Attachment C – Subsidence Predictions and Impact Assessments

ILLAWARRA METALLURGICAL COAL:

Dendrobium – Longwalls 22 and 23

Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwalls 22 and 23 in Area 3C at Dendrobium Mine

DOCUMENT REGISTER

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01	Draft issue	JB	-	12 Oct 20
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A	Final issue	JB	KK	31 Mar 21
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Report produced to: Support the Subsidence Management Plan Application for the proposed Longwalls 22 and 23 at Dendrobium Mine to be issued to the Department of Planning and Environment.

Previous reports:

WKA77 (January 2001) – Dendrobium Mine Project – Report on the Prediction of Mining Subsidence Parameters and the Assessment of Impacts on Surface Infrastructure – Longwalls 1 to 18 (In support of the EIS).

MSEC311 (Rev. D) – The Prediction of Subsidence Parameters and the Assessment of Mine Subsidence Impacts on Natural Features and Surface Infrastructure Resulting from the Extraction of Proposed Longwalls 6 to 10 in Area 3A and Future Longwalls in Areas 3B and 3C at Dendrobium Mine (October 2007).

MSEC459 (Rev. B) – Subsidence Predictions and Impact Assessments for Natural Features and Surface Infrastructure in Support of the SMP Application (September 2012).

MSEC865 (Rev. C) – Review of the Subsidence Predictions and Impact Assessments for Natural and Built Features in Dendrobium Area 3B based on Observed Movements and Impacts during Longwalls 9 and 10 (December 2015).

MSEC978 (Rev. E) – Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwalls 20 and 21 in Area 3C at Dendrobium Mine (August 2019)

Background reports available at *www.minesubsidence.com*[1]:

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

[1] Direct link: http://www.minesubsidence.com/index_files/page0004.htm

South32 Illawarra Metallurgical Coal (IMC) has approval to mine longwalls in Area 3C at Dendrobium Mine. IMC proposes to extract Longwalls 22 and 23 (LW22 and LW23) within the Wongawilli Seam. There are also additional longwalls in Area 3C that are proposed to be mined, but these will be the subject of separate Subsidence Management Plan (SMP) Applications.

The predicted subsidence effects for the proposed LW22 and LW23 have been obtained using the Incremental Profile Method (IPM). The IPM has been calibrated for the local conditions at Dendrobium Mine using the available ground movement monitoring data. The maximum predicted effects are 3000 mm vertical subsidence, 40 mm/m tilt (i.e. 4 %, or 1 in 25), 1.0 km^{-1} hogging and sagging curvatures (i.e. 1 km minimum radius).

The maximum predicted subsidence effects for the proposed LW22 and LW23 are the same as the maximum predicted values for the LW6 to LW8 and LW19 in Area 3A and less than the maximum predicted values for LW9 to LW18 in Area 3B. It is noted that the maximum measured vertical subsidence in Areas 3A and 3B obtained using LiDAR surveys, to date, are less than the maximum predicted values.

The *Study Area* has been defined, as a minimum, as the surface area enclosed by the: 35° angle of draw line from the extents of the proposed LW22 and LW23; the predicted total 20 mm subsidence contour due to the extraction of the proposed longwalls; natural features located within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d) of the Development Consent; and features that are predicted to experience either far-field horizontal or valley-related movements and could be sensitive to these effects.

Natural and built features have been identified within or in the vicinity of the Study Area, including Wongawilli Creek, drainage lines, cliffs, minor cliffs, rock outcrops, steep slopes, swamps, unsealed roads and tracks, a 330 kV transmission line, 33 kV powerline, Aboriginal heritage sites, the Cordeaux and Avon Reservoirs and associated dam walls, and survey control marks.

The assessments provided in this report should be read in conjunction with the assessments provided in the reports by other specialist consultants on the project. The main findings from this report are as follows:

- Wongawilli Creek is located west of the proposed LW22 and LW23. The thalweg (i.e. base or centreline) of the creek is 345 m and 320 m from the finishing ends of LW22 and LW23, respectively, at its closest points.

  The maximum predicted additional subsidence effects for Wongawilli Creek, due to the extraction of LW22 and LW23 only, are less than 20 mm vertical subsidence, 50 mm upsidence and 80 mm closure. The maximum predicted total subsidence effects along the section of the creek within the Study Area, including the movements from the existing and approved longwalls in Areas 3A, 3B and 3C, are less than 20 mm vertical subsidence, 90 mm upsidence and 190 mm closure.

  Fracturing could occur along the section of Wongawilli Creek that is located within a distance of approximately 400 m from the proposed longwalls. The rate of Type 3 impacts (i.e. fracturing resulting in surface water flow diversions) for the rockbars located within the Study Area has been assessed as low, i.e. less than 10 %.

  The section of Wongawilli Creek located further upstream experienced fracturing in one pool due to the previous mining in Areas 3A and 3B. These longwalls were mined to within 110 m of the creek. Pool water levels below baseline conditions have been observed in this pool during low flow conditions and, therefore, it has been considered a Type 3 impact. The total length of creek located within a distance of 400 m of the as-extracted longwalls is 2 km. The rate of impact from mining-induced fracturing along Wongawilli Creek due to the previous mining in Area 3B, therefore, is considered to be low.

- Drainage lines are located directly above and adjacent to the proposed longwalls. These drainage lines are first and second-order streams that form tributaries to Lake Cordeaux in the eastern part of the Study Area and to Wongawilli Creek in the western part of the Study Area. The drainage lines could experience the full range of predicted subsidence effects.

  It is expected that fracturing would occur along the sections of the drainage lines that are located directly above the proposed LW22 and LW23. Fracturing can also occur outside the extents of the proposed longwalls at distances up to approximately 400 m. Surface water flow diversions are also likely to occur along the sections of drainage lines that are located directly above and adjacent to the proposed longwalls. Further discussions on the potential changes in surface water flow are provided in the report by the specialist surface water consultant on the project.

- Four cliffs have been identified within the Study Area. Two cliffs (Refs. WC26-CL1 and WC26-CL2) are located directly above the proposed LW23 and the other two cliffs (Refs. LC6-CL1 and WC26-CL3) are located outside and adjacent to this longwall. The cliffs have overall lengths ranging between 25 m and 60 m and heights of approximately 11 m or 12 m.

  The cliffs within the Study Area could experience adverse impacts including fracturing, rockfalls and cliff instabilities. It is unlikely that other cliffs located outside the Study Area based on the 35° angle of draw would experience adverse impacts due to their distances from the mining area.

- Rock outcrops and steep slopes are located across the Study Area. These features could experience the full range of predicted subsidence effects. It is likely that fracturing and cracking would occur where these features are located directly above the proposed longwalls. The crack widths could be similar to those previously observed at the mine, which were up to approximately 400 mm in width, but typically in the order of 50 mm to 150 mm in width.

- There are two swamps (Refs. Den07 and Den153) that have been identified directly above the proposed longwalls. There are four additional swamps located wholly or partially within the Study Area based on the 35° angle of draw line and a further eight swamps located wholly or partially within the Study Area based on the 600 m boundary.

  There are predicted reductions in grade along Stream LC5 and within the extent of Swamp Den07. There is potential for minor and localised increased ponding upstream of these locations and within this swamp. The areas of the swamp further up the valley sides have higher natural grades and there are no predicted reductions in grade away from the valley base.

  There are no predicted reductions in grade along the remaining streams or within the remaining swamps within the Study Area. It is unlikely, therefore, that these swamps would experience adverse changes in ponding or scouring due to the mining-induced tilt or vertical subsidence.

  Fracturing of the bedrock could occur beneath Swamps Den07 and Den153 as they are located directly above the mining area. The fracture widths are expected to be similar to those previously observed at the Mine, which were typically in the order of 50 mm to 150 mm in width. These swamps have layers of organic soil and, in most cases, cracking would not be visible at the surface within these swamps, except where the depths of bedrock are shallow or exposed.

  The dilated strata beneath the drainage lines, upstream of Swamps Den07 and Den153, could result in the diversion of some surface water flows beneath parts of these swamps. The drainage lines upstream of these swamps flow during and shortly after rainfall events. On the basis that there is no connective fracturing to any deeper storage, it is likely that the diverted surface water flows will re-emerge at the limits of fracturing and dilation.

  The remaining swamps are located outside the proposed mining area at distances ranging between 70 m and 540 m. Fracturing could occur along the streams within the swamps located closest to the proposed longwalls. The fracture widths could be similar to those previously observed outside the Mine, in the order of 20 mm to 50 mm at Swamp Den09 and less than 20 mm at Swamp Den157. Minor and isolated fracturing could occur at distances up to 400 m outside the mining area.

  Further discussions on the potential environmental consequences for the swamps are provided by the other specialist consultants on the project.

- Unsealed roads and tracks are located across the Study Area. It is likely that cracking and heaving of the unsealed road surfaces would occur where they are located directly above the proposed longwalls. It is expected that these features can be maintained in safe and serviceable conditions using normal road maintenance techniques.

- A 330 kV transmission line crosses directly above the proposed LW22 and LW23. Four transmission towers located within or adjacent to the Study Area based on the 35° angle of draw. TWR17-20 is a suspension tower located directly above LW22 and TWR17-21 is a tension tower located directly above LW23. The other two towers are located at distances of 300 m or greater outside the proposed longwalls.

  It is recommended that TransGrid undertake a structural analysis of the transmission towers. If adverse impacts are anticipated, then these could be managed using strategies similar to those adopted where similar transmission lines have been directly mined beneath or adjacent to by previously extracted longwalls elsewhere in the NSW coalfields.

- A 33 kV powerline crosses directly above the proposed LW22 and LW23. The powerline comprises aerial copper conductors supported by metal and timber poles. Preventive measures may be required, including the installation of cable rollers, guy wires or additional poles, or the adjustment of cable catenaries. With the implementation of these measures, it is expected that the 33 kV powerline can be maintained in safe and serviceable conditions.

- The Cordeaux Reservoir is located east of the proposed longwalls. The Full Supply Level is at a distance of 300 m from each of the proposed LW22 and LW23, at the closest points. The Avon Reservoir is located more than 3 km from the proposed longwalls.

  Minor and isolated fracturing could occur in the bedrock beneath the Cordeaux Reservoir within a distance of approximately 400 m from the proposed mining. However, the fracturing is unlikely to be visible at the surface due to the alluvial deposits. An assessment of the surface water storage is provided in the report by the specialist groundwater consultant on the project.

  The Cordeaux Dam Wall is located approximately 2.8 km north the proposed LW23 and the Avon Dam Wall is located more than 8 km west of the proposed longwalls. At these distances, the dam walls are not expected to experience measurable differential horizontal movements over their lengths. It is not anticipated that adverse impacts would occur to the dam walls due to the proposed mining. It is recommended that IMC consult with WaterNSW and the DS NSW to develop the appropriate monitoring and management strategies for the reservoirs and dam walls.

- There are three Aboriginal heritage sites (Refs. 52-2-1632, 52-2-2219 and 52-2-4499) that have been identified within or adjacent to the Study Area based on the 35° angle of draw. There are eight additional Aboriginal heritage sites (Refs. 52-2-0019, 52-2-0535, 52-2-1633, 52-2-1634, 52-5-0275, 52-5-0276, 52-2-4656 and 52-2-4657) that are located within the Study Area based on the 600 m boundary.

  There is one site (Ref. 52-2-2219) that is located directly above the proposed mining area. This rock shelter could experience adverse impacts including fracturing resulting in spalling or rockfalls. Another site (Ref. 52-2-1634) is located under a waterfall on a side of a tributary at a distance of 335 m from the proposed longwalls. It is possible, but unlikely, that fracturing could occur along the tributary near this site.

  The remaining sites are located outside the mining area and on the sides of ridgelines. These sites are predicted to experience less than 20 mm vertical subsidence and not expected to experience valley-related effects. Adverse impacts on these remaining sites are therefore not anticipated due to the mining of LW22 and LW23.

- Survey control marks are located within and in the vicinity of the Study Area. The affected survey control marks that are required for future use will need to be re-established after they have stabilised.

The assessments provided in this report indicate that the levels of impact on the natural and built features can be managed by the preparation and implementation of appropriate management strategies. It should be noted, however, that more detailed assessments of some natural and built features have been undertaken by other specialist consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

CONTENTS

LIST OF TABLES, FIGURES AND DRAWINGS

Tables

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

Figures

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

Drawings

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

1.1. Background

Illawarra Metallurgical Coal Holdings Pty Ltd (IMC), a wholly owned subsidiary of South32 Limited (South32), operates Dendrobium Mine (the Mine), which is located in the Southern Coalfield of New South Wales (NSW). The Mine is located to the west of Wollongong and the Illawarra Escarpment and to the east of the township of Bargo.

IMC previously prepared an Environmental Impact Statement for the Mine that included longwalls in Areas 1, 2 and 3, referred to herein as the 2001 EIS. Mine Subsidence Engineering Consultants (MSEC), formally trading as Waddington Kay & Associates, provided the subsidence predictions and impact assessments for the proposed mining in Report No. WKA77 (January 2001), which supported the 2001 EIS. The Mine was approved by the Minister for Urban Affairs and Planning on the 20 November 2001.

The longwall layout originally adopted in the 2001 EIS for Area 3 comprised a series of ten east-west orientated longwalls. Subsequent to the 2001 EIS, Area 3 was separated into three sub-areas for mining purposes, which are referred to as Areas 3A, 3B and 3C. Longwalls 6 to 8 (LW6 to LW8) in Area 3A have been completed and Longwalls 9 to 18 (LW9 to LW18) in Area 3B are currently being extracted. The future Longwall 19 (LW19) in Area 3A is proposed to be extracted after the completion of the longwalls in Area 3B.

IMC previously submitted a Subsidence Management Plan (SMP) Application for Longwalls 20 and 21 (LW20 and LW21) within the Wongawilli Seam in Area 3C. Report No. MSEC978 (Rev. C) was issued in August 2019 in support of that application. The mining of LW21 was approved by the Department of Planning, Industry and Environment (DPIE) on the 19 December 2019.

IMC is now preparing an SMP Application for Longwalls 22 and 23 (LW22 and LW23) within the Wongawilli Seam in Area 3C. These two proposed longwalls are located on the northern side of LW21 and to the east of Wongawilli Creek. There are also additional longwalls in Area 3C that are proposed to be mined, but these will be the subject of separate SMP Applications.

The locations of the existing and approved longwalls in Areas 3A and 3B and the approved and proposed longwalls in Area 3C are shown in Fig. 1.1. The Area 3 approval boundary is also shown in this figure.

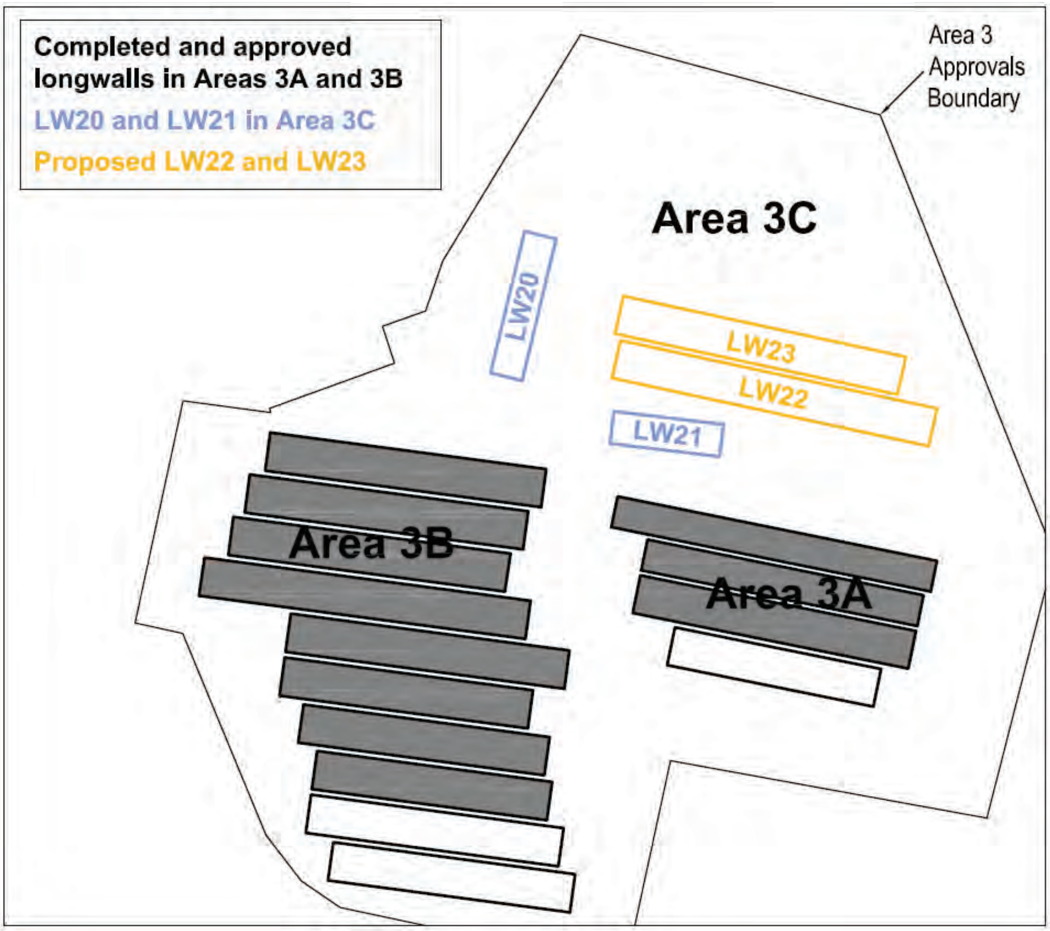

Fig. 1.1 Existing, approved and proposed longwalls in Areas 3A, 3B and 3C

The existing and approved longwalls at the Mine and the proposed LW22 and LW23 are shown in Drawings Nos. MSEC1104-01 and MSEC1104-02, respectively, in Appendix D. The proposed LW22 and LW23 and the Study Area, as defined in Section 2.2, have been overlaid on an orthophoto of the area, and is shown in Fig. 1.2.

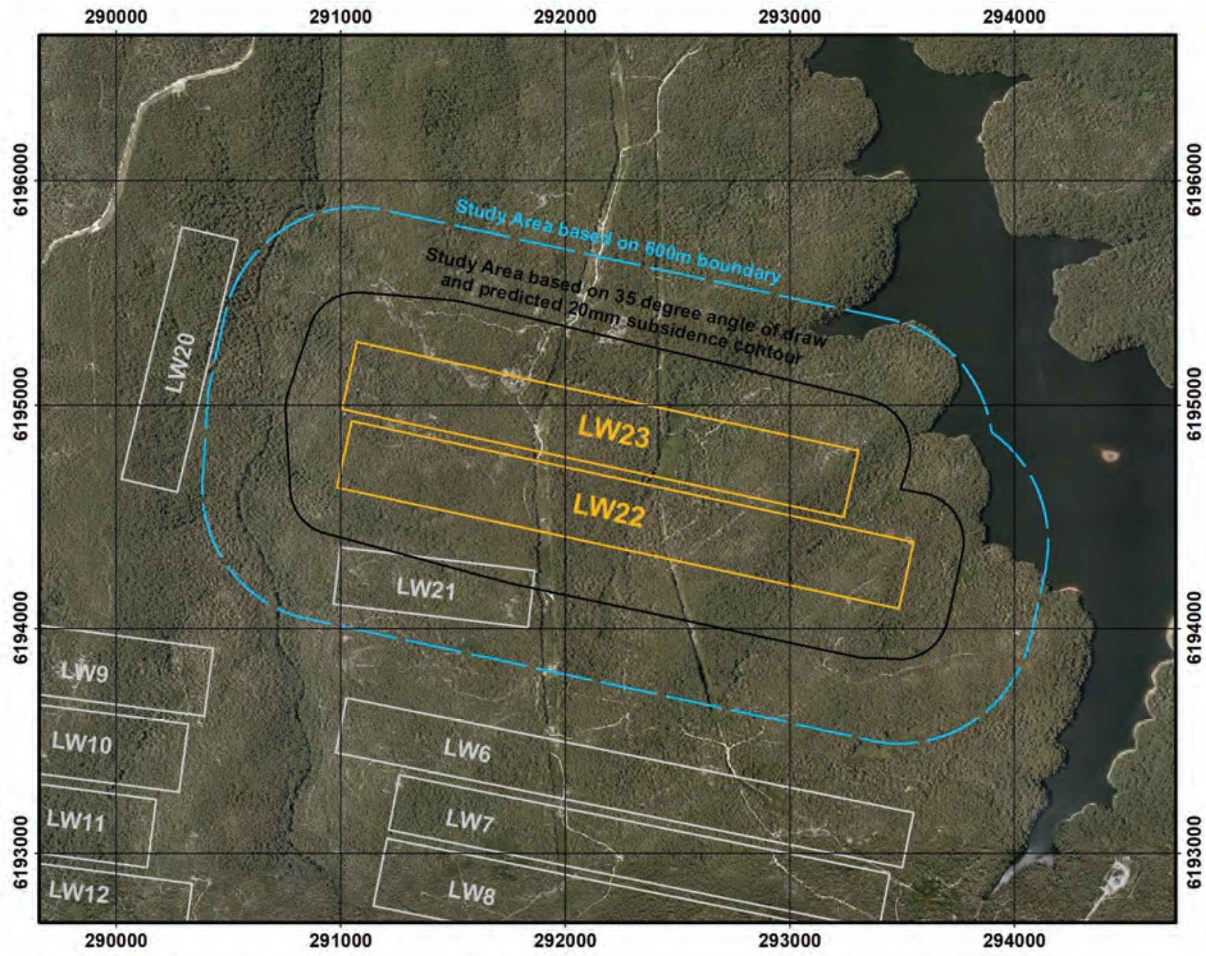

Fig. 1.2 Aerial photograph showing the proposed longwalls and the Study Area

MSEC has been commissioned by IMC to:

- prepare subsidence predictions for the proposed LW22 and LW23, including the cumulative movements due to the previously extracted and approved longwalls in Areas 3A, 3B and 3C;
- identify the natural and built features in the vicinity of the proposed longwalls;
- provide subsidence predictions for each of these features;
- prepare impact assessments, in conjunction with other specialist consultants, for each of the natural and built features; and
- recommend management strategies and monitoring.

This report has been prepared to support the SMP Application for the proposed LW22 and LW23 which will be submitted to the DPIE. In some cases, this report will refer to other sources of information on specific natural and built features. This report, therefore, should be read in conjunction with the other relevant reports associated with this application.

Chapter 1 provides background information on the study, including the mining geometry, surface and seam and overburden lithology.

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

Chapter 4 provides the maximum predicted subsidence effects resulting from the extraction of the proposed longwalls.

Chapters 5 and 6 provide the descriptions, predictions and impact assessments for each of the natural and built features that 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.

1.2. Mining geometry

The layouts of the proposed LW22 and LW23 are shown in Drawings Nos. MSEC1104-01 and MSEC1104-02, in Appendix D. A summary of the dimensions of these longwalls is provided in Table 1.1. The longwalls are proposed to be extracted from the Wongawilli Seam.

Table 1.1 Geometry of the proposed longwalls

Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
LW22	2561	305	-
LW23	2283	305	42

The lengths of longwall extraction excluding the installation headings are approximately 9 m less than the overall void lengths provided in the above table, i.e. 2552 m for LW22 and 2274 m for LW23. The longwall face widths excluding the first workings are 295 m for both longwalls.

The proposed longwalls are located north of and slightly oblique to LW21 and they are situated east of LW20. LW22 is a minimum distance of 175 m from LW21 and there is a 42 m chain pillar between LW22 and LW23. The proposed longwalls will be extracted within the Wongawilli Seam towards the main headings, i.e. retreat mining from east to west.

1.3. Surface and seam levels

The levels of the natural surface and the Wongawilli Seam are illustrated along the centrelines of LW22 and LW23 in Fig. 1.3 and Fig. 1.4, respectively. The definition of the Study Area is provided in Section 2.2.

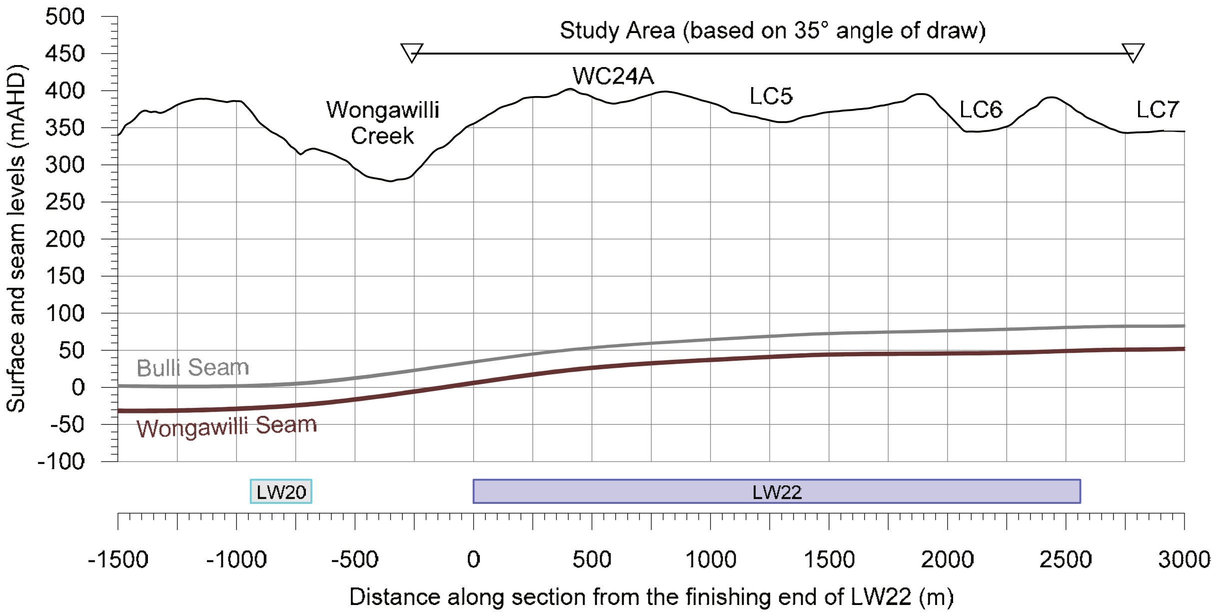

Fig. 1.3 Surface and seam levels along the centreline of LW22

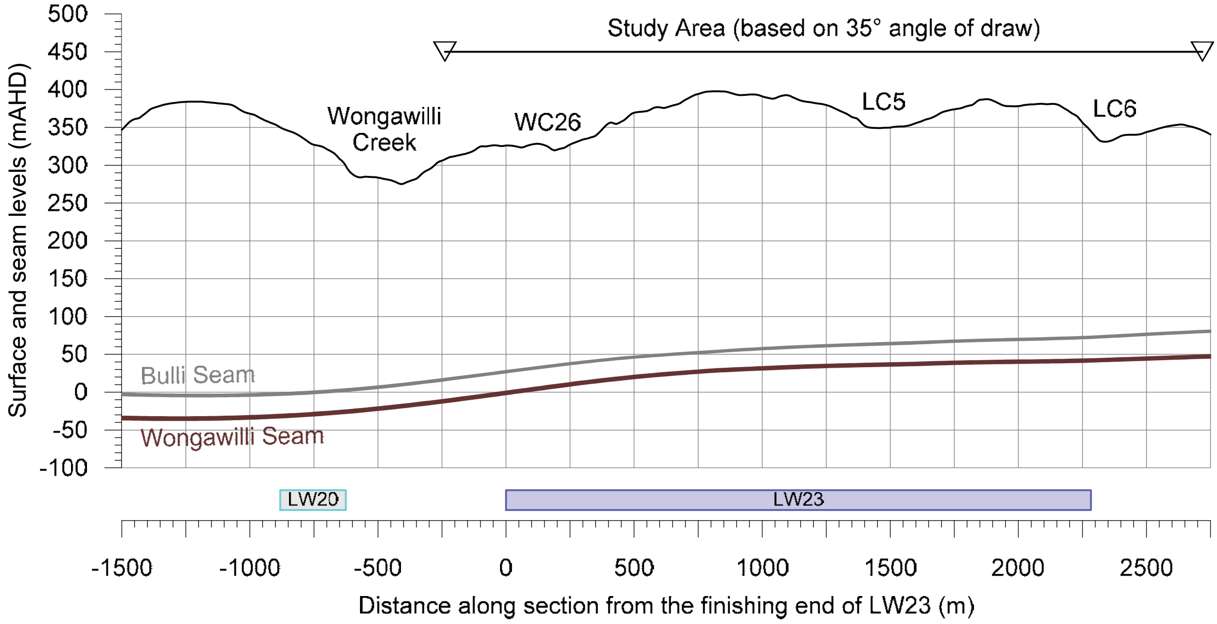

Fig. 1.4 Surface and seam levels along the centreline of LW23

The surface level contours are shown in Drawing No. MSEC1104-03, in Appendix D. The proposed longwalls are located between Wongawilli Creek to the west and Lake Cordeaux to the east. A ridgeline crosses near the middle of the longwalls, with the natural surface fall towards Wongawilli Creek in the western part of the mining area and towards Lake Cordeaux in the eastern part of the mining area.

The surface levels directly above the proposed LW22 and LW23 vary between 300 metres above Australian Height Datum (mAHD) along a tributary to Wongawilli Creek above the finishing end of LW23, and 415 mAHD at the top of the ridgeline near the commencing end of LW23.

The seam floor contours, seam thickness contours and depth of cover contours for the Wongawilli Seam are shown in Drawings Nos. MSEC1104-04, MSEC1104-05 and MSEC1104-06, respectively. The contours are based on the latest information provided by the Mine.

The floor of the Wongawilli Seam generally dips from the east to the west. The average gradient of the seam within the mining area is approximately 3 % or 1 in 33. The depths of cover to the Wongawilli Seam vary between 290 m along a tributary to Lake Cordeaux above the commencing end of LW23, and 390 m along the ridgeline above the maingate of LW23.

The Wongawilli Seam is nominally 10 m thick and contains numerous bands of non-coal material. The economic section of the Wongawilli Seam is the basal 3 m to 5 m. IMC has reviewed the nature of the banding in Area 3C and propose to extract a height of 3.9 m using conventional longwall mining techniques.

1.4. Geological details

The Mine is located in the southern part of the Sydney Basin. The landform is hilly and the area is crossed by the Avon River, the Cordeaux River and their associated creeks and tributaries. The geology mainly comprises sedimentary sandstones, shales and claystones of the Permian and Triassic Periods, which have been intruded by igneous sills. A typical stratigraphic section for the Mine is provided in Fig. 1.5 (Source: IMC).

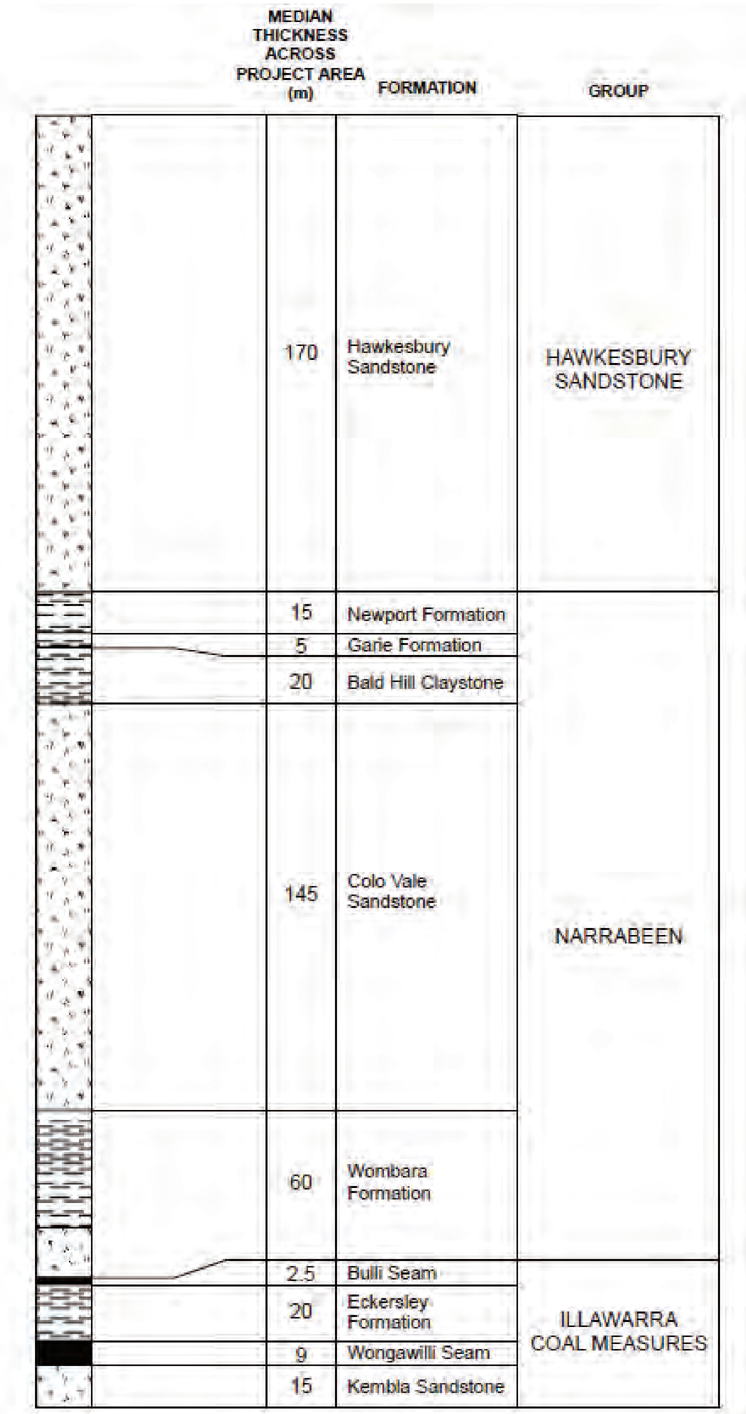

Fig. 1.5 Typical stratigraphic section for the Mine (Source: IMC)

The major sedimentary units at the Mine are, from the top down, the Hawkesbury Sandstone, the Narrabeen Group and the Illawarra Coal Measures. The Wianamatta Group is only present as a very limited residual in localised areas.

Hawkesbury Sandstone is the largest member in the overburden, with an average thickness of approximately 170 m at the Mine. The Narrabeen Group contains the Newport Formation (sometimes referred to as the Gosford Formation), Garie Formation, Bald Hill Claystone, Colo Vale Sandstone (also referred to as Bulgo Sandstone), and the Wombarra Formation comprising Stanwell Park Claystone, Scarborough Sandstone, Wombarra Shale and Coalcliff Sandstone.

The Bulli Seam is the top unit in the Illawarra Coal Measures. The interval between the Bulli Seam and the Wongawilli Seam is known as the Eckersley Formation which consists of sandstones, shales and minor coal seams. The proposed LW22 and LW23 will be extracted from the Wongawilli Seam.

The major claystone units are the Bald Hill and Stanwell Park Claystones that lie above and below the Colo Vale Sandstone and at the base of the Hawkesbury Sandstone. The Wombarra Shale will be located within the collapsed zone above the proposed longwalls.

The Mine sits at the southern end of the Nepean/Kurrajong Fault and Lapstone Monocline system. The area is therefore imprinted with the north-westerly trending structures that connect to these large scale geological features to the north. The large north-west and north-north-west displacement faults are the primary deformational set in the area. However, those faults trend north-east in the coastal fault zone. The geological structures identified or inferred at the Mine are shown in Drawing No. MSEC1104-07.

Igneous sills have intruded into the coal seams in parts of the Mine. A sill has intruded into the Wongawilli Seam north-west of the proposed longwalls. A sill has also intruded into the overlying Bulli Seam directly above the proposed longwalls. This sill will be located within the collapsed zone above the proposed longwalls and, therefore, is unlikely to affect the mine subsidence movements at the surface.

A series of east-west orientated dykes and associated minor faulting are situated on the southern side of the tailgate of the proposed LW22. The locations and sizes of these structures will be better defined through ongoing investigations and the development of the first workings.

The surface lithology in the area can be seen in Fig. 1.6, which shows the longwalls and the Study Area overlaid on the Geological Map *Bargo 9029-3-N*, which was published by the DMR (1988), now known as the Resources Regulator. The surface lithology in Area 3C generally comprises Hawkesbury Sandstone (Rh), with localised areas of Quaternary Alluvium (Qs).

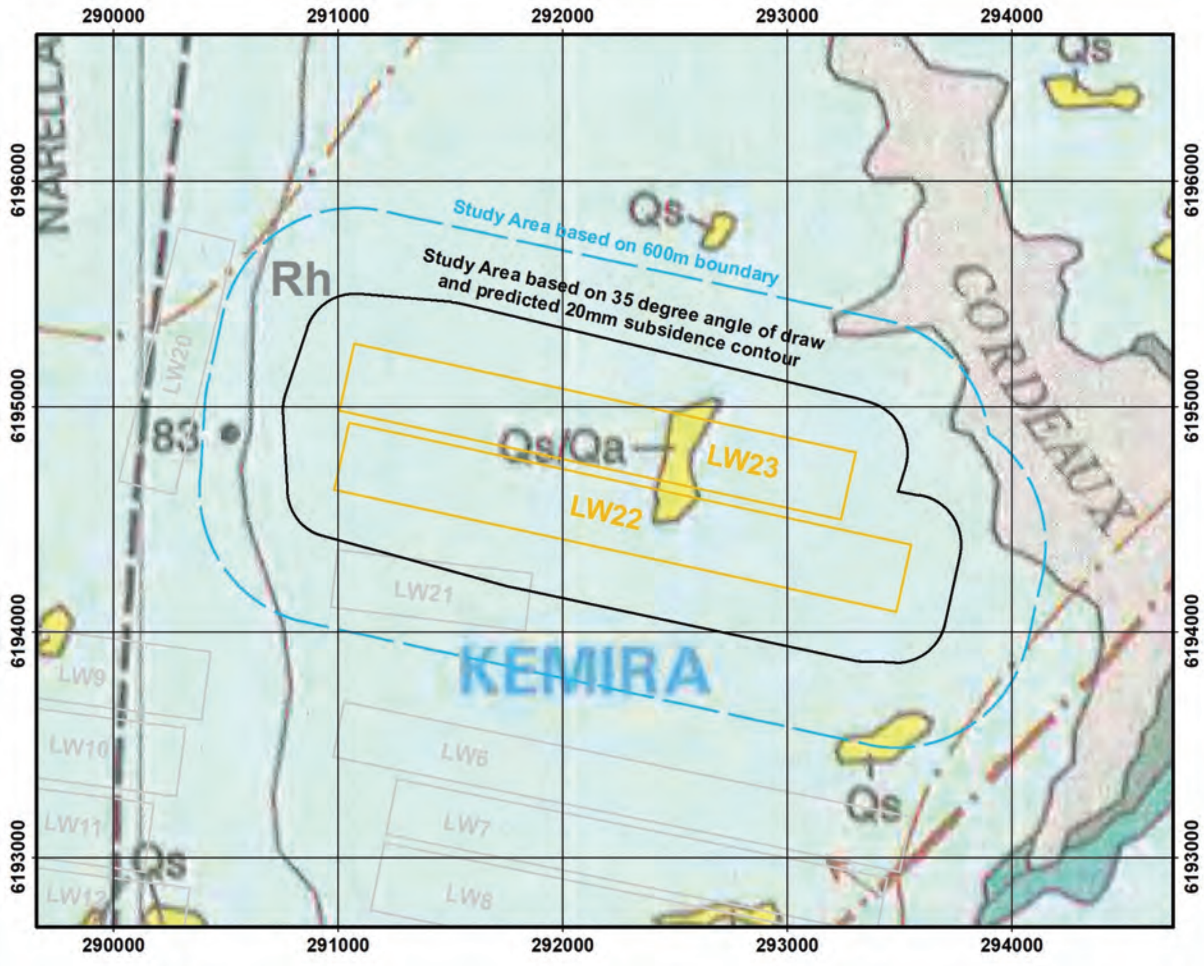

Fig. 1.6 The proposed longwalls overlaid on Geological Map *Bargo 9029-3-N* (DMR, 1988)

2.1. Definition of the Extent of the Longwall Mining Area

The *Extent of the Longwall Mining Area* is defined as the overall void area for the proposed LW22 and LW23 (i.e. second workings plus the immediately adjacent roadways), indicated by the orange outlines shown in Drawings Nos. MSEC1104-01 and MSEC1104-02.

2.2. Definition of the Study Area

The *Study Area* is defined as the surface area that could be affected by the mining of the proposed LW22 and LW23. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:

- The 35° angle of draw line from the extents of the proposed LW22 and LW23;
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, resulting from the extraction of the proposed longwalls; and
- The natural features located within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d) of the Development Consent.

The depths of cover contours are shown in Drawing No. MSEC1104-06. The depth of cover varies between 290 m and 390 m directly above the proposed LW22 and LW23. The 35° angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 200 m and 275 m around the extents of the longwall voids.

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, has been determined using the calibrated Incremental Profile Method (IPM), which is described in Chapter 3. The predicted total subsidence contours after the mining of LW23, including the 20 mm subsidence contour, are shown in Drawing No. MSEC1104-12, in Appendix D. The predicted 20 mm subsidence contour is located entirely within the 35° angle of draw line.

The Study Area based on the 35° angle of draw line is shown in Drawings Nos. MSEC1104-01 and MSEC1104-02, in Appendix D. The Study Area based on a 600 m boundary around the extents of the proposed longwalls is also shown in those drawings. The features that are located within the 600 m boundary that are predicted to experience valley-related effects and could be sensitive to these movements have been included in the assessments provided in this report. These features include the streams and upland swamps.

There are additional features that are located outside the 600 m boundary that could experience either far-field horizontal or valley-related effects. The surface features that could be sensitive to such movements have been identified and have also been included in the assessments provided in this report. These features include the reservoirs, dam walls and survey control marks.

2.3. Natural and built features within the Study Area

A summary of the natural and built features located within the Study Area is provided in Table 2.1. The locations of these features are shown in Drawings Nos. MSEC1104-08 to MSEC1104-11, in Appendix D. The descriptions, predictions and impact assessments for the natural and built features are provided in Chapters 5 and 6. The section number references are provided in Table 2.1.

Table 2.1 Natural and built features within the Study Area

Item	Within Study Area	Section number reference
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	✓	5.1
Rivers or Creeks	✓	5.2 & 5.3
Aquifers or Known Groundwater Resources	✓	5.4
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.5
Steep Slopes	✓	5.6
Escarpments	×	
Land Prone to Flooding or Inundation	×	
Swamps, Wetlands or Water Related Ecosystems	✓	5.9
Threatened or Protected Species	✓	5.10
National Parks	×	
State Forests	×	
State Conservation Areas	×	
Natural Vegetation	✓	5.10
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	×	
Roads (All Types)	✓	6.1
Bridges	×	
Tunnels	×	
Culverts	×	
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	✓	6.2 & 6.3
Telecommunication Lines or Associated Plants	×	
Water Tanks, Water or Sewage Treatment Works	×	
Dams, Reservoirs or Associated Works	✓	6.4
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	×	
Shopping Centres	×	
Community Centres	×	
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

Item	Within Study Area	Section number reference
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	×	
Farm Buildings or Sheds	×	
Tanks	×	
Gas or Fuel Storages	×	
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	×	
Farm Dams	×	
Wells or Bores	×	
Any Other Farm Features	×	
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Factories	×	
Workshops	×	
Business or Commercial Establishments or Improvements	×	
Gas or Fuel Storages or Associated Plants	×	
Waste Storages or Associated Plants	×	
Buildings, Equipment or Operations that are Sensitive to Surface Movements	×	
Surface Mining (Open Cut) Voids or Rehabilitated Areas	×	
Mine Infrastructure Including Tailings Dams or Emplacement Areas	×	
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL OR HERITAGE SIGNIFICANCE	✓	6.5
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.6
RESIDENTIAL ESTABLISHMENTS		
Houses	×	
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

3.1. Introduction

The following sections provide overviews of conventional and non-conventional mine subsidence effects and the methods that have been used to predict these movements. Further information is also 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 effects

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/kilometres* (km^{-1}), but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.
- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile Strains** occur where the distances between two points increase and **Compressive Strains** occur when the distances between two points decrease. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

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

The **incremental** subsidence, tilts, curvatures and strains are the additional effects which result from the extraction of each longwall. The **cumulative** subsidence, tilts, curvatures and strains are the accumulated effects which result from the extraction of a series of longwalls. The **total** subsidence, tilts, curvatures and strains are the final effects at the completion of a series of longwalls. The **travelling** tilts, curvatures and strains are the transient movements as the longwall extraction face mines directly beneath a given point.

3.3. Far-field movements

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

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

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

Far-field horizontal movements and the method used to predict such movements are described further in Section 4.6.

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 400 m, such as the case over a large part of the Study Area, the observed subsidence profiles along monitoring lines are generally smooth. Where the depth of cover is less than 100 metres, the observed subsidence profiles along monitoring lines are generally irregular. Very irregular subsidence movements are observed with much higher tilts, curvatures and strains at very shallow depths of cover where the collapsed zone above the extracted longwalls extends up to or near to the surface.

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

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

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

3.4.1. Non-conventional subsidence movements due to changes in geological conditions

Most non-conventional ground movements are a result of the reaction of near surface strata to increased horizontal compressive stresses due to mining operations. Some of the geological conditions that influence these irregular subsidence movements are the blocky nature of near surface sedimentary strata layers and the 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, curvatures 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 cannot be explained with available 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 and 6, 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 on 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 include the development of tension cracks at the tops and on the sides of the steep slopes and compression ridges at the bottoms of the steep slopes.

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

3.4.3. Valley-related effects

The streams within the Study Area will be affected by valley-related effects, which are commonly observed in the Southern Coalfield. 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 is influenced by the geomorphology of the valley.

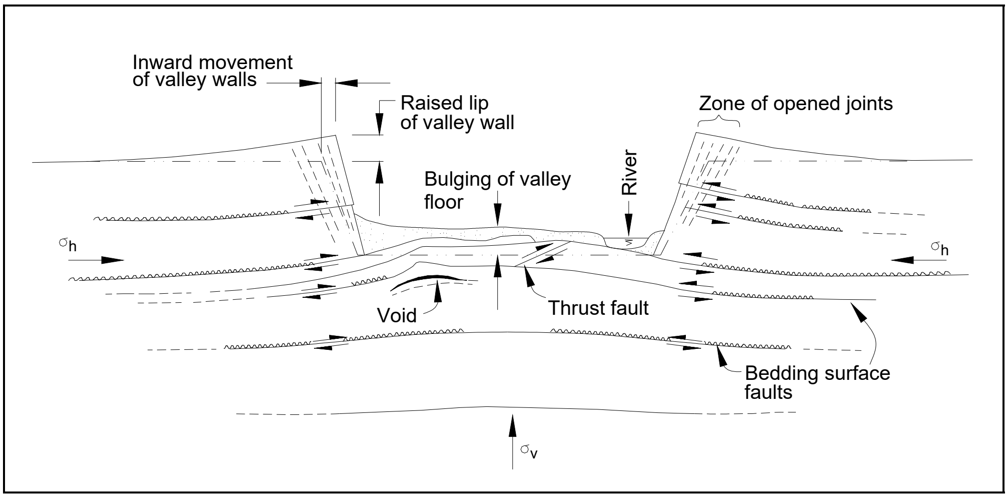

Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

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

The predicted valley-related effects for the streams in the existing and approved mining Areas 2, 3A and 3B at the Mine were determined using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002), referred to as the 2002 ACARP method.

More recently, the empirical prediction method has been refined based on further research undertaken as part of ACARP Research Project No. 18015 (Kay and Waddington, 2014), referred to as the 2014 ACARP method. This method only provides predictions for valley closure and not for upsidence.

The predicted valley closure movements for the streams in Area 3C have been determined using both methods. The predictions based on the 2002 ACARP method can be directly compared with the predictions provided in previous MSEC subsidence reports for Areas 2, 3A and 3B at the Mine and with other case studies. The assessments provided in this report, therefore, have been based on the predictions obtained using the 2002 ACARP method.

The reliability of the predicted valley-related closure movements is discussed in Section 3.6.2.

The predicted strains resulting from valley-related effects for the streams in the Study Area have been determined using the ground monitoring data for longwalls that have previously mined beneath or near to streams in the Southern Coalfield, including at Dendrobium Mine. Refer to the impact assessments for the streams in Chapter 5 for further details.

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

3.5. The Incremental Profile Method

The predicted conventional subsidence effects for the proposed longwalls have been determined using the Incremental Profile Method (IPM), which has been developed by MSEC. The method is an empirical model based on a large database of observed monitoring data from previous mining within the Southern, Newcastle, Hunter and Western Coalfields of New South Wales.

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

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

Subsidence predictions made using the IPM use the database of observed incremental subsidence profiles, the longwall geometries, local surface and seam information and geology. The method tends to over-predict the conventional subsidence effects (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 when observed monitoring data is available close to the mining area.

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

3.6. Calibration of the IPM

The use of the IPM at Dendrobium Mine has been continually reviewed and refined based on the latest available ground movement monitoring data.

Initially, the standard model for the Southern Coalfield was used for the predictions in Areas 1, 2 and 3A at the Mine. This standard model is predominately based on the ground monitoring data for mining in the Bulli Seam in the Southern Coalfield.

The model was then calibrated for Area 3B based on the available monitoring data from the Mine at the time of the SMP Application for LW9 to LW18. The calibration of the model is described in Section 3.6 of Report No. MSEC459 and was based on the monitoring data from LW3 to LW5 in Area 2 and LW6 in Area 3A at the Mine. The initial calibration of the subsidence model is referred to as the '*MSEC459 prediction curves*' in this report.

The calibrated model based on the MSEC459 prediction curves was then later reviewed based on the additional ground movement monitoring data collected from the Mine, which included LW7 and LW8 in Area 3A and LW9 and LW10 in Area 3B. The review of the calibrated model was discussed in Report No. MSEC792 based on the monitoring data from Areas 2, 3A and 3B.

The mine subsidence movements in Areas 2, 3A and 3B were measured using Airborne Laser Scan (ALS) / Light Detection and Ranging (LiDAR) surveys. The changes in surface level were determined by taking the differences between the measured surface levels before and after the extraction of each longwall.

It was considered that the calibrated IPM based on the MSEC459 prediction curves provided reasonable predictions in Area 2, i.e. LW3 to LW5, based on the ALS surveys. This is not unexpected, as the subsidence prediction method was calibrated using the monitoring data from LW3 to LW5 in Area 2 and LW6 in Area 3B, as described in Section 3.6 of Report No. MSEC459.

However, it was found for LW7 and LW8 in Area 3A and LW9 and LW10 in Area 3B, that the maximum measured vertical subsidence exceeded the predictions, in many locations, with these exceedances being typically up to 1.3 times those predicted. The measured subsidence directly above the tailgate chain pillars for LW7 and LW8 in Areas 3A and LW10 in Area 3B were also greater than predicted.

It was considered that the measured vertical subsidence exceeded that predicted in Areas 3A and 3B due to the higher depths of cover and wider longwall void widths, as compared with those in Area 2. This resulted in pillar compression greater than that predicted by the subsidence model based on the MSEC459 prediction curves. It is also possible that higher subsidence has developed in Area 3B, as the Coal Cliff Sandstone is not present in this area, with higher compression of the overburden occurring within the thicker Wombarra Formation above the chain pillars.

Vertical subsidence predominately develops from two components: sagging of the overburden strata above the longwall voids; and compression of the chain pillars and the immediate seam floor and roof. At higher depths of cover, the component of vertical subsidence due to pillar compression increases, but the component due to sagging of the overburden strata decreases.

The original IPM over-predicted the component of vertical subsidence due to sagging of the overburden and under-predicted the component due to pillar compression. This model therefore provided reliable predictions of vertical subsidence in Area 3A (i.e. lower depth of cover), but the predictions were exceeded in Area 3B (i.e. higher depth of cover).

The subsidence model was then further refined for Area 3B based on the latest available monitoring data from the Mine by increasing the component of vertical subsidence due to pillar compression. This resulted in the maximum predicted incremental subsidence increasing by 30 %. The latest calibration of the subsidence model is referred to as the '*MSEC792 prediction curves*' in this report.

The comparisons between the measured ground movements with those predicted using the calibrated IPM based on the MSEC792 prediction curves are provided in the following sections.

3.6.1. Review of the calibrated model based on the ALS monitoring data

The changes in surface level due to the current mining in Area 3B at the Mine are being measured using ALS and LiDAR surveys. The measured changes in surface level due to the extraction of LW9 to LW16 are shown in Fig. 3.2. The extent of the latest ALS survey covers the area above LW13 to LW16 and, therefore, the contours are not shown above the earlier longwalls.

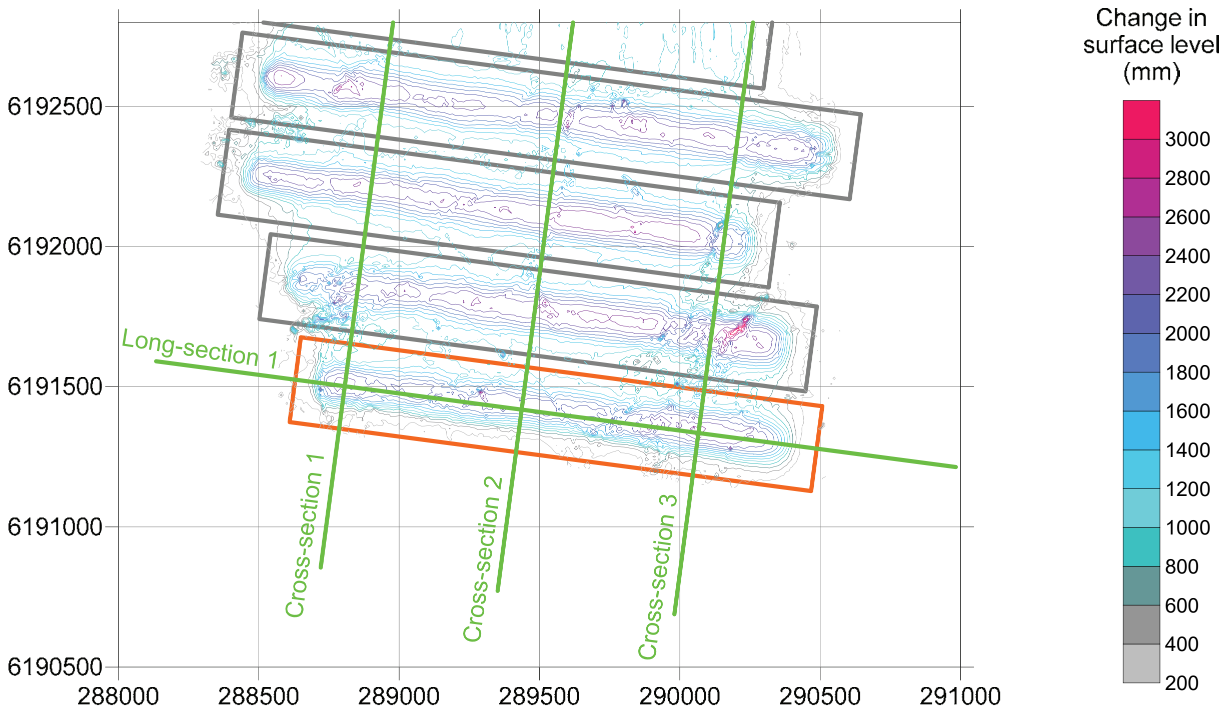

Fig. 3.2 Measured changes in surface level due to LW9 to LW16 in Area 3B

It should be noted that the contours of the measured changes in surface level, developed from the ALS / LiDAR, show the change in the heights of two surfaces defined by multiple points, not necessarily the same points. This differs from traditional subsidence contours that include both the vertical and horizontal components of the surface movements of points fixed to the surface. Horizontal movements are usually included in the subsidence profiles, as traditional ground monitoring data is based on the movements of survey marks, which are fixed to the ground.

The contours developed from the ALS / LiDAR can contain artefacts, particularly in the locations of steeply incised terrain, such as at cliffs or steep slopes. The reason for this is that the surface can move horizontally downslope, or towards the centre of the goaf, as the ground subsides and, therefore, the level changes at a fixed position can be large and do not provide a true indication of the actual subsidence at a point on the ground. Where the ground is reasonably flat, however, the contours of the observed changes in surface level should provide a good indication of the actual subsidence.

In comparison to traditional remote sensing topographic mapping techniques, ALS / LiDAR generally offers excellent 'vegetation penetration'. Vegetation penetration can be further enhanced by using narrower swathe angles as per the capture specifications used for mine subsidence determination at the Mine. Despite these attributes there are still limitations and ultimately if there are areas where 'light' cannot get to the ground then any optical or ALS / LiDAR system will have limitations in these locations.

The ALS / LiDAR suppliers state that the default vertical accuracy of each ALS / LiDAR dataset is around ±100 mm and, therefore, the expected accuracy of the measured vertical movements (i.e. the difference between two datasets) is around ±200 mm.

The profiles of measured (i.e. green) and predicted (i.e. red) changes in surface level along Cross-sections 1 to 3 and Long-section 1 are illustrated in Fig. 3.3 to Fig. 3.6. The predicted profiles in these figures have been obtained from the calibrated IPM based on the MSEC792 prediction curves. The locations of the sections are shown in Fig. 3.2.

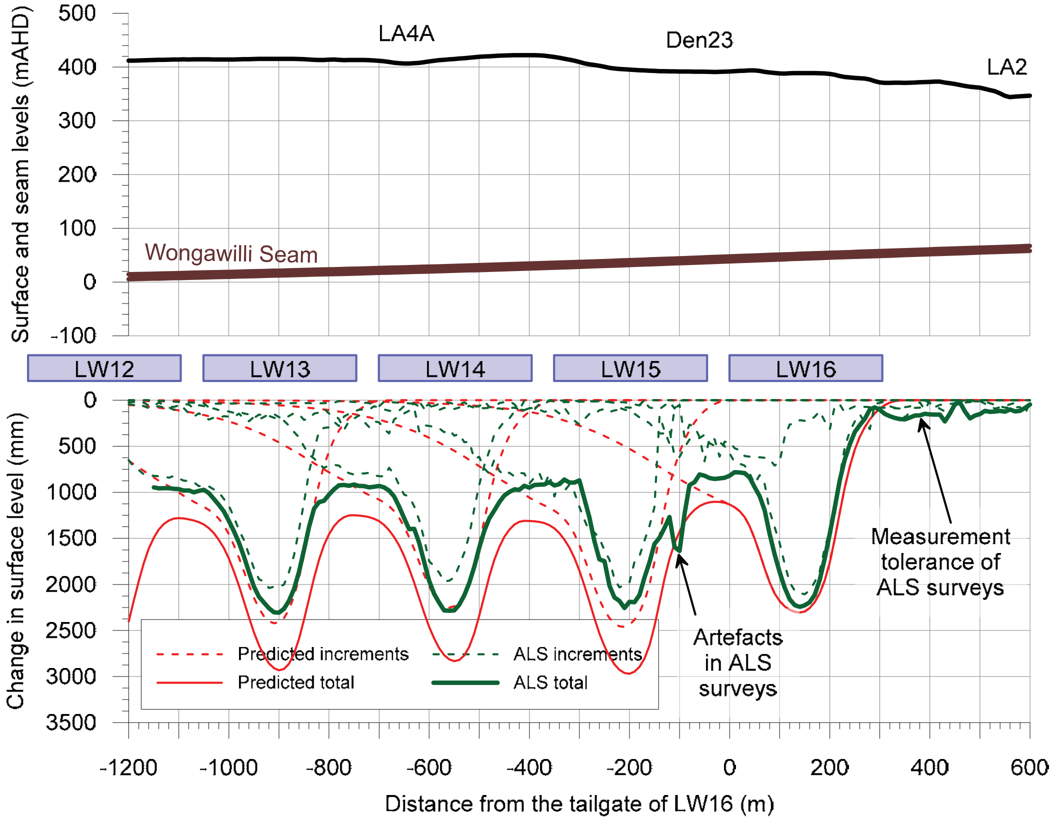

Fig. 3.3 Measured and predicted changes in surface level along Cross-section 1

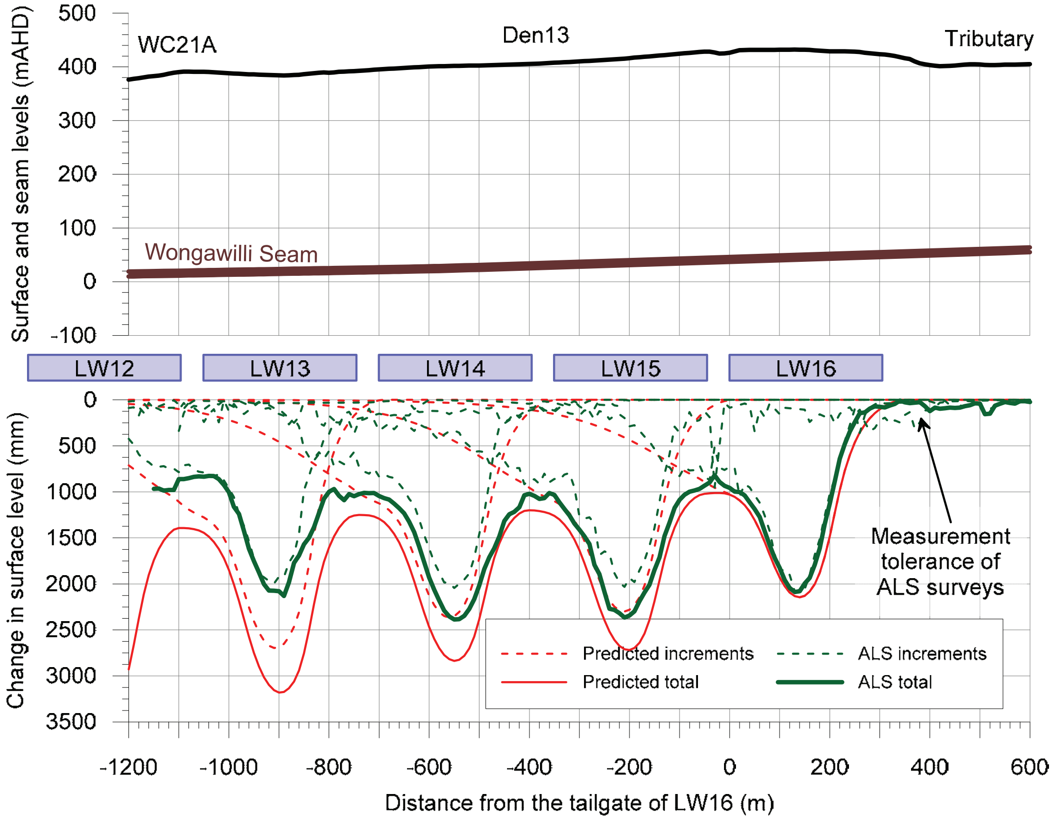

Fig. 3.4 Measured and predicted changes in surface level along Cross-section 2

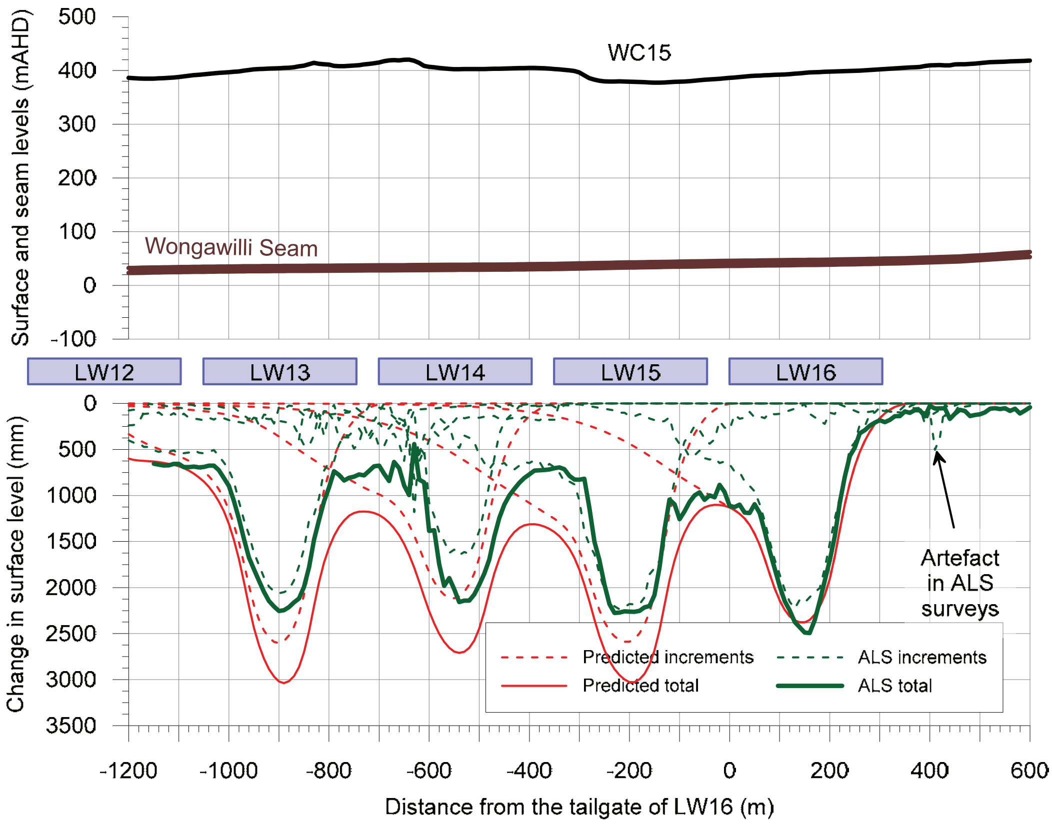

Fig. 3.5 Measured and predicted changes in surface level along Cross-section 3

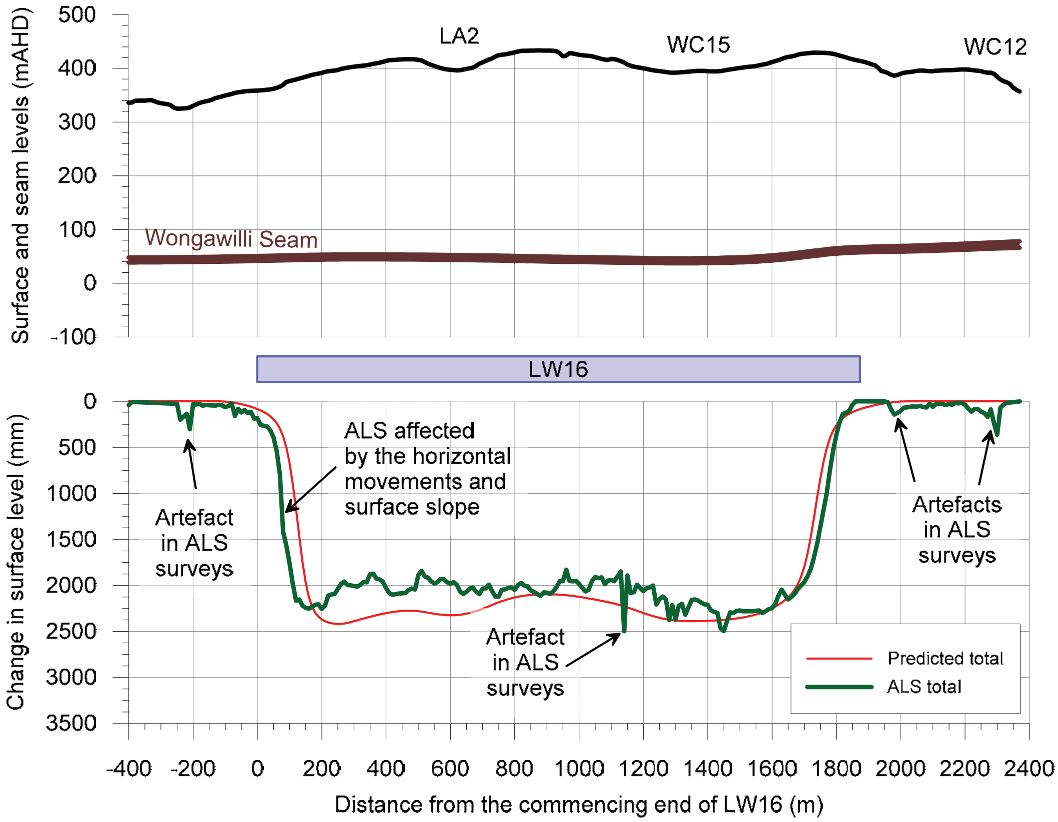

Fig. 3.6 Measured and predicted changes in surface level along Long-section 1

The profiles of the measured changes in surface level reasonably match the predicted profiles of vertical subsidence along each of the cross-sections and long-section. The maximum measured changes in surface level above each of the longwalls are similar to or less than the maximum predicted values. Also, the measured changes in surface level above each of the chain pillars are similar to or less than the predicted values in these locations.

The measured change in surface level along Cross-section 3 (refer to Fig. 3.5) is slightly greater than the predicted vertical subsidence above LW16. However, the difference between the measured and predicted movements are in the order of accuracy of the measurement method.

The measured change in surface level along Long-section 1 (refer to Fig. 3.6) is greater than the predicted vertical subsidence above the commencing end of LW16 (i.e. left side of figure). However, this may be partly due to the surveying tolerance and the effects of the horizontal movements and sloping terrain on the LiDAR surveys. The ground directly above the commencing end of LW16 has moved towards the longwall (i.e. following the extraction face). The natural surface dips towards the west in this location (i.e. towards Lake Avon). The mining-induced horizontal movement, therefore, results in the measured changes in level at a fixed position to be greater than the true vertical subsidence above the commencing end of LW16.

There are localised areas outside of the longwalls where the measured changes in surface level exceed the predicted vertical subsidence. However, these are artefacts of the LiDAR surveys and are not real movements. Elsewhere, the low-level movements are in the order of accuracy of the measurement method.

It can be inferred from the slopes of the profiles, that the measured changes in grade are similar to the predicted tilts along each of the cross-sections and long-section. It is not possible to derive the curvature nor the horizontal movements from the LiDAR surveys.

It is considered that the ground movements measured using the LiDAR surveys are consistent with the predictions provided in Reports Nos. MSEC792 and MSEC865.

3.6.2. Review of the calibrated model based on the traditional ground monitoring data

The vertical subsidence and valley closure were monitored during the extraction of LW9 to LW16 in Area 3B using the Wongawilli Creek Closure Lines, Donalds Castle Creek Cross Lines, Tributary Cross Lines and Swamp Cross Lines.

The comparisons of the measured and predicted total vertical subsidence for the traditional ground monitoring lines at the completion of LW16 are illustrated in Fig. 3.7. The measured versus the predicted values are shown on the left side of this figure. The ratios of the measured to predicted values (for magnitudes greater than 50 mm) are shown on the right side of this figure. The predictions are based on the re-calibrated subsidence model using the MSEC792 prediction curves.

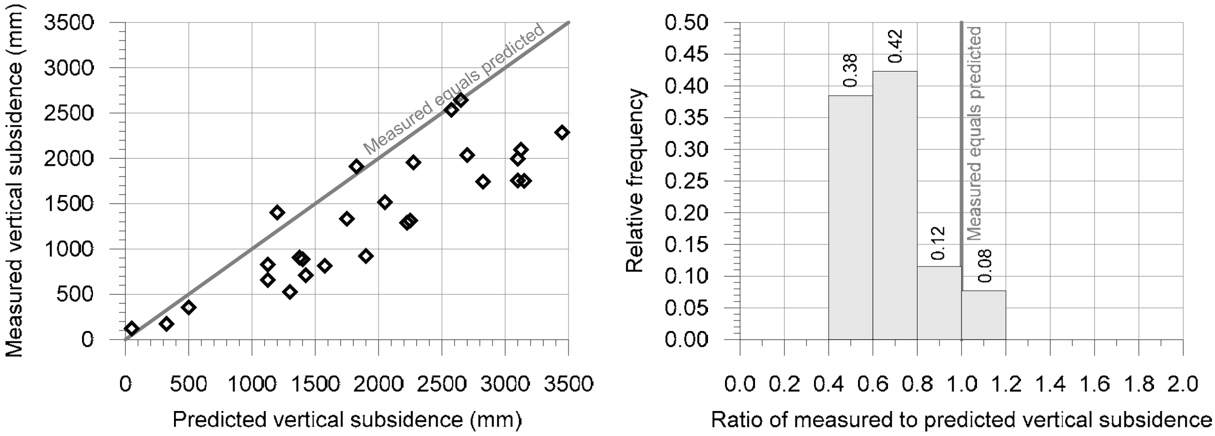

Fig. 3.7 Comparison of measured and predicted subsidence for the ground monitoring lines

The measured total vertical subsidence movements are typically less than the predicted total values for each of the monitoring lines. The average ratio of the measured to predicted vertical subsidence for these monitoring lines is 0.68.

The measured total vertical subsidence movements exceed the predicted total values in three of the 26 cases (i.e. 12 % of the monitoring lines). The exceedances occur where the monitoring lines are located near to or above the chain pillars and these measured movements are less than the maximum values that occur directly above the longwalls. The ratios of the measured to predicted total vertical subsidence for these three monitoring lines range between 1.05 to 1.17 and, therefore, are within the order of accuracy of the predictive method for vertical subsidence of ±15 % to ±25 %.

The comparisons of the measured and predicted total closure for the traditional ground monitoring lines at the completion of LW16 are illustrated in Fig. 3.8. The measured versus the predicted values are shown on the left side of this figure. The ratios of the measured to predicted values (for magnitudes greater than 50 mm) are shown on the right side of this figure. The predictions are based on the 2002 ACARP method.

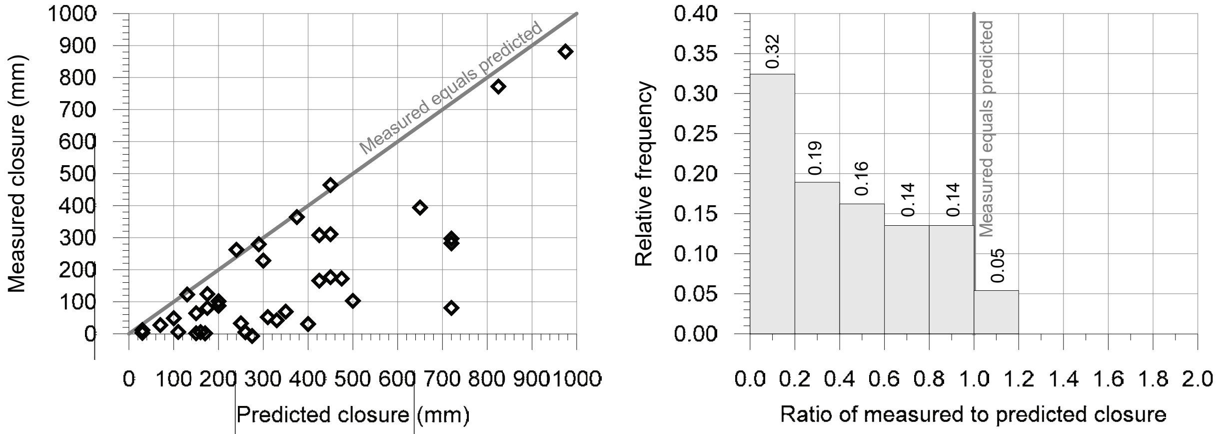

Fig. 3.8 Comparison of measured and predicted closure for the ground monitoring lines

The measured total closure movements are typically less than the predicted total values for each of the monitoring lines. The average ratio of the measured to predicted total closure for these monitoring lines is 0.45, i.e. the measured closures are, on average, around half of those predicted.

The measured total closure movements exceed the predicted values in two of the 38 cases (i.e. 5 % of the monitoring lines). It is noted that there were two additional cases where the measured closures exceeded the predicted values at the completion of LW12. However, the measured closures for these two cases were less than the predicted values after the completion of LW13. The ratio of the measured to predicted total closure for the remaining monitoring lines range between 1.03 and 1.09 and, therefore, are within the order of accuracy of the predictive method for valley closure of ±15 % to ±25 %.

It is considered that the calibrated prediction model based on the MSEC792 prediction curves provides adequate predictions of vertical subsidence and valley closure based on the available ground monitoring lines. The measured movements can be greater than the predicted values, in some cases, but these exceedances are expected to be within the orders of accuracy of the predictive methods of ±15 % to ±25 %.

3.6.3. Use of the calibrated IPM for the proposed longwalls

The calibrated IPM based on the MSEC792 prediction curves has been reviewed based on the ground movement monitoring data from LW9 to LW16 in Area 3B. A comparison of the mining geometry for the proposed LW22 and LW23 with that for the completed longwalls in Area 3B is provided in Table 3.1.

Table 3.1 Comparison of the mine geometry for the longwalls in Areas 3B and 3C

Parameter	Proposed LW22 and LW23 (Area 3C)		Completed LW9 to LW16 (Area 3B)	
	Range	Average	Range	Average
Longwall widths	305	305	305	305
Depth of cover	290 ~ 390	340	310 ~ 410	380
W/H ratio	0.78 ~ 1.05	0.90	0.74 ~ 0.98	0.80
Extraction height	3.9	3.9	3.4 ~ 4.5	3.9

The range of depths of cover above the proposed LW22 and LW23 is similar to but slightly less than the range for the completed LW9 to LW16. The mining height for the proposed LW22 and LW23 is similar to the average extraction height for the completed LW9 to LW16. The longwalls in Areas 3B and 3C are all within the Wongawilli Seam.

It is considered appropriate, therefore, to adopt the MSEC792 prediction curves for the proposed LW22 and LW23. These prediction curves provide an additional 30 % to the maximum incremental vertical subsidence for each of the longwalls, when compared with that predicted using the standard IPM model.

3.7. Numerical model

A numerical model has been developed for the Mine using Universal Distinct Element Code (UDEC). This method is a two-dimensional Discrete Element Method (DEM) comprising deformable elements that interact via compliant contacts (Itasca, 2015). The numerical modelling has been undertaken to supplement the predictions obtained using the empirical IPM.

The UDEC model has been derived from the *base model* that was developed for the Southern Coalfield for mining in the Bulli Seam (Barbato, 2017). The numerical model has been updated for the local stratigraphy (refer to Section 1.4) and has been calibrated for the local mining conditions using the ground monitoring data from Areas 3A and 3B at the Mine.

3.7.1. Calibration of the UDEC model for Dendrobium Mine

The numerical model has been calibrated using ground monitoring data from Areas 3A and 3B at the Mine.

The widths of the longwalls in Area 3A are 250 m for LW6 and LW7 and 305 m for LW8. The average depth of cover to the Wongawilli Seam is 370 m. The width-to-depth ratios for these longwalls therefore vary between 0.68 and 0.82. The maximum mining height for the longwalls in Area 3A is 3.9 m.

The widths of LW9 to LW15 in Area 3B are also 305 m. It is noted that LW16 has not been included in the calibration, as the ALS survey carried out in February 2020 does not cover that longwall. The latest ALS in November 2020 only covers LW13 to LW16 and, therefore, the previous survey in February 2020 has been adopted. The average depth of cover to the Wongawilli Seam is 380 m. The average width-to-depth ratio for these longwalls therefore is 0.80. The average mining heights at the cross-section considered are 3.5 m for LW9, 4.5 m for LW10, 4.0 m for LW11 to LW13 and 3.9 m for LW14 and LW15.

The element (i.e. block) size adopted in the numerical model has been based on Block Type B1 for the *base model* (refer to Section 6.4.3.1 of Barbato, 2017). Minor adjustments of the element sizes have been made to suit the depths of each stratigraphic unit. The element aspect ratio has been taken as 1.5:1.0 (H:V) as per the *base model*.

The horizontal in situ stress has been based on Stress Type S2 for the *base model* (refer to Section 6.4.4 of Barbato, 2017). The stress at the surface is 1.5 MPa and the stress gradient through the overburden strata is 36 kPa/m.

The parametric analysis of the *base model* (refer to Section 6.9 of Barbato, 2017) showed that the appropriate material and joint properties are dependent on the other properties adopted in the numerical model, including the element size and aspect ratio. The appropriate properties are also dependent on the depth of cover and mining height, as these affect the relative contributions of vertical subsidence due to sagging of the overburden strata and pillar compression.

The material and joint properties have been calibrated for the local conditions using the available ground monitoring data for each mining area. The initial calibration of the numerical model using the ground monitoring data from Areas 3A and 3B at the Mine found that the *base model* (i.e. Material Type M1 and Joint Type J2) underpredicted the vertical subsidence above the longwalls and the chain pillars.

The magnitudes and the profiles of vertical subsidence obtained from the numerical model better matched those measured in Area 3A by adopting material bulk and shear moduli and joint cohesions that were 70 % of those used in the *base model*. The magnitudes and profiles better matched those measured in Area 3B by adopting material bulk and shear moduli that were 50 % of those used in the *base model*, with no changes to the joint properties. The differences in the appropriate material and joint properties adopted in the model for Areas 3A and 3B are due to the varying contributions of the components of vertical subsidence due to sagging of the overburden strata and pillar compression.

The comparison between the modelled and measured vertical subsidence are illustrated in Fig. 3.9 for Area 3A and Fig. 3.10 for Area 3B. The measured subsidence is based on the difference between the LiDAR surface levels measured prior to and after the completion of mining in each area.

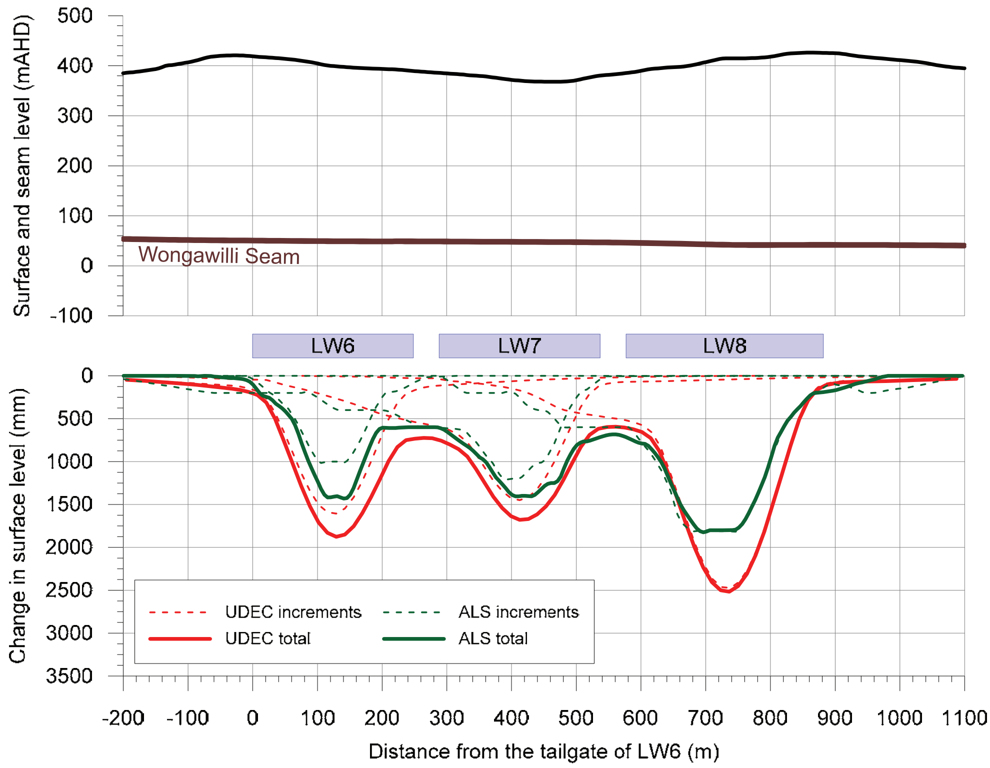

Fig. 3.9 Comparison of modelled and measured subsidence for Dendrobium Area 3A

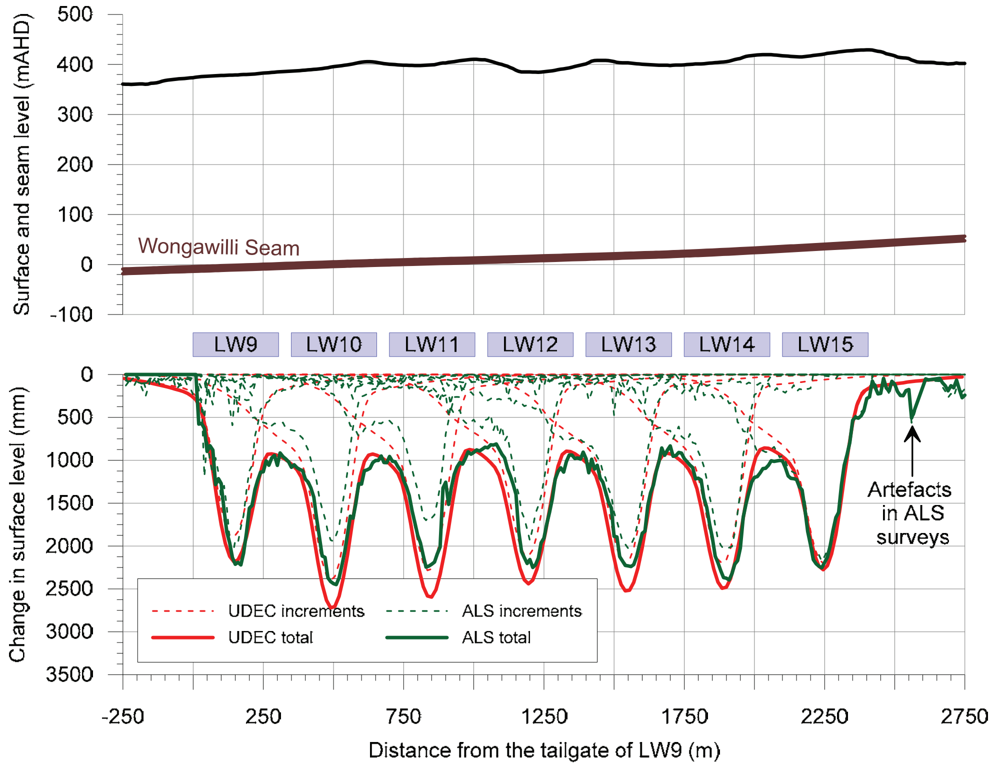

Fig. 3.10 Comparison of modelled and measured subsidence for Dendrobium Area 3B

It is considered that the profiles of vertical subsidence obtained from the UDEC model reasonably match those measured using the LiDAR surveys in Areas 3A and 3B. The numerical model slightly overpredicts the vertical subsidence for Area 3A, whereas there is a better match for Area 3B. The main difference is due to the lower depth of cover and mining height in Area 3A compared to those in Area 3B.

The mining geometries for the proposed LW22 and LW23 are similar to those for LW9 to LW15 in Area 3B. The numerical model should therefore provide reasonable, if not, slightly conservative predictions of vertical subsidence for the proposed longwalls.

3.7.2. UDEC model for the proposed longwalls

The void widths of the proposed LW22 and LW23 are 305 m. The average depth of cover to the Wongawilli Seam within the mining area is 340 m. The width-to-depth ratios for these longwalls therefore vary between 0.78 ~ 1.03, with an average value of 0.90. The longwalls are proposed to extract a thickness of 3.9 m in the basal section of the Wongawilli Seam which is approximately 10 m thick.

The edges of the numerical model have been taken as the greater of two times the longwall void widths and 600 m from the longwall maingate and tailgate. The overall width of the model therefore is 1875 m. The numerical model extends down to 100 m below the Wongawilli Seam which has an average depth of cover of 340 m and a nominal thickness of 10 m. The overall height of the model therefore is 450 m.

A summary of the stratigraphy adopted in the UDEC model is provided in Table 3.2. The element sizes have been based on Block Type B1 of the *base model*, with minor adjustments to suit the depths of each stratigraphic unit.

Table 3.2 Stratigraphy adopted in the UDEC model

Unit	Thickness (m)	Depth to base on unit (m)	Block size (H x V, m x m)
Hawkesbury Sandstone	120	120	15 x 10
Newport/Garie Formation	20	140	6 x 4
Bald Hill Claystone	20	160	6 x 4
Bulgo Sandstone	120	280	15 x 10
Wombarra Claystone	37	317	6 x 4
Bulli Coal	3	320	4.5 x 3
Eckersley Formation	20	340	7.5 x 5
Wongawilli Coal	10	350	2 x 1
Sub-Wongawilli	100	450	15 x 10

Summaries of the material and joint properties adopted in the UDEC model are provided in Table 3.3 and Table 3.4, respectively. The joint normal stiffness and shear stiffness have been taken as 30 GPa/m and 3 GPa/m, respectively. The parameter analysis of the joint stiffness properties found that the numerical model is not sensitive to these two parameters (refer to Section 6.9.4 of Barbato, 2017).

Table 3.3 Material properties adopted in the UDEC model

Unit	ρ (kg/m^3)	K (GPa)	G (GPa)	C (MPa)	φ (deg.)	T (MPa)
Hawkesbury Sandstone	2400	1.67	1.00	7.0	34	0.5
Newport/Garie Formations	2400	1.73	1.24	4.0	30	0.5
Bald Hill Claystone	2700	2.50	1.16	6.0	25	0.5
Bulgo Sandstone	2500	2.78	2.09	10	30	0.5
Wombarra Claystone	2600	3.45	2.48	10	25	0.5
Bulli Coal	1500	0.77	0.49	2.0	25	0.5
Eckersley Formation	2500	4.0	2.4	15	25	0.5
Wongawilli Coal	1500	0.77	0.49	2.0	25	0.5
Sub-Wongawilli	2500	4.0	2.4	15	25	0.5

Table 3.4 Joint properties adopted in the UDEC model

Unit	Cohesion (MPa)		Friction angle (deg.)	
	Peak	Residual	Peak	Residual
Hawkesbury Sandstone	2.50	1.50	25	15
Newport/Garie Formations	2.25	1.35	24	14
Bald Hill Claystone	2.75	1.65	21	13
Bulgo Sandstone	4.50	2.70	24	14
Wombarra Claystone	3.00	1.80	22	13
Eckersley Formation	4.25	2.55	22	13
Sub-Wongawilli	4.25	2.55	22	13

The modelled profile of vertical subsidence obtained from the UDEC model is illustrated as the red line in Fig. 3.11. The predicted profile based on the IPM has also been shown in this figure as the blue line for comparison.

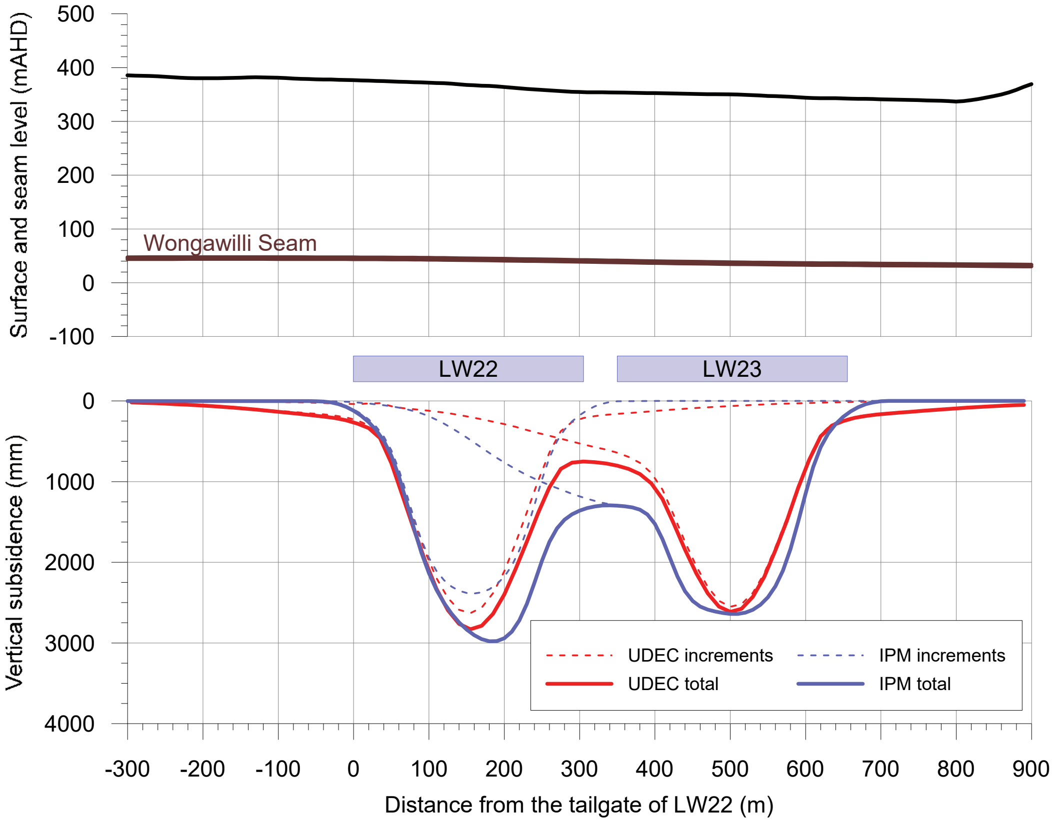

Fig. 3.11 UDEC modelled and IPM predicted profiles of vertical subsidence

The profile of vertical subsidence obtained from the UDEC model reasonably matches that predicted using the IPM. The values of maximum predicted vertical subsidence directly above the proposed longwalls are within ±10 %. The numerical model predicts less subsidence directly above the chain pillar, as the IPM has been calibrated using ground monitoring data to increase the component of pillar compression. The numerical model predicts slightly higher vertical subsidence outside the extents of the proposed longwalls; however, the differences in magnitude are in the order of 200 mm or less.

The maximum predicted tilts and curvatures obtained from the UDEC model are similar to but slightly less than the maximum predicted values based on the IPM. This is due to the UDEC model predicting slightly narrower profiles of vertical subsidence compared to the IPM. The maximum predicted tilts and curvatures obtained from the two models are in similar positions.

It is considered that the profile of vertical subsidence obtained from the UDEC model reasonably matches that predicted using the IPM. It is not considered necessary, therefore, to further calibrate the IPM based on the outcomes of the numerical model.

The modelled profiles of vertical subsidence and horizontal movement through the overburden strata are illustrated in Fig. 3.12. The profiles have been taken through the longwall centreline, midway between the centreline and tailgate (referred to as the quarter point) and at the longwall tailgate.

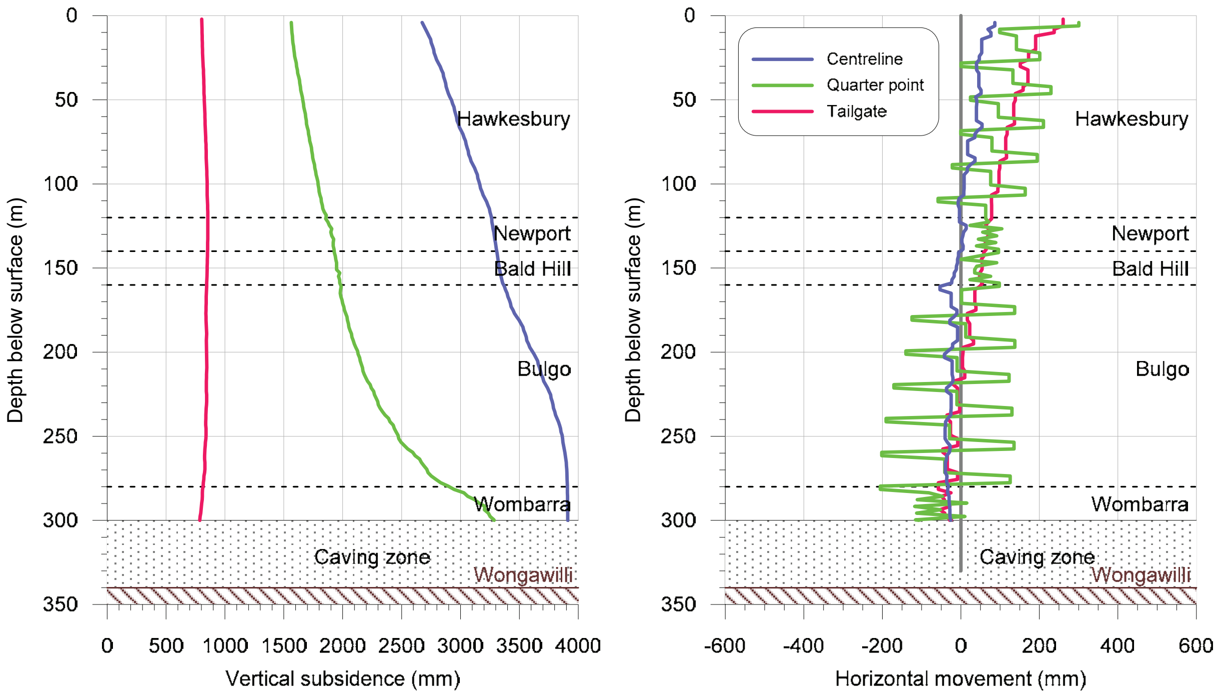

Fig. 3.12 Modelled profiles of vertical subsidence and horizontal movement through the overburden at the longwall centreline, quarter point and longwall tailgate

The vertical subsidence at the longwall centreline varies between 68 % of the mining height at the surface through to 100 % of the mining height at the caving zone. The vertical subsidence adjacent to the longwall tailgate varies between 18 % and 22 % of the mining height.

The vertical strain (over a 20 m height) within the Hawkesbury Sandstone varies between approximately 4 mm/m at the surface and 5 mm/m at the base of the unit. The maximum vertical strain within the Hawkesbury Sandstone occurs at the longwall centreline with the strains reducing towards the longwall maingate and tailgate.

The vertical strain within the Bulgo Sandstone, at the longwall centreline, varies between approximately 4 mm/m at the top, 7 mm/m near mid-height and 4 mm/m at the base of the unit. The vertical strain at the quarter-point of the longwall varies between approximately 4 mm/m at the top and 23 mm/m at the base of the Bulgo Sandstone.

The vertical strain within the Wombarra Claystone varies between 9 mm/m and 23 mm/m. The maximum vertical strain occurs at the longwall quarter-point, with the strains reducing towards the longwall centreline, maingate and tailgate. The vertical strains within the Newport Formation and the Bald Hill Claystone are typically 5 mm/m or less.

The horizontal shear on the bedding plane partings varies between approximately 150 mm and 250 mm within the Hawkesbury Sandstone and varies between approximately 200 mm and 350 mm within the Bulgo Sandstone. The maximum horizontal shear occurs at the quarter point within the Bulgo Sandstone.

It is noted that the magnitudes of horizontal shear are dependent on their spacings. Hence, fewer but larger horizontal shears, or more but smaller horizontal shears could develop compared with that predicted, depending on their actual spacing.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence effects resulting from the extraction of the proposed LW22 and LW23 in Area 3C. The predicted subsidence effects and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

The predicted vertical subsidence, tilt and curvature have been obtained using the IPM, which has been calibrated based on the latest monitoring data from the Mine, as described in Section 3.6. The predicted strains have been determined by analysing the strains measured at other NSW collieries, where the longwall width-to-depth ratios and extraction heights are similar to those for the proposed longwalls.

The maximum predicted subsidence effects 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 and 6.

4.2. Maximum predicted conventional subsidence, tilt and curvature

A summary of the maximum predicted values of incremental conventional vertical subsidence, tilt and curvature due to the extraction of each of LW22 and LW23 is provided in Table 4.1. The incremental values are the additional movements due to each proposed longwall.

Table 4.1 Maximum predicted incremental conventional subsidence, tilt and curvature resulting from the extraction of each of the proposed longwalls

Due to longwall	Maximum predicted incremental subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
LW22	2550	35	0.90	0.90
LW23	2500	35	0.90	0.90

The predicted total vertical subsidence contours after the extraction of LW22 and LW23 are shown in Drawing No. MSEC1104-12, in Appendix D. A summary of the maximum predicted values of total vertical subsidence, tilt and curvature is provided in Table 4.2. The total effects represent the accumulated movements within the Study Area due to the extraction of the existing and proposed longwalls.

Table 4.2 Maximum predicted total conventional subsidence, tilt and curvature after the extraction of the proposed longwalls

After longwalls	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
LW22 and LW23	3000	40	1.0	1.0

The maximum predicted total vertical subsidence of 3000 mm represents 77 % of the proposed extraction height of 3.9 m. This is considered to be conservative as it is greater than the maximum measured vertical subsidence in the NSW coalfields for single-seam mining conditions of 65 % of the mining height.

The maximum predicted total tilt for the proposed longwalls is 40 mm/m (i.e. 4.0 %, or 1 in 25). The maximum predicted total conventional curvatures are 1.0 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 1 km.

The predicted conventional subsidence effects vary across the Study Area as the result of, amongst other factors, variations in the longwall geometry, depths of cover, seam thickness and overburden geology. To illustrate this variation, the predicted profiles of vertical subsidence, tilt and curvature have been determined along two prediction lines. The predicted profiles of total vertical subsidence, tilt and curvature along Prediction Lines 1 and 2 are shown in Figs. C.01 and C.02, respectively, in Appendix C. The locations of these prediction lines are shown in Drawing No. MSEC1104-12.

4.3. Comparison of predictions with those in Areas 3A and 3B

A comparison of the maximum predicted total conventional subsidence effects with the maximum predicted values for the existing and approved longwalls in Areas 3A and 3B is provided in Table 4.3. The predictions for each of these mining areas are based on the calibrated IPM as described in Section 3.6.

Table 4.3 Comparison of maximum predicted total subsidence effects

Area (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})
Area 3A (LW6 to LW8 and LW19)	3000	40	1.0	1.0
Area 3B (LW9 to LW18)	3600	50	1.4	1.4
Area 3C (LW22 and LW23)	3000	40	1.0	1.0

The maximum predicted subsidence effects for the proposed LW22 and LW23 are the same as the maximum predicted values for LW6 to LW8 and LW19 in Area 3A. The reason is that the longwalls in Area 3A and the proposed longwalls have the same maximum void width of 305 m, similar ranges of depths of cover and the same maximum mining height of 3.9 m.

The predicted subsidence effects for LW22 and LW23 are less than the maximum predicted values for LW9 to LW18 in Area 3B. The predicted values for the proposed longwalls are less as the extraction height of 3.9 m is less than the extraction height for LW10 to LW13 in Area 3B of up to 4.6 m.

It is noted that the maximum measured vertical subsidence in Areas 3A and 3B, to date, are less than the maximum predicted values as provided in Table 4.3. The maximum measured vertical subsidence movements based on the LiDAR surveys are approximately 2000 mm due to LW6 to LW8 in Area 3A and approximately 2700 mm due to LW9 to LW16 in Area 3B.

While not all longwalls have been extracted in Areas 3A and 3B, it is expected that the maximum measured vertical subsidence will be less than the maximum predicted values at the completion of mining in these areas. It is expected, therefore, that the actual measured vertical subsidence for the proposed LW22 and LW23 will also be less than the maximum predicted values obtained using the calibrated IPM model.

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.

In previous MSEC subsidence reports, predictions of conventional strain were provided based on the best estimate of the average relationship between curvature and strain. Similar relationships have been proposed by other authors. The reliability of the strain predictions was highlighted in these reports, where it was stated that measured strains can vary considerably from the predicted conventional values.

Adopting a linear relationship between curvature and strain provides a reasonable prediction for the conventional tensile and compressive 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 Southern Coalfield, it has been found that a factor of 15 provides a reasonable relationship between the predicted maximum curvatures and the predicted maximum conventional strains.

The maximum predicted conventional strains resulting from the extraction of proposed LW22 and LW23, based on applying a factor of 15 to the maximum predicted curvatures, are 15 mm/m tensile and compressive. These strains represent typical values when the ground subsides regularly with no localised or elevated strains due to near-surface geological structures or valley closure effects. The maximum strains can be much greater than these typical values, especially in the locations of near-surface geological structures and in the bases of valleys.

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. In this report, therefore, we have provided a statistical approach to account for the variability, instead of just providing a single predicted conventional strain.

There are two traditional ground monitoring lines at Dendrobium Mine that do not cross streams or valleys, being the SCW North and South Lines in Area 3A. The ranges of potential strains above the proposed longwalls, therefore, have been determined using these ground monitoring lines as well as data from the NSW coalfields, where the mining geometries are reasonably similar to that at the Mine.

A comparison of the mining geometry for the proposed LW22 and LW23 with that for the previously extracted longwalls used in the strain analysis is provided in Table 4.4. There is a total of 46 ground monitoring lines located above 111 previously extracted longwalls in the Hunter and Newcastle Coalfields.

Table 4.4 Comparison of the mine geometry for the proposed LW22 and LW23 with the longwalls from the NSW coalfields used in the strain analysis

Parameter	Proposed LW22 and LW23		Longwalls used in strain analysis	
	Range	Average	Range	Average
Longwall width	305	305	120 ~ 410	190
Depth of cover	290 ~ 390	340	100 ~ 360	180
W/H ratio	0.78 ~ 1.05	0.90	0.8 ~ 1.2	1.06
Extraction height	3.9	3.9	3.0 ~ 4.8	4.2

The range of width-to-depth ratios and extraction heights for the longwalls used in the strain analysis are similar to values for the proposed LW22 and LW23. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains resulting from the extraction of the proposed 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 effects, which are addressed separately in this report. The strains resulting from damaged or disturbed survey marks have been excluded.

The survey database has been analysed to extract the maximum tensile and compressive strains that have been measured at any time during the extraction of the previous longwalls in the NSW coalfields, for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls. A number of probability distribution functions were fitted to the empirical data. It was found that a *Generalised Pareto Distribution (GPD)* provided a good fit to the raw strain data.

The histogram of the maximum observed tensile and compressive strains measured in survey bays above goaf, for the selected monitoring lines from the NSW coalfields, is provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

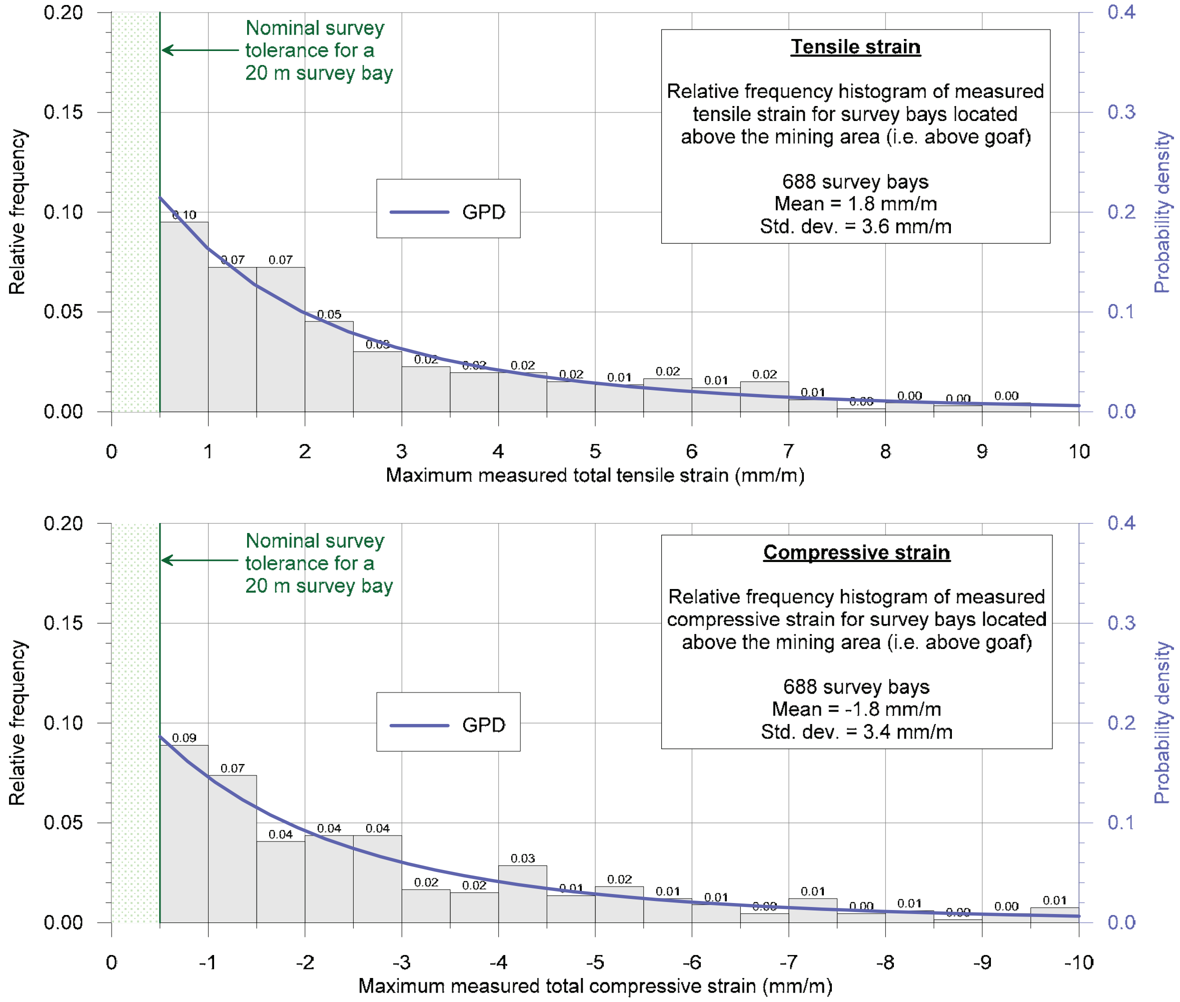

Fig. 4.1 Distributions of the measured maximum tensile and compressive strains during the extraction of previous longwalls in the NSW coalfields for bays located above goaf

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 8 mm/m tensile and compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining are 17 mm/m tensile and compressive.

4.5. Predicted conventional horizontal movements

The predicted conventional horizontal movements over the existing and proposed longwalls are calculated by applying a factor to the predicted conventional tilt values. In the Southern Coalfield a factor of 15 is generally adopted, being the same factor as that used to determine the conventional strains from the conventional curvatures, and this has been found to give a reasonable correlation with measured data. This factor will 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 conventional tilt for the proposed LW22 and LW23 is 40 mm/m. The maximum predicted conventional horizontal movement, therefore, is approximately 600 mm, i.e. 40 mm/m multiplied by a factor of 15. Greater movements can develop in incised terrain, due to the increased horizontal movements that develop in the downslope direction.

The distribution of the maximum observed horizontal movements for the 3D survey marks located directly above the longwalls in Dendrobium Areas 1, 2, 3A and 3B is provided in Fig. 4.2. It can be seen from this figure, that horizontal movements have been measured up to 700 mm at the Mine, with an average measured value of approximately 300 mm.

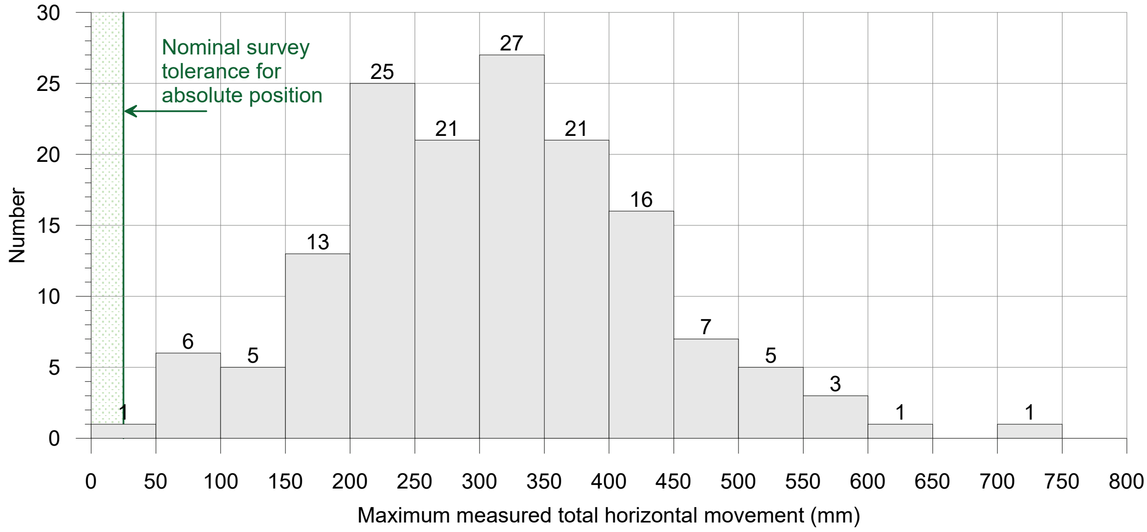

Fig. 4.2 Distribution of the maximum measured horizontal movements for the 3D marks located directly above the longwalls in Dendrobium Areas 1, 2, 3A and 3B

Conventional horizontal movements do not directly impact on natural and built features, rather impacts occur as the result of differential horizontal movements. Strain is the rate of change of horizontal movement. The impacts of strain on the natural features and items of surface infrastructure are addressed in the impact assessments for each feature, which have been provided in Chapters 5 and 6.

4.6. Predicted far-field horizontal movements

In addition to the conventional subsidence movements that have been predicted above and adjacent to the existing and proposed longwalls, and the predicted valley-related effects along the streams, it is also likely that far-field horizontal movements will be experienced during the extraction of the proposed longwalls.

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data from Dendrobium Mine, as well as from other collieries in the Southern Coalfield, including Appin, Metropolitan, Tahmoor, Tower and West Cliff. The far-field horizontal movements resulting from longwall mining were generally observed to be orientated towards the extracted longwall. At very low levels of far-field horizontal movements, however, there was a high scatter in the orientation of the observed movements.

The measured incremental far-field horizontal movements, resulting from the mining of longwalls at Dendrobium Areas 1, 2, 3A and 3B, as well as other collieries in the Southern Coalfield, are provided in Fig. 4.3. The mean and the 95 % confidence level for the 3D monitoring data at Dendrobium Mine are also shown in this figure.

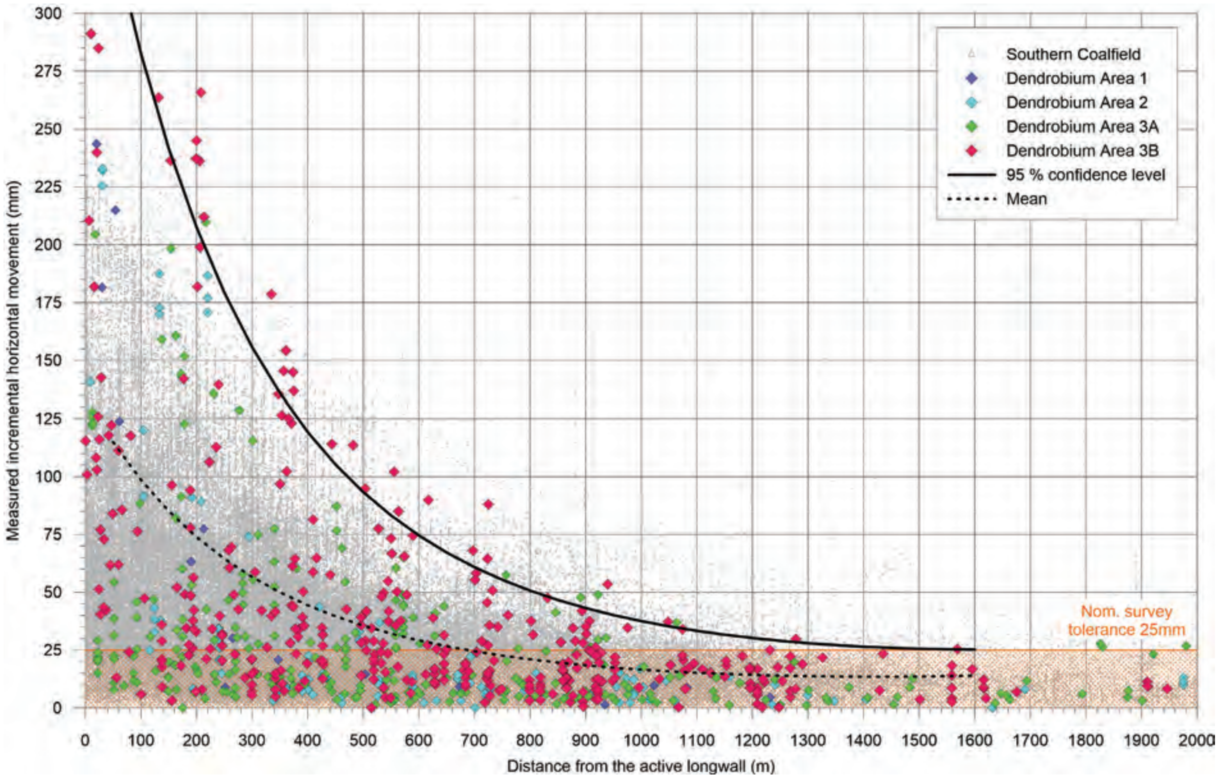

Fig. 4.3 Measured incremental far-field horizontal movements at Dendrobium Mine and elsewhere in the Southern Coalfield

As successive longwalls within a series of longwalls are mined, the magnitudes of the incremental far-field horizontal movements tend to decrease. The total far-field horizontal movement is not, therefore, the sum of the incremental far-field horizontal movements for the individual longwalls.

The predicted far-field horizontal movements resulting from the mining of the longwalls are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than survey tolerance. The impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the vicinity of the Study Area are not expected to be significant, except where they occur at large structures which are sensitive to small differential movements.

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, steep topography and valley-related effects, which are discussed in Section 3.4. These non-conventional movements are often accompanied by elevated tilts and curvatures that are likely to exceed the conventional predictions.

Specific predictions of upsidence, closure and compressive strain due to the valley-related effects are provided for the streams in Sections 5.2 to 5.3. The impact assessments for the streams are based on both the conventional and valley-related effects. The potential for non-conventional movements associated with steep topography is discussed in the impact assessments for the steep slopes provided in Section 5.6.

In most cases, it is not possible to predict the exact locations or magnitudes of the non-conventional anomalous movements due to near surface geological conditions. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains in the NSW coalfields, including both conventional and non-conventional anomalous strains and are discussed in Section 4.4. In addition to this, the impact assessments for the natural features and items of surface infrastructure, which are provided in Chapters 5 and 6, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

4.8. Surface 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 jointing in the bedrock and the presence of near-surface geological structures.

Faults and joints in bedrock develop during the formation of the strata and from subsequent destressing associated with movement of the strata. 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.

Surface deformations can also develop as the result of downslope movements where longwalls are extracted beneath steep slopes. In these cases, the downslope movements can result in the development of tension cracks at the tops and on the sides of the steep slopes and compression ridges at the bottoms of the steep slopes. The impact assessments for downslope movements are provided in Section 5.6.

Fracturing of bedrock can also occur in the bases of stream valleys due to the compressive strains associated with valley related upsidence and closure effects. The impact assessments for valley related movements are provided in Sections 5.2 to 5.3.

Soil crack and rock fracture widths were measured at impact sites located above LW3 to LW5 in Area 2, LW6 to LW8 in Area 3A and LW9 to LW16 in Area 3B. The distribution of the measured widths of these surface deformations is illustrated in Fig. 4.4.

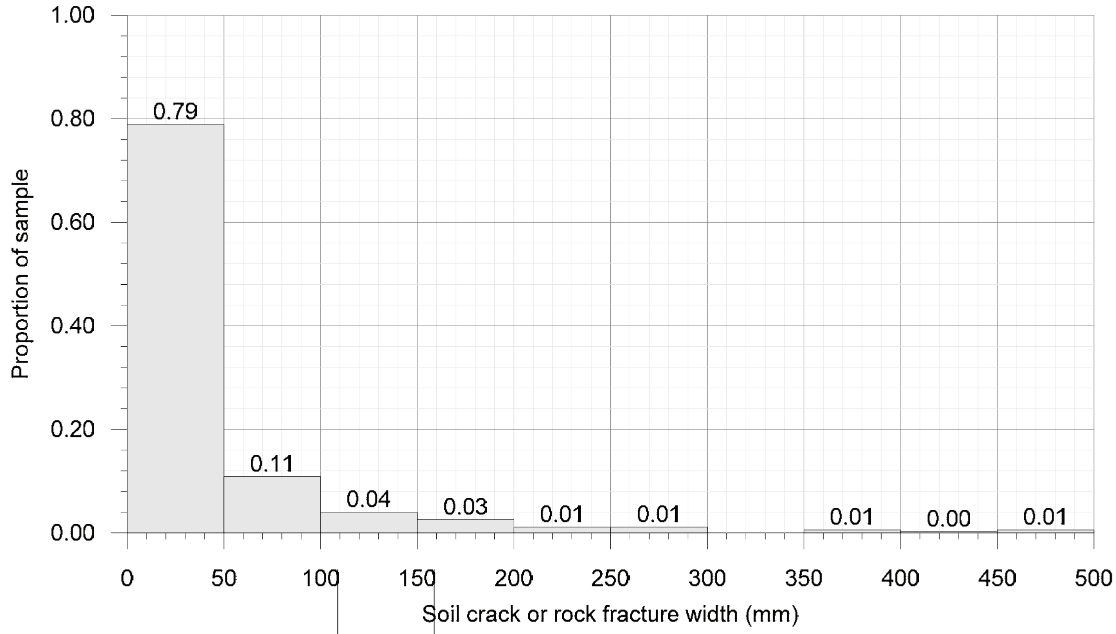

Fig. 4.4 Distribution of measured soil crack and rock fracture widths in Areas 2, 3A and 3B

The soil crack and rock fracture widths were generally observed to be less than 50 mm (i.e. 79 % of the cases). However, the widths of the surface deformations were between 50 mm and 150 mm in 15 % of cases, between 150 mm and 300 mm in 5 % of cases and greater than 300 mm in 2 % of cases. The maximum measured crack width was approximately 500 mm.

It is noted that there was a series of cracks up to 1.5 m wide located above the commencing end of LW3 (not shown in the above figure for clarity) that developed due to downslope movement on the steep slopes, the shallower depth of cover (less than 200 m at that location) and fretting of the crack edges. Localised erosion has also occurred at several sites causing surface deformations with widths up to 0.75 m (not shown in the above figure for clarity).

The predicted subsidence effects for the proposed LW22 and LW23 are less than the predicted values for the previously extracted longwalls in Area 3B at the Mine, as shown in Table 4.3. Soil crack and rock fracture widths due to the extraction of the proposed longwalls, therefore, are expected to be similar or less than those previously measured in Areas 3A and 3B.

The following sections provide the descriptions, predictions and impact assessments for the natural features located within the Study Area. All significant natural features located outside the Study Area, which may be subjected to far-field or valley-related effects and may be sensitive to these movements, have also been included as part of this assessment.

5.1. Catchment Areas and Declared Special Areas

The Study Area lies entirely within the Metropolitan Catchment Area, which is a special declared area controlled by WaterNSW. The eastern ends of the proposed LW22 and LW23 are partially located inside the Dams Safety (DS) NSW Notification Area for Lake Cordeaux, as shown in Drawing No. MSEC1104-01. The proposed longwalls are located 2.9 km outside the notification area for Lake Avon, at its closest point.

The water storages in the Metropolitan Catchment Area provide the sole water supply for the Macarthur and Illawarra regions and the townships of Campbelltown, Camden, Bargo, Picton, Thirlmere, Tahmoor, The Oaks, Buxton and Oakdale, and provide approximately 20 % of the supply to the Sydney Metropolitan Area, via the Prospect Reservoir.

Further discussions on Lake Cordeaux and Lake Avon are provided in Section 6.4.

5.2. Wongawilli Creek

5.2.1. Description of Wongawilli Creek

The location of Wongawilli Creek is shown in Drawing No. MSEC1104-09.

Wongawilli Creek is located on the western side of the proposed longwalls. The thalweg (i.e. base or centreline) of the creek is 345 m and 320 m from the finishing ends of LW22 and LW23, respectively, at its closest points. Further upstream, the creek is located between the completed longwalls in Areas 3A and 3B. The minimum distances between the thalweg of the creek and the completed longwalls are 110 m for Area 3A and 260 m for Area 3B.

Wongawilli Creek is located outside the Study Area based on the 35° angle of draw line; however, it is partially located within the Study Area based on the 600 m boundary. The total length of the creek within the 600 m boundary is approximately 1.8 km.

Wongawilli Creek is a third-order perennial stream with a small base flow and increased flows for short periods of time after significant rain events. The creek generally flows in a northerly direction and drains into the Cordeaux River approximately 2.7 km to the north of the proposed longwalls.

Pools in the creek naturally develop behind the rockbars and at the sediment and debris accumulations. The locations of the mapped stream features along Wongawilli Creek are shown in Drawings Nos. MSEC1104-09 and MSEC1104-10. Summaries of the features mapped along the section of creek located within the Study Area based on the 600 m boundary are provided in Table 5.1 to Table 5.3.

Table 5.1 Rockbars mapped along Wongawilli Creek

Label	Approximate size	Location at closest point to proposed longwalls
WC-RB13	25 m long x 6 m wide	600 m north-west of LW23
WC-RB14	10 m long x 15 m wide	550 m north-west of LW23
WC-RB15	5 m long x 6 m wide	545 m north-west of LW23
WC-RB16	6 m long x 10 m wide	535 m north-west of LW23
WC-RB17	10 m long x 4 m wide	485 m west of LW23
WC-RB18	15 m long x 4 m wide	490 m west of LW23
WC-RB19	4 m long x 3 m wide	480 m west of LW23
WC-RB20	55 m long x 15 m wide	480 m west of LW23
WC-RB21	4 m long x 10 m wide	395 m west of LW23
WC-RB22	30 m long x 15 m wide	375 m west of LW23
WC-RB23	30 m long x 15 m wide	355 m west of LW23
WC-RB24	6 m long x 4 m wide	340 m west of LW23
WC-RB25	10 m long x 6 m wide	350 m west of LW22
WC-RB26	35 m long x 9 m wide	405 m west of LW22
WC-RB27	30 m long x 10 m wide	430 m west of LW22
WC-RB28	10 m long x 4 m wide	440 m south-west of LW22
WC-RB29	20 m long x 10 m wide	440 m south-west of LW22

Label	Approximate size	Location at closest point to proposed longwalls
WC-RB30	10 m long x 6 m wide	435 m south-west of LW22
WC-RB31	20 m long x 7 m wide	450 m south-west of LW22
WC-RB32	30 m long x 10 m wide	495 m south-west of LW22
WC-RB33	5 m long x 9 m wide	570 m south-west of LW22

Table 5.2 Pools mapped along Wongawilli Creek

Label	Approximate size	Location at closest point to the proposed longwalls
WC-P24	90 m long x 25 m wide	555 m north-west of LW23
WC-P25	15 m long x 5 m wide	545 m north-west of LW23
WC-P26	30 m long x 9 m wide	540 m north-west of LW23
WC-P27	130 m long x 15 m wide	490 m north-west of LW23
WC-P28	30 m long x 5 m wide	480 m north-west of LW23
WC-P29	45 m long x 10 m wide	485 m north-west of LW23
WC-P30	200 m long x 20 m wide	395 m west of LW23
WC-P31	50 m long x 15 m wide	380 m west of LW23
WC-P32	65 m long x 8 m wide	360 m west of LW23
WC-P33	25 m long x 10 m wide	345 m west of LW23
WC-P34	15 m long x 6 m wide	330 m west of LW23
WC-P35	135 m long x 20 m wide	310 m west of LW23
WC-P36	110 m long x 15 m wide	345 m west of LW22
WC-P37	45 m long x 15 m wide	390 m west of LW22
WC-P38	50 m long x 15 m wide	420 m west of LW22
WC-P39	30 m long x 5 m wide	440 m west of LW22
WC-P40	100 m long x 20 m wide	435 m south-west of LW22
WC-P41	100 m long x 15 m wide	425 m south-west of LW22
WC-P42	20 m long x 10 m wide	440 m south-west of LW22
WC-P43	95 m long x 15 m wide	450 m south-west of LW22
WC-P44	75 m long x 15 m wide	515 m south-west of LW22
WC-P45	50 m long x 15 m wide	575 m south-west of LW22

Table 5.3 Channels mapped along Wongawilli Creek

Label	Approximate size	Location at closest point to the proposed longwalls
WC-CH09	65 m long x 4 m wide	365 m west of LW22

The surface mapping and geological modelling undertaken by IMC indicate that the base of the creek rises up through the stratigraphy as it runs from the south to the north. The section of Wongawilli Creek located within the Study Area is founded in Bulgo Sandstone.

Photographs of Wongawilli Creek at the crossing with Fire Road 6 are provided in Fig. 5.1. This crossing is located approximately 2 km north of the proposed LW23.

Fig. 5.1 Wongawilli Creek at crossing with Fire Road 6

The natural surface level along Wongawilli Creek, within the extents of the Study Area based on the 600 m boundary, varies from 280 mAHD at the upstream end to 272 mAHD at the downstream end. The average natural grade over the 1.8 km length, therefore, is approximately 4.5 mm/m (i.e. 0.45 %, or 1 in 222).

The valley of Wongawilli Creek has an overall height of approximately 100 m to 120 m within the Study Area. The valley is steeply sided, comprising cliffs, minor cliffs and talus slopes in a number of locations. The descriptions of the cliffs, minor cliffs, rock outcrops and steep slopes within the valley are included in Sections 5.5 and 5.6.

Sections A and B through the valley of Wongawilli Creek and the proposed LW22 and LW23 are provided in Fig. 5.2 and Fig. 5.3, respectively. The locations of these sections are shown in Drawing No. MSEC1104-09.

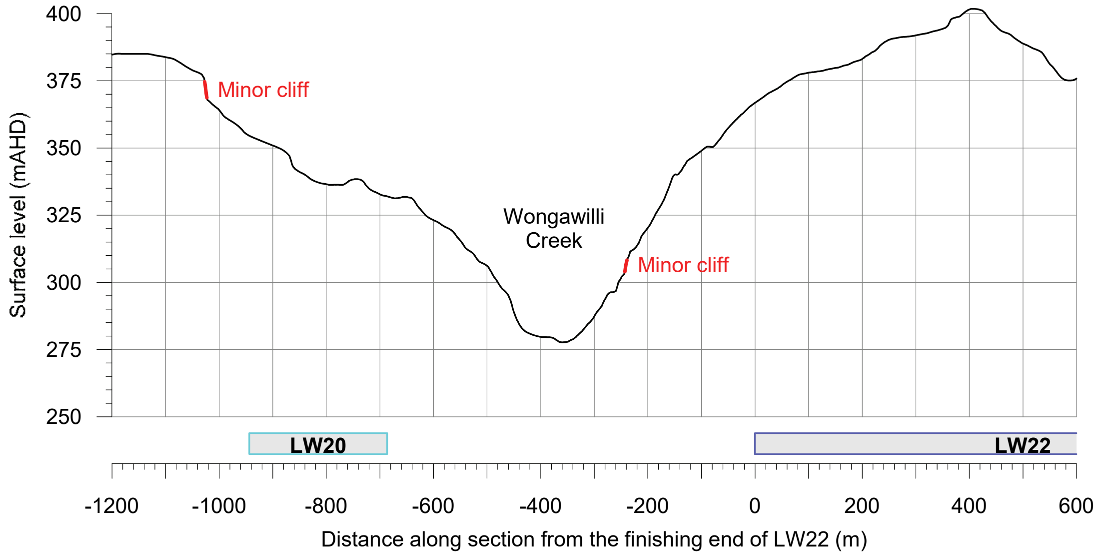

Fig. 5.2 Section A through Wongawilli Creek valley and the finishing end of LW22

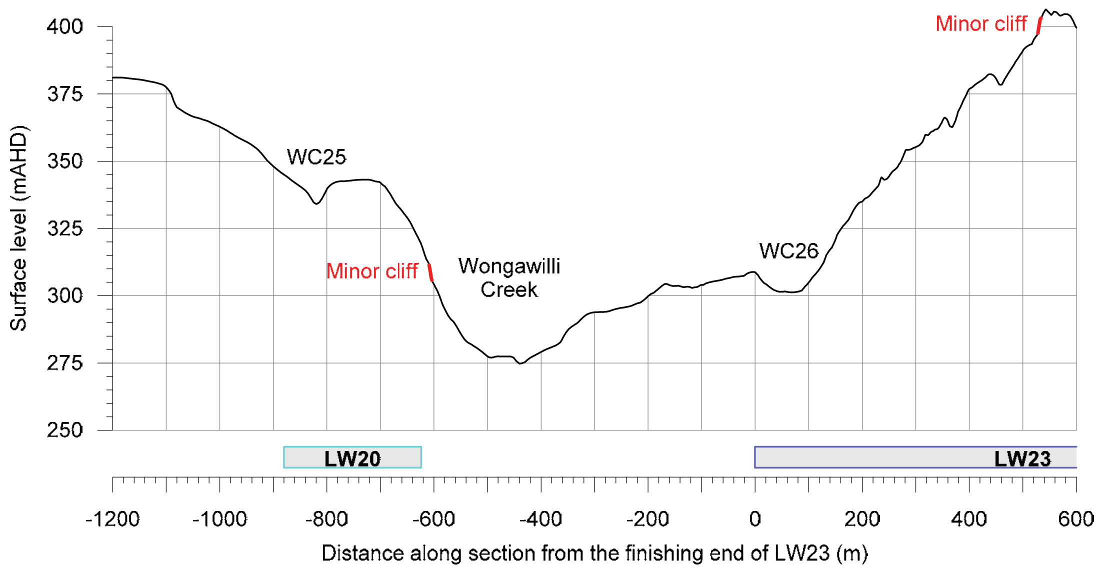

Fig. 5.3 Section B through Wongawilli Creek valley and the finishing end of LW23

Further descriptions of Wongawilli Creek are provided in the reports by other specialist consultants on the project.

5.2.2. Predictions for Wongawilli Creek

The predicted profiles of total vertical subsidence, upsidence and closure along Wongawilli Creek are shown in Fig. C.03, in Appendix C. The predicted total profiles after the completion of LW6 to LW19 in Areas 3A and 3B and LW20 and LW21 in Area 3C are shown as cyan lines. The predicted total profiles after the mining of each of the proposed LW22 and LW23 are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for Wongawilli Creek is provided in Table 5.4. The values are the maxima anywhere along the section of the creek located within the Study Area based on the 600 m boundary.

Table 5.4 Maximum predicted total vertical subsidence, upsidence and closure for Wongawilli Creek within the Study Area based on the 600 m boundary

Location	Longwalls	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Wongawilli Creek	LW9 to LW21	< 20	60	150
	LW22	< 20	70	160
	LW23	< 20	90	190

The section of Wongawilli Creek located within the Study Area is predicted to experience less than 20 mm vertical subsidence. While the creek could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains.

The maximum predicted total valley-related effects for the section of creek located within the Study Area are 90 mm upsidence and 190 mm closure. The predicted valley related effects within the Study Area are less than the maximum values further upstream, adjacent to Areas 3A and 3B, of 150 mm upsidence and 210 mm closure.

The maximum predicted additional valley-related effects for Wongawilli Creek, due to the mining of the proposed LW22 and LW23 only, are 50 mm upsidence and 80 mm closure. The remaining valley-related effects within the Study Area predominantly occur due to LW20 on the western side of the creek.

Wongawilli Creek could experience compressive strains due to the valley closure movements. The predicted strains have been determined based on an analysis of ground monitoring lines for valleys with similar heights located at similar distances from previously extracted longwalls in the Southern Coalfield, as for Wongawilli Creek. The maximum predicted compressive strain for Wongawilli Creek due to the extraction of LW20 to LW23 is 8 mm/m based on the 95 % confidence level.

Summaries of the maximum predicted values of total vertical subsidence, upsidence and closure at the mapped stream features along Wongawilli Creek are provided in Table 5.5 to Table 5.7. The locations of these features are shown in Drawing No. MSEC1104-10.

Table 5.5 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along Wongawilli Creek

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Rockbars along Wongawilli Creek	WC-RB13	< 20	40	80
	WC-RB14	< 20	50	100
	WC-RB15	< 20	50	100
	WC-RB16	< 20	50	110
	WC-RB17	< 20	60	150
	WC-RB18	< 20	60	160
	WC-RB19	< 20	60	160
	WC-RB20	< 20	70	190
	WC-RB21	< 20	80	190
	WC-RB22	< 20	80	190
	WC-RB23	< 20	70	190
	WC-RB24	< 20	70	180
	WC-RB25	< 20	80	150
	WC-RB26	< 20	50	100
	WC-RB27	< 20	50	80
	WC-RB28	< 20	40	80
	WC-RB29	< 20	40	70
	WC-RB30	< 20	50	60
	WC-RB31	< 20	60	60
	WC-RB32	< 20	60	60
	WC-RB33	< 20	50	70

Table 5.6 Maximum predicted total vertical subsidence, upsidence and closure at the mapped pools along Wongawilli Creek

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Pools along Wongawilli Creek	WC-P24	< 20	50	100
	WC-P25	< 20	50	100
	WC-P26	< 20	50	110
	WC-P27	< 20	60	140
	WC-P28	< 20	60	160
	WC-P29	< 20	70	180
	WC-P30	< 20	80	190
	WC-P31	< 20	80	190
	WC-P32	< 20	70	190
	WC-P33	< 20	70	180
	WC-P34	< 20	70	180
	WC-P35	< 20	90	180
	WC-P36	< 20	80	150
	WC-P37	< 20	50	110
	WC-P38	< 20	50	90
	WC-P39	< 20	40	80
	WC-P40	< 20	40	70
	WC-P41	< 20	50	70
	WC-P42	< 20	60	60
	WC-P43	< 20	60	60
	WC-P44	< 20	50	70
	WC-P45	< 20	50	80

Table 5.7 Maximum predicted total vertical subsidence, upsidence and closure at the mapped channels along Wongawilli Creek

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Channels along Wongawilli Creek	WC-CH09	< 20	60	120

The remaining stream features along Wongawilli Creek are predicted to experience less than 20 mm of additional vertical subsidence, upsidence and closure due to the extraction of the proposed longwalls.

5.2.3. Comparison between measured and predicted movements for Wongawilli Creek due to the extraction of LW9 to LW16

The closure movements across Wongawilli Creek have been measured using the Wong X A-Line to Wong X E-Line. The locations of these monitoring lines are shown in Drawing No. MSEC1104-01.

A review of the ground monitoring data was carried out as part of the End of Panel Report for LW16 and is summarised in Report MSEC1155 (MSEC, 2021). The measured and predicted total closures along Wongawilli Creek due to the mining of LW6 to LW16 are illustrated in Fig. 5.4. The last surveys for the Wong X A-Line and Wong X B-Line are after the completion of LW11 and LW15, respectively, due to their distances north of the following longwalls.

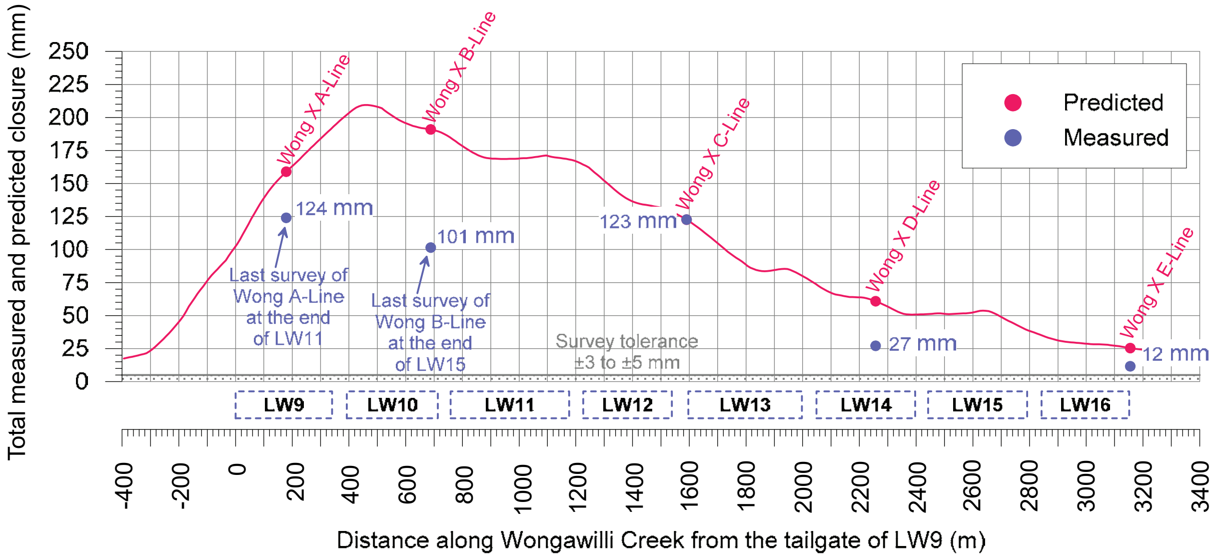

Fig. 5.4 Measured and predicted closure along Wongawilli Creek

The maximum measured total closures at each of the Wongawilli Creek closure lines are similar to or less than the predicted values at the completion of LW16. It is considered that the movements measured using the Wongawilli Creek closure lines are reasonably consistent with the predictions provided in Reports Nos. MSEC792 and MSEC865.

5.2.4. Observed impacts along Wongawilli Creek due to LW9 to LW16

The section of Wongawilli Creek upstream of the Study Area is located between the previously extracted LW6 to LW8 in Area 3A and LW9 to LW16 in Area 3B. The minimum distances between the thalweg of the creek and the completed longwalls are 110 m for Area 3A and 260 m for Area 3B.

The reported impacts for Wongawilli Creek have been summarised in the End of Panel reports for each of the extracted longwalls. The extraction of LW6 to LW16 has resulted in one Type 3 impact along Wongawilli Creek. A Type 3 impact is defined as *fracturing in a rockbar or upstream pool resulting in a reduction in standing water level based on current rainfall and surface water flow*.

Fracturing was first observed in the bed of Pool 43a after the completion of LW9. This pool is located at distances of 200 m west of LW6 in Area 3A and 410 m east of LW9 in Area 3B. Pool water levels below baseline conditions were observed in this pool during low flow conditions (i.e. Type 3 impact) after the completion of LW13. No other fractures have been observed along Wongawilli Creek due to the longwalls extracted in Areas 3A and 3B.

The longwalls in Areas 3A and 3B were setback from Wongawilli Creek so that the predicted closure is less than 200 mm at the mapped rockbars. It was assessed that the likelihood of significant fracturing resulting in surface water flow diversions along Wongawilli Creek would be low, i.e. affecting less than 10 % of the pools and channels. It is considered that the observed rate of impact (i.e. one Type 3 impact along the 2 km length of Wongawilli Creek) is similar to the MSEC assessments.

5.2.5. Impact assessments of Wongawilli Creek

The impact assessments for Wongawilli Creek are provided in the following sections. The assessments provided in this report should be read in conjunction with the assessments provided in the reports by the other specialist consultants on the project.

Potential for increased levels of ponding, flooding and scouring due to the mining-induced tilts

Wongawilli Creek is predicted to experience less than 20 mm vertical subsidence due to the extraction of the proposed LW22 and LW23. While the creek could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional tilts. That is, the predicted changes in grade along the creek due to the conventional movements are less than 0.5 mm/m (i.e. less than 0.05 %, or 1 in 2000).

The maximum predicted total upsidence for the section of Wongawilli Creek within the Study Area based on the 600 m boundary is 90 mm. While the magnitudes of the predicted upsidence vary along the alignment of the creek, as illustrated in Fig. C.03, the predicted changes in grade are less than 0.5 mm/m (i.e. less than 0.05 %, or 1 in 2000).

The average natural grade of the section of Wongawilli Creek within the Study Area is approximately 4.5 mm/m (i.e. 0.45 %, or 1 in 222). The predicted changes in grade due to the mining of LW22 and LW23, therefore, are considerably less than the average natural grade. It is unlikely, therefore, that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilt.

It is possible, however, that there could be some localised changes in the levels of ponding or flooding where the maximum changes in grade coincide with existing pools, steps or cascades along Wongawilli Creek. It is not anticipated that these changes would result in adverse impacts on the creek, due to the mining-induced tilt, since the predicted changes in grade are less than 0.05 %.

Potential for fracturing of bedrock and surface water flow diversions

Fractures and joints in bedrock and rockbars occur naturally from erosion and weathering processes and from natural valley bulging movements. Where longwall mining occurs in the vicinity of streams, mine subsidence movements can result in additional fracturing or the reactivation of the existing joints. The main mining-related mechanisms for these impacts are conventional subsidence and valley-related upsidence and closure movements.

Diversions of surface water flow also occur naturally from erosion and weathering processes and from natural valley bulging movements. Mining-induced surface water flow diversions into the strata occur where there is an upwards thrust of bedrock, resulting in a redirection of some water flows into the dilated strata beneath the creek beds. At higher depths of cover, where a constrained zone exists or where the creek is not directly mined beneath, the water generally reappears further downstream of the fractured zone as the surface flow is only redirected below the creek bed where the fractured zone exists.

Wongawilli Creek is located at minimum distances of 345 m and 320 m from the finishing ends of LW22 and LW23, respectively. While the creek could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional strains. That is, the strains due to the conventional ground movements are expected to be less than 0.3 mm/m.

The maximum predicted total closure for the section of Wongawilli Creek located within the Study Area based on the 600 m boundary is 190 mm. The maximum predicted compressive strain for the creek due to the valley closure effects is 8 mm/m based on the 95 % confidence level.

Fracturing in bedrock has been observed due to previous longwall mining where the tensile strains are greater than 0.5 mm/m or where the compressive strains are greater than 2 mm/m. It is possible, therefore, that fracturing could occur along Wongawilli Creek due to the valley-related compressive strains. Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield. Fracturing has been observed at distances up to 300 m from the completed longwalls in Area 3B.

The impact assessment for Wongawilli Creek has been based on the potential for Type 3 impacts, defined as *fracturing in rockbar or upstream pool resulting in a reduction in standing water level based on current rainfall and surface water flow*. The rockbar impact model based on the experience of longwall mining in the Southern Coalfield is described in Section 5.3.4 of Report No. MSEC459 and is illustrated in Fig. 5.5.

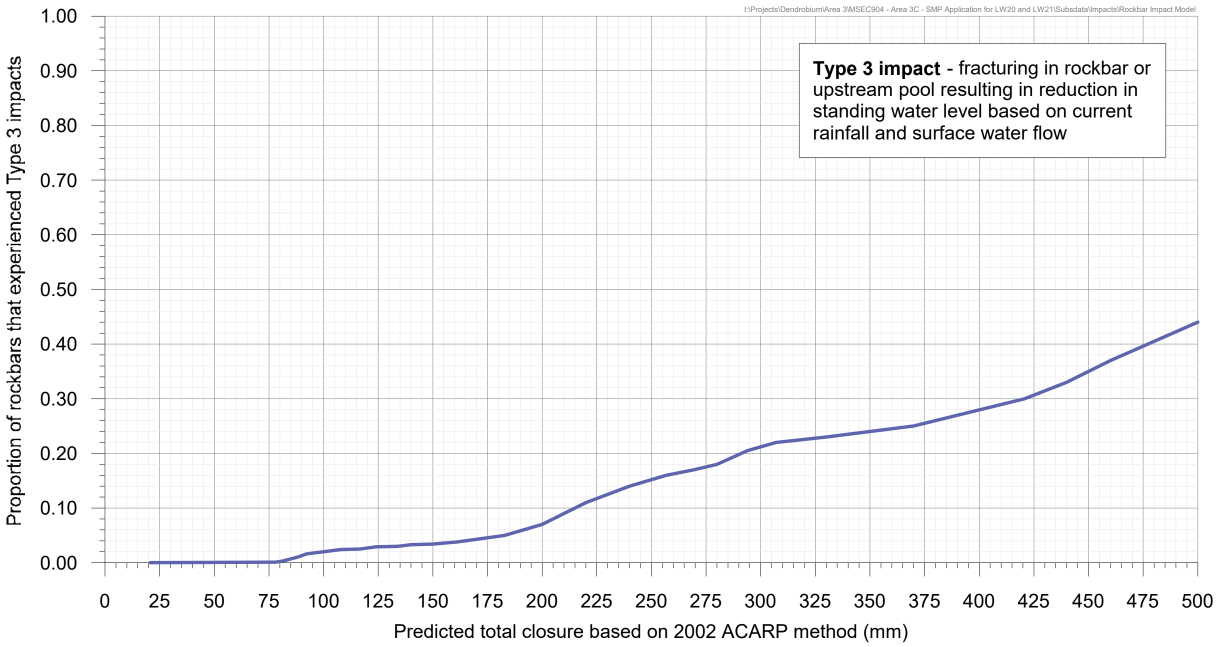

Fig. 5.5 Rockbar impact model based on predicted valley closure

The maximum predicted total closure along the section of Wongawilli Creek within the Study Area, after the extraction of the proposed LW22 and LW23, is 190 mm. The predicted rate of impact for the rockbars along this creek after the extraction of the proposed longwalls, therefore, is in the order of 6 % based on the maximum predicted closure.

Fracturing has occurred in one pool (Pool 43a) along Wongawilli Creek due to the previous mining in Areas 3A and 3B. The impact site is located 200 m west of LW6 and 410 m east of LW9. The fracturing was first observed during the extraction of LW9. Pool water levels below baseline conditions have been observed in this pool at low flow conditions during the mining of LW13. This site has therefore been considered a Type 3 impact. The total length of creek located within a distance of 400 m of the as-extracted longwalls is 2 km. The rate of impact along Wongawilli Creek due to the previous mining, therefore, is considered to be low.

It has been assessed that the likelihood of fracturing resulting in surface water flow diversions along Wongawilli Creek, due to the extraction of the proposed LW22 and LW23, is low, i.e. affecting approximately 6 % of rockbars located within the Study Area. However, minor fracturing could still occur elsewhere along the creek, at distances up to approximately 400 m from the proposed longwalls.

Further assessments of the potential impacts on surface water are provided in the report by HGeo (2021).

5.2.6. Recommendations for Wongawilli Creek

It is recommended that the closure movements are measured and that inspections are carried out along Wongawilli Creek during active subsidence. It is also recommended that the Dendrobium Watercourse Impact Management Monitoring and Contingency Plan is revised to consider the extraction of the proposed LW22 and LW23.

5.3. Drainage lines

5.3.1. Descriptions of the drainage lines

The locations of the drainage lines are shown in Drawing No. MSEC1104-09. There are unnamed drainage lines that are located directly above and adjacent to the proposed LW22 and LW23. These drainage lines are first and second-order streams that form tributaries to Lake Cordeaux in the eastern part of the Study Area and to Wongawilli Creek in the western part of the Study Area.

The drainage lines have been labelled for reference as shown in Drawing No. MSEC1104-09. The tributaries to Lake Cordeaux have a prefixed of “LC” and the tributaries to Wongawilli Creek have a prefix “WC”. The drainage lines located directly above the proposed longwalls include LC5, LC6, WC24A, WC26 and WC26A.

The beds of the drainage lines generally comprise exposed bedrock containing rockbars with some standing pools. There are also steps and cascades along the steeper sections. Debris accumulations have formed along the flatter sections that include sand deposits or islands, loose rocks and tree branches.

The natural gradients of the drainage lines vary between 20 mm/m (i.e. 2.0 %, or 1 in 50) and 500 mm/m (i.e. 50 %, or 1 in 2), with average natural gradients typically ranging between 50 mm/m (i.e. 5 %, or 1 in 20) and 200 mm/m (i.e. 20 %, or 1 in 5). The drainage lines have localised areas with natural grades greater than 500 mm/m where there are steps and cascades.

5.3.2. Predictions for the drainage lines

The drainage lines are located across the Study Area and, therefore, could experience the full range of predicted subsidence effects. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4.

The predicted profiles of total vertical subsidence, upsidence and closure along LC5, LC6, LC7, WC24 and WC26 are shown in Figs. C.04 to C.08, respectively, in Appendix C. The predicted total profiles after the completion of LW6 to LW19 in Areas 3A and 3B and LW20 and LW21 in Area 3C are shown as cyan lines. The predicted total profiles after the mining of each of the proposed LW22 and LW23 are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the drainage lines is provided in Table 5.8. The total effects represent the accumulated movements within the Study Area due to the extraction of the existing and proposed longwalls.

Table 5.8 Maximum predicted total subsidence, tilt and curvature for the drainage lines

Type	Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Drainage lines	LC5	3000	35	0.90	0.70
	LC6	2800	35	0.90	0.60
	LC7	< 20	< 0.5	< 0.01	< 0.01
	WC24	150	4.0	0.08	< 0.01
	WC26	2500	25	0.40	0.60
	Other	3000	40	1.0	1.0

The maximum predicted total tilt for the drainage lines is 40 mm/m (i.e. 4.0 %, or 1 in 25). The maximum predicted total conventional curvatures are 1.0 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 1 km.

The maximum predicted conventional strains for the drainage lines, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 15 mm/m tensile and compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.4. The predicted strains directly above the mining area are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The drainage lines will also experience valley-related effects. The range of closure movements for the drainage lines within the Study Area is expected to be similar to those measured across the streams above the existing longwalls in Area 3B. The data includes monitoring across Donalds Castle Creek, WC21 and the swamp cross-lines. The maximum measured closure for the streams in Area 3B due to the mining of LW9 to LW16 is 880 mm. The average measured values for the streams above the mining area is 240 mm and the 95-percentile is 700 mm.

The predicted compressive strains due to the valley related effects are in the order of 10 mm/m to 20 mm/m.

5.3.3. Review of the assessed and observed impacts for the drainage lines due to LW9 to LW16

First and second-order drainage lines are located above the previously extracted LW9 to LW16 in Area 3B. The impact assessments for these drainage lines were provided in Report No. MSEC459, which related to the physical impacts, i.e. cracking, fracturing and deformation of the bedrock and surface soils as the result of mining. The assessments of the environmental consequences were provided in the other specialist consultants' reports and, therefore, the discussions below should be read in conjunction with those provided by the other specialist consultants.

The impacts observed along the drainage lines due to LW9 are described in the End of Panel Report (IMC, 2014) and these have been summarised below:

> *Drainage line DC13*: impacts observed at five sites including: change in water appearance with orange precipitate from DC13_Pool20 to DC13_Pool14; multiple fractures upstream of Pool DC13_Pool20, in Rockbar DC13_RB21 and in Rockbar DC13_RB17 from less than 1 mm and up to 5 mm in width and up to 4 m in length; soil cracking downstream of DC13_RB21; and flow diversions in Pool DC13_Pool20 and upstream of Rockbar DC13_RB21.
>
> *Drainage line WC21*: impacts observed at nine sites (including at and between Pools 10, 11, 16, 17, 18 and 19) including: multiple fractures from 3 mm and up to 20 mm in width and up to 5.5 m in length; dilation and uplift up to 20 mm; iron staining; and water loss in Pool WC21_Pool16.

The impacts observed along the drainage lines due to LW10 are described in the End of Panel Report (IMC, 2015) and these have been summarised below:

> *Drainage line WC21*: impacts observed at 17 sites including: additional fracturing at the sites previously impacted by LW9; fracturing from hairline and up to 30 mm in width and up to 5.5 m in length; iron staining; dilation and uplift; and localised flow diversion upstream of Rockbar WC21_RB26 and in Pool WC21_Pool 24.

The impacts observed in the drainage lines due to LW11 are described in the End of Panel Report (IMC, 2016) and these have been summarised below:

> Multiple fractures, uplift and displacement in two locations along WC21, in Rockbar 27 and upstream of Pool 30. Loss of surface water flows along Watercourse WC21 in Pool 30.

The impacts observed along the drainage lines due to LW12 are described in the End of Panel Report (IMC, 2017) and these have been summarised below:

> Rock fractures and uplift were identified at four sites along WC21, LA4 and LA4B with widths up to approximately 50 mm. Loss of surface water flows along stream LA4 and possible diversion along stream LA4B. Fracturing observed outside of mining along LA4B and WC21 at distances of 290 m and 110 m, respectively.

The impacts observed along the drainage lines due to LW13 are described in the End of Panel Report (IMC, 2018) and these have been summarised below:

> Rock fractures and uplift were identified at six sites along WC21, at eight sites along WC15 and two sites along LA4. The fracture widths varied between 2 mm and approximately 220 mm, with the majority (83 %) of the widths being 50 mm or less. The impacts along WC21 occurred directly above LW12 and LW13. The impacts along WC21 and LA4 were located at distances between 120 m and 280 m outside the extents of LW13.
>
> Loss of surface water flows along WC21 observed directly above LW13. Loss of surface flow along WC15 at six sites and along LA4 at one site at distances between 140 m and 260 m from LW13. Iron staining observed in one location along each of WC21, WC15 and LA4.

The impacts observed along the drainage lines due to LW14 are described in the End of Panel Report (IMC, 2019) and these have been summarised below:

> Rock fracturing was observed along WC15, LA4 and LA4B at distances ranging between 30 m and 300 m from the longwall mining area. It was assessed that rock fracturing could occur along the streams up to approximately 400 m from the mining area.
>
> No new surface water diversions were identified due to the mining of LW14. However, fracturing along WC15 is located along the main channel and surface water diversions are possible during higher flow conditions. There are seven sites with identified or with possible Type 3 impacts along WC15 due to the mining of both LW13 and LW14, being Rockbars 0/1, Rockbar 5, Rockbar 18, Rockbar 21, Rockbar 25, Rockbar 26 and Pool 30/Channel 30.

The impacts observed along the drainage lines due to LW15 are described in the End of Panel Report (IMC, 2020) and these have been summarised below:

> Rock fracturing was observed along WC15 and LA4A at distances ranging between 30 m and 140 m from the longwall mining area. It was assessed that rock fracturing could occur along the streams up to approximately 400 m from the mining area.
>
> No new surface water diversions were identified due to the mining of LW15. However, fracturing along WC15 and LA4A are located along the main channels and surface water diversions are possible during higher flow conditions. There are seven sites with identified or possible Type 3 impacts located along WC15 due to the mining of LW13 to LW15, being Rockbars 0/1, Rockbar 5, Rockbar 18, Rockbar 21, Rockbar 25, Rockbar 26 and Pool 30/Channel 30. There are also two sites with identified or possible Type 3 impacts located along LA4A and LA4B which were previously observed due to the mining of LW12 and LW13.

The impacts observed along the drainage lines due to LW16 are described in the End of Panel Report (IMC, 2021) and these have been summarised below:

> New rock fracturing was identified along stream WC15 at one site and additional fracturing was identified at two other sites after the mining of LW16. Fracturing was previously recorded along this tributary due to the mining of LW13 (8 sites), LW14 (8 sites) and LW15 (3 sites).
>
> Surface water diversion was identified along stream WC15 in one new location due to the mining of LW16. Surface water diversions previously recorded along this stream at two other sites where additional fracturing was observed due to the mining of LW16.
>
> Iron staining was observed along stream LA2 after the mining of LW16. Fracturing and surface water diversions were not observed along this tributary. However, fracturing and soil cracking were observed further up the valley sides on the western valley side in one location.

The environmental consequences due to the abovementioned physical impacts are described by the specialist consultants' reports attached to each of the End of Panel reports.

5.3.4. Impact assessments for the drainage lines

The impact assessments for the drainage lines are provided in the following sections. The assessments provided in this report should be read in conjunction with the assessments provided in the reports by the other specialist consultants on the project.

Potential for increased levels of ponding, flooding and scouring due to the mining-induced tilts

Mining can result in increased levels of ponding in locations where the mining-induced tilts oppose and are greater than the natural drainage line gradients that exist before mining. Mining can also potentially result in an increased likelihood of scouring of the banks in the locations where the mining-induced tilts considerably increase the natural drainage line gradients that exist before mining.

The maximum predicted tilt for the drainage lines within the Study Area is 40 mm/m (i.e. 4.0 % or 1 in 25). The predicted mining-induced tilts are less than the natural gradients of the drainage lines that typically vary between 50 mm/m and 200 mm/m (i.e. 5 % to 20 %).

The natural grades and the predicted post-mining grades along LC5, LC6 and WC26 are illustrated in Fig. 5.6 to Fig. 5.8, respectively. Drainage lines LC7 and WC24 are located outside the mining area and, therefore, are predicted to experience lower levels of vertical subsidence and tilt.

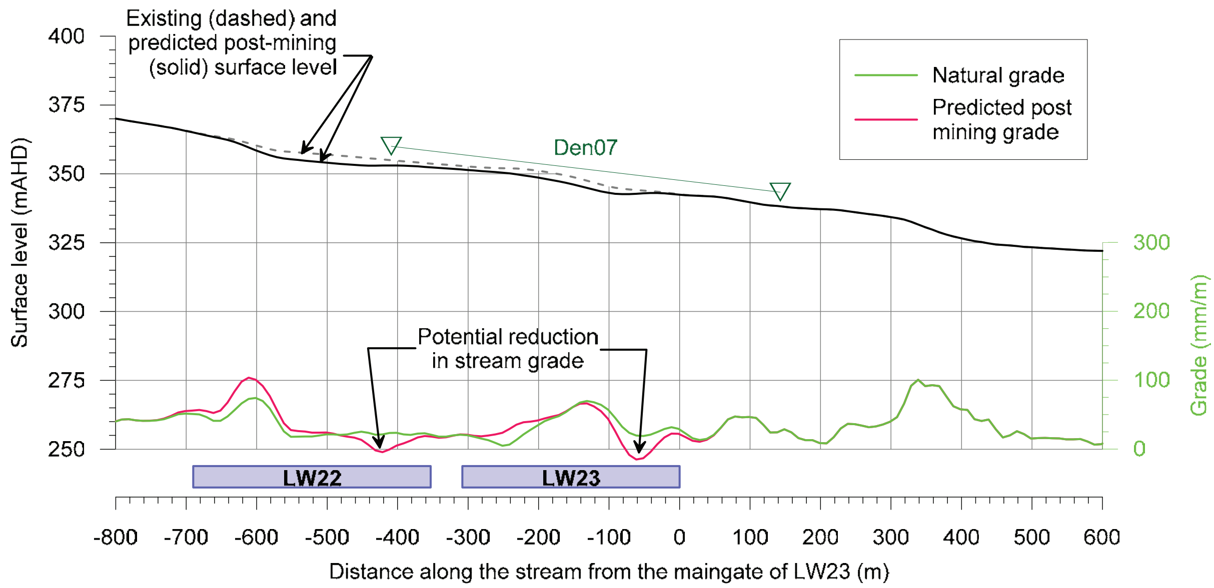

Fig. 5.6 Natural and predicted post-mining surface levels along drainage line LC5

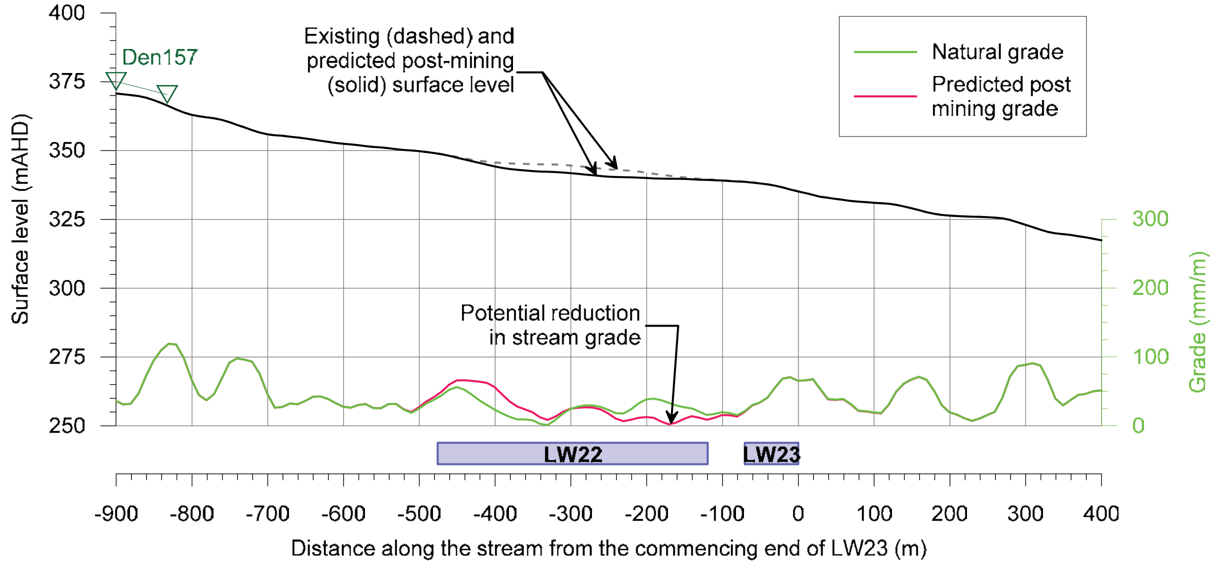

Fig. 5.7 Natural and predicted post-mining surface levels along drainage line LC6

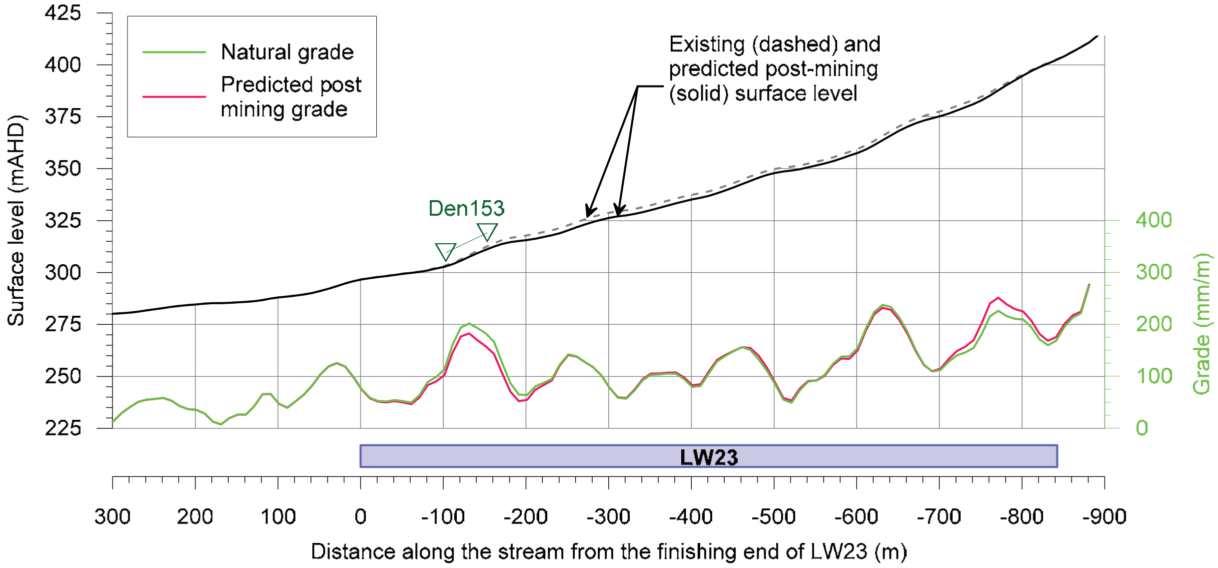

Fig. 5.8 Natural and predicted post-mining surface levels along drainage line WC26

There are predicted reductions in grades along drainage lines LC5 and LC6 upstream of the chain pillars and the perimeter of the mining area. Other potential reductions in grade could also occur along other drainage lines located directly above the proposed longwalls. There could be increased potentials for localised ponding upstream of these locations due to the mining-induced tilt.

It is unlikely that there would be large-scale adverse changes in the levels of ponding or scouring of the banks along these drainage lines due to the mining-induced tilt. It is possible that localised increased ponding could develop in some isolated locations, where the natural grades are small and where the drainage lines exit the mining area. It is also possible, that there could be localised areas that experience increased scouring of the banks, in the locations of the predicted maximum increasing tilts, such as downstream of the longwall chain pillars.

There are no predicted reductions in grade along drainage line WC26 due to its higher natural grades above the mining area. Similarly, reductions in grade are not predicted for the drainage lines that are located outside the mining area due to the low levels of predicted vertical subsidence and tilt.

The potential impacts of increased ponding and scouring of the drainage lines, therefore, are expected to be minor and localised. The impacts resulting from the changes in surface water flows due to the mining-induced tilt are expected to be small in comparison with those which occur during natural flooding conditions.

Potential for cracking in the creek bed and fracturing of bedrock

Impacts have been observed along the drainage lines above and adjacent to the previously extracted LW9 to LW16 in Area 3B, including fracturing in the rockbars and exposed bedrock, dilation and uplift of the bedrock, iron staining, surface water flow diversions and reduction in pool water levels. These impacts predominately occurred directly above the extracted longwalls. However, fracturing was also observed up to 290 m from the extracted longwalls in Area 3B.

A comparison of the maximum predicted subsidence effects for the proposed LW22 and LW23 with the maximum predicted values for the longwalls in Area 3B is provided in Table 4.3. The predicted subsidence effects for the proposed longwalls are similar to but less than the maximum predicted values for the existing and approved longwalls in Area 3B.

It is expected that fracturing of the bedrock would occur along the sections of the drainage lines that are located directly above the proposed LW22 and LW23. Fracturing can also occur outside the extents of the proposed longwalls, with minor and isolated fracturing previously observed at distances up to approximately 400 m.

The mining-induced compression due to valley closure effects can also result in dilation and the development of bed separation in the topmost bedrock, as it is less confined. This valley-related dilation is expected to develop predominately within the top 10 m to 20 m of the bedrock. Compression can also result in buckling of the topmost bedrock resulting in heaving in the overlying surface soils.

Surface water flow diversions are likely to occur along the sections of drainage lines that are located directly above and adjacent to the proposed longwalls.

Further assessments of the potential impacts on surface water are provided in the report by HGeo (2021).

5.3.5. Recommendations for the drainage lines

IMC has developed management strategies for drainage lines that have been directly mined beneath by previously extracted longwalls at Dendrobium Mine. It is recommended that these management strategies are reviewed and updated to incorporate the proposed LW22 and LW23. It is also recommended that periodic inspections are carried out along the drainage lines during active subsidence.

5.4. Aquifers and known groundwater resources

Shallow aquifers have been identified within the Study Area and these are associated with the drainage lines and upland swamps. The potential impacts on the aquifers and groundwater resources are provided by the specialist groundwater consultant.

5.5. Cliffs

5.5.1. Descriptions of the 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"*

The cliffs and minor cliffs within the Study Area have been identified from the LiDAR surface level contours and field investigations. The locations of these features are shown in Drawing No. MSEC1104-08.

There are four cliffs that have been identified within the Study Area based on the 35° angle of draw line. These cliffs are located along the valley sides of streams LC6, WC26 and their tributaries, as shown in Drawing No. MSEC1104-08. The cliffs have been prefixed with the label of the drainage line.

There are also additional cliffs located within the Study Area based on the 600 m boundary. While the valleys along which the cliffs are located could experience valley-related effects, the cliffs themselves are unlikely to experience upsidence and compressive strain due to valley closure, as they are located along the valley sides. The cliffs located outside the Study Area based on the 35° angle of draw, therefore, have not been assessed further in this report.

A summary of the four cliffs that have been identified within the Study Area based on the 35° angle of draw is provided in Table 5.9.

Table 5.9 Cliffs located within the Study Area

Reference	Location	Overall length (m)	Maximum height (m)
LC6-CL1	Outside the mining area, 10 m east of the finishing end of LW23	60	12
WC26-CL1	Directly above LW23, adjacent to the tailgate chain pillar	25	12
WC26-CL2	Directly above LW23, adjacent to the longwall maingate	25	11
WC26-CL3	Outside the mining area, 20 m north of the maingate of LW23	25	11

The cliffs have formed from Hawkesbury Sandstone, with the faces being at various stages of weathering and erosion. The cliffs have many overhangs and undercuts that are generally less than 6 m in depth. Photographs of typical cliffs at Dendrobium Mine are provided in Fig. 5.9 (Source: IMC).

Fig. 5.9 Typical cliffs at Dendrobium Mine (Source: IMC)

The minor cliffs within the Study Area are located within the valleys of Lake Cordeaux, Wongawilli Creek and their tributaries. The lengths of each of the minor cliffs typically range between 20 m and 50 m and have heights up to 10 m. There are also many rock outcrops and rock platforms that are located across the Study Area. The rock outcrops are generally less than 5 m in height.

5.5.2. Predictions for the cliffs

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the cliffs located within the Study Area is provided in Table 5.10. The values are the maximum predicted subsidence effects within 20 m of the mapped extents of each of the cliffs.

Table 5.10 Maximum predicted total vertical subsidence, tilt and curvatures for the cliffs

Reference	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
LC6-CL1	30	1	0.02	< 0.01
WC26-CL1	1700	20	0.50	0.50
WC26-CL2	650	17	0.40	0.05
WC26-CL3	125	5	0.11	0.04

Cliffs WC26-CL1 and WC26-CL2 are located directly above the proposed LW23. The maximum predicted tilt for these cliffs is 20 mm/m (i.e. 2.0 %, or 1 in 50). The maximum predicted curvatures for these cliffs are 0.50 km^{-1} hogging and sagging, which represents minimum radius of curvature of 2.0 km.

The maximum predicted conventional strains for WC26-CL1 and WC26-CL2, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 7.5 mm/m tensile and compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted strains directly above the proposed longwalls are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Cliffs LC6-CL1 and WC26-CL3 are located outside the mining area at minimum distances of 10 m and 30 m, respectively, from the proposed LW23. The maximum predicted tilt for these cliffs is 5 mm/m (i.e. 0.5 %, or 1 in 200). The maximum predicted curvatures for these cliffs are 0.11 km^{-1} hogging and 0.04 km^{-1} sagging, which represent minimum radii of curvatures of 9 km and 25 km, respectively. The maximum predicted conventional strains for LC6-CL1 and WC26-CL3, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 1.5 mm/m tensile and 0.5 mm/m compressive.

The minor cliffs are located across the Study Area and, therefore, they are expected to experience the full range of predicted subsidence effects. A summary of the maximum predicted subsidence effects within the Study Area is provided in Chapter 4.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.5.3. Comparison of the predictions for the cliffs

Cliffs are located directly or partially above the previously extracted longwalls in Areas 1, 2 and 3A at the Mine. Cliffs are also located outside the extents of the previously extracted and approved longwalls in Area 3B. A comparison of the maximum predicted total subsidence effects for the cliffs at the Mine is provided in Table 5.11.

Table 5.11 Comparison of the maximum predicted subsidence effects for the cliffs

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 1 (LW1 and LW2)	2800	20	0.35	0.75
Area 2 (LW3 to LW5)	1275	17	0.50	0.60
Area 3A (LW6 to LW8)	700	13	0.20	0.06
Area 3B (LW9 to LW15)	25	1	0.09	< 0.01
LW22 and LW23	1700	20	0.50	0.50

The maximum predicted subsidence effects for the cliffs located within the Study Area are of similar order to the predicted values for the cliffs in Areas 1 and 2. The predicted subsidence effects are greater than the predicted values for the cliffs in Areas 3A and 3B as those cliffs are located around the perimeter or outside the mining areas.

5.5.4. Impact assessments for the cliffs

Cliffs WC26-CL1 and WC26-CL2 are located directly above LW23 and Cliffs LC6-CL1 and WC26-CL3 are located outside and adjacent to this longwall. While Cliffs LC6-CL1 and WC26-CL3 are located outside the mining area, the ridgelines on which they are formed continue across the proposed LW23.

It is difficult to assess the likelihood of cliff instabilities based upon predicted ground movements. The likelihood of a cliff becoming unstable is dependent on many factors that are difficult to quantify. Some of 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 a cliff naturally or when it is exposed to mine subsidence movements. It is therefore possible that cliff instabilities may occur during mining that may be attributable to either natural causes, mine subsidence, or both.

The likelihood of instability for the cliffs within the Study Area has been assessed using the previous experience of mining beneath cliffs at the Mine. The cliffs that were located above the previously extracted longwalls in Area 1 are considered to be a relevant case study.

LW1 and LW2 at the Mine had void widths of 250 m and a solid chain pillar width of 50 m. The longwalls were extracted from the Wongawilli Seam, at depths of cover varying between 170 m and 320 m and were also located beneath existing bord and pillar workings in the overlying Bulli Seam, i.e. partial multi-seam mining conditions. The maximum predicted conventional curvatures, resulting from the extraction of these longwalls, were 0.35 km^{-1} hogging and 0.75 km^{-1} sagging.

These longwalls were extracted directly beneath a ridgeline and rockfalls were observed in eight locations directly above the mining area. The total length of disturbance resulting from the extraction of LW1 and LW2 was approximately 135 m to 175 m. The total plan length of ridgeline located directly above the longwalls was between approximately 1800 m to 2000 m. It should be noted that there are two levels of cliffs in some locations and, therefore, the total length of cliffline is greater than the total plan length of the ridgeline.

The length of ridgeline disturbed due to the extraction of LW1 and LW2 is therefore estimated to be between 7 % and 10 % of the total plan length of ridgeline directly above the longwalls. The length of rockfalls that occurred due to the extraction of LW1 and LW2; however, is less than the length of the disturbed ridgeline.

It has been assessed that Cliffs WC26-CL1 and WC26-CL2 and to lesser extents Cliffs LC6-CL1 and WC26-CL3 could be impacted due to the proposed mining directly beneath or adjacent to them. While Cliffs LC6-CL1 and WC26-CL3 are located outside the mining area, the ridgelines on which they are formed continue across the proposed LW23. The potential impacts include fracturing in the exposed rockface and, if it is marginally stable, this could then result in cliff instabilities.

Based on the experience in Area 1 at the Mine, it has been estimated that between 7 % and 10 % of the total length, or between 3 % and 5 % of the total face area of the cliffs located directly above or adjacent to the proposed longwalls would be impacted. The actual impacts could be greater or lesser than these ranges, as it is more difficult to predict the extents of impact due to the relatively short lengths of cliffs located above and adjacent to the proposed longwalls.

It is unlikely that other cliffs located outside the Study Area based on the 35° angle of draw would experience adverse impacts due to their distances from the proposed longwalls. This is based on the extensive experience of mining near to but not directly beneath cliffs in the NSW coalfields, where no large cliff falls have occurred when the cliffs are located completely outside the angle of draw from mining. It is still possible, but unlikely, that isolated rockfalls could occur due to mining, natural processes, or both.

5.5.5. Recommendations for the cliffs

It is recommended that periodic inspections of the cliffs and minor cliffs located within the Study Area are undertaken during active subsidence and at the completion of mining, where it is safe to do so.

5.6. Rock outcrops and steep slopes

5.6.1. Descriptions of the rock outcrops and 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 18.3º) and 2 in 1 (200% or 63.4º)"*. 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 areas identified as having steep slopes are shown in Drawing No. MSEC1104-08.

The steep slopes within the Study Area have been identified within the valleys of Lake Cordeaux, Wongawilli Creek and their tributaries. The natural grades of the steep slopes typically vary up to approximately 1 in 2 (i.e. 27°, or 50 %), with isolated areas with natural grades up to 1 in 1 (i.e. 45° or 100 %).

Rock outcrops are defined as exposed rockfaces with heights of less than 10 m or slopes of less than 2 in 1. There are rock outcrops located across the Study Area, primarily within the valleys of Lake Cordeaux, Wongawilli Creek and their tributaries. The rock outcrops have not been shown in the drawings, as their specific locations could not be derived from the aerial laser scan or the orthophotograph.

Photographs of typical rock outcropping at the Mine are provided in Fig. 5.10.

Fig. 5.10 Typical rock outcropping at the Mine

5.6.2. Predictions for the rock outcrops and steep slopes

The rock outcrops and steep slopes are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence effects. A summary of the maximum predicted values of total vertical subsidence, tilt and curvatures for the rock outcrops and steep slopes within the Study Area is provided in Table 5.12.

Table 5.12 Maximum predicted total vertical subsidence, tilt and curvatures for the rock outcrops and steep slopes

Location	After longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Rock outcrops and steep slopes	LW22 and LW23	3000	40	1.0	1.0

The maximum predicted total tilt for the rock outcrops and steep slopes is 40 mm/m (i.e. 4.0 %, or 1 in 25). The maximum predicted total conventional curvatures are 1.0 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 1 km.

The maximum predicted conventional strains for the rock outcrops and steep slopes, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 15 mm/m tensile and compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted strains directly above the proposed longwalls are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.6.3. Impact assessments for the rock outcrops and steep slopes

The maximum predicted tilt for the rock outcrops and steep slopes within the Study Area is 40 mm/m (i.e. 4.0 %, or 1 in 50). The predicted changes in grade are very small when compared to the natural surface grades, which are greater than 1 in 3. It is unlikely, therefore, that the mining-induced tilts themselves would result in any adverse impact on the stability of the rock outcrops or steep slopes.

The rock outcrops and steep slopes are more likely to be impacted by curvature and strain, rather than tilt. The potential impacts would generally result from the increased horizontal movements in the downslope direction, resulting in tension cracks appearing at the tops and on the sides of the rock outcrops and steep slopes, buckling of the bedrock at the bottoms of the rock outcrops, and compression ridges forming at the bottoms of the steep slopes.

The maximum predicted total curvatures for the rock outcrops and steep slopes within the Study Area are 1.0 km^{-1} hogging and sagging. The maximum predicted curvatures and strains for these features are similar to those predicted to have occurred for Dendrobium LW1 and LW2, which mined directly beneath a ridgeline comprising cliffs, rock outcrops and steep slopes. The impacts observed from this case study, therefore, can be used to provide an indication of the potential impacts on the rock outcrops and steep slopes located within the Study Area.

Dendrobium LW1 and LW2 mined directly beneath a ridgeline where steep slopes had natural surface gradients of up to 1 in 1 (i.e. 100 %, or an angle to the horizontal of 45°). A number of surface cracks were observed along the steep slopes located directly above Dendrobium LW1 and LW2 which are shown in Fig. 5.11.

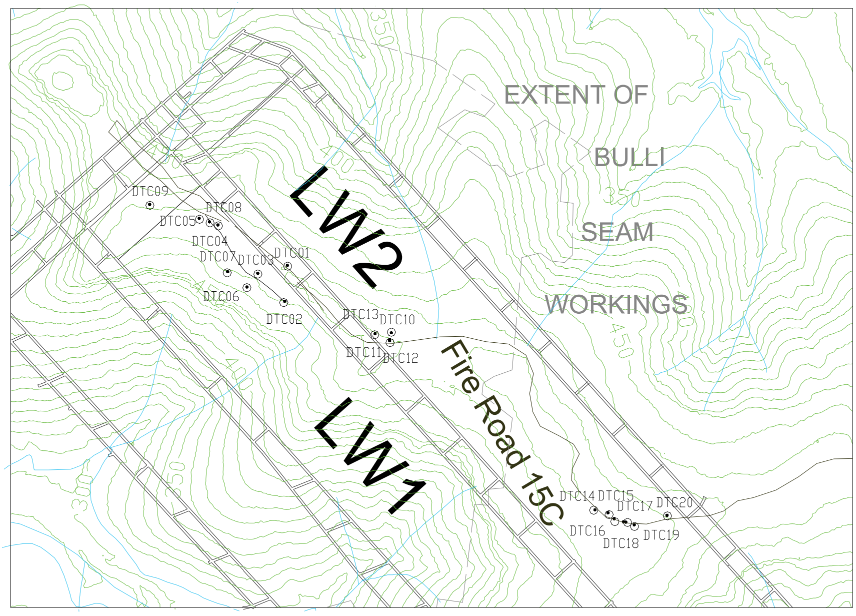

Fig. 5.11 Locations of observed surface cracking above Dendrobium LW1 and LW2

The largest surface cracks observed in Dendrobium Area 1 occurred along the top of the ridgeline, having widths of up to 400 mm, which were associated with the downslope movement of the surface soils. Additional surface cracks, typically in the order of 100 mm to 150 mm in width, were also observed further down the ridgeline and the steep slopes.

Photographs of the surface cracking at Dendrobium Mine are provided in Fig. 5.12.

Fig. 5.12 Surface tension cracking due to downslope movements at Dendrobium Mine

It is expected, therefore, that the downslope movement of the ground would also occur along rock outcrops and steep slopes within the Study Area. The steep slopes are heavily vegetated and erosion due to soil instability (i.e. downslope movements) was not readily apparent from the site investigations undertaken. If tension cracks were to develop, due to the extraction of the proposed longwalls, it is possible that soil erosion could occur and require treatment.

It is possible, therefore, that some remediation might be required, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the surface soils in the longer term. Similarly, where cracking restricts the passage of vehicles along the tracks and fire trails that are required to be open for access, it is recommended that these cracks are treated in the same way.

5.6.4. Recommendations for the rock outcrops and steep slopes

It is recommended that periodic inspections of the rock outcrops and steep slopes located directly above the proposed longwalls are undertaken during or after active subsidence and that any remedial measures required to prevent erosion are implemented in consultation with WaterNSW.

5.7. Escarpments

There are no escarpments located within the Study Area. The *Illawarra Escarpment* is located more than 12 km to the east of the proposed longwalls. At this distance, the escarpment is not expected to experience measurable subsidence effects or adverse impacts due to the extraction of the proposed longwalls.

5.8. Land prone to flooding and inundation

The catchment areas of the streams within the Study Area are relatively small and the land drains freely into Lake Cordeaux and Wongawilli Creek. There are no major flood-prone areas identified within the Study Area. As discussed in Section 5.3, the predicted changes in the surface levels of the streams, resulting from the extraction of the proposed longwalls, will have only a marginal effect on their natural gradients, and hence, on their discharge characteristics.

5.9. Swamps, wetlands and water-related ecosystems

5.9.1. Descriptions of the swamps

The locations of the swamps are shown in Drawing No. MSEC1104-09. The locations and extents of the upland swamps have been interpreted from detailed aerial photogrammetry and site inspections.

Two swamps (Refs. Den07 and Den153) have been identified directly above the proposed longwalls. There are four additional swamps (Refs. Den09, Den154, Den155 and Den156) located wholly or partially within the Study Area based on the 35° angle of draw line and a further eight swamps (Refs. Den06, Den16, Den140, Den141, Den144, Den145, Den152 and Den157) located wholly or partially within the Study Area based on the 600 m boundary.

A summary of the swamps that are located within the Study Area based on the 600 m boundary is provided in Table 5.13.

Table 5.13 Swamps located within the Study Area based on the 600 m boundary

Reference	Location	Description
Den06	490 m north of LW23	On valley side of Stream CR3
Den07	Partially above LW22 and directly above LW23	Near the valley base of Stream LC5
Den09	90 m south of LW22	Near the valley base of Stream LC5
Den16	540 m south of LW22	Near the valley base of Stream LC1
Den140	525 m north-west of LW23	On the valley side of Wongawilli Creek
Den141	360 m west of LW23	On the valley side of Wongawilli Creek
Den144	500 m south of LW22	Near the valley base of Stream WC20
Den145	500 m south of LW22	At the headwaters of Steam LC5
Den152	435 m north-west of LW23	On the valley side of Wongawilli Creek
Den153	Directly above LW23	Near the valley base of Stream WC26
Den154	70 m north of LW22 and 95 m east of LW23	On the valley side of Stream LC6
Den155	210 m east of LW22	On the valley side of Stream LC7
Den156	130 m south-east of LW22	On side of ridgeline south of mining area
Den157	335 m south of LW22	Near the valley base of Stream LC6

The upland swamps can be categorised into two types, the *valley infill* swamps that form within the drainage lines, and *headwater* swamps that form within relatively low sloped areas of weathered Hawkesbury Sandstone where hillslope aquifers exist. Photographs of typical valley infill swamps at Dendrobium Mine are provided in Fig. 5.13. Photographs of a typical headwater swamp are provided in Fig. 5.14.

Fig. 5.13 Typical valley infill swamps

Fig. 5.14 Typical headwater swamp

Further descriptions of the swamps are provided in the report by Niche (2021a).

5.9.2. Predictions for the swamps

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the swamps located within the Study Area is provided in Table 5.14. The values are the maxima within 20 m of the mapped extents of each of the swamps within the Study Area due to the extraction of the existing and approved longwalls in Areas 3A, 3B and 3C.

Table 5.14 Maximum predicted total vertical subsidence, tilt and curvatures for the swamps

Reference	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Den06	< 20	< 0.5	< 0.01	< 0.01
Den07	2650	35	0.90	0.70
Den09	< 20	< 0.5	< 0.01	< 0.01
Den16	30	< 0.5	< 0.01	< 0.01
Den140	< 20	< 0.5	< 0.01	< 0.01
Den141	< 20	< 0.5	< 0.01	< 0.01
Den144	< 20	< 0.5	< 0.01	< 0.01
Den145	< 20	< 0.5	< 0.01	< 0.01
Den152	< 20	< 0.5	< 0.01	< 0.01
Den153	2100	30	0.50	0.60
Den154	< 20	< 0.5	< 0.01	< 0.01
Den155	< 20	< 0.5	< 0.01	< 0.01
Den156	< 20	< 0.5	< 0.01	< 0.01
Den157	< 20	< 0.5	< 0.01	< 0.01

Swamps Den07 and Den153 are located directly above the proposed longwalls. These two swamps are predicted to experience subsidence effects up to 2650 mm vertical subsidence, 35 mm/m tilt (i.e. 3.5 %, or 1 in 29), 0.90 km^{-1} hogging curvature (1.1 km minimum radius) and 0.70 km^{-1} sagging curvature (1.4 km minimum radius).

The maximum predicted conventional strains for Swamps Den07 and Den153, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 14 mm/m tensile and 11 mm/m compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.4. The maximum predicted strains directly above the mining area are 8 mm/m tensile and compressive based on the 95 % confidence levels.

The remaining swamps are located outside the mining area, at minimum distances ranging between 70 m and 540 m from the proposed longwalls. These swamps are predicted to experience up to 30 mm vertical subsidence due to the mining of LW22 and LW23. While the swamps located outside the mining area could experience low levels of vertical subsidence, they are not expected to experience measurable conventional tilts, curvatures or strains.

Swamps Den07, Den09, Den16, Den144, Den153 and Den157 are located near the bases of the valleys associated with the streams. These swamps could experience valley-related effects due to the extraction of the proposed longwalls. The remaining swamps within the Study Area are located further up the valley sides and, therefore, are unlikely to experience upsidence or compressive strain due to valley closure effects.

A summary of the maximum predicted total upsidence and closure for the swamps within the Study Area is provided in Table 5.15. The values are the maxima within 20 m of the mapped extents of each of the swamps within the Study Area due to the extraction of the existing and approved longwalls in Areas 3A, 3B and 3C.

Table 5.15 Maximum predicted total upsidence and closure for the swamps

Location	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Den07	325	475
Den09	125	200
Den16	40	60
Den144	125	225
Den153	275	400
Den157	80	150

The predicted strains due to the valley-related effects have been determined from analyses of ground monitoring data for valleys with similar heights and located at similar distances from previously extracted longwalls in the Southern Coalfield.

Swamps Den07 and Den153 are located directly above the proposed longwalls and they are within valleys with equivalent heights ranging between 25 m and 50 m. The maximum predicted compressive strain for the parts of these two swamps located directly above the proposed mining area is 17 mm/m based on the 95 % confidence level.

The remaining swamps are located outside the mining area, at minimum distances ranging between 70 m and 540 m from the proposed longwalls, and they are within valleys with equivalent heights ranging between 5 m and 25 m. The maximum predicted compressive strain for these swamps is 3 mm/m based on the 95 % confidence level.

5.9.3. Previous experience of mining beneath swamps at Dendrobium Mine

Discussions on the previous experience of mining beneath swamps at Dendrobium Mine are provided below. These discussions relate to the reported physical impacts, which include surface cracking and fracturing of bedrock at the swamps. Detailed discussions on the environmental consequences are provided by the other specialist consultants on the project.

- *Dendrobium Area 2*

  LW4 and LW5 in Area 2 were extracted directly beneath Swamp Den01, which is both a headwater and valley infill swamp located along Drainage Line A2-14. Cracking was observed within the extent of the swamp in three locations and fracturing was observed in the downstream rockbar. A photograph of the fracturing in the downstream rockbar is provided in Fig. 5.15.

Fig. 5.15 Fracturing in the rockbar downstream of Swamp Den01 (Source: IMC)

Whilst reductions in groundwater levels in the soil were observed in the swamp and the upstream hillslope aquifer, the groundwater levels respond to significant recharge events. Based on the observations to date, there has been no erosion or other physical changes observed within Swamp Den01 resulting from the mining in Area 2.

- *Dendrobium Area 3A*

  LW7 in Area 3A was extracted directly beneath Swamp Den12, which is a headwater swamp located on the valley side of Drainage Line WC17. One fracture was identified in a rock outcrop after mining beneath this swamp. Regular monitoring has been undertaken and, to date, no erosion or other changes have been observed. Four piezometers have been installed in and around the swamp to measure the shallow groundwater levels within the sediments above the sandstone bedrock. One of the piezometers has measured a reduction in the groundwater level, two of the piezometers show no change and one is providing poor quality data.

- *Dendrobium Area 3B*

  LW9 in Area 3B was extracted directly beneath Swamp Den05, which is a valley infill swamp located along the alignment of Donalds Castle Creek. The impacts to this swamp were described in the End of Panel Report (IMC, 2014) which states "*Site DA3B_LW9_006: Multiple fractures and uplift on DC_RB33 at basal step of Swamp 5; up to 0.015m wide, 2m long and 0.040m of uplift. Exfoliation from the step. Associated flow diversion" and "TARP triggers in relation to shallow groundwater levels (reduction and recession rates) in Swamps 1a, 1b and Swamp 5 were also reported during Longwall 9 extraction*".

  Impacts were also observed to the swamps due to the extraction of LW10 to LW16 which were described in each of the End of Panel Reports (IMC, 2015, 2016, 2017, 2018, 2019, 2020 and 2021). The groundwater levels were lower than baseline and recession rates greater than baseline for Swamps Den03, Den05, Den10, Den11, Den13, Den14 and Den23. Soil moisture levels below baseline were also reported in Swamps Den05, Den11 and Den23.

5.9.4. Impact assessments for the swamps

The assessments of the potential physical impacts (i.e. soil cracking and rock fracturing) on the swamps based on the predicted mine subsidence effects are provided in the following sections. Discussions on the potential environmental consequences are provided in the reports by the other specialist consultants on the project. The assessments and discussions provided in this report should be read in conjunction with those provided in the reports by the other specialist consultants.

Potential for changes in surface water flow due to the mining-induced tilts

Mining can potentially affect surface water flows through swamps, if the mining-induced tilts are much greater than the natural gradients, potentially resulting in increased levels of ponding or scouring, or affecting the distribution of the water within the swamps.

Swamps Den07 and Den153 are located directly above the proposed longwalls. The maximum predicted tilt for these two swamps is 35 mm/m (i.e. 3.5 %, or 1 in 29). The natural grades within the swamps are lowest along the streams in the bases of the valleys. The predicted changes in grade for the streams are illustrated in Fig. 5.7 to Fig. 5.8.

There are predicted reductions in grade along Stream LC5 and within the extent of Swamp Den07 (refer to Fig. 5.6). There is potential for minor and localised increased ponding upstream of these locations and within this swamp. The topographical depressions are predicted to be less than 0.4 m deep and 60 m long and are localised in the base of the valley. The areas of the swamp further up the valley sides have higher natural grades and there are no predicted reductions in grade away from the valley base.

There are no predicted reductions in grade along Stream WC26 nor within the extent of Swamp Den153 (refer to Fig. 5.8). Similarly, there are no predicted reductions in grade along the remaining streams nor within the remaining swamps in the Study Area, as they are located outside the mining area and they are predicted to experience tilts of less than 0.5 mm/m (i.e. less than 0.5 %, or 1 in 2000). It is unlikely, therefore, that these swamps would experience adverse changes in the levels of ponding or scouring based on the predicted vertical subsidence and tilt.

Potential for cracking in the swamps and fracturing of bedrock

Fracturing of the bedrock has been observed in the past, as a result of longwall mining, where the tensile strains have been greater than approximately 0.5 mm/m or where the compressive strains have been greater than approximately 2 mm/m.

Swamps Den07 and Den153 are located directly above the proposed longwalls. The maximum predicted compressive strain due to the valley-related effects for the parts of these swamps located directly above the proposed mining area is 17 mm/m based on the 95 % confidence level. Away from the valley base, the maximum predicted strains for the parts of these two swamps located directly above the proposed mining area are 8 mm/m tensile and compressive based on the 95 % confidence levels.

The typical fracture widths in the bedrock beneath Swamps Den07 and Den153 could be similar to the surface deformations previously observed at the Mine, as described in Section 4.8. The soil crack and rock fracture widths were generally observed to be less than 50 mm (i.e. 79 % of the cases). However, the widths of the surface deformations were between 50 mm and 150 mm in 15 % of cases, between 150 mm and 300 mm in 5 % of cases and greater than 300 mm in 2 % of cases. Fracturing would only be visible at the surface where the bedrock is exposed, or where the thickness of the overlying soil is relatively shallow.

Swamps Den07 and Den153 are also predicted to experience up to 325 mm upsidence and 475 mm closure. These valley-related effects could result in the dilation of the strata beneath these two swamps. It has been previously observed that the depth of fracturing and dilation of the uppermost bedrock, resulting from valley-related effects, is generally in the order of 10 m to 15 m (Mills 2003, Mills 2007, and Mills and Huuskes 2004).

The dilated strata beneath the drainage lines and within Swamps Den07 and Den153 could result in the diversion of some surface water flows beneath parts of these swamps. The drainage lines upstream of these swamps flow during and shortly after rainfall events. Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation.

The remaining swamps are located outside the mining area, at minimum distances ranging between 70 m and 540 m from the proposed longwalls. Fracturing has been observed in streams located outside the extents of previously extracted longwalls in the NSW coalfields. Fracturing has been observed in the drainage lines at distances of up to 290 m from the previously extracted longwalls in Area 3B. Minor and isolated fracturing has also been observed up to 400 m outside of longwalls extracted elsewhere in the Southern Coalfield.

Swamp Den09 is located near the base of Stream LC5 and it is at a minimum distance of 90 m from the proposed longwalls. Fracturing could occur in the base of the valley and within this swamp. Fracture widths in the order of 20 mm to 50 mm have been observed due to valley-related effects at similar distances from previous longwall mining.

Swamp Den157 is located near the base of Stream LC6 and it is at a minimum distance of 335 m from the proposed longwalls. It is possible, but unlikely, that fracturing could occur in the base of the valley and within this swamp. Fracture widths less than 20 mm have been observed due to valley-related effects at similar distances from previous longwall mining.

The remaining swamps within the Study Area are either located on the valley sides or are more than 400 m outside the proposed mining area. It is unlikely therefore that fracturing would develop in the bedrock beneath these remaining swamps.

Discussions on the potential impacts due to changes in the surface water flows, groundwater and the environmental consequences are provided by the specialist surface water, groundwater and ecology consultants on the project.

5.9.5. Recommendations for the swamps

Management plans have been developed for the swamps at the Mine. It is recommended, that the existing management strategies are reviewed, based on the assessments provided in this report and the reports by other specialist consultants.

5.10. Flora and fauna

The land above the proposed longwalls largely consists of undisturbed native bush, as shown in Fig. 1.2. Only limited clearing has been undertaken for the tracks and fire trails within the Study Area. Descriptions of the flora and fauna within the Study Area are provided by the specialist ecology consultant on the project.

The potential for impacts on the vegetation in the mining area is dependent on the surface cracking, changes in surface water and changes in groundwater. Assessments of the physical impacts due to the proposed longwalls are provided in Sections 5.2 to 5.9. Assessments of the environmental consequences have been provided by the other specialist consultants on the project.

Assessments for the terrestrial and aquatic ecology are provided by Cardno (2021) and Niche (2021a).

The following sections provide the descriptions, predictions and impact assessments for the built features within the Study Area. All significant features located outside the Study Area, which may be subjected to far-field or valley-related effects and may be sensitive to these movements, have also been included as part of these assessments.

6.1. Unsealed roads and tracks

6.1.1. Descriptions of the unsealed roads and tracks

The locations of the unsealed roads and tracks are shown in Drawing No. MSEC1104-11.

Fire Roads 6C and 6F cross directly above the proposed LW22 and LW23. There are also other unsealed roads and tracks in the area that are used by WaterNSW and other groups for access to the catchment, fire-fighting and other activities.

A photograph of a typical unsealed road in the mining area is provided in Fig. 6.1.

Fig. 6.1 Typical unsealed road

6.1.2. Predictions for the unsealed roads and tracks

The unsealed roads and tracks are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence effects. A summary of the maximum predicted values of total vertical subsidence, tilt and curvatures for the unsealed roads and tracks within the Study Area is provided in Table 6.1.

Table 6.1 Maximum predicted total vertical subsidence, tilt and curvatures for the unsealed roads and tracks

Location	After longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Unsealed roads and tracks	LW22 and LW23	3000	40	1.0	1.0

The maximum predicted total tilt for the unsealed roads and tracks is 40 mm/m (i.e. 4.0 %, or 1 in 25). The maximum predicted total conventional curvatures are 1.0 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 1 km.

The maximum predicted conventional strains for the unsealed roads and tracks, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 15 mm/m tensile and compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted strains directly above the proposed longwalls are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

6.1.3. Impact assessments for the unsealed roads and tracks

Fire Roads 6C and 6F cross directly above the proposed LW22 and LW23. It is likely that cracking, rippling and stepping of the unsealed road surfaces would occur due to the mining of these longwalls.

The estimated crack widths in Fire Roads 6C and 6F, based on the maximum predicted conventional tensile strain of 15 mm/m and a typical bedrock joint spacing of 10 m, is in the order of 150 mm. However, wider cracks could develop along the road due to topographic effects. It is possible that a series of smaller cracks, rather than one single crack, could develop in the road surfaces.

The predicted subsidence effects for Fire Roads 6C and 6F are similar to but less than the predicted values for the previously extracted longwalls in Areas 3A and 3B. The potential impacts on these fire roads, therefore, are expected to be similar to or less than the levels of impacts that occurred for the roads and tracks previously mined beneath at the Mine.

Examples of the impacts on unsealed roads and tracks in Areas 3A and 3B are provided in Fig. 6.2 (Source: IMC). The impacts on the unsealed roads and tracks were repaired by regrading and recompacting the road surfaces.

Fig. 6.2 Impacts along the unsealed roads and tracks above LW6 in Area 3A (left side) and above LW11 in Area 3B (right side) (Source: IMC)

It is expected that Fire Roads 6C and 6F can be maintained in safe and serviceable conditions throughout the mining period using normal road maintenance techniques. The remaining unsealed roads and tracks are located outside of the mining area and it is unlikely that they would experience adverse impacts.

6.1.4. Recommendations for the unsealed roads and tracks

IMC has developed management strategies for unsealed roads and tracks that have been impacted by subsidence at Dendrobium Mine. It is recommended that these management strategies are reviewed and updated to incorporate the proposed LW22 and LW23. It is also recommended that periodic inspections are carried out along the unsealed roads and tracks during active subsidence.

6.2. 330 kV transmission line

6.2.1. Description of the 330 kV transmission line

The Avon-to-Macarthur 330 kV transmission line (Line 17) owned by TransGrid crosses directly above the proposed LW22 and LW23. This transmission line also crosses directly above the completed LW6 to LW8 in Area 3A and is located adjacent to and immediately east of the approved LW21 in Area 3C. The location of the 330 kV transmission line is shown in Drawing No. MSEC1104-11.

There are four transmission towers (Refs. TWR17-19 to TWR17-22) that are located within or adjacent to the Study Area based on the 35° angle of draw. A summary of the transmission towers located within or adjacent to the Study Area is provided in Table 6.2.

Table 6.2 330 kV transmission towers located within or adjacent to the Study Area

Reference	Type	Location relative to the longwalls
TWR17-19	Suspension	60 m east of the approved LW21 and 300 m south of the proposed LW22
TWR17-20	Suspension	Directly above the proposed LW22, adjacent to the longwall tailgate
TWR17-21	Tension	Directly above the proposed LW23, adjacent to the tailgate chain pillar
TWR17-22	Suspension	320 m north of the proposed LW23

Three towers are suspension towers (Refs. TWR17-19, TWR17-20 and TWR-22) and one is a tension tower (Ref. TWR17-21). All four towers within the Study Area have pile footings. Photographs of a typical transmission tower at Dendrobium Mine is provided in Fig. 6.3.

Fig. 6.3 330 kV transmission tower

6.2.2. Predictions for the 330 kV transmission line

The predicted profiles of vertical subsidence, tilt along and tilt across the alignment of the 330 kV transmission line are shown in Fig. C.09, in Appendix C. The predicted total profiles after the completion of LW6 to LW8 and LW19 in Areas 3A and LW20 and LW21 in Area 3C are shown as cyan lines. The predicted total profiles after the mining of each of the proposed LW22 and LW23 are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, tilt along the alignment and tilt across the alignment of the 330 kV transmission line is provided in Table 6.3. The values are the maximum predicted subsidence effects anywhere along the transmission line (i.e. not necessarily at the tower locations) within the Study Area based on the 35° angle of draw.

Table 6.3 Maximum predicted total vertical subsidence and tilt for the 330 kV transmission line

Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)
LW21	30	< 0.5	< 0.5
LW22	2100	25	6.5
LW23	2450	30	7.0

The maximum predicted total vertical subsidence for the section of the 330 kV transmission line located within the Study Area is 2450 mm, which occurs above the proposed LW22 after the mining of LW23. The maximum predicted conventional tilts are 30 mm/m (i.e. 3.0 %, or 1 in 33) along the alignment and 7.0 mm/m (i.e. 0.7 %, or 1 in 143) across the alignment of the transmission line.

Four transmission towers are located within or immediately adjacent to the Study Area based on the 35° angle of draw. A summary of the maximum predicted total vertical subsidence, tilt and curvature at each of the tower locations is provided in Table 6.4. The values are the maximum predicted subsidence effects within a distance of 20 m from the centre of each tower due to the mining of the existing, approved and proposed longwalls in Areas 3A and 3C.

Table 6.4 Maximum predicted total vertical subsidence and tilt for the 330 kV transmission towers

Tower	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
TWR17-19	50	0.5	0.01	< 0.01
TWR17-20	1050	25	0.50	0.07
TWR17-21	2050	15	0.20	0.30
TWR17-22	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted total vertical subsidence for the transmission towers is 2050 mm at Tower TWR17-21, which is located directly above the proposed LW23. The predicted vertical subsidence at Tower TWR17-20 of 1050 mm is less than the maximum value at TWR17-21, as it is located near the tailgate of the proposed LW22.

The maximum predicted total tilts are 25 mm/m (i.e. 2.5 %, or 1 in 40) at Tower TWR17-20 and 15 mm/m (i.e. 1.5 %, or 1 in 67) at TWR17-21. These tilts are orientated towards the north-northeast, approximately 12° clockwise of true north, i.e. perpendicular to the proposed LW22 and LW23 and towards the centre of the mining area. The predicted tilts for Towers TWR17-19 and TWR17-22 are 0.5 mm/m (i.e. 0.05 %, or 1 in 2000) or less and these are unlikely to be measurable.

The maximum predicted conventional strains for Towers TWR17-20 and TWR17-21, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 7.5 mm/m tensile and 4.5 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted strains directly above the proposed longwalls are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The maximum predicted strains for Towers TWR17-19 and TWR17-22 are less than 0.5 mm/m tensile and compressive. The strains are not expected to be measurable at these towers due to their distances from the proposed longwalls.

Towers TWR17-20 and TWR17-21 are located directly above the mining area and, therefore, they will experience conventional horizontal movements. The predicted horizontal movements at the bases of these towers are obtained by multiplying the predicted tilts by a factor of 15, being the same factor used to predict the conventional strains from curvature. The predicted horizontal movements at the bases of the towers therefore are 375 mm for Tower TWR-20 and 225 mm for TWR17-21.

The predicted horizontal movement at the top of each tower is equal to the horizontal movement at its base plus the tilt multiplied by the tower height. The maximum predicted horizontal movements at the tops of the towers based on an overall tower height of 50 m, therefore, are 1625 mm at TWR17-20 and 975 mm at TWR17-21. The maximum horizontal movements are orientated towards the north-northeast, approximately 12° clockwise of true north, i.e. perpendicular to the proposed LW22 and LW23 and towards the centre of the mining area.

Towers TWR17-19 and TWR17-22 are located outside the mining area at distances of 300 m and 320 m, respectively, from the proposed longwalls. These two towers could experience far-field horizontal movements towards the mining area. The far-field horizontal movements measured at Dendrobium Mine are illustrated in Fig. 4.3. The predicted far-field horizontal movements for TWR17-19 and TWR17-22 are 60 mm based on the mean and 150 mm based on the 95 % confidence interval. These two towers are predicted to experience low-level tilts that are unlikely to be measurable.

The differential horizontal movements between the tops of adjacent towers, due to the mining of the proposed LW22 and LW23, can result in opening or closure over the intermediate spans. A summary of the maximum predicted values of total opening and closure between the tops of the transmission towers is provided in Table 6.5. The values are the maximum predicted changes at any time during or after the mining of each of the proposed longwalls.

Table 6.5 Maximum predicted total opening and total closure movements between the tops of the 330 kV transmission towers

Span	Maximum predicted total opening (mm)	Maximum predicted total closure (mm)	Final predicted opening (+ve) or closure (-ve) after the completion of all proposed longwalls (mm)
TWR17-19 to TWR17-20	+1050	< -20	+1050
TWR17-20 to TWR17-21	< 20	-1000	-100
TWR17-21 to TWR17-22	< 20	-950	-950

The maximum predicted total final differential movements between the tops of the transmission towers are +1050 mm opening between TWR17-19 and TWR17-20 and -950 mm closure between TWR17-21 and TWR17-22. There is a transient closure of -1000 mm between TWR17-20 and TWR17-21 after the mining of LW22 that reduces to a final closure of -100 mm after the mining of LW23.

6.2.3. Comparisons of the predictions for the 330 kV transmission line

The 330 kV transmission line crosses above the existing LW6 to LW8 and the future LW19 in Area 3A at the Mine. A comparison of the maximum predicted total conventional subsidence effects for the 330 kV transmission line is provided in Table 6.6. The values are the maximum predicted subsidence effects anywhere along the transmission line, i.e. not just at the tower locations. The predictions for Area 3A are based on the latest subsidence model described in Report No. MSEC1082, which supported the Subsidence Management Plan Application for LW19.

Table 6.6 Comparison of the maximum predicted total subsidence effects for the 330 kV transmission line

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Existing LW6 to LW8	2300	25	7.0	0.40	0.65
LW6 to LW8 and future LW19	2800	35	10	0.60	0.80
LW22 and LW23	2450	30	7.0	0.50	0.30

The maximum predicted subsidence effects for the section of the 330 kV transmission line within the Study Area are similar to or slightly greater than the maximum predicted values due to the existing LW6 to LW8 in Area 3A. However, the maximum predicted subsidence effects for the section of transmission line within the Study Area is less than the maximum predicted values in Area 3A after the mining of the future LW19.

6.2.4. Impact assessments for the 330 kV powerline

The maximum predicted total final differential movements between the tops of the transmission towers are +1050 mm opening between TWR17-19 and TWR17-20 and -950 mm closure between TWR17-21 and TWR17-22. There is a transient closure of -1000 mm between TWR17-20 and TWR17-21 after the mining of LW22 that reduces to a final closure of -100 mm after the mining of LW23.

It is recommended that the predicted movements of the tops of the transmission towers are reviewed by TransGrid to assess the potential impacts on the cable catenaries and the subsequent loads induced into the towers. If adverse impacts are anticipated due to the mining-induced horizontal movements and tilt, then the potential impacts could be managed with the installation of cable rollers on these towers. However, consideration should be given to Tower TWR17-21 as it is a tension tower.

The predicted strains at Towers TWR17-20 and TWR17-21 are 8 mm/m tensile and compressive based on the 95 % confidence levels. The predicted changes in the k-point distances (i.e. spacing between the tower legs at the pile connections) based on an 8 m span, therefore, are ±64 mm opening and closure. These predicted changes in k-point distances will induce loads into the transmission tower frames and the pile foundations.

The predicted strains at Towers TWR17-19 and TWR17-22 are less than 0.5 mm/m tensile compressive. The predicted changes in the k-point distances therefore are less than ±4 mm opening and closure at these towers. The predicted strains for Towers TWR17-19 and TWR17-22 are based on ground monitoring data that includes the survey tolerance and, therefore, the actual changes in k-point distances for these two towers are likely to be less than the predicted values.

The measured changes in k-point distances for the transmission towers located above the existing LW6 to LW8 in Area 3A were very small, in the order of ±1 mm. However, the movements of the tower legs were constrained due to the construction of cruciform bases. Another 330 kV transmission line is located above the completed LW30 to LW35 at West Cliff Colliery and only one tower had a cruciform base installed. The measured changes in the k-point distances for the five suspension towers without cruciform bases were between +6 mm opening and -4 mm closure. The transmission towers did not experience adverse impacts due to the mining at West Cliff Colliery.

It is recommended that TransGrid undertake a structural analysis of the transmission towers within the Study Area based on the predicted subsidence effects. If adverse impacts on the transmission tower frames or pile foundations are anticipated, then these could be managed with the installation of cruciform bases, as undertaken for the transmission towers in Area 3A. However, Tower TWR17-21 is a tension tower and, therefore, consideration should be given to the appropriate management strategies for this tower.

With the implementation of the appropriate monitoring and management strategies, it is expected that the 330 kV transmission line could be maintained in a safe and serviceable condition throughout the mining period, similar to that during the extraction of the completed longwalls in Area 3A.

6.2.5. Recommendations for the 330 kV transmission line

It is recommended that the predicted subsidence effects for the 330 kV transmission line are provided to TransGrid to assess the potential impacts due to mining. It is also recommended that monitoring and management strategies are developed, in consultation with TransGrid, which could include the installation of cable rollers, the construction of cruciform bases, the provision of monitoring points on the tower bases and tops, and the development of a Trigger Action Response Plan (TARP).

6.3. 33 kV powerline

6.3.1. Description of the 33 kV powerline

A 33 kV powerline owned by Endeavour Energy crosses directly above the proposed LW22 and LW23. This powerline line is also located above the existing LW6 and LW7 in Area 3A. The location of the 33 kV powerline is shown in Drawing No. MSEC1104-11.

The 33 kV powerline comprises aerial copper conductors supported by metal and timber poles. Photographs of the powerline at Dendrobium Mine are provided in Fig. 6.4.

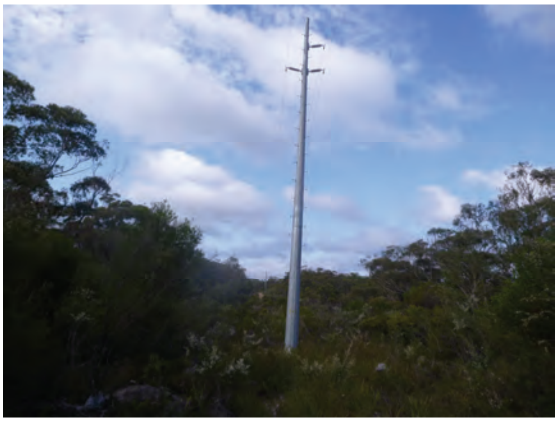 

Fig. 6.4 33 kV powerline

6.3.2. Predictions for the 33 kV powerline

The predicted profiles of vertical subsidence, tilt along and tilt across the alignment of the 33 kV powerline are shown in Fig. C.10, in Appendix C. The predicted total profiles after the completion of LW6 to LW8 and LW19 in Areas 3A and LW20 and LW21 in Area 3C are shown as cyan lines. The predicted total profiles after the mining of each of the proposed LW22 and LW23 are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, tilt along the alignment and tilt across the alignment of the 33 kV powerline is provided in Table 6.7. The values are the maximum predicted subsidence effects anywhere along the powerline (i.e. not necessarily at the pole locations) within the Study Area based on the 35° angle of draw.

Table 6.7 Maximum predicted total subsidence and tilt for the 33 kV powerline

Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)
LW21	< 20	< 0.5	< 0.5
LW22	2400	30	14
LW23	3000	35	15

The maximum predicted total vertical subsidence for the section of the 33 kV powerline located within the Study Area is 3000 mm, which occurs above the proposed LW22 after the mining of LW23. The maximum predicted conventional tilts are 35 mm/m (i.e. 3.5 %, or 1 in 29) along the alignment and 15 mm/m (i.e. 1.5 %, or 1 in 67) across the alignment of the powerline.

The maximum predicted total tilt in any direction (i.e. combined tilt along and across the powerline) is 35 mm/m (i.e. 3.5 %, or 1 in 29). The maximum predicted horizontal movement of the ground associated with the maximum predicted tilt is 525 mm, i.e. 15 times the maximum total tilt of 35 mm/m. The predicted horizontal movement at the top of each power pole is equal to the horizontal movement at its base plus the tilt multiplied by the pole height. The maximum predicted horizontal movement at the tops of the power poles based on an overall pole height of 15 m, therefore, is 1050 mm.

6.3.3. Comparisons of the predictions for the 33 kV powerline

The 33 kV powerline crosses above the existing LW6 and LW7 in Area 3A at the Mine. A comparison of the maximum predicted total conventional subsidence effects for the 33 kV powerline is provided in Table 6.8. The values are the maximum predicted subsidence effects anywhere along the powerline, i.e. not just at the pole locations. The predictions for Area 3A are based on the latest subsidence model described in Report No. MSEC1082, which supported the Subsidence Management Plan Application for LW19.

Table 6.8 Comparison of the maximum predicted total subsidence parameters for the 33 kV powerline

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)
Existing LW6 to LW8	2300	15	25
LW22 and LW23	3000	35	15

The maximum predicted vertical subsidence and tilt along the alignment of the 33 kV powerline located within the Study Area are greater than the maximum predicted values in Area 3A. However, the maximum predicted tilt across the alignment of the section of powerline within the Study Area is less than the maximum predicted value in Area 3A. While the predicted vertical subsidence and tilt above the proposed longwalls are greater than the predicted values above the existing longwalls in Area 3A, it is expected that similar management strategies could be used to manage the potential impacts.

6.3.4. Impact assessments for the 33 kV powerline

The 33 kV powerline will not be directly affected by the ground strains, as the cables are supported by the power poles above ground level. However, the cables may be affected by the changes in bay lengths, i.e. the distances between the poles at the levels of the cables, resulting from the differential subsidence, horizontal movements and tilt at the pole locations. The stabilities of the poles and the cable clearances may also be affected by the mining-induced tilts and the changes in the catenary profiles of the cables.

The maximum predicted tilt in any direction for the 33 kV powerline is 35 mm/m (i.e. 3.5 %, or 1 in 29). A rule of thumb used by some electrical engineers is that the tops of the poles may displace up to two pole diameters horizontally before remediation works are considered necessary. Based on pole heights of 15 m and pole diameters of 250 mm, the maximum tolerable tilt at the pole locations is in the order of 20 mm/m.

It is possible, therefore, that the 33 kV powerline could experience adverse impacts due to the mining of LW22 and LW23. It is recommended that preventive measures are implemented, if required, which could include the installation of cable rollers, guy wires or additional poles, or the adjustment of cable catenaries.

Extensive experience of mining beneath powerlines in the NSW coalfields, where the subsidence effects are similar to those predicted for the proposed longwalls, indicates that incidence of impacts is very low and of a minor nature. Some remedial measures have been required, in the past, which included adjustments to cable catenaries, pole tilts and to short span cables.

6.3.5. Recommendations for the 33 kV powerline

It is recommended that the predicted movements are provided to Endeavour Energy so that the necessary preventive measures can be developed, which may include the installation of cable rollers, guy wires or additional poles, or the adjustment of cable catenaries. It is recommended that the powerlines are visually monitored during active subsidence, to maintain them in safe and serviceable conditions at all times.

6.4. Dams, reservoirs or associated works

6.4.1. Descriptions of the reservoirs

Dendrobium Mine is located within the Metropolitan Special Area. The proposed LW22 and LW23 are located near two reservoirs, as shown in Drawing No. MSEC1104-01.

The Cordeaux Reservoir, also known as Lake Cordeaux, is located to the east of the proposed longwalls. The reservoir has been formed within the valley of the Cordeaux River. The overall size of the reservoir is 7.8 km^2 and the total operating capacity is 93,640 ML (WaterNSW, 2017). The Full Supply Level (FSL) of the reservoir is 303.9 mAHD.

The eastern ends of the proposed longwalls extend into the DS NSW Notification Area for the Cordeaux Reservoir. Sections through the Cordeaux Reservoir and the proposed LW22 and LW23 are provided in Fig. 6.5 and Fig. 6.6, respectively.

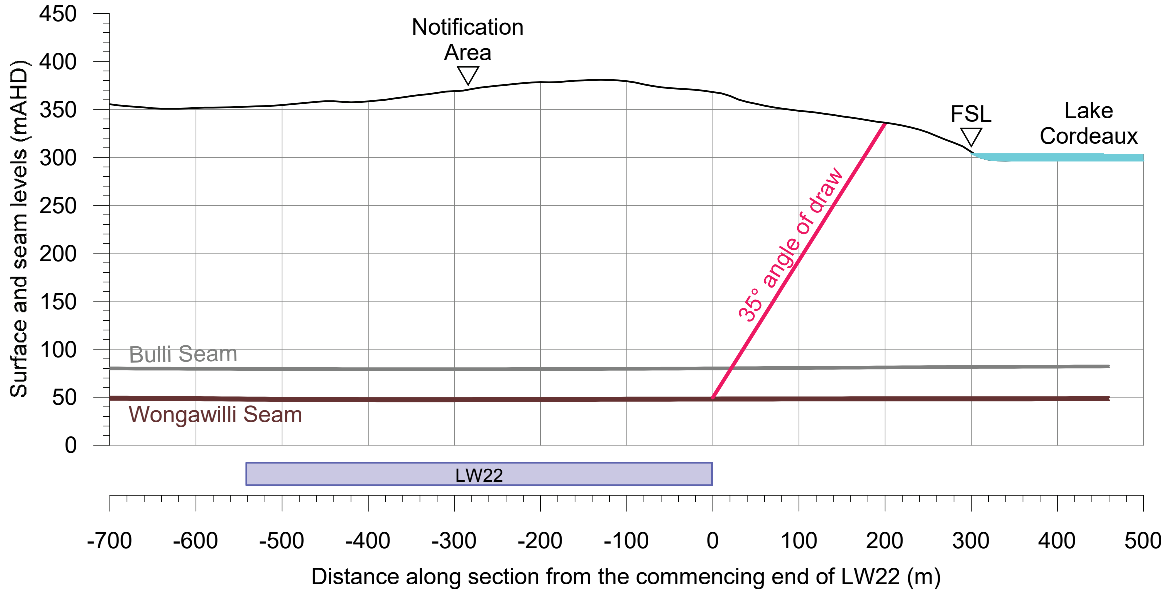

Fig. 6.5 Section through Lake Cordeaux and the proposed LW22

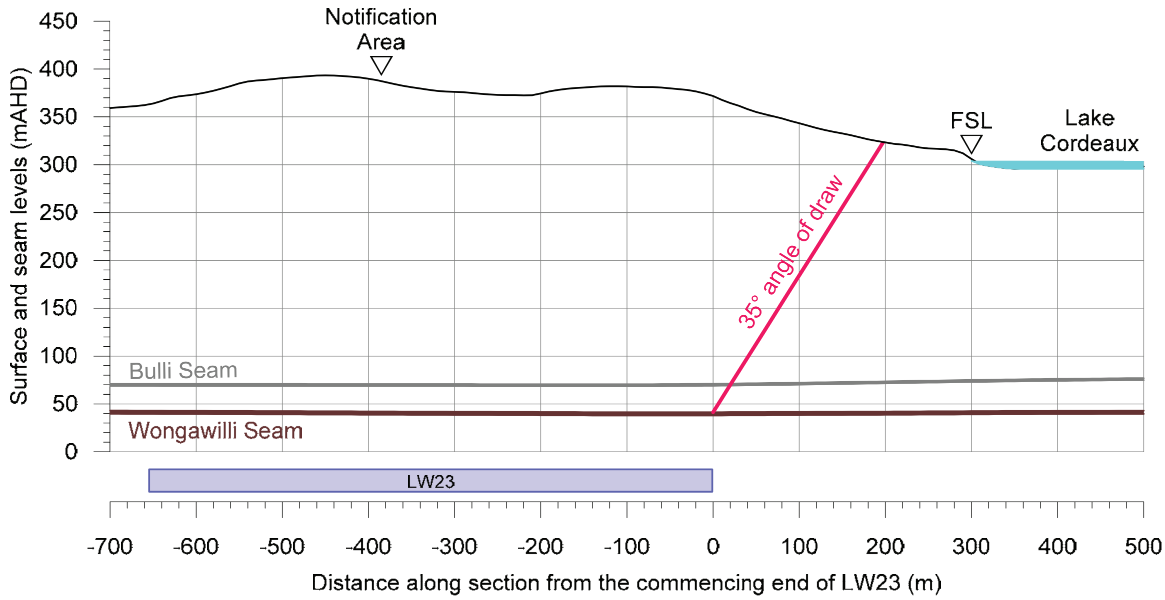

Fig. 6.6 Section through Lake Cordeaux and the proposed LW23

The FSL of the Cordeaux Reservoir is at a distance of 300 m from each of the proposed LW22 and LW23, at the closest points. The FSL is also located outside the 35° angle of draw at a distance of 100 m from each of the proposed longwalls, at the closest points to the surface projections of the angles of draw.

The Cordeaux Dam Wall is near the northern end of the Cordeaux Reservoir and it is located approximately 2.8 km from the proposed LW23. The Upper Cordeaux No. 1 and No. 2 Dams are near the southern end of the reservoir and they are more than 4 km south-east of the proposed LW22.

The Cordeaux Dam Wall is a mass gravity structure constructed using Hawkesbury Sandstone blocks embedded in concrete. The dam wall has a blue metal and sandstone concrete facing on the upstream side and a sandstone concrete facing on the downstream side (WaterNSW, 2015).

The overall length of the dam crest is 405 m and the maximum height is 57 m. The radius of curvature of the dam wall in plan is 875 m. An elevation and a cross-section of the Cordeaux Dam Wall are provided in Fig. 6.7 and Fig. 6.8, respectively. Photographs of the dam wall are provided in Fig. 6.9.

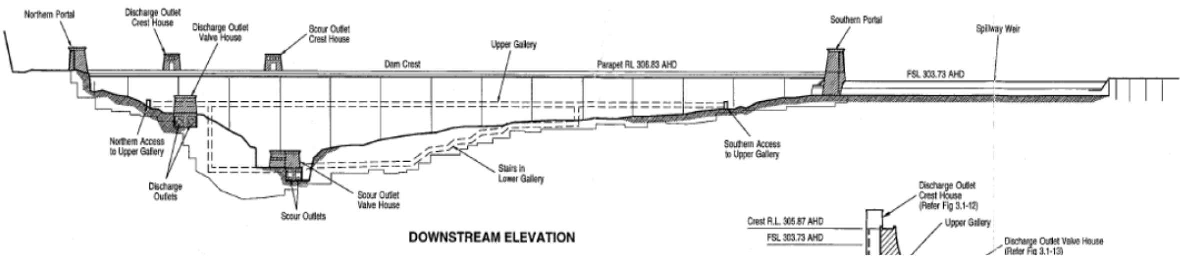

Fig. 6.7 Elevation of the Cordeaux Dam Wall (Source: WaterNSW, 2015)

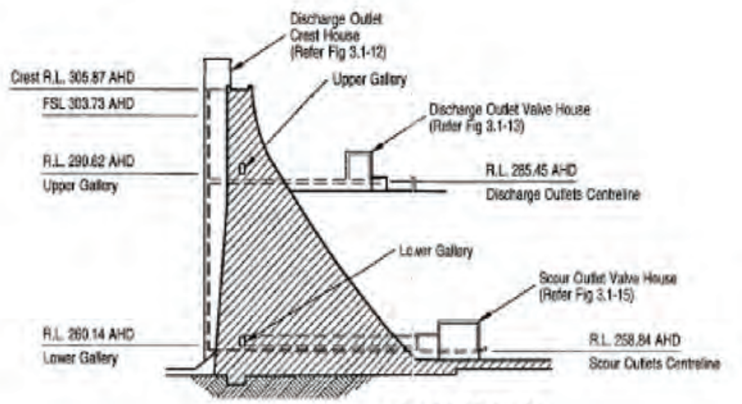

Fig. 6.8 Cross-section of the Cordeaux Dam Wall (Source: WaterNSW, 2015)

Fig. 6.9 Cordeaux Dam Wall

The dam wall is founded on Hawkesbury Sandstone. The foundation has been pressure grouted forming a grout curtain with a depth up to 10 m to 20 m. The foundation was re-grouted and additional drainage was installed between 1977 and 1978.

The Avon Reservoir, also known as Lake Avon, is located to the south-west of the proposed longwalls. The reservoir is at a distance of more than 3 km from the proposed LW22, at its closest point. The existing longwalls in Area 3B are located between the proposed longwalls and the reservoir, where it is located closest to the proposed longwalls. The Avon Dam Wall is located more than 8 km west of the proposed longwalls.

6.4.2. Predictions for the reservoirs

The FSL of the Cordeaux Reservoir is located outside the 35° angle of draw for the proposed longwalls. At this distance, the reservoir is predicted to experience less than 20 mm vertical subsidence. While the reservoir could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains.

The Cordeaux Reservoir will experience far-field horizontal movements orientated towards the mining area. The far-field horizontal movements measured at Dendrobium Mine are illustrated in Fig. 4.3. Far-field horizontal movements up to 180 mm have been measured at distances of 300 m from the completed longwalls at the Mine. These far-field effects are global movements towards the mining area that are associated with very low levels of strain.

The Cordeaux Reservoir could also experience valley-related effects. The section of reservoir nearest to the longwalls comprises a broad river valley and, therefore, only low-level closure effects are anticipated. The net closure or opening movements will comprise a combination of the valley-related effects (i.e. closure) and the far-field horizontal movements (i.e. opening).

Dendrobium LW12 to LW16 mined adjacent to the Avon Reservoir at a minimum distance of 300 m from its FSL. The measured subsidence effects due to mining adjacent to the Avon Reservoir should indicate the potential movements at the Cordeaux Reservoir due to the mining of the proposed longwalls.

The Avon Dam monitoring lines measured the net movements across the Avon Reservoir due to mining in Area 3B. The net opening and closure movements for these monitoring lines after the completion of LW16 are shown in Fig. 6.10.

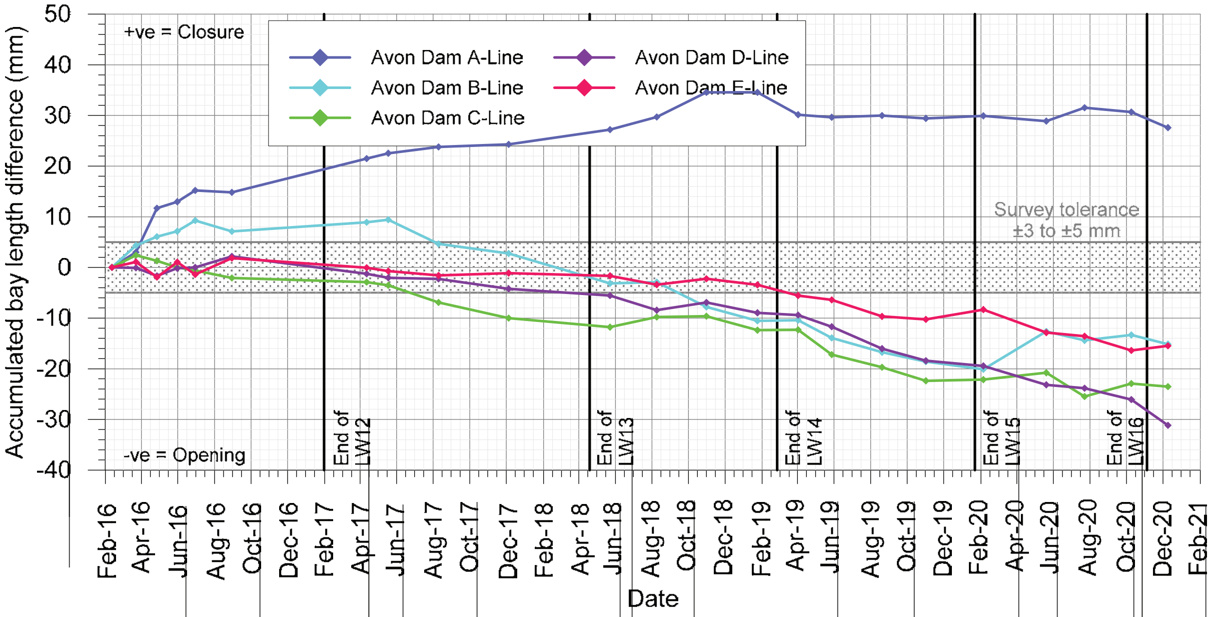

Fig. 6.10 Measured net opening and closure movements for the Avon Dam monitoring lines

The Avon Dam monitoring lines measured up to +35 mm net opening and -31 mm net closure due to the mining of LW11 to LW16. These net movements occurred over distances ranging between 180 m and more than 700 m and, therefore, represent net strains of less than ±0.5 mm/m. Similar movements are expected for the Cordeaux Reservoir due to the mining of the proposed LW22 and LW23.

The Cordeaux Dam Wall is located approximately 2.8 km north the proposed LW23 and the Upper Cordeaux No. 1 and No. 2 Dam Walls are located more than 4 km south-east of the proposed LW22. At these distances, the dam walls are not predicted to experience measurable conventional subsidence effects.

The dam walls could experience very low level far-field horizontal movements, of less than 20 mm, due to the mining of the proposed longwalls. These far-field horizontal movements are expected to be global movements towards the mining area that are not associated with measurable strains. The differential horizontal movements (i.e. opening or closure) over the lengths of the dam walls are also not expected to be measurable.

The Avon Reservoir is located more than 3 km from the proposed LW22. The existing longwalls in Area 3B are located between the proposed longwalls and the reservoir, where it is located closest to the proposed longwalls. The Avon Reservoir could experience very low levels of far-field horizontal movement. These far-field horizontal movements are expected to be global movements towards the mining area that are not associated with measurable strains.

The Avon Dam Wall is located more than 8 km west of the proposed longwalls. At this distance, the dam wall is not expected to experience measurable conventional, far-field or valley-related effects.

6.4.3. Previous experience of mining near the reservoirs

The longwalls at Dendrobium Mine have been extracted near the Upper Cordeaux No. 2 reservoir. The dam wall is located approximately 1.5 km from LW1 in Area 1 and approximately 0.9 km from LW3 in Area 2 at the mine.

The mine subsidence effects at the Upper Cordeaux No. 2 reservoir were measured by the, then, Sydney Catchment Authority (SCA) using 3D survey marks located on and around the dam wall. The latest available survey, Survey No. 9a, was carried out in April 2010, during the extraction of LW6 in Area 2. The results of this survey were provided in the monitoring report by SCA (2010).

The maximum measured movements at the Upper Cordeaux No. 2 dam wall were ±1 mm vertical, +3 mm horizontal in the downstream direction and ±1 mm in the east and west directions. The SCA monitoring report states that:

> *"The centre of the dam crest is at its maximum downstream position near July of each year and maximum upstream position near January of each year. This change is very probably caused by the overall change in dam wall temperature as well as the change in the temperature gradient across the dam wall section. The water storage level has remained within 0.1m of FSL since April 2005 and so has no significant effect on deflection. Towards the right bank the movement on the crest is generally smaller and more complex due to the reduced height and the changing curvature of the dam wall. The several cracks in this section of the dam wall may also be influencing how the dam wall moves as it expands and contracts. The fact that both ground and dam wall are vertically stable reduces the likelihood that mining is a factor in the measured horizontal movement."*

The detailed ground monitoring data indicated that the measured movements were very small and were within the order of survey tolerance. That is, the mining-induced movements at the Upper Cordeaux No. 2 dam wall were not measurable above seasonal variations.

6.4.4. Impact assessments for the reservoirs

The Cordeaux Reservoir could experience low-level net opening or net closure movements in the order of ±25 mm to ±35 mm due to the mining of the proposed longwalls. The strains associated with the net movements are expected to be less than ±0.5 mm/m.

Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield. The furthest reported fracture outside of the previously extracted longwalls at the Mine was located approximately 290 m south of LW12 in Area 3B.

It is possible that fracturing could occur in the bedrock beneath the Cordeaux Reservoir where it is located within approximately 400 m of the proposed longwalls. However, it is unlikely that fracturing would be visible in the bed of the reservoir due to the alluvial deposits. An assessment of the surface water storage is provided in the report by HGeo (2021).

The Cordeaux Dam Wall and Upper Cordeaux No. 1 and No. 2 Dam Walls could experience very low levels of far-field horizontal movements of less 20 mm. The potential for impacts on the dam walls does not result from the absolute far-field horizontal movement but from differential horizontal movements. The differential horizontal movements (i.e. opening or closure) over the lengths of the dam walls are not expected to be measurable. Adverse impacts on the dam walls are not anticipated due to the mining of the proposed LW22 and LW23.

The Avon Dam wall is located more than 8 km west of the proposed longwalls. At this distance, the dam wall is unlikely to experience measurable movements and, therefore, it is not expected to experience adverse impacts.

6.4.5. Recommendations for the reservoirs

It is recommended that IMC consult with WaterNSW and the DS NSW to develop the appropriate monitoring and management strategies for the reservoirs and dam walls.

6.5. Aboriginal heritage sites

6.5.1. Descriptions of the Aboriginal heritage sites

The locations of the Aboriginal heritage sites are shown in Drawing No. MSEC1104-11. The details of the heritage sites have been provided by Niche (2021b).

There are three Aboriginal heritage sites (Refs. 52-2-1632, 52-2-2219 and 52-2-4499) that have been identified within or adjacent to the Study Area based on the 35° angle of draw. There are eight additional Aboriginal heritage sites (Refs. 52-2-0019, 52-2-0535, 52-2-1633, 52-2-1634, 52-5-0275, 52-5-0276, 52-2-4656 and 52-2-4657) that are located within or adjacent to the Study Area based on the 600 m boundary. Some of these sites could experience far-field or valley-related effects and could be sensitive to these movements and, therefore, they have been included in the assessments.

A summary of the Aboriginal heritage sites identified within the Study Area based on the 600 m boundary is provided in Table 6.9.

Table 6.9 Aboriginal heritage sites identified within the Study Area

Reference	Type	Location relative to the longwalls
52-2-0019	Shelter with Art and Deposit	375 m north of LW23
52-2-0535	Stone Arrangement	335 m north of LW23
52-2-1632	Shelter with Art	230 m north-west of LW23
52-2-1633	Shelter with Art	360 m north-west of LW23
52-2-1634	Shelter with Art	335 m north-west of LW23
52-2-2219	Shelter with Art	Directly above LW22
52-2-4499	Isolated Artefact	270 m north of LW23
52-5-0275	Shelter with Art	300 m south of LW22
52-5-0276	Shelter with Art and Deposit	610 m south of LW22
52-2-4656	Shelter with Art	420 m north of LW23
52-2-4657	Shelter with Deposit	320 m west of LW23

The Aboriginal heritage sites within the Study Area comprise six Shelters with Art, one Shelter with Deposit, two Shelters with Art and Deposits, one Stone Arrangement and one Isolated Artefact. Site Ref. 52-2-2219 is located directly above the proposed LW22. The remaining sites are located outside the proposed mining area at distances ranging between 230 m and 610 m.

Further details on the Aboriginal cultural heritage sites are provided in the report by Niche (2021b).

6.5.2. Predictions for the Aboriginal heritage sites

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the Aboriginal heritage sites within the Study Area is provided in Table 6.10. The values are the maximum predicted subsidence effects within 20 m of each of the sites due to the mining of the existing, approved and proposed longwalls.

Table 6.10 Maximum predicted total vertical subsidence, tilt and curvatures for the Aboriginal heritage sites within the Study Area

Reference	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
52-2-0019	< 20	< 0.5	< 0.01	< 0.01
52-2-0535	< 20	< 0.5	< 0.01	< 0.01
52-2-1632	< 20	< 0.5	< 0.01	< 0.01
52-2-1633	< 20	< 0.5	< 0.01	< 0.01
52-2-1634	< 20	< 0.5	< 0.01	< 0.01
52-2-2219	1400	10	0.30	0.08
52-2-4499	< 20	< 0.5	< 0.01	< 0.01
52-5-0275	< 20	< 0.5	< 0.01	< 0.01
52-5-0276	< 20	< 0.5	< 0.01	< 0.01
52-2-4656	< 20	< 0.5	< 0.01	< 0.01
52-2-4657	< 20	< 0.5	< 0.01	< 0.01

Site 52-2-2219 is located directly above the proposed LW22. The maximum predicted conventional strains for this site, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 4.5 mm/m tensile and 1.0 mm/m compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.4. The maximum predicted strains directly above the mining area are 8 mm/m tensile and compressive based on the 95 % confidence levels.

The remaining Aboriginal heritage sites within the Study Area are located well outside the proposed mining area and they are predicted to experience less than 20 mm vertical subsidence. While these sites could experience very low levels of vertical subsidence, they are not predicted to experience measurable tilts, curvatures or strains.

Site 52-2-1634 is located along a tributary to Wongawilli Creek (ref. WC28) and therefore it could experience valley-related effects. The predicted valley-related effects for this site after the mining of LW22 and LW23 are 60 mm upsidence and 125 mm closure. The remaining sites within the Study Area are located on the sides or near the tops of ridgelines and, therefore, they are not expected to experience valley-related effects.

6.5.3. Impact assessments for the Aboriginal heritage sites

Site 52-2-2219 is located directly above the proposed LW22. The rock shelter has formed by blockfall and it is approximately 10.8 m long, 3 m deep and 2.3 m high (NPWS, 2002). The extraction of LW22 is likely to result in fracturing of the exposed bedrock along the ridgeline and, where the rock is marginally stable, it could then result in rockfalls or instabilities. The fracturing and rockfalls could therefore adversely impact this rock shelter.

It is extremely difficult to assess the likelihood of impacts on the rock shelters based upon predicted ground movements. The likelihood of a rockfall or instability is dependent on many factors that are difficult to fully quantify. Some of 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 rock shelter naturally or when it is exposed to mine subsidence movements.

It has been assessed that between 7 % and 10 % of the total length, or between 3 % and 5 % of the total face area, of the cliffs located directly or partially above the mining area would be impacted by the extraction of the proposed longwalls. It has also been assessed that between 3 % and 5 % of the total length of the minor cliffs and rock outcrops located directly or partially above the mining area would experience adverse impacts.

Fracturing resulting in spalling or rockfalls could occur at Site 52-2-2219. The potential for adverse impacts at this site has been assessed as *unlikely* (i.e. less than 10 %).

Site 52-2-1634 is located 335 m north-west of the proposed LW23. The rock shelter is located under a waterfall on a side tributary, formed by chemical weathering and exfoliation, and it is approximately 18 m long, 8.2 m deep and 4 m high (NPWS, 1991).

Fracturing has been observed in the Southern Coalfield at distances up to approximately 400 m outside the mining area. It is possible, but unlikely, that fracturing could occur along the tributary near Site 52-2-1634. The potential for adverse impacts at this site has been assessed as *rare* (i.e. less than 5 %).

The remaining Aboriginal heritage sites are predicted to experience less than 20 mm vertical subsidence and are not expected to experience valley-related effects. Adverse impacts on these sites therefore are not anticipated due to the mining of LW22 and LW23.

Further discussions on the potential impacts on the Aboriginal heritage sites within the Study Area are provided in the report by Niche (2021b).

6.5.4. Recommendations for the Aboriginal heritage sites

It is recommended that IMC develop an Aboriginal Heritage Management Plan in consultation with the registered parties for the Aboriginal heritage sites.

6.6. Survey control marks

The locations of the survey control marks are shown in Drawing No. MSEC1104-11. The locations and details of the survey control marks were obtained from *Spatial Services* using the *SCIMS Online* website (SCIMS, 2020).

Survey control mark SS 60972 and TS10825 are located directly above the proposed LW23. These marks could experience the full range of predicted subsidence effects. A summary of the maximum predicted subsidence effects within the Study Area is provided in Chapter 4.

The remaining survey control marks are located outside the Study Area based on the 35° angle of draw. The marks that are located closest to the proposed mining area could experience small amounts of vertical subsidence and small far-field horizontal movements. It is possible that the survey control marks could be affected by far-field horizontal movements at distances of 1 km to 2 km outside the mining area. Far-field horizontal movements and the methods used to predict such movements are described further in Sections 3.3 and 4.6.

It is recommended that the survey control marks that are required for future use are re-established after the completion of mining in the area and after the ground has stabilised. Consultation between IMC and Spatial Services will be required to ensure that these survey control marks are reinstated at the appropriate time, as required.

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

Glossary of terms and definitions

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

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

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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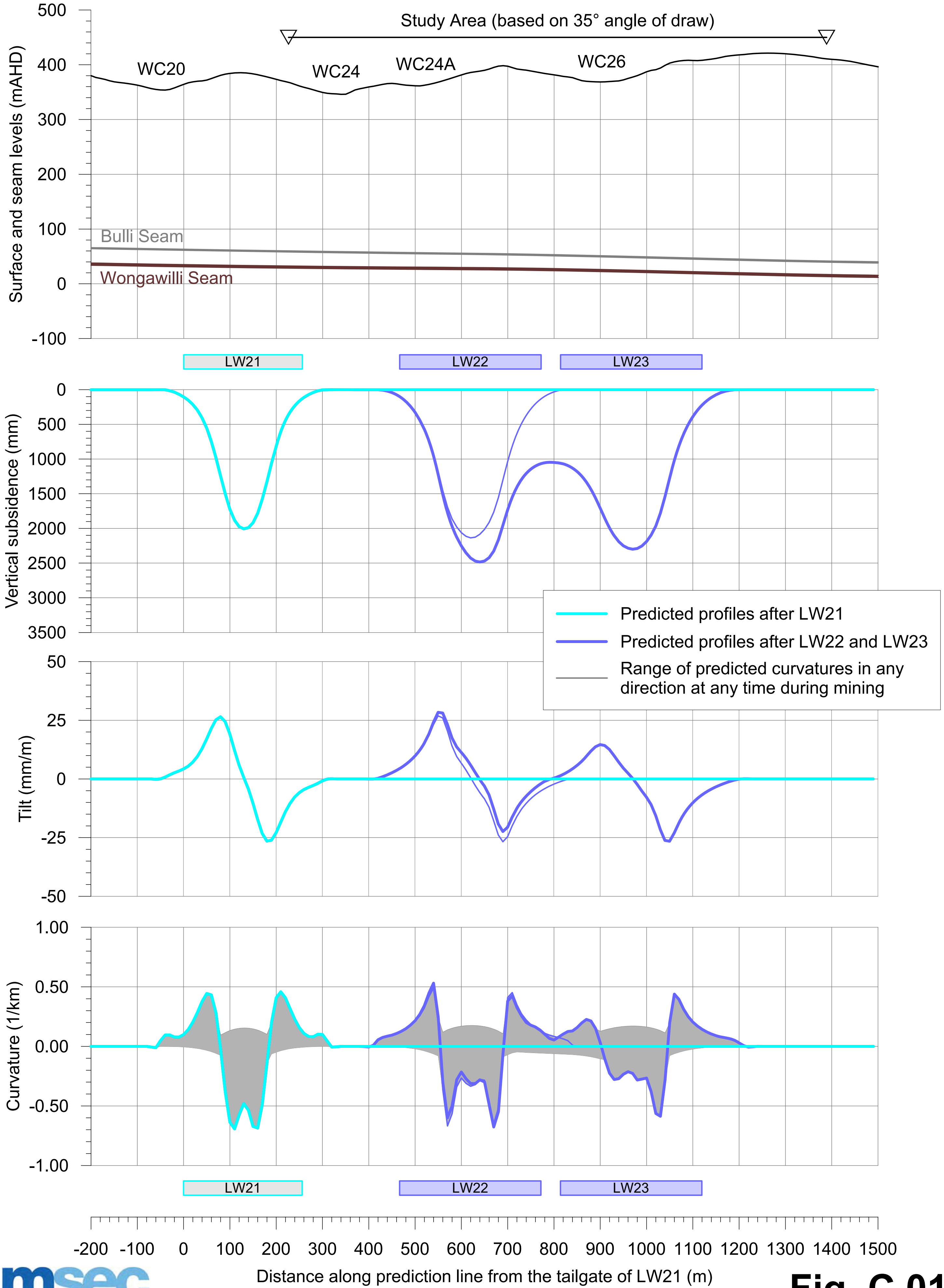
APPENDIX C. FIGURES

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to the extraction of LW21 to LW23



msec

Fig. C.01

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to the extraction of LW22 and LW23

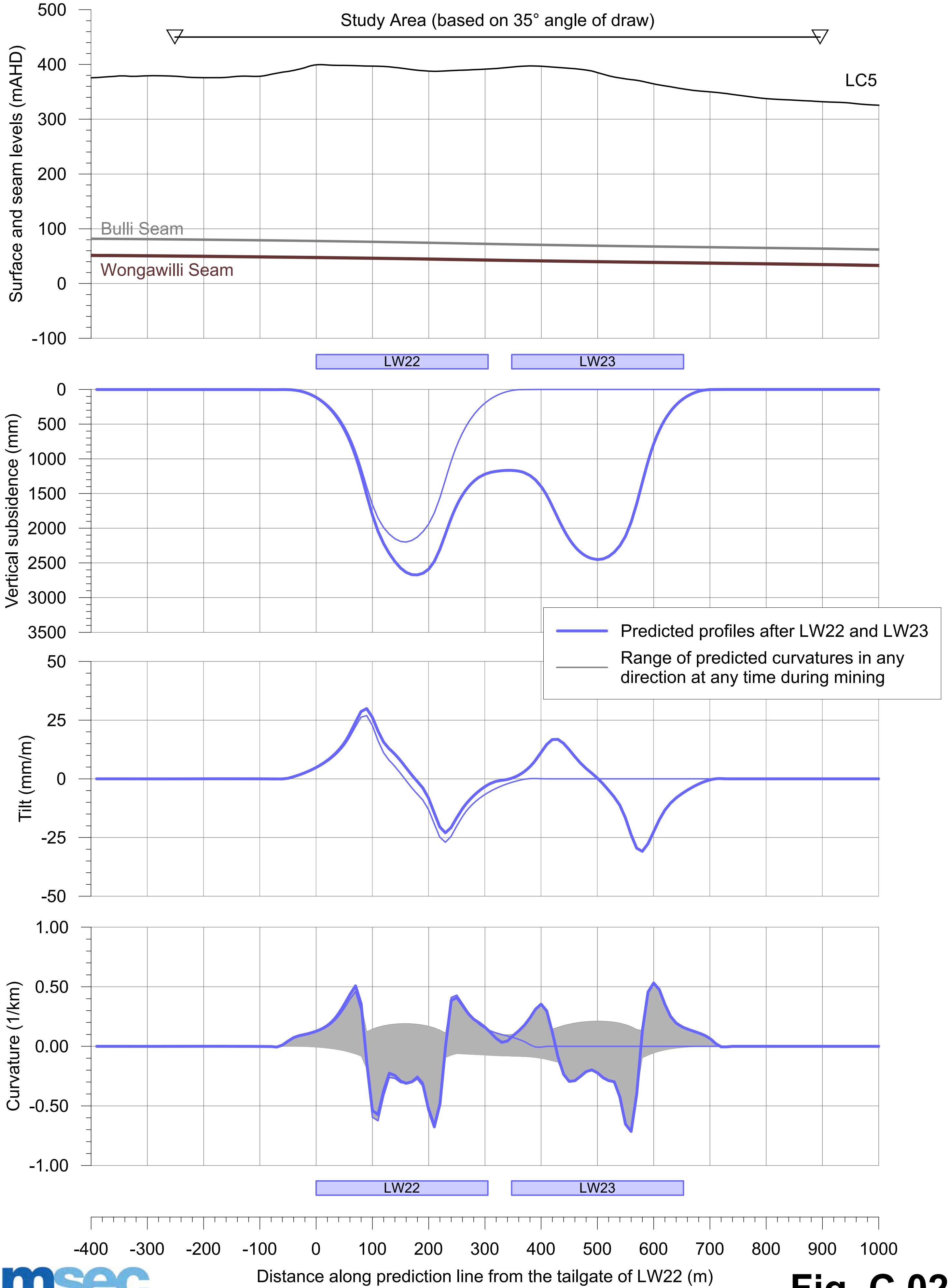


Fig. C.02

Predicted profiles of vertical subsidence, upsidence and closure along Wongawilli Creek due to mining in Areas 3A, 3B and 3C

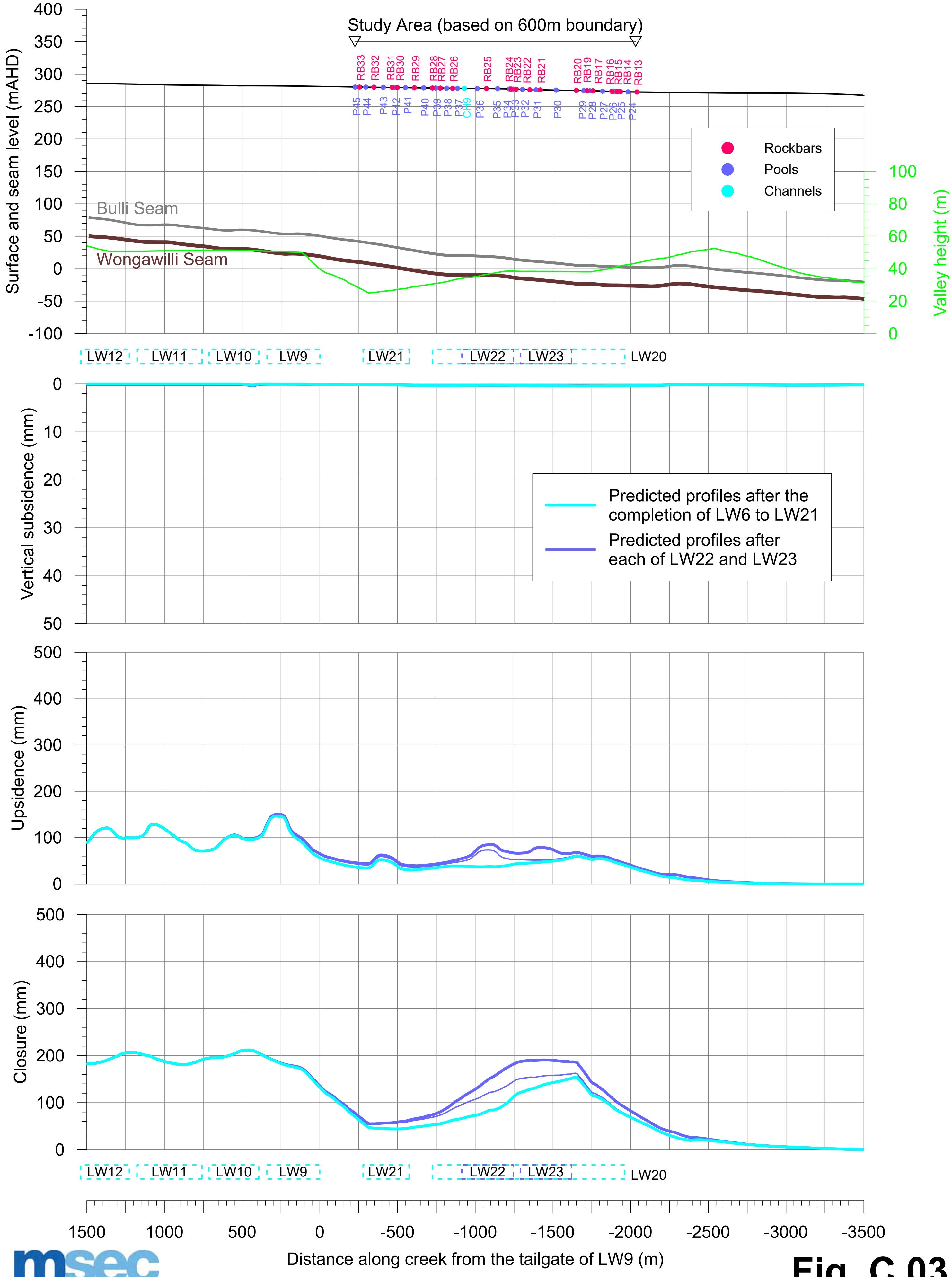


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Fig. C.03

Predicted profiles of vertical subsidence, upsidence and closure along Stream LC5 due to the mining of LW20 to LW23

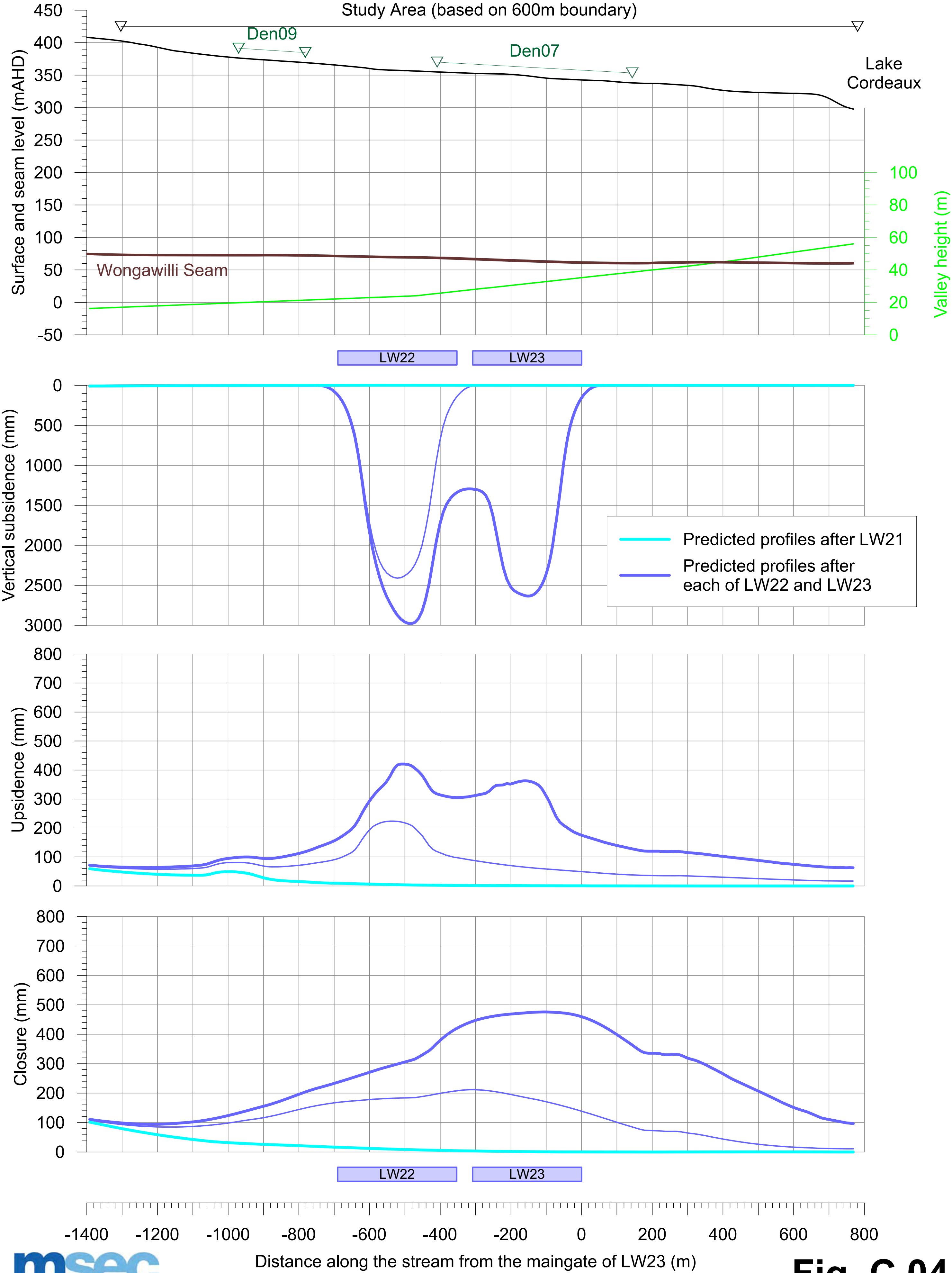

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Fig. C.04

Predicted profiles of vertical subsidence, upsidence and closure along Stream LC6 due to the mining of LW20 to LW23

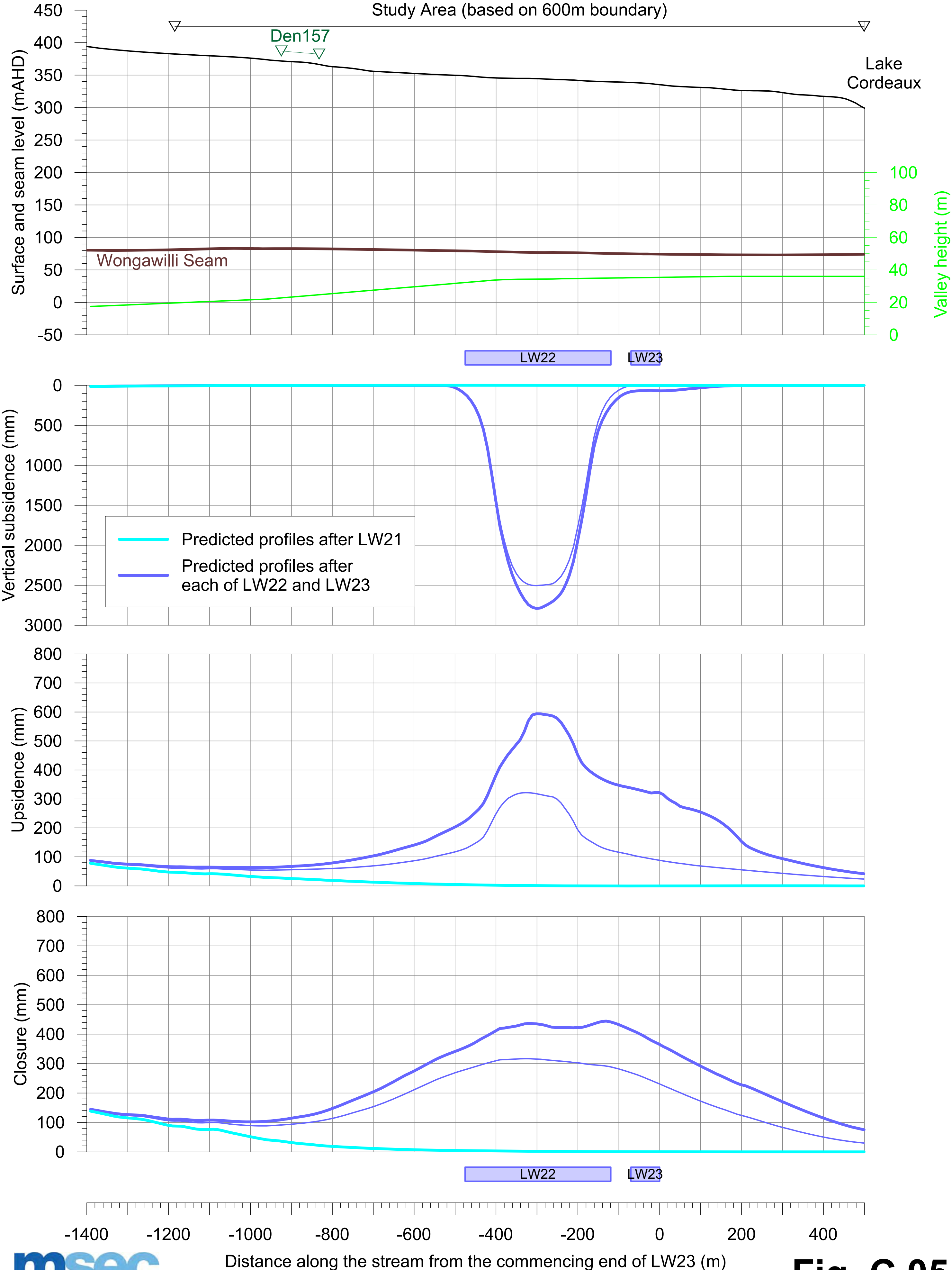
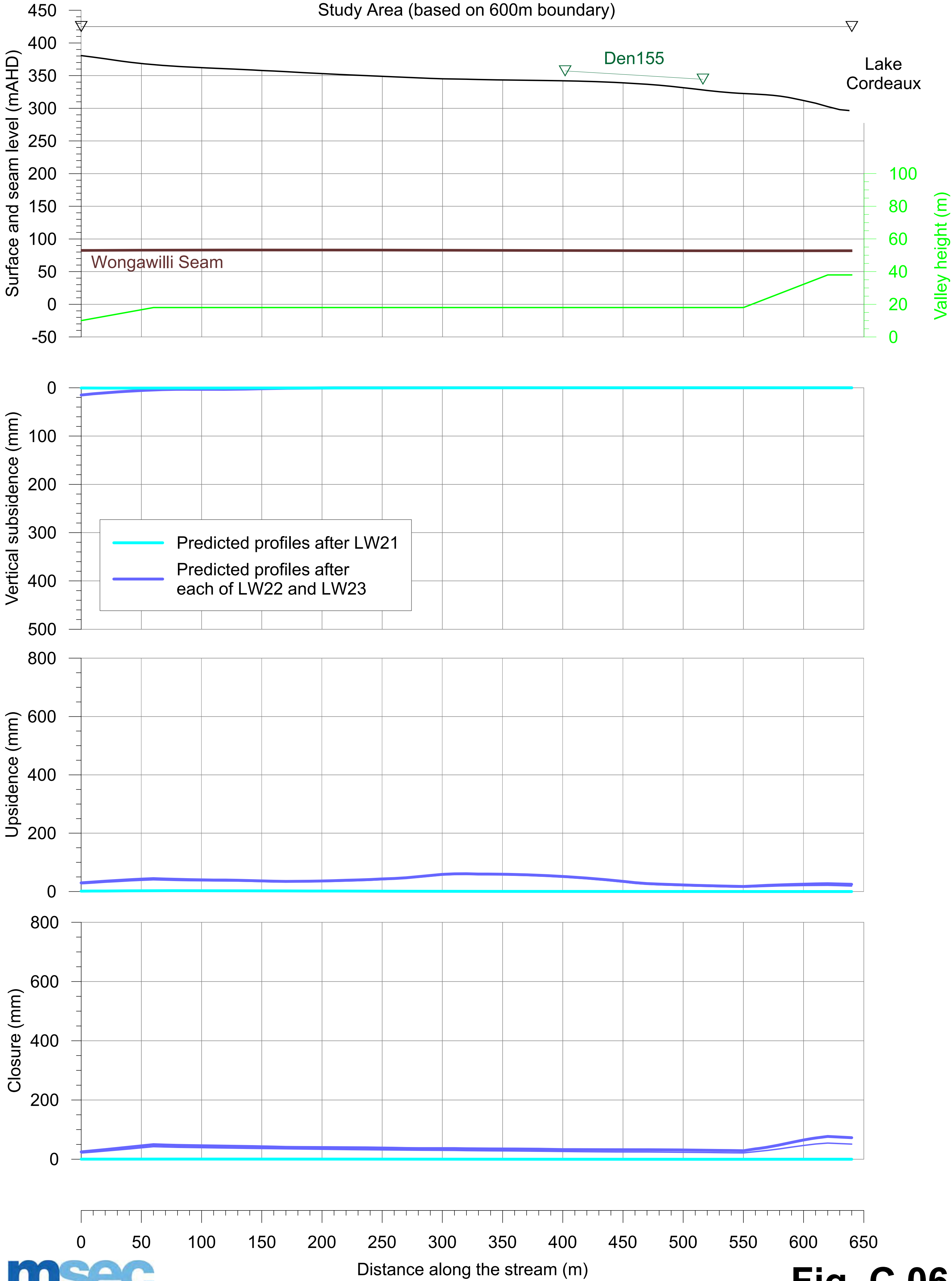


Fig. C.05

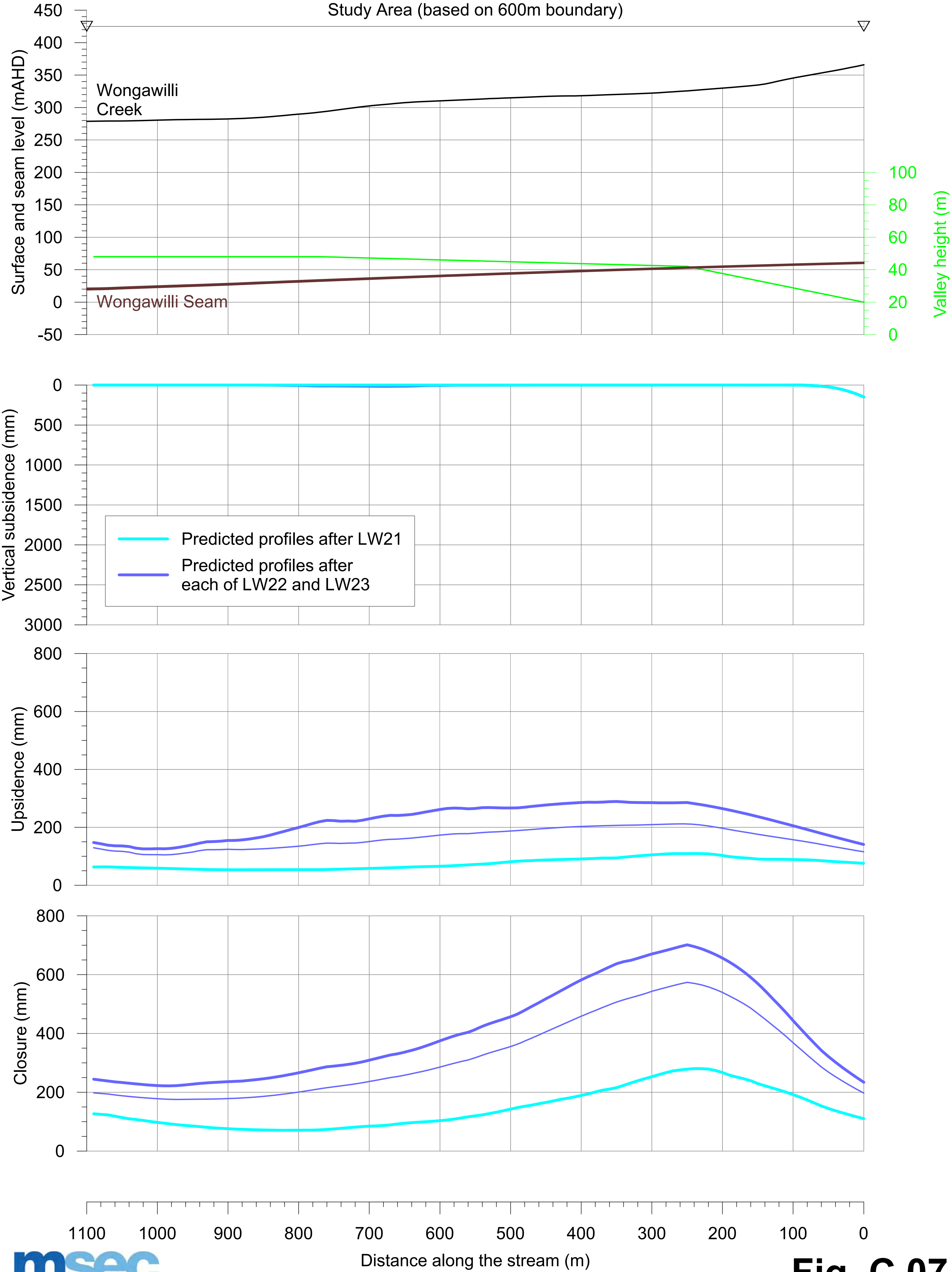
Predicted profiles of vertical subsidence, upsidence and closure along Stream LC7 due to the mining of LW20 to LW23



msec

Fig. C.06

Predicted profiles of vertical subsidence, upsidence and closure along Stream WC24 due to the mining of LW20 to LW23



msec

Fig. C.07

Predicted profiles of vertical subsidence, upsidence and closure along Stream WC26 due to the mining of LW20 to LW23

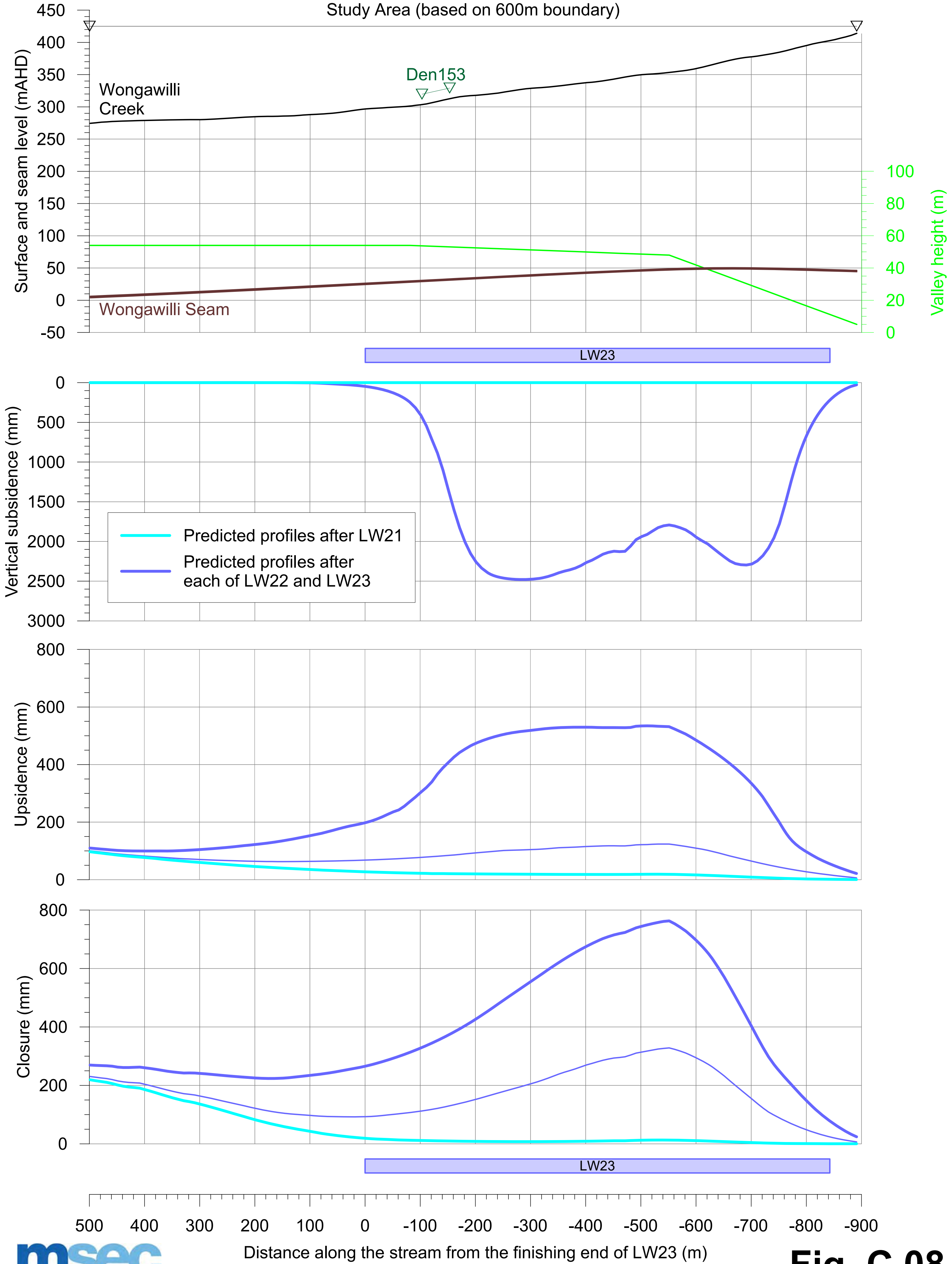


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Fig. C.08

Predicted profiles of vertical subsidence, tilt along and tilt across the 330 kV transmission line due to mining in Areas 3A and 3C

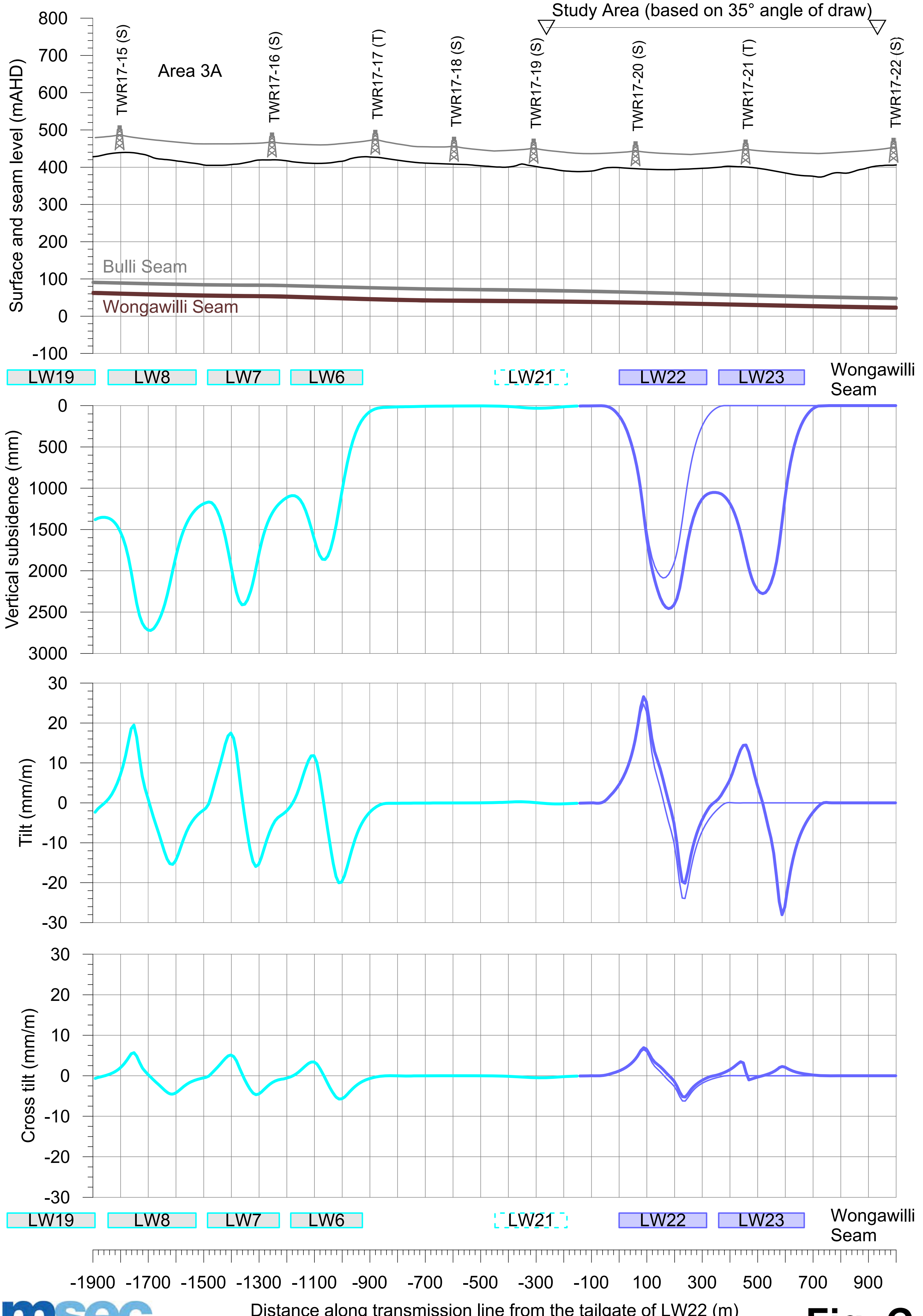
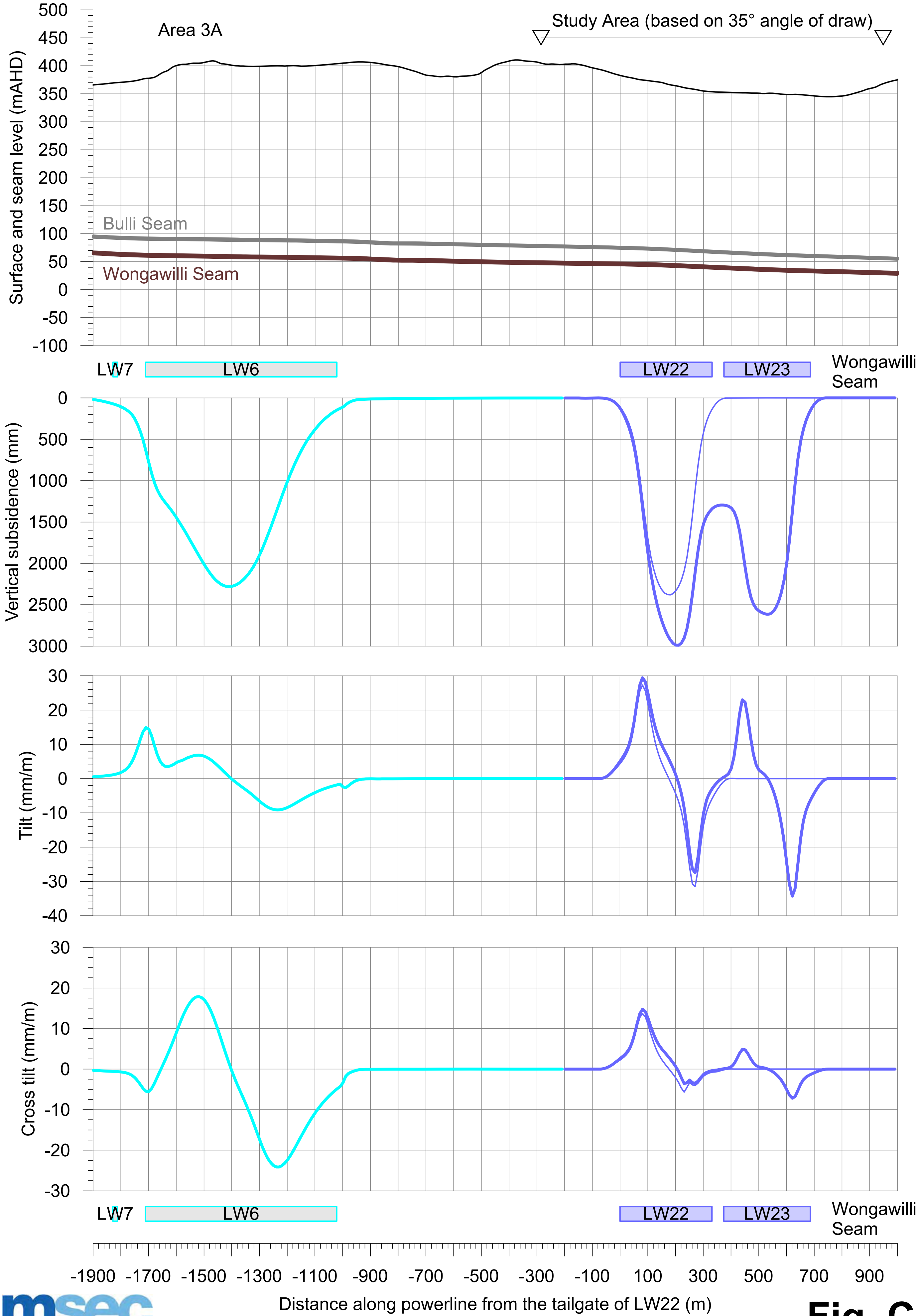


Fig. C.09

Predicted profiles of vertical subsidence, tilt along and tilt across the 33 kV powerline due to mining in Areas 3A and 3C



msec

Fig. C.10

APPENDIX D. DRAWINGS

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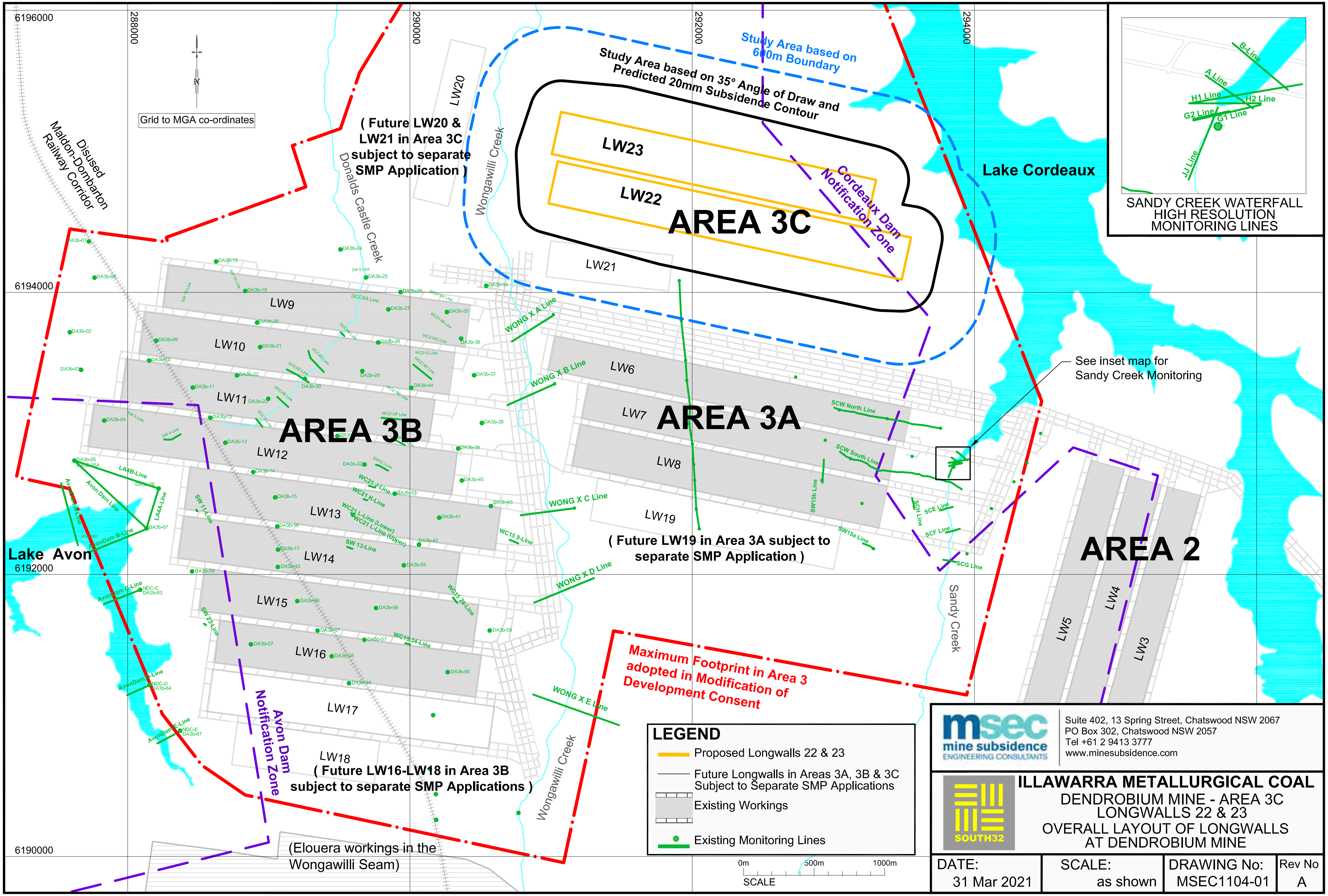

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ILLAWARRA METALLURGICAL COAL
DENDROBIUM MINE - AREA 3C
LONGWALLS 22 & 23
OVERALL LAYOUT OF LONGWALLS
AT DENDROBIUM MINE

DATE:	SCALE:	DRAWING No:	Rev No
31 Mar 2021	as shown	MSEC1104-01	A

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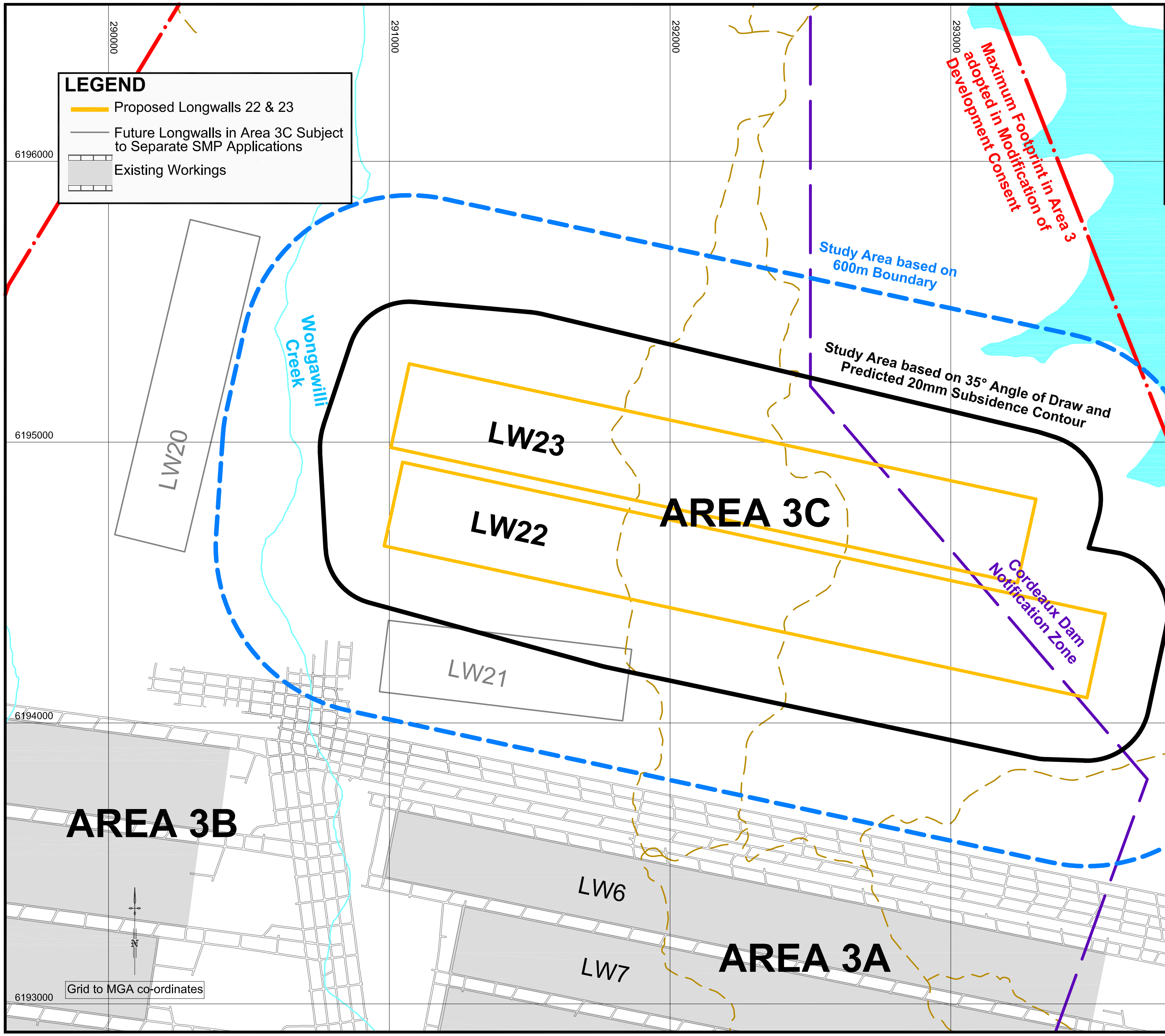

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ILLAWARRA METALLURGICAL COAL
DENDROBIUM MINE - AREA 3C
LAYOUT OF LONGWALLS 22 & 23

DATE:	SCALE:	DRAWING No:	Rev No
31 Mar 2021	1:20000	MSE1104-02	A

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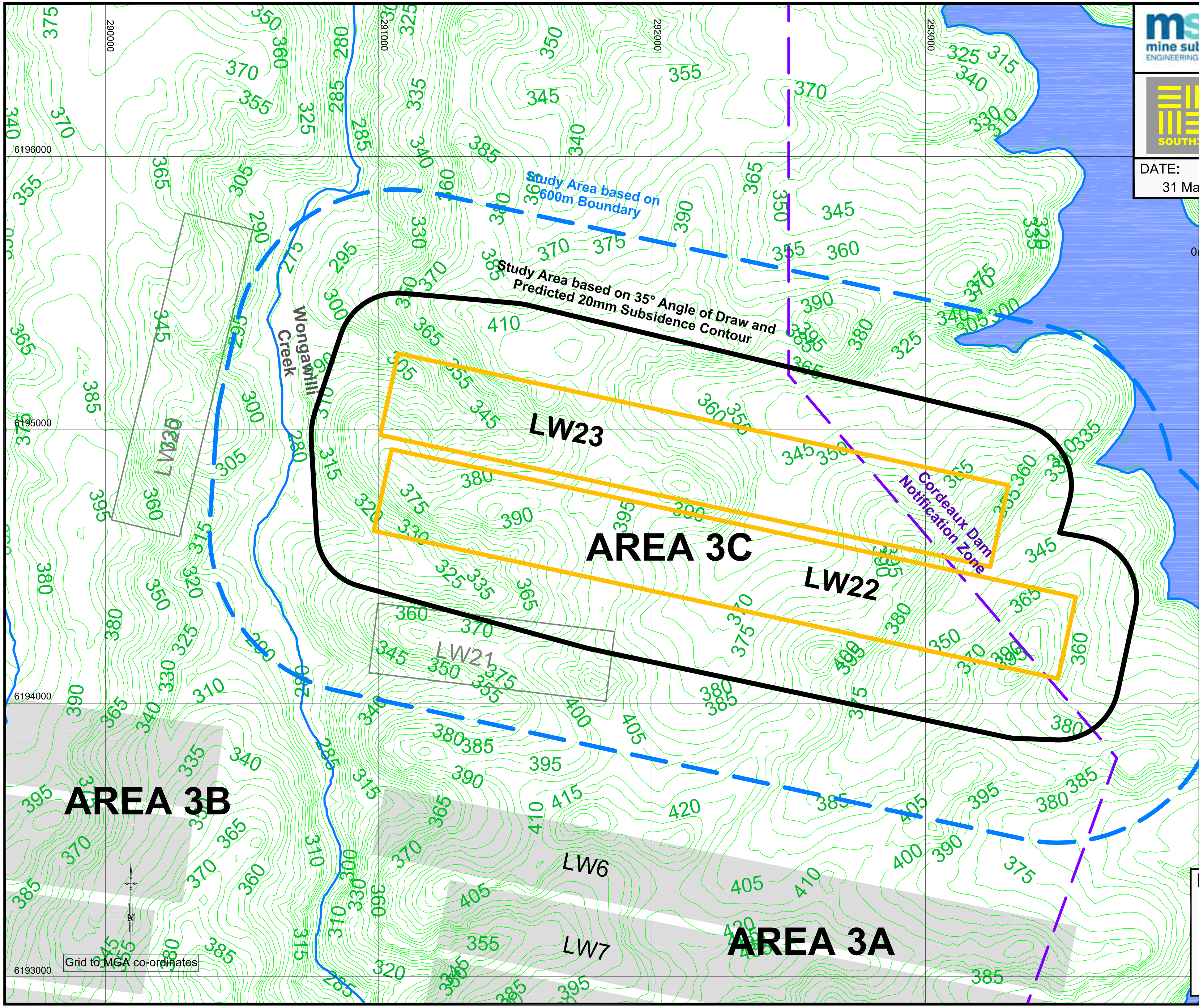

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DENDROBIUM MINE - AREA 3C
SURFACE LEVEL CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
31 Mar 2021	1:20000	MSE1104-03	A

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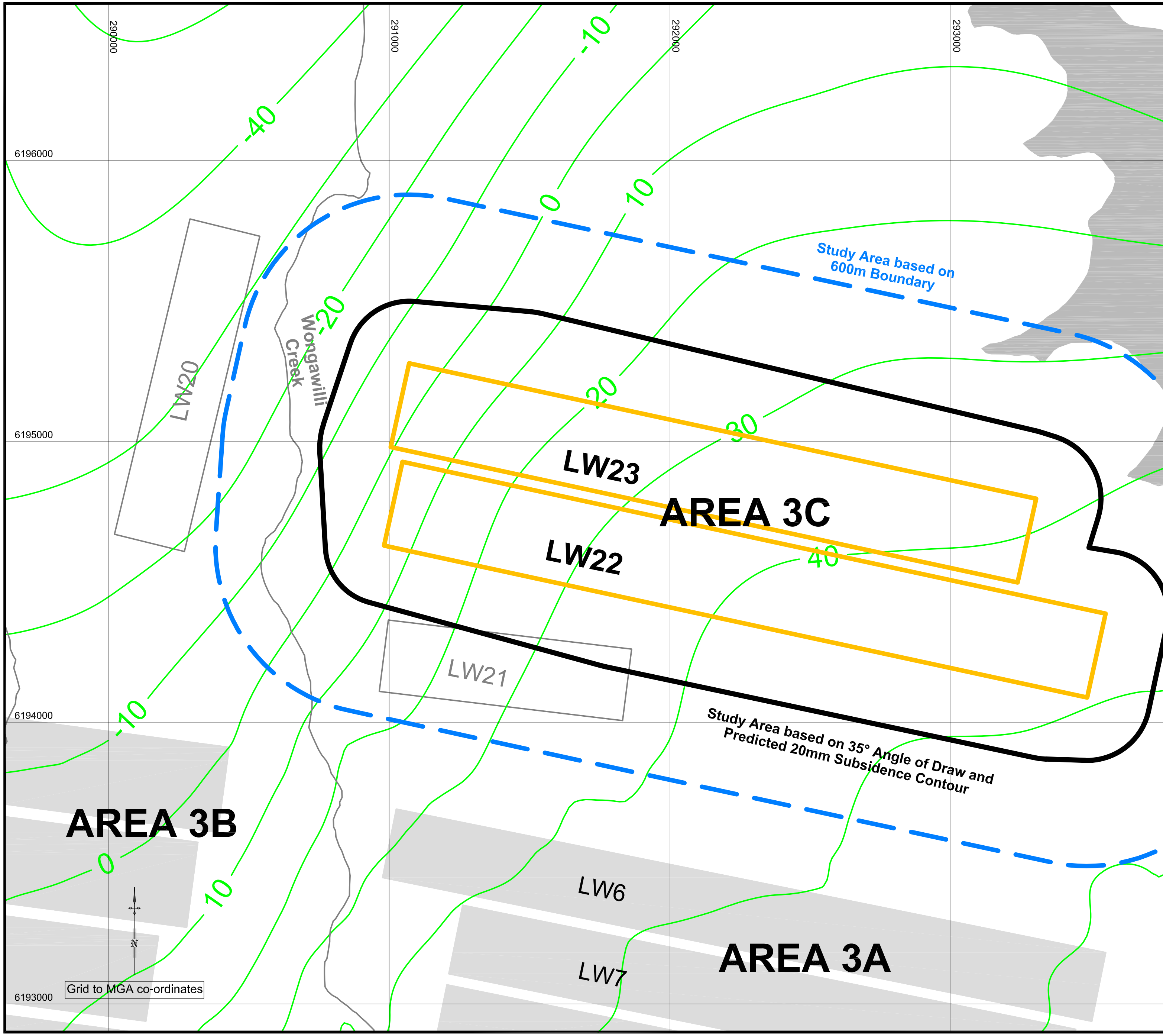

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ILLAWARRA METALLURGICAL COAL
DENDROBIUM MINE - AREA 3C
WONGAWILLI SEAM FLOOR CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
31 Mar 2021	1:20000	MSE1104-04	A

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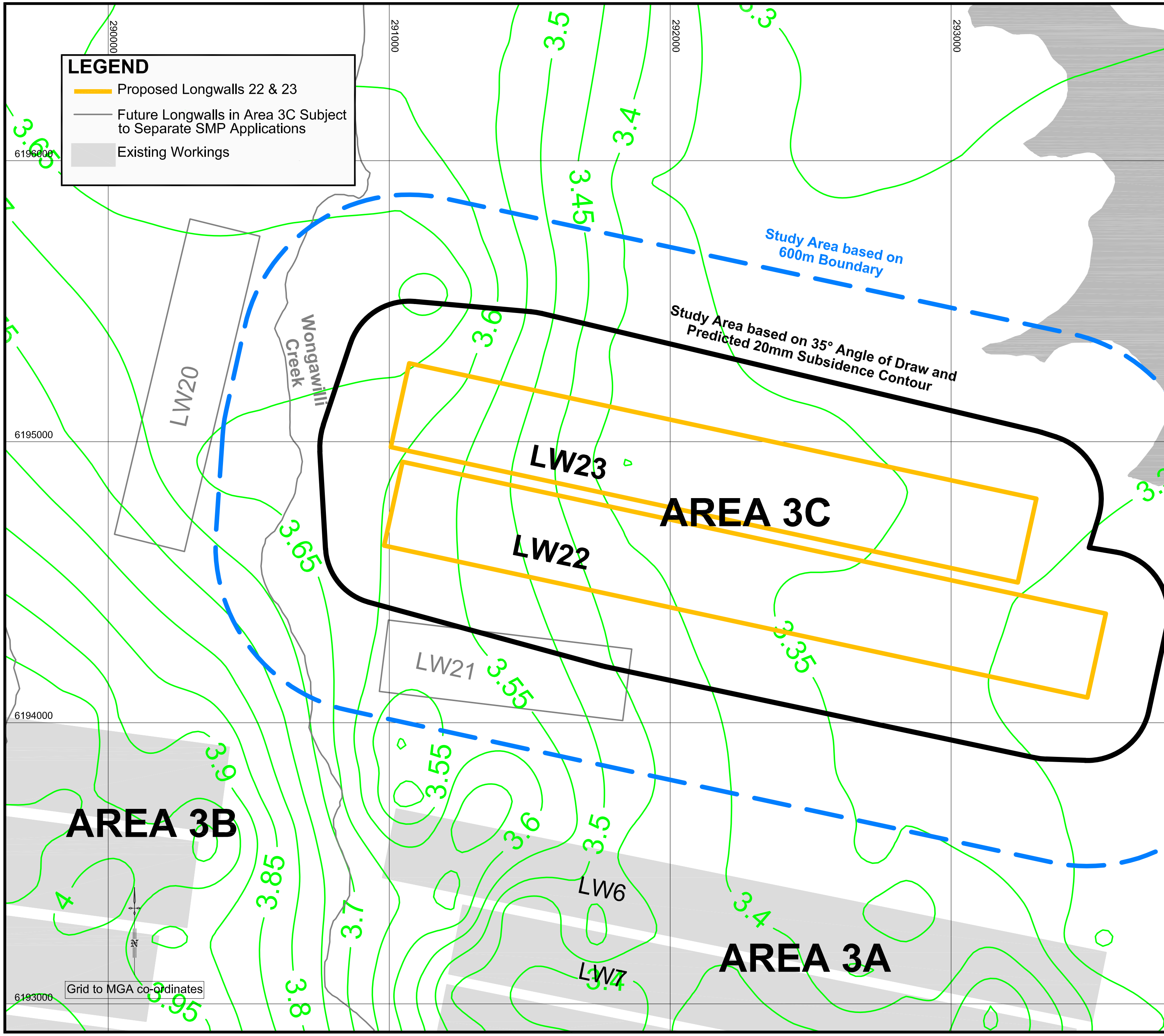

Contours show the thickness of the basal section for the Wongawilli Seam. The extraction height for the proposed longwalls is 3.9 m.

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DENDROBIUM MINE - AREA 3C
WONGAWILLI SEAM THICKNESS
CONTOURS FOR THE BASL SECTION

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31 Mar 2021	1:20000	MSE1104-05	A

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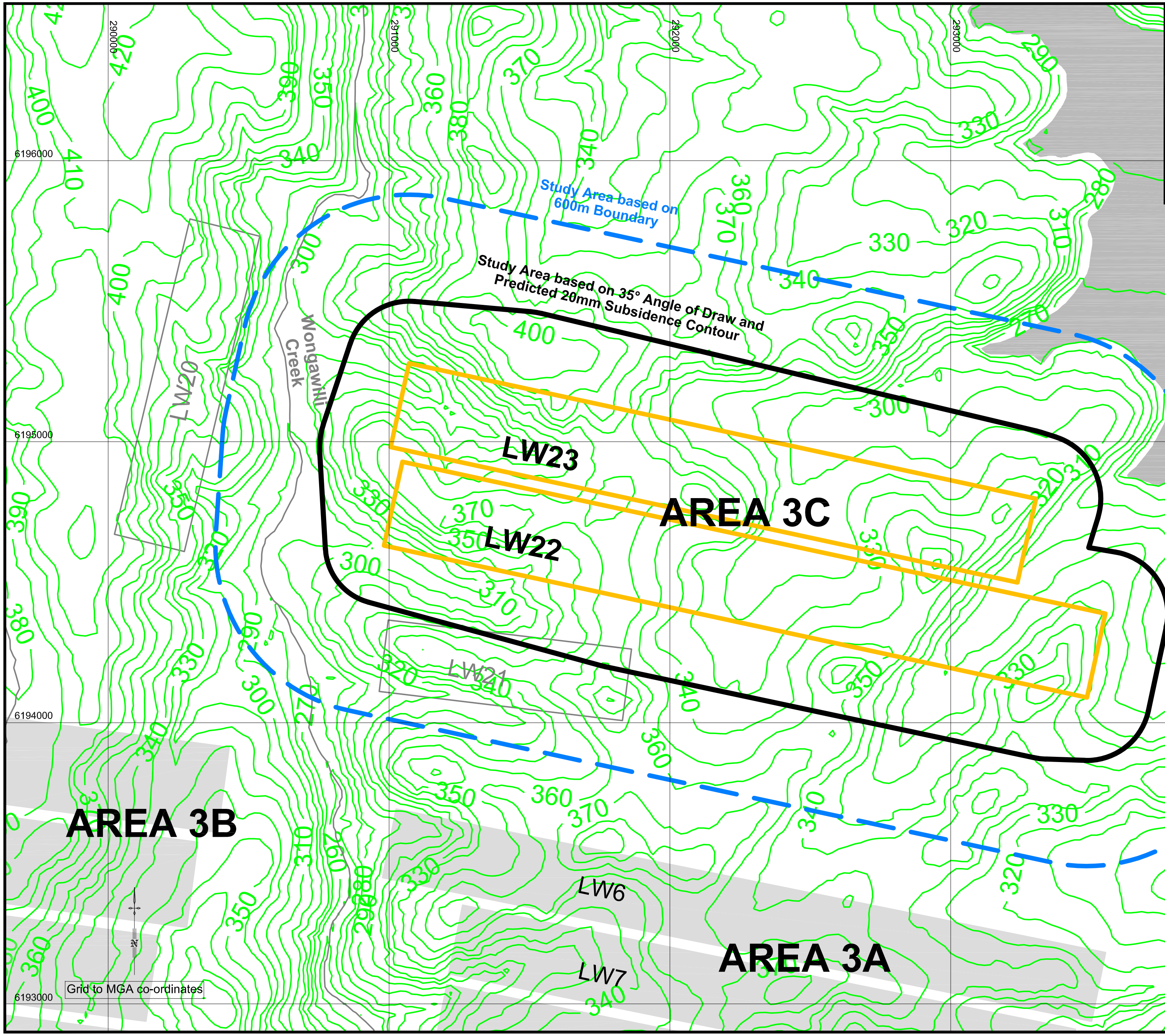

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DENDROBIUM MINE - AREA 3C
WONGAWILLI SEAM
DEPTH OF COVER CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
31 Mar 2021	1:20000	MSE1104-06	A

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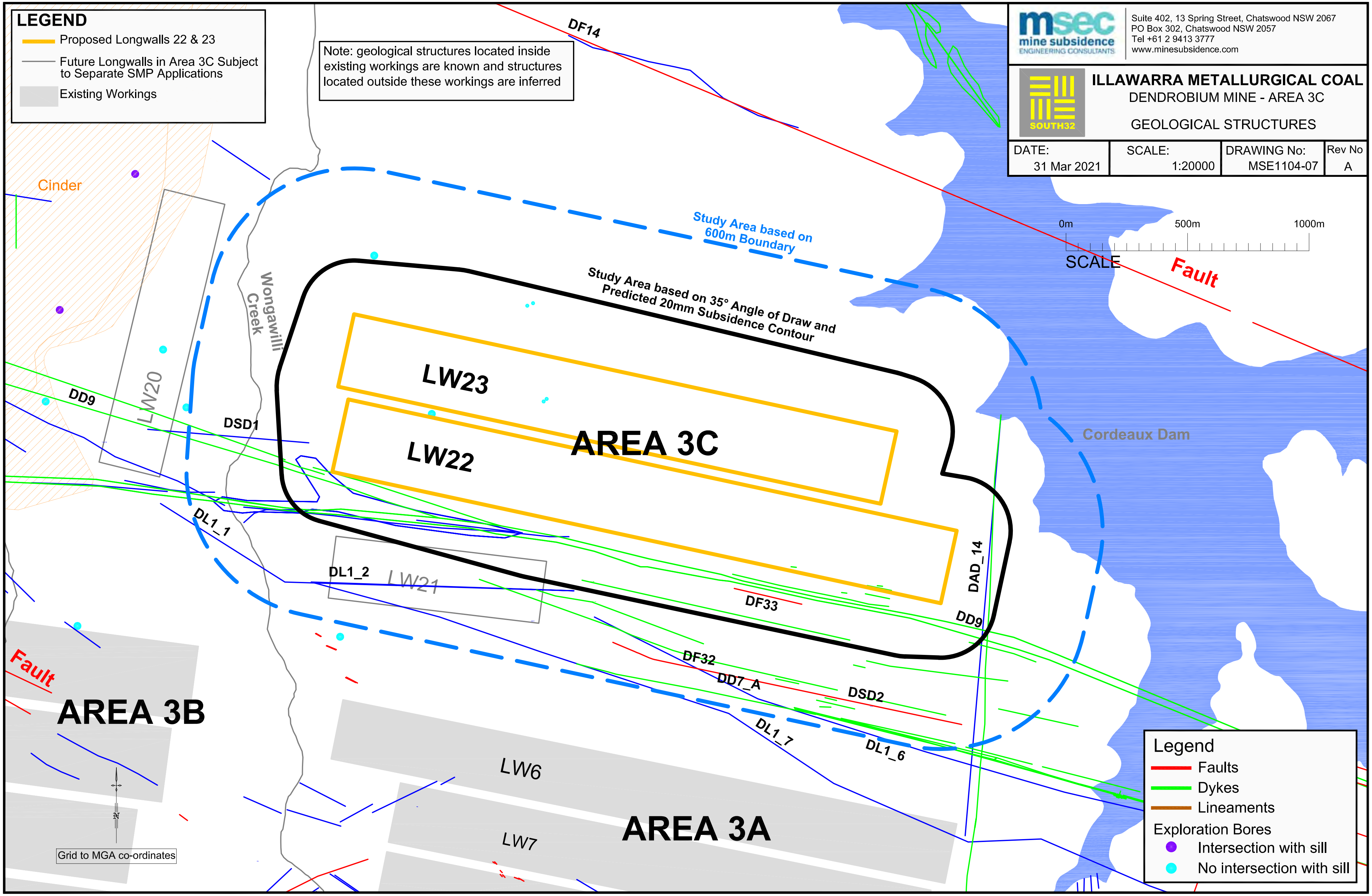

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DENDROBIUM MINE - AREA 3C
GEOLOGICAL STRUCTURES

DATE:	SCALE:	DRAWING No:	Rev No
31 Mar 2021	1:20000	MSE1104-07	A

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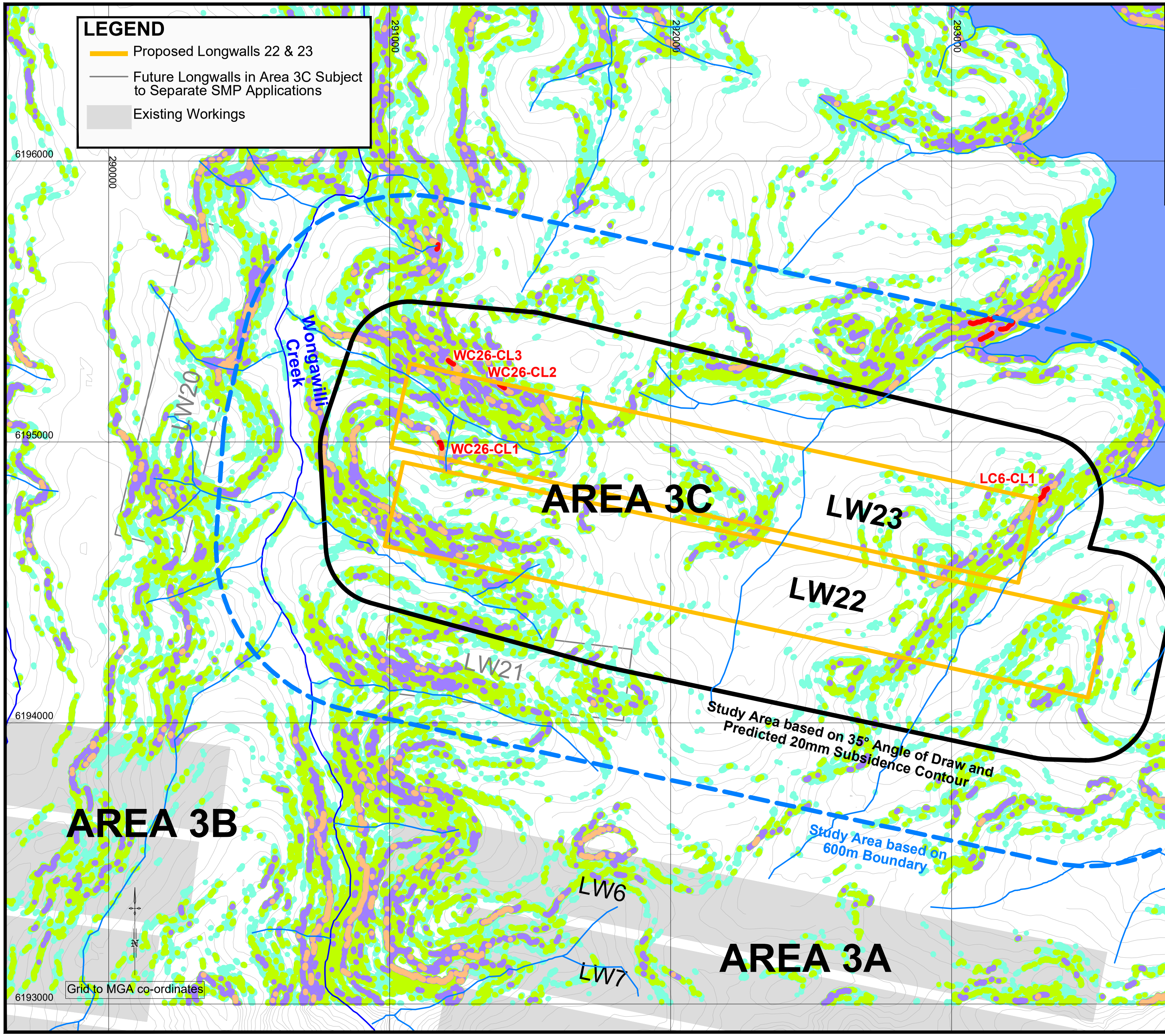

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DENDROBIUM MINE - AREA 3C

CLIFFS & STEEP SLOPES

DATE:	SCALE:	DRAWING No:	Rev No
22 Jun 2021	1:20000	MSE1104-08	B

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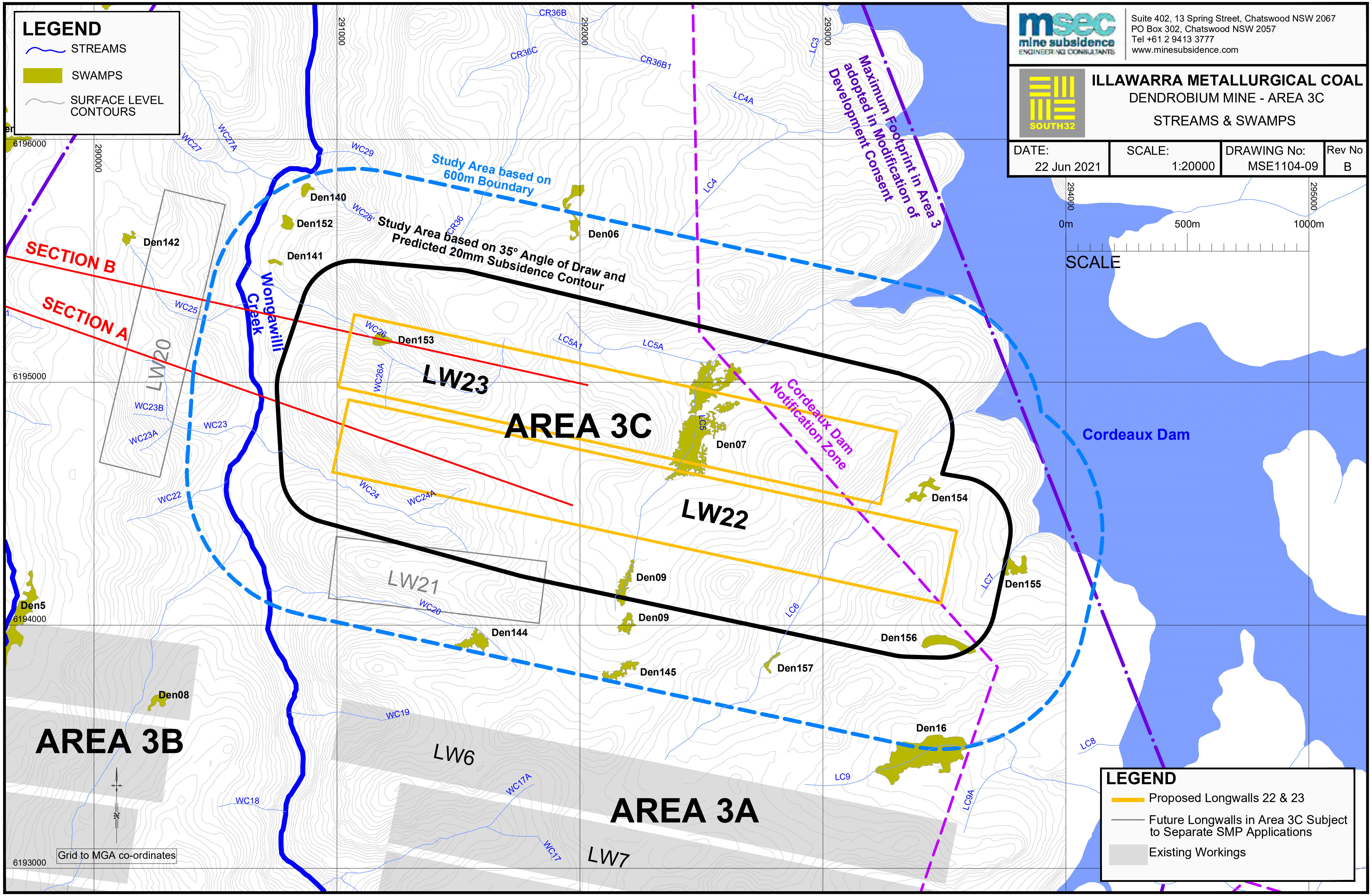

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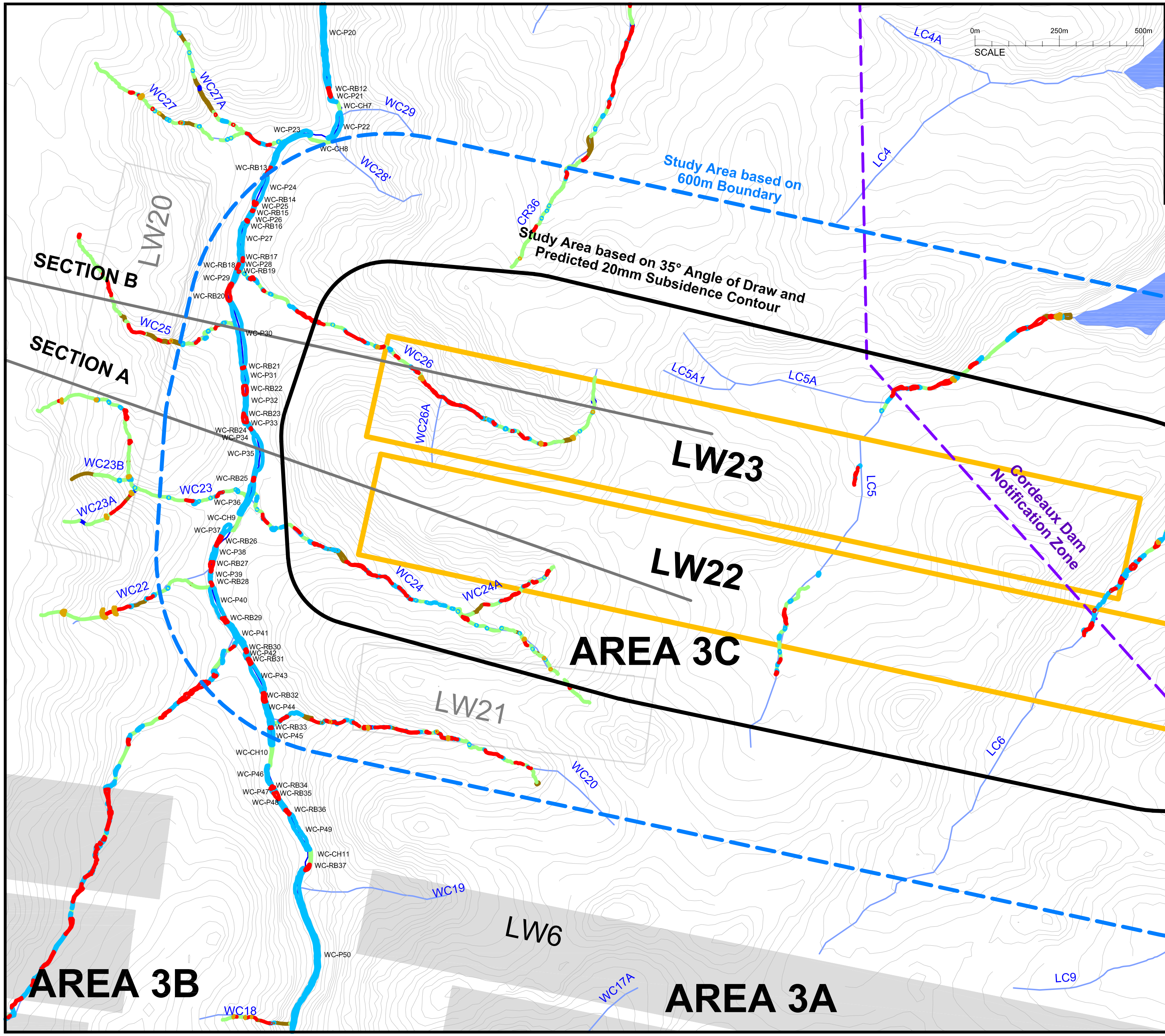

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ILLAWARRA METALLURGICAL COAL
DENDROBIUM MINE - AREA 3C
LONGWALLS 22 & 23
STREAM FEATURES

DATE:	SCALE:	DRAWING No:	Rev No
22 Jun 2021	AS SHOWN	MSE1104-10	B

LEGEND
- STREAMS
- STREAM FEATURES
  - POOLS
  - ROCKBARS
  - RIFFLES
  - BOULDERFIELD
  - CHANNEL
  - ISLAND
  - ROCKSHELF
- SURFACE LEVEL CONTOURS

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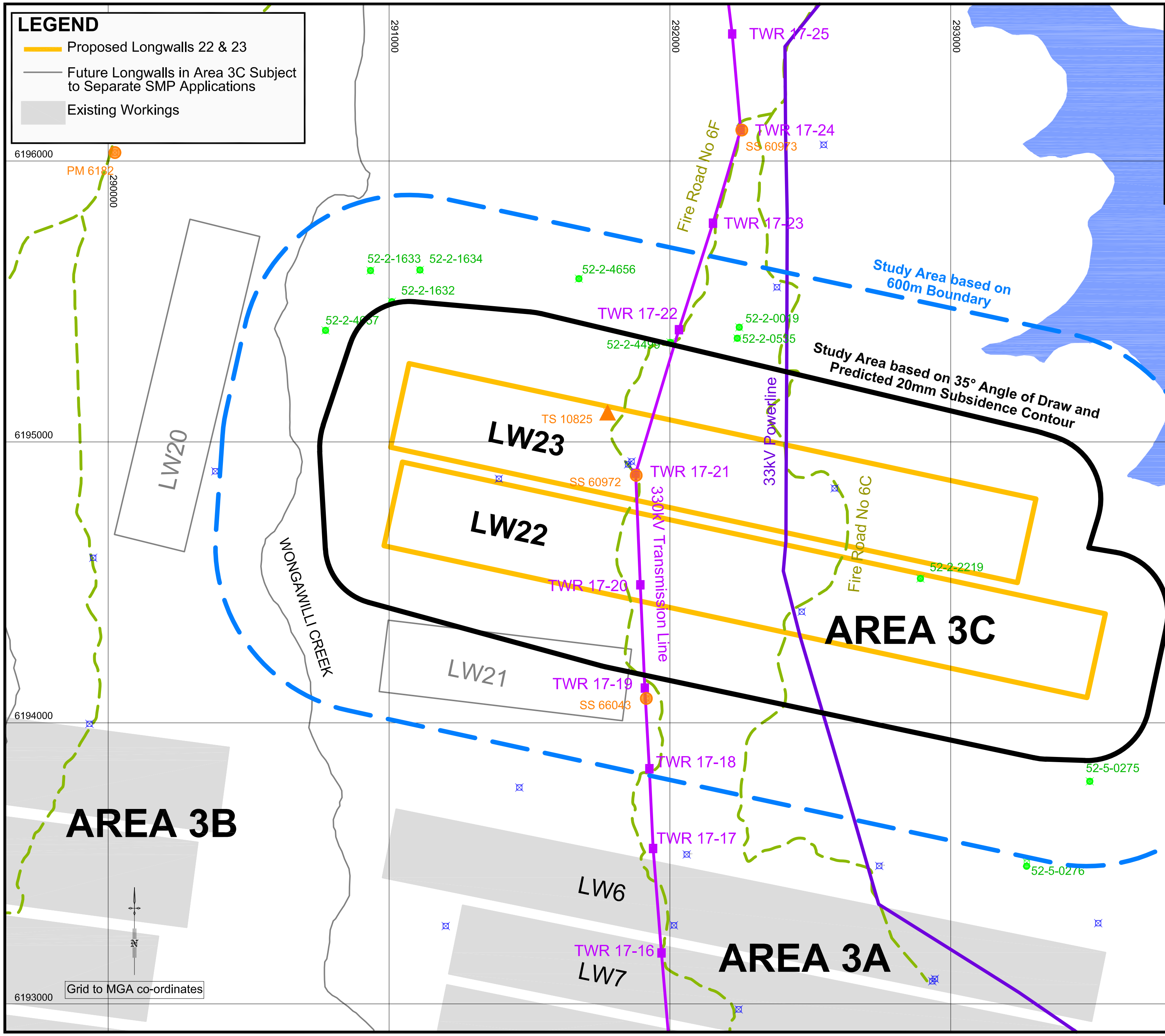

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BUILT FEATURES

DATE:	SCALE:	DRAWING No:	Rev No
31 Mar 2021	1:20000	MSE1104-11	A

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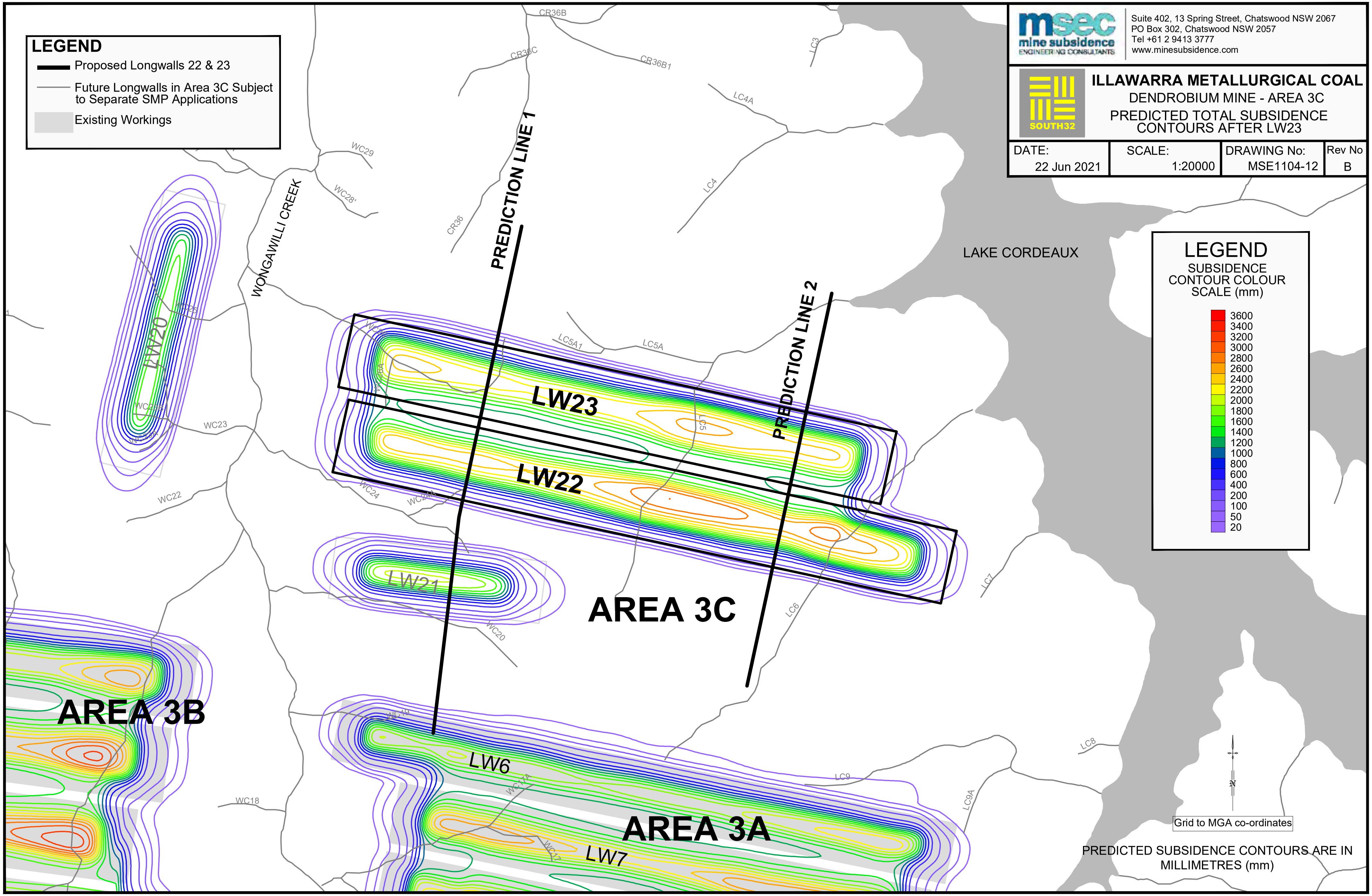

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ILLAWARRA METALLURGICAL COAL

DENDROBIUM MINE - AREA 3C

PREDICTED TOTAL SUBSIDENCE CONTOURS AFTER LW23

DATE:	SCALE:	DRAWING No:	Rev No
22 Jun 2021	1:20000	MSE1104-12	B