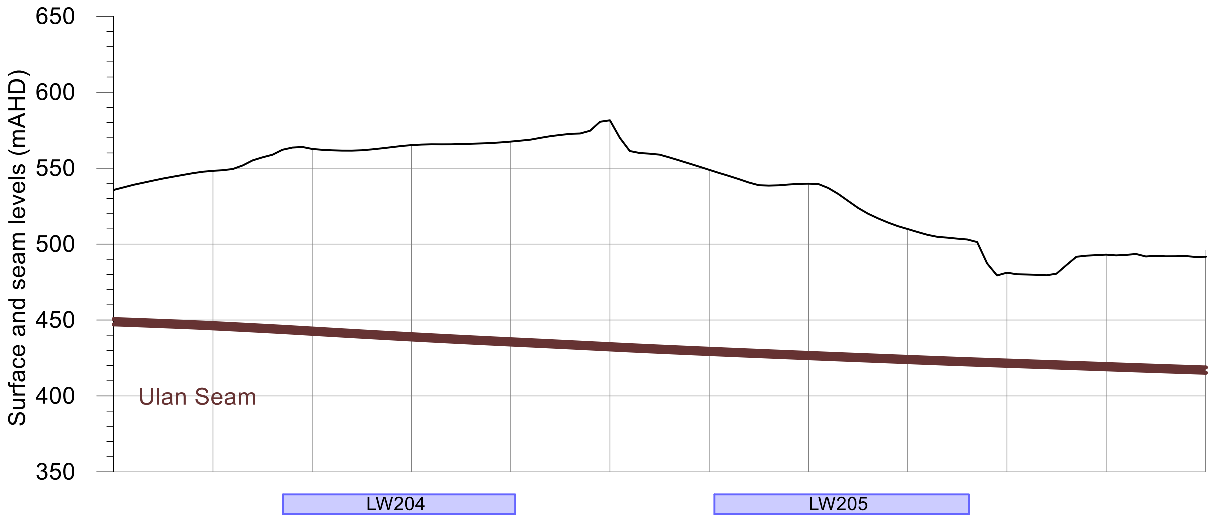

Fig. 1.4 Surface and Seam Levels along Cross-section 3

1.4. Geological Details

The surface lithology in the vicinity of the UG2 longwalls are shown in Fig. 1.5.

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.

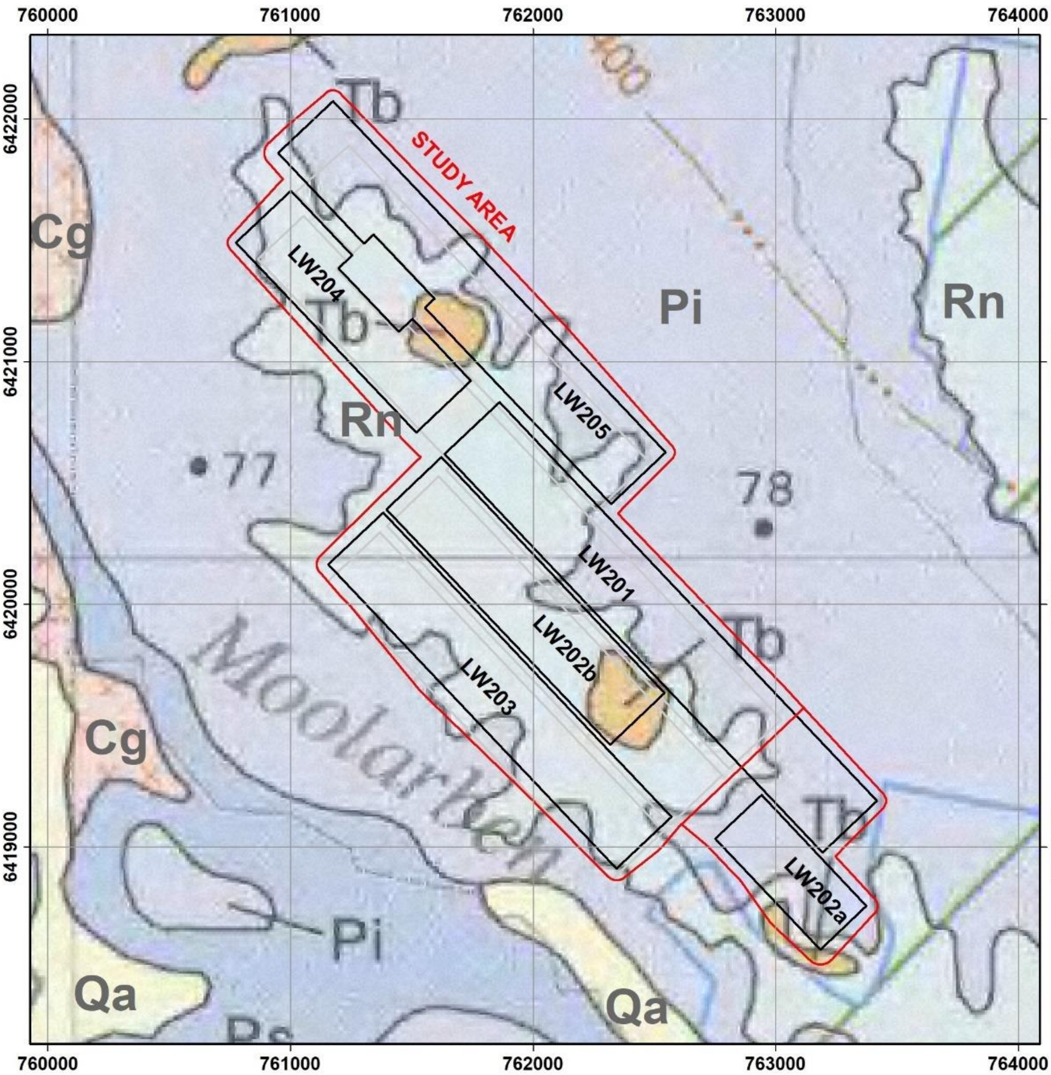

Fig. 1.5 Surface Geological Map Showing Longwalls 201 to 205 and the Study Area
(Source-1:100000 Western Coalfield Map)

As can be seen in this figure, the surface lithology of most of the areas over UG2 is predominantly units from the Narrabeen Group Sandstones and Conglomerates, (Rn), as well as areas of Basalt, (Tb). These units overlie the longwalls which are located within the Illawarra Coal Measures (Pi). Other surface lithology units that are shown in this figure, but are not within the Study Area, are areas of Quaternary Alluvials (Qa) and Granite (Cg).

A typical stratigraphic section for the Study Area, which was provided by Minerva Geological Services Pty Ltd, is shown in Fig. 1.6. A discussion of the geological units is provided below in Section 1.4.1.

1.4.1. Lithology

The major geological units in the 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 Study Area, known as basalt caps, are shown on Fig. 1.5.

The Triassic sandstone, known as Wollar Sandstone, is part of the Narrabeen Group and this sandstone unit is the main outcropping rock formation over the Study Area. Where present, the sandstones are between 14 m and 55 m thick within UG2 with both massive and strongly cross-bedded units of individual thickness in the range of 1.5 m to 3 m.

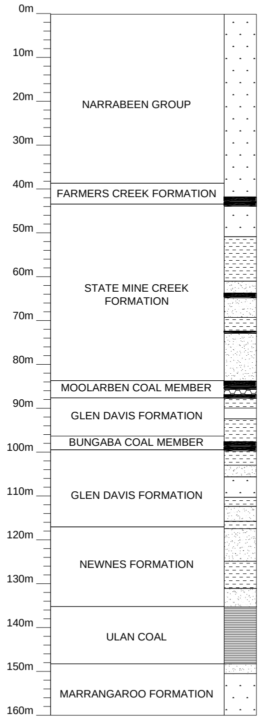

Fig. 1.6 Stratigraphic Column (based on WMLB117)

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

- Farmers Creek Formation: between 6 m to 10 m of siltstone, sandstone, and white cherty claystone;
- State Mine Creek Formation: up to 30 m of interbedded sandstone, siltstone and claystone. The Middle River Coal Member occurs at the top of the State Mine Creek Formation and is generally less than 2 m thick, consisting of stony coal and claystone. The Moolarben Coal Member occurs at the base of the State Mine Creek Formation and is between 2 m and 4 m thick, consisting of tuffaceous mudstone and claystone;
- Cockabutta Creek Sandstone Member: up to 9 m of predominantly medium to very coarse-grained quartzose sandstone, similar to the Marrangaroo Conglomerate (not shown on Fig 1.6);
- Glen Davis and Newnes Formations: each up to 20 m thickness of laminated mudstones, siltstones and find-grained sandstones;
- Ulan Coal: the major coal development in the licence area. The seam thickness varies from approximately 6 m to 15 m and is divided into 2 units – Upper (comprising, from top down, ULA, UB1, UB2, UC1, UC2) and Lower (comprising from top down, UCL, DTP, DWS, ETP, EBT and ELR). CMK defines the boundary between upper and lower units; and
- Marrangaroo Conglomerate: generally between 2 m and 6 m thick. The conglomerate is quartzose, commonly porous, and has a “gritty” sucrosic texture.

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

2.1. Definition of the Study Area and Surface Features

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

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

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

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

The line defining the Study Area, based on the further extent of the 26.5° angle of draw and the predicted 20 mm subsidence contour is shown in Drawing No. MSEC1167-01. The predicted total 20 mm subsidence contour line resulting from the extraction of LW 201 to 205 is located entirely within the area bounded by the 26.5° angle of draw line.

As the depth of cover above the proposed longwall varies between 40 and 155 m, 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 20 and 78 m.

The Study Area has been further divided into the following sub-areas:

- Approved Mining Area – incorporates the approved mining area component inside the Study Area and is approximately 326 hectares; and
- Extended Mining Area – incorporates the LW 201 and 202A extension area and is approximately 47 hectares.

The Study Area and its sub-areas are shown in Drawing No. MSEC1167-01.

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

- Munghorn Gap Nature Reserve;
- Survey Control Marks; and
- Highwalls of the proposed open cut mines.

2.2. Natural and Built Features within the Study Area

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

There are no private landowners within the Study Area.

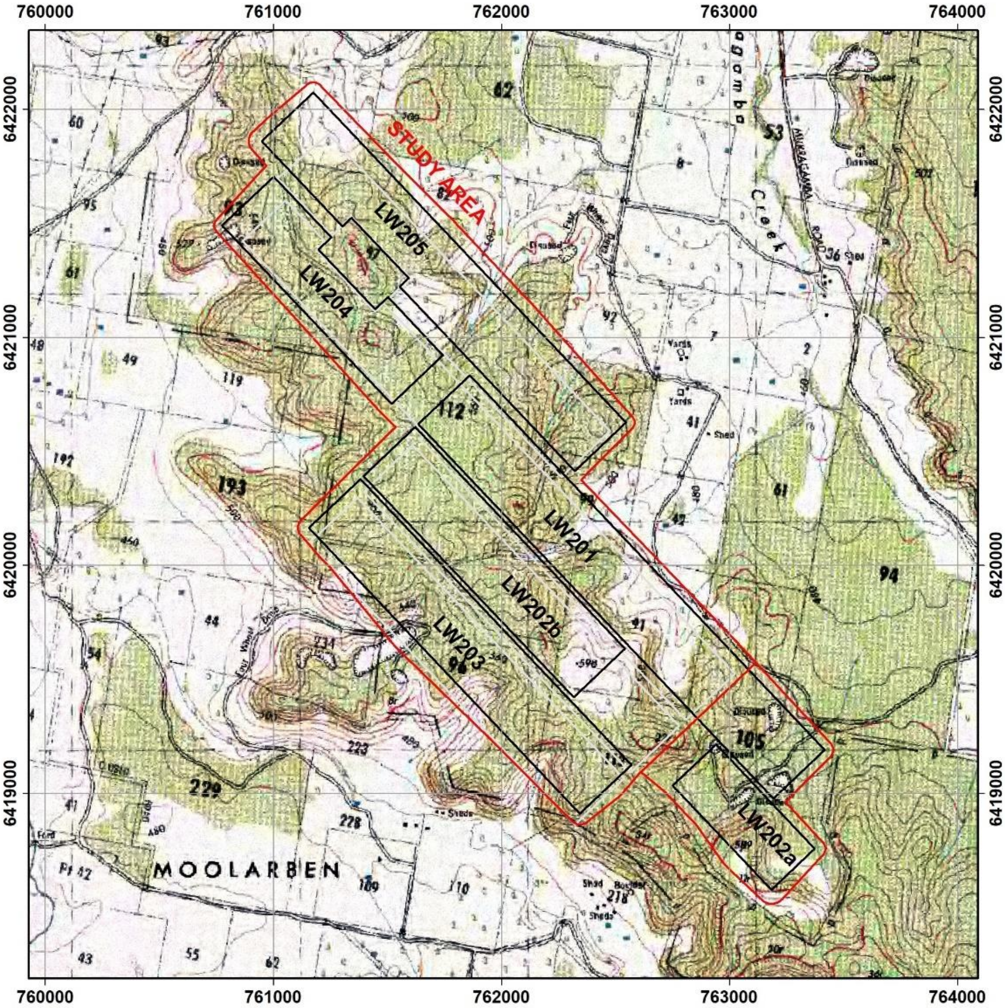

Fig. 2.1 Topographic Map Showing Longwalls 201 to 205 and the Study Area (source: CMA Map No. Wollar 88332N)

A summary of the natural and built features within the Study Area, or relevant to this report with respect to potential far-field movements, is provided in Table 2.1. The locations of these features are shown in Drawings Nos. MSEC1167-07 and MSEC1167-08, in Appendix E.

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

Table 2.1 Natural and Built Features

Item	Within Study Area	Section Number Reference
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	×	
Rivers or Creeks	×	
Aquifers or Known Groundwater Resources	✓	5.2
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.4
Steep Slopes	✓	5.6
Escarpments	×	
Land Prone to Flooding or Inundation	×	
Swamps, Wetlands or Water Related Ecosystems	×	
Threatened or Protected Species	✓	0 & 5.8
National Parks	×	
State Forests	×	
State Conservation Areas	×	
Natural Vegetation	✓	5.9
Areas of Significant Geological Interest	✓	5.10
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	×	
Roads (All Types)	✓	6.1 to 6.2
Bridges	×	
Tunnels	×	
Culverts	×	
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	×	
Telecommunication Lines or Associated Plants	×	
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	Section Number Reference
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	×	
Farm Buildings or Sheds	×	
Tanks	×	
Gas or Fuel Storages	×	
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	✓	8.1
Farm Dams	×	
Wells or Bores	×	
Any Other Farm Features	×	
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Factories	×	
Workshops	×	
Business or Commercial Establishments or Improvements	×	
Gas or Fuel Storages or Associated Plants	×	
Waste Storages or Associated Plants	×	
Buildings, Equipment or Operations that are Sensitive to Surface Movements	×	
Surface Mining (Open Cut) Voids or Rehabilitated Areas	✓	9.1
Mine Infrastructure Including Tailings Dams or Emplacement Areas	×	
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL OR HERITAGE SIGNIFICANCE	✓	10.1
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓ *	10.3
RESIDENTIAL ESTABLISHMENTS		
Houses	×	
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

* outside Study Area

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

3.1. Introduction

This chapter provides overviews of mine subsidence parameters and the methods that have been used to predict the mine subsidence movements resulting from the extraction of the longwalls. Further details on longwall mining, the development of subsidence and the methods used to predict mine subsidence movements are provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements,* which can be obtained from *www.minesubsidence.com*.

3.2. Overview of Conventional Subsidence Parameters

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

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.
- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/km* (km^{-1}), but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *km*.
- **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 *mm/m*. **Tensile Strains** occur where the distance between two points increases and **Compressive Strains** occur when the distance between two points decreases. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

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

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

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

3.3. Far-field Movements

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

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

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

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.

3.4. Overview of Non-Conventional Subsidence Movements

Conventional subsidence profiles are typically smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata spanning the extracted void. Subsidence profiles that do not conform to these typically smooth shapes are termed non-conventional subsidence movements.

Normal conventional subsidence movements due to longwall extraction are easy to identify where longwalls are regular in shape, the extracted coal seams are relatively uniform in thickness, the geological conditions are consistent and surface topography is relatively flat.

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near surface strata layers. Where the depth of cover is greater than say 400 m, the observed subsidence profiles along monitoring survey lines are generally smooth. Where the depth of cover is less than say 100 m, such as the case in some areas within the Study Area, the observed subsidence profiles along monitoring lines are generally irregular. Very irregular subsidence movements are observed with much higher tilts and strains at very shallow depths of cover where the collapsed zone above the extracted longwalls extends up to or near to the surface.

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

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

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

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

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

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

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

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

3.4.2. Non-conventional Subsidence Movements due to Steep Topography

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

Further discussions on the potential for down slope movements for the steep slopes within the Study Area are provided in Section 5.6.

3.4.3. Valley Related Movements

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

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

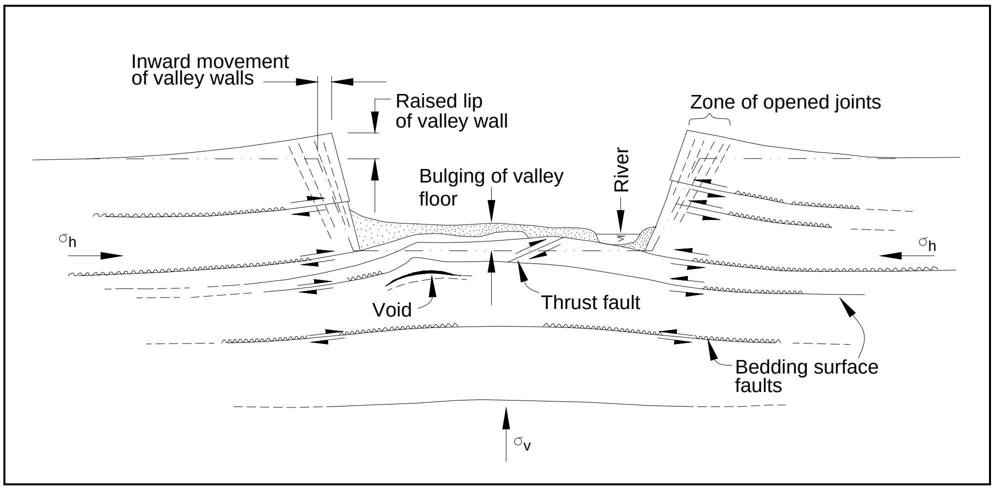

Fig. 3.1 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

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

- **Upsidence** is the reduced subsidence, or the relative uplift within a valley which results from the dilation or buckling of near surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in *mm*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.
- **Closure** is the reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in *mm*, is the greatest reduction in distance between any two points on the opposing valley sides.

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

Valley related movements are made using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002). Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

The drainage lines within the UG2 Study Area are less likely to experience noticeable mining induced valley related movements, (i.e. valley closure movements and upsidence in the floors of valleys), because of the relatively shallow depths of cover over these longwalls and the nearby presence of the deep open cut pits that would have reduced the in situ compressive horizontal stresses of the overburden strata between these open cut pits.

3.5. The Incremental Profile Method

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

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

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

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

Further details on the IPM can be obtained from *www.minesubsidence.com*.

3.6. Calibration and Testing of the Incremental Profile Method

The IPM subsidence prediction model for standard cases in the Southern Coalfields, where the depths of cover are around 500 m, 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.

Initial predicted conventional subsidence parameters that were determined in previous reports for MCC longwalls 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 suit the particular geological and the overburden depth conditions at MCC. The IPM model for MCC was adjusted to predict a maximum subsidence factor value of 60% of the extracted seam thickness for supercritical panels in single seam conditions.

The model for UG1 was subsequently increased to allow a maximum vertical subsidence of 65% based on the absence of thick and massive strata units above the proposed UG1 longwall panels.

Since the commencement of longwall mining operations, four annual reviews have been completed (2017 to 2020) to assess the observed monitoring data due to the extraction of UG1 LW 101 to 104. The ground movements measured during the annual review were similar to or less than those predicted in Report No. MSEC867 and MSEC1084, which supported the Extraction Plan for LW 101 to 105. Monitoring to date shows a maximum observed subsidence of 79% of the predicted maximum subsidence, which equates to approximately 55% of the modelled seam thickness for a single panel. A graph showing predicted and observed subsidence, tilt and strain for LW 101 to 103 is shown in Fig. 3.2 for the main cross line above LW 101 to 105 in UG1.

The model for the UG2 Modified Layout adopts the same maximum vertical subsidence of 65% based on the similar overburden to UG1.

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

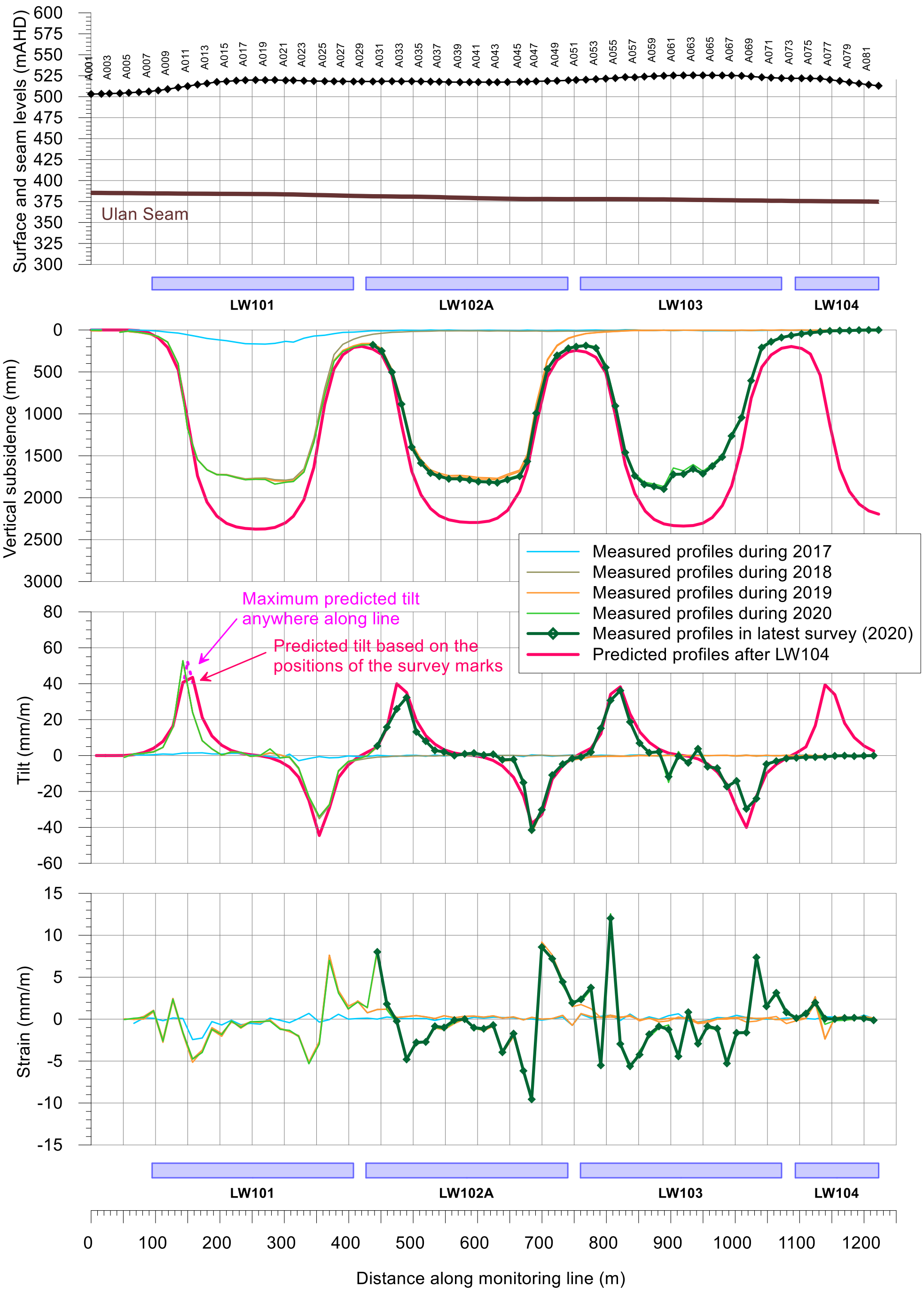

Fig. 3.2 Measured and Predicted Vertical Subsidence, Tilt and Strain Along the A Line

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the Modified Layout and a comparison relative to the Approved Layout. The predicted subsidence parameters and the impact assessments for the natural and built features due to the extraction of Modified Layout are provided in Chapters 5 to 11.

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

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

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

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

The maximum predicted conventional subsidence parameters resulting from the extraction of LW 201 to 205 were determined using the calibrated IPM. The predicted subsidence contours are irregular due to the varying and shallow depths of cover. The maximum predicted tilts and curvatures are very localised and therefore do not necessarily represent the overall (i.e. macro) ground movements. The magnitudes of the localised tilts greater than 100 mm/m and the localised curvatures greater than 3.0 km^{-1} become less meaningful and, therefore, the specific values have not been presented. Revised standards for reporting adopted by MSEC may result in slight differences in reported values compared with previous reports.

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

Table 4.1 Maximum Predicted Incremental Conventional Subsidence, Tilt and Curvature Resulting from the Extraction of Each of the Longwalls 201 to 205

Longwall	Maximum Predicted Incremental Conventional Subsidence (mm)	Maximum Predicted Incremental Conventional Tilt (mm/m)	Maximum Predicted Incremental Conventional Hogging Curvature (km^{-1})	Maximum Predicted Incremental Conventional Sagging Curvature (km^{-1})
Due to LW 201	2300	> 100	> 3	> 3
Due to LW 202A	2300	90	> 3	> 3
Due to LW 202B	2300	75	> 3	> 3
Due to LW 203	2300	95	> 3	> 3
Due to LW 204	2300	70	> 3	> 3
Due to LW 205	2300	> 100	> 3	> 3

The predicted total conventional subsidence contours, resulting from the extraction of LW 201 to 205 are shown in Drawing No. MSEC1167-10. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature, after the extraction of each of the longwalls based on the Modified Layout, is provided in Table 4.2.

Table 4.2 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature after the Extraction of Each of the Longwalls 201 to 205

Longwalls	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
After LW 201	2300	> 100	> 3	> 3
After LW 202A	2400	> 100	> 3	> 3
After LW 202B	2400	> 100	> 3	> 3
After LW 203	2450	> 100	> 3	> 3
After LW 204	2450	> 100	> 3	> 3
After LW 205	2500	> 100	> 3	> 3

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

The predicted conventional subsidence parameters vary across the Study Area as the result of, amongst other factors, variations in the depths of cover. To illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along Prediction Lines 1, 2 and 3, the locations of which are shown in Drawings Nos. MSEC1167-09 and MSEC1167-10.

The predicted profiles of vertical subsidence, tilt and curvature along Prediction Lines 1, 2 and 3, resulting from the extraction of LW 201 to 205, are shown in Figs. C.01 to C.03, in Appendix C. The predicted incremental profiles along the prediction lines, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles along the prediction lines, after the extraction of each of the longwalls based on the Modified Layout, are shown as solid blue lines. The predicted total profiles based on the Approved Layout are shown as red lines for comparison.

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

A comparison of the maximum predicted subsidence parameters resulting from the extraction of LW 201 to 205, based on the Modified Layout, with those based on the Approved Layout is provided in Table 4.3. Table 4.3 includes the maximum predicted subsidence parameters for the Approved Mining Area, Extended Mining Area and the overall Study Area. The values are the maxima anywhere above the longwall layouts.

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

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (LW 10-13) (Report No. MSEC353)	1980	> 100	> 3	> 3
Modified Layout (Approved Mining Area)	2500	> 100	> 3	> 3
Modified Layout (Extended Mining Area)	2400	95	> 3	> 3
Modified Layout (Study Area)	2500	> 100	> 3	> 3

It can be seen from the above table, that the maximum predicted total subsidence based on the Modified Layout, including the Approved Mining Area and Extended Mining Areas, is greater than that based on the Approved Layout. The increased subsidence is the result of the increase in extraction height from 3.0 to 3.5 m. The maximum predicted total tilt based on the Modified Layout within the Approved Mining Area is the same as that for the Approved Layout, whilst the maximum predicted total tilt based on the Modified Layout within the Extended Mining Area is slightly less. The maximum predicted total hogging curvature and sagging curvature based on the Modified Layout are the same as those for the Approved Layout. Whilst the specific values of the maximum tilt and curvatures are not shown, due to these representing the localised irregular movements rather than the macro (i.e. overall) movements, these parameters do not change significantly.

4.4. Predicted Strains

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

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

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

The maximum predicted conventional curvatures resulting from the extraction of the longwalls are greater than 3 km^{-1} hogging and sagging. Adopting a factor of 10, the maximum predicted conventional strains, due to the proposed mining are greater than 30 mm/m tensile and compressive. Localised and elevated strains greater than the predicted conventional strains can also occur, as the result of non-conventional movements, which was discussed in Section 3.4.

At a point, however, there can be considerable variation from the linear relationship, resulting from non-conventional movements or from the normal scatters which are observed in strain profiles. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strain for low magnitudes of curvature.

The range of potential strains above the longwalls has been assessed using monitoring data from previously extracted panels in the Hunter, Newcastle and Western Coalfields, for single-seam conditions, where the longwall width-to-depth ratios and extraction heights were similar to those of the longwalls. Comparisons of the void widths, depths of cover, width-to-depth ratios and extraction heights for the longwalls with those for the historical cases are provided in Table 4.4.

Table 4.4 Comparison of the Mine Geometry for the Longwalls 201 to 205 with Longwalls in the Hunter, Newcastle and Western Coalfields used in the Strain Analysis

Parameter	Longwalls 201 to 205		Longwalls Used in Strain Analysis	
	Range	Average	Range	Average
Width	199 ~ 311	306	210 ~ 410	285
Depth of Cover	40 ~ 155	110	40 ~ 239	130
W/H Ratio	1.3 ~ 6.2	2.8	1.7 ~ 6.4	2.5
Extraction Height	3.5	3.5	2.2 ~ 4.2	3.0

It can be seen from the above table that the range of the panel width-to-depth ratios used in the strain analysis are between 1.7 and 6.4, with an average ratio of 2.5, which is similar to the range for LW 201 to 205. The range of extraction heights for the longwalls used in the strain analysis are between 2.2 m and 4.2 m, with an average of 3.0 m, which is slightly less than the average extraction height for LW 201 to 205. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains for the longwalls.

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

A number of probability distribution functions were fitted to the empirical monitored strain data. It was found that a *Generalised Pareto Distribution (GPD)* provided a good fit to the raw strain data. Confidence levels have been determined from the empirical strain data using the fitted GPDs. In the cases where survey bays were measured multiple times during a longwall extraction, the maximum tensile strain and the maximum compressive strain were used in the analysis (i.e. single tensile strain and single compressive strain measurement per survey bay).

4.4.1. Analysis of Strains Measured in Survey Bays

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

Predictions of Strain Above Goaf

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

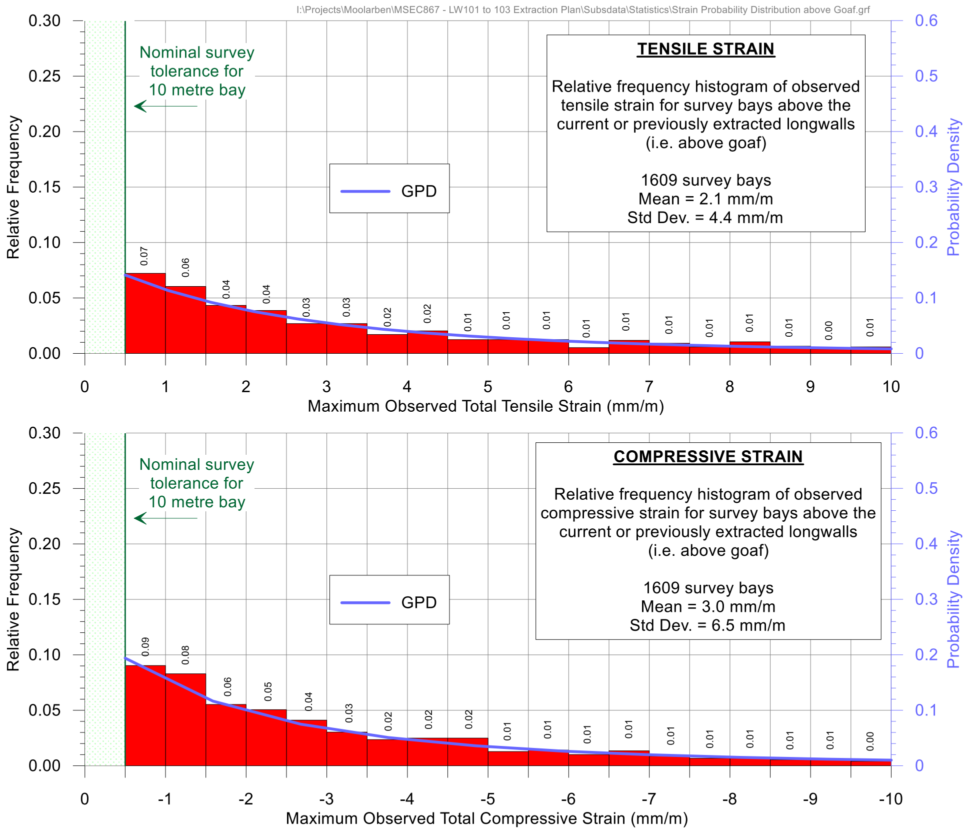

Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains in the Hunter, Newcastle and Western Coalfields for Longwalls having W/H Ratios between 1.7 and 6.4

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

The 95 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining are 10 mm/m tensile and 13 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining were 22 mm/m tensile and 31 mm/m compressive. The maximum strains measured along the monitoring lines were greater than 50 mm/m tensile and 100 mm/m compressive. These maximum strains represent very localised movements in the locations of large surface deformations.

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

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

Predictions of Strain Above Solid Coal

The survey database has also been analysed to extract the maximum tensile and compressive strains that have been measured at any time during mining for survey bays that were located beyond the goaf edges of the mined panels and positioned on unmined areas of coal, i.e. outside the longwall panels, but within 200 m of the nearest longwall goaf edge.

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

The 95 % confidence levels for the maximum total strains that the individual survey bays *above solid coal* experienced at any time during mining are 3.3 mm/m tensile and 3.0 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 9.2 mm/m tensile and 14.4 mm/m compressive.

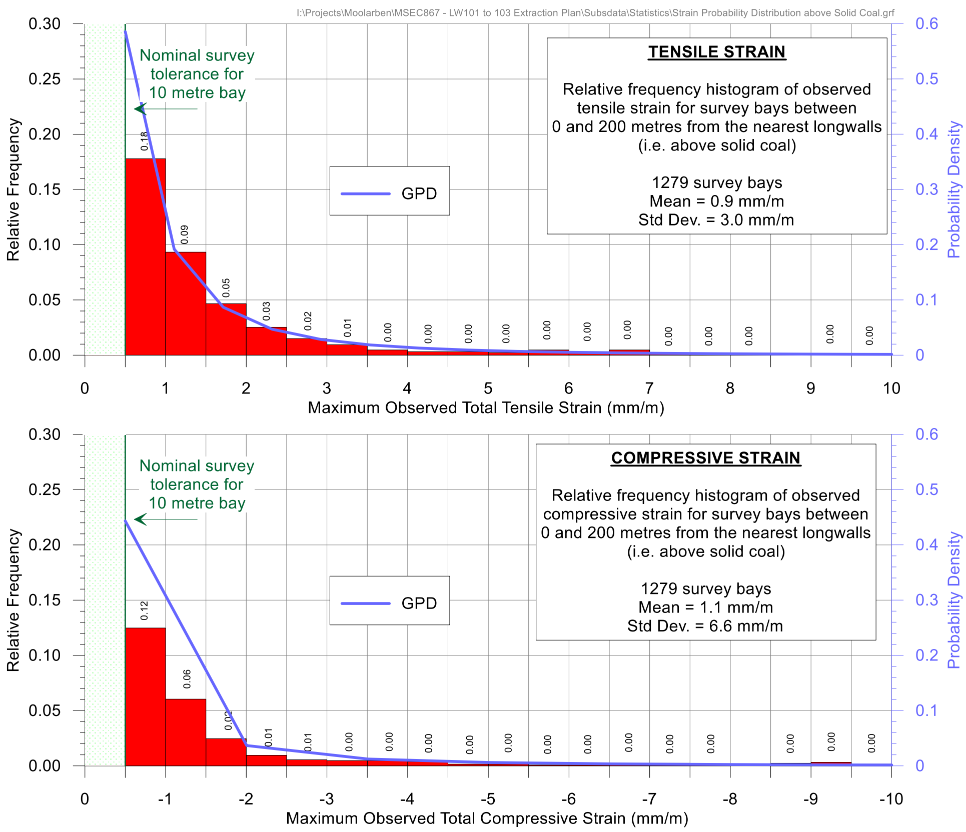

Fig. 4.2 Distributions of the Measured Maximum Tensile and Compressive Strains in the Hunter, Newcastle and Western Coalfields for Survey Bays Located Above Solid Coal Within 200 m of the Nearest Longwall

4.4.2. Analysis of Strains Measured Along Whole Monitoring Lines

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

A histogram of maximum observed total tensile and compressive strains measured anywhere along the monitoring lines, at any time during or after mining, is provided in Fig. 4.3.

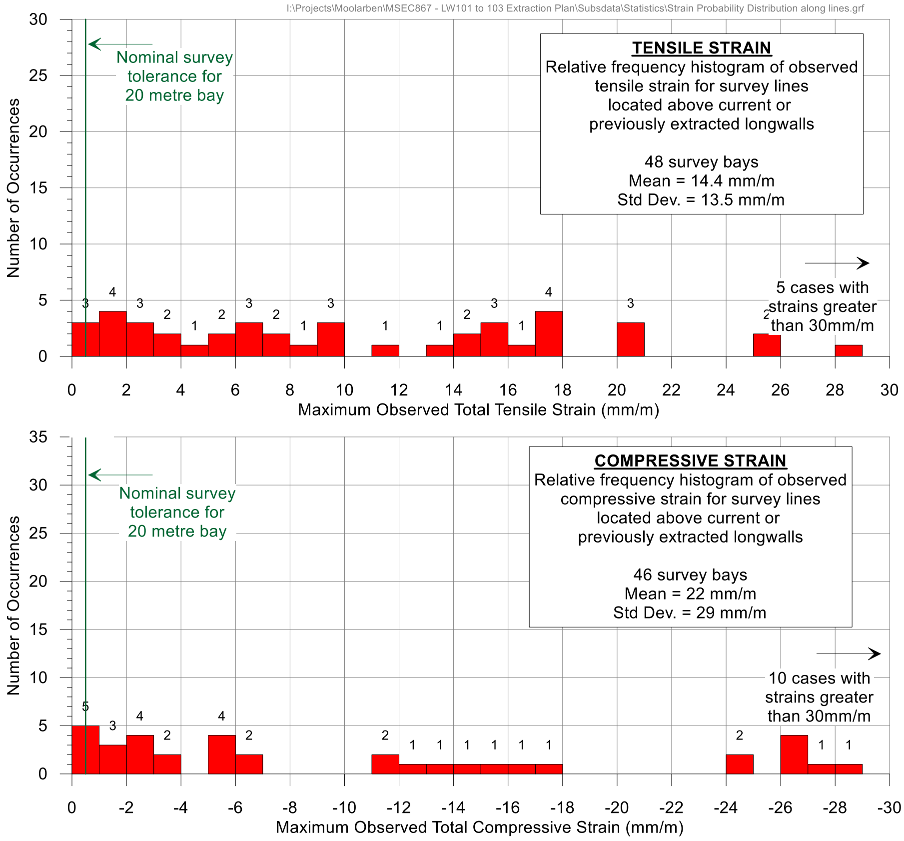

Fig. 4.3 Distributions of Measured Maximum Tensile and Compressive Strains Anywhere along the Monitoring Lines in the Hunter, Newcastle and Western Coalfields

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

The predicted impacts of strain on the natural and built features are addressed in the impact assessments for each feature, which are provided in Chapters 5 to 11.

4.5. Horizontal Movements

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

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

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

4.6. Predicted Far-field Horizontal Movements

In addition to the conventional subsidence movements that have been predicted above and adjacent to LW 201 to 205, it is also likely that far-field horizontal movements will be experienced during the extraction of the longwalls.

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

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

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

This database includes available observed far-field horizontal movements that have been measured at Ulan Coal Mine, MCC and observed data from other regions where the depths of cover are also relatively shallow compared to the Southern Coalfield of NSW. The observed far-field horizontal movements in the database represent large variations in depth of cover from less than 50 m to greater than 600 m. In order to utilise the observed far-field horizontal data at the MCC where depth of cover is relatively shallow, the data has been plotted, as shown in Fig. 4.4, against the distances from the nearest edge of the incremental panel divided by the depth of cover. This plot excludes those cases where higher movements occurred because of multi-seam mining and valley closure effects.

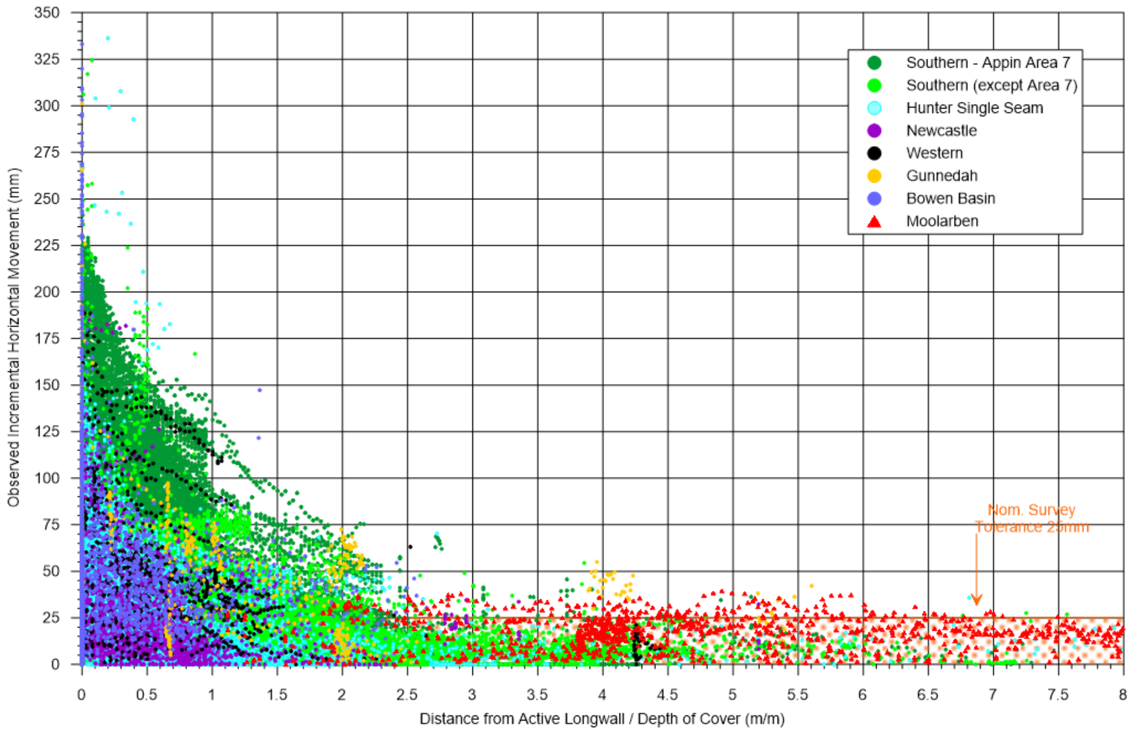

Fig. 4.4 Observed Incremental Far-Field Horizontal Movements (mm) from many Regions in NSW versus the Distance to the Nearest Edge of the Mined Panel Divided by the Depth of Cover (m/m)

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

Monitoring lines located at surface features to the north east of UG1 LW 101 to 103 at MCC have been surveyed since the commencement of LW 101. The observed far-field horizontal movements for MCC have been plotted on Fig. 4.4. It can be seen from Fig. 4.4 that the majority of the observed far-field horizontal movements at MCC are less than 25 mm. The maximum observed far-field horizontal movement is 40 mm.

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

Open cut mining areas OC2 and OC4 are located adjacent to the Modified Layout as shown in Drawing No. MSEC1167-02.

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

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

4.7. Potential for increased subsidence between longwalls

The layout of longwalls for the Modified Layout will result in three areas of solid unmined coal surrounded by longwall panels, between LW 201 and 203, LW 201 and 204, and LW 204 and 205.

It is possible that increased vertical subsidence will be observed above these areas of unmined coal. There have been a number of examples in NSW where subsidence monitoring has shown increased vertical subsidence of the surface in areas that are located directly above an isolated coal barrier. Magnitudes of settlement have been observed between 50 and 150 mm above an isolated coal barrier which is greater than predicted using the Standard IPM. The cause of the additional subsidence has not been proven, but it is thought that it is a result of factors including a general relaxation of in-situ stress in the strata within the coal barrier and additional vertical load on the coal barrier.

Whilst additional subsidence has not always been observed in these situations, they have occurred in a sufficient number of cases to acknowledge that a similar occurrence may be observed at UG2. Additional vertical movements up to approximately 50 mm to 150 mm for the areas of solid unmined coal between LW 201 and 203, LW 201 and 204, and LW 204 and 205 may therefore occur. The additional vertical movements for the areas of solid unmined coal between LW 204 and 205 would not be significantly different compared to the Approved Layout.

While observed subsidence may exceed predictions for the areas of solid unmined coal, subsidence monitoring has shown that it is usually accompanied by relatively low conventional tilts, curvature and strains. The potential for impacts above the areas of solid unmined coal, therefore, do not significantly change.

4.8. Non-Conventional Ground Movements

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

The potential for non-conventional movements associated with steep topography is discussed in the impact assessments for the steep slopes provided in Section 5.6.

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

4.9. General Discussion on Mining Induced Ground Deformations

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

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

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

At shallow depths of cover, it is also likely that transient surface cracks will occur above and parallel to the moving extraction face, i.e. at right angles to the longitudinal edges of the longwall, as the subsidence trough develops. The larger and more permanent cracks, however, are usually located in the final tensile zones around the perimeters of the longwalls. Open fractures and heaving, however, can also occur due to the buckling of surface beds that are subject to compressive strains. An example of crack patterns that develop in shallow depths of cover is shown in Fig. 4.5 below.

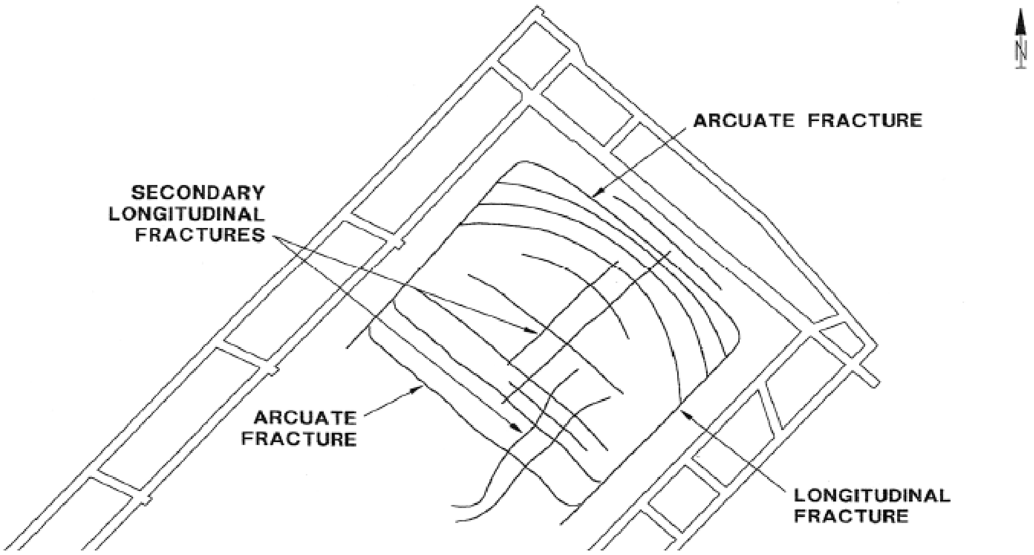

Fig. 4.5 Survey of Major Fracture Pattern at Approx. 110m Cover (Source: Klenowski, ACARP C5016, 2000)

Over previously mined longwalls at the MCC, typical surface crack widths in the order of 100 mm and step heights in the order of 100 mm have been commonly observed at shallow depths of cover, say less than 200 m. Larger crack widths have been observed with shallow depths of cover where thicker seams are extracted, where mining occurs near or beneath steep terrain, where thick massive strata beams are present, or where multiple cracks join to form a broader surface deformation.

Localised cracking and stepping greater than 500 mm have been observed at other collieries with similar depths of cover in the NSW Coalfields. These larger tensile cracks tend to be isolated and located above and around the perimeters of the longwalls and along the tops of steep slopes, due to down slope movements resulting from the extraction of the longwalls. The typical surface cracks and these larger isolated cracks can normally be easily identified and remediated to prevent loss of surface water – Klenowski (ACARP C5016, 2000).

Crack mapping has been undertaken during the extraction of LW 101 to 103 at UG1. Of a total of over 22 km of mapped cracks, the crack widths were generally less than 100 mm in 78 % of cases. Crack widths were measured between 100 mm and 200 mm in 18 % of cases, and between 200 mm and 300 mm in 4 % of cases. A small number of larger isolated cracks up to approximately 500 mm were also identified. The following photographic records in Fig. 4.6 and Fig. 4.7 provide examples of surface cracking above extracted LW 101 to 103.

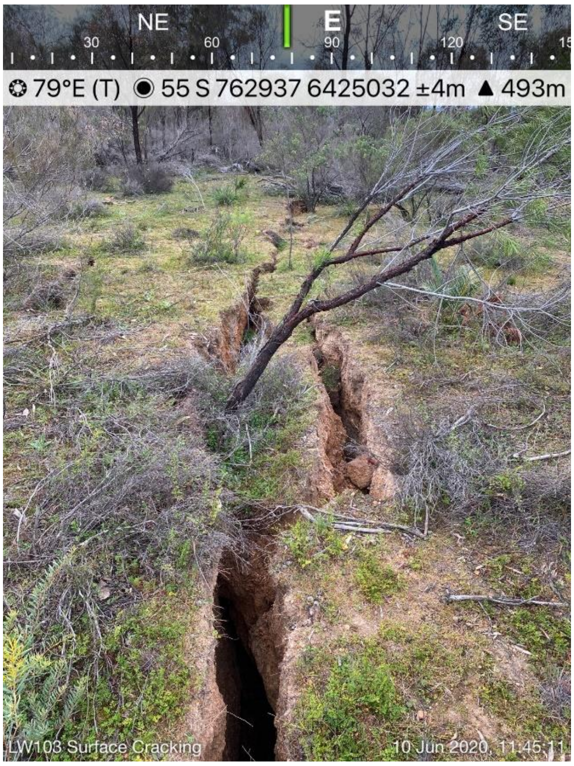

Fig. 4.6 Isolated Surface Cracking (150mm to 250mm wide) above UG1 Longwall 103

Fig. 4.7 Surface steps (150mm to 400mm in height) above UG1 Longwall 103

The depths of cover over the UG2 mining areas vary from 40 m to 155 m. Where the depths of cover above LW 201 to 205 are less than 100 m, surface cracking is expected to be typically in the order of 150 to 200 mm wide, but could be as large as 500 mm wide where the depths of cover are the shallowest. The surface crack widths are likely to be smaller where the depths of cover are greater, or where the surface cracks result from the travelling wave. Where the depths of cover above LW 201 to 205 are 100 to 150 m, the surface crack widths are expected to be typically in the order of 100 to 150 mm wide.

Where massive basalt layers are present, they could resist the deformation and cracking that occurs in the sandstone layers and potentially result in more significant deformations at the edges of the intrusions.

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

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

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

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

The following sections provide the descriptions, predictions of subsidence movements and impact assessments for the natural features located within the Study Area for LW 201 to 205. The predicted parameters for each of the natural features have been compared to the predicted parameters based on the Approved Layout. Supporting impact assessments for the natural features have also been undertaken by other specialist consultants for the Modified Layout.

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

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

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

5.1. Munghorn Gap Nature Reserve

Munghorn Gap Nature Reserve is located outside and to the south east of the Study Area (i.e. outside the 26.5° angle of draw). Minor far-field horizontal movements (Section 4.6) may occur outside of the Study Area, including within the Munghorn Gap Nature Reserve. However, impacts to the Munghorn Gap Nature Reserve (landforms or features) resulting from the Modification are considered unlikely.

5.2. Aquifers and Known Groundwater Resources

The aquifers and groundwater resources within the vicinity of UG2 have been investigated and are described in the reports by Aquaterra (2011) and AGE (2021).

5.3. Drainage Lines

5.3.1. Description of the Drainage Lines

A number of small ephemeral drainage lines have been identified above the longwalls and within the Study Area as shown in Drawing No. MSEC1167-07. The numbered Drainage Lines 1, 2 and 3 as identified in the EA are located in the Approved Mining Area as shown in Drawing No. MSEC1167-07. An additional numbered drainage line is shown in the Extended Mining Area (Drainage Line 08).

The Stage 2 Project Approval (08_0135) lists the following Subsidence Impact Performance Measures for the drainage lines:

Drainage Lines (DL1 – DL7)	*No greater subsidence impacts or environmental consequences than predicted in the EA*

5.3.2. Predictions for the Drainage Lines

Drainage lines across the Study Area are likely to be subjected to the full range of predicted conventional subsidence movements which are provided in Section 4.0 .

The predicted profiles of vertical subsidence, tilt and curvature along the alignments of Drainage Lines 1, 2, 3 and 8, based on the Modified Layout, are shown in Fig. C.04, 05, 06 and 07 respectively in Appendix C. The predicted incremental profiles along the drainage line, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles along the drainage line, after the extraction of each of the longwalls, are shown as solid blue lines. The predicted total profiles based on the Approved Layout are shown as solid red lines for comparison.

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for Drainage Lines 1, 2, 3 and 8, after the extraction of LW 201 to 205, is provided in Table 5.1. The values are the predicted maxima within the Study Area.

Table 5.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for Drainage Lines 1, 2 and 3 after the Extraction of Longwalls 201 to 205

Drainage Line	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Drainage Line 1	2400	60	> 3.0	> 3.0
Drainage Line 2	2400	95	> 3.0	> 3.0
Drainage Line 3	2400	85	> 3.0	> 3.0
Drainage Line 8	2400	75	> 3.0	> 3.0

The maximum predicted conventional tilt for Drainage Lines 1, 2 and 3 is 95 mm/m (i.e. 9.5 %, or 1 in 10). The maximum predicted conventional tilt for Drainage Line 8 is 75 mm/m (i.e. 7.5 %, or 1 in 13). Other drainage lines located across the Study Area could experience greater than 100 mm/m (i.e. 10 %, or 1 in 10) as outlined in Table 4.2. The maximum predicted conventional curvatures are greater than 3.0 km^{-1} hogging and sagging, which equate to minimum radii of curvature of 0.3 km. The predicted conventional strains based on 10 times the curvature are greater than 30 mm/m tensile and compressive.

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

It is also possible that the drainage lines could experience some valley-related movements resulting from the extraction of LW 201 to 205, however these movements should be small due to reduced ground stresses resulting from the presence of adjoining open cut pits. It is also noted that the magnitudes of these upsidence and closure movements are expected to be much lower than the conventional movements and hence may not be significant.

5.3.3. Comparison of the Predictions for Drainage Lines

A comparison of the maximum predicted subsidence parameters for Drainage Lines 1, 2, 3 and 8 within the Approved Mining Area and Extended Mining Area, after the extraction of LW 201 to 205, with those based on the Approved Layout is provided in Table 5.2. The values are the maxima along the section of the drainage line located within the Study Area.

Table 5.2 Comparison of Maximum Predicted Conventional Subsidence Parameters for Drainage Lines 1, 2, 3 and 8 based on the Approved Layout and the Modified Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (Report No. MSEC353)	1980	90	> 3.0	> 3.0
Modified Layout (Study Area)	2400	95	> 3.0	> 3.0
Modified Layout (Approved Mining Area)	2400	95	> 3.0	> 3.0
Modified Layout (Extended Mining Area)	2400	75	> 3.0	> 3.0

The maximum predicted total subsidence for the drainage lines based on the Modified Layout, including the Approved Mining Area and Extended Mining Area is higher than that based on the Approved Layout due to the increased cutting height. The Maximum predicted tilt and curvatures for the drainage lines based on the Modified Layout are similar to those based on the Approved Layout.

5.3.4. Impact Assessments and Recommendations for the Drainage Lines

While there is an increase in the predicted vertical subsidence due to the increased extraction height in the Approved Mining Area, the maximum predicted tilt and curvatures based on the Modified Layout are similar to the maxima based on the Approved Layout. The potential impacts to the drainage lines in the Approved Mining Area, based on the Modified Layout, therefore, are the same as those assessed based on the Approved Layout, including:

- The drainage lines within the Study Area are ephemeral as water only flows during and for short periods after each rain event. Ponding naturally develops along some sections of the drainage lines, for short periods of time, after major rain events. Ponding resulting from the extraction of the longwalls may also occur along the drainage lines.
- Sections of beds downstream of the subsidence-related ponding areas may erode during subsequent rain events, especially during times of high flow. It is expected that, over time, the gradients along the drainage lines would approach grades similar to those that existed before mining. The extent of subsidence-related ponding along the drainage lines would, therefore, be expected to decrease with time.
- Fracturing and dilation of the bedrock would occur as a result of the extraction of the longwalls.
- In times of heavy rainfall, the majority of the surface water runoff would be expected to flow over the surface cracking in the beds and only a small proportion of the flow would be diverted into the fractured and dilated strata below. In times of low flow (e.g. after less intense rainfall events), 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 quantity and quality of water flowing out of the drainage lines.

The potential impacts for the drainage lines in the Extended Mining Area would be similar to those assessed for the Approved Mining Area as outlined above.

Given the above, no changes to the drainage line Subsidence Impact Performance Measure outlined in the Stage 2 Project Approval (08_0135) would be required for the Modification.

It is recommended that the drainage lines within the Approved Mining Area and Extended Mining Area are visually monitored as the longwalls mine beneath them. It is 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. These management strategies would be similar to those outlined in the UG1 Extraction Plan (MSEC 2020), including erosion management, water ponding management (e.g. drainage works) and remediation of vegetation impacted by erosion and /or ponding.

5.4. Cliffs

5.4.1. Descriptions of the Cliffs

A total of four cliffs were identified within or near the Study Area. All of these cliffs were previously assessed as part of the approved UG2 (i.e. no new cliffs have been included in this assessment). The locations of the identified cliffs are shown in Drawing No. MSEC1167-07. Details of the cliffs are provided in Table 5.3

Table 5.3 Summary of Cliffs located within the Study Area

Cliff	Approximate Overall Length (m)	Approximate Maximum Height (m)	Approximate Maximum Overhang (m)
C7	100	10	6
C8	50	20	5
C9	100	20	7
C10	200	40	10

Cliff C7 is located within the Approved Mining Area above a wide coal barrier pillar between LW 204 and 205. Cliff C8 is located within the Approved Mining Area directly above LW 204. Cliff C9 is located in both the Approved Mining Area and the Extended Mining Area adjacent to the commencing end of LW 202A. Cliff C10 is located outside the Study Area above solid coal approximately 125 m from the finishing end of LW 203 and 265 m from LW 202A. Of the four cliffs, Cliff C8 is the only cliff that would continue to be directly undermined by longwall mining. Coal barriers or pillars have been retained under the remaining three cliffs.

The Stage 2 Project Approval (08_0135) lists the following Subsidence Impact Performance Measures for the cliffs:

Cliffs C7, C9 and C10	*Negligible environmental consequences (that is occasional rockfalls, displacement or dislodgement of boulders or slabs or fracturing, that in total do not impact more than 0.5% of the total face of such cliffs within any longwall mining domain).*
Other cliffs	*No greater subsidence impacts or environmental consequences than predicted in the EA.*

Photographs of some of the cliff faces are shown in Fig. 5.1 to Fig. 5.3.

Fig. 5.1 Cliff C7

Fig. 5.2 Cliff C9

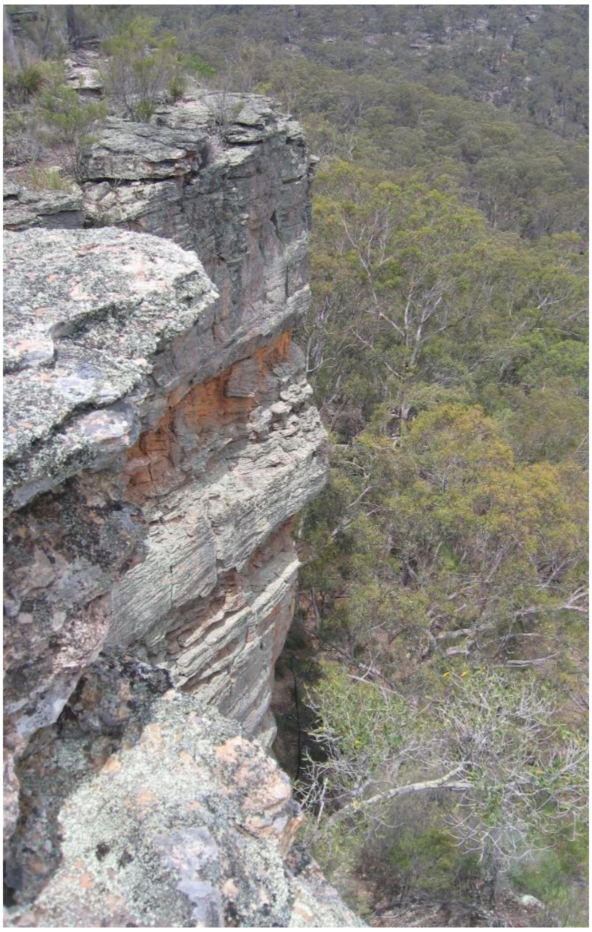

Fig. 5.3 Cliff C10

5.4.2. Predictions for the Cliffs

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the cliffs, resulting from the extraction of LW 201 to 205 for the Modified Layout, is provided in Table 5.4. The values are the maximum predicted parameters within 20 m of their mapped extents. The predicted tilts provided in this table are the maxima after the completion of all the longwalls. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 5.4 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Cliffs within the Study Area Resulting from the Extraction of Longwalls 201 to 205

Cliff	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
C7	<20	1.0	0.13	< 0.01
C8	2450	55	> 3.0	> 3.0
C9	<20	< 0.5	0.03	< 0.01
C10	<20	< 0.5	< 0.01	< 0.01

Cliffs C7 and C9 are located above pillars confined by longwalls on all sides. As a result, increased vertical subsidence of 50 mm to 150 mm in addition to the vertical subsidence listed in Table 5.4 may be observed at these locations as discussed in Section 4.7. The increased vertical subsidence is not expected to significantly increase the predicted tilt and curvature at the cliffs.

The predicted strains for Cliff C8, above LW 204, are provided in Table 5.5. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis provided in Section 4.4).

Table 5.5 Predicted Strains for the Cliff C8 based on Conventional and Non-Conventional Anomalous Movements

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

The predicted strains for Cliffs C7, C9 and C10 are provided in Table 5.6. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements for sites located above solid coal and within 200 m of an extracted longwall (based on the statistical analysis provided in Section 4.4).

Table 5.6 Predicted Strains for the Cliffs C7, C9 and C10 based on Conventional and Non-Conventional Anomalous Movements

Type	Cliff	Conventional strain based on 10 times Curvature (mm/m)	Non-conventional strain based on the 95 % Confidence Level (mm/m)	Non-conventional strain based on the 99 % Confidence Level (mm/m)
Tension	C7 C9 C10	1.5 0.5 < 0.5	3.3	9.2
Compression	C7 C9 C10	< 0.5	3.0	14.4

5.4.3. Comparison of the Predictions for the Cliffs

A comparison of the maximum predicted subsidence parameters for the cliffs within the Study Area, resulting from the Approved Layout, with those based on the Modified Layout is provided in Table 5.7.

Table 5.7 Comparison of Maximum Predicted Conventional Subsidence Parameters for the Cliffs based on the Approved and Modified Layouts

Layout	Cliff	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (Report No. MSEC353)	C7	80	2.0	0.15	0.09
	C8	1760	40	> 3.0	2.0
	C9	1360	45	2.5	1.8
	C10	< 20	< 0.5	< 0.01	< 0.01
Modified Layout	C7	< 20	1.0	0.13	< 0.01
	C8	2450	55	> 3.0	> 3.0
	C9	< 20	< 0.5	0.03	< 0.01
	C10	< 20	< 0.5	< 0.01	< 0.01

It can be seen from Table 5.7, that the maximum predicted conventional subsidence parameters based on the Modified Layout increase or decrease compared to those based on the Approved Layout depending on the cliff.

The predicted vertical subsidence, tilt and curvature at Cliff C7 based on the Modified Layout are slightly less than those based on the Approved Layout due to changes in the longwall geometry surrounding this feature.

The predicted subsidence, tilt and curvature at Cliff C8 based on the Modified Layout are greater than or equal to those based on the Approved Layout, which is predominantly a result of the proposed increased extraction height.

The predicted subsidence, tilt and curvature at Cliff C9 based on the Modified Layout are less than those based on the Approved Layout due to changes to the longwall footprints.

The predicted subsidence parameters at Cliff C10 are unchanged for the Modified Layout.

5.4.4. Impact Assessments and Recommendations for the Cliffs

Cliff C7

The impact assessments for this cliff do not change as a result of the Modified Layout. Cliff C7 is protected by a sterilised wide coal pillar based on 0.5 times the depth of cover from the cliff line. The predicted conventional strain of 1.5 mm/m is considered to be of sufficient magnitude to result in tensile cracking in sandstone, however this strain is considered conservative as it is located at the extremity of the 20 m radius of surrounding the cliff and away from the main continuous section of cliff. The potential for impacts at Cliff C7 based on conventional subsidence movements is considered to be negligible.

Cliff C8

While there is an increase in the predicted subsidence parameters, the impact assessments for Cliff C8 are based on the assessment of historical instabilities for cliffs that have been mined beneath and are the same for the Approved Layout and Modified Layout (i.e. no incremental change in subsidence impact). The following summary outlines the potential impacts to the cliff lines provided in the report MSEC353:

- rock falls can be expected at this cliff line; and
- cliff instabilities could occur on up to approximately 15% of the length of the exposed cliffs.

The potential for impacts of the Modified Layout at Cliff C8 would not be greater than for the Approved Layout.

Cliff C9

The western side of Cliff C9 is located in the Approved Mining Area and is over 70 m from LW 203. The Approved Layout included longwall extraction beneath about 50% of the western side of Cliff C9. The Modified Layout has been designed to avoid longwall extraction directly beneath the cliff. Non-subsiding secondary workings are located adjacent to the western end of Cliff C9. Impacts to Cliff C9 resulting from this extraction are considered unlikely.

The eastern end of Cliff C9 is located in the Extended Mining Area and is approximately 80 m from the commencing end of LW 202A.

Cliff C9 is located greater than 0.5 times the depth of cover from the nearest longwalls LW202A and LW 203. At greater than 0.5 times the depth of cover, the potential for impacts at Cliff C9 based on conventional subsidence movements is considered to be negligible.

Cliff C10

Cliff C10 is located outside the Study Area boundary for both the Approved Layout and Modified Layout. The distance to the nearest longwalls increases slightly from 95 m for the Approved Layout to 125 m for the Modified Layout. The impact assessments for Cliff C10 do not change due to the Modified Layout. The distance from the longwalls to Cliff C10 represents approximately one times the depth of cover and impacts to this cliff are considered unlikely.

Recommendations

Given the assessments above, no changes to the cliff Subsidence Impact Performance Measure outlined in the Stage 2 Project Approval (08_0135) would be required for the Modification.

It is recommended that the baseline condition of the cliffs should be documented and photographed prior to mining. 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.

The Modified Layout has been designed to achieve the outcomes as required in the approval conditions for the cliffs and also to maximise recovery of the coal resource. Given the significance of features at Cliff C7 (including Aboriginal heritage site S2MC236, refer Section 10.1) and Cliff C9 (including threatened species habitat, refer Section 5.7) and close proximity of LW 202A to Cliff C9, it is recommended that a monitoring program is established to:

- Monitor the behaviour of ground movements adjacent to extracted longwalls at MCC; and
- Monitor rockfalls (if any) at cliff lines adjacent to extracted longwalls at MCC, including the timing of rockfalls (if any) relative to the position of the longwall face.

Adopt an adaptive management approach and adjust the mine layout, if required, to achieve the Subsidence Impact Performance Measure outlined in the Stage 2 Project Approval (08_0135) for Cliffs C7 and C9.

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.

It is 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 longwalls by appropriate signs and temporary fencing. Management strategies should be developed to ensure the safety of people that may be within the vicinity of the cliffs during the mining period.

5.5. Minor Cliffs and Rock Face Features

In addition to the defined cliffs, numerous smaller sandstone features are present across the Study Area with slopes greater than 2 in 1 (63.4°). Such features in the Approved Mining Area were previously identified as smaller cliffs or rock ledges in MSEC353. The Stage 2 Project Approval (08_0135) however, identifies the following features which are subject to subsidence impact performance measures:

- Minor cliffs – A continuous rock face, including overhangs, which has a:
  - Minimum length of 20 m and a height between 5 m and 10 m, or a maximum length of 20 m and a minimum height of 10 m; and
  - Minimum slope of 2 to 1 (>63.4°)
- Rock face features - A continuous rock face, including overhangs, which has a:
  - Minimum length of 20 m and a height between 3 m and 5 m, or a maximum length of 20 m and a minimum height of 5 m; and
  - Minimum slope of 2 to 1 (>63.4°).

The Stage 2 Project Approval (08_0135) lists the following Subsidence Impact Performance Measures for the Minor cliffs and Rock face features:

Minor cliffs *Rock face features* *Steep slopes*	*Minor environmental consequences (that is, occasional rockfalls, displacement of or dislodgement of boulders or slabs, or fracturing, that in total do not impact more than 5% of the total face of such feature within any longwall mining domain).*

The minor cliffs and rock face features are located across the Study Area and are likely to experience the full range of predicted subsidence movements, as summarised in Section 4.2.

For the Approved Mining Area, while there is an increase in the predicted vertical subsidence due to the increased extraction height, the maximum predicted tilt and curvatures based on the Modified Layout are similar to the maxima based on the Approved Layout. The impact assessments for the minor cliffs and rock face features inside the Approved Mining Area, based on the Approved Layout therefore do not change for the Modified Layout.

The potential impacts to the minor cliffs and rock face features include fracturing, rock falls and slabbing. As a result of changes in the longwall layouts, some locations will experience a reduction in observed impacts and some locations will experience an increase in observed impacts. The main reductions in impacts will be observed between LW 201 and 204, and between LW 202A and 202B. The main increases in impacts within the Approved Mining Area will be observed to the north west of LW 204.

It is very difficult to quantify the expected extent of impacts to the minor cliffs and rock face features. Impacts to features located outside the longwall footprints are expected to be unlikely to occur. Where features are located above the longwall panels, there is considered to be a higher likelihood of impacts to features with longer continuous lengths of sandstone and a lower likelihood of impacts to shorter isolated features. Notwithstanding the above, the majority of features within the Study Area comprise shorter isolated lengths and it is expected that the cumulative impacts would not be greater than 5% of the total face area (i.e. would be of minor environmental consequence). The potential impacts for the minor cliffs and rock face features inside the Approved Mining Area, based on the Approved Layout therefore do not change for the Modified Layout.

The predicted vertical subsidence, maximum predicted tilt and curvatures in the Extended Mining Area based on the Modified Layout are similar to those predicted for the Approved Mining Area and therefore the potential impacts to the minor cliffs and rock face features in the Extended Mining Area would be similar to the Approved Mining Area (i.e. minor environmental consequence).

Given the assessments above, no changes to the minor cliffs and rock face features Subsidence Impact Performance Measure outlined in the Stage 2 Project Approval (08_0135) would be required for the Modification.

The minor cliffs and rock face features are located within areas of steep slopes and some locations may be difficult to access or may not be accessible for monitoring. In such cases, alternative monitoring methods such as drone photography may be necessary.

It is recommended that minor cliffs and rock face features should be visually monitored during the mining period from a remote and safe location until such time that the mine subsidence movements have ceased. Management strategies should be developed to ensure the safety of people that may be within the vicinity of the minor cliffs and rock face features during the mining period.

5.6. Steep Slopes

The locations of steep slopes are shown on Drawing No. MSEC1167-07. The steep slopes are defined in MSEC353 and the Stage 2 Project Approval (08_0135) as an area of land having a gradient between 1 in 3 (33% or 18.3°) and 2 in 1 (200% or 63.4°). The Stage 2 Project Approval (08_0135) lists the following Subsidence Impact Performance Measures for the steep slopes:

Minor cliffs *Rock face features* *Steep slopes*	*Minor environmental consequences (that is, occasional rockfalls, displacement of or dislodgement of boulders or slabs, or fracturing, that in total do not impact more than 5% of the total face of such feature within any longwall mining domain).*

The steep slopes within the Study Area could experience the full range of predicted subsidence movements, as summarised in Section 4.2.

For the Approved Mining Area, while there is an increase in the predicted vertical subsidence due to the increased extraction height, the maximum predicted tilt and curvatures based on the Modified Layout are similar to the maxima based on the Approved Layout. The potential impacts to the steep slopes, based on the Modified Layout, therefore, are the same as those assessed based on the Approved Layout inside the Approved Mining Area. The potential for ground surface cracking is discussed in Section 4.9.

As a result of changes in the longwall layouts, some locations will experience a reduction in observed impacts and some locations will experience an increase in observed impacts. The main reductions in impacts will be observed between LW 201 and 204, and between LW 202A and 202B. The main increases in impacts within the Approved Mining Area will be observed to the north west of LW 204.

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

The predicted vertical subsidence, maximum predicted tilt and curvatures in the Extended Mining Area based on the Modified Layout are similar to those predicted for the Approved Mining Area and therefore the potential impacts to the steep slopes in the Extended Mining Area would be similar to the Approved Mining Area (i.e. minor environmental consequence).

Given the assessments above, no changes to the steep slope Subsidence Impact Performance Measure outlined in the Stage 2 Project Approval (08_0135) would be required for the Modification.

It is 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. Management strategies should be developed, to ensure that the steep slopes are maintained throughout the mining period.

5.7. Threatened Species and Populations

Threatened fauna species listed under the NSW *Biodiversity Conservation Act 2016* and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* are known to occur in the Study Area (Ecovision Consulting 2008, EcoLogical Australia 2018; Niche Environment and Heritage 2021a). The most likely habitat to be impacted by subsidence impacts are caves, crevices and rock overhangs, associated with cliffs and steep slopes.

Threatened bats are known to be associated with cliffs and steep slopes in the Study Area, namely the Large-eared Pied Bat and Eastern Cave Bat. The cliffs and steep slopes in the Study Area are shown on Drawing No. MSEC1167-07. Specific mapping of bat habitat in the Extended Mining Area was prepared by AMBS (2021) and is also shown on Drawing No. MSEC1167-07 (including a 100 m buffer).

One threatened flora species listed under the Biodiversity Conservation Act has been recorded in the Study Area, namely Ausfeld's Wattle (*Acacia ausfeldii*) a shrub that grows between 2 to 4 m high. Multiple plants of this species were recorded by EcoLogical Australia (2018) within the Study Area above LW 205 of the Approved Mining Area. The records are not located near sleep slopes or cliffs (Drawing No MSEC1167-07).

No threatened populations listed under the NSW *Biodiversity Conservation Act 2016* are known to occur within the Study Area (Niche Environment and Heritage 2021a)

The Stage 2 Project Approval (08_0135) lists the following Subsidence Impact Performance Measures for Biodiversity:

Threatened species, threatened populations, or endangered ecological communities	*Negligible subsidence impacts or environmental consequences*

This Stage 2 Project Approval (08_0135) performance measure was developed based on the following predicted subsidence impacts on Large-eared Pied Bat habitat described in MSEC Report No. MSEC353:

- *The Large-eared Pied Bat resides predominantly in caves and rock overhangs, which are likely to be impacted by the proposed Longwalls 1 to 13.*
- *It is expected that the impacts, particularly if rock falls should occur, could damage the habitats and affect some of the bats.*

The bat habitat within the Study Area (cliffs and steep slopes) could experience the full range of predicted subsidence movements, as summarised in Section 4.2.

For the Approved Mining Area, while there is an increase in the predicted vertical subsidence due to the increased extraction height, the maximum predicted tilt and curvatures based on the Modified Layout are similar to the maxima based on the Approved Layout. The potential impacts to the bat habitat (cliffs and steep slopes) from the Modified Layout, therefore, are the same as those assessed based on the Approved Layout.

As a result of changes in the longwall layouts, some steep slopes are likely to experience a relative reduction in observed impacts and some steep slopes are likely to experience a relative increase in observed impacts. The main reductions in impacts would likely be observed between LW 201 and 204, and between LW 202A and 202B. The main increases in impacts to steep slopes within the Approved Mining Area would likely be observed to the north west of LW 204. As a result of the Modified Layout, the relevant cliffs (i.e. C9 and C10) would experience negligible impacts based on conventional subsidence movements (Section 5.3.4).

Where the bat habitats associated with steep slopes (caves, crevices and rock overhangs) are located above the extracted longwalls, the habitats would experience the full range of predicted subsidence movements. The caves, crevices and rock overhangs would likely experience impacts due to the extraction of the longwalls, including cracking, rockfalls, slabbing and movement (closing or opening) within the habitats. The extent of rockfalls is expected to be consistent with those described in Sections 5.4, 5.5 and 5.5. Within the areas of steep slopes, there is likely to be occasional rockfalls, displacement of or dislodgement of boulders or slabs, or fracturing, that in total do not impact more than 5% of the total face of such feature within any longwall mining domain (i.e. would be of minor environmental consequence).

The predicted impacts for the bat habitat (cliffs and steep slopes) based on the Approved Layout were considered to result in ‘negligible subsidence impacts or environmental consequences’ (as per the Subsidence Impact Performance Measure for “Threatened species …”). As the potential impacts to habitat features for the Modified Layout are predicted to be the same as for the Approved Layout, the Modified Layout is expected to result in a similar level of impact to bat habitat (i.e. ‘negligible subsidence impacts or environmental consequences’).

The bat habitats within the Extended Mining Area are located north of the commencing end of LW 202A surrounding Cliff C9 and above the middle of LW 202A. As a result of the Modified Layout, Cliff C9 would experience negligible impacts based on conventional subsidence movements (Section 5.3.4).

The predicted vertical subsidence, maximum predicted tilt and curvatures in the Extended Mining Area based on the Modified Layout are similar to those predicted for the Approved Mining Area and therefore the potential impacts to the bat habitat associated with steep slopes in the Extended Mining Area would be similar to the Approved Mining Area (i.e. occasional rockfalls, displacement of or dislodgement of boulders or slabs, or fracturing, that in total do not impact more than 5% of the total face of such feature within any longwall mining domain or minor environmental consequence).

Bat habitats located outside the longwall panels are unlikely to experience subsidence related impacts.

The predicted subsidence parameters and impact assessments for the Ausfeld's Wattle will be similar to those outlined in Section 5.9 for natural vegetation.

While the maximum predicted subsidence based on the Approved Layout increases due to the increased extraction height for the Modified Layout, the maximum predicted tilt and curvature are similar for the Approved and Modified Layouts. The potential impacts to the natural vegetation inside the Approved Mining Area, based on the Modified Layout, therefore, are the same as those assessed based on the Approved Layout. The potential for ground surface cracking is discussed in Section 4.9.

Given the assessments above, no changes to the threatened species and populations Subsidence Impact Performance Measure outlined in the Stage 2 Project Approval (08_0135) would be required for the Modification.

Further discussion of the effects of subsidence on flora and fauna within the Study Area is included in a report by Niche Environment and Heritage (2021a).

5.8. Threatened Ecological Communities

5.8.1. Descriptions of the TECs

The following Threatened Ecological Communities (TECs) listed under the NSW *Biodiversity Conservation Act 2016* and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* are located within the Study Area as shown on Drawing No. MSEC1167-07:

- *White Box, Yellow Box, Blakely's Redgum Grassy Woodland, and Derived Native Grasslands and Central Hunter Grey Box – Ironbark Woodland in the NSW North Coast and Sydney Basin Bioregions*;
- *White box – Yellow box – Blakely's red gum grassy woodlands and derived native grassland;*
- *Hunter Valley Footslopes Slaty Gum Woodland in the Sydney Basin Bioregion; and*
- *Central Hunter Valley eucalypt forest and woodland.*

The Stage 2 Project Approval lists the following Subsidence Impact Performance Measures for Biodiversity:

Threatened species, threatened populations, or endangered ecological communities	*Negligible subsidence impacts or environmental consequences*

This Stage 2 Project Approval (08_0135) performance measure was developed based on the following predicted subsidence impacts on TECs described in MSEC Report No. MSEC353:

- *The predicted systematic tilts at the vegetation communities are likely to result in changes in surface gradients in the CEECs* [TECs] *by factors of up to about 2. The changes in gradients will result in reduced grades and increased grades depending on the position of the CEECs* [TECs] *in the subsidence bowl. These changes in grade may result in ponding of surface water runoff where existing natural grades are relatively shallow, …*
- *It is expected, 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 longwalls. It is possible that below some of the CEECs* [TECs]*, 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, …*

The effects of subsidence on flora and fauna within the Study Area are considered in the report by Niche Environment and Heritage (2021a).

5.8.2. Predictions for the TECs

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the TECs within the Study Area, resulting from the extraction of the Modified Layout, is provided in Table 5.8. The values are the maximum predicted parameters within 20 m of the perimeter of the TECs. The predicted tilts provided in this table are the maxima after the completion of all the longwalls. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 5.8 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the TECs within the Study Area Resulting from the Extraction of Longwalls 201 to 205

ID	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
TEC04	2400	60	> 3	> 3
TEC05	300	20	1.7	< 0.01
TEC06	2400	55	> 3	> 3
TEC07	< 20	2.5	0.3	0.15
TEC08	2400	55	> 3	> 3

The predicted strains for the TECs are provided in Table 5.9. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis provided in Section 4.4).

Table 5.9 Predicted Strains for the TECs based on Conventional and Non-Conventional Anomalous Movements

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

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

5.8.3. Comparison of the Predictions for the TECs

A comparison of the maximum predicted subsidence parameters for the TECs within the Study Area, resulting from the extraction of Longwalls 201 to 205, with those based on the Approved Layout, is provided in Table 5.10. Table 5.10 includes the maximum predicted subsidence parameters for the TECs in the Approved Mining Area, Extended Mining Area and the overall Study Area.

Table 5.10 Comparison of Maximum Predicted Conventional Subsidence Parameters for the TECs based on the Modified Layout and the Approved Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (Report No. MSEC353)	1980	65	> 3	> 3
Modified Layout (Study Area)	2400	60	> 3	> 3
Modified Layout (Approved Mining Area)	2400	60	> 3	> 3
Modified Layout (Extended Mining Area)	2400	55	> 3	> 3
Modified Layout (Study Area)	2400	60	> 3	> 3

It can be seen from the above table, that the maximum predicted total subsidence for the TECs based on the Modified Layout, including the Approved Mining Area and Extended Mining Area, is greater than that based on the Approved Layout. The increased subsidence is the result of the increase in extraction height from 3.0 to 3.5 m. The maximum predicted total tilt based on the Modified Layout within the Approved Mining Area and the Extended Mining Area is slightly less than that for the Approved Layout. The maximum predicted total hogging curvature and sagging curvature based on the Modified Layout are the same as those for the Approved Layout.

The maximum predicted subsidence parameters at the individual TECs locations within the Approved Mining Area vary significantly due to changes in the Approved Layout and Modified Layout. The maximum predicted subsidence parameters at TEC05 and TEC06 reduce due to the reduced extent of extraction beneath these TECs.

5.8.4. Impact Assessments and Recommendations for the TECs

For the Approved Mining Area, the maximum predicted total tilt and curvature for the TECs based on the Modified Layout are similar to those for the Approved Layout. The potential impacts for the TECs inside the Approved Mining Area, based on the Modified Layout, therefore, are the same as those assessed based on the Approved Layout. The potential subsidence impacts apply primarily to areas of the TECs located above the longwall panels as follows:

- The likely changes in gradients will result in reduced grades and increased grades depending on the position of the TECs in the subsidence bowl. These changes in grade may result in ponding of surface water runoff where existing natural grades are relatively shallow. It is expected that, over time, the gradients along the drainage lines would approach grades similar to those that existed before mining. The extent of subsidence-related ponding along the drainage lines would, therefore, be expected to decrease with time.
- It is expected that fracturing and dilation of the bedrock would occur as a result of the extraction of the longwalls. It is possible that below some of the TECs, massive basalt layers could be present that could resist the deformation and cracking that occurs in the sandstone layers. Fracturing and dilation of the bedrock could result in surface cracking, as described in Section 4.9.
- It is expected that the surface cracking could be easily and quickly remediated, if required, by infilling with soil or other suitable materials, or by locally regrading and compacting the surface.

The predicted impacts for the TECs based on the Approved Layout were considered to result in 'negligible subsidence impacts or environmental consequences' (as per the Subsidence Impact Performance Measure for "… endangered ecological communities …"). As the potential impacts for the Modified Layout to TECs are predicted to be the same as for the Approved Layout, the Modified Layout is expected to result in a similar level of impact to threatened species (i.e. 'negligible subsidence impacts or environmental consequences').

The predicted vertical subsidence, maximum predicted tilt and curvatures in the Extended Mining Area based on the Modified Layout are similar to those predicted for the Approved Mining Area and therefore the potential impacts to the TECs in the Extended Mining Area would be similar to the Approved Mining Area (i.e. 'negligible subsidence impacts or environmental consequences').

Outside the longwall panels in the Approved Mining Area, subsidence impacts to the TECs are expected to be no greater than negligible.

Given the assessments above, no changes to the threatened ecological communities Subsidence Impact Performance Measure outlined in the Stage 2 Project Approval (08_0135) would be required for the Modification.

It is also recommended that management strategies are developed for the TECs, such 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 TECs resulting from the extraction of the proposed longwalls. Further discussion on potential impacts to TECs are provided in the report by Niche Environment and Heritage (2021a).

5.9. Natural Vegetation

Natural vegetation covers the majority of the Study Area. The natural vegetation could, therefore, experience the full range of predicted subsidence movements, as summarised in Section 4.0 . Areas within the Approved Mining Area and Extended Mining Area are also proposed Biodiversity Offset Areas. The Biodiversity Offset Areas are located above LW 201, 202A and 202B and are shown in Drawing MSEC-1167-07. A comparison of the maximum predicted values of total conventional subsidence, tilt and curvature for the Biodiversity Offset Areas based on the Modified Layout, is provided in Table 5.11.

Table 5.11 Comparison of Maximum Predicted Total Conventional Subsidence, Tilt and Curvature within the Biodiversity Offset areas after the Extraction of Longwalls 201 to 205

	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (Report No. MSEC353)	1980	> 100	> 3	> 3
Modified Layout (Study Area)	2450	100	> 3	> 3
Modified Layout (Approved Mining Area)	2450	100	> 3	> 3
Modified Layout (Extended Mining Area)	2400	95	> 3	> 3

It can be seen from the above table, that the maximum predicted total subsidence for the Biodiversity Offset Areas based on the Modified Layout, including the Approved Mining Area and Extended Mining Area, is greater than that based on the Approved Layout. The increased subsidence is the result of the increase in extraction height from 3.0 to 3.5 m. The maximum predicted total tilt based on the Modified Layout within the Approved Mining Area is the same as that for the Approved Layout. The maximum predicted total tilt based on the Modified Layout within the Extended Mining Area is the slightly less than that for the Approved Layout. The maximum predicted total hogging curvature and sagging curvature based on the Modified Layout are the same as those for the Approved Layout.

For the Approved Mining Area, while the maximum predicted subsidence increases due to the increased extraction height, the maximum predicted tilt and curvature for the natural vegetation and Biodiversity Offset Areas, based on the Modified Layout are the same as the maxima based on the Approved Layout. The potential impacts to the natural vegetation inside the Approved Mining Area, based on the Modified Layout, therefore, are the same as those assessed based on the Approved Layout. The potential for ground surface cracking is discussed in Section 4.9.

As a result of changes in the longwall layouts, some locations will experience a reduction in observed impacts and some locations will experience an increase in observed impacts. The main reductions in impacts will be observed between LW 201 and 204, and between LW 202A and LW 202B. The main increases in impacts within the Approved Mining Area will be observed to the north west of LW 204.

The predicted vertical subsidence, maximum predicted tilt and curvatures in the Extended Mining Area based on the Modified Layout are similar to those predicted for the Approved Mining Area and therefore the potential impacts to natural vegetation in the Extended Mining Area would be similar to the Approved Mining Area.

5.10. Areas of Significant Geological Interest

A brief description of the geology within the Study Area is provided in Section 1.4. The presence of basalt may result in spanning and reduced surface impacts which are discussed in Section 4.9. There are no other areas of significant geological interest within the Study Area.

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

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

- Railways;
- Tunnels;
- Liquid Fuel Pipelines;
- Gas pipelines;
- Liquid fuel pipelines;
- Electricity Transmission Lines or Associated Plants;
- Telecommunication Lines or Associated Plants;
- Water and sewage treatment works;
- Dams, Reservoirs or Associated works; and
- Air strips.

6.1. Roads

There are no publicly owned roads within the Study Area.

6.2. Four Wheel Drive Tracks

There are a number of four wheel drive tracks through the Study Area, some which are shown on Drawing No. MSEC1167-08. These tracks are not publicly accessible.

The tracks could experience the full range of predicted subsidence movements, as summarised in Section 4.2. While there is an increase in the predicted vertical subsidence due to the increased extraction height, the maximum predicted tilt and curvatures based on the Modified Layout are similar to the maxima based on the Approved Layout.

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

7.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE PUBLIC AMENITIES

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

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

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

The following sections provide the descriptions, predictions of subsidence movements and impact assessments for the farm land and facilities located within the Study Area.

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

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

8.1. Fences

Fences are located within the Study Area and are constructed in a variety of ways, generally using either timber or metal materials. Apart from delineating the boundary of the Munghorn Gap Nature Reserve, fences within the Study Area represent prior land ownership and use demarcation and are typically redundant.

The fences could experience the full range of predicted subsidence movements, as summarised in Section 4.2. While there is an increase in the predicted vertical subsidence due to the increased extraction height, the maximum predicted tilt and curvatures based on the Modified Layout are similar to the maxima based on the Approved Layout.

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

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

It is recommended that management strategies be developed to manage potential impacts on fences during the mining of the longwalls, where required.

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

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

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

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

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

9.1. Mine Infrastructure Including Emplacement Areas

Open cut mine operations are located to the north east of LW 201 and 205 (OC4) and south west of LW 203 and 204 (OC2) the locations of which are shown in Drawing No. MSEC1167-08. The changes to the longwall layouts result in an increase in distance from the highwall to the underground voids on the south western side and a reduction in distance from the highwall to the underground voids on the north eastern side. To the south west, the boundary of OC2 is approximately 60 m from LW 204 and 80 m from LW 203. To the north east, the boundary of OC4 is approximately 20 m from LW 205 and 45 m from LW 201. It is understood that a barrier of solid coal would be maintained between the open cut high walls and the underground longwalls consistent with mine safety requirements.

It is understood extraction in OC4 and OC2 will be completed prior to the extraction of LW 201 to 205 and the majority of backfilling and remediation operations will be completed. If any exposed highwalls are present during the extraction of the longwalls, it is recommended that a geotechnical assessment of the highwalls near extracted longwalls is undertaken to assess the potential for instability to develop in the highwalls.

Longwall extraction near the open cut highwalls also increases the potential for larger surface cracking and irregular surface deformation above and adjacent to the longwalls. It is recommended that the high walls are monitored if present during longwall extraction and, if cracking, deformation, or other indications of potential instability are observed, then access is restricted adjacent to the highwall.

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

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

10.1. Aboriginal Heritage Sites

10.1.1. Descriptions of the Aboriginal Heritage Sites

There are 48 Aboriginal heritage sites identified within the Study Area which include rock shelters, isolated finds, artefact scatters, and potential archaeological deposits (PAD). There are 43 known Aboriginal heritage sites identified in the Approved Mining Area and five (5) known Aboriginal heritage sites identified in the Extended Mining Area. Six (6) of the sites have been salvaged. Impact assessments have been provided below for the remaining 42 in-situ sites. The locations of the Aboriginal heritage sites within the Study Area boundary are shown in Drawing No. MSEC1167-08.

The Stage 2 Project Approval lists the following Subsidence Impact Performance Measures for Heritage Sites:

Aboriginal heritage site S2MC 236 (AHIMS No.s 36-3-0016 and 36-3-0134)	*Negligible subsidence impact or environmental consequences*

Detailed descriptions of the Aboriginal heritage sites and surveys conducted in December 2019 and May 2021 are provided in the report by Niche Environment and Heritage (2021b).

10.1.2. Predictions for the Aboriginal Heritage Sites

The maximum predicted subsidence parameters for each of the Aboriginal heritage sites located within the Study Area is provided in Table D.01, in Appendix D. The values are the maximum predicted parameters within 20 m of the site locations. The predictions have been provided based on the Modified Layout, as well as for the Approved Layout for comparison.

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

Table 10.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Aboriginal Heritage Sites within the Study Area after the Extraction of Longwall 205

Site Type	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Rock shelter with Art and Artefacts (S2MC236)	< 20	< 0.5	< 0.01	< 0.01
Shelters with Artefacts and PAD	2350	65	> 3	2.3
Open Artefacts Sites	2400	60	> 3	2.5
PAD	2500	55	> 3	1.9
Isolated Find	2350	85	> 3	> 3
Artefact Scatter	2400	65	> 3	2.0
Artefact Scatter and PAD	2450	17	> 3	0.8

Site S2MC236 is located above a pillar confined by longwalls on all sides. As a result, increased vertical subsidence of 50 mm to 150 mm may be observed at this location as discussed in Section 4.7. The increased vertical subsidence is not expected to significantly increase the predicted tilt and curvature.

The maximum predicted conventional tilt for the Aboriginal heritage sites is 85 mm/m (i.e. 8.5 %, or 1 in 12). The maximum predicted conventional curvatures for these sites are greater than 3 km^{-1} hogging and sagging, which represent minimum radii of curvature of greater than approximately 0.33 km.

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

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

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

The predicted strains for sites located above solid coal are provided in Table 10.3. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements for sites located above solid coal and within 200 m of an extracted longwall (based on the statistical analysis provided in Section 4.4).

Table 10.3 Predicted Strains for the Aboriginal Heritage Sites above Solid Coal based on Conventional and Non-Conventional Anomalous Movements

Type	Conventional strain based on 10 times Curvature (mm/m)	Non-conventional strain based on the 95 % Confidence Level (mm/m)	Non-conventional strain based on the 99 % Confidence Level (mm/m)
Tension	< 0.5	3.3	9.2
Compression	< 0.5	3.0	14.4

10.1.3. Comparisons of the Predictions for the Aboriginal Heritage Sites

Comparisons of the maximum predicted conventional subsidence parameters for the Aboriginal heritage sites within the Study Area, based on the Modified Layout with those based on the Approved Layout are provided in Table 10.4. Table 10.4 includes the maximum predicted subsidence parameters for the Approved Mining Area, Extended Mining Area and the overall Study Area. A comparison of the maximum predicted subsidence parameters for each of the Aboriginal heritage sites located within the Study Area is also provided in Table D.01, in Appendix D.

Table 10.4 Comparison of Maximum Predicted Conventional Subsidence Parameters for the Aboriginal Heritage Sites based on the Approved Layout and the Modified Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout (Report No. MSEC353)	1950	60	> 3	> 3
Modified Layout (Study Area)	2500	75	> 3	> 3
Modified Layout (Approved Mining Area)	2500	85	> 3	> 3
Modified Layout (Extended Mining Area)	1600	60	2.6	2.3
Modified Layout (Study Area)	2500	75	> 3	> 3

The maximum predicted subsidence parameters for the Aboriginal heritage sites in Table 10.4 and Table D.01 within the Approved Mining Area based on the Modified Layout, are generally greater than those based on the Approved Layout. The increases are mainly due to the increased cutting height for the Modified Layout. The maximum predicted total subsidence and curvature based on the Modified Layout within the Extended Mining Area is less than that for the Approved Layout. The maximum predicted total tilt for sites within the Extended Mining Area based on the Modified Layout are slightly greater than those for the Approved Layout. At some locations the predicted subsidence parameters based on the Modified Layout are significantly lower than those based on the Approved Layout, due to changes in the longwall footprints.

10.1.4. Impact Assessments and Recommendations for the Aboriginal Heritage Sites

While there is an increase in the predicted subsidence parameters at several sites, the overall impact assessments for the Aboriginal heritage sites within the Approved Mining Area based on the Approved Layout do not change for the Modified Layout.

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

Whilst it is unlikely that the open sites themselves would be impacted by mine subsidence, it is possible that, if remediation works to the surface areas around the Aboriginal heritage sites was required after mining, these works could potentially impact on the Aboriginal heritage sites. A discussion on surface cracking resulting from the extraction of the Modified Layout is provided in Section 4.9.

Open sites located near outcropping sandstone features above the longwalls could potentially be affected by rock falls. If impacts are considered likely based on monitoring, salvage activities should be considered based on the significance of the site.

Site S2MC236 is located at Cliff C7 within the Approved Mining Area and includes a rock shelter, artwork and artefact scatter. Cliff C7 is protected by a sterilised coal pillar based on 0.5 times the depth of cover from the Cliff. Based on the low magnitude of predicted subsidence parameters, the artefact scatter is unlikely to be directly impacted by subsidence movements. The predicted subsidence parameters and impact assessment for Cliff C7 are outlined in Section 5.4. The potential for impacts at Cliff C7 based on conventional subsidence movements is considered to be negligible and the same for the Modified Layout as for the Approved Layout. It is recommended in Section 5.4 that a survey monitoring program is established to study the behaviour of ground movements adjacent to extracted longwalls at MCC to enable an adaptive management approach to satisfy the performance measures for Cliffs (including Cliff C7). Such an approach should include assessment for Site S2MC236.

The predicted vertical subsidence, maximum predicted tilt and curvatures in the Extended Mining Area based on the Modified Layout are similar to those predicted for the Approved Mining Area and therefore the potential impacts to the Aboriginal Heritage Sites in the Extended Mining Area would be similar to the Approved Mining Area.

Given the above, no changes to the Aboriginal heritage site Subsidence Impact Performance Measure outlined in the Stage 2 Project Approval (08_0135) would be required for the Modification.

Further details and discussions on the potential impacts on the archaeological sites resulting from the extraction of the Modified Layout are provided in the report by Niche Environment and Heritage (2021b). Management of Aboriginal heritage sites will be outlined in the MCC Heritage Management Plan.

10.2. Items of Architectural Significance

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

10.3. Survey Control Marks

There are no survey control marks identified within the Study Area. The nearest survey mark is Murragamba Trig Station, which is located above UG1 LW 105 and is approximately 390 m from the nearest UG2 longwall. The locations of survey marks are shown in Drawing No. MSEC1167-08.

The Murragamba Trig Station will be impacted by the UG1 mining operations and it may be necessary on the completion of the longwalls, i.e. when the ground has stabilised, to re-establish the location of the survey marks. Consultation between MCO and Spatial Services NSW will be required throughout the mining period to ensure that the survey marks are not used for detailed surveying purposes by others and if required they are removed or reinstated at an appropriate time.

As the Murragamba Trig Station is 390 m from the nearest UG2 longwall, it is not expected to experience measurable subsidence movements from extraction of the Modified Layout however it may experience minor far field horizontal movements which are discussed in Section 4.6.

Consistent with the approved Moolarben Coal Complex, it is recommended that management strategies are developed for the extraction of the Modified Layout, in consultation with Spatial Services NSW, as required by the *Surveyor General's Directions No.11 Preservation of Survey Infrastructure*."

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

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

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

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

Glossary of Terms and Definitions

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

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

Shear deformations	The horizontal displacements that are measured across monitoring lines and these can be described by various parameters including; horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.
Strain	The change in the horizontal distance between two points divided by the original horizontal distance between the points, i.e. strain is the relative differential displacement of the ground along or across a subsidence monitoring line. Strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation. **Tensile Strains** are measured where the distance between two points or survey pegs increases and **Compressive Strains** where the distance between two points decreases. Whilst mining induced **strains** are measured **along** monitoring lines, ground **shearing** can occur both vertically, and horizontally **across** the directions of the monitoring lines.
Sub-critical area	An area of panel smaller than the critical area.
Subsidence	The vertical movement of a point on the surface of the ground as it settles above an extracted panel, but, 'subsidence of the ground' in some references can include both a vertical and horizontal movement component. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of *millimetres (mm)*. Sometimes the horizontal component of a peg's movement is not measured, but in these cases, the horizontal distances between a particular peg and the adjacent pegs are measured.
Super-critical area	An area of panel greater than the critical area.
Tilt	The change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the horizontal distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
Uplift	An increase in the level of a point relative to its original position.
Upsidence	Upsidence results from the dilation or buckling of near surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.

APPENDIX B. REFERENCES

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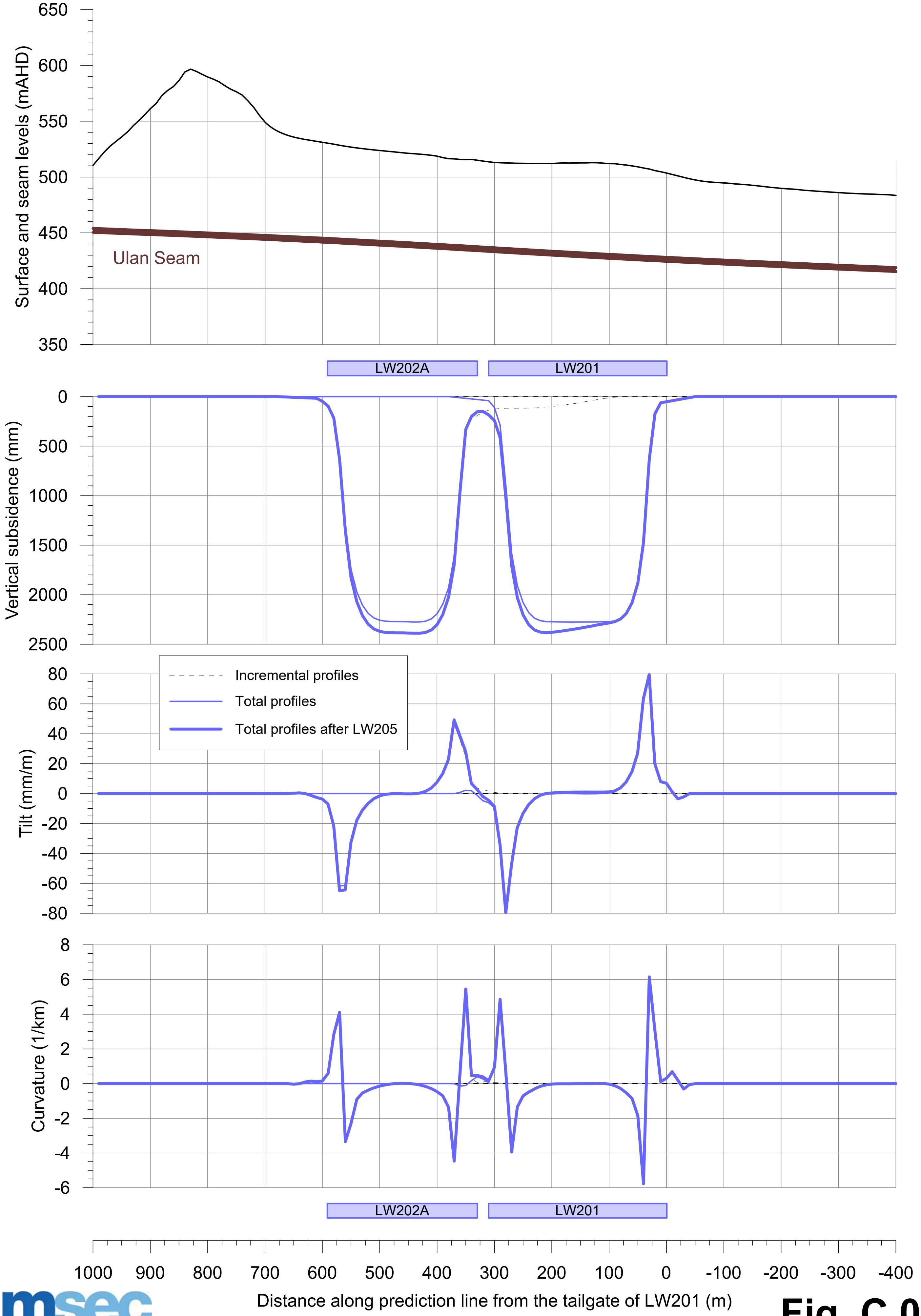
APPENDIX C. FIGURES

I:\Projects\Moolarben\MSEC1167 - UG2 Modification Subsidence Assessment\Subsdata\Impacts\Prediction Lines\Fig. C.01 - Prediction Line 1.grf

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to UG2 LW201 to LW205

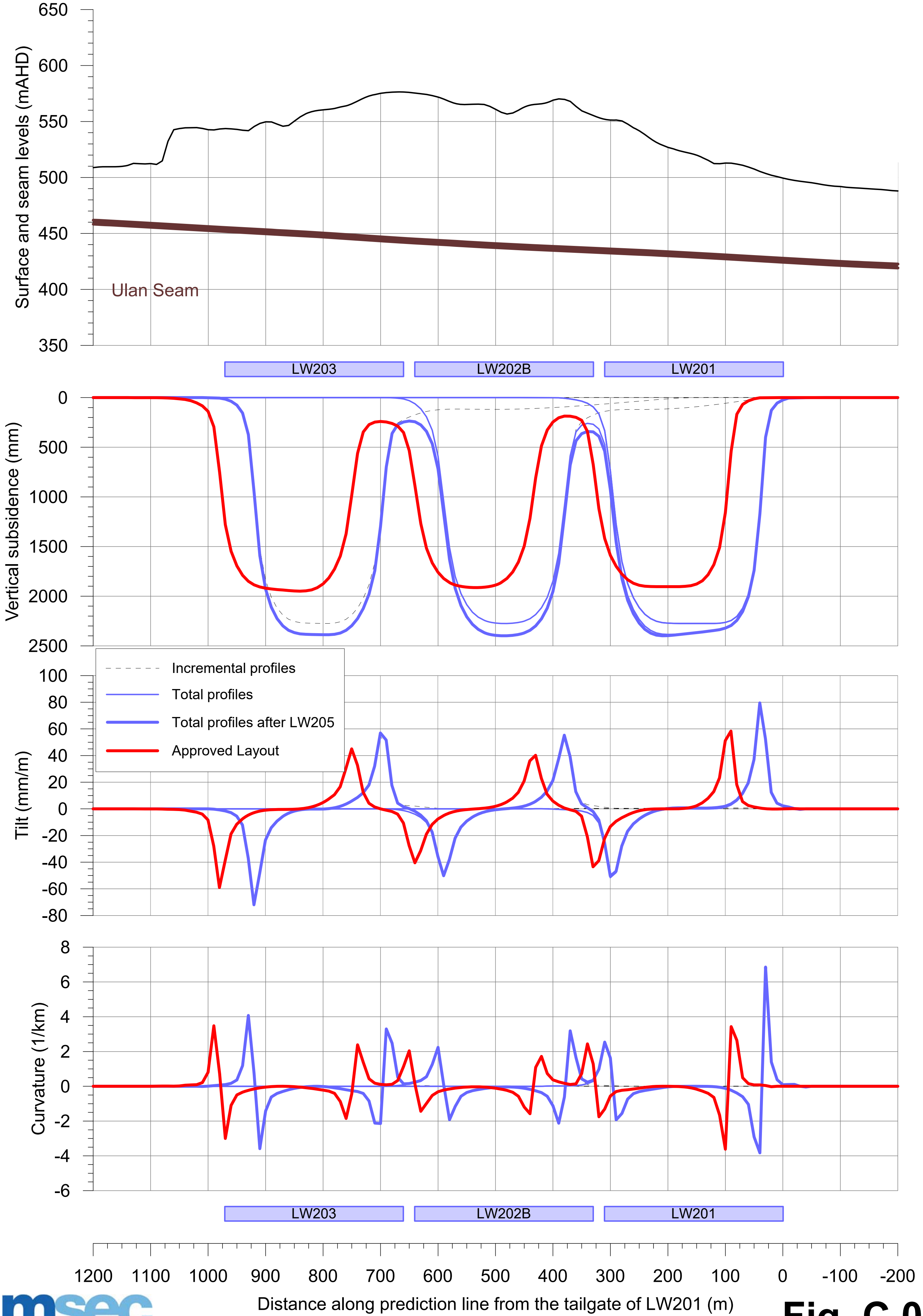


msec

Fig. C.01

I:\Projects\Moolarben\MSEC1167 - UG2 Modification Subsidence Assessment\Subsdata\Impacts\Prediction Lines\Fig. C.02 - Prediction Line 2.grf

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to UG2 LW201 to LW205



msec

Fig. C.02

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 3 due to UG2 LW201 to LW205

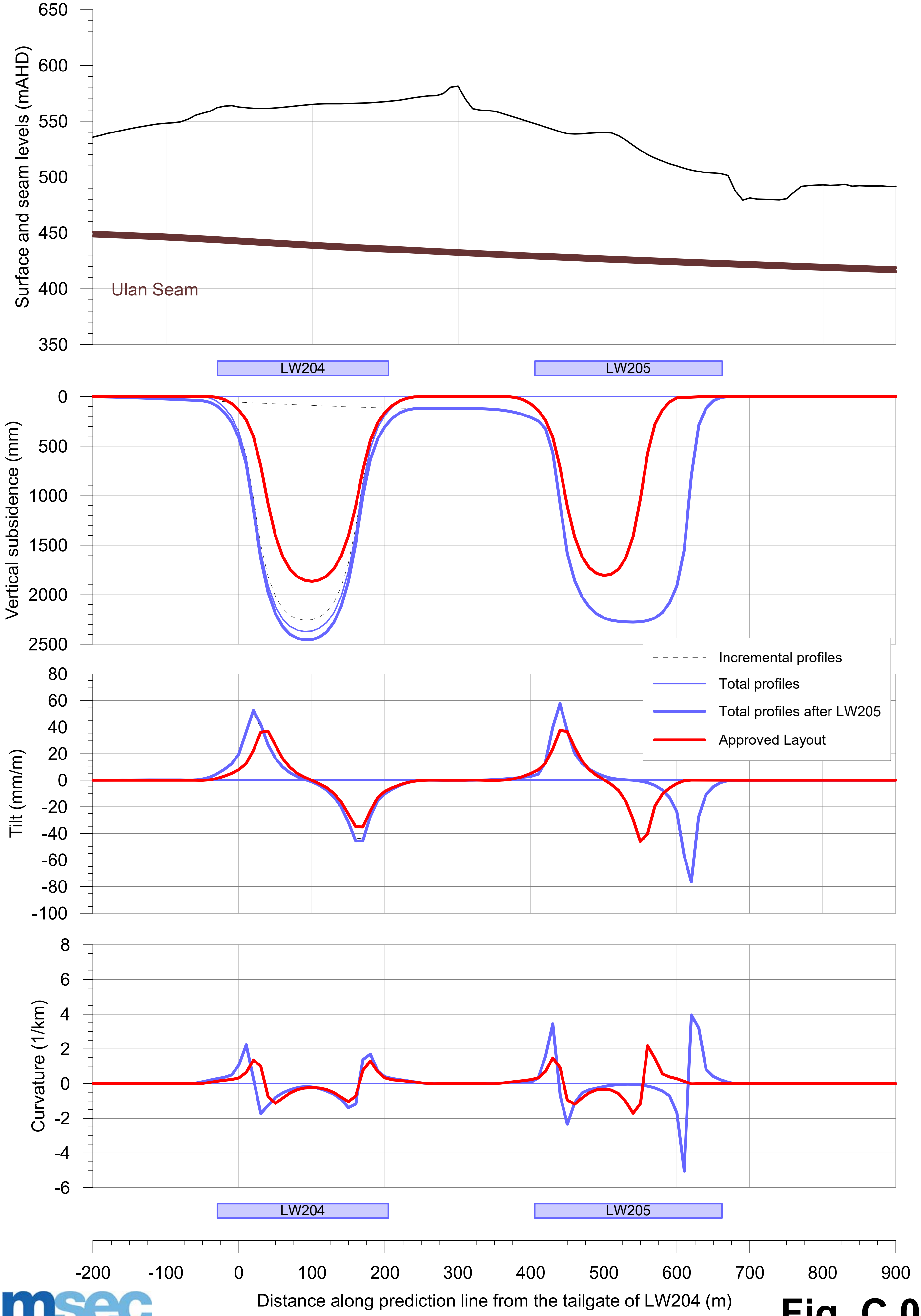


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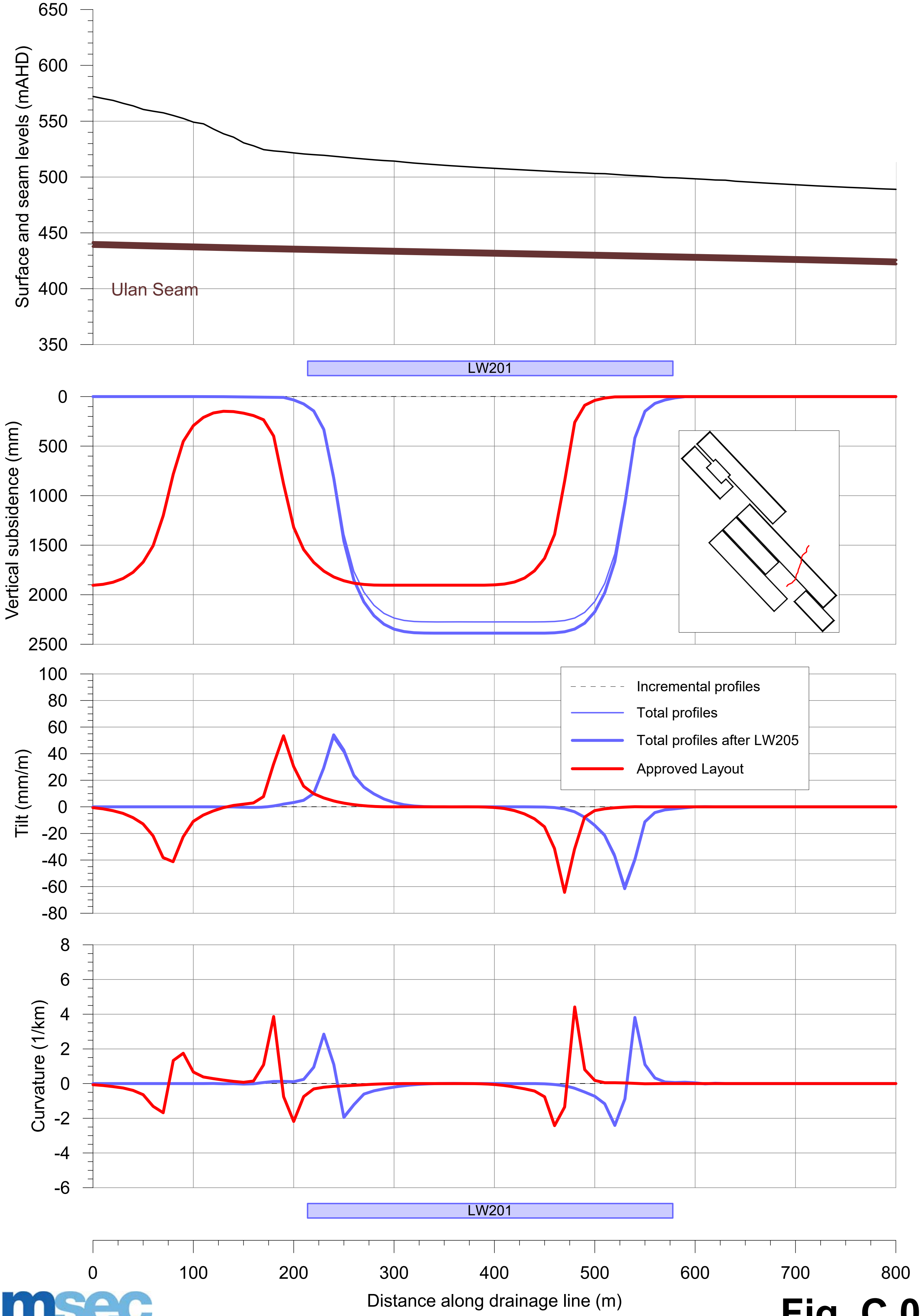
Fig. C.03

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 1 due to UG2 LW201 to LW205



msec

Fig. C.04

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 2 due to UG2 LW201 to LW205

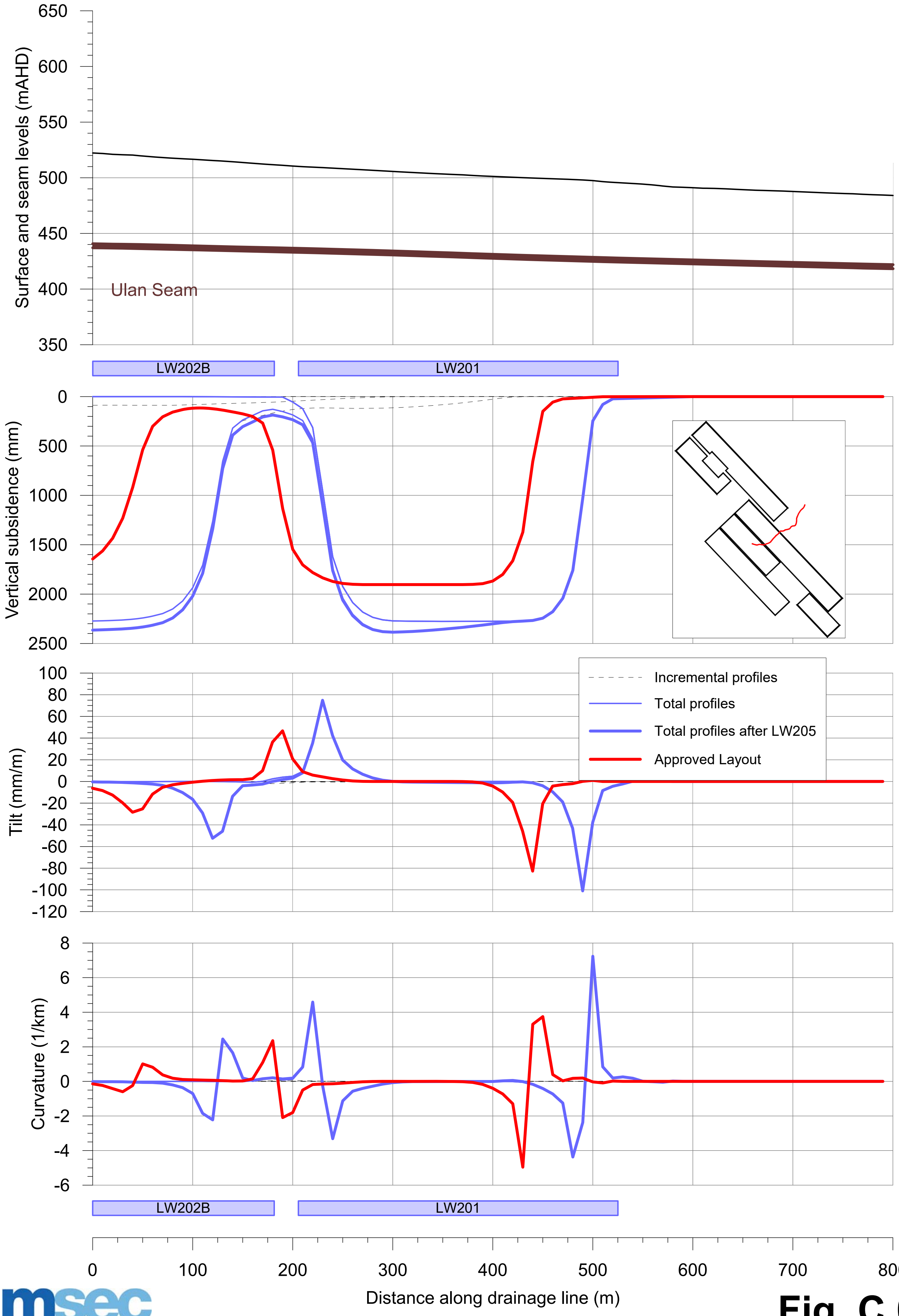


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Fig. C.05

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 3 due to UG2 LW201 to LW205

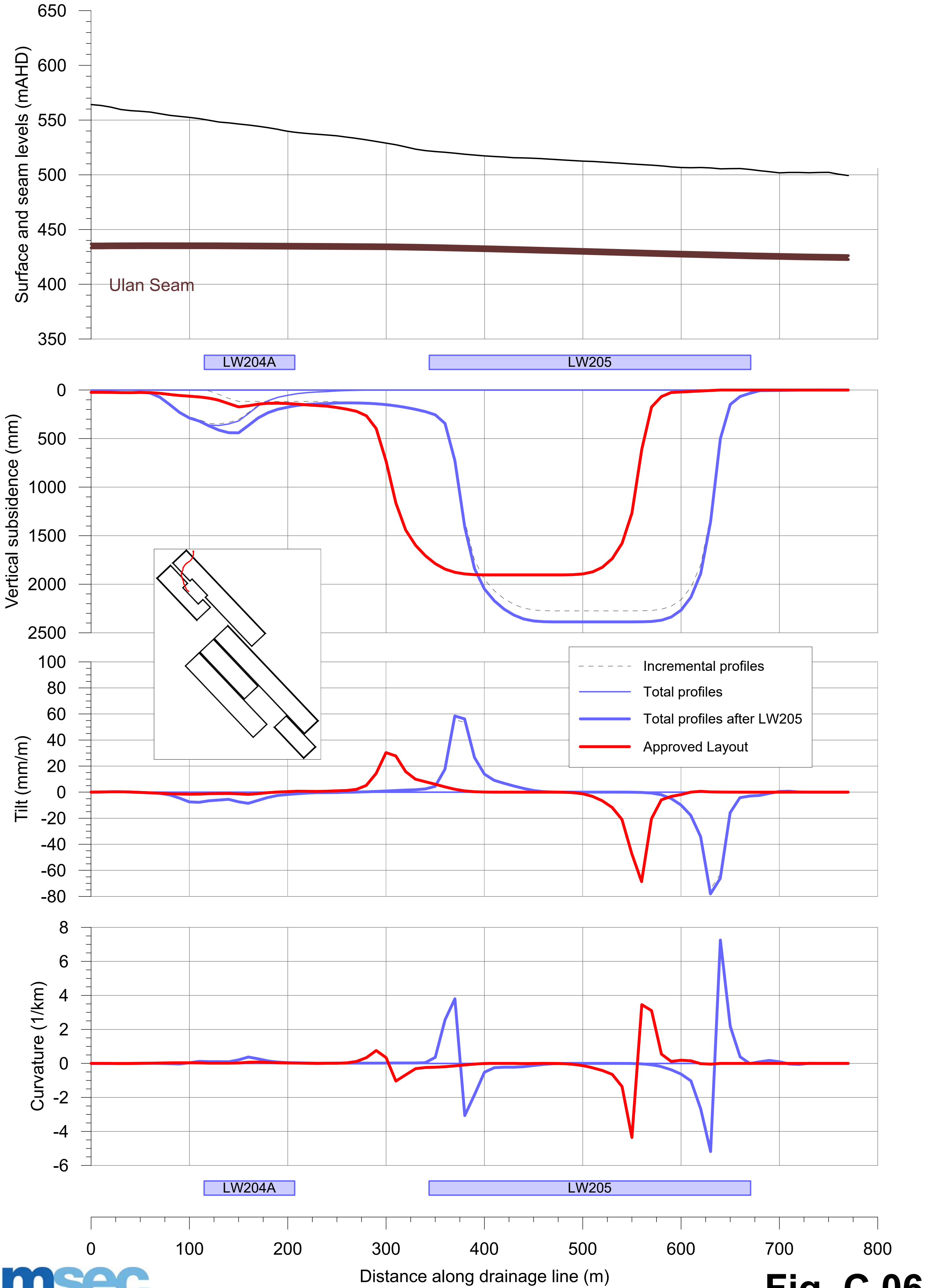

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Fig. C.06

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 8 due to UG2 LW201 to LW205

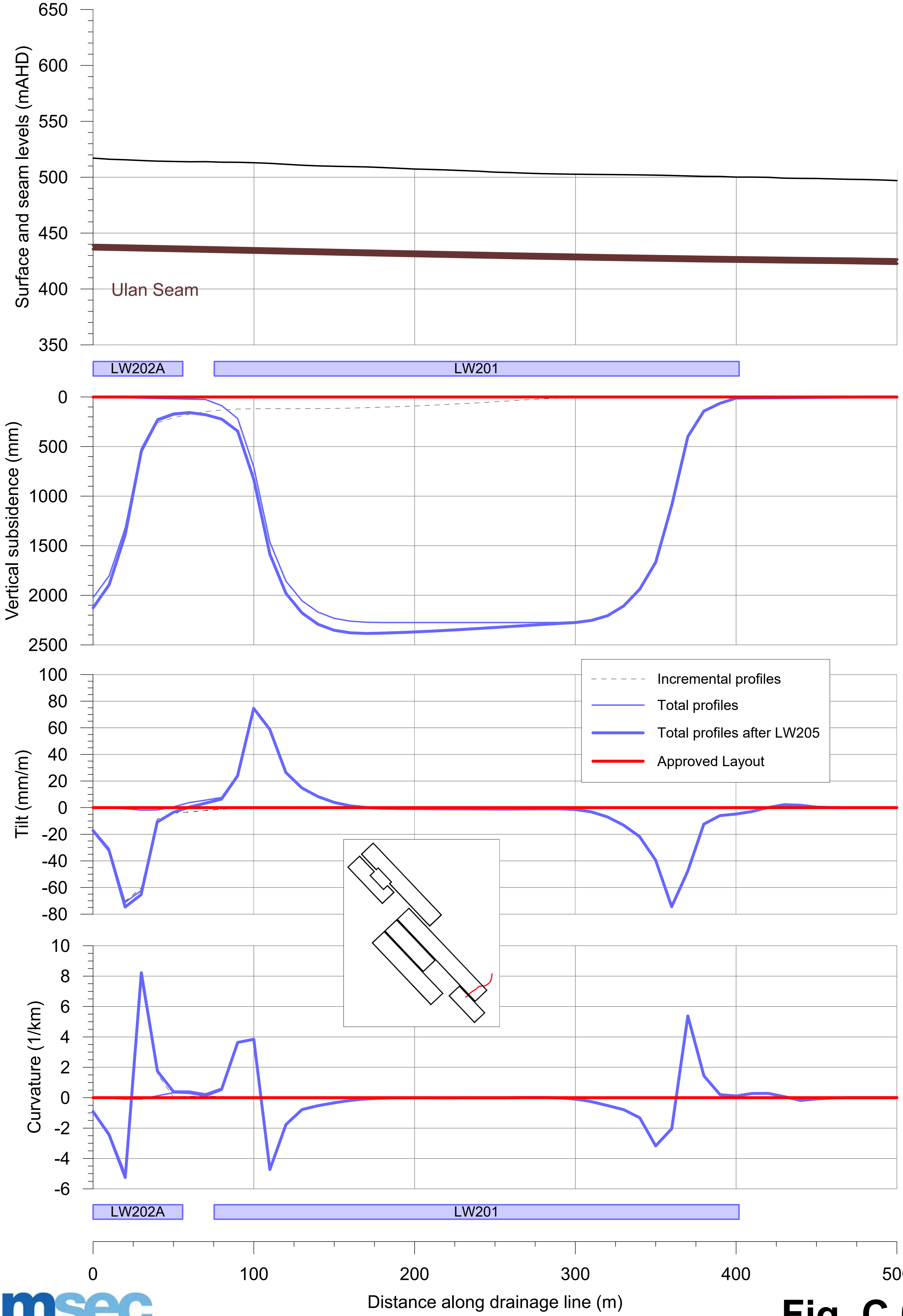


Fig. C.07

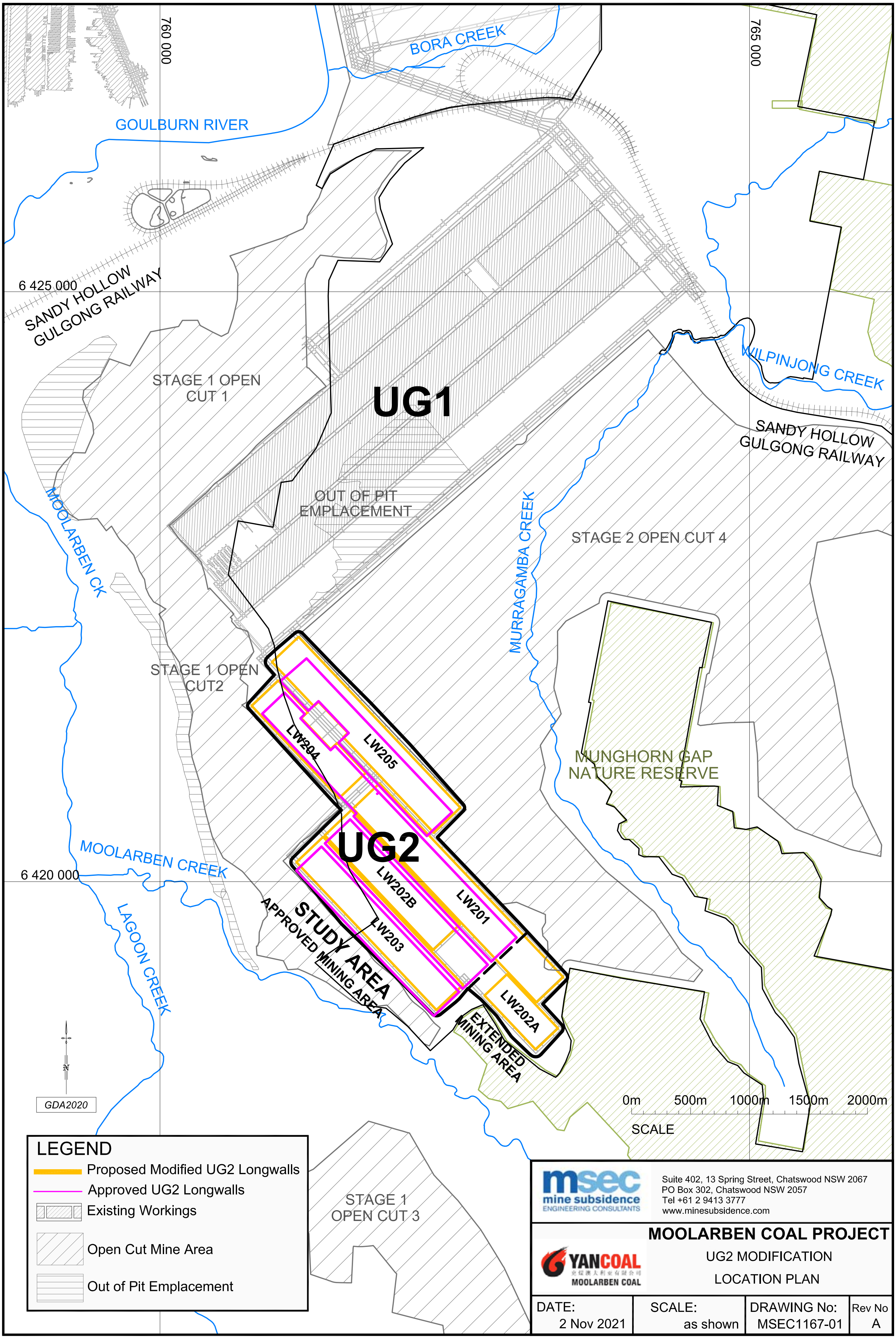
APPENDIX D. TABLES

Table D.01 - Maximum Predicted Subsidence Parameters for the Aboriginal Heritage Sites

Site	Description	*Maximum Predicted Subsidence based on the Approved Layout (LW10-13) (mm)*	Maximum Predicted Subsidence based on the Modified Layout after LW201 (mm)	Maximum Predicted Subsidence based on the Modified Layout after LW202a (mm)	Maximum Predicted Subsidence based on the Modified Layout after LW202b (mm)	Maximum Predicted Subsidence based on the Modified Layout after LW203 (mm)	Maximum Predicted Subsidence based on the Modified Layout after LW204 (mm)	Maximum Predicted Subsidence based on the Modified Layout after LW205 (mm)	*Maximum Predicted Tilt based on the Approved Layout (LW1-8) (mm/m)*	Maximum Predicted Tilt based on the Modified Layout (mm/m)	*Maximum Predicted Hogging Curvature based on the Approved Layout (LW1-8) (1/km)*	Maximum Predicted Hogging Curvature based on the Modified Layout (1/km)	*Maximum Predicted Sagging Curvature based on the Approved Layout (LW1-8) (1/km)*	Maximum Predicted Sagging Curvature based on the Modified Layout (1/km)
PAD 10 Moolarben Coal	Rock Shelter with PAD	*800*	< 20	< 20	< 20	< 20	1850	1950	*35.0*	55.0	*1.60*	> 3	*< 0.01*	1.90
PAD 11 Moolarben Coal	Rock Shelter with PAD	*1950*	< 20	< 20	< 20	< 20	2350	2500	*30.0*	20.0	*> 3*	> 3	*1.30*	0.90
PAD 4 Moolarben Coal	PAD	*1900*	< 20	< 20	< 20	2350	2350	2350	*< 0.5*	19.0	*> 3*	> 3	*0.03*	0.95
PAD 5 Moolarben Coal	Rock Shelter with PAD	*1900*	< 20	< 20	< 20	2350	2350	2350	*< 0.5*	19.0	*> 3*	> 3	*0.03*	0.95
PAD 8 Moolarben Coal	Rock Shelter with Artefacts and PAD	*1900*	< 20	< 20	< 20	< 20	2350	2450	*40.0*	17.0	*> 3*	> 3	*1.40*	0.75
PAD 9 Moolarben Coal	Rock Shelter with PAD	*1100*	< 20	< 20	< 20	< 20	2000	2150	*40.0*	55.0	*2.20*	> 3	*0.70*	1.90
S1MC054	Artefacts	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	*< 0.5*	1.0	*< 0.01*	0.02	*< 0.01*	< 0.01
S1MC055	Rock Shelter with Artefacts	*< 20*	< 20	< 20	< 20	< 20	< 20	20	*< 0.5*	2.0	*< 0.01*	0.03	*< 0.01*	< 0.01
S1MC056	Rock Shelter with Artefacts	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	*< 0.5*	1.0	*< 0.01*	0.01	*< 0.01*	< 0.01
S1MC057	Artefacts	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S1MC074	Isolated Artefact	*1900*	< 20	< 20	< 20	2350	2350	2350	*0.5*	20.0	*> 3*	> 3	*0.04*	1.10
S1MC075	Isolated Artefact	*1900*	< 20	< 20	< 20	2300	2300	2300	*1.0*	35.0	*> 3*	> 3	*0.07*	2.70
S1MC076	Isolated Artefact	*1900*	< 20	< 20	< 20	2300	2300	2300	*1.0*	35.0	*> 3*	> 3	*0.07*	2.70
S1MC077	Isolated Artefact	*1000*	< 20	< 20	< 20	< 20	< 20	< 20	*60.0*	1.5	*2.00*	0.01	*2.20*	0.03
S1MC406	Artefacts	*350*	< 20	< 20	< 20	1900	1900	1900	*14.0*	60.0	*0.70*	> 3	*< 0.01*	2.50
S1MC407	Artefacts	*1950*	< 20	< 20	< 20	2400	2400	2400	*8.5*	1.0	*> 3*	> 3	*0.35*	0.07
S1MC409	Rock shelter with PAD	*1950*	< 20	< 20	< 20	2350	2350	2350	*1.0*	12.0	*> 3*	> 3	*0.05*	0.55
S1MC438	Isolated Artefact	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S2MC236	Rock Shelters with Art and Artefacts	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S2MC237	Isolated Artefact	*1550*	< 20	< 20	< 20	< 20	1950	1950	*35.0*	50.0	*> 3*	> 3	*1.00*	1.50
S2MC238	Artefacts	*1650*	< 20	< 20	< 20	< 20	< 20	175	*50.0*	3.0	*> 3*	0.30	*2.50*	< 0.01
S2MC239	Artefacts	*1850*	< 20	< 20	< 20	< 20	< 20	2400	*35.0*	1.5	*> 3*	> 3	*2.60*	0.10
S2MC411	Artefacts	*1150*	< 20	< 20	< 20	< 20	< 20	1400	*40.0*	55.0	*2.30*	2.30	*0.95*	2.00
S2MC412	Isolated Artefact	*1600*	< 20	< 20	< 20	< 20	< 20	1550	*7.0*	50.0	*> 3*	2.60	*0.08*	2.00
S2MC413	Isolated Artefact	*1150*	< 20	< 20	< 20	< 20	< 20	150	*45.0*	2.0	*2.30*	0.25	*1.60*	< 0.01
S2MC414	Isolated Artefact	*1600*	< 20	< 20	< 20	< 20	2250	2350	*40.0*	55.0	*> 3*	> 3	*1.40*	2.10
S2MC415	Isolated Artefact	*1550*	< 20	< 20	< 20	< 20	1450	1500	*55.0*	85.0	*> 3*	2.50	*> 3*	> 3
S2MC416	Artefacts	*1750*	750	750	800	800	800	800	*45.0*	65.0	*> 3*	1.30	*1.60*	0.06
S2MC417	Artefacts	*825*	30	30	40	40	40	30	*45.0*	2.5	*1.60*	0.06	*< 0.01*	< 0.01
S2MC418	Isolated Artefact	*625*	< 20	< 20	< 20	< 20	1650	1800	*30.0*	55.0	*1.20*	2.90	*< 0.01*	2.00
S2MC419	Artefacts	*225*	< 20	< 20	< 20	< 20	450	575	*7.0*	25.0	*0.45*	0.95	*< 0.01*	< 0.01
S2MC420	Artefacts	*1900*	< 20	< 20	< 20	< 20	< 20	< 20	*8.0*	< 0.5	*> 3*	< 0.01	*0.35*	< 0.01
S2MC438	Isolated Artefact	*1750*	< 20	< 20	< 20	< 20	< 20	< 20	*40.0*	< 0.5	*> 3*	< 0.01	*1.20*	0.02
S2MC439	Rock Shelter with PAD	*200*	< 20	< 20	< 20	< 20	< 20	< 20	*5.5*	0.5	*0.40*	< 0.01	*< 0.01*	0.06
S2MC440	Rock Shelter with Artefacts and PAD	*1750*	< 20	< 20	< 20	< 20	< 20	< 20	*40.0*	< 0.5	*> 3*	< 0.01	*> 3*	< 0.01
S2MC441	Rock Shelter with Artefacts and PAD	*30*	< 20	< 20	< 20	< 20	< 20	< 20	*1.5*	< 0.5	*0.06*	< 0.01	*< 0.01*	< 0.01
S2MC442	Rock Shelter with PAD	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S2MC443	Rock Shelter with PAD	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S2MC444	Rock Shelter with PAD	*800*	< 20	< 20	< 20	< 20	< 20	< 20	*40.0*	< 0.5	*1.60*	< 0.01	*1.50*	< 0.01
S2MC445	Rock Shelter with PAD	*1100*	< 20	< 20	< 20	< 20	< 20	< 20	*45.0*	< 0.5	*2.20*	< 0.01	*2.20*	< 0.01
S2MC446	Rock Shelter with Artefacts and PAD	*< 20*	< 20	725	750	750	750	750	*< 0.5*	60.0	*< 0.01*	1.20	*< 0.01*	< 0.01
S2MC447	Rock shelter with artefacts	*< 20*	< 20	1550	1600	1600	1600	1600	*< 0.5*	55.0	*< 0.01*	2.60	*< 0.01*	2.30

APPENDIX E. DRAWINGS

I:\Projects\Moolarben\MSEC1167 - UG2 Modification Subsidence Assessment\AcadData\MSEC1167-01 Location.dwg



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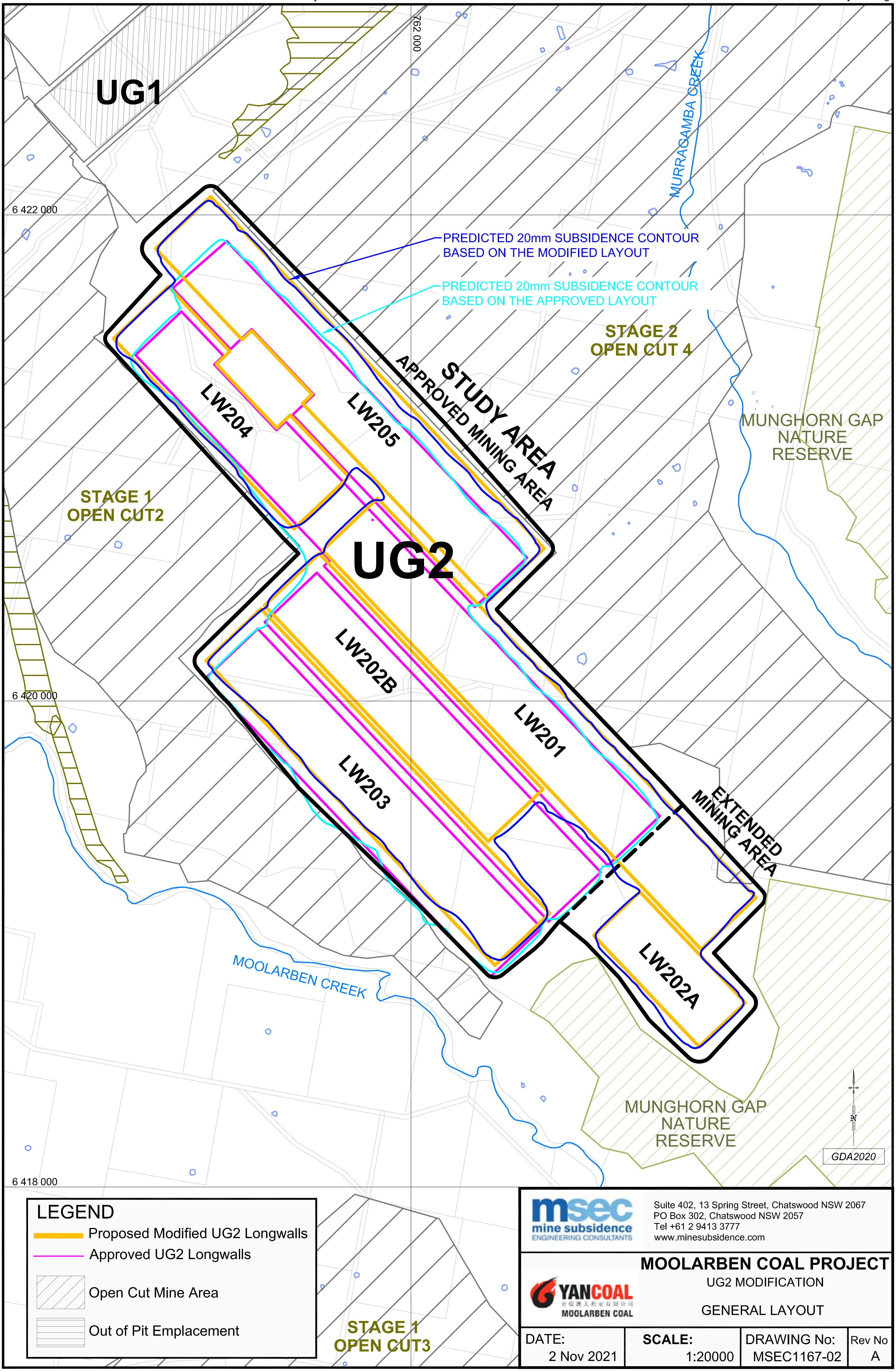

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UG2 MODIFICATION

GENERAL LAYOUT

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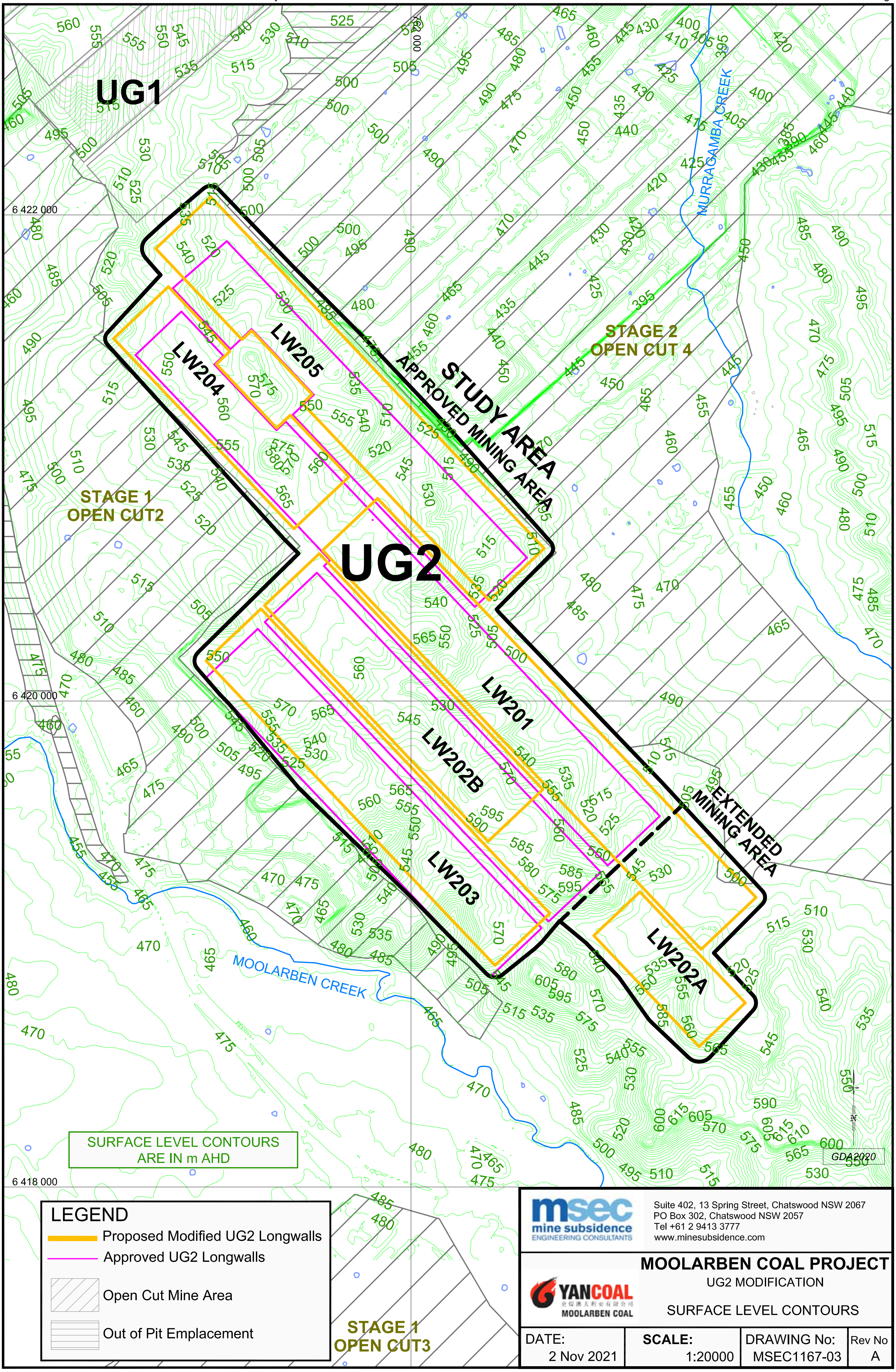

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SURFACE LEVEL CONTOURS

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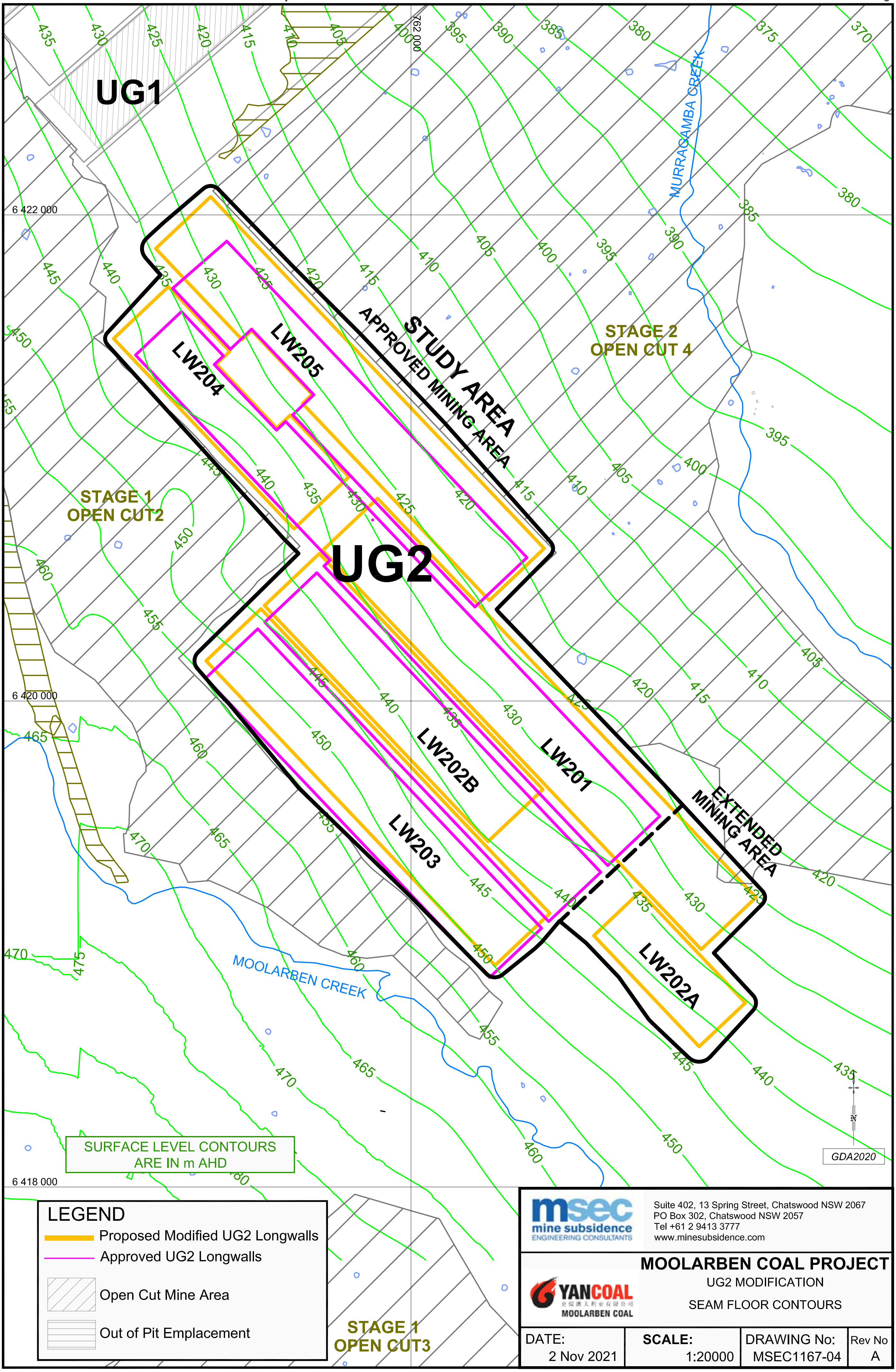

LEGEND

- Proposed Modified UG2 Longwalls
- Approved UG2 Longwalls
- Open Cut Mine Area
- Out of Pit Emplacement

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SEAM FLOOR CONTOURS

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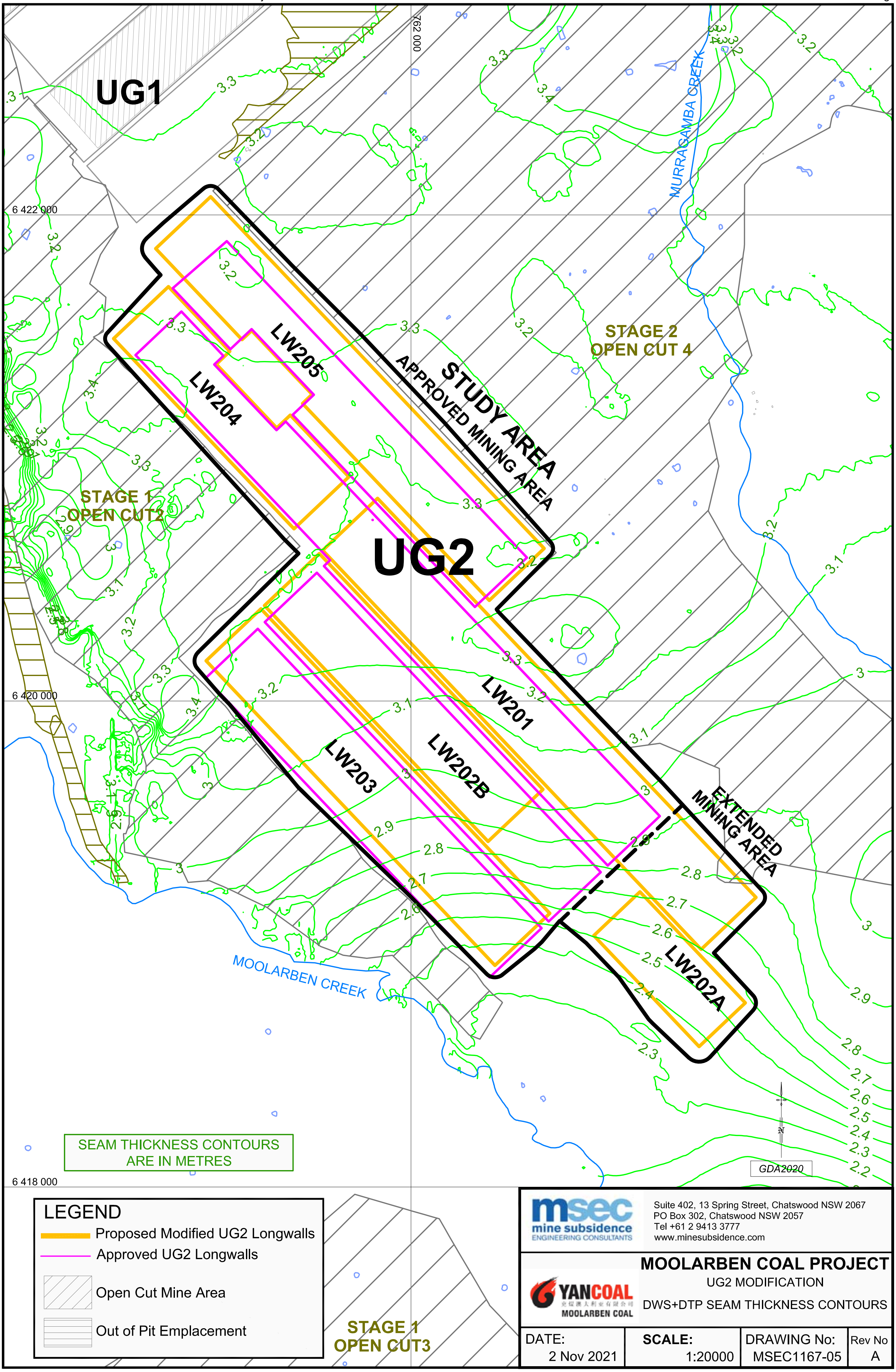

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DWS+DTP SEAM THICKNESS CONTOURS

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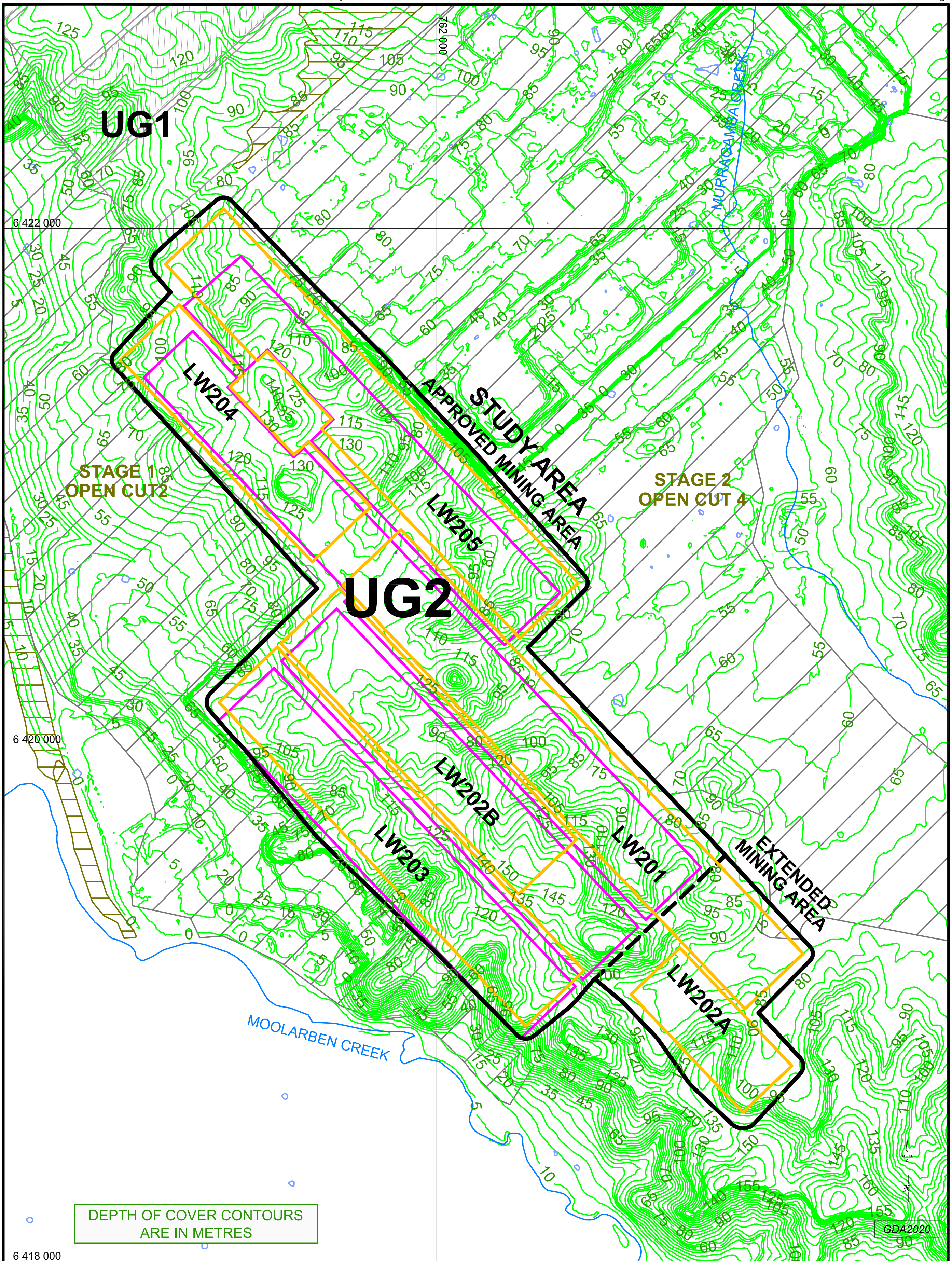

LEGEND

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STAGE 1
OPEN CUT3

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DEPTH OF COVER CONTOURS

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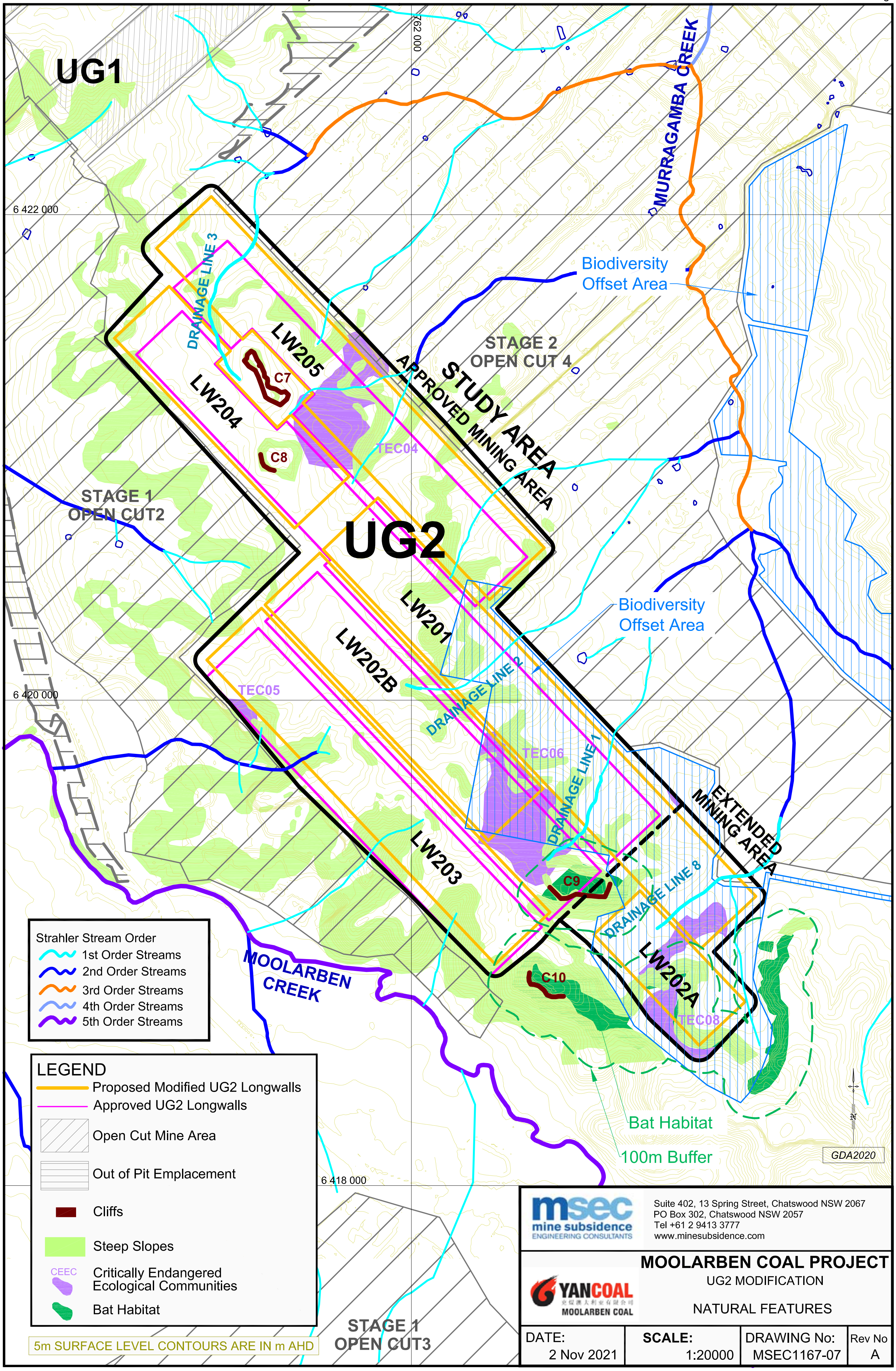
I:\Projects\Moolarben\MSEC1167 - UG2 Modification Subsidence Assessment\AcadData\MSEC1167-07 Natural Features.dwg



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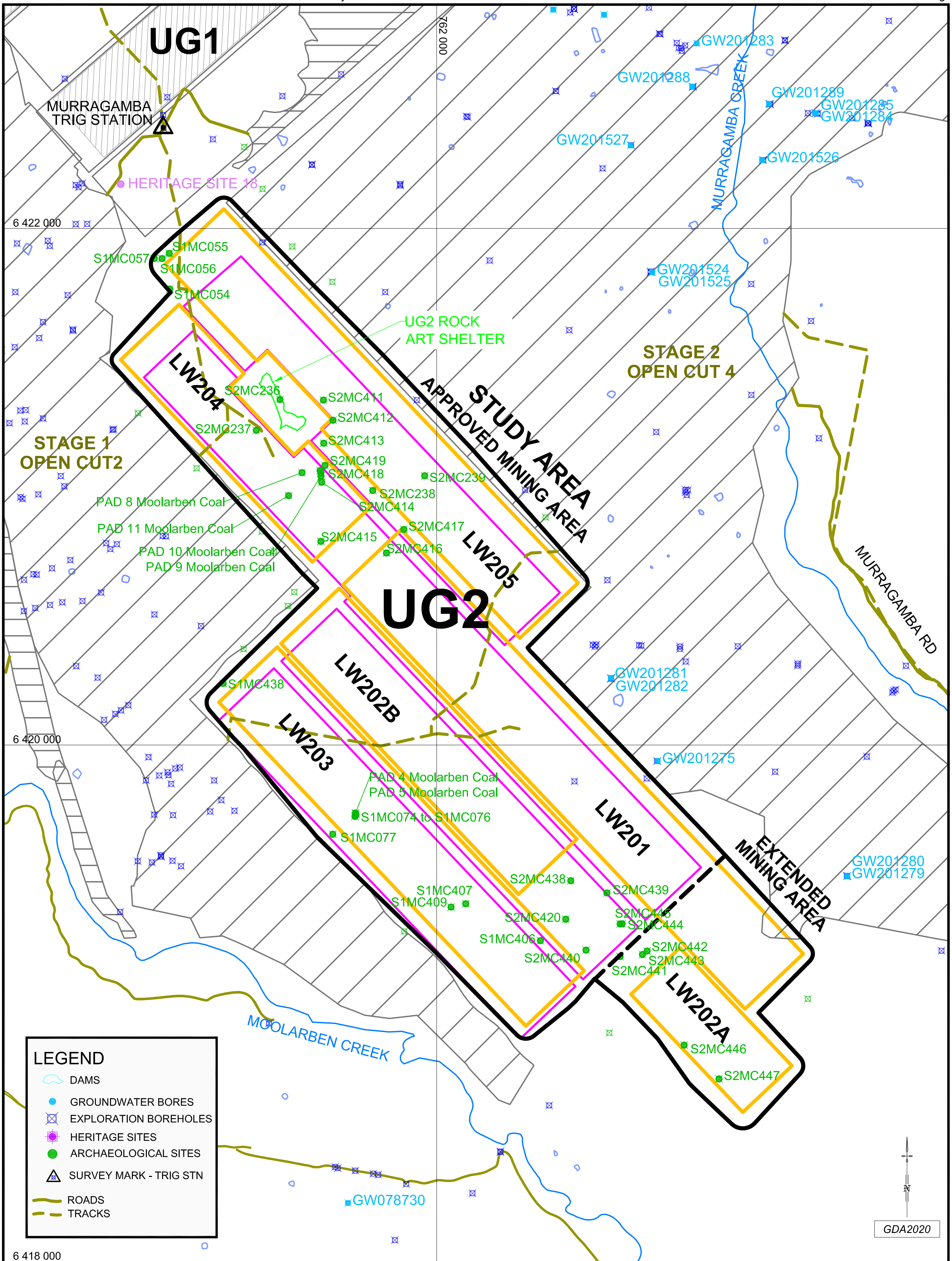

LEGEND

Proposed Modified UG2 Longwalls

Approved UG2 Longwalls

Open Cut Mine Area

Out of Pit Emplacement

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BUILT FEATURES

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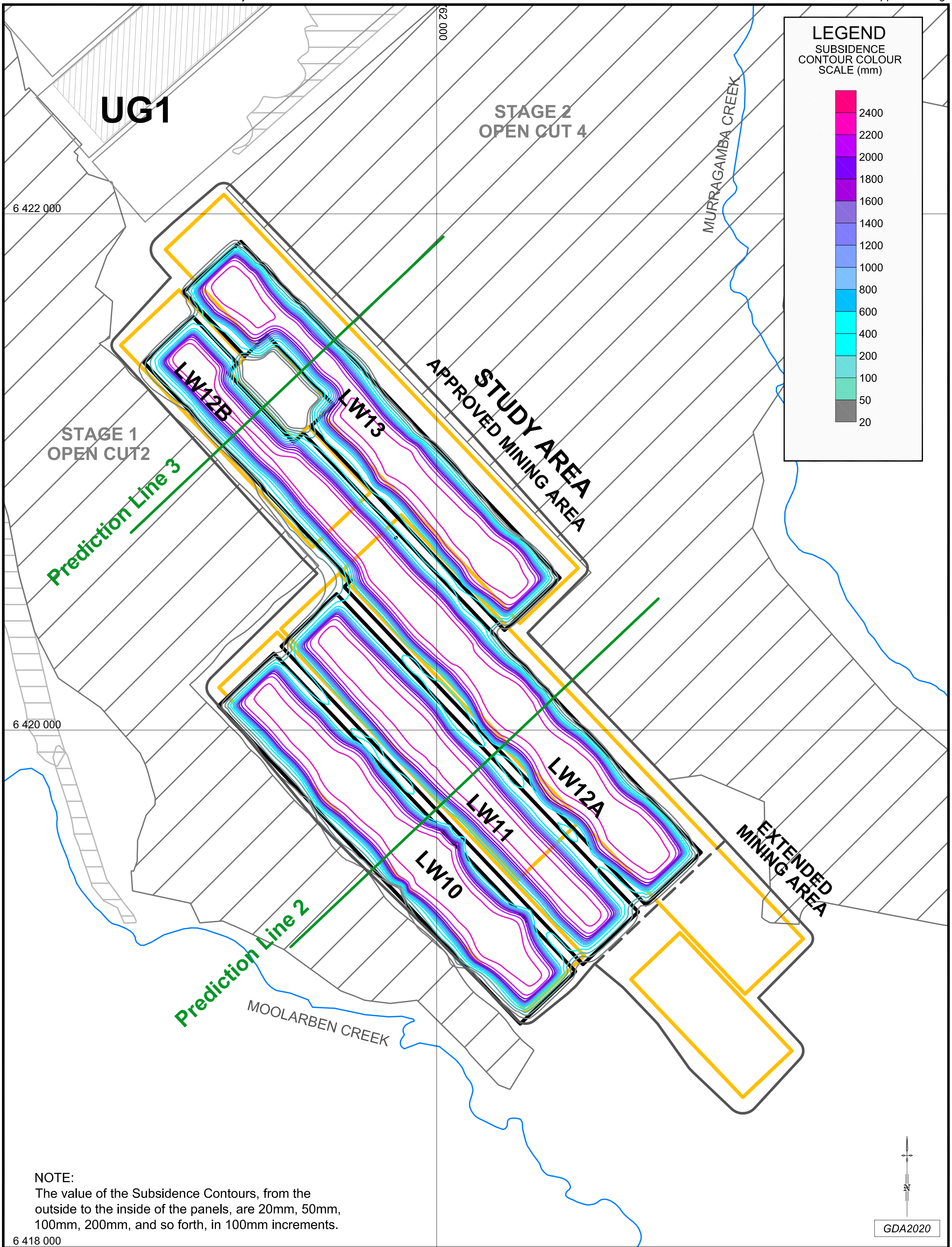

NOTE:
The value of the Subsidence Contours, from the outside to the inside of the panels, are 20mm, 50mm, 100mm, 200mm, and so forth, in 100mm increments.

LEGEND
- Proposed Modified UG2 Longwalls
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PREDICTED TOTAL SUBSIDENCE CONTOURS AFTER APPROVED LAYOUT

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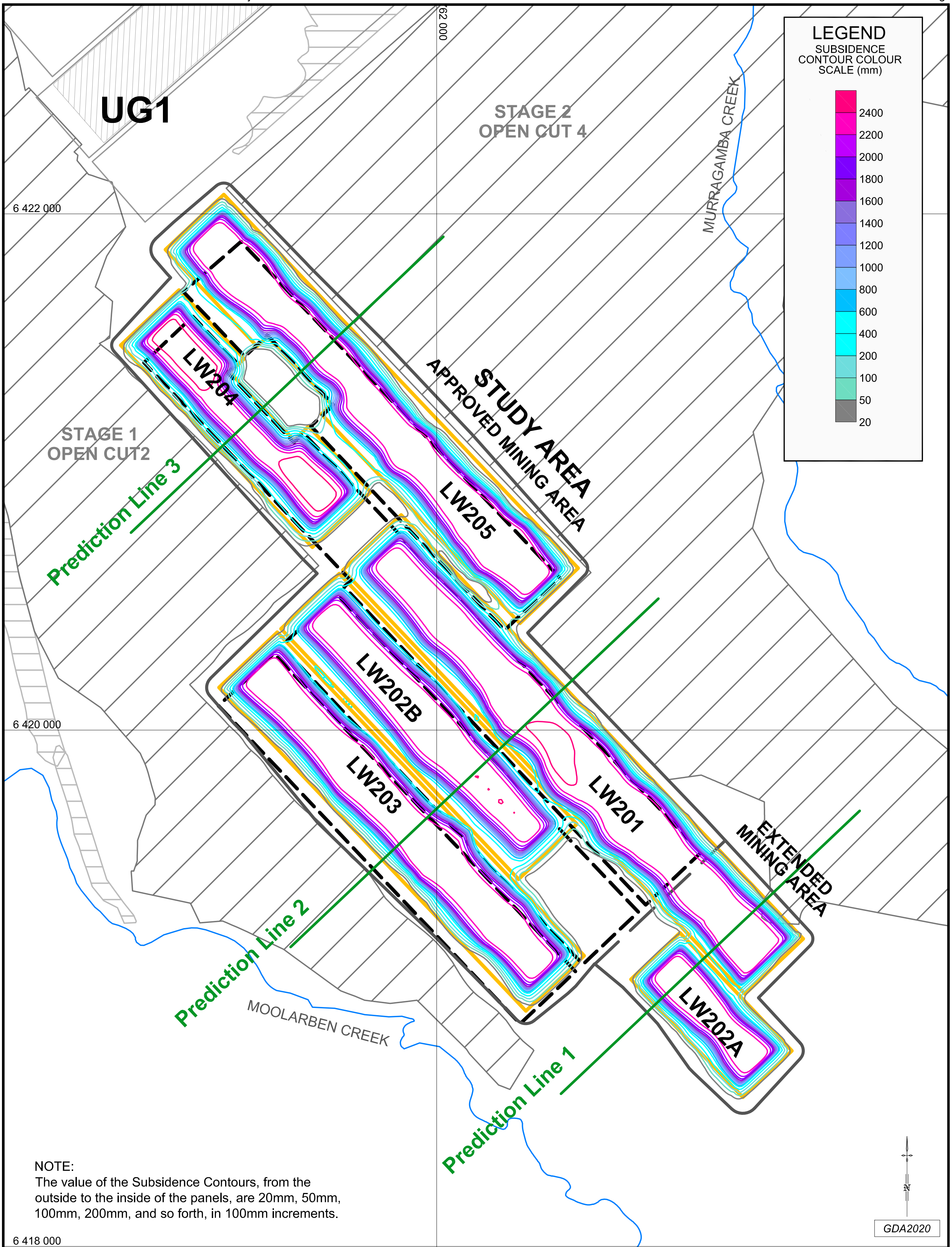
2 Nov 2021	1:20000	MSEC1167-09	A

I:\Projects\Moolarben\MSEC1167 - UG2 Modification Subsidence Assessment\AcadData\MSEC1167-10 Pred Total Subs due to Modified.dwg



LEGEND

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