REPORT: SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

MOOLARBEN COAL COMPLEX:

Moolarben Project Stage 1 – Longwalls 401 to 408

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

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Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

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

Project Approval (05_0117) has been subject to 15 approved modifications with Modification 15 granted in June 2020. The *Approved Layout* extent is consistent with the Project Approval (05_0117), as modified, with an extraction height of 3.0m.

The MCC includes four approved open cut mines, (known as Open Cut 1 mine (OC1), Open Cut 2 mine (OC2), Open Cut 3 mine (OC3) and Open Cut 4 mine (OC4)), and three approved underground mines, (known as Underground Area 1 (UG1), Underground Area 2 (UG2) and Underground Area 4 (UG4)) and the associated infrastructure.

MCO commenced open cut coal mining from OC1 in May 2010 and underground mining in UG1 in 2016, and are currently preparing for commencement of underground longwall mining operations in UG4. MCO is now preparing an Extraction Plan for the extraction of Longwalls 401 to 408 within UG4. The layout of Longwalls 401 to 408 that incorporates minor shortening of lengths of extraction is referred to as the *Extraction Plan Layout* in this report.

The locations of the approved MCC open cut mines and underground mines, including the UG4, are shown in Drawing No. MSEC1165-01, which together with all other drawings is included in Appendix E.

Mine Subsidence Engineering Consultants (MSEC) has prepared this subsidence report to support the Extraction Plan for Longwalls 401 to 408. The predictions and impact assessments provided in this report are based on the Extraction Plan Layout, as shown in Drawing No. MSEC1165-02. The report includes a comparison to the subsidence predictions of the *Approved Layout*. As the assumed extraction height of the *Approved Layout* has been reduced to 3.0m, the subsidence predictions will be less than that assessed as part of the Stage 1 Project Approval.

The Study Area has been defined, as a minimum, as the surface area enclosed by a 26.5° angle of draw line from the extents of secondary extraction and by the predicted total 20 mm subsidence contour based on the Extraction Plan Layout and Approved Layout. Other features which could be subjected to far-field or valley related movements and could be sensitive to such movements have also been assessed in this report.

A number of natural and built features have been identified within or in the vicinity of the Study Area including: Bora Creek, Goulburn River and ephemeral drainage lines; cliffs; the Goulburn River National Park; Sandy Hollow – Gulgong Railway Line; roads; unsealed tracks and trails; electrical and telecommunications infrastructure; dams; a quarry; bores; mine infrastructure; exploration drill holes; archaeological sites; and survey control marks.

The maximum predicted total conventional subsidence based on the Extraction Plan Layout is 1,900 mm. The maximum predicted total conventional tilt based on the Extraction Plan Layout is 60 mm/m. The maximum predicted total systematic curvature based on the Extraction Plan Layout is greater than 3 km^{-1} for both hogging and sagging curvature. The maximum predicted conventional subsidence parameters based on the Extraction Plan Layout are the same as those based on the Approved Layout.

The predicted levels of subsidence, tilt, curvature and strain that are expected to be experienced at the natural features and items of surface infrastructure vary depending on their positions in relation to the Extraction Plan Layout and Approved Layout. The proposed panel and pillar widths for the Extraction Plan Layout and Approved Layout are unchanged and minor changes are proposed to the commencing and finishing ends of the longwalls. Hence there are some locations near the ends of the longwalls where slightly reduced levels of subsidence, tilt, curvature and strain are now expected and some locations where slightly increased levels of subsidence, tilt, curvature and strain are expected. Generally, the maximum predicted subsidence parameters at the surface features are similar for the Extraction Plan Layout and Approved Layout.

Aboriginal heritage sites 264, 282, 283, 286 and 287 are located at, or outside the Study, Area and the likelihood of impacts to these features is considered to be very low. Site 280 includes a rock shelter with art, artefacts and grinding grooves and is located centrally above the chain pillar between Longwalls 402 and 403. The risk of subsidence impacts to Site 280 is low to moderate consistent with the approved impacts, and includes tensile cracks and instabilities. Large scale failure of the rock shelter is not expected to occur and the likelihood of tensile cracks coinciding with the location of the grinding grooves and art is considered to be low.

The majority of the built features are located outside the Study Area and the predictions and impact assessments generally do not change based on the Extraction Plan Layout.

This report is structured as follows:

Chapter 1 provides an introduction and information on the mine layout, surface topography, seam and geological information.

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

Chapter 3 provides an overview of the methods that have been used to predict the mine subsidence movements resulting from the extraction of the proposed and approved longwalls.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of the Approved Layout and Extraction Plan Layout.

Chapters 5 to 10 provide the descriptions, predictions and impact assessments for each of the natural and built features which have been identified within the Study Area. Recommendations for each of these features are also provided, which have been based on the predictions and impact assessments.

The overall findings of the subsidence predictions and impact assessments that have been undertaken by MSEC for this report due to the Extraction Plan Layout are that the levels of ground movements, and any potential impacts to the identified natural features and built infrastructure can be managed to maintain safety and serviceability by the preparation and implementation of Management Plans for the features.

Monitoring and management strategies will be developed for the identified natural features as part of the Extraction Plan process for Longwalls 401 to 408 based on the Extraction Plan Layout.

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

It should also be noted that more detailed assessments on some natural features and items of surface infrastructure have been undertaken by other consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

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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.

1.0 INTRODUCTION

1.1. Background

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

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The MCC includes four approved open cut mines, (known as Open Cut 1 mine (OC1), Open Cut 2 mine (OC2), Open Cut 3 mine (OC3) and Open Cut 4 mine (OC4)), and three approved underground mines, (known as Underground Area 1 (UG1), Underground Area 2 (UG2) and Underground Area 4 (UG4)) and the associated infrastructure.

MCO commenced open cut coal mining from OC1 in May 2010, and underground mining in UG1 in 2016, and are currently preparing for commencement of underground longwall mining operations in UG4. MCO is now preparing an Extraction Plan for the extraction of Longwalls 401 to 408 within UG4. The layout of Longwalls 401 to 408 that incorporates minor shortening of lengths of extraction is referred to as the *Extraction Plan Layout* in this report. The report includes a comparison to the subsidence predictions of the *Approved Layout*. As the assumed extraction height of the *Approved Layout* has been reduced to 3.0m, the subsidence predictions will be less than that assessed as part of the Stage 1 Project Approval.

The locations of the approved MCC open cut mines and underground mines, including the UG4, are shown in Drawing No. MSEC1165-01, which together with all other drawings is included in Appendix E. This regional drawing also shows the locations of the adjoining Ulan Coal Mine (UCM), Wilpinjong Coal Mine, Goulburn River National Park, Munghorn Gap Nature Reserve and Sandy Hollow Gulgong Railway Line.

The following subsidence reports were prepared to provide the necessary mine subsidence predictions and subsidence impact assessments for the project approval for Stage 1 of the MCP:

- Strata Engineering, Mine Subsidence Impact Assessment for the Proposed Longwall Panels LWs 1 to 14, No. 4 Underground Area, Moolarben Coal Project, Report No. 04-001-WHT/1 Rev D, 7th September 2006, Moolarben Coal Project Appendix 8 Subsidence Impact Assessment;
- Strata Engineering, Preferred Project Report for the Proposed Longwalls 1 to 14 in the No. 4 Underground Area, Moolarben (Stage 1), Report No. 06-002-WHT/1, 1st December 2006, Moolarben Coal Project Response to Submissions Appendix A8 Subsidence Response; and
- Mine Subsidence Engineering Consultants, Supplementary Notes on Predictions of Subsidence, Valley Upsidence and Closure and Impacts of Subsidence, Upsidence and Closure on the Goulburn River and Cliff Lines, Based on the Preferred Project Mine Layout, Report No. MSEC287 Rev D, November 2006, Moolarben Coal Project Response to Submissions Appendix A9 Valley Closure.

Mine Subsidence Engineering Consultants (MSEC) has prepared this subsidence report to support the Extraction Plan for Longwalls 401 to 408. The predictions and impact assessments provided in this report are based on the Extraction Plan Layout, as shown in Drawing No. MSEC1165-02.

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

Chapter 3 provides an overview of the methods that have been used to predict the mine subsidence movements resulting from the extraction of the proposed and approved longwalls.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of the Approved Layout and Extraction Plan Layout.

Chapters 5 and 6 provide the descriptions, predictions and impact assessments for each of the natural and built features which have been identified within the Study Area. Recommendations for each of these features are also provided, which have been based on the predictions and impact assessments.

The Extraction Plan Layout and Study Area Boundary, as defined in Section 2.1, have been overlaid on an orthophoto of the area, which is shown in Fig. 1.1.

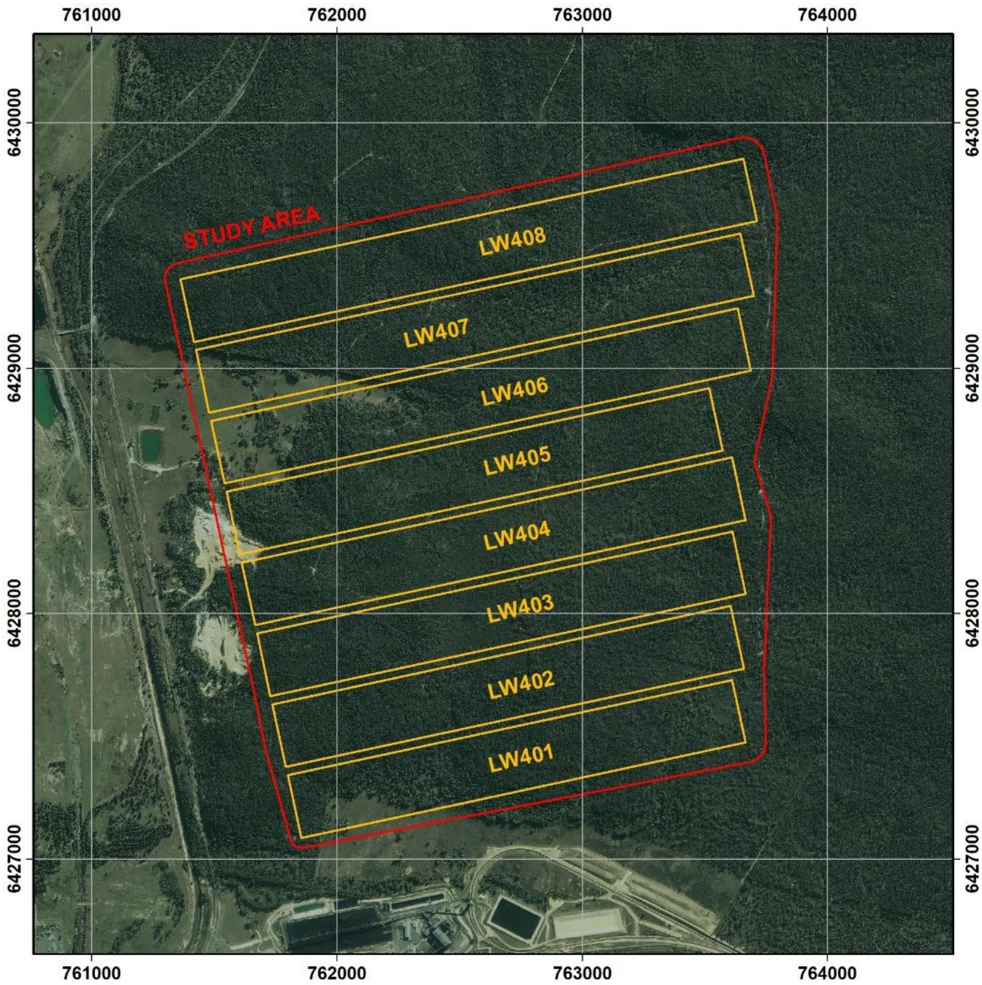

Fig. 1.1 Aerial Photograph Showing Location of Extraction Plan Layout and the Study Area

1.2. Mining Geometry

The layout of Longwalls 401 to 408 is shown in Drawing No. MSEC1165-01 in Appendix E. Longwall lengths based on the Extraction Plan Layout are slightly shorter than those based on the Approved Layout. The lengths have been shortened from 10 m (LW401) to 85 m (LW405). With the exception of the shortened lengths, the longwall geometry for the Extraction Plan Layout is the same as that for the Approved Layout. A summary of the longwall dimensions is provided in Table 1.1.

Table 1.1 Geometry of the Longwalls 401 to 408 based on the Extraction Plan Layout

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
LW401	1854	260	-
LW402	1912	260	35
LW403	1982	260	35
LW404	2046	260	35
LW405	2014	260	35
LW406	2196	260	35
LW407	2271	260	35
LW408	2348	260	35

1.3. Surface Topography and Seam Information

The surface level contours are shown in Drawing No. MSEC1165-03. The surface levels directly above the proposed longwalls in the Extraction Plan Layout vary from a high point of 500 m above Australian Height Datum (mAHD) above the commencing (eastern) end of Longwall 404 to a low point of 405 mAHD above finishing end of Longwall 407.

The seam floor contours, seam thickness contours and depth of cover contours for the Ulan Seam (DWS) are shown in Drawings Nos. MSEC1165-04, MSEC1165-05, and MSEC1165-06, respectively. The contours are based on the latest seam information provided by MCO.

The depth of cover to the Ulan Seam above these longwalls varies between a minimum of 83 m at the finishing end of LW401 and 407, and a maximum of 205 m at the commencing end of LW404.

The seam floor within the mining area generally dips from the south-west towards the north-east. The average dip of the seam within the extents of the proposed longwalls is around 1.6 %. The thickness of the Ulan Seam (DWS) within the extents of the proposed longwalls varies between 2.8 m and 3.2 m. The proposed mining height for the longwalls is 3.0 m.

The variations in the surface and seam levels across the mining area are illustrated along Prediction Line 1 Fig. 1.2. The location of the prediction line is shown in Drawing No. MSEC1165-09.

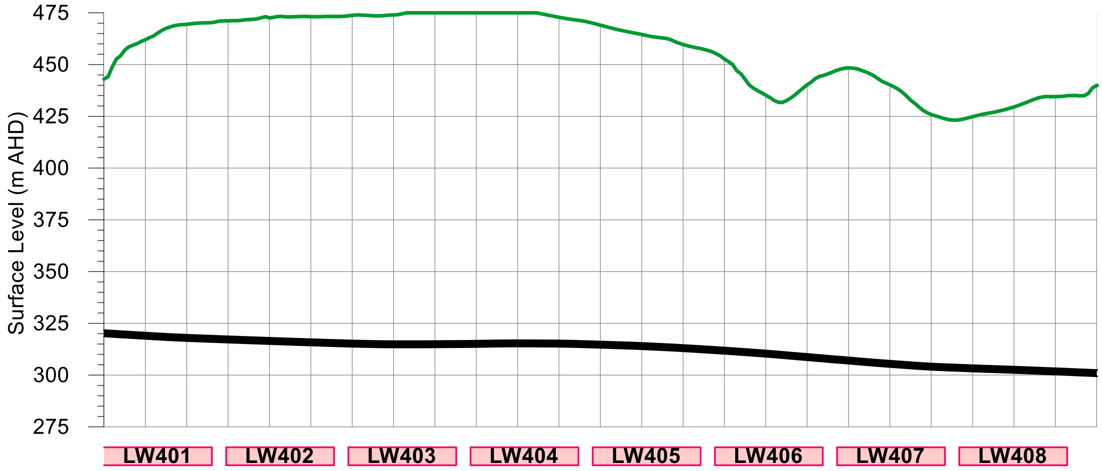

Fig. 1.2 Surface and Seam Levels along Prediction Line 1

1.4. Geological Details

The surface lithology in the vicinity of the UG4 is shown in Fig. 1.3.

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

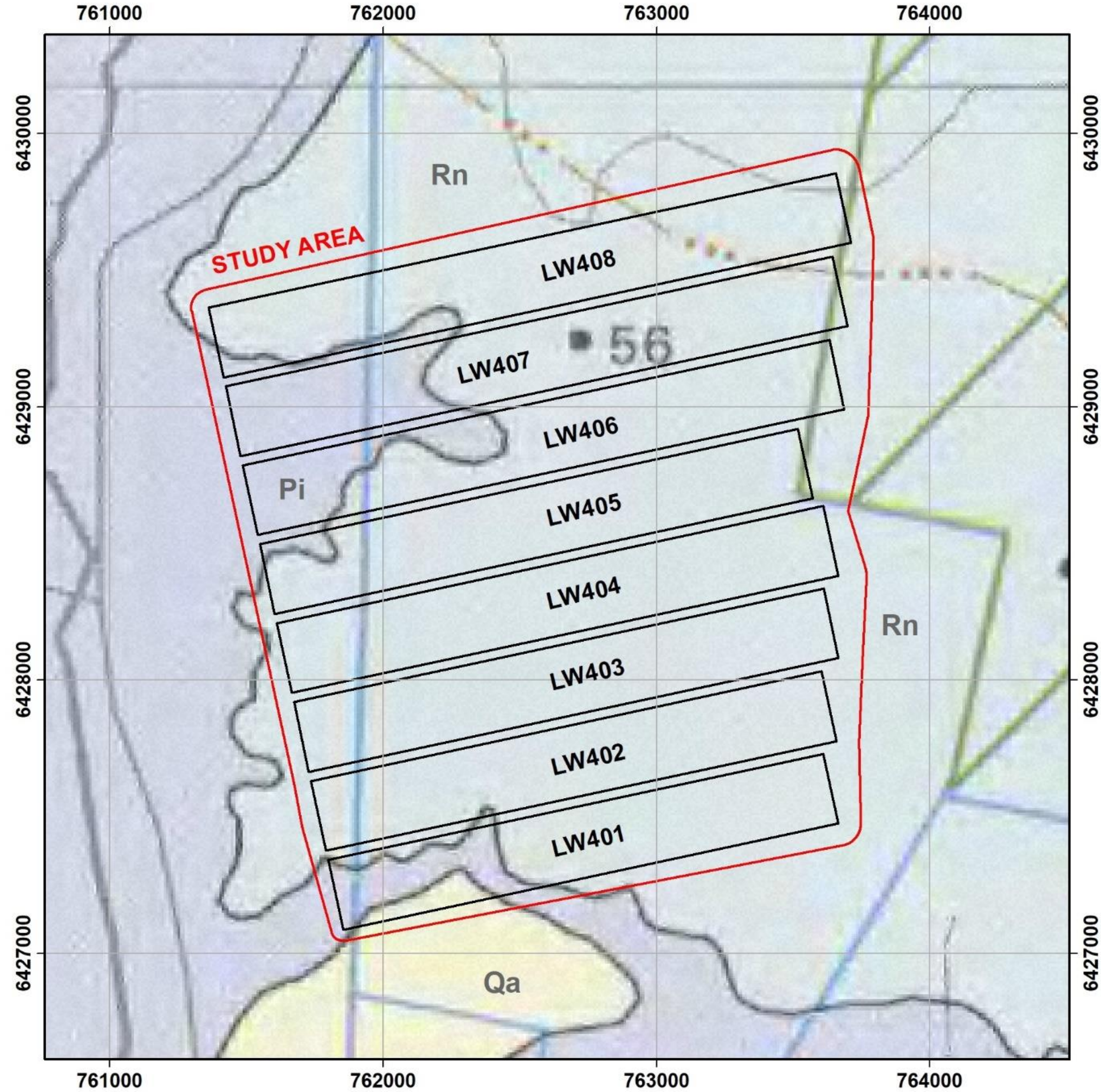

Fig. 1.3 Surface Geological Map Showing Longwall 401 to 408 and the Study Area
(Source-1:100000 Western Coalfield Map)

As can be seen in this figure the surface geology of most of the areas over the UG4 is predominantly units from the Narrabeen Group Sandstones and Conglomerates, (Rn), which are coloured in a light green hatching. These units overlie areas, which are hatched in a violet colour, that indicates the surface geology around the longwalls are from the Illawarra Coal Measures (Pi). A small area of Alluvials (Qa) is located at the southern end of Longwall 401.

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

1.4.1. Lithology

The major geological units in the UG4 Study Area are, from the youngest to oldest:-

- Tertiary aged 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.

Tertiary alluvial palaeochannel deposits, with a maximum thickness of 40-50 m, have been identified and described in Australasian Groundwater & Environmental Consultants (2021) to the south of the proposed UG4 longwalls, as shown in Drawing No. MSEC1165-06. The infill sediments consist of poorly-sorted semi-consolidated quartzose sands and gravels in a clayey matrix.

The Triassic sandstone, known as Wollar Sandstone, is part of the Narrabeen Group and this sandstone unit is the main outcropping rock formation over the UG4 Study Area. Where present, the sandstones are between 14 metres and 70 metres thick and normally about 60 m with both massive and strongly cross-bedded units of individual thickness in the range of 1.5 metres to 3 metres.

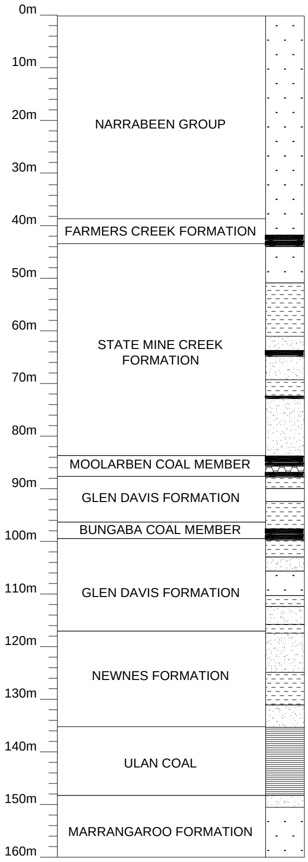

Fig. 1.4 Stratigraphic Column (based on WMLB117)

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

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

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

2.1. Definition of the Study Area

The Study Area is defined as the surface area that is likely to be affected by the proposed mining of Longwalls 401 to 408 (*Extraction Plan 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;
- The predicted vertical limit of subsidence, taken as the 20 mm subsidence contour; and
- Features sensitive to far-field movements.

As the depth of cover above the longwalls varies between 83 and 205 m, the 26.5° angle of draw line has been conservatively determined by drawing a line around the outer edge of the longwall voids at a horizontal distance that varies between 42 and 103 m.

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

The 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. MSEC1165-01. The predicted total 20 mm subsidence contour line resulting from the extraction of Longwalls 401 to 408 was found to be located entirely within the area bounded by the 26.5° angle of draw line.

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

- Sandy Hollow – Gulgong Railway Line;
- Electrical Infrastructure;
- Optical Fibre and Copper Cables;
- Roads;
- Survey Control Marks; and
- Ulan Coal Mine Infrastructure.

2.2. Natural and Built Features within the Study Area

A number of the 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 Durridgere 88331S. The proposed longwalls and the Study Area have been overlaid on an extract of this CMA map in Fig. 2.1.

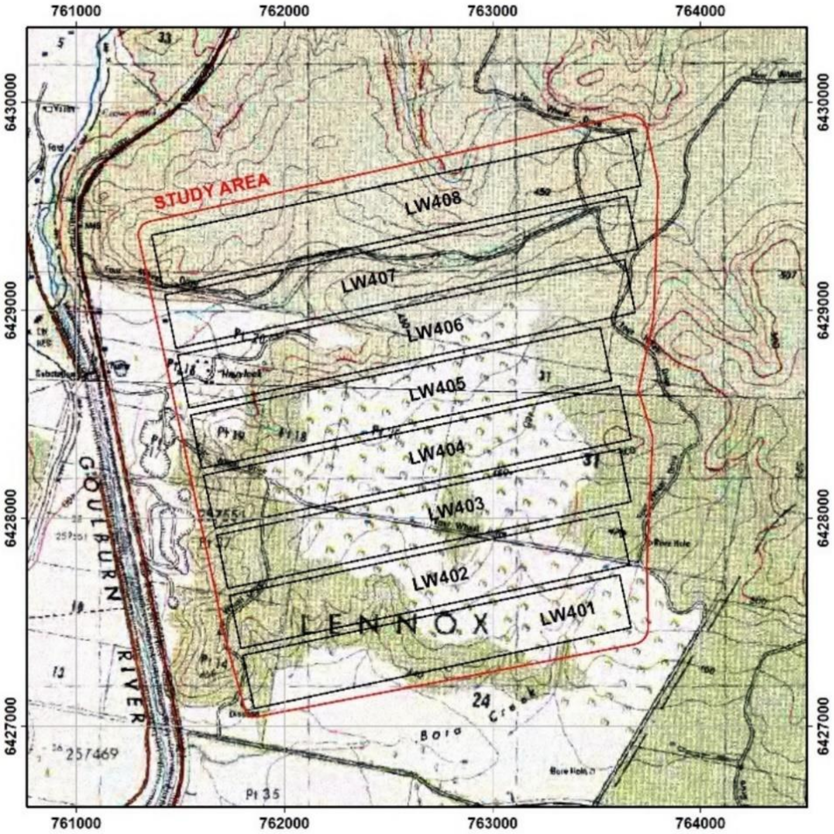

Fig. 2.1 Topographic Map Showing Longwalls 401 to 408 and the Study Area (source: CMA Map No. Durridgere 88331S)

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. MSEC1165-07 and MSEC1165-08, 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
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	×	
Streams	✓	5.2 & 5.3
Aquifers or Known Groundwater Resources	✓	5.5
Springs or Groundwater Seeps	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.6
Steep Slopes	✓	5.7
Escarpments	×	
Land Prone to Flooding or Inundation	✓	5.8
Swamps or Wetlands	×	
Water Related Ecosystems	×	
Threatened or Protected Species	✓	5.9 & 5.10
Lands Defined as Critical Habitat	×	
National Parks	✓	5.11
State Forests	×	
State Recreation or Conservation Areas	×	
Natural Vegetation	✓	5.12
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	✓	6.1
Roads (All Types)	✓	6.2 & 6.3
Bridges	✓	6.2
Tunnels	×	
Culverts	✓	6.2
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	✓	6.5
Telecommunication Lines or Associated Plants	✓	6.6
Water Tanks, Water or Sewage Treatment Works	×	
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
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	×	
Farm Buildings or Sheds	×	
Tanks	×	
Gas or Fuel Storages	×	
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	✓	8.1
Farm Dams	✓	8.2
Wells or Bores	✓	9.3
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	×	
Mine Related Infrastructure Including Exploration Bores and Gas Wells	✓	9.2, 9.3 & 9.4
Any Other Industrial, Commercial or Business Features	✓	9.1
AREAS OF ARCHAEOLOGICAL SIGNIFICANCE	✓	10.1
AREAS OF HISTORICAL SIGNIFICANCE	×	
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	✓	6.5

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

3.1. Introduction

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

3.2. Overview of Conventional Subsidence Parameters

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

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.

- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.

- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/km (km^{-1})*, but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *km (km)*.

- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile Strains** occur where the distance between two points increases and **Compressive Strains** occur when the distance between two points decreases. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

  Whilst mining induced normal strains are measured along monitoring lines, ground shearing can also occur both vertically and horizontally across the directions of monitoring lines. Most of the published mine subsidence literature discusses the differential ground movements that are measured along subsidence monitoring lines, however, differential ground movements can also be measured across monitoring lines using 3D survey monitoring techniques.

- **Horizontal shear deformation** across monitoring lines can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. It is not possible, however, to determine the horizontal shear strain across a monitoring line using 2D or 3D monitoring techniques.

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

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

3.3. Far-field Movements

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

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

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

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

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

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

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

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

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

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

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

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

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

3.4.2. Non-conventional Subsidence Movements due to Steep Topography

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

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 systematic subsidence movements are typically much larger than those observed in the Southern Coalfield, which tend to mask any smaller valley related movements which may occur.

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

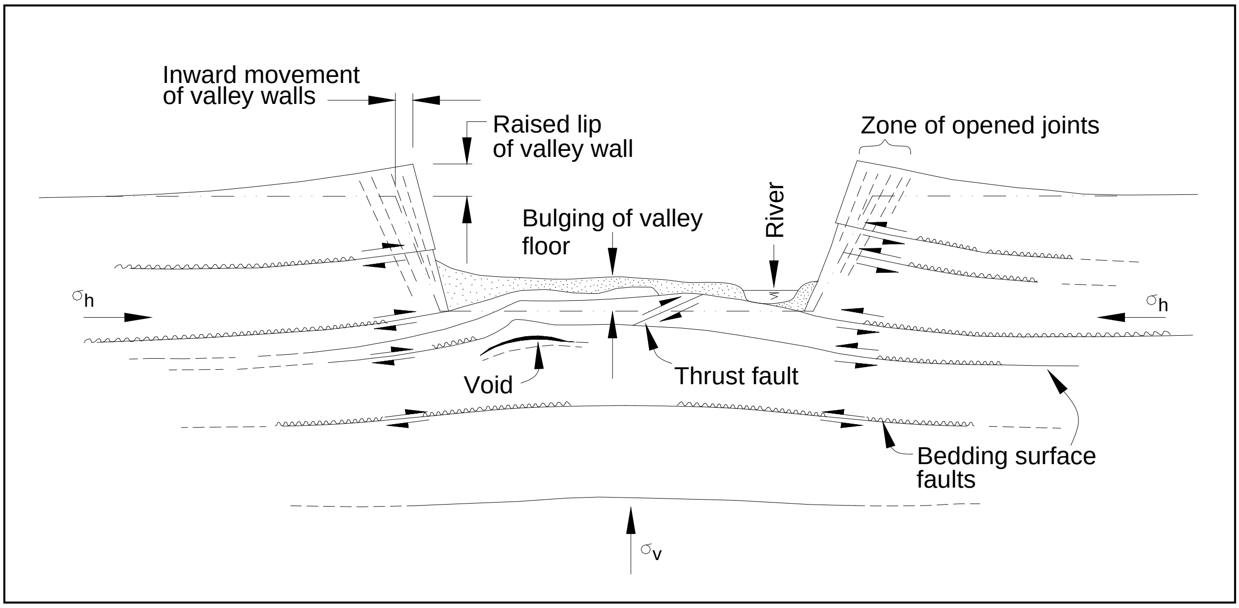

Fig. 3.1 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

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

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

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

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

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 streams above the Approved and Extraction Plan Layouts are unlikely to experience noticeable mining induced valley related movements, (valley closure movements and upsidence in the floors of valleys), because of the relatively shallow depths of cover over these longwalls.

3.5. The Incremental Profile Method

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

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

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

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

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

3.6. Calibration and Testing of the Incremental Profile Method

Initial predicted conventional subsidence parameters that were provided in previous reports for MCC longwalls at Moolarben in 2009 were determined based on the standard IPM model for the Hunter, Newcastle and Western Coalfields, after applying some local calibrations that were determined to 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 a review of the overburden geology 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 Longwalls 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 Longwalls 101 to 105. Monitoring to date shows a maximum observed subsidence of 79% of the predicted maximum subsidence, which equates to between approximately 55% and 60% of the modelled seam thickness for a single panel. A graph showing predicted and observed subsidence, tilt and strain for Longwalls 101 to 103 is show in Fig. 3.2 for the main cross line above Longwalls 101 to 105 in UG1.

Borehole logs for the MCC indicate the presence of thicker or massive units with UG4. The units vary in thickness from less than 10m to greater than 30 m and are likely to be absent in some locations. The thicker units have a greater potential to bulk and span and hence reduce the magnitude of subsidence above the mined panels. Given the broader extent of thicker or massive units, it is considered that a maximum incremental subsidence of 60% of the extracted seam thickness is appropriate for modelling and assessment of subsidence parameters for UG4.

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

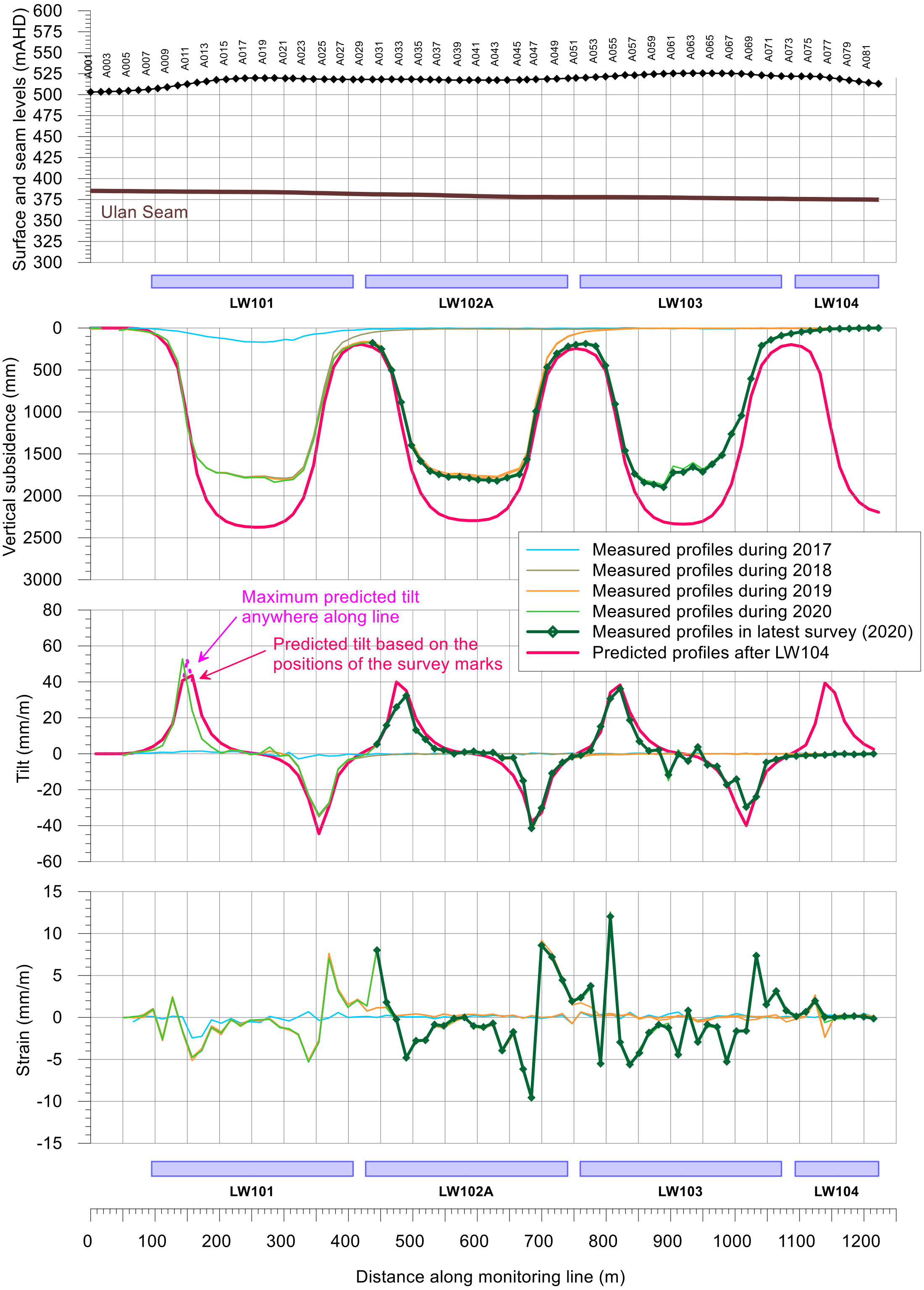

Fig. 3.2 Measured and predicted vertical subsidence, tilt and strain along the A Line

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of Longwalls 401 to 408. The predicted subsidence parameters and the impact assessments for the natural and built features are provided in Chapters 5 to 11.

It should be noted that the predicted conventional subsidence parameters were obtained using the Incremental Profile Method, which was calibrated to local conditions based on the available monitoring data as discussed in Section 3.6.

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

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

The maximum predicted conventional subsidence parameters resulting from the extraction of Longwalls 401 to 408 were determined using the calibrated Incremental Profile Method. The predicted subsidence contours are irregular due to the shallow depths of cover. The maximum predicted tilts and curvatures are very localised and therefore do not necessarily represent the overall (i.e. macro) ground movements. The magnitudes of the localised tilts greater than 100 mm/m and the localised curvatures greater than 3.0 km^{-1} become less meaningful and, therefore, the specific values have not been presented. Revised standards for reporting adopted by MSEC may result in slight differences in reported values compared with previous reports.

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

Table 4.1 Maximum Predicted Incremental Conventional Subsidence, Tilt and Curvature Resulting from the Extraction of Each of the Longwalls 401 to 408

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})
LW401	1800	60	> 3.0	> 3.0
LW402	1800	40	1.9	1.3
LW403	1800	35	1.5	1.2
LW404	1800	40	1.7	1.4
LW405	1800	45	2.4	2.1
LW406	1800	60	> 3.0	> 3.0
LW407	1800	60	> 3.0	> 3.0
LW408	1800	45	2.6	1.6

The predicted total conventional subsidence contours, resulting from the extraction of Longwalls 401 to 408 are shown in Drawing No. MSEC1165-09. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature, after the extraction of each of the longwalls based on the Extraction Plan Layout, is provided in Table 4.2. The predicted tilts provided in this table are the maxima after the completion of each of the longwalls. The predicted curvatures are the maxima at any time during or after the extraction of each of the longwalls.

Table 4.2 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature after the Extraction of Each of the Longwalls 401 to 408

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})
LW401	1800	60	> 3.0	> 3.0
LW402	1900	60	> 3.0	> 3.0
LW403	1900	60	> 3.0	> 3.0
LW404	1900	60	> 3.0	> 3.0
LW405	1900	60	> 3.0	> 3.0
LW406	1900	60	> 3.0	> 3.0
LW407	1900	60	> 3.0	> 3.0
LW408	1900	60	> 3.0	> 3.0

The maximum predicted total conventional tilt is 60 mm/m (i.e. > 6 %), which represents a change in grade greater than 1 in 17. 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 profiles of conventional subsidence, tilt and curvature have been determined along Prediction Line 1, the location of which is shown in Drawing No. MSEC1165-09. The predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1, resulting from the extraction of Longwalls 401 to 408, are shown in Fig. C.01 in Appendix C. The predicted incremental profiles along the prediction line, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles along the prediction line, after the extraction of each of the longwalls based on the Extraction Plan Layout, are shown as solid blue lines. The predicted total profiles based on the Approved Layout are shown as the 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 Longwalls 401 to 408, based on the Extraction Plan Layout, with those based on the Approved Layout with a 3 m cutting height is provided in Table 4.3. The values are the maxima anywhere above the longwall layouts.

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

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Stage 1 EA Preferred Project Report (Strata Engineering 2006-2)	2440	96	> 3	> 3
Approved Layout	1900	60	> 3	> 3
Extraction Plan Layout	1900	60	> 3	> 3

It can be seen from the above table, that the maximum predicted total subsidence parameters based on the Approved Layout are the same as those for the Extraction Plan Layout for Longwalls 401 to 408. The maximum predicted total subsidence parameters based on the extraction plan layout are also less than the maximum predicted total subsidence parameters for Stage 1 EA project approval which are based on a cutting height of 4.2 m as outlined in the Preferred Project Report by Strata Engineering (2006-2). Whilst the specific values of the maximum curvatures are not shown, due to these representing the localised irregular movements rather than the macro (i.e. overall) movements, these parameters do not change.

4.4. Predicted Strains

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

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

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

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

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

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

Table 4.4 Comparison of the Mine Geometry for the Longwalls 401 to 408 with Longwalls in the Hunter, Newcastle and Western Coalfields used in the Strain Analysis

Parameter	Longwalls 401 to 408		Longwalls Used in Strain Analysis	
	Range	Average	Range	Average
Width	260	260	210 ~ 410	285
Depth of Cover	83 ~ 205	150	40 ~ 239	130
W/H Ratio	1.3 ~ 3.1	1.7	1.7 ~ 6.4	2.5
Extraction Height	3.0	3.0	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 slightly more than the range for Longwalls 401 to 408. 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 the same as the average extraction height for Longwalls 401 to 408. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains for the longwalls.

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

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

4.4.1. Analysis of Strains Measured in Survey Bays

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

Predictions of Strain Above Goaf

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

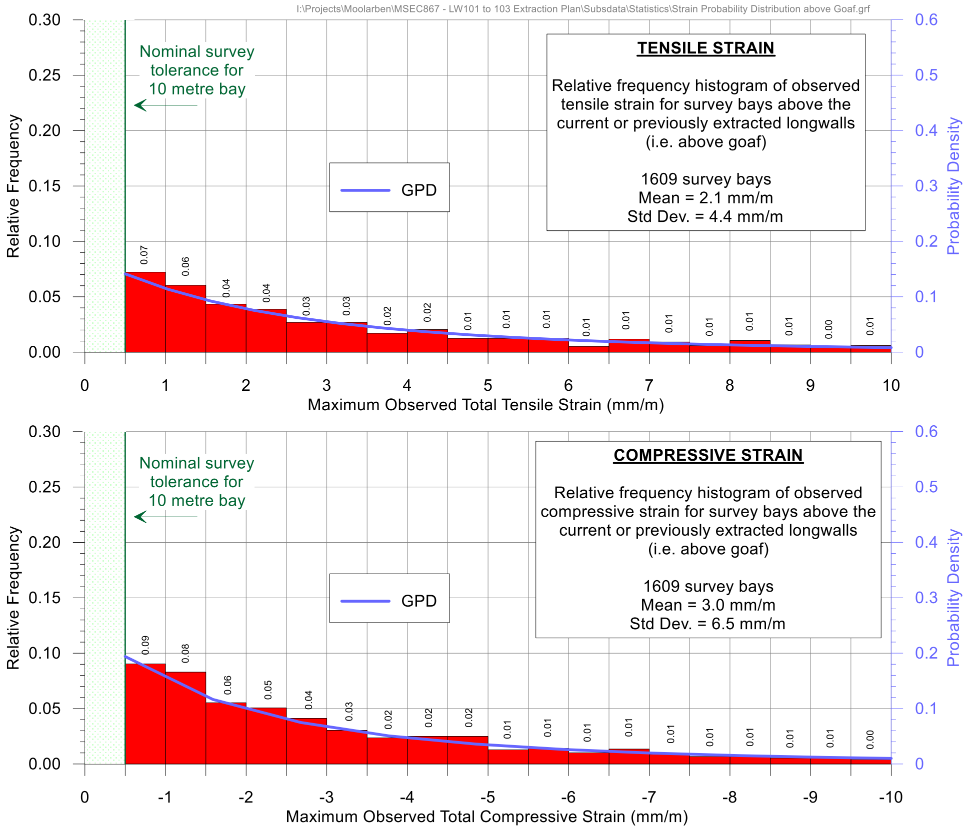

Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains in the Hunter, Newcastle and Western Coalfields for Longwalls having W/H Ratios between 1.7 and 6.4

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

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

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

It is noted, that these strains are based on monitoring data having an average width-to-depth ratio of 2.5 and, therefore, the strains above the longwalls are expected to be greater, on average, where the width-to-depth ratios are greater than 2.5 (i.e. depths of cover less than 105 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 105 m).

Predictions of Strain Above Solid Coal

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

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

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

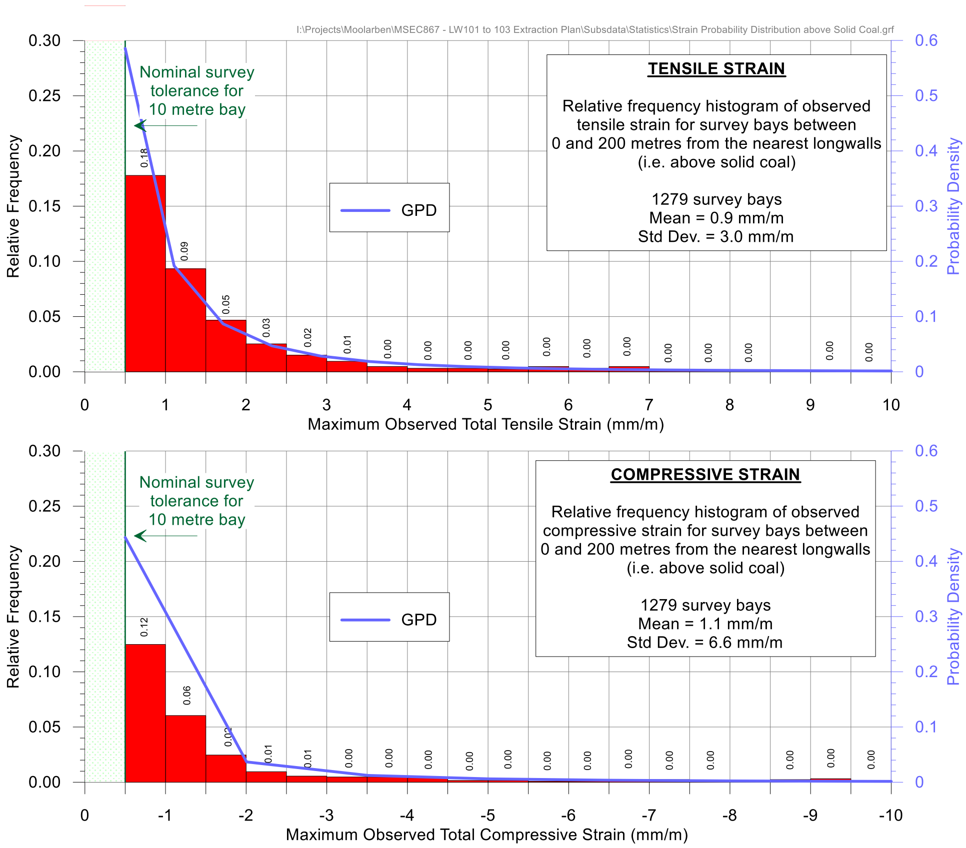

Fig. 4.2 Distributions of the Measured Maximum Tensile and Compressive Strains in the Hunter, Newcastle and Western Coalfields for Survey Bays located above Solid Coal within 200 m of the nearest longwall

Some surface features discussed in this report are located greater than 200 m from the Longwalls 401 to 408, including the railway line, transmission line and fibre optic cable. The survey database has been analysed to extract the maximum tensile and compressive strains that have been measured at any time during mining for survey bays that were located beyond the goaf edges of the mined panels and positioned on unmined areas of coal between 200 m and 600 m of the nearest longwall goaf edge.

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

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

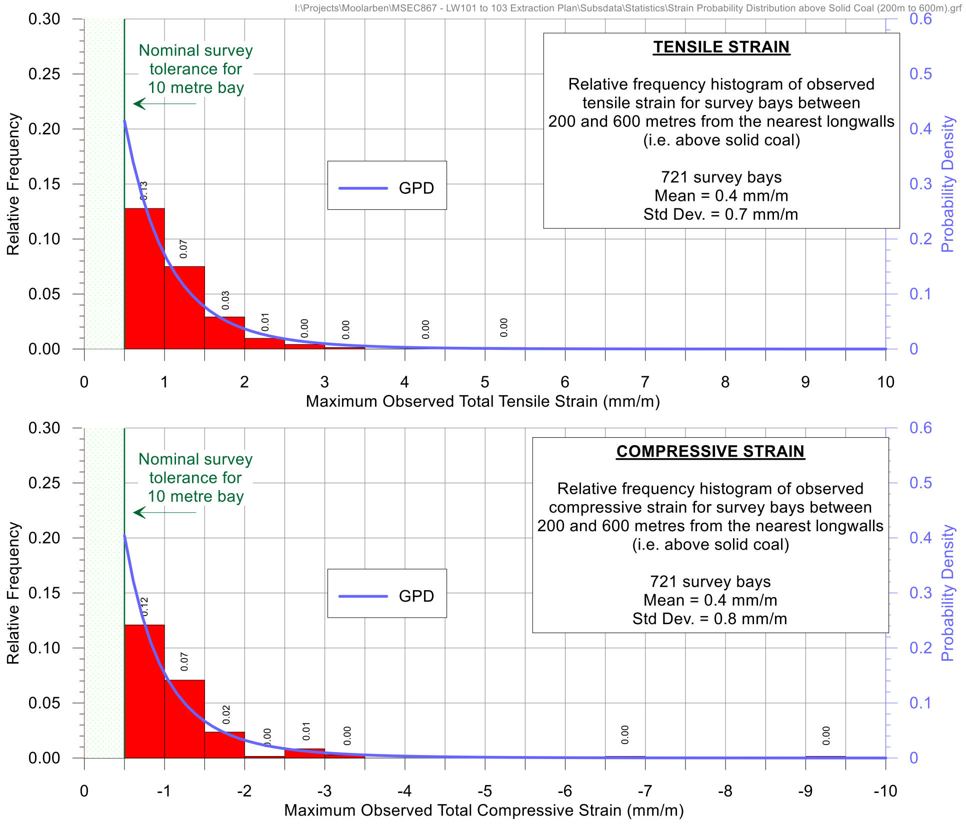

Fig. 4.3 Distributions of the Measured Maximum Tensile and Compressive Strains in the Hunter, Newcastle and Western Coalfields for Survey Bays located above Solid Coal between 200 m and 600 m of the nearest longwall

4.4.2. Analysis of Strains Measured Along Whole Monitoring Lines

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

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

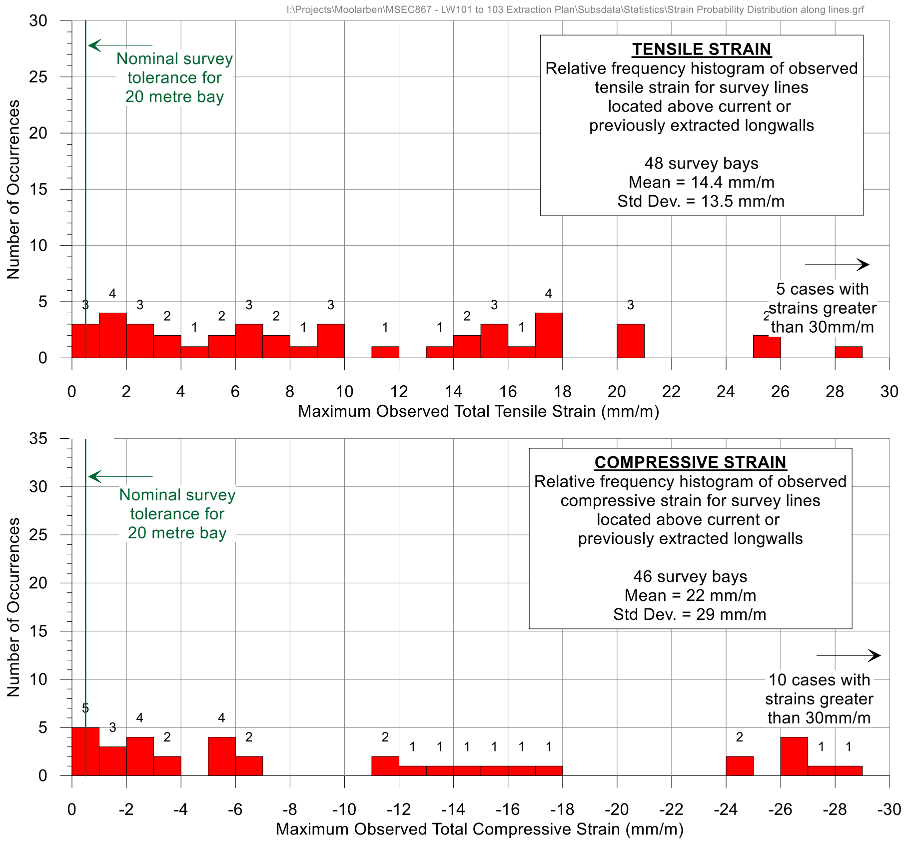

Fig. 4.4 Distributions of Measured Maximum Tensile and Compressive Strains Anywhere along the Monitoring Lines in the Hunter, Newcastle and Western Coalfields

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

4.5. Horizontal Movements

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

The maximum predicted total conventional tilt within the Study Area, at any time during or after the extraction of the longwalls, is greater than 60 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 600 mm, i.e. 60 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 400 mm.

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

4.6. Predicted Far-field Horizontal Movements

In addition to the conventional subsidence movements that have been predicted above and adjacent to Longwalls 401 to 408, it is also likely that far-field horizontal movements will be experienced during the extraction of the longwalls.

An empirical database of observed incremental far-field horizontal movements has been compiled using available monitoring data from the NSW Coalfields, but this database predominately includes measurements from the Southern Coalfield. The far-field horizontal movements are generally observed to be orientated towards the extracted longwall. At very low levels of far-field horizontal movements, however, there 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, Moolarben Mine and observed data from other regions where the depths of cover are also relatively shallow compared to the Southern Coalfield of NSW. The observed far-field horizontal movements in the database represent large variations in depth of cover from less than 50 m to greater than 600 m. In order to utilise the observed far-field horizontal data at the Moolarben Coal Complex where depth of cover is relatively shallow, the data has been plotted, as shown in Fig. 4.5, against the distances from the nearest edge of the incremental panel divided by the depth of cover. This plot excludes those cases where higher movements occurred because of multi-seam mining and valley closure effects.

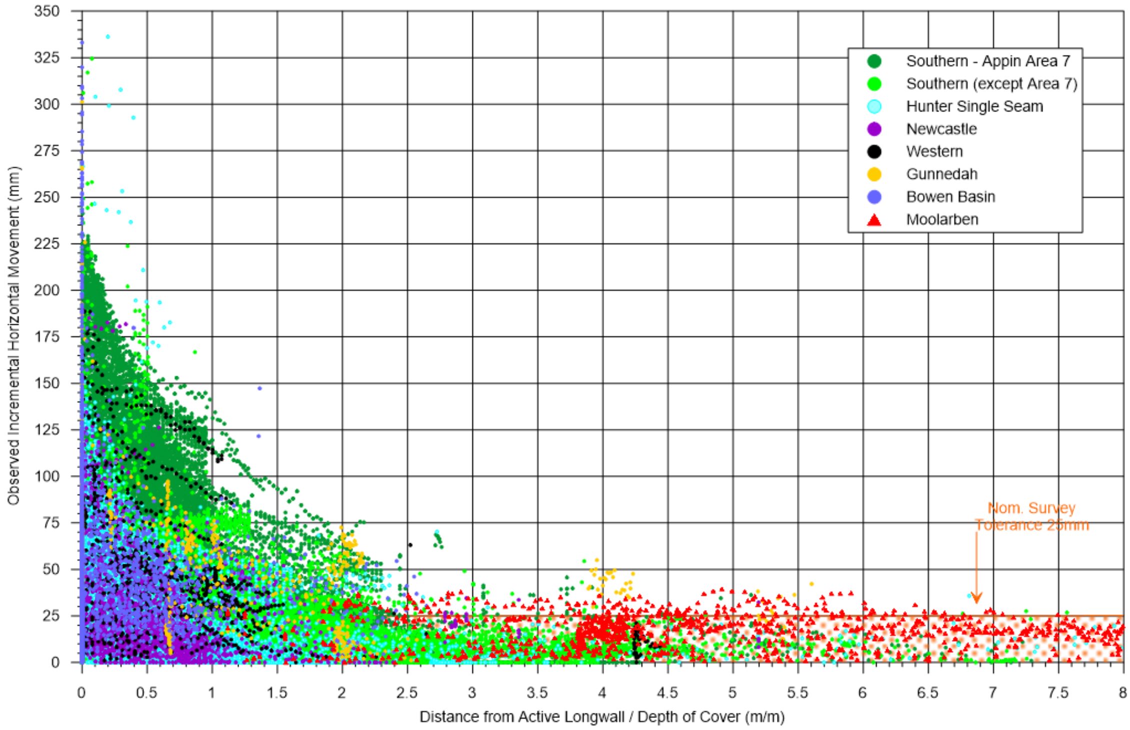

Fig. 4.5 Observed Incremental Far-Field Horizontal Movements (mm) from many regions in NSW versus the distance to the nearest edge of the mined panel divided by the depth of cover (m/m)

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

Monitoring lines located at surface features to the north east of UG1 have been surveyed since the commencement of Longwall 101. The observed far-field horizontal movements for Moolarben have been plotted on Fig. 4.5. It can be seen from Fig. 4.5 that the majority of the observed far-field horizontal movements at MCC are less than 25 mm. The maximum observed far-field horizontal movement is 40 mm.

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

4.6.1. Influence of Palaeochannel on Horizontal Far-field Movements

As detailed in Section 1.4.1 there are palaeochannel deposits, with a maximum thickness of 50-60 m, located to the south of Longwall 401, where the depths of cover range from 90 to 120 m. The palaeochannel deposits are described in Australasian Groundwater & Environmental Consultants 2021

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

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

At MCC the palaeochannel sediments to the south of the proposed UG4 longwalls were formed when Permian strata layers were replaced with infill sediments consisting of poorly-sorted semi-consolidated quartzose sands and gravels in a clayey matrix, i.e. unconsolidated sediments, unsaturated alluvium and low permeability clays. The presence of these palaeochannel materials can modify the subsidence ground movements beyond the end of the longwalls (depending on the depth of the channel, and its location with respect to the panel edges). Groundwater associated with the palaeochannel is discussed in a report by Australasian Groundwater & Environmental Consultants (2021).

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

4.7. Non-Conventional Ground Movements

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

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

4.8. General Discussion on Mining Induced Ground Deformations

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

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

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

At shallow depths of cover, it is also likely that transient surface cracks will occur above and parallel to the moving extraction face, i.e. at right angles to the longitudinal edges of the longwall, as the subsidence trough develops. The larger and more permanent cracks, however, are usually located in the final tensile zones around the perimeters of the longwalls. Open fractures and heaving, however, can also occur due to the buckling of surface beds that are subject to compressive strains. An example of crack patterns that develop in shallow depths of cover is shown in Fig. 4.6 below.

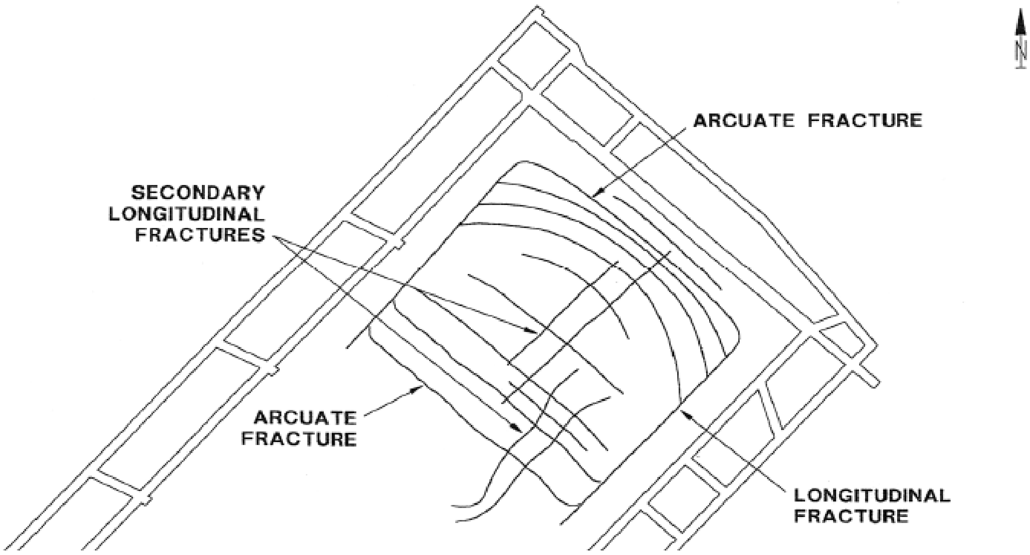

Fig. 4.6 Survey of Major Fracture Pattern at Approx. 110m Cover (Source: Klenowski, ACARP C5016, 2000)

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

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

Experience in NSW has found that the severity and frequency of surface cracking reduces as the depth of cover to the extraction increases.

Crack mapping has been undertaken during the extraction of Longwalls 101 to 103. Of a total of over 22km of mapped cracks, the crack widths were generally less than 100 mm is 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 provide examples of surface cracking above extracted Longwalls 101 to 103.

Fig. 4.7 Photograph of Isolated Surface Cracking above Longwall 103

Fig. 4.8 Surface steps above Longwall 103

The depths of cover over the underground mining areas vary from 83 m to 205 m. Where the depths of cover above Longwalls 401 to 408 are less than 100 m, surface cracking is expected to be typically in the order of 150 to 200 mm wide, but could be as large as 500 mm wide where the depths of cover are the shallowest. The surface crack widths are likely to be smaller where the depths of cover are greater, or where the surface cracks result from the travelling wave. Where the depths of cover above Longwalls 401 to 408 are 100 to 150 m, the surface crack widths are expected to be typically in the order of 100 to 150 mm wide.

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 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. In some cases, remediation may be required and could include infilling, regrading or erosion protection measures.

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 Longwalls 401 to 408. The predicted parameters for each of the natural features have been compared to the predicted parameters based on the Approved Layout. Supporting impact assessments for the natural features have also been undertaken by other specialist consultants for the Extraction Plan Layout.

5.1. Natural Features

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

- drinking water catchment areas or declared special areas;
- seas or lakes;
- escarpments;
- shorelines;
- natural dams;
- water relater ecosystems;
- lands declared as critical habitat under the *Threatened Species Conservation Act 1995*;
- State Recreation Areas or State Conservation Areas;
- State Forests;
- areas of significant geological interest; 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.

5.2. Drainage Lines

5.2.1. Description of the Drainage Lines

There are no perennial streams within the Study Area. The Goulburn River Diversion is the nearest major stream, located on the western side of the Study Area and is 425 m from the finishing end of Longwall 406 at its nearest point. The only named stream within the Study Area is Bora Creek, which is an ephemeral stream and is located above the commencing ends of Longwalls 401 and 402. A number of other small ephemeral drainage lines have been identified above the longwalls and within the Study Area. The drainage lines are shown in Drawing No. MSEC1165-07. The main drainage lines flowing through the Study Area have been labelled in Drawing No. MSEC1165-07 (Bora Creek, Drainage Line 1 and Drainage Line 2).

The drainage lines within the Study Area flow to the Goulburn River. The predictions and impact assessments for the drainage lines within the Study Area are provided in the following sections.

The drainage lines within the Study Area comprise a rounded gravel to sandy and silty base. There is also debris along sections of the streams, including boulders, tree branches and other vegetation. The valley profiles of the drainage lines are predominantly broad and shallow with some incised sections as shown in Fig. 5.1.

Fig. 5.1 Drainage Line 2

The natural grades of the main drainage lines within the Study Area typically vary between 5 mm/m (i.e. 0.5 % or 1 in 200) and 100 mm/m (i.e. 10 % or 1 in 10), with average natural grades of approximately 20 mm/m (i.e. 2 % or 1 in 50).

5.2.2. Predictions for the Drainage Lines

The drainage lines are located across the Study Area and are likely, therefore, to be subjected to the full range of predicted systematic subsidence and valley related movements, as discussed in Section 4.2. The predicted profiles of conventional subsidence, tilt and curvature along Bora Creek, Drainage Line 1 and Drainage Line 2 are shown in Fig. C.02, Fig. C.03, and Fig. C.04 in Appendix C. The predicted total profiles along the drainage lines, after the extraction of each of the proposed longwalls, are shown as blue lines.

A summary of the maximum predicted total systematic subsidence parameters along these drainage lines, after the extraction of Longwalls 401 to 408, is provided in Table 5.1.

Table 5.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for Drainage Lines after the Extraction of Longwalls 401 TO 408

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})
Bora Creek	1800	25	0.55	0.40
Drainage Line 1	1900	60	> 3.0	> 3.0
Drainage Line 2	1000	20	0.85	0.75

The maximum predicted conventional tilt for the drainage lines is 60 mm/m (i.e. 6 %, or 1 in 17). The maximum predicted conventional curvatures are greater than 3.0 km^{-1} hogging and sagging, which equate to minimum radii of curvature of 0.33 km.

The predicted strains for the drainage lines are provided in Table 5.2. The values have been provided for conventional movements (based on 10 times the curvature) and for non-conventional anomalous movements (based on the statistical analysis provided in Section 4.4).

Table 5.2 Predicted Strains for the Drainage Lines based on Conventional and Non-Conventional Anomalous Movements

Drainage Line	Conventional tensile strain based on 10 times Curvature (mm/m)	Conventional compressive strain based on 10 times Curvature (mm/m)	Tensile strain based on the 95 % Confidence Level (mm/m)	Compressive strain based on the 95 % Confidence Level (mm/m)
Bora Creek	6	4	10	13
Drainage Line 1	> 30	> 30	10	13
Drainage Line 2	9	8	10	13

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

It is also possible that the drainage lines could experience some valley related movements resulting from the extraction of Longwalls 401 to 408, however the magnitudes of these upsidence and closure movements are expected to be much lower than the conventional movements and hence may not be significant.

5.2.3. Comparison of the Predictions for Drainage Lines

A comparison of the maximum predicted subsidence parameters for Bora Creek, Drainage Line 1 and Drainage Line 2, resulting from the extraction of Longwalls 401 to 408, with those based on the Approved Layout is provided in Table 5.3. The values are the maxima along the section of the drainage lines located within the Study Area.

Table 5.3 Maximum Predicted Systematic Subsidence Parameters along the Alignments of the Drainage Lines Resulting from the Extraction of the Approved Layout and Extraction Plan Layout

Layout	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})
Approved Layout	Bora Creek	1800	25	0.50	0.45
	Drainage Line 1	1900	60	> 3.0	> 3.0
	Drainage Line 2	1000	20	0.75	0.70
Extraction Plan Layout	Bora Creek	1800	25	0.55	0.40
	Drainage Line 1	1900	60	> 3.0	> 3.0
	Drainage Line 2	1000	20	0.85	0.75

The predicted total subsidence for the drainage lines based on the Extraction Plan Layout is the same as that for the Approved Layout. The predicted total curvature and tilt based on the Extraction Plan Layout is similar to that based on the Approved Layout.

5.2.4. Impact Assessments and Recommendations for the Drainage Lines

The maximum predicted total subsidence parameters for the drainage lines based on the Approved Layout are similar to those for the Extraction Plan Layout for Longwalls 401 to 408. The potential impacts for the drainage lines, based on the Extraction Plan Layout are the same as those assessed based on the Approved Layout. The following summary outlines the potential impacts to the drainage lines:

- 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. The predicted changes in grade along the drainage lines after the completion of the longwalls are generally less than most of the natural grades, however the magnitudes of tilt will result in increases and decreases in grade and reversal of grade at some locations. Additional ponding may occur along the drainage lines resulting from the extraction of Longwalls 401 to 408, predominantly upstream of the chain pillars.

- Sections of beds downstream of the additional ponding areas may erode during subsequent rain events, especially during times of high flow. It is expected that, over time, the gradients along the drainage lines would approach grades similar to those that existed before mining. The extent of additional ponding along the drainage lines would, therefore, be expected to decrease with time.
- Fracturing, dilation and buckling of the bedrock would occur as a result of the extraction of these longwalls. Surface cracking is expected to develop in the bases of the drainage lines as outlined in Section 4.8.
- In times of heavy rainfall, the majority of the surface water runoff would be expected to flow over the surface cracking in the beds and only a small proportion of the flow would be diverted into the fractured and dilated strata below. In times of low flow, however, a larger proportion of the surface water flow could be diverted into the strata below the beds and this could affect the quality and quantity of this water flowing through the cracked strata beds. Nevertheless, during high flow or low flow times, this small quantity is expected to have little impact on the overall quality of water flowing out of the drainage lines.

If adverse impacts were to develop as the result of increased ponding along the streams, these could be remediated by locally regrading the beds, so as to re-establish the natural gradients. The streams have shallow incisions in the natural surface soils and, therefore, it is expected that the mining induced ponding areas could be reduced by locally excavating the channels downstream of these areas. The larger ponding areas may require excavation into the topmost bedrock, depending on the thickness of the overlaying surface soils. It would be expected that the majority of fracturing in the underlying bedrock would gradually be filled with the surface soils during subsequent flow events, especially during times of heavy rainfall. If the surface cracks were found not to fill naturally, some remedial measures may be required at the completion of mining. Where necessary, any significant surface cracks in the stream beds could be remediated by infilling with the surface soil or other suitable materials, or by locally regrading and recompacting the surface.

The shallow depth of cover will result in the development of a network of fractures in the overburden above the extracted longwalls. The changes in permeability and the potential hydrogeological impacts above proposed longwalls are discussed in the specialist groundwater consultant in the report by *Australasian Groundwater & Environmental Consultants* (2021). The hydrogeological modelling indicates that continuous fracturing is not predicted to occur at the land surface with the zone of continuous fracturing being 16 m or more below the ground surface.

5.2.5. Recommendations for the Drainage Lines

It is recommended that the drainage lines are visually monitored as the longwalls mine beneath them and that management strategies are developed for the drainage lines, such that the impacts can be identified and remediated if and as they are required. Management strategies based on extraction of the Extraction Plan Layout are the same as those for the Approved Layout.

5.3. The Goulburn River

5.3.1. Description of the Goulburn River

The Goulburn River is located on the western side of Longwalls 401 to 408 at distances of 425 m to 500 m from the longwall finishing ends. The location of the Goulburn River is shown in Drawing No. MSEC1165-07. The river flows in a northerly direction and comprises a diverted section of the river around UCM.

The distances to the Goulburn River represent about 5 to 6 times the depth of cover from Longwalls 401 to 408. At these distances conventional mine subsidence ground movements and valley related movements are expected to be less than limits of survey accuracy. However, the river may experience far-field horizontal movements, which are discussed in Sections 3.3 and 4.6. The predicted upper limit of observed horizontal movements at 5 times the depth of cover from the Extraction Plan Layout is 50 mm with the majority of the observed data less than typical limits of survey accuracy of 25 mm.

The impact assessments for the Goulburn River based on the Approved Layout do not change based on the Extraction Plan Layout. It is unlikely that fracturing of the bed of the Goulburn River would occur due to the extraction of the Extraction Plan Layout. If fracturing does occur, it is likely that the fractures will be localised in nature and relatively minor in size, and they will only be visible in areas where the bedrock is exposed. It is expected that the majority of the bedrock in the bed of the river will be covered with alluvial deposits, which would cover any minor fractures that may develop in the bedrock. Minor fractures that potentially develop outside extracted longwalls are not generally associated with any increased rate of diversion of surface water into near-surface substrata.

5.4. The Drip and Corner Gorge

The Drip and Corner Gorge (also called Goulburn River Gorge) are natural features located on the Goulburn River. The Drip is the more prominent feature comprising a south facing cliff with sheer to sub-vertical faces up to approximately 30 m high. The Drip and Corner Gorge are located over 2.7 km and 2.2 km respectively from Longwall 408.

At over 2.2 km from Longwall 408, The Drip and Corner Gorge will not experience measurable conventional tilts, curvatures or strains from the extraction of Longwalls 401 to 408.

The database of observed far-field horizontal movements beyond approximately 2.2 km are within the order of survey tolerance or accuracy. Monitoring for potential far-field horizontal movements has been undertaken at MCC up to approximately 4.5 km from active longwalls during the extraction of Longwalls 101 to 103, with no observations greater than survey accuracy of 25 mm beyond approximately 550 m from an active longwall. Measurable far-field horizontal movements are therefore not expected at The Drip and Corner Gorge.

At a distances of 2.2 km or more, impacts to The Drip and Corner Gorge due to the extraction of Longwalls 401 to 408 are considered to be unlikely to occur

5.5. Aquifers and Known Ground Water Resources

The descriptions, predictions and the assessment of potential impacts on the aquifers and groundwater resources within the Study Area are provided in the Groundwater Assessment report prepared by *Australasian Groundwater & Environmental Consultants* (2021).

There are no *Ground Water Management Areas*, within the Study Area.

5.6. Cliffs

5.6.1. Descriptions of the Cliffs

The subsidence impact assessments for the Approved Layout in 2006 were based on 8 defined areas containing a range of cliffs.

The definitions of cliffs and minor cliffs provided in the NSW DP&E *Standard and Model Conditions for Underground Mining* (DP&E, 2012) are:

> *"Cliff* — *Continuous rock face, including overhangs, having a minimum length of 20 metres, a minimum height of 10 metres and a minimum slope of 2 to 1 (>63.4º)*
>
> *Minor Cliff* — *A continuous rock face, including overhangs, having a minimum length of 20 metres, heights between 5 metres and 10 metres and a minimum slope of 2 to 1 (>63.4º); or a rock face having a maximum length of 20 metres and a minimum height of 10 metres"*

A detailed assessment of cliffs and minor cliffs was carried out using 1 m surface level contours generated from a Light Detection and Ranging (LiDAR) survey and from site investigations. A summary of the cliffs and minor cliffs at each of the Cliff Line areas within or near the Study Area (including The Drip) is provided in Table 5.4. Only cliff areas CL3 and CL5 meet the definitions of cliffs provided in the NSW DP&E *Standard and Model Conditions for Underground Mining* (DP&E, 2012). The locations of the cliff areas are shown in Drawing No. MSEC1165-07.

Table 5.4 Cliff areas assessed for the Approved Layout

Cliff Line Area ID	Maximum Height (m)	Maximum Length (m)	Classification	Location
CL3	15	500	Cliff	Outside of Study Area
CL5 (The Drip)	30	330	Cliff	Outside of Study Area
CL6	10	30	Minor Cliff*	Above LW 406
CL7	6	30	Minor Cliff	160 m from LW 406

*Note: CL6 height is predominantly 5 m to 10 and does not meet the conditions of 10m minimum height over at least 20m continuous length for cliffs.

Cliff CL5 is located over 2.7 km from Longwall 408 and is unlikely to experience subsidence related movements due to the extraction of Longwalls 401 to 408. Cliff CL3 is located over 165 m to the north of Longwall 408.

In addition to the minor cliffs listed above, there are other minor cliffs within the Study Area as shown in Drawing No. MSEC1165-07.

5.6.2. Predictions for the Cliffs

Cliff Line CL3 is located outside the Study Area and is 165 m to 440 m from Longwall 408. With a depth of cover of approximately 165 m at the northern end of the longwalls, Cliff Line CL3 is located over 1 depth of cover from the longwalls. At this distance conventional mine subsidence ground movements and valley related movements are expected to be less than limits of survey accuracy. However, the cliff may experience far-field horizontal movements, which are discussed in Sections 3.3 and 4.6.

Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located greater than 1 depth of cover from longwalls, is less than 145 mm.

The predicted maximum far-field horizontal movements of 145 mm at the cliff are expected to be bodily movements towards the extracted goaf area and should be accompanied by very low levels of strain.

The range of potential strains associated with non-conventional movements has been assessed using monitoring data from previously extracted panels in the NSW Coalfields, for single-seam conditions, where the width-to-depth ratios and extraction heights were similar to those of Longwalls 401 to 408. The 95 % confidence levels for the maximum total strains that the individual survey bays *above solid coal* (between 200 m and 600 m from extracted goaf) experienced at any time during mining are 1.6 mm/m tensile and 1.5 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 2.9 mm/m tensile and 3.0 mm/m compressive. The 75 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 0.5 mm/m both tensile and compressive, which is the typical limit of accuracy of strain measurement by conventional survey methods. It is noted that these results comprise a component of survey tolerance and have also been affected by disturbed survey marks and survey errors.

The minor cliffs are located across the Study Area and will be subjected to the full range of predicted subsidence movements which are outlined in Section 4.2.

5.6.3. Impact Assessments and Recommendations for the Cliffs

The Stage 1 Project Approval lists the following Subsidence Impact Performance Measures in Table 14 for Land:

Cliff Line 3	*Minimise subsidence damage*

Cliff CL3 is located outside the Study Area boundary and is over one depth of cover from the longwalls. While the cliff may experience far-field horizontal movements, impacts to the cliff due to the extraction of Longwalls 401 to 408 are considered to be unlikely to occur.

The minor cliffs located above the proposed longwalls are predicted to experience up to 1900 mm vertical subsidence. These movements are predicted to be associated with conventional tilt of up to 60 mm/m, or 1 in 17, and curvature greater than 3 km^{-1}, or a minimum radius of curvature of 300 metres.

It is extremely difficult to assess the likelihood of instabilities for the cliffs based upon predicted ground movements. The likelihood of the cliffs becoming unstable is dependent on a number of factors which are difficult to fully quantify. These factors include jointing, inclusions, weaknesses within the rockmass, groundwater pressure and seepage flow behind the rockface. Even if these factors could be determined, it would still be difficult to quantify the extent to which these factors may influence the stability of the cliff naturally or when it is exposed to mine subsidence movements.

Some of the minor cliffs are located within the Study Area and are outside the extents of the longwalls. There is extensive experience of mining adjacent to (i.e. not directly beneath) cliffs in the NSW Coalfields which indicates that the likelihood of impacts is very low. Whilst minor and isolated rockfalls have occurred at some cliffs which are located outside the extents of active longwalls, there have been no large cliff instabilities where the cliffs have been wholly located outside the extents of mining.

It is expected that the minor cliffs located above the extracted longwalls and chain pillars will experience impacts including fracturing, rockfalls and slabbing. The percentage of the length of each minor cliff likely to experience rockfalls is likely to vary considerably due to the variability in geological and geometric factors. It is, however, expected that minor cliffs that have greater height and continuous length, are considered to be more susceptible to impacts.

The overall assessed impacts to the minor cliff lines located above the extracted longwalls does not change for the Extraction Plan Layout compared with the Approved Layout. The slightly reduced footprint at the ends of the longwalls based on the Extraction Plan Layout slightly reduces the expected impacts to the minor cliffs in those areas.

It is recommended that monitoring and management strategies are developed for UG4 to manage the hazards associated with potential impacts to the cliffs and minor cliffs. Management strategies including site access control and signage, visual inspections, and mitigation/remediation strategies should be developed to ensure the safety of persons that may be within the vicinity of the cliffs and minor cliffs during the mining period.

Baseline monitoring of the cliff CL3 should be established prior to longwall extraction for identification and reporting of impacts.

5.7. Steep Slopes

The definition of a steep slope provided in the NSW DP&E Standard and Model Conditions for Underground Mining (DP&E, 2012) is: "An area of land having a gradient between 1 in 3 (33% or 18.3°) and 2 in 1 (200% or 63.4°)". The locations of the steep slopes were identified from the 1 m surface level contours which were generated from the LiDAR survey of the area.

The steep slopes within the Study Area could experience the full range of predicted subsidence movements, as summarised in Section 4.2. The maximum predicted subsidence parameters for the steep slopes, based on the Extraction Plan Layout, are the same as those based on the Approved Layout.

The longwall panel extraction is supercritical and magnitudes of differential movements are high for both the Extraction Plan Layout and Approved Layout. The overall assessed impacts to the steep slopes located above the extracted longwalls does not change for the Extraction Plan Layout compared with the Approved Layout. The potential for ground surface cracking, is discussed in Section 4.8.

It has been observed that down slope movements occur on slopes that are located over or near extracted longwalls. Sometimes these movements are observed to be directed down the hill slope rather than towards the extracted goaf area. Where such movements occur on steep slopes, there is a higher likelihood that surface tension cracking can occur near the tops of the slopes. It is unlikely that mine subsidence would result in large-scale slope failure, since such failures have not been observed elsewhere as the result of longwall mining.

5.8. Land Prone to Flooding or Inundation

There are no major natural flood prone areas identified within the. Surface water and flood modelling identifies potential minor flooding areas along Drainage Line 1 at the western (finishing) end of Longwall 407. The subsided surface levels are expected to result in increased ponding along the drainage lines as discussed in Section 5.2.4 and are likely to increase the areas of potential flooding located above the extracted longwalls.

5.9. Threatened, Protected Species or Critical Habitats

An investigation of the flora and fauna within the Study Area was undertaken by Niche Environment and Heritage (2021-b). Flora and fauna surveys within these areas were undertaken and did not identify any threatened flora species under the *Threatened Species Conservation Act, 1995*. There is known and potential habitat for a number of threatened fauna species within the Study Area as described in Niche Environment and Heritage (2021-b).

There is no change in subsidence impacts expected to threatened flora or fauna species based on the Extraction Plan Layout. The effects of subsidence on flora and fauna within the Study Area are considered in the report by Niche Environment and Heritage (2021-b).

5.10. Threatened Ecological Communities

5.10.1. Descriptions of the TEC

One Threatened Ecological Communities (TEC) occurs within the Study Area above the western end of LW406 and 407, as shown on Drawing No. MSEC1165-07. The TEC is listed under the NSW *Biodiversity Conservation Act 2016* and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The TEC is listed as White Box - Yellow Box - Blakely's Red Gum Grassy Woodland and Derived Native Grassland in the NSW North Coast, New England Tableland, Nandewar, Brigalow Belt South, Sydney Basin, South Eastern Highlands, NSW South Western Slopes, South East Corner and Riverina Bioregions.

5.10.2. Predictions for the TEC

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the TEC within the Study Area, resulting from the Extraction Plan Layout, is provided in Table 5.5. The values are the maximum predicted parameters within 20 m of the perimeter of the TEC. 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 5.5 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the TECs within the Study Area Resulting from the Extraction of Longwalls 401 to 408

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})
TEC01	1900	60	> 3	> 3

The predicted strains for the TEC 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 (based on the statistical analysis provided in Section 4.4).

Table 5.6 Predicted Strains for the TEC 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.

5.10.3. Comparison of the Predictions for the TEC

A comparison of the maximum predicted subsidence parameters for the TEC within the Study Area, resulting from the extraction of Longwalls 401 to 408, with those based on the Approved Layout, is provided in Table 5.7.

Table 5.7 Comparison of Maximum Predicted Conventional Subsidence Parameters for the TEC based on the Extraction Plan Layout and the Approved Layout

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	1900	60	> 3	> 3
Extraction Plan Layout	1900	60	> 3	> 3

It can be seen from the above table, that the maximum predicted total subsidence for the TEC based on the Extraction Plan Layout is the same as that based on the Approved Layout.

5.10.4. Impact Assessments and Recommendations for the TEC

The maximum predicted total tilt and curvature for the TEC based on the Extraction Plan Layout are the same as those for the Approved Layout. The potential impacts for the TEC based on the Extraction Plan Layout, therefore, are the same as those assessed based on the Approved Layout. The following summary outlines the potential impacts to the TEC:

- The likely changes in gradients will result in reduced grades and increased grades depending on the position within 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 as described in Section 4.8.
- 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.

Discussion on potential impacts to the TEC are provided in the report by Niche Environment and Heritage (2021-b).

5.11. National Parks or Wilderness Areas

The Goulburn River National Park boundary is located to the east of the Extraction Plan Layout and is 110 m from the nearest longwall. The location of the National Park is shown in Drawing Nos. MSEC1165-01.

The land within the National Park is predicted to experience less than 20 mm vertical subsidence resulting from the extraction of the Approved Layout and Extraction Plan Layout i.e. the boundary is located outside of the limit of vertical subsidence. The magnitude of the predicted vertical subsidence is similar to the natural movements that occur due to the wetting and drying of the surface soils. Whilst the National Park could experience very low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains. The National Park is expected to experience far-field horizontal movements.

The Goulburn River National Park is over 0.5 times the depth of cover from the longwalls. Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located greater than 0.5 times the depth of cover from longwalls, is less than 210 mm.

These far-field horizontal movements generally do not result in impacts at surface features unless they are very sensitive to differential horizontal movements. The predicted maximum far-field horizontal movements of 210 mm at the Goulburn River National Park are expected to be bodily movements and should be accompanied by very low levels of strain.

An assessment of surface features carried out for the Goulburn River National Park identified no features considered to be sensitive to far-field movements. It is unlikely, therefore, that the Goulburn River National Park would be adversely impacted by the far-field horizontal movements.

5.12. Natural Vegetation

There is natural vegetation located throughout the Study Area, as can be seen from the aerial photograph in Fig. 1.1. Biodiversity Offset Areas are also present within the northern portion of the Study Area. A detailed survey of the natural vegetation has been undertaken and is described and assessed in the report prepared by Niche Environment and Heritage (2021-b). The natural vegetation could, therefore, experience the full range of predicted subsidence movements, as summarised in Section 4.0 . The maximum predicted subsidence parameters for the natural vegetation, based on the Extraction Plan Layout, are the same as the maxima based on the Approved Layout. The potential impacts on the natural vegetation, based on the Extraction Plan Layout, therefore, are the same as those assessed based on the Approved Layout.

The assessment of mine subsidence impacts by Niche Environment and Heritage (2021-b) indicates that the extraction of Longwalls 401 to 408 will not significantly impact the biodiversity values within the Study Area.

5.13. Areas of Significant Geological Interest

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

6.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE PUBLIC UTILITIES

The following sections provide the descriptions, predictions of subsidence movements and impact assessments for the public utilities located within the Study Area for Longwalls 401 to 408. The predicted parameters for each of the built features have been compared to the predicted parameters based on the Approved Layout.

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

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

6.1. Railways

The Sandy Hollow – Gulgong Railway Line is located to the south of the Study Area as shown in Drawing No. MSEC1165-08.

The shortest distance from the Extraction Plan Layout to the Sandy Hollow – Gulgong Railway Line is 660 m. A rail loop owned and operated by MCO is located a minimum distance of 230 m from Longwall 401 and is discussed further in Section 9.4. The depth of cover along the southern side of Longwall 401 varies from approximately 83 m to 155 m and the distances to the railway line from Longwall 401 equate to 5 to 8 times the depths of cover.

The distances to the railway line based on the Extraction Plan Layout are the same as those for the Approved Layout. Therefore, the predictions and impact assessments based on the Extraction Plan Layout are similar to those for the Approved Layout. A discussion of the predicted subsidence movements and impact assessments is provided below.

As detailed in Section 1.4.1, there are unconsolidated materials associated with a palaeochannel, with a maximum thickness of 40 m to 50 m, to the south of the Study Area. Section 4.6.1 notes that the presence of a palaeochannel should result in a reduced likelihood of far-field movements.

6.1.1. Predictions for the Sandy Hollow – Gulgong Railway Line

At distances of over 660 m between the longwalls and the railway track and based on these depths of cover, the rail track will not be subjected to measurable tilts, curvatures or strains; however, the railway line may experience far-field horizontal movements which are discussed in Section 3.3 and 4.6.

Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located greater than 5 times the depths of cover from longwalls, is less than 40 mm.

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

These far-field horizontal movements generally do not result in impacts at structures unless they are very sensitive to differential horizontal movements. The predicted maximum far-field horizontal movements of 40 mm at the railway track are expected to be bodily movements that are directed across the track towards the extracted goaf area and should be accompanied by very low levels of strain.

The range of potential strains associated with non-conventional movements has been assessed using monitoring data from previously extracted panels in the NSW Coalfields, for single-seam conditions, where the width-to-depth ratios and extraction heights were similar to those of Longwalls 401 to 408.

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

The Sandy Hollow – Gulgong Railway Line is located more than 660 m from the Extraction Plan Layout. The railway line is not expected to experience to measurable conventional vertical subsidence, tilt, curvature or conventional strain. However, the railway may experience far-field horizontal movements of up to 40 mm. The presence of unconsolidated sediments should result in a reduced likelihood of far-field movements at the railway line.

The predicted far-field horizontal movements at the railway lines are expected to be bodily movements that are directed across the track towards the extracted goaf area and should be accompanied by very low levels of strain that are in the order of survey tolerance. The horizontal movement are unlikely to adversely impact on the railway line.

It is recommended that monitoring and management strategies including baseline subsidence surveys, communications protocols and trigger action response plans are adopted for at least the extraction of Longwalls 401 and 402 in consultation with ARTC. Further monitoring beyond Longwall 402 may be required if subsidence related movements are identified. It is expected that potential impacts on the ARTC infrastructure can be managed with the implementation of the necessary monitoring and management strategies.

6.2. Roads

6.2.1. Descriptions of the Roads

The locations of the roads maintained by Mid-Western Regional Council (MWRC) are shown in Drawing No. MSEC1165-08. The roads in the vicinity of the Study Area include:

- Ulan Road;
- Ulan Road bridge (over the Sandy Hollow – Gulgong Railway);
- Ulan Road bridge (over Goulburn River);

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

Ulan Road is a sealed bitumen pavement with no kerb and gutter located to the west of the Study Area. The road is approximately parallel with the finishing ends of Longwalls 401 to 408 and is approximately 375 m from the longwall voids. Features along the road include cuttings in sandstone bedrock, 3 m to 15 m. Culverts beneath Ulan Road range from 400 mm to 1500 mm diameter concrete pipes with the largest pipes located at Bora Creek to the south west of Longwall 401. The depth of cover along the western side of Longwall 401 to 408 varies from approximately 83 m to 130 m and the distances to the road from these longwalls equate to 2.9 to 4.5 times the depths of cover.

The bridge over the Sandy Hollow – Gulgong Railway line, is over 1 km from the finishing end of Longwall 401. The bridge over the Goulburn River, is over 2.3 km from Longwall 408. The bridge over the Goulburn River is unlikely to experience subsidence related movements due to the extraction of Longwalls 401 to 408 and is therefore not considered further in this report.

6.2.2. Predictions for the Roads

At distances of over 340 m between the longwalls and Ulan Road, the road will not be subjected to measurable tilts, curvatures or strains; however, the road may experience far-field horizontal movements which are discussed in Section 3.3 and 4.6.

Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located greater than 2.9 times the depth of cover from longwalls, is less than 55 mm.

These far-field horizontal movements generally do not result in impacts at structures unless they are very sensitive to differential horizontal movements. The predicted maximum far-field horizontal movements of 55 mm at the road are expected to be bodily movements that are directed across the road towards the extracted goaf area and should be accompanied by very low levels of strain.

The range of potential strains associated with non-conventional movements has been assessed using monitoring data from previously extracted panels in the NSW Coalfields, for single-seam conditions, where the width-to-depth ratios and extraction heights were similar to those of Longwalls 401 to 408. The 95 % confidence levels for the maximum total strains that the individual survey bays *above solid coal* (between 200 m and 600 m from extracted goaf) experienced at any time during mining are 1.6 mm/m tensile and 1.5 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 2.9 mm/m tensile and 3.0 mm/m compressive. The 75 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 0.5 mm/m both tensile and compressive, which is the typical limit of accuracy of strain measurement by conventional survey methods. It is noted that these results comprise a component of survey tolerance and have also been affected by disturbed survey marks and survey errors.

The bridge over the Sandy Hollow – Gulgong Railway line, is over 1 km from the finishing end of Longwall 401 which equates to over 10 times the depth of cover from the longwalls. At this distance the bridge is unlikely to experience measurable subsidence related movements.

6.2.3. Impact Assessments and Recommendations for the Roads

Ulan Road is located to the west of the Extraction Plan Layout. The distance from Ulan Road to the Extraction Plan Layout is the same as that for the Approved Layout. The potential subsidence movements and impacts based on the Extraction Plan Layout are therefore the same as those based on the Approved Layout.

Ulan Road is located outside the Study Area and is predicted to experience far-field horizontal movements of up to 55 mm. The predicted maximum far-field horizontal movements are expected to be bodily movements that are accompanied by very low levels of strain.

The statistical analysis of observed strain data between 200 m and 600 m from extracted longwalls shows a 25% probability of exceedance of 0.5 mm/m tensile and compressive, and a 5% probability of exceedance of approximately 1.5 mm/m tensile and compressive.

Road cuttings along Ulan Road are located near the finishing ends of Longwalls 401 and 408. These cuttings are located adjacent to steep slopes which are shown in Drawing MSEC1165-07. Downslope movements can occur on slopes that are located over or near extracted longwalls. Such movements may result in an increased likelihood of horizontal movements at the road cuttings. The directions of these movements are also likely to oppose the direction of far-field horizontal movements. Increased horizontal movements would be expected to be minor and unlikely to result in slope failure, rockfalls or pavement impact.

Adverse impacts to the road, culverts and cuttings resulting from the extraction of Longwalls 401 to 408 are considered to be unlikely to occur. Should impacts occur, they are expected to be isolated and of a minor nature and readily repairable.

Ground monitoring and visual monitoring is recommended for Ulan Road and the cuttings adjacent to Longwalls 401 and 408 to check for the potential development of irregular subsidence movements.

It is expected that the potential impacts on the MWRC infrastructure can be managed with the implementation of the necessary monitoring and management strategies. It is recommended that monitoring and management strategies developed for UG1 are adopted for UG4.

6.3. Four Wheel Drive Tracks

There are a number of four wheel drive tracks through the Study Area, some of which are shown on Drawing No. MSEC1165-08. These tracks are not publicly accessible.

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

The potential impacts on the tracks, based on the Extraction Plan Layout, therefore, 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 surface using standard road maintenance techniques.

6.4. Road Drainage Culverts

No drainage culverts were identified within the Study Area; however, drainage culverts are located along Ulan Road and are discussed in Section 6.2.

6.5. Electrical Infrastructure

6.5.1. Descriptions of the Electrical Infrastructure

The locations of the electrical infrastructure within the vicinity of Longwalls 401 to 408 are shown in Drawing No. MSEC1165-08.

The Essential Energy infrastructure in the vicinity of Longwalls 401 to 408 comprises a 22kV powerline supported on timber poles located along the southern end of Ulan Road from Ulan Wollar Road to a telecommunications tower. At changes in the alignment of the 22kV powerline, the timber poles have guy wires for additional lateral restraint. A powerline owned by Ulan Coal Mine (Ulan powerline) is located further to the north along Ulan Road. A proposed future powerline by Tilt Renewables is located along the side of Ulan Road.

The Essential Energy and Ulan powerlines are approximately 400 m or more from the longwalls. The depth of cover along the western end of Longwall 401 varies from approximately 83 m to 120 m which equates to 3.3 to 5 times the depths of cover from the Essential Energy powerline to Longwall 401. The depth of cover along the western end of Longwall 406 and 407 is approximately 85 m which equates to 4.7 times the depth of cover from the Ulan powerline to the nearest longwall. The proposed location of the Tilt Renewables powerline is not yet finalised. It is anticipated that the powerline will be approximately 370 m from the longwalls at its nearest point, which equates to 2.8 to 4.6 times the depths of cover from the longwalls.

A 330kV electricity transmission line owned by TransGrid is located to the south of the Study Area. The transmission tower locations are shown in Drawing No. MSEC1165-08. The nearest tower of the 330kV powerline to the longwalls is 725 m from Longwall 401. The 330kV transmission towers to the south of the longwalls are 7 to 9 times the depth of cover from the longwalls.

6.5.2. Predictions for the Powerlines

At distances of 370 m or more from the longwalls, the Essential Energy powerline, Ulan powerline and Tilt Renewables powerline are outside the Study Area and are predicted to experience less than 20 mm vertical subsidence resulting from the extraction of the Approved Layout and Extraction Plan Layout. Whilst the powerlines could experience very low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains. The powerlines will experience far-field horizontal movements.

Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for sites located greater than 2.8 and 3.3 times the depth of cover from longwalls, is less than 55 mm.

These far-field horizontal movements generally do not result in impacts at structures unless they are very sensitive to differential horizontal movements. The predicted maximum far-field horizontal movements of 55 mm at the powerlines are expected to be bodily movements that are directed across the powerlines towards the extracted goaf area and should be accompanied by very low levels of strain.

The range of potential strains associated with non-conventional movements has been assessed using monitoring data from previously extracted panels in the NSW Coalfields, for single-seam conditions, where the width-to-depth ratios and extraction heights were similar to those of Longwalls 401 to 408. The 95 % confidence levels for the maximum total strains that the individual survey bays *above solid coal* (between 200 m and 600 m from extracted goaf) experienced at any time during mining are 1.6 mm/m tensile and 1.5 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 2.9 mm/m tensile and 3.0 mm/m compressive. The 75 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 0.5 mm/m both tensile and compressive, which is the typical limit of accuracy of strain measurement by conventional survey methods. It is noted that these results comprise a component of survey tolerance and have also been affected by disturbed survey marks and survey errors.

6.5.3. Predictions for the 330 kV Electricity Transmission Line

At distances of 725 m or more between the longwalls and the transmission line towers and at over 7 times the depth of cover, the towers will not be subjected to measurable conventional mine subsidence ground movements (i.e. less than limits of survey accuracy). The towers may experience minor far-field horizontal movements however, the movements are expected to be less than the limits of survey accuracy. Monitoring of transmission towers at similar distances from UG1 did not measure horizontal movements greater than the levels of survey accuracy.

6.5.4. Impact Assessments and Recommendations for the Electrical Infrastructure

The maximum predicted total subsidence parameters for the electrical infrastructure based on the Extraction Plan Layout are the same as or less than those for the Approved Layout for Longwalls 401 to 408. The potential impacts for the electrical infrastructure, based on the Extraction Plan Layout, therefore, are the same as or lower than those assessed based on the Approved Layout.

Essential Energy, Ulan and Tilt Renewables Powerlines

The predicted subsidence movements at the powerlines are expected to be less than typical measurable limits for conventional vertical subsidence, tilt, curvature or strain. However, the powerlines may experience far-field horizontal movements. The upper limit of previously observed absolute far-field horizontal movements for sites located greater than 2.8 and 3.3 times the depth of cover from longwalls, is 55 mm.

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

The statistical analysis of observed strain data between 200 m and 600 m from extracted longwalls shows a 25% probability of exceedance of 0.5 mm/m tensile and compressive, and a 5% probability of exceedance of approximately 1.5 mm/m tensile and compressive.

With the location of the powerlines outside the longwall footprint and the low probability of significant observed strains developing based on statistical analysis, the development of adverse impacts to the powerlines due to the extraction of Longwalls 401 to 408 is considered to be unlikely to occur.

Ground monitoring and visual monitoring is recommended along the alignment of the Essential Energy infrastructure for at least the extraction of Longwalls 401 and 402 to check for the potential development of irregular subsidence movements. Further monitoring beyond Longwall 402, including monitoring for the Ulan powerline, may be required if subsidence related movements are identified.

It is recommended that similar monitoring and management strategies developed for UG1 are adopted for UG4, in consultation with Essential Energy and UCM, to manage the infrastructure for potential irregular ground movements. These strategies could include visual inspections, surveys, communications protocols and trigger action response plans. The development of management strategies for the proposed Tilt Renewables powerline should be assessed during the design phase of the powerline and should be included in the powerline design. Baseline monitoring of the pole positions and tilt should be established for later comparison, should subsidence related ground movements be measured to the west of Longwalls 401 and 402. It is expected that the Essential Energy infrastructure can be maintained in a safe and serviceable condition with the implementation of the appropriate monitoring and management strategies.

330 kV Electricity Transmission Line

The 330kV transmission towers are located over 725 m or over 7 times the depth of cover from Longwall 401. At these distances the towers will not be subjected to measurable conventional mine subsidence ground movements and are unlikely to experience measurable far-field horizontal movements. The potential for non-conventional movements in the locations of the towers is very low, due to their distances from the longwalls. Unless greater than predicted, or anomalous movements are observed at monitoring sites for other features located to the south of Longwalls 401 to 408, regular monitoring of the 330kV transmission towers is not considered necessary.

6.6. Telecommunications Infrastructure

6.6.1. Descriptions of the Telecommunications Infrastructure

The locations of the telecommunications infrastructure are shown in Drawing No. MSEC1165-08.

The telecommunications infrastructure in the vicinity of Longwalls 401 to 408 comprises Telstra owned optical fibre and copper cables that follow the general alignments of the roads.

Copper cables are located along Ulan road to the west of Longwall 401 to 408 and to the South along Ulan-Wollar Road. The nearest point of the copper cables along Ulan Road is approximately 310 m to the finishing ends of LW402 to 406. The distance to the copper cables represents greater than 2.4 times the depth of cover from the longwalls.

Optical fibre cables are located to the south west of the Study Area along Ulan Road, and to the south along Ulan-Wollar Road. A telecommunications tower is located 410 m to the west of the finishing end of Longwall 401. The nearest point of the optical fibre cables is 390 m from Longwall 401. A photo of the Telstra tower is shown in Fig. 6.1. The distances to the Telstra tower and optical fibre cables represent approximately 5 and 4.5 times the depth of cover respectively from Longwall 401.

Fig. 6.1 Telstra tower

6.6.2. Predictions for the Telecommunications Infrastructure

At distances of 310 m or more between the longwalls and the copper cables along Ulan Road the cables will not be subjected to measurable conventional mine subsidence ground movements (i.e. less than limits of survey accuracy); however, the cables may experience far-field horizontal movements. Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located greater than 2.4 times the depth of cover from longwalls, is less than 70 mm.

The optical fibre cables and telecommunications tower are located greater than 390 m from the nearest longwalls. At distances of 390 m or more the cables and tower will not be subjected to measurable conventional mine subsidence ground movements (i.e. less than limits of survey accuracy); however, they may experience far-field horizontal movements. Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located greater than 4.5 and 5 times the depth of cover from longwalls, is less than 40 mm.

The range of potential strains associated with non-conventional movements has been assessed using monitoring data from previously extracted panels in the NSW Coalfields, for single-seam conditions, where the width-to-depth ratios and extraction heights were similar to those of Longwalls 401 to 408. The 95 % confidence levels for the maximum total strains that the individual survey bays *above solid coal* (between 200 m and 600 m from extracted goaf) experienced at any time during mining are 1.6 mm/m tensile and 1.5 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 2.9 mm/m tensile and 3.0 mm/m compressive. The 75 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 0.5 mm/m both tensile and compressive, which is the typical limit of accuracy of strain measurement by conventional survey methods. It is noted that these results comprise a component of survey tolerance and have also been affected by disturbed survey marks and survey errors.

6.6.3. Impact Assessment and Recommendations for the Telecommunications Infrastructure

The maximum predicted total subsidence parameters for the telecommunications infrastructure based on the Extraction Plan Layout are the same as or less than those for the Approved Layout for Longwalls 401 to 408. The potential impacts for the electrical infrastructure, based on the Extraction Plan Layout, therefore, are the same as or lower than those assessed based on the Approved Layout.

The copper cables located outside the Study Area boundary are not expected to be subjected to measurable conventional vertical subsidence, tilt, curvature or strain. However, the cables may experience far-field horizontal movements of up to 70 mm. Based on the low magnitude of mine subsidence movements outside the Study Area boundary, the development of adverse impacts to the copper cables due to extraction of Longwalls 401 to 408 is considered to be unlikely to occur.

With the location of the optical fibre cable and tower at 390 m or more from the longwalls, and the low likelihood of significant observed strains developing based on statistical analysis, the development of adverse impacts to the optical fibre cable and tower due to the extraction of Longwalls 401 to 408 is considered to be unlikely to occur.

It is recommended that similar monitoring and management strategies developed for UG1 are adopted for UG4, in consultation with Telstra, to manage the telecommunications infrastructure for potential irregular ground movements. These strategies could include visual inspections, communications protocols and trigger action response plans. Baseline monitoring is recommended for comparison, should subsidence related ground movements be measured to the west of Longwalls 401 to 408. It is expected that the telecommunications infrastructure can be maintained in a safe and serviceable condition with the implementation of the appropriate monitoring and management strategies.

7.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE PUBLIC AMENITIES

As listed in Table 2.1, the following public amenities were not identified within the 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 for Longwalls 401 to 408.

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;
- 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. All fences are on Moolarben owned lands.

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

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

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

It is recommended that management plans be developed to manage potential impacts on fences during the mining of the longwalls.

8.2. Farm Dams

8.2.1. Descriptions of the Farm Dams

There are five farm dams that have been identified within the Study Area (D6, D7, D11, D12 and D13) and their locations are shown in Drawing No. MSEC1165-08. The dams are shallow with maximum dimensions of approximately 10 m to 20 m and were understood to be previously used for livestock watering but are no longer in use.

Dams D8, D9 and D10 are polymer lined storage dams used by Ulan Coal and are part of the Millers Dam Compound as discussed in Section 9.2.

The farm dams are located on land owned by MCO.

8.2.2. Predictions for the Farm Dams

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the farm dams, resulting from the extraction of Longwalls 401 to 408 for the Extraction Plan Layout, is provided in Table 8.1. The predicted tilts provided in this table are the maxima after the completion of all the longwalls. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 8.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Farm Dams within the Study Area Resulting from the Extraction of Longwalls 401 to 408

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})
D6	290	35	> 3.0	0.02
D7	975	60	> 3.0	0.14
D11	400	14	1.0	< 0.01
D12	1875	25	1.2	1.5
D13	1875	14	1.2	1.5

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

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

Type	Conventional based on 10 times Curvature	Non-conventional based on the 95 % Confidence Level	Non-conventional based on the 99 % Confidence Level
Tension	30	10	22
Compression	15	13	31

8.2.3. Comparison of the Predictions for the Farm Dams

A comparison of the maximum predicted subsidence parameters for the farm dams within the Study Area, resulting from the extraction of Longwalls 401 to 408, with those based on the Approved Layout is provided in Table 8.3.

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

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	1875	60	> 3.0	1.5
Extraction Plan Layout	1875	60	> 3.0	1.5

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

8.2.4. Impact Assessments and Recommendations for the Farm Dams

The maximum predicted total subsidence parameters for the farm dam within the Study Area based on the Extraction Plan Layout are less than the parameters for the Approved Layout for Longwalls 401 to 408. The changes to the predicted subsidence parameters for the dams do not change the impact assessments for the dams. The following summary outlines the potential impacts to the farm dams:

- Change in freeboard of up to 200 mm for the farm dams located above the extracted longwalls.

- Farm dams are typically constructed of cohesive soils with reasonably high clay contents, and are likely to be capable of withstanding tensile ground strains up to 3 mm/m without impact. The predicted strains based on the Extraction Plan Layout are greater than 3 mm/m.
- The farm dams located above the extracted longwalls are expected to experience cracking and leakage of water. Any loss of water from the farm dams would flow into the drainage line in which the dam was formed. Impacts to the farm dams located outside the longwall footprints is considered unlikely to occur.

It is recommended that farm dams, where not decommissioned, are visually monitored as the longwalls are extracted, such that any impacts can be identified and remediated accordingly. In this way the farm dams within the Study Area can be maintained in a safe condition throughout the mining period.

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

The following sections provide the descriptions, predictions of subsidence movements and impact assessments for the industrial, commercial and business establishments located within the Study Area for Longwalls 401 to 408. 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; and
- Waste storages and associated plant.

9.1. Dronvisa Quarry

9.1.1. Description of Dronvisa Quarry

The Dronvisa Quarry is a gravel/clay quarry located to the west of the finishing ends of Longwalls 403 to 405 with part of one active pit located above Longwall 404 and 405. The location of the quarry is shown in Drawing No. MSEC1165-08.

The quarry selectively extracts layers of clay, mudstone, siltstone or sandstone for processing and sale. There are two main extraction pits (northern and southern), comprising benches at different elevations with batters up to approximately 15 m height. The average slopes of the batters is about 45 °, with some steeper faces within the batters up to about 75 °. In addition to the northern and southern quarry pits, other features of the quarry include sedimentation ponds, access tracks, rehabilitation areas and a site shed. The detailed features at the quarry are shown in Fig. 9.1.

The current mapped extent of the northern and southern pits show the northern pit to be located partly above Longwalls 404 and 405. The southern pit is located to the west of Longwall 403 and is approximately 25 m from the finishing end of the longwall.

Future expansion areas covering approximately the next 7 years at the quarry are shown in black in Fig. 9.1. The Dronvisa tenements extend beyond the active areas and 7 year expansion areas, which are the focus of this report. The proposed extraction of Longwall 403 is expected to occur in 2023, therefore the southern quarry pit expansion is likely to extend above Longwall 403 and 404 prior to their extraction.

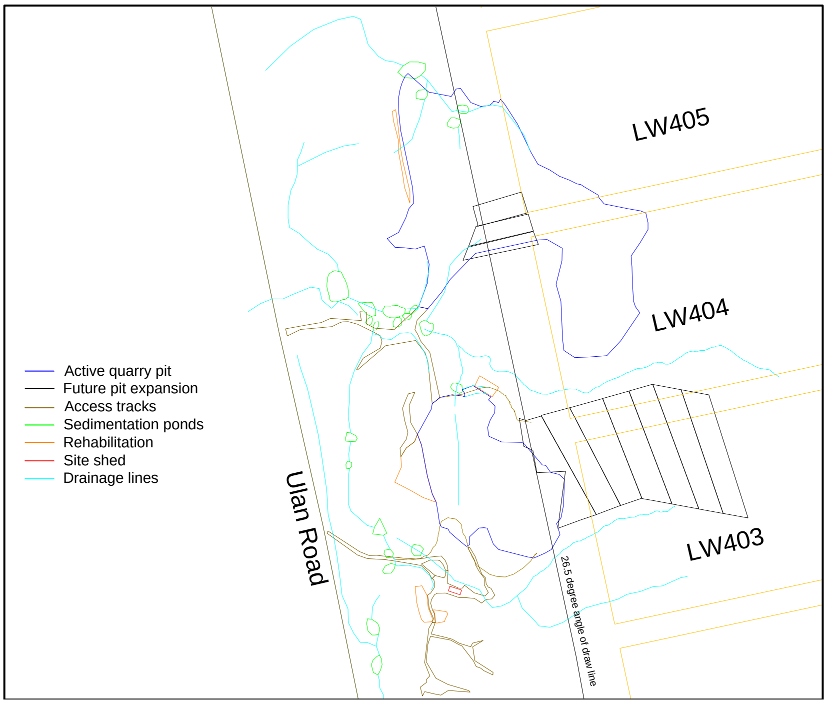

Fig. 9.1 Dronvisa Quarry

9.1.2. Predictions for the Dronvisa Quarry

The features at the quarry including access tracks, sedimentation ponds, rehabilitation areas and the site shed are located near to or outside the Study Area Boundary, between 65 m and 300 m from the longwalls. These distances equate to approximately 0.5 to 2.5 times the depth of cover from the longwalls. These features are predicted to experience less than 20 mm vertical subsidence resulting from the extraction of the Extraction Plan Layout and are not expected to experience measurable tilts, curvatures or strains. The features will however experience far-field horizontal movements.

Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located 0.5 to 2.5 times the depth of cover from longwalls, is less than 210 mm to 70 mm.

These far-field horizontal movements are expected to be bodily, accompanied by very low levels of strain, and generally do not result in impacts at structures unless they are very sensitive to differential horizontal movements.

A summary of the maximum predicted values of incremental conventional subsidence, tilt and curvature for the portions of the quarry pits above the longwalls, resulting from the extraction of Longwalls 401 to 408 for the Extraction Plan Layout, is provided in Table 9.1. The predicted tilts provided in this table are the maxima after the completion of each longwall. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 9.1 Maximum Predicted Incremental Conventional Subsidence, Tilt and Curvature for the Dronvisa Quarry within the Study Area Resulting from the Extraction of Longwalls 401 to 408

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})
401 to 402	< 20	< 0.5	< 0.01	< 0.01
403	< 20	0.5	0.09	< 0.01
404	1800	60	2.4	1.3
405	825	60	> 3.0	1.9
406	50	2.0	0.30	0.30
407 to 408	<20	< 0.5	< 0.01	< 0.01

A summary of the maximum predicted values of incremental conventional subsidence, tilt and curvature for the portions of the quarry pits above the longwalls including the proposed future quarry expansion, resulting from the extraction of Longwalls 401 to 408 for the Extraction Plan Layout, is provided in Table 9.3. The predicted tilts provided in this table are the maxima after the completion of each longwall. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 9.2 Maximum Predicted Incremental Conventional Subsidence, Tilt and Curvature for the Dronvisa Quarry (including Future Expansion) Resulting from the Extraction of Longwalls 401 to 408

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})
401 to 402	< 20	< 0.5	< 0.01	< 0.01
403	1800	50	> 3.0	0.55
404	1800	60	2.4	1.3
405	825	60	> 3.0	1.9
406	50	2.0	0.30	0.30
407 to 408	< 20	< 0.5	< 0.01	< 0.01

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the portions of the quarry pits above the longwalls, resulting from the extraction of Longwalls 401 to 408 for the Extraction Plan Layout, is provided in Table 9.3. 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 9.3 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Dronvisa Quarry within the Study Area Resulting from the Extraction of Longwalls 401 to 408

Quarry 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})
Current	1900	60	> 3.0	2.2
Future 7 year plan	1900	60	> 3.0	2.2

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

Table 9.4 Predicted Strains for the Dronvisa Quarry 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	22	13	31

9.1.3. Comparison of the Predictions for the Dronvisa Quarry

A comparison of the maximum predicted subsidence parameters for the quarry resulting from the extraction of Longwalls 401 to 408, with those based on the Approved Layout is provided in Table 8.3.

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

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	1900	60	> 3.0	> 3.0
Extraction Plan Layout	1900	60	> 3.0	2.2

It can be seen from Table 9.5, that the maximum predicted conventional subsidence parameters based on the Extraction Plan Layout are the same or less than those for the Approved Layout.

9.1.4. Impact Assessments and Recommendations for the Dronvisa Quarry

The current extent of the quarry includes a portion of the northern pit located above Longwalls 404 and 405. Future expansion plans for the quarry would result in the southern pit located partially above Longwalls 403 and 404.

The maximum predicted total subsidence parameters for the Dronvisa Quarry based on the Extraction Plan Layout are the same as or less than those for the Approved Layout for Longwalls 401 to 408. The potential impacts for the infrastructure, based on the Extraction Plan Layout, therefore, are the same as or lower than those assessed based on the Approved Layout.

The areas of the quarry located outside the Study Area boundary are not expected to be subjected to measurable conventional vertical subsidence, tilt, curvature or strain. However, the features may experience far-field horizontal movements of up to 70 mm to 200 mm. Based on the low magnitude of mine subsidence movements outside the Study Area boundary the development of adverse impacts to the quarry surface features due to extraction of Longwalls 401 to 408 is considered to be unlikely to occur.

The potential impacts for the current and future areas of the quarry located above the longwalls will experience the full range of predicted conventional subsidence movements. Potential impacts to the quarry pits include cracking, stepping, rippling and ponding of the surfaces. Further discussion on ground surface deformations is provided in Section 4.8.

Future stripping activities within the quarry pits will reduce the depth of cover above the longwall panels. It is expected that the depth of cover would not reduce to below 90 m however surface levels and depth of cover should be confirmed prior to the longwall extraction beneath the quarry. Reducing the depth of cover will not change the maximum predicted subsidence. A reduced depth of cover will however result in an increased risk of irregular movements and associated ground deformations above the longwalls.

It is expected that the impacts to the quarry pits could be remediated by standard ground surface maintenance techniques with the equipment available at the quarry. The repairs would be progressive and, therefore, could be staged to suit the mining of each longwall in sequence.

Management strategies for the quarry should include a monitoring program, trigger action response plans, and mitigation strategies, such as avoidance of active subsidence zones and batter stability.

It is recommended that management strategies be developed in consultation with Dronvisa Quarry to maintain the safety of quarry operations throughout the mining period.

9.2. Millers Dam Compound

9.2.1. Descriptions of the Millers Dam Compound

The Millers Dam compound is located to the west of Longwalls 406 and 407. There are three dams located 200 m to 310 m from the longwalls. Two of the dams have plan dimensions of approximately 70 m x 30 m, in and one larger dam has plan dimensions of approximately 85 m x 130 m. Embankments surrounding the dams are up to approximately 2 m height. Other features located 320 m to 350 m from the longwalls include a groundwater bore, pump house, two above ground concrete storage tanks, telecommunications tower, reverse osmosis plant, cyclone fencing, and underground pipes and power lines. Water pipelines are also located along Ulan road from the Millers Dam compound to the UCM entry road. It is understood that the Dams and plant will be decommissioned in 2021.

The depth of cover at the finishing ends of Longwalls 406 and 407 is approximately 85 m. The Millers Dam Compound are therefore located at 2.4 to 4 times the depth of cover from the longwalls. The water pipelines are located more than 4 times the depth of cover from the longwalls.

9.2.2. Predictions for the Millers Dam Compound

At distances of 200 m or more between the longwalls and the Millers Dam Compound, the site features will not be subjected to measurable conventional mine subsidence ground movements (i.e. less than limits of survey accuracy); however, the site features may experience far-field horizontal movements. Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located greater than 2.4 times the depth of cover from longwalls, is less than 70 mm.

The range of potential strains associated with non-conventional movements has been assessed using monitoring data from previously extracted panels in the NSW Coalfields, for single-seam conditions, where the width-to-depth ratios and extraction heights were similar to those of Longwalls 401 to 408. The 95 % confidence levels for the maximum total strains that the individual survey bays *above solid coal* (between 200 m and 600 m from extracted goaf) experienced at any time during mining are 1.6 mm/m tensile and 1.5 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 2.9 mm/m tensile and 3.0 mm/m compressive. The 75 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 0.5 mm/m both tensile and compressive, which is the typical limit of accuracy of strain measurement by conventional survey methods. It is noted that these results comprise a component of survey tolerance and have also been affected by disturbed survey marks and survey errors.

9.2.3. Impact Assessment and Recommendations for the Millers Dam Compound

The maximum predicted total subsidence parameters for the Millers Dam Compound based on the Extraction Plan Layout are the same as or less than those for the Approved Layout for Longwalls 401 to 408. The potential impacts for the Millers Dam Compound, based on the Extraction Plan Layout, therefore, are the same as or lower than those assessed based on the Approved Layout.

The Millers Dam Compound and water pipelines are located outside the Study Area boundary and are not expected to be subjected to measurable conventional vertical subsidence, tilt, curvature or strain. However, the surface features may experience far-field horizontal movements of up to 70 mm.

At these distances, impacts to the Millers Dam Compound is considered unlikely. The water pipelines are polyethylene pipes laid on or under the ground surface and are able to tolerate significant ground movements. Impacts to the water pipelines at these distances are considered unlikely.

It is recommended that monitoring and management strategies are developed, in consultation with Ulan Coal Mine, to monitor far-field horizontal movements and potential non-conventional movements and manage potential impacts to the compound. It is expected that the Millers Dam Compound and water pipelines can be maintained in serviceable condition with the implementation of the appropriate monitoring and management strategies.

9.3. Exploration Drill Holes

The locations of the exploration drill holes within the Study Area are shown in Drawing No. MSEC1165-08. The drill holes are located directly above and adjacent to the proposed longwalls and, therefore, could experience the full range of predicted subsidence movements, which are described in Chapter 4. It is likely, therefore, that fracturing and shearing would occur in the drill holes as the result of mining. It is recommended that the exploration drill holes are capped (if not already completed) prior to being directly mined beneath.

9.4. Mine Infrastructure Including Tailings Dams or Emplacement Areas

The Coal Handling and Preparation Plant (CHPP) is located 230 m to 650 m to the south of Longwall 401. At these distances, the CHPP is located over 1.5 times the depth of cover from the longwalls.

Dewatering infrastructure is located above the Extraction Plan Layout as shown in Drawing MSEC1165-08. The dewatering infrastructure includes dewatering bores, water pipelines and electrical cables. The polyethylene pipelines and cables are flexible and laid on the ground surface.

At distances of 230 m or more, the CHPP will not be subjected to measurable conventional mine subsidence ground movements (i.e. less than limits of survey accuracy); however, the site features may experience far-field horizontal movements. Fig. 4.5 shows the upper limit of previously observed absolute far-field horizontal movements for the sites located greater than 1.5 times the depth of cover from longwalls, is less than 95 mm.

The CHPP is located above the palaeochannel as shown in Drawing No. MSEC1165-08. As discussed in Section 4.6, the predicted far-field horizontal movements at the CHPP line are expected to be less than the normally predicted far-field horizontal movements because of the presence of unconsolidated sediments in palaeochannels that are up to 40 m thick.

The range of potential strains associated with non-conventional movements has been assessed using monitoring data from previously extracted panels in the NSW Coalfields, for single-seam conditions, where the width-to-depth ratios and extraction heights were similar to those of Longwalls 401 to 408. The 95 % confidence levels for the maximum total strains that the individual survey bays *above solid coal* (between 200 m and 600 m from extracted goaf) experienced at any time during mining are 1.6 mm/m tensile and 1.5 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 2.9 mm/m tensile and 3.0 mm/m compressive. The 75 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining are 0.5 mm/m both tensile and compressive, which is the typical limit of accuracy of strain measurement by conventional survey methods. It is noted that these results comprise a component of survey tolerance and have also been affected by disturbed survey marks and survey errors.

The distances to the CHPP represent greater than 1.5 times the depth of cover from the longwalls. At these distances, it is unlikely that the CHPP will experience impacts due to the extraction of the longwalls.

The dewatering infrastructure is located above the longwalls and will therefore experience the full range of predicted subsidence movements as outlined in Section 4.0 . The pipelines and electrical cables are flexible and laid on the ground surface and are therefore able to tolerate significant ground movements. It is considered unlikely that the pipelines and electrical cables would experience impacts due to conventional ground movements. Potential impacts could occur as a result of irregular movements such as ground heave, stepping, large cracks, rockfalls or tree falls. It is expected that impacts to the pipelines and cables could be readily remediated if they occur. Where dewatering bores are located above the extracted panels, it is likely, that fracturing and shearing would occur in the drill holes as the result of mining. It is recommended that the bores are capped prior to being directly mined beneath.

It is recommended that monitoring and management strategies are developed, to monitor far-field horizontal movements and potential non-conventional movements and manage potential impacts to the CHPP. Visual monitoring and management strategies should also be developed for the dewatering infrastructure. It is expected that the CHPP and dewatering infrastructure can be maintained in serviceable condition with the implementation of the appropriate monitoring and management strategies.

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

The following sections provide the descriptions, predictions of subsidence movements and impact assessments for the archaeological and heritage sites located within the Study Area for Longwalls 401 to 408. 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 46 Aboriginal heritage sites identified within the Study Area which include rock shelters, isolated finds, artefact scatters, PADs and grinding grooves. Eight of the sites have been salvaged. Impact assessments have been provided below for the remaining 38 unsalvaged sites. The locations of the Aboriginal heritage sites within the Study Area are shown in Drawing No. MSEC1165-08.

Detailed descriptions and assessments of the Aboriginal heritage sites are provided in the report by Niche Environment and Heritage (2021-a).

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 predictions have been provided based on the Extraction Plan Layout, as well as for the Approved Layout (LW1 to 8) for comparison.

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the Aboriginal heritage sites, resulting from the extraction of Longwalls 401 to 408 for the Extraction Plan Layout, is provided in Table 10.1. The predicted tilts provided in this table are the maxima after the completion of all the longwalls. The predicted curvatures are the maxima at any time during or after the extraction of the longwalls.

Table 10.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Aboriginal Heritage Sites within the Study Area due to the Extraction of Longwalls 401 to 408

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})
Artefacts	1850	35	2.8	0.95
Artefacts and PAD	1650	30	2.5	0.70
Artefacts (Isolated Find)	1900	30	2.9	0.9
Shelter	80	5	0.1	<0.01
Shelter with Artefacts	1850	35	2.9	1.1
Shelter with Art, Artefacts and Grinding Grooves (S1MC280; Ulan Creek 2)	150	4	0.25	<0.01
Shelter with Artefacts and PAD	1500	35	2.4	0.85
Shelter with Grinding Groove, Artefact and PAD	1150	30	1.8	0.6
Shelter with PAD	1900	40	2.9	1.0

The maximum predicted conventional tilt for the Aboriginal heritage sites is 40 mm/m (i.e. 4.0 %, or 1 in 25). The maximum predicted conventional curvatures for these sites are greater than 2.9 km^{-1} hogging and 1.1 km^{-1} sagging, which represents minimum radii of curvature of 340 m and 900 m respectively.

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

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

Type	Conventional based on 10 times Curvature (mm/m)	Non-conventional based on the 95 % Confidence Level (mm/m)	Non-conventional based on the 99 % Confidence Level (mm/m)
Tension	25	10	22
Compression	9	13	31

10.1.3. Comparisons of the Predictions for the Aboriginal Heritage Sites

Comparisons of the maximum predicted conventional subsidence parameters for the Aboriginal heritage sites within the Study Area, resulting from the extraction of Longwalls 401 to 408, with those based on the Approved Layout are provided in Table 10.3. A comparison of the maximum predicted subsidence parameters for each of the Aboriginal heritage sites located within the Study Area is also provided in Table D.01, in Appendix D.

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

Layout	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Approved Layout	1900	40	2.9	1.0
Extraction Plan Layout	1900	40	2.9	1.0

It can be seen from Table D.01 in Appendix D that the predicted subsidence parameters based on the Extraction Plan Layout are the same as those based on the Approved Layout. The potential impacts for the Aboriginal heritage sites based on the Extraction Plan Layout, therefore, are the same as those based on the Approved Layout.

10.1.4. Impact Assessments and Recommendations for the Aboriginal Heritage Sites

The Stage 1 Project Approval lists the following Subsidence Impact Performance Measures in Table 14 for the Aboriginal Heritage Sites:

Aboriginal heritage sites 264, 282, 283, 286 and 287 (see Appendix 7)	*Reduce the likelihood of subsidence damage to low*
Aboriginal heritage site 280 (see Appendix 7)	*Reduce the likelihood of subsidence damage to moderate*

Aboriginal heritage sites 264, 282, 283, 286 and 287 are located to the north of the Study Area and are unlikely to experience impacts due to the extraction of Longwalls 401 to 408.

Site 280 includes a rock shelter with hand stencils, artefacts and grinding grooves and has jointing at 5 m to 10 m spacing with some collapsed rock. The site is located centrally above the chain pillar between Longwalls 402 and 403.

The predicted total vertical subsidence at Site 280 is 150 mm and total tilt is 4.0 mm/m (i.e. 0.4 %, or 1 in 250). The site is unlikely to be impacted by this magnitude of tilt. The site will experience hogging curvature due to the extraction of Longwalls 402 and 403. The maximum predicted total hogging curvature during or after the extraction of the longwalls is 0.25 km^{-1}, which equates to a radius of curvature of 5 km. The site is located in a net tensile zone. The predicted tensile strain based on 10 times hogging curvature is 2 mm/m. Tensile strains of greater than approximately 0.5 mm/m are considered to be sufficient to result in tensile cracking of sandstone. The rock shelter is an isolated site within a small area of steep slopes at a topographical high point. The risk of subsidence impacts to Site 280 is low to moderate consistent with the approved impacts, and includes tensile cracks and instabilities. Large scale failure of the rock shelter is not expected to occur and the likelihood of tensile cracks coinciding with the location of the grinding grooves and art is considered to be low.

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

Whilst it is unlikely that the scattered artefacts or isolated finds themselves would be impacted by mine subsidence, it is possible that, if remediation works to the surface areas around the Aboriginal heritage sites was required after mining, these works could potentially impact on the Aboriginal heritage sites. A discussion on surface cracking resulting from the extraction of Longwalls 401 to 408 is provided in Section 4.8.

Rock shelters and overhangs in the Study Area and above the extracted longwalls are predicted to be subject to similar impacts as described for minor cliffs in Section 5.6 (i.e. potential for fracturing of sandstone and subsequent rockfalls).

Further details and discussions on the potential impacts on the archaeological sites resulting from the extraction of the Extraction Plan Layout are provided in the report by Niche Environment and Heritage (2021-a). Management of Aboriginal heritage sites will be outlined in a 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 locations of survey marks outside the Study Area are shown in Drawing No. MSEC1165-08. The survey marks are predominantly located along road and railway easements.

At these locations the survey marks will not be subjected to measurable conventional mine subsidence ground movements due to the Extraction Plan Layout; however, they may experience far-field horizontal movements as discussed in Section 4.6. The potential impacts on the survey marks based on the Extraction Plan Layout, are the same as those based on the Approved Layout.

It will be necessary on the completion of the longwalls, i.e. when the ground has stabilised, to re-establish the exact location of the survey marks. Consultation between MCO and Land and Property Information (LPI) NSW will be required throughout the mining period to ensure that the survey marks are not used for detailed surveying purposes by others and that they are reinstated at an appropriate time, as required.

It is recommended that management strategies are developed, in consultation with LPI 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;
- 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).
Approved Layout	Secondary extraction footprint consistent with the Project Approval (05_0117), as modified, with an extraction height of 3.0m.
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.
Extraction Plan Layout	Secondary extraction footprint of the extraction plan
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

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 1 Resulting from the Extraction of Longwalls 401 to 408

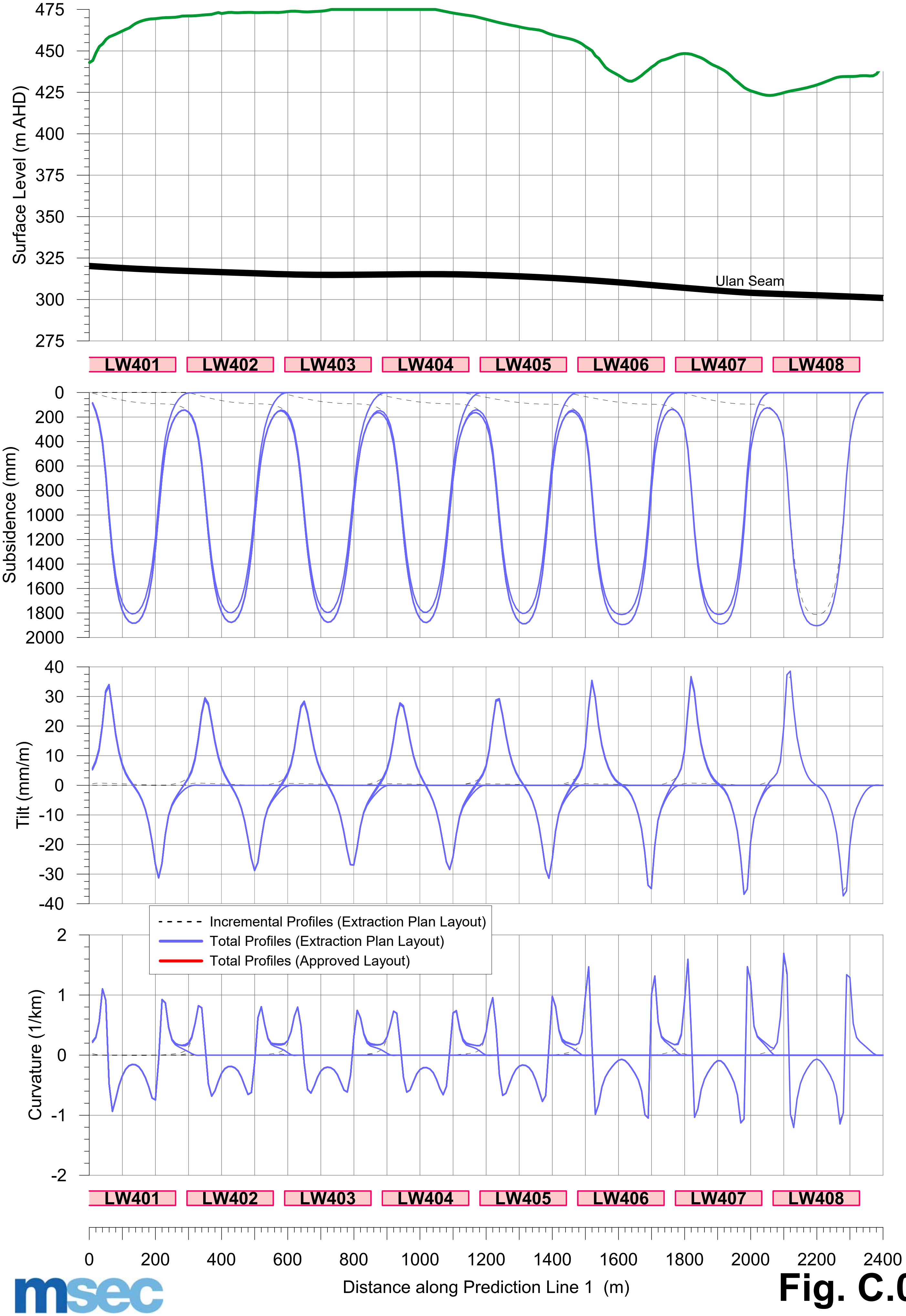

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Fig. C.01

Predicted Profiles of Subsidence, Tilt and Curvature along Bora Creek due to LW401 to 408

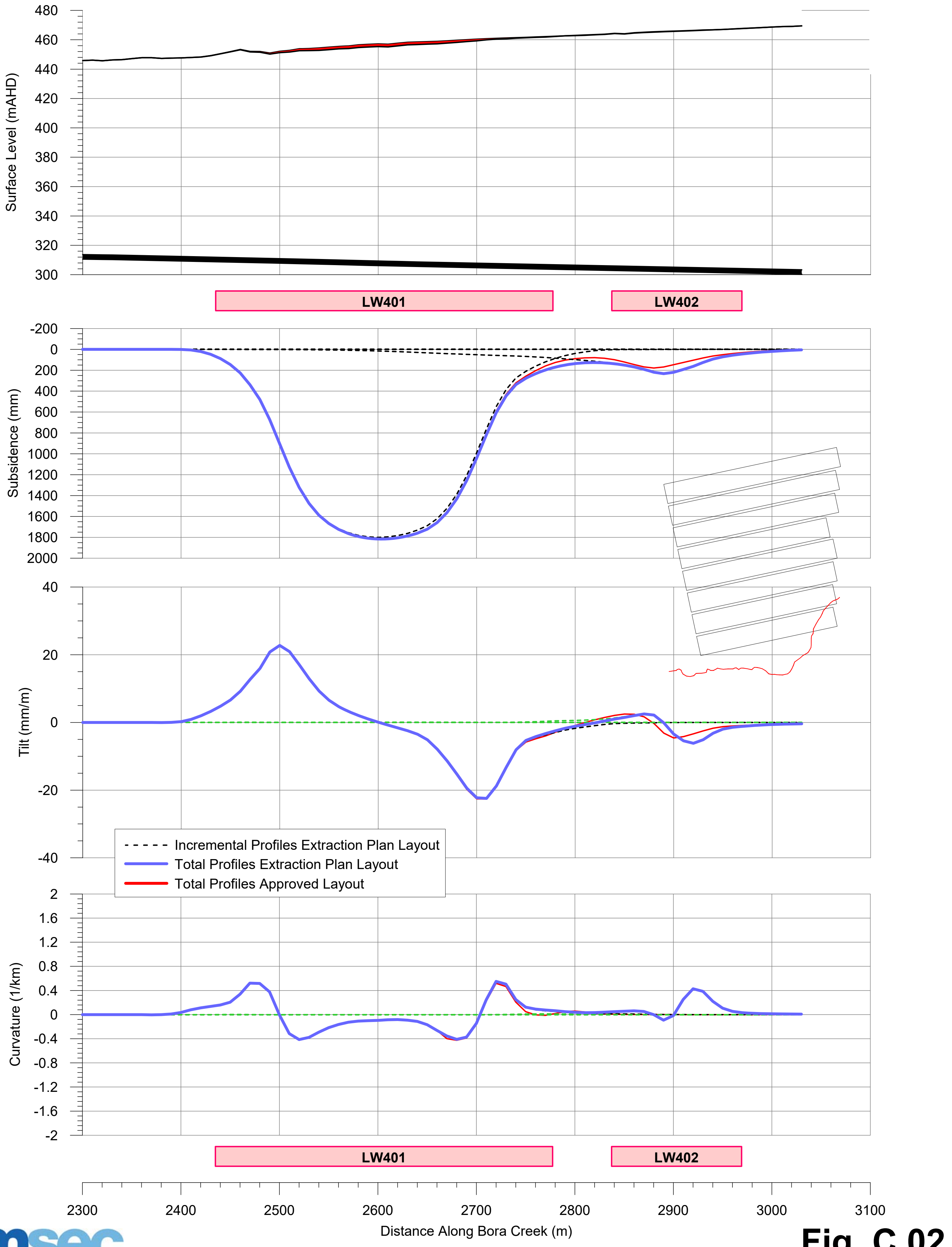

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Fig. C.02

Predicted Profiles of Subsidence, Tilt and Curvature along Drainage Line 1 due to LW401 to 408

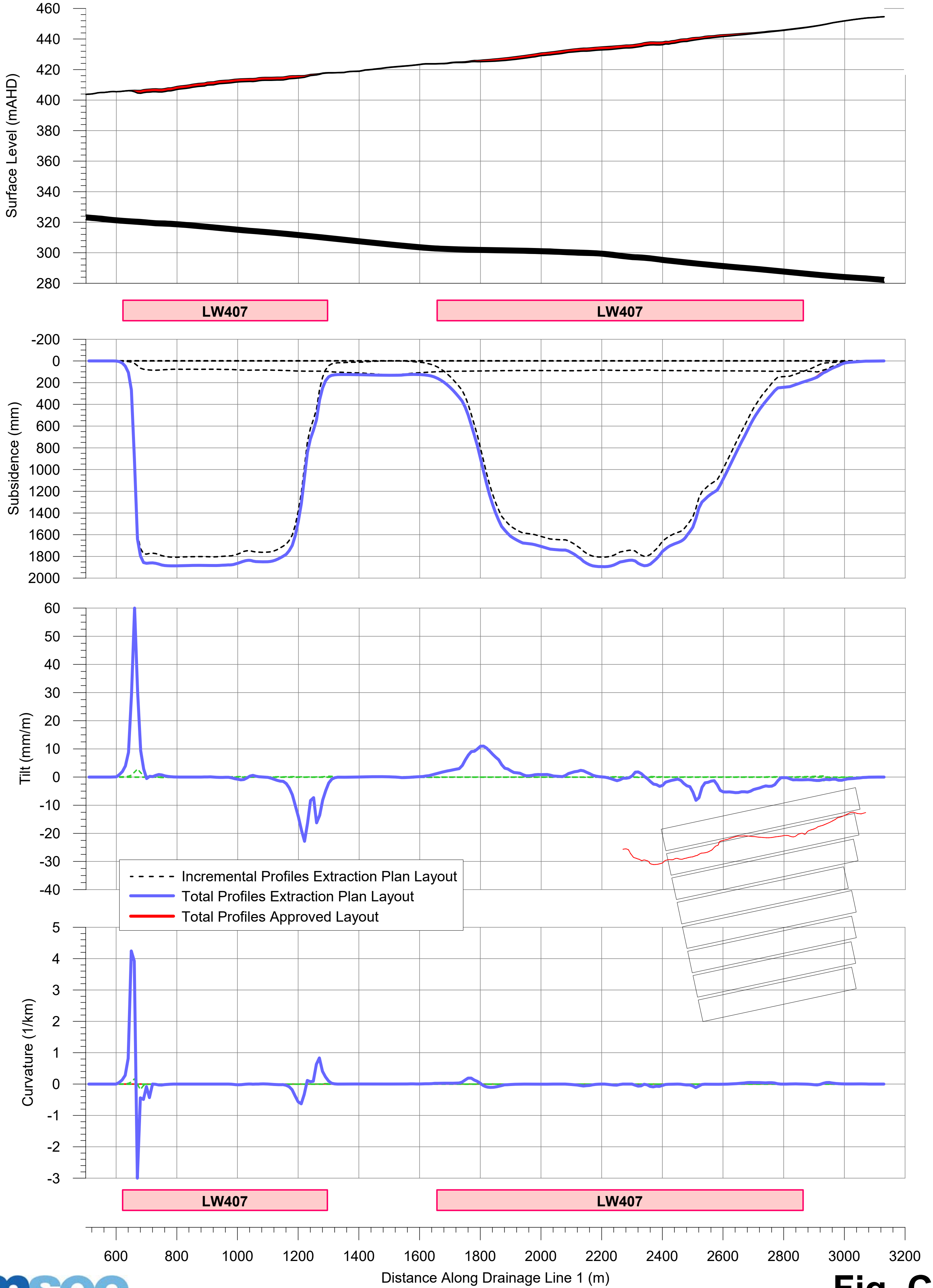

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Fig. C.03

Predicted Profiles of Subsidence, Tilt and Curvature along Drainage Line 2 due to LW401 to 408

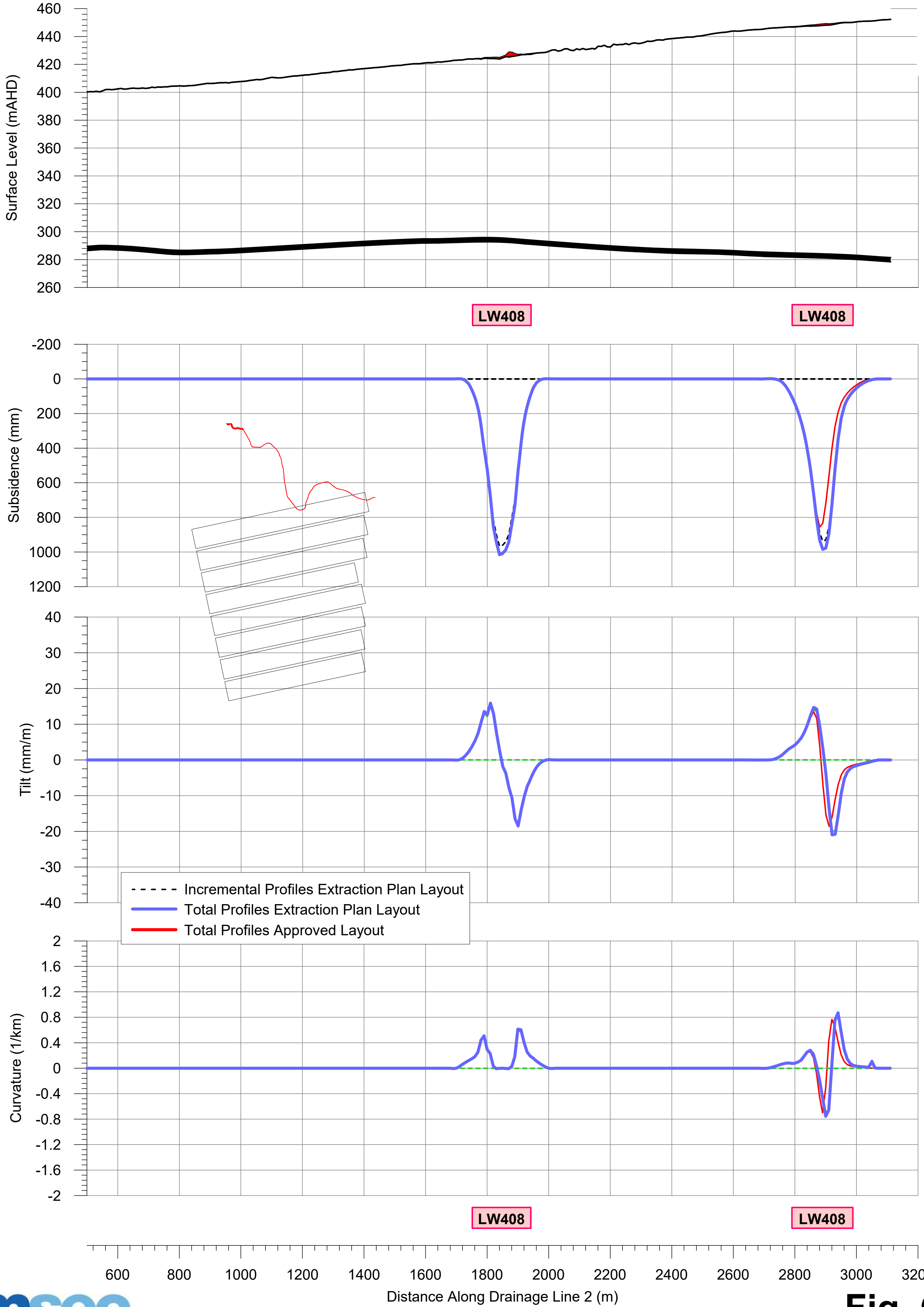

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Fig. C.04

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 (LW401-408) (mm)*	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW401 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW402 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW403 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW404 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW405 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW406 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW407 (mm)
S1MC256	Artefact Scatter	*1750*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC257	Artefact Scatter	*1850*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC258	Artefact Scatter	*1000*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC259	Isolated Find	*550*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC260	Isolated Find	*1800*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC261	Shelter with Artefacts	*800*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC262	Isolated Find	*375*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC271	Shelter with Artefacts	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC273	Isolated Find	*225*	< 20	< 20	< 20	< 20	50	200	225
S1MC280; Ulan Creek 2	Shelter with Artefacts and Grinding	*150*	< 20	100	150	150	150	150	150
S1MC290	Shelter with Artefacts	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC291	Isolated Find	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC294	Shelter with Artefacts	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC321 (NB9)	Isolated Find	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC322 (NB10)	Artefact Scatter and PAD	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC356b	Isolated Find	*1900*	< 20	< 20	< 20	< 20	< 20	1800	1900
S1MC358b	Shelter with PAD	*725*	< 20	< 20	< 20	< 20	625	725	725
S1MC465	Artefact Scatter	*1650*	< 20	< 20	< 20	< 20	< 20	< 20	1550
S1MC464	Artefact Scatter	*1650*	< 20	< 20	< 20	< 20	< 20	< 20	1550
S1MC466	Shelter with Artefacts and PAD	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC468	Shelter with Artefacts and PAD	*1400*	< 20	< 20	< 20	< 20	< 20	< 20	1300
S1MC478	Artefact Scatter	*1800*	1800	1800	1800	1800	1800	1800	1800
S1MC474	Shelter with Artefacts and PAD	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC475	Shelter with Grinding Groove	*1150*	1150	1150	1150	1150	1150	1150	1150

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

Site	Description	*Maximum Predicted Subsidence based on the Approved Layout (LW401-408) (mm)*	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW401 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW402 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW403 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW404 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW405 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW406 (mm)	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW407 (mm)
S1MC479	Artefact Scatter and PAD	*50*	325	375	375	375	375	375	375
S1MC484	Shelter with Artefacts	*1850*	< 20	< 20	< 20	< 20	< 20	1800	1850
S1MC471	Shelter with PAD	*1850*	< 20	< 20	< 20	< 20	< 20	1800	1850
S1MC485	Shelter with PAD	*1800*	< 20	< 20	< 20	< 20	1750	1800	1800
S1MC472	Shelter with Artefacts and PAD	*200*	30	200	200	200	200	200	200
S1MC473	Shelter with PAD	*1900*	< 20	1800	1900	1900	1900	1900	1900
S1MC477	Shelter with PAD	*1500*	< 20	< 20	< 20	< 20	< 20	< 20	1450
S1MC486	Shelter with PAD	*1800*	< 20	1750	1800	1800	1800	1800	1800
S1MC487	Shelter	*80*	70	80	80	80	80	80	80
S1MC488	Shelter with Artefacts and PAD	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	< 20
S1MC490	Shelter with PAD	*60*	60	60	60	60	60	60	60
S1MC491	Shelter with PAD	*325*	325	325	325	325	325	325	325
S1MC494	Shelter with Artefacts and PAD	*1500*	< 20	< 20	< 20	< 20	< 20	< 20	1450
S1MC483	Shelter with PAD	*< 20*	< 20	< 20	< 20	< 20	< 20	< 20	< 20

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

Site	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW408 (mm)	*Maximum Predicted Tilt based on the Approved Layout (LW401-408) (mm/m)*	Maximum Predicted Tilt based on the Extraction Plan Layout (mm/m)	*Maximum Predicted Hogging Curvature based on the Approved Layout (LW401-408) (1/km)*	Maximum Predicted Hogging Curvature based on the Extraction Plan Layout (1/km)	*Maximum Predicted Sagging Curvature based on the Approved Layout (LW401-408) (1/km)*	Maximum Predicted Sagging Curvature based on the Extraction Plan Layout (1/km)
S1MC256	1750	*35.0*	35.0	*2.70*	2.70	*0.90*	0.90
S1MC257	1850	*30.0*	30.0	*2.80*	2.80	*0.90*	0.90
S1MC258	1000	*35.0*	35.0	*1.60*	1.60	*0.40*	0.35
S1MC259	550	*25.0*	25.0	*0.85*	0.85	*< 0.01*	< 0.01
S1MC260	1800	*30.0*	30.0	*2.80*	2.80	*0.90*	0.90
S1MC261	800	*35.0*	35.0	*1.30*	1.30	*< 0.01*	< 0.01
S1MC262	375	*18.0*	18.0	*0.60*	0.60	*< 0.01*	< 0.01
S1MC271	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S1MC273	225	*5.0*	5.0	*0.35*	0.35	*< 0.01*	< 0.01
S1MC280; Ulan Creek 2	150	*4.0*	4.0	*0.25*	0.25	*< 0.01*	< 0.01
S1MC290	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S1MC291	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S1MC294	30	*0.5*	1.0	*0.03*	0.04	*< 0.01*	< 0.01
S1MC321 (NB9)	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S1MC322 (NB10)	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S1MC356b	1900	*9.0*	9.0	*2.90*	2.90	*0.40*	0.40
S1MC358b	725	*40.0*	40.0	*1.10*	1.10	*< 0.01*	< 0.01
S1MC465	1650	*30.0*	30.0	*2.50*	2.50	*0.70*	0.70
S1MC464	1650	*35.0*	35.0	*2.60*	2.60	*0.95*	0.95
S1MC466	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01
S1MC468	1400	*30.0*	30.0	*2.20*	2.20	*0.85*	0.85
S1MC478	1800	*5.5*	5.5	*2.80*	2.80	*0.25*	0.25
S1MC474	< 20	*1.0*	1.0	*0.01*	0.01	*< 0.01*	< 0.01
S1MC475	1150	*30.0*	30.0	*1.80*	1.80	*0.60*	0.60

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

Site	Maximum Predicted Subsidence based on the Extraction Plan Layout after LW408 (mm)	*Maximum Predicted Tilt based on the Approved Layout (LW401-408) (mm/m)*	Maximum Predicted Tilt based on the Extraction Plan Layout (mm/m)	*Maximum Predicted Hogging Curvature based on the Approved Layout (LW401-408) (1/km)*	Maximum Predicted Hogging Curvature based on the Extraction Plan Layout (1/km)	*Maximum Predicted Sagging Curvature based on the Approved Layout (LW401-408) (1/km)*	Maximum Predicted Sagging Curvature based on the Extraction Plan Layout (1/km)
S1MC479	375	*1.5*	18.0	*0.08*	0.60	*< 0.01*	0.10
S1MC484	1850	*20.0*	20.0	*2.90*	2.90	*1.10*	1.10
S1MC471	1850	*25.0*	25.0	*2.90*	2.90	*1.00*	1.00
S1MC485	1800	*30.0*	30.0	*2.80*	2.80	*1.00*	1.00
S1MC472	200	*5.5*	5.5	*0.30*	0.30	*< 0.01*	< 0.01
S1MC473	1900	*13.0*	13.0	*2.90*	2.90	*0.55*	0.55
S1MC477	1500	*35.0*	35.0	*2.40*	2.30	*0.85*	0.85
S1MC486	1800	*25.0*	25.0	*2.80*	2.80	*0.90*	0.90
S1MC487	80	*5.0*	5.0	*0.10*	0.10	*< 0.01*	< 0.01
S1MC488	< 20	*1.0*	1.0	*0.01*	0.01	*< 0.01*	< 0.01
S1MC490	60	*4.0*	4.0	*0.09*	0.09	*< 0.01*	< 0.01
S1MC491	325	*13.0*	13.0	*0.50*	0.50	*< 0.01*	< 0.01
S1MC494	1500	*35.0*	35.0	*2.40*	2.40	*0.80*	0.80
S1MC483	< 20	*< 0.5*	< 0.5	*< 0.01*	< 0.01	*< 0.01*	< 0.01

APPENDIX E. DRAWINGS

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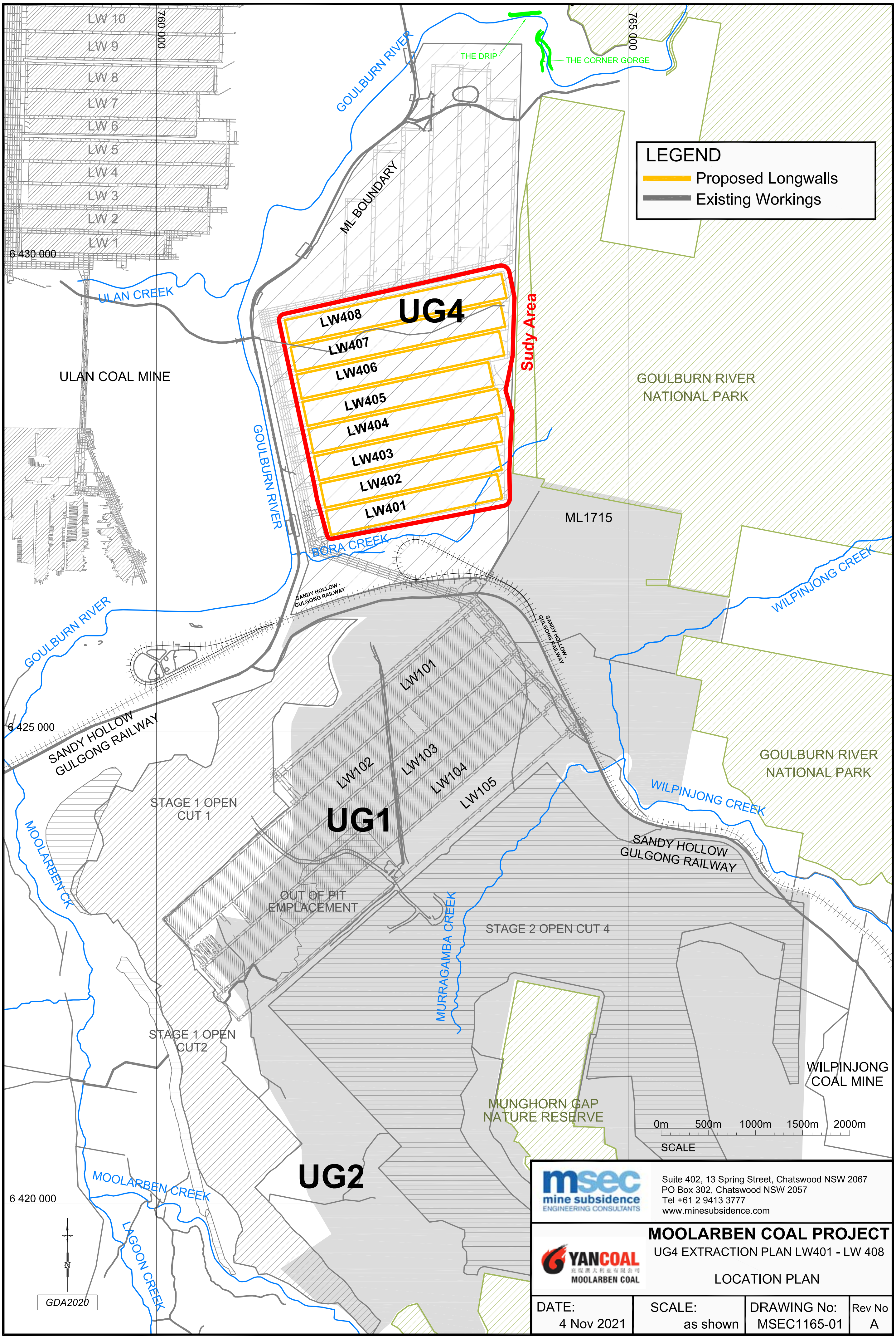

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UG4 EXTRACTION PLAN LW401 - LW 408

LOCATION PLAN

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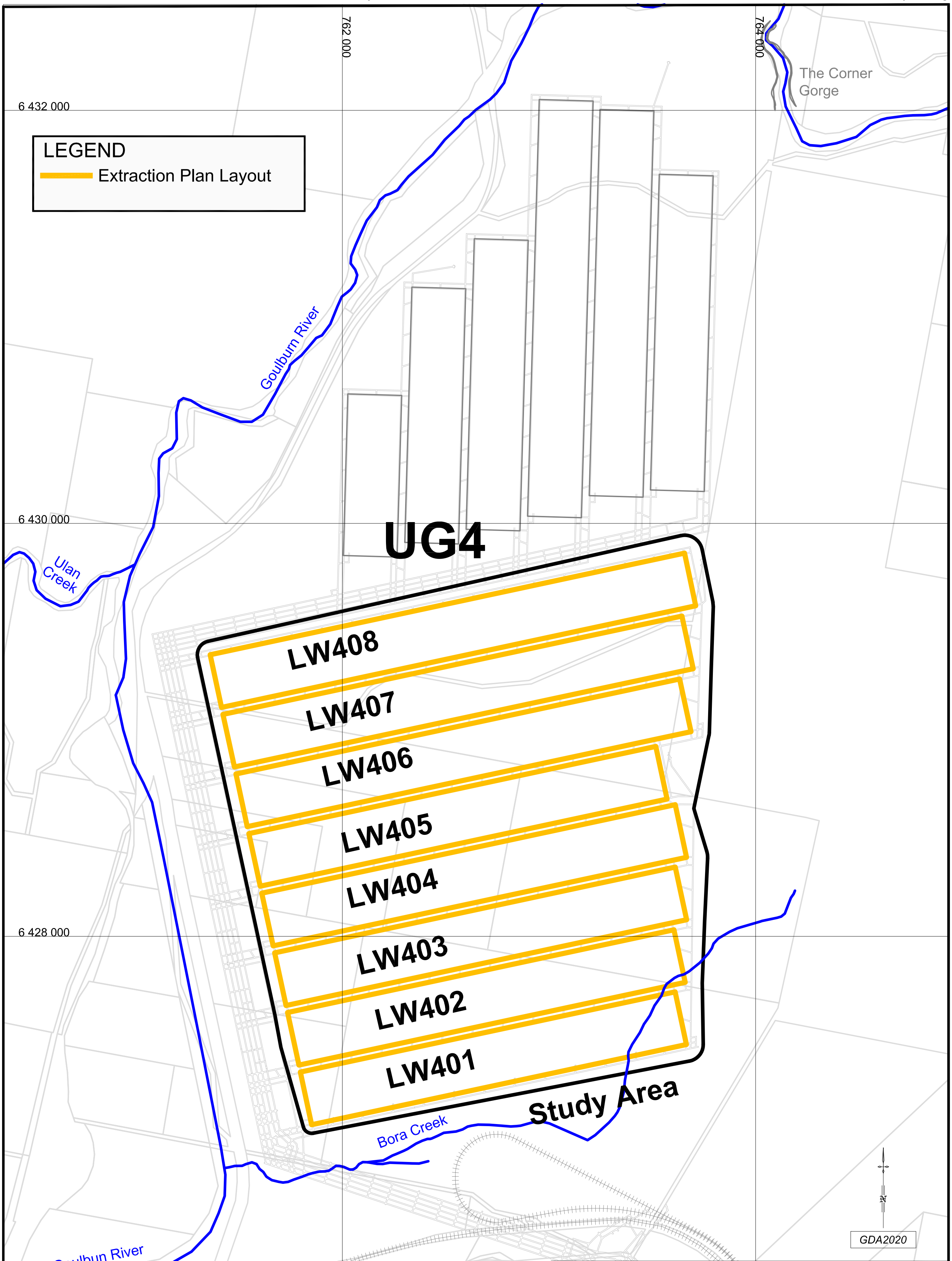
4 Nov 2021	as shown	MSEC1165-01	A



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GENERAL LAYOUT

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4 Nov 2021	as shown	MSEC1165-02	A

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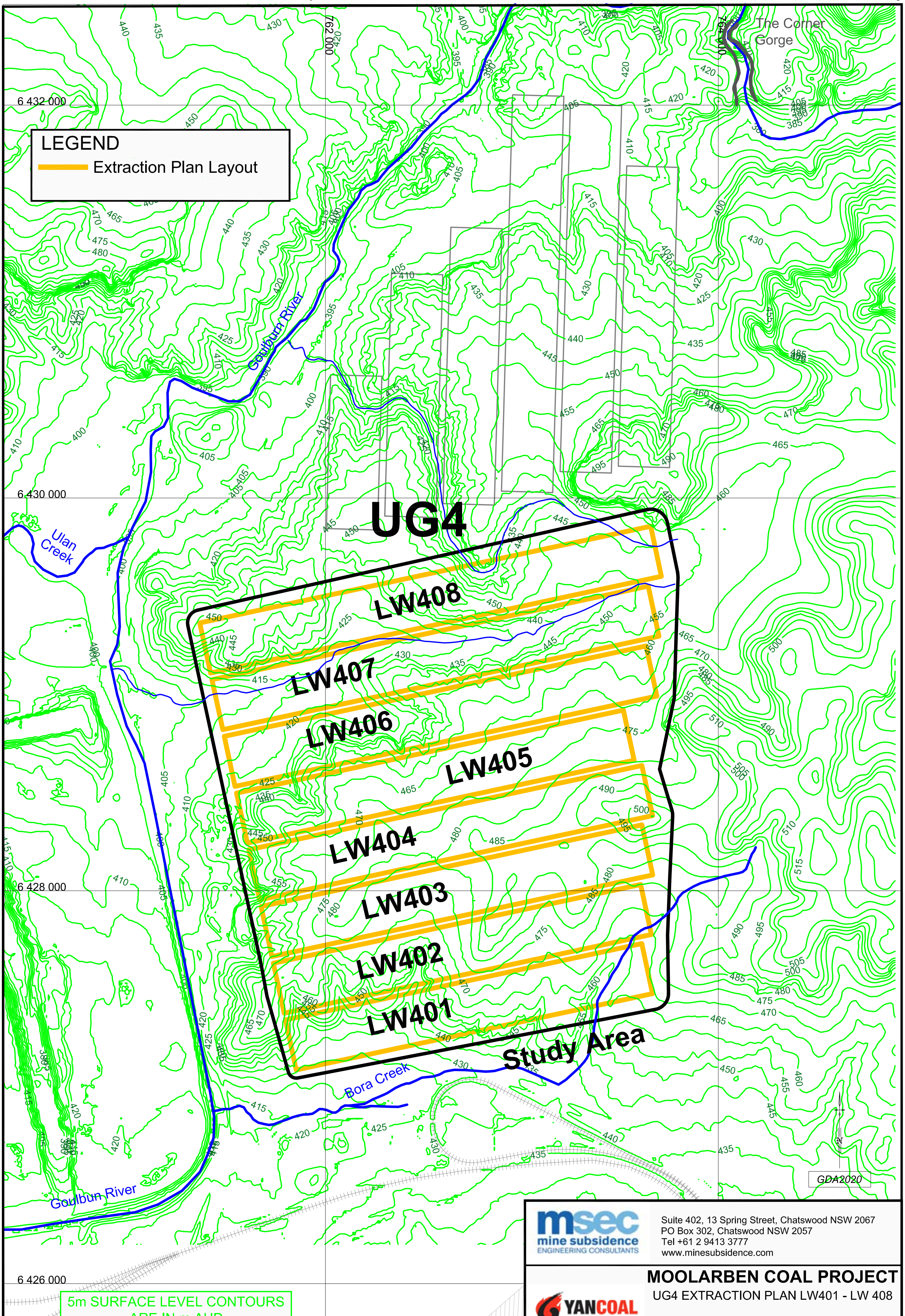

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YANCOAL MOOLARBEN COAL	**MOOLARBEN COAL PROJECT** UG4 EXTRACTION PLAN LW401 - LW 408 SURFACE LEVEL CONTOURS

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4 Nov 2021	as shown	MSEC1165-03	A

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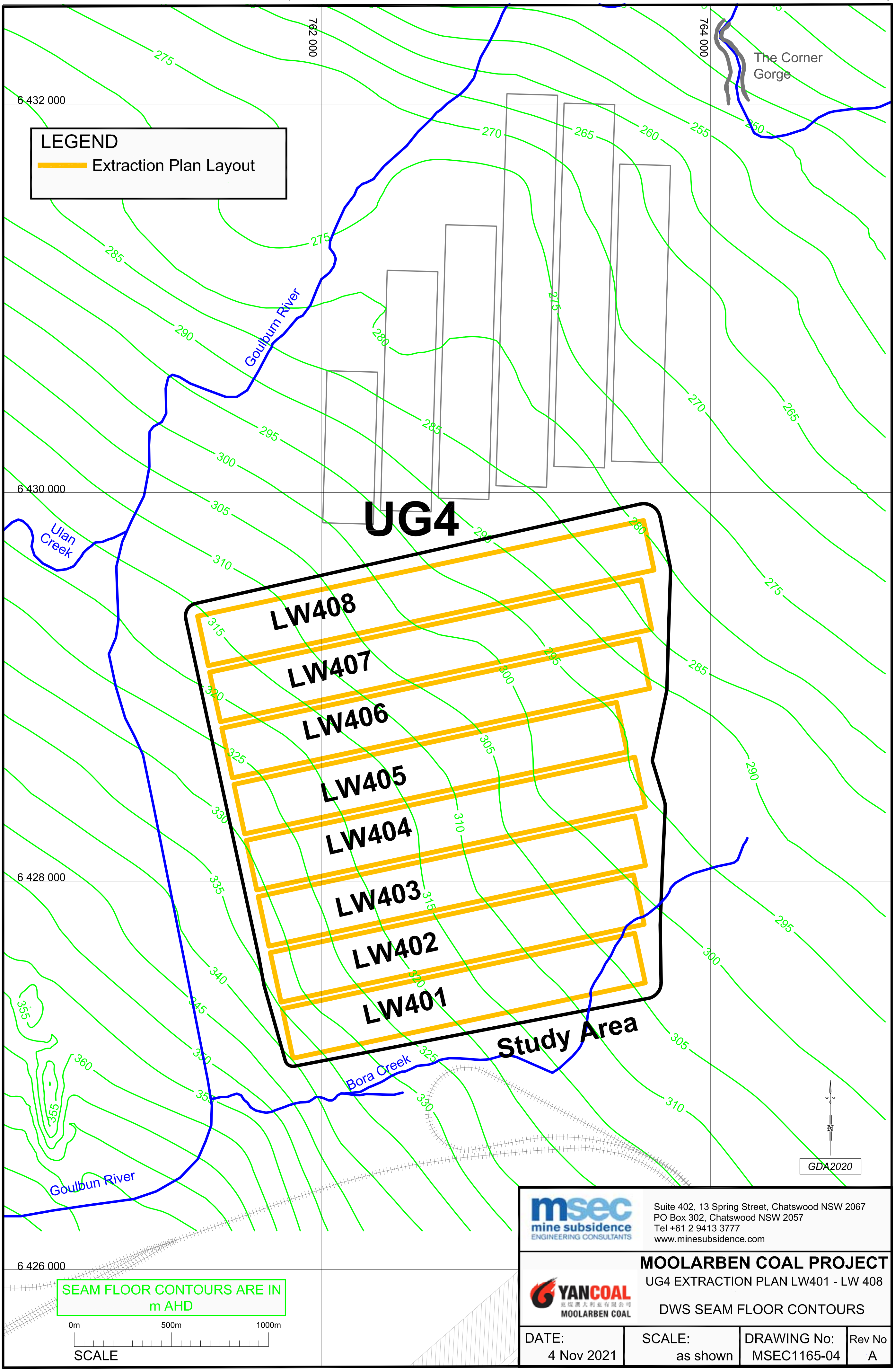

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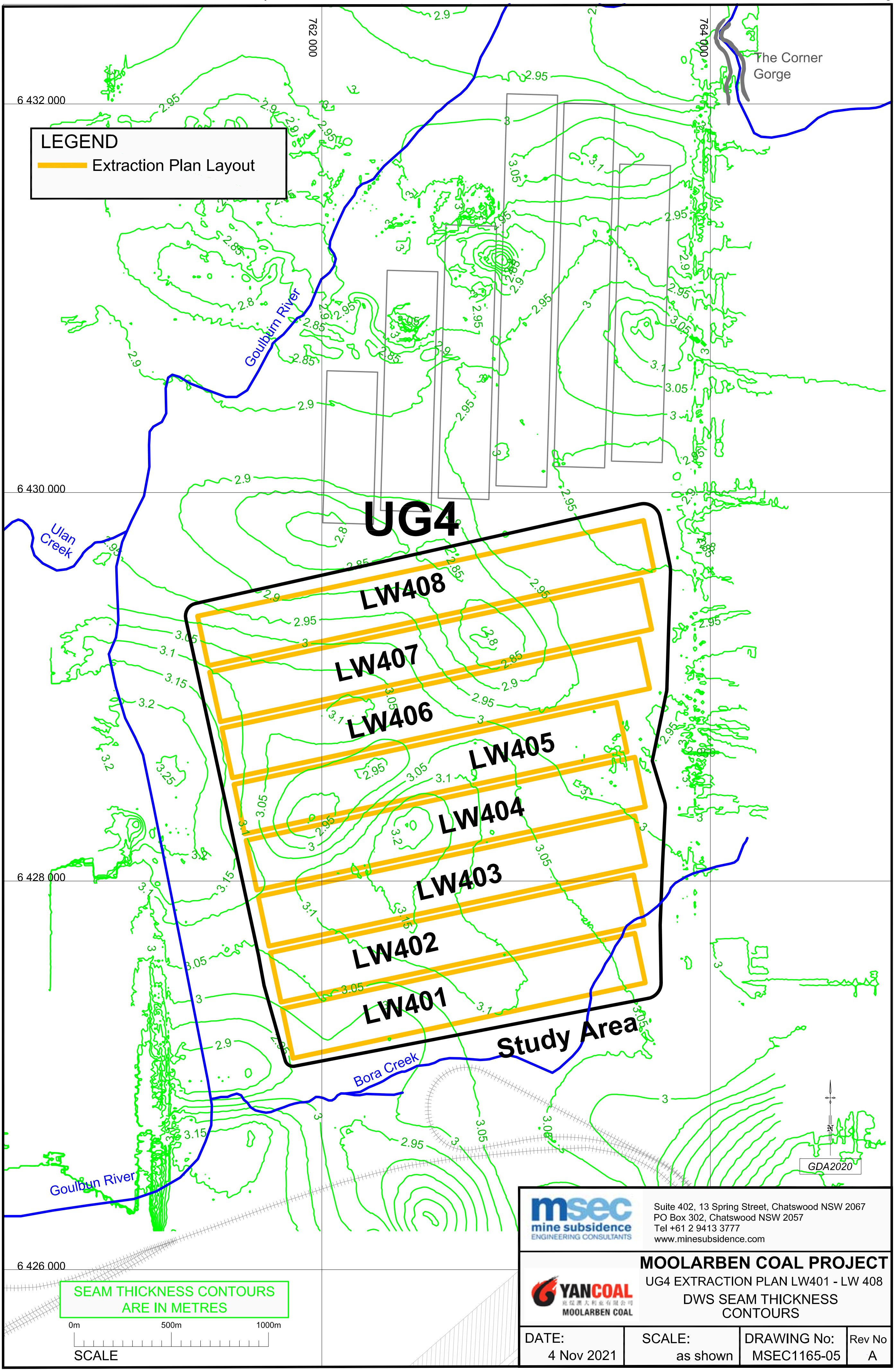

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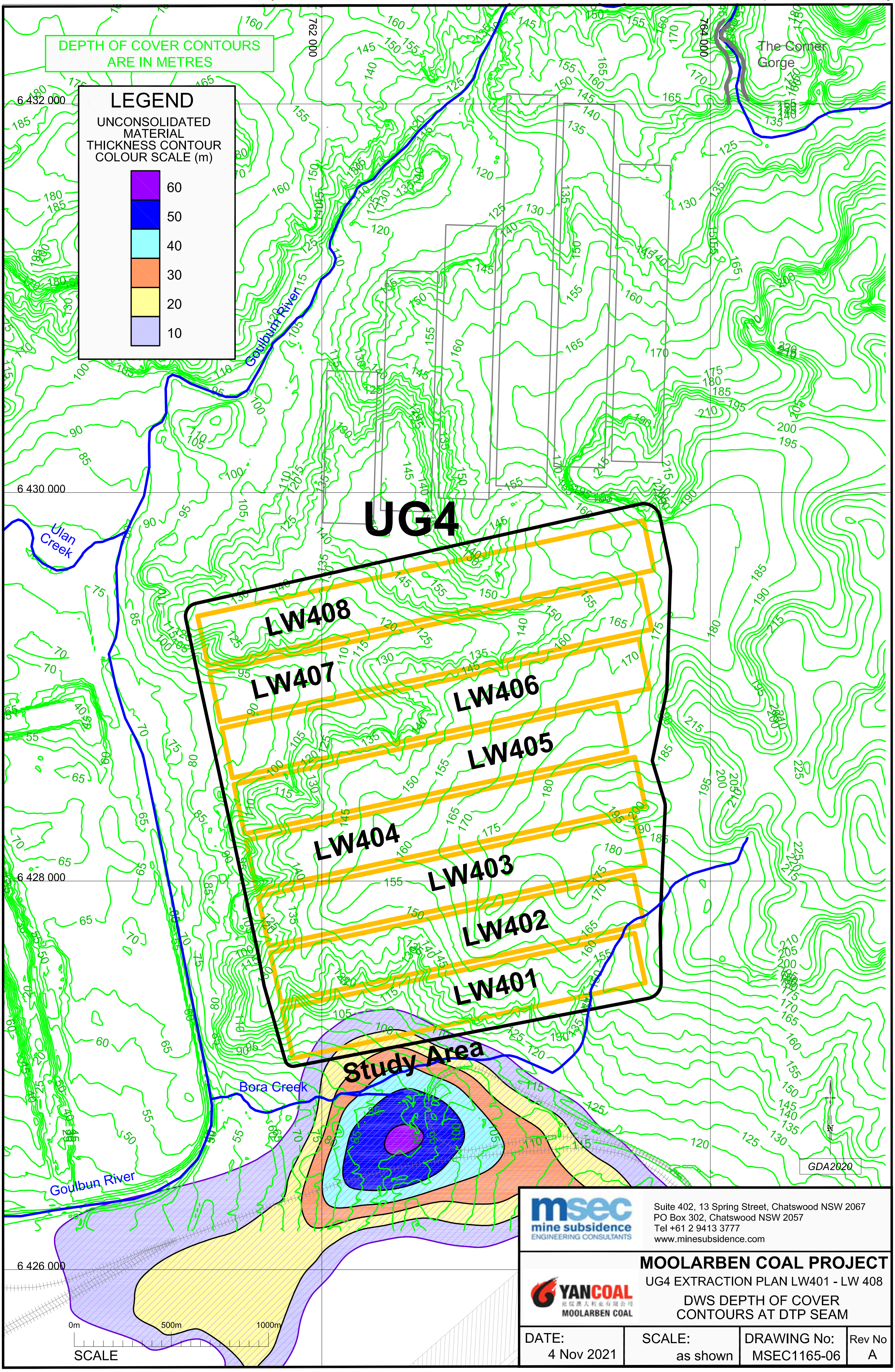

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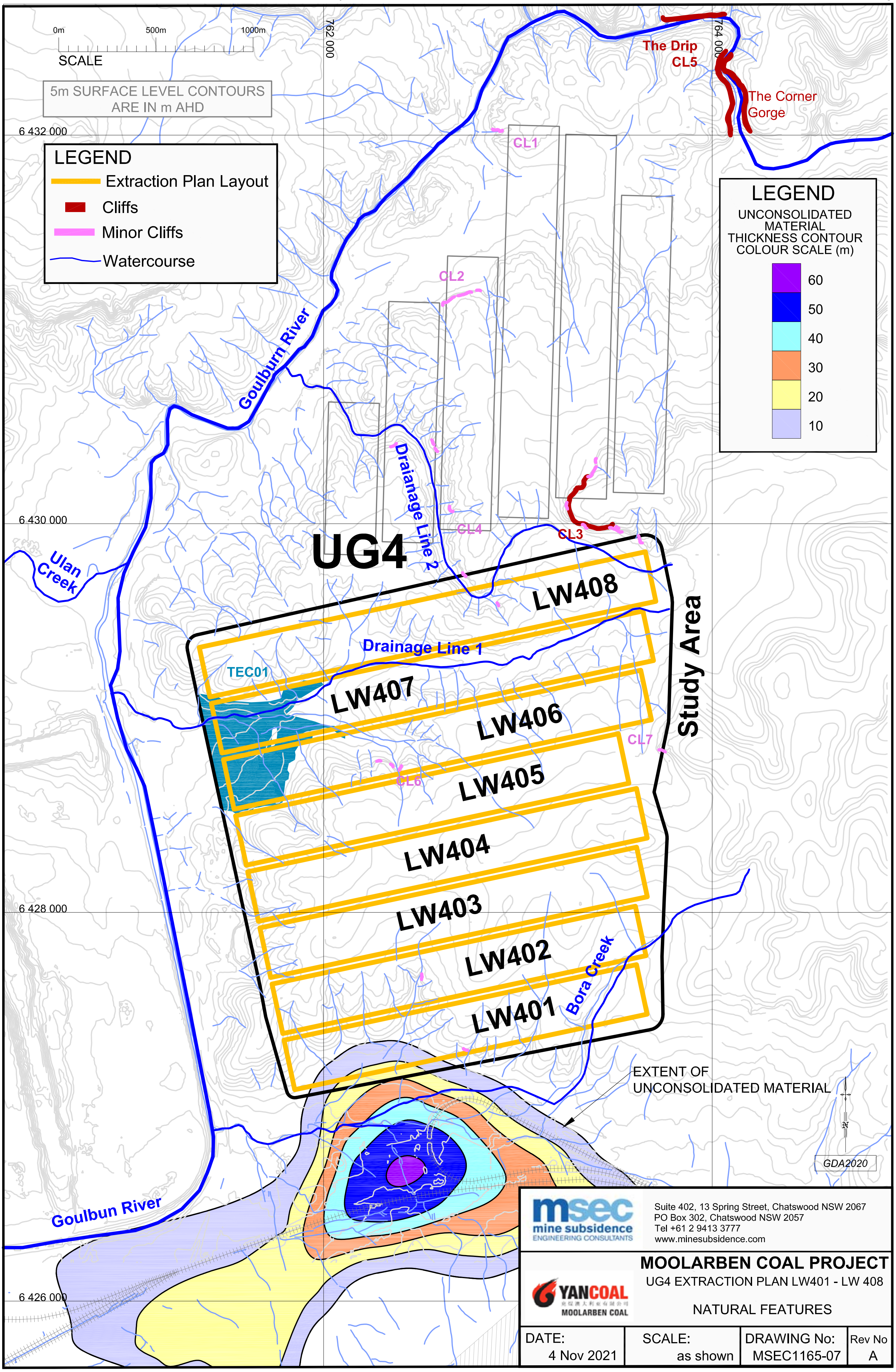

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NATURAL FEATURES

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UG4 EXTRACTION PLAN LW401 - LW 408

BUILT FEATURES

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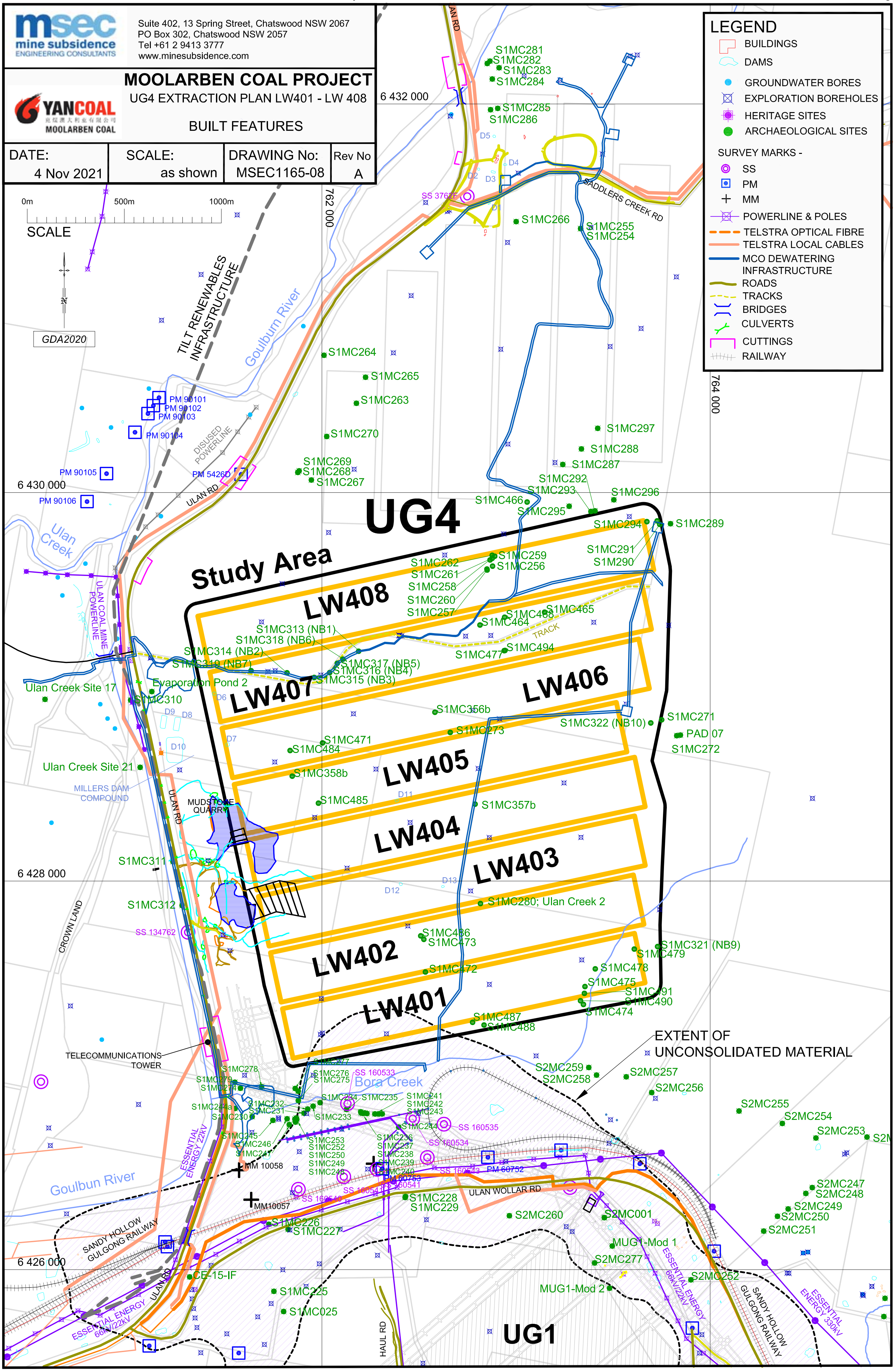
4 Nov 2021	as shown	MSEC1165-08	A



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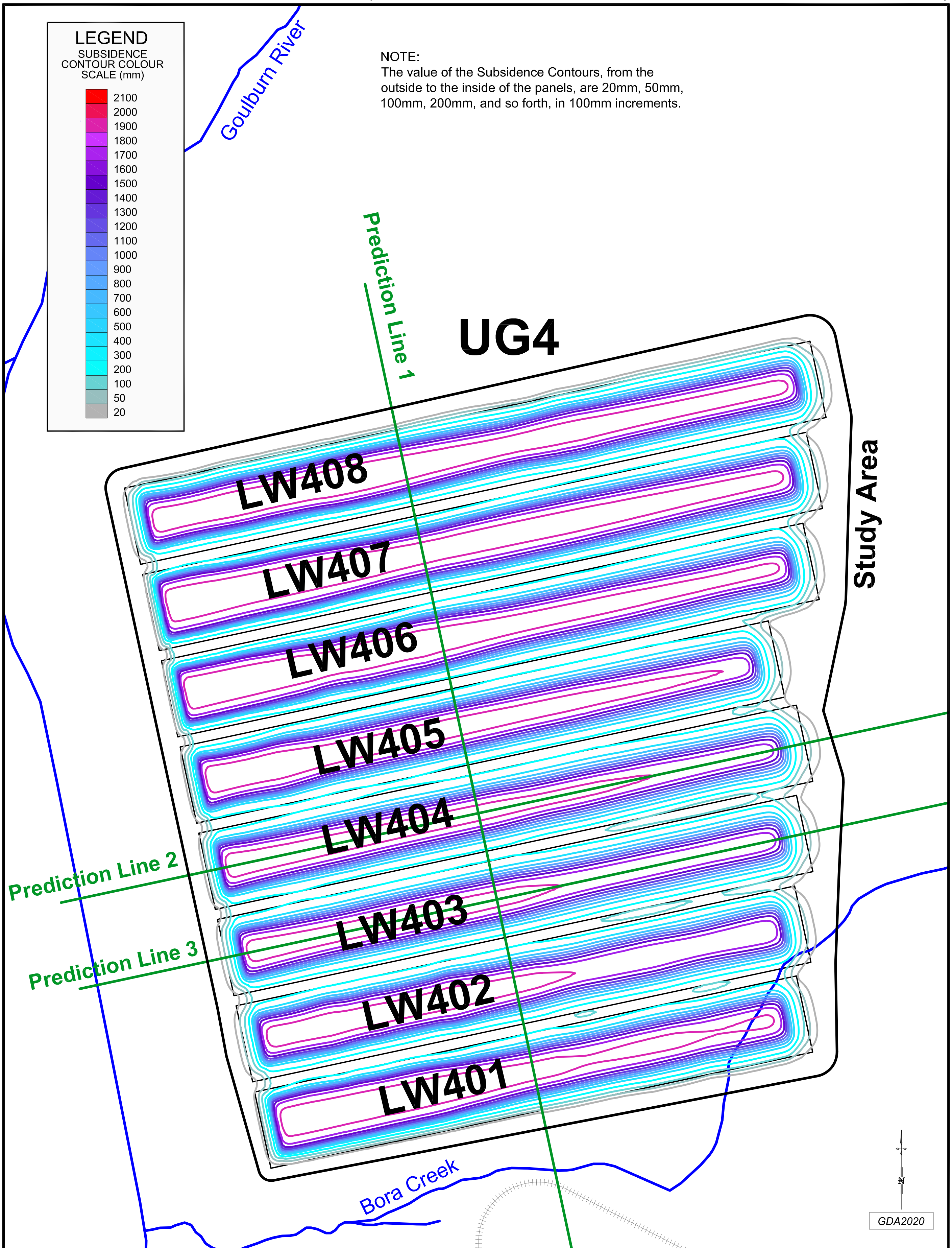

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UG4 EXTRACTION PLAN LW401 - LW 408

PREDICTED TOTAL SUBSIDENCE CONTOURS AFTER LW408

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4 Nov 2021	as shown	MSEC1165-09	A