ILLAWARRA METALLURGICAL COAL:

Dendrobium – Longwall 19A

Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwall 19A in Area 3A at Dendrobium Mine

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Report produced to: support the Subsidence Management Plan Application for the proposed Longwall 19A at Dendrobium Mine to be issued to the Department of Planning, Industry 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).

MSEC437 (Rev. D) – The Effects of the Proposed Modifications to the Longwalls in Area 3A at Dendrobium Mine on the Subsidence Predictions and Impact Assessments (February 2010).

MSEC1082 (Rev. C) – Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwall 19 in Area 3A at Dendrobium Mine (March 2020).

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 completed the mining of Longwalls 6 to 8 (LW6 to LW8) in Area 3A at Dendrobium Mine and has approval for the mining of Longwall 19 (LW19) as part of a separate Subsidence Management Plan (SMP). IMC now proposes to mine an additional longwall in the current series, being Longwall 19A (LW19A), after the completion of the future LW19.

The predicted subsidence effects for the proposed LW19A 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 total subsidence effects are 3250 mm vertical subsidence, 40 mm/m tilt (i.e. 4 %, or 1 in 25), 1.0 km^{-1} hogging and sagging curvatures (i.e. minimum radius of curvature of 1 km).

The maximum predicted total subsidence effects for the existing, future and proposed longwalls in Area 3A (i.e. LW6 to LW8, LW19 and LW19A) are less than the maximum predicted values for the existing and approved longwalls in Area 3B (i.e. LW9 to LW18). The predicted subsidence effects are less, as the maximum mining height for Area 3A of 3.9 m is less than the maximum mining height for Area 3B of 4.6 m.

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 LW19A; the predicted incremental 20 mm subsidence contour due to the extraction of the proposed longwall; natural features located within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d), Schedule 3, of the Development Consent (DA 60-03-2001); and features that are expected to experience either far-field or valley-related effects and which could be sensitive to these movements.

Natural and built features have been identified within or in the vicinity of the Study Area, including Wongawilli Creek, Sandy Creek, drainage lines, cliffs, minor cliffs, rock outcrops, steep slopes, swamps, unsealed roads and tracks, a 330 kV transmission line and Aboriginal heritage sites. Assessments have also been carried out for Sandy Creek Waterfall, Cordeaux and Avon Reservoirs and their associated dam walls, and survey control marks, as these features could be sensitive to far-field effects.

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 situated on the western side of the longwalls in Area 3A. The currently active longwalls in Area 3B are being mined on the western side of the creek. The thalweg (i.e. base or centreline) of the creek is located 390 m west of the finishing end of LW19A, at its closest point.

  The maximum predicted total subsidence effects for the section of Wongawilli Creek within the Study Area, due to the mining in Areas 3A, 3B and 3C, are less than 20 mm vertical subsidence, 120 mm upsidence and 200 mm closure. The maximum predicted incremental movements along the creek, due to the mining of the proposed LW19A only, are less than 20 mm vertical subsidence, 40 mm upsidence and 40 mm closure.

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

- Sandy Creek is located 1200 m east of the commencing end of LW19A, at its closest point to the proposed longwall. At this distance, the creek is not predicted to experience measurable conventional or valley-related effects due to the mining of LW19A. It is unlikely, therefore, that Sandy Creek would experience adverse impacts due to the mining of the proposed longwall.

- Sandy Creek Waterfall is located 1400 m north-east of the commencing end of LW19A. The total closure measured at the waterfall, due to the previous mining of LW6 to LW8 in Area 3A is approximately 17 mm. The predicted incremental closure for Sandy Creek Waterfall due to the mining of LW19 and LW19A are less than 2 mm each. These movements are similar to the order of survey tolerance and environmental effects.

  It is considered unlikely, therefore, that Sandy Creek Waterfall would experience adverse impacts due to the mining of LW19 and LW19A. It is recommended that the closure across the waterfall is measured monthly during the first 1000 m of mining of LW19A. A Trigger Action Response Plan (TARP) should also be established based on these measured movements.

- Drainage lines are located directly above and adjacent to the proposed longwall. These drainage lines are first and second order streams that form tributaries to Wongawilli and Sandy Creeks. The drainage lines could experience the full range of predicted subsidence effects.

  Localised ponding could develop along some sections of the drainage lines, upstream of the chain pillars and the edges of the mining area, and where the natural stream gradients are relatively low.

It is expected that fracturing would occur along the sections of the drainage lines that are located directly above the proposed LW19A. Fracturing can also occur outside the extents of the proposed longwall 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 mining area.

- There are no cliffs identified within the Study Area based on the 35° angle of draw line and the predicted 20 mm subsidence contour. There are six cliffs located within the Study Area based on the 600 m boundary, with DA3-CF7 and DA3-CF8 located on a ridgeline above the eastern end of the future LW19 and DA3-CF16 to DA3-CF18 and DA3-CF24 situated within the valley of Wongawilli Creek.

  There are no cliffs located directly above the proposed LW19A. However, two cliffs (DA3-CF7 and DA3-CF17) are located above the future LW19 and they could experience some additional movements due to the mining of the proposed LW19A. It is therefore possible that isolated rock falls could occur at DA3-CF7 and DA3-CF17, due to the mining of LW19A, where they are located above the mining area. The remaining cliffs located outside the longwall mining area are not expected to experience adverse impacts due to the mining of LW19A.

- 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 longwall. 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 100 mm to 150 mm in width.

- There are five swamps that have been identified wholly or partially within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. There are two additional swamps that are located within the Study Area based on the 600 m boundary.

  Parts of Den15c and Den148 are partially located above the tailgate of the proposed LW19A and part of Den34 is partially located above the maingate of this longwall. The remaining four swamps (Den12, Den15a, Den15b and Den96) are located outside the extents of the proposed LW19A at distances ranging between 60 m and 580 m at their closest points.

  There are no predicted substantial reductions or reversals of stream grade along the drainage lines within the extents of the swamps. However, there are small reductions in stream grade near to Den34 and Den148. There is potential for minor and localised increased ponding upstream of these locations.

  Fracturing of the bedrock could occur beneath Den12, Den15a, Den15b, Den15c and Den148 where they are located above and adjacent to the mining area. 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 could result in the diversion of some surface water flows beneath parts of the swamps where they are located above and adjacent to the proposed longwall. 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.

  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 mining area. It is likely that cracking and heaving of the unsealed road surfaces would occur where they are located directly above the proposed longwall. It is expected that these features can be maintained in safe and serviceable condition using normal road maintenance techniques.

- A 330 kV transmission line crosses directly above the existing LW6 to LW8, the future LW19 and the proposed LW19A in Area 3A. There are two suspension towers located within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. One tower (Ref. 14) is located directly above the proposed LW19A and it has a piled footing. The other tower (Ref. 15) is located directly above the existing LW8 and it has a cruciform base.

  The maximum predicted subsidence effects for the towers are 2400 mm vertical subsidence, 35 mm/m tilt (i.e. 3.5 %, or 1 in 29) and 0.80 km^{-1} curvature (i.e. minimum radius of curvature of 1.3 km). The maximum predicted strains are 8 mm/m tensile and compressive based on the 95 % confidence levels.

  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 Tower 14 are anticipated, then these could be managed with the installation of a cruciform base, as previously carried out on Towers 15 and 16. Cable rollers may also need to be installed to accommodate the mining-induced vertical subsidence, tilt and horizontal movements.

- Cordeaux and Avon Reservoirs are located at minimum distances of 1.4 km and more than 3 km, respectively, from the proposed LW19A. The Cordeaux Dam Wall and Avon Dam Wall are located at distances of more than 5 km from the proposed longwall.

  The predicted vertical and horizontal movements at the Cordeaux and Avon Reservoirs and their associated dam walls are very small and are unlikely to be measurable. Previous experience of mining in Areas 1, 2, 3A and 3B has not resulted in adverse impacts on these structures. It is unlikely, therefore, that the reservoirs and dam walls would experience adverse impacts due to the extraction of the proposed LW19A.

- There are four Aboriginal heritage sites that have been identified within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. There are also five additional sites that are located within the Study Area based on the 600 m boundary. These sites comprise rock shelters with deposits and/or art.

  There are no rock shelters located directly above the proposed LW19A. However, there are three rock shelters (Sites 52-2-3639, 52-2-3644 and 52-5-0273) located above the adjacent future LW19. The extraction of the future LW19 and proposed LW19A is likely to result in fracturing of the exposed bedrock along the ridgelines and, where the rock is marginally stable, could then result in rockfalls or instabilities. The potential for adverse impacts on the three rock shelters located directly above the mining area has been assessed as unlikely (i.e. less than 10 %) for each of these sites. Hence, it is possible that at least one of these sites could experience fracturing that could potentially cause spalling or rock falls.

  Site 52-2-1646 is a significant rock shelter located approximately 200 m west of the finishing end of the proposed LW19A. At this distance, this site is predicted to experience vertical subsidence of less than 20 mm. The predicted tensile strain at Site 52-2-1646 is less than 0.5 mm/m. Based on the predicted subsidence effects and the distance of the site from the proposed LW19A, the likelihood of adverse physical impacts (i.e. rock fracturing, spalling, etc.) for Site 52-2-1646 is considered to be very rare (i.e. less than 1 %).

  The remaining five sites (Refs. 52-2-1643, 52-2-1644, 52-2-1645, 52-5-0271 and 52-5-0272) are located outside the mining area at distances ranging between 320 m and 590 m from the proposed LW19A. The likelihood of adverse physical impacts (i.e. rock fracturing, spalling, etc.) for these sites is considered to be very rare (i.e. less than 1 %).

- 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.

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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 (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 in Area 3A originally comprised five longwalls, referred to as Longwalls 6 to 10 (LW6 to LW10), each with a void width of 250 m. The subsidence predictions and impact assessments for the original longwall layout were provided in Report No. MSEC311 (Rev. D).

IMC has completed the extraction of LW6 to LW8 in Area 3A and has approval for the mining of the future LW19 as part of a separate Subsidence Management Plan (SMP). IMC now proposes to mine an additional longwall in the series, being LW19A, after the completion of the future LW19.

The existing LW6 to LW8, the future LW19 and the proposed LW19A are shown in Drawings Nos. MSEC1234-01 and MSEC1234-02, in Appendix D. The proposed LW19A and the Study Area, as defined in Section 2.1, have been overlaid on an orthophoto of the area, and are shown in Fig. 1.1.

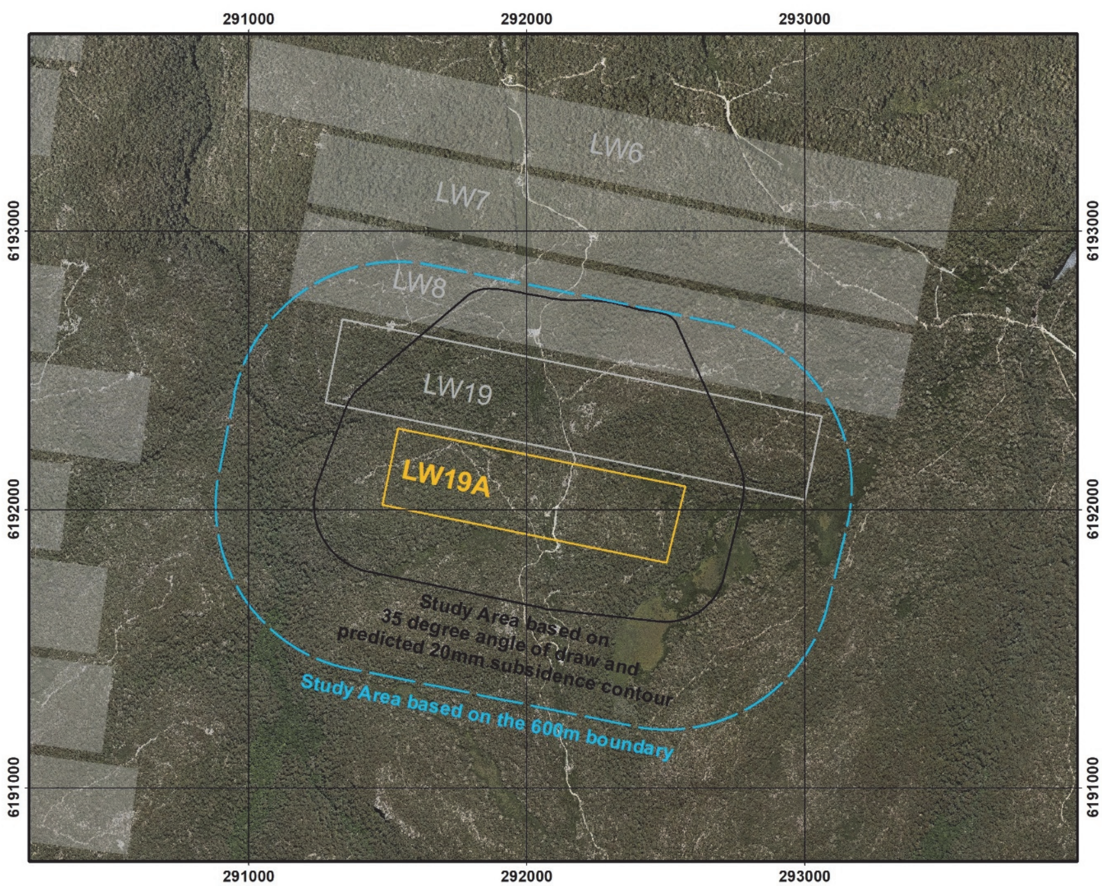

Fig. 1.1 Orthophotograph showing LW19A and the Study Area

IMC is now preparing an SMP Application for the proposed LW19A in Area 3A. MSEC has been commissioned by IMC to:

- prepare subsidence predictions for the proposed LW19A, 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 longwall;
- 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 LW19A which will be submitted to the Department of Planning, Industry and Environment (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 effects resulting from the extraction of the existing, future and proposed longwalls.

Chapter 4 provides the maximum predicted subsidence effects resulting from the extraction of the existing, future and 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 layout of the proposed LW19A is shown in Drawings Nos. MSEC1234-01 and MSEC1234-02, in Appendix D. A summary of the dimensions for this longwall is provided in Table 1.1. The longwall is proposed to be extracted from the Wongawilli Seam.

Table 1.1 Geometry of the proposed LW19A

Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
LW19A	1009	275	45

The length of longwall extraction excluding the installation heading is approximately 9 m less than the overall void length provided in the above table, i.e. approximately 1000 m. The longwall face width excluding the first workings is 265 m. The solid tailgate chain pillar width is approximately 45 m.

The longwall will be extracted towards the main headings (i.e. retreat mining from the east towards the west) within the Wongawilli Seam. LW19 will be extracted after LW21 in Area 3C and prior to the extraction of Longwall 20 (LW20) in Area 3C.

1.3. Surface and seam levels

The levels of the natural surface and the Wongawilli Seam are illustrated along Section 1 and Section 2 in Fig. 1.2 and Fig. 1.3, respectively. The locations of these sections are shown in Drawings Nos. MSEC1234-03 to MSEC1234-05. The definition of the Study Area is provided in Section 2.1.

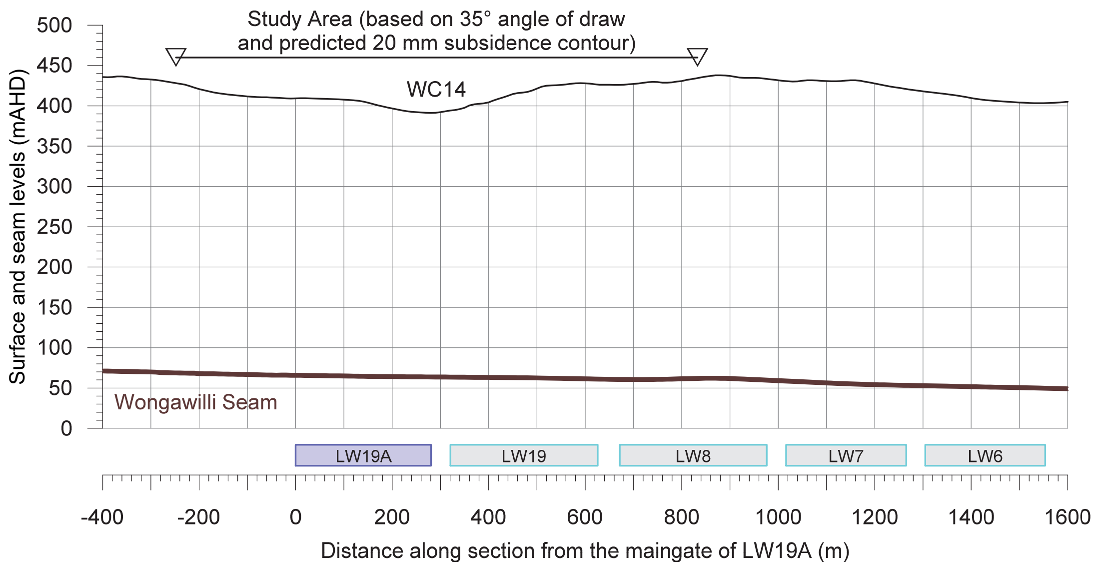

Fig. 1.2 Surface and seam levels along Section 1 (cross-section)

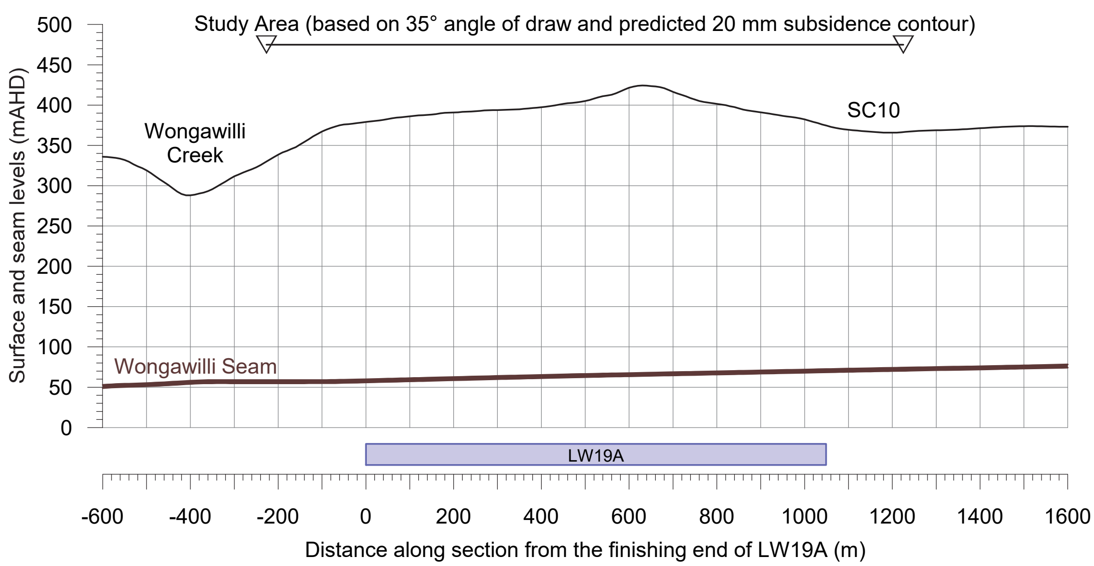

Fig. 1.3 Surface and seam levels along Section 2 (long-section)

The surface level contours are shown in Drawing No. MSEC1234-03. The longwalls in Area 3A are located between Wongawilli Creek to the west and Sandy Creek to the east. The natural ground falls towards these creeks and their tributaries. The surface levels directly above the proposed LW19A vary between 350 metres above Australian Height Datum (mAHD) near the longwall finishing (i.e. western) end and 430 mAHD towards the middle of the longwall.

The seam floor contours, seam thickness contours (for the basal section) and depth of cover contours for the Wongawilli Seam are shown in Drawings Nos. MSEC1234-04, MSEC1234-05 and MSEC1234-06, respectively. The seam floor generally dips from the south-east to the north-west. The average gradient of the seam within the extents of the mining area is approximately 2 %, or 1 in 50.

The depths of cover to the Wongawilli Seam directly above the proposed LW19A vary between 290 m and 360 m. The minimum depth of cover occurs along Drainage Line WC14 above the north-western corner of the proposed longwall. The maximum depth of cover occurs along the ridgeline towards the middle of the longwall.

The Wongawilli Seam is nominally 9 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. The thickness contours for the basal section of the Wongawilli Seam are shown in Drawing No. MSEC1234-05.

IMC has reviewed the nature of the banding and proposes to extract a maximum height of 3.9 m using conventional longwall mining techniques. The actual mining height may be less than this, depending on the banding, typically ranging between 3.5 m and 3.9 m. The subsidence predictions and impact assessments for the proposed LW19A have been based on a constant cutting height of 3.9 m.

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. 1.4 (Source: IMC).

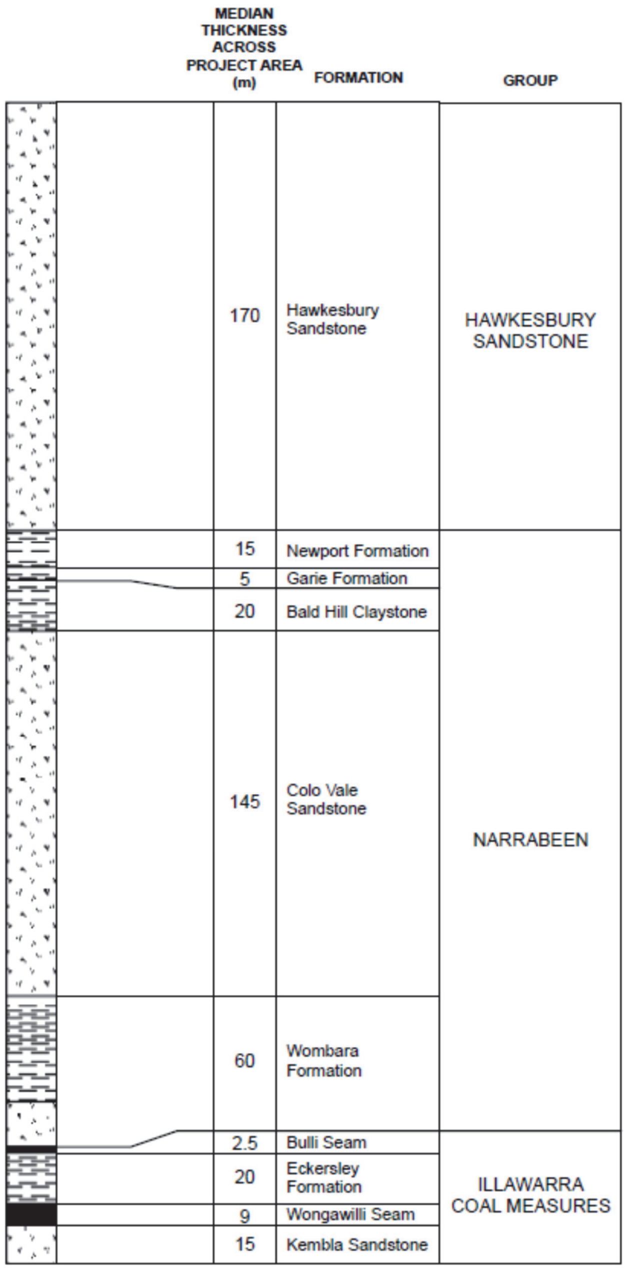

Fig. 1.4 Typical stratigraphic section for the Mine (Source: IMC)

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 LW19A 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 longwall.

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. MSEC1234-07.

An igneous sill has intruded into the Wongawilli Seam near the southern boundary of the mining area. The longwall has been set back to avoid the cinder zone within the Wongawilli Seam. There are no major faults or dykes identified within the extents of the proposed LW19A. The locations and sizes of the geological structures will be better defined through ongoing investigations and during the development of the first workings.

Surface lineaments with WNW-ESE orientations have been identified near the western end of the proposed LW19A. These structures are not coincident with the valleys or other topographical features and they do not appear to be associated with underground geological structures.

A review was carried out on the effects of lineaments, faults and dykes on the measured surface subsidence above LW9 to LW13 in Area 3B (MSEC, 2019). The available monitoring data suggest that there was no apparent increase in the subsidence measured in the mapped locations of the lineaments, minor faults and dykes. There also does not appear to be an association between the observed surface impacts and the mapped lineaments, minor faults and dykes.

IMC has advised that the surface lineaments, minor faults and dykes above and near to the proposed LW19A are similar to those mapped in Area 3B. It is considered unlikely, therefore, that these structures would adversely affect the subsidence predictions and assessed impacts for the proposed LW19A.

The surface lithology in the area can be seen in Fig. 1.5, which shows the existing, future and proposed longwalls in Area 3A and the Study Area overlaid on Geological Series Sheet *Wollongong 9029*, which was published by the DMR (1999), now known as the Resources Regulator. The surface lithology in Area 3A generally comprises Hawkesbury Sandstone (Rh), with localised areas of Quaternary Alluvium (Qs).

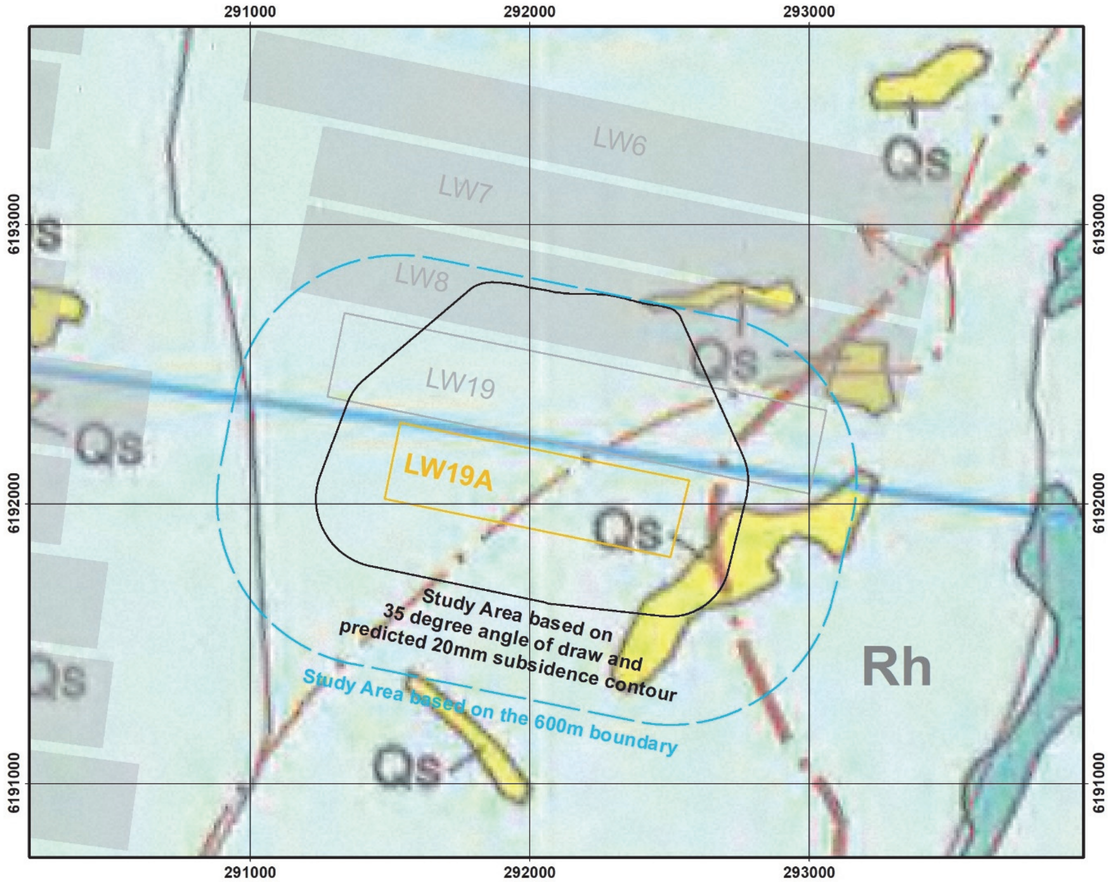

Fig. 1.5 LW19A overlaid on Geological Series Sheet *Wollongong 9029* (DMR, 1999)

2.1. Definition of the Study Area

The *Study Area* is defined as the surface area that could be affected by the extraction of the proposed LW19A. Two areas have been considered in this report, being the *Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour* and the *Study Area based on the 600 m boundary*.

The Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour represents the minimum extent for the assessments for the conventional ground movements (i.e. vertical subsidence and its associated effects). Low level conventional ground movements can extend beyond this area. The natural and built features located outside this area, which could experience these low level movements and could be sensitive to these movements, have also been included in the assessments provided in this report.

The Study Area based on the 600 m boundary represents the minimum extent of the assessments for the valley-related effects. This distance is based on the recommendations from the Southern Coalfield Inquiry (DPIE, 2008) for the risk management zones. The natural and built features located outside the 600 m boundary, which could experience valley-related effects and could be sensitive to these movements, have also been included in the assessments provided in this report.

The extent of the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour has been calculated by combining the areas bounded by the following limits:

- The 35° angle of draw line from the extent of the proposed LW19A; and
- The predicted limit of vertical subsidence, taken as the incremental 20 mm subsidence contour, due to the mining of LW19A only.

The depths of cover contours for the Wongawilli Seam are shown in Drawing No. MSEC1234-06. The depth of cover varies between 290 m and 360 m directly above the proposed LW19A. The 35° angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 203 m and 252 m around the extents of the longwall void.

The predicted limit of vertical subsidence, taken as the predicted incremental 20 mm subsidence contour due to the mining of LW19A, has been determined using the calibrated Incremental Profile Method (IPM), which is described in Chapter 3. The predicted incremental subsidence contours, including the 20 mm subsidence contour, are shown in Drawing No. MSEC1234-11, in Appendix D.

The predicted incremental 20 mm subsidence contour extends beyond the 35° angle of draw above the existing LW6 to LW8 and future LW19. Elsewhere, the contour is located inside the angle of draw. The Study Area based on the 35° angle of draw line and predicted 20 mm subsidence contour is shown in Drawings Nos. MSEC1234-01 and MSEC1234-02, in Appendix D.

The Study Area based on a 600 m boundary around the extents of the proposed LW19A is also shown in Drawings Nos. MSEC1234-01 and MSEC1234-02. The features that are located within the 600 m boundary that are predicted to experience valley-related effects and which could be sensitive to these movements have been included in the assessments provided in this report, in accordance with Condition 8(d), Schedule 3 of the Development Consent. These features include streams, upland swamps and Aboriginal heritage sites.

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 Sandy Creek Waterfall, the reservoirs, dam walls and survey control marks.

2.2. 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. MSEC1234-08 to MSEC1234-10, 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 to 5.4
Aquifers or Known Groundwater Resources	✓	5.5
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.6
Steep Slopes	✓	5.7
Escarpments	×	
Land Prone to Flooding or Inundation	×	
Swamps, Wetlands or Water Related Ecosystems	✓	5.10
Threatened or Protected Species	✓	5.11
National Parks	×	
State Forests	×	
State Conservation Areas	×	
Natural Vegetation	✓	5.11
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
Telecommunication Lines or Associated Plants	×	
Water Tanks, Water or Sewage Treatment Works	×	
Dams, Reservoirs or Associated Works	✓	6.3
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	✓	6.4
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.5
RESIDENTIAL ESTABLISHMENTS		
Houses	×	
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

3.0 OVERVIEW OF MINE SUBSIDENCE AND THE METHODS USED TO PREDICT THE SUBSIDENCE EFFECTS FOR THE EXISTING, FUTURE AND PROPOSED LONGWALLS

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 parameters which result from the extraction of each longwall. The **cumulative** subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of a series of longwalls. The **total** subsidence, tilts, curvatures and strains are the final parameters 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, greater 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 is 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 m, 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 movements 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 explain 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 5.7.

3.4.3. Valley-related movements

The streams within the Study Area will be affected by valley-related movements, 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.

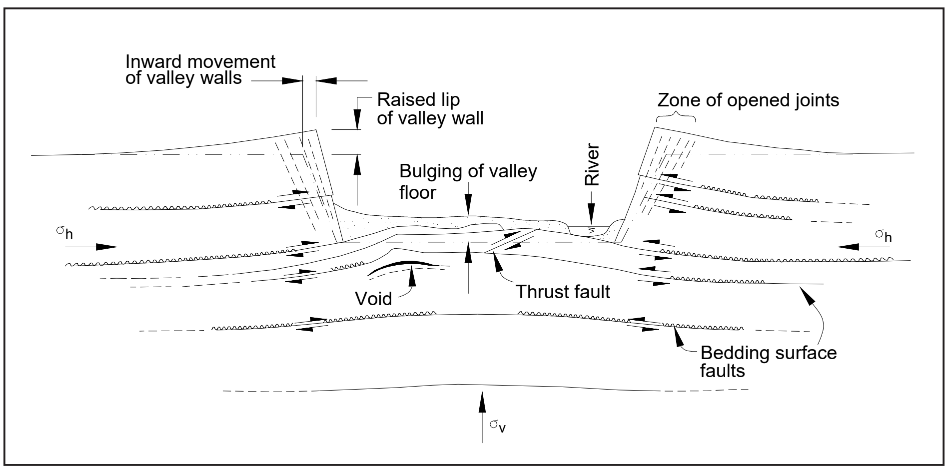

Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

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

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

- **Closure** is the reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in 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 movements 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 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 movements 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 existing, future and 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 where 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 it 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) and 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 model 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, with these exceedances being typically up to 1.3 times the predicted values. 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 the predicted values 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.

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 for the initial longwalls 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 Areas 3A and 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.

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 previous mining in Area 3A were measured using ALS and LiDAR surveys. The measured changes in surface level due to the extraction of LW6 to LW8 are shown in Fig. 3.2.

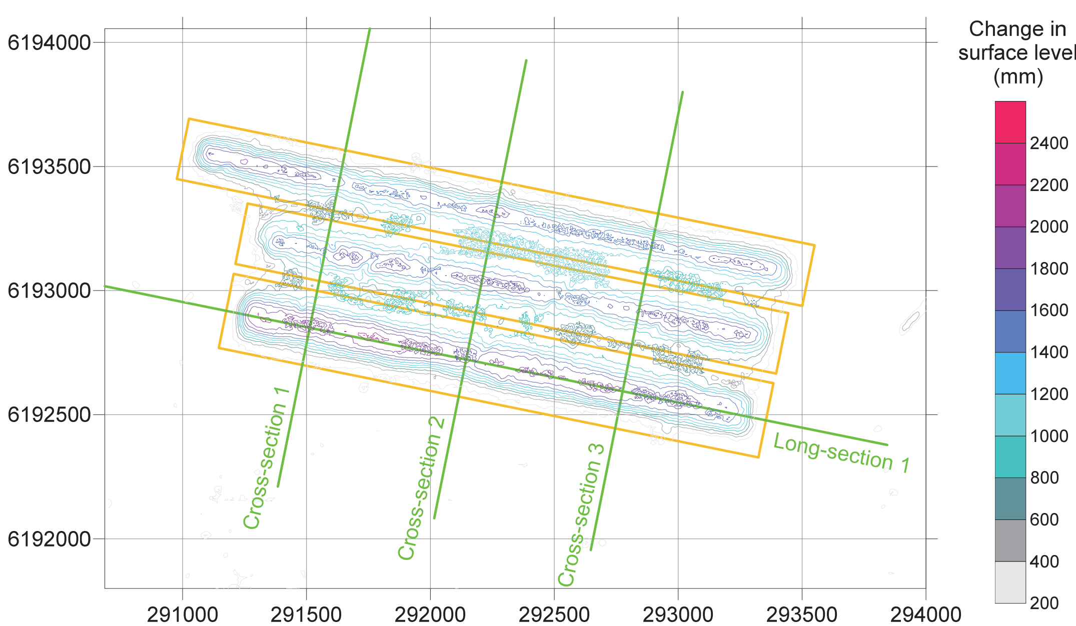

Fig. 3.2 Measured changes in surface level due to LW6 to LW8 in Area 3A

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 predicted vertical subsidence has been obtained using the calibrated subsidence model based on the MSEC792 prediction curves. The calibrated model was designed to provide reasonable but slightly conservative predictions for the active longwalls in Area 3B. However, it was found that the calibrated model provided overly conservative predictions for LW8 in Area 3A, based on the review of the LiDAR monitoring data at the completion of that longwall.

It was found that the subsidence model provided more reasonable but still conservative predictions for LW8 without the application of the +30 % factor for that longwall. It was therefore considered appropriate to remove this factor for LW8 only. The removal of the +30 % factor for LW8 does not affect the maximum predicted vertical subsidence directly above the proposed LW19A.

The subsidence model provides reasonable and conservative predictions for LW6 and LW7 based on the MSEC792 prediction curves. No changes therefore have been made for these two longwalls based on the LiDAR monitoring data (i.e. the +30% factors still apply to LW6 and LW7).

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.

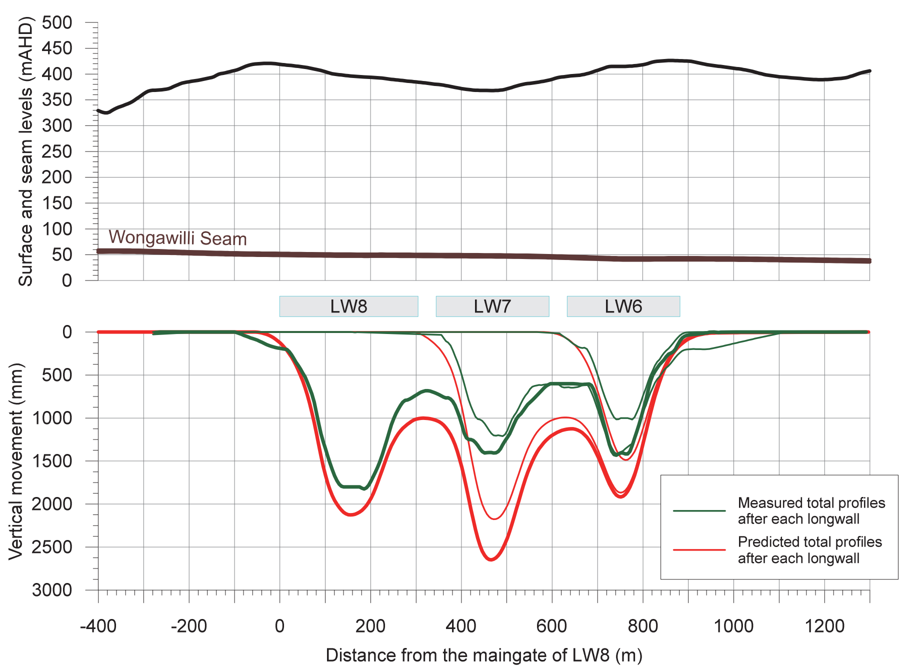

Fig. 3.3 Measured and predicted changes in surface level along Cross-section 1

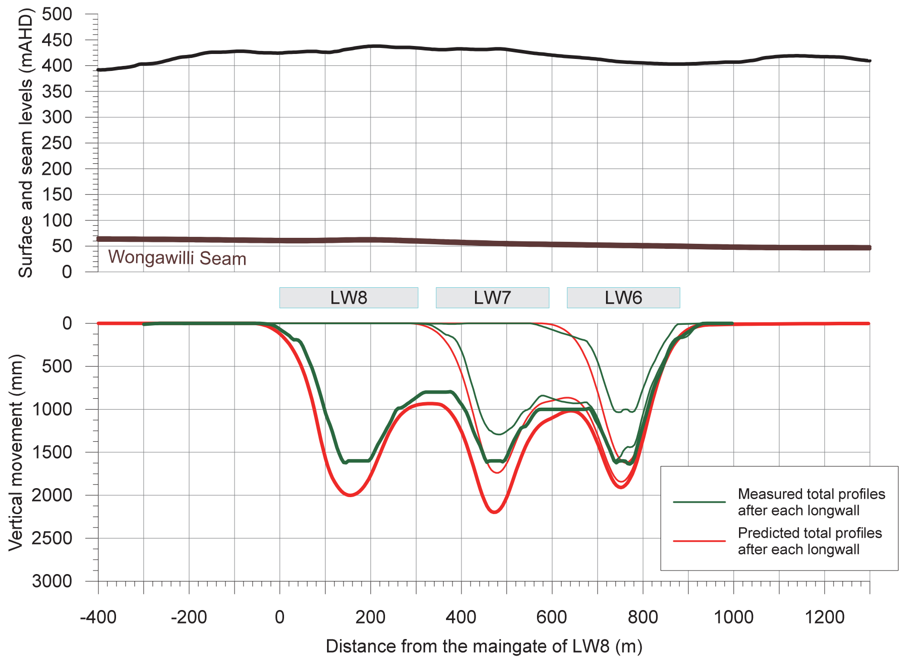

Fig. 3.4 Measured and predicted changes in surface level along Cross-section 2

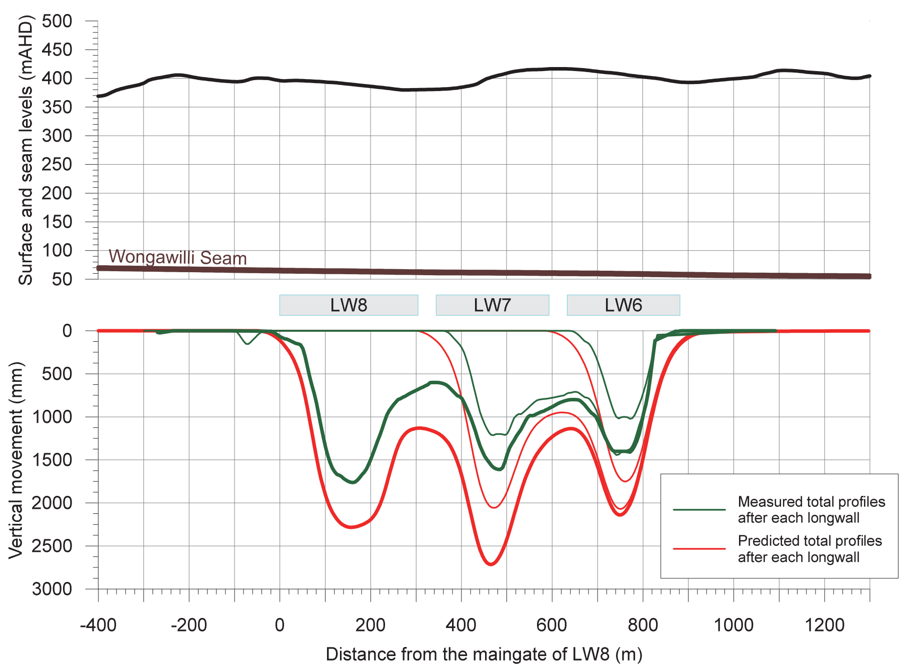

Fig. 3.5 Measured and predicted changes in surface level along Cross-section 3

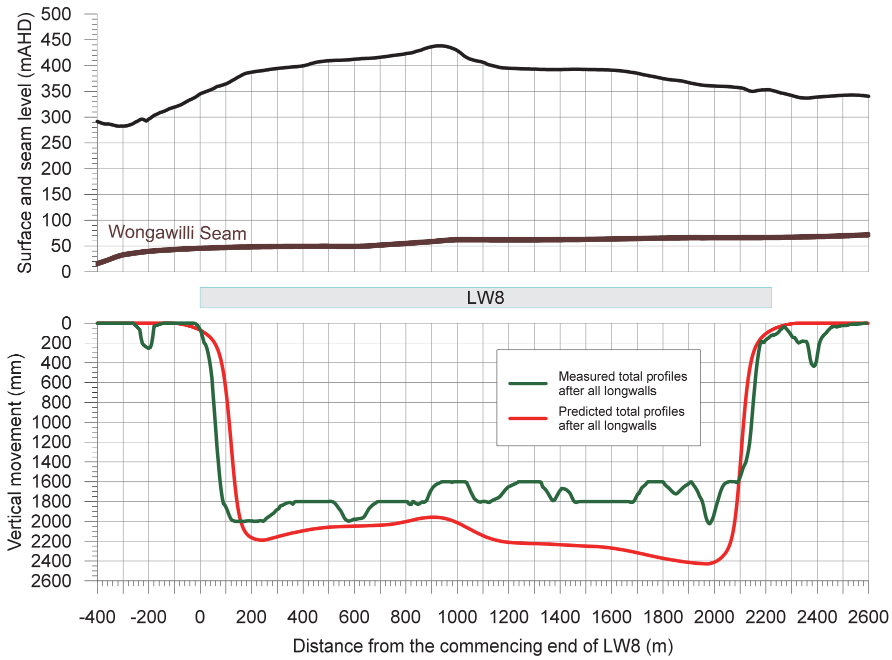

Fig. 3.6 Measured and predicted changes in surface level along Long-section 1

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 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.

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.

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 based on the calibrated IPM based on the MSEC792 prediction curves. This includes the removal of the +30 % factor for LW8 so as to reduce the overly conservative predictions for this longwall. The removal of the subsidence factor for LW8 does not affect the maximum predicted vertical subsidence above the proposed LW19A. No changes have been made in the subsidence model for LW6 and LW7.

It is considered appropriate, therefore, to adopt the MSEC792 prediction curves for the future LW19 and the proposed LW19A. These prediction curves provide an additional 30 % to the maximum incremental vertical subsidence for the longwalls when compared with that predicted using the standard IPM model.

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 mining of LW9 to LW17 in Area 3B using the Wongawilli Creek Closure Lines, Tributary Cross Lines, Donalds Castle Creek Cross Lines and Swamp Cross Lines.

Comparisons of the measured and predicted total vertical subsidence for the traditional ground monitoring lines at the completion of LW17 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.

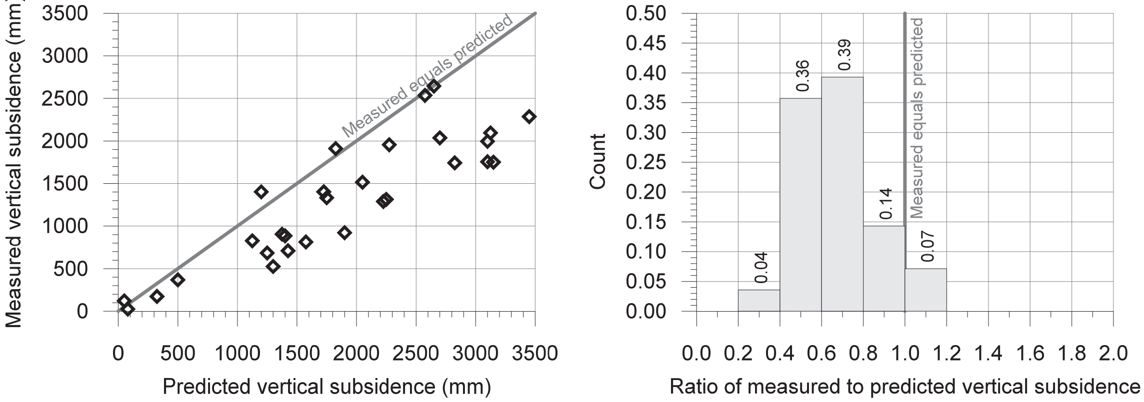

Fig. 3.7 Comparison of measured and predicted subsidence for the ground monitoring lines

The measured total vertical subsidence movements are typically less than the predicted total vertical subsidence 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 values in 2 of the 28 cases (i.e. 7 % of the monitoring lines). The exceedances occur where the monitoring lines are located near to or above the chain pillars and the measured movements are less than the maximums that occur directly above the longwalls. The ratios of the measured to predicted total vertical subsidence for these two 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 %.

Comparisons of the measured and predicted total closure for the traditional ground monitoring lines at the completion of LW17 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.

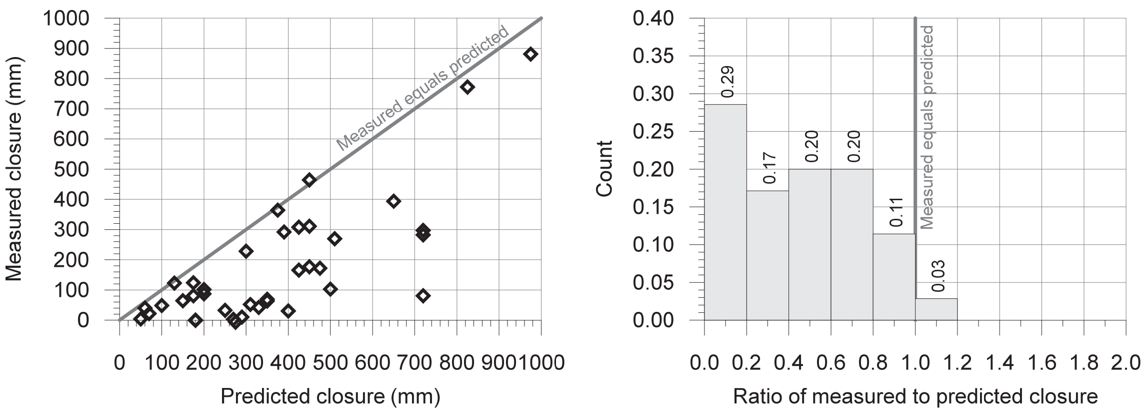

Fig. 3.8 Comparison of measured and predicted closure for the ground monitoring lines

The measured total closure movements are typically less than the predicted total closure values for each of the monitoring lines. The average ratio of the measured to predicted total closure for these monitoring lines is 0.43, i.e. the measured closures are, on average, less than half of those predicted.

The measured total closure movements exceed the predicted values in 1 of the 37 cases (i.e. 3 % of the monitoring lines). It is noted that there were additional cases where the measured closures exceeded the predicted values at the completion of earlier longwalls; however, the measured closures are now less than the predicted values after the completion of LW17. The ratio of the measured to predicted total closure for the monitoring line is 1.03 and, therefore, is 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 data. 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 %.

3.7. Numerical model

A numerical model has been developed for Area 3A 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 Area 3A.

3.7.1. Calibration of the UDEC model for Area 3A

The void widths of the existing longwalls in Area 3A are 250 m for LW6 and LW7 and 305 m for LW8. The solid chain pillar widths between each of the existing longwalls are 40 m. The maximum extraction height for LW6 to LW8 was 3.9 m.

The edges of the numerical model have been taken as the greater of two times the longwall widths and 600 m from the edges of the mining area. The overall width of the model therefore is 2105 m. The average depth of cover to the Wongawilli Seam along Prediction Line 1 and above the existing longwalls is 370 m.

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*. A summary of the stratigraphy adopted in the UDEC model is provided in Table 3.1.

Table 3.1 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	135	135	13.5 x 9
Newport/Garie Formation	20	155	6 x 4
Bald Hill Claystone	20	175	6 x 4
Bulgo Sandstone	130	305	15 x 10
Wombarra Claystone	42	347	6 x 4
Bulli Coal	3	350	4.5 x 3
Eckersley Formation	20	370	7.5 x 5
Wongawilli Coal	10	380	1.5 x 1
Sub-Wongawilli	100	480	15 x 10

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 from this mining area. The initial calibration of the numerical model using the LiDAR monitoring data from Area 3A found that the *base model* (i.e. Material Type M1 and Joint Type J2) slightly underpredicted the vertical subsidence above the longwalls and above 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 that are 70 % of those used in the *base model*. The joint cohesion and friction angles are 90 % of those used in the *base model*. These adjustments to the material and joint properties improve the modelling of the components of vertical subsidence due to sagging of the overburden strata and pillar compression.

Summaries of the material and joint properties adopted in the UDEC model are provided in Table 3.2 and Table 3.3, 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 3.2 Material properties adopted in the UDEC model

Unit	ρ (kg/m³)	K (GPa)	G (GPa)	C (MPa)	φ (deg.)	T (MPa)
Hawkesbury Sandstone	2400	2.33	1.40	7.0	34	0.5
Newport/Garie Formations	2400	2.42	1.74	4.0	30	0.5
Bald Hill Claystone	2700	3.50	1.62	6.0	25	0.5
Bulgo Sandstone	2500	3.89	2.92	10	30	0.5
Wombarra Claystone	2600	4.83	3.47	10	25	0.5
Bulli Coal	1500	1.08	0.68	2.0	25	0.5
Eckersley Formation	2500	5.60	3.36	15	25	0.5
Wongawilli Coal	1500	1.08	0.68	2.0	25	0.5
Sub-Wongawilli	2500	5.60	3.36	15	25	0.5

Table 3.3 Joint properties adopted in the UDEC model

Unit	Cohesion (MPa)		Friction angle (deg.)	
	Peak	Residual	Peak	Residual
Hawkesbury Sandstone	2.25	1.35	22	13
Newport/Garie Formations	2.03	1.22	22	13
Bald Hill Claystone	2.48	1.49	19	11
Bulgo Sandstone	4.05	2.43	22	13
Wombarra Claystone	2.70	1.62	20	12
Eckersley Formation	3.83	2.30	20	12
Sub-Wongawilli	3.83	2.30	20	12

A comparison between the modelled and measure vertical subsidence for LW6 to LW8 in Area 3A is illustrated in Fig. 3.9. The measured subsidence is based on the difference between the LiDAR surface levels measured prior to and after the completion of each longwall.

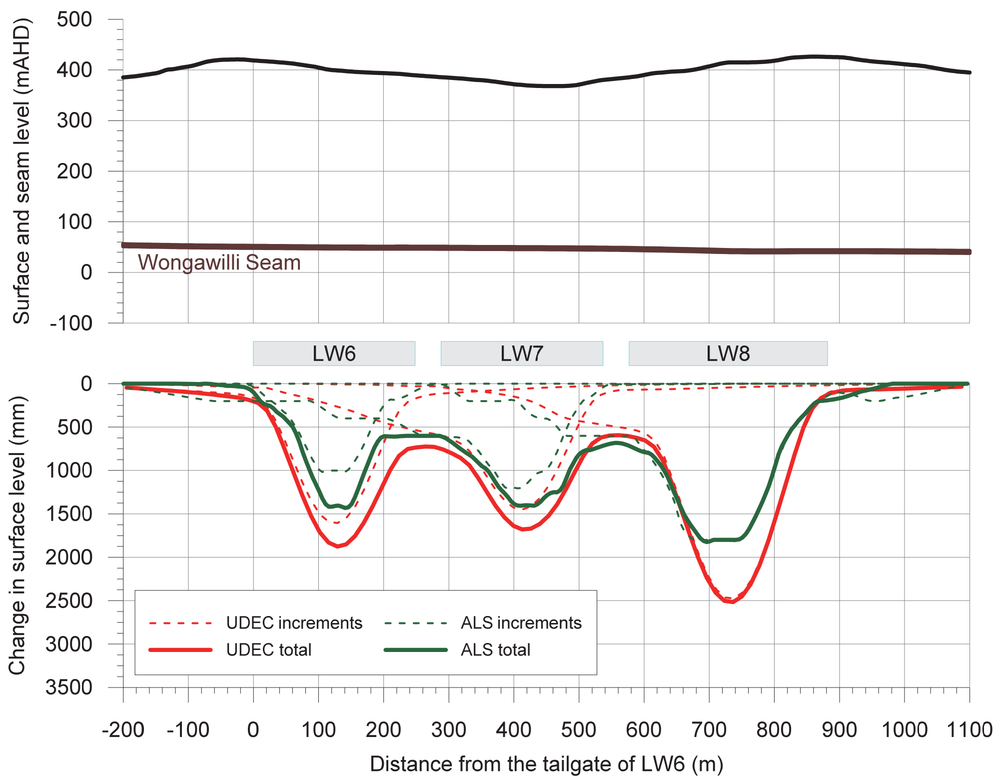

Fig. 3.9 Comparison of modelled and measured subsidence for Dendrobium Area 3A

It is considered that the profiles of vertical subsidence obtained from the UDEC model reasonably match the profiles measured using the LiDAR surveys for LW6 to LW8 in Area 3A. However, the numerical model slightly overpredicts the vertical subsidence for LW8 and, to lesser extents, LW6 and LW7.

The mining geometry for the proposed LW19A is similar to that for the existing LW8 in Area 3A. It is considered, therefore, that the numerical model should therefore provide reasonable, if not, slightly conservative predictions of vertical subsidence for the proposed longwall.

3.7.2. UDEC model for the existing, future and proposed longwalls

The future LW19 and proposed LW19A have been incorporated into the UDEC model for Area 3A. The modelled profile of vertical subsidence obtained from the numerical model is illustrated as the red line in Fig. 3.10. The predicted profile based on the IPM has also been shown as the blue line for comparison.

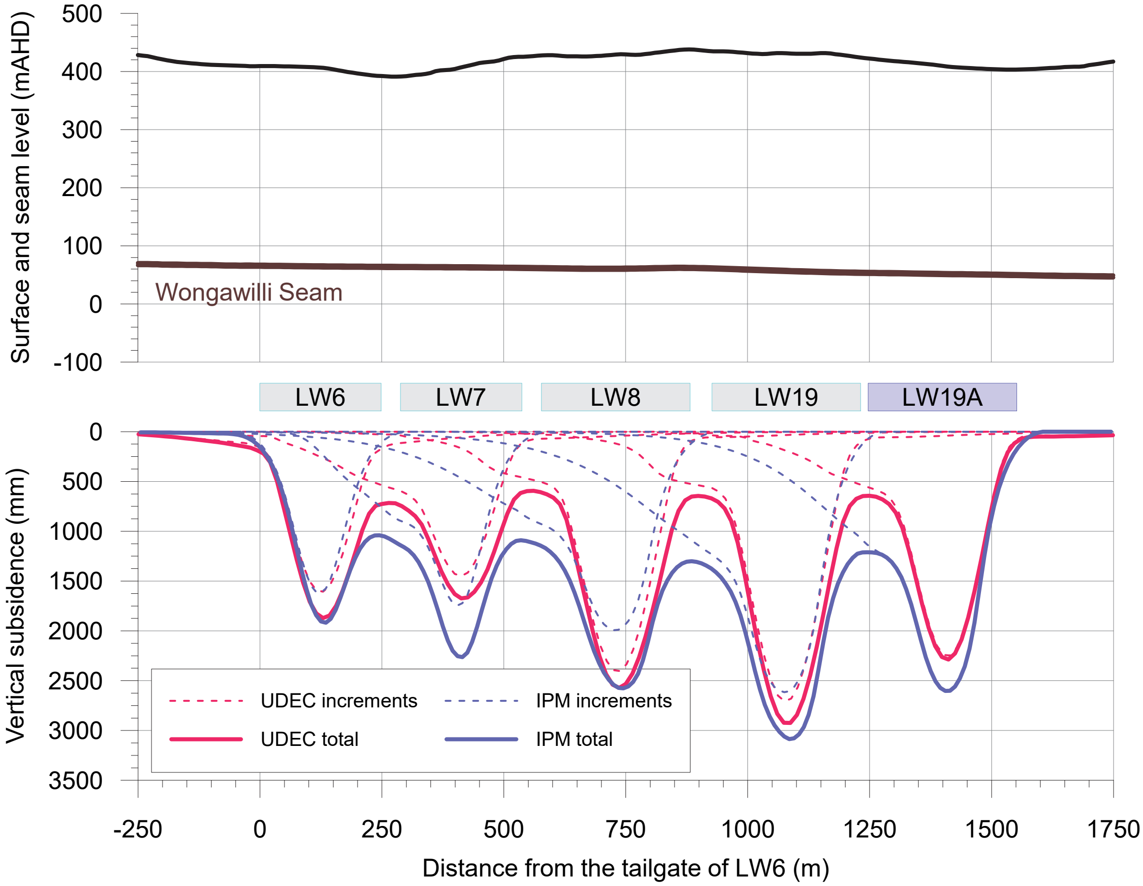

Fig. 3.10 UDEC modelled and IPM predicted profiles of vertical subsidence

The profile of total vertical subsidence obtained from the UDEC model reasonably matches the predicted total profile obtained using the IPM. The values of maximum predicted vertical subsidence directly above the proposed LW19A are within ±10 %. The numerical model predicts slightly lower values of vertical subsidence above the existing LW7 and above each of the chain pillars.

The maximum predicted tilts and curvatures obtained from the UDEC model, directly above the proposed LW19A, are reasonably similar to the values predicted using the IPM. The predicted tilts and curvatures above the existing longwalls are slightly greater than the values obtained from the IPM due to the lower predicted vertical subsidence above each of the chain pillars.

The predicted subsidence effects from the proposed LW19A obtained from the UDEC model are reasonably similar to the predicted values obtained 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. 3.11. The profiles have been taken through the centreline, midway between the centreline and tailgate (referred to as the quarter-point) and the tailgate of the proposed LW19A.

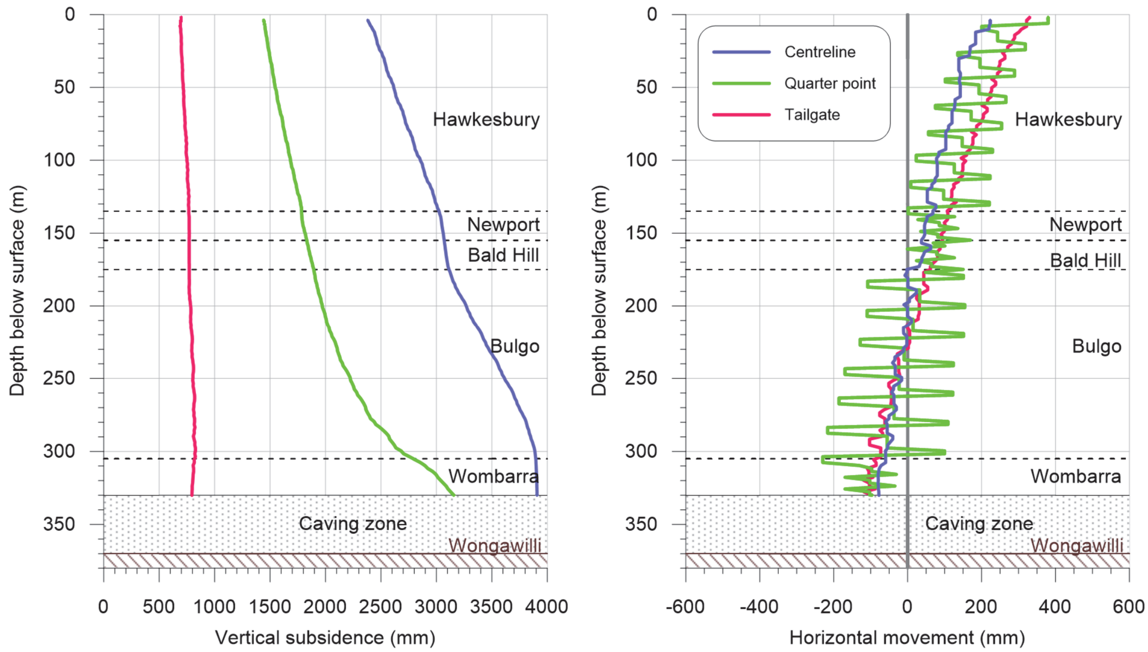

Fig. 3.11 Modelled profiles of vertical subsidence and horizontal movement through the overburden at the centreline, quarter-point and tailgate of LW19A

The vertical subsidence at the proposed LW19A centreline varies between 61 % of the mining height at the surface through to 100 % of the mining heights at the caving zone. The vertical subsidence adjacent to the longwall tailgate varies between 18 % of the mining height at the surface through to 22 % of the mining height at the caving zone.

The vertical strain (over a 20 m height) within the Hawkesbury Sandstone varies between approximately 4 mm/m at the surface and 6 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 varies between approximately 4 mm/m at the top and 16 mm/m at the base of the unit. The vertical strain within the Wombarra Claystone varies between 8 mm/m and 16 mm/m. The maximum vertical strain within these two units occur at the longwall quarter-points, with the strains reducing towards the longwall centreline, maingate and tailgate.

The horizontal shear on the bedding plane partings varies between approximately 150 mm and 250 mm within the Hawkesbury Sandstone and varies between approximately 250 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 due to the mining of the existing and proposed LW6 to LW8, LW19 and LW19A in Area 3A. 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 Dendrobium and other NSW collieries, where the longwall width-to-depth ratios and extraction heights are similar to those for the existing, future and 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 mining of LW19A is provided in Table 4.1. The incremental values represent the additional movements due to the mining of this longwall only.

Table 4.1 Maximum predicted incremental vertical subsidence, tilt and curvature due to the mining of LW19A only

Due to longwall	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
LW19A	2500	35	0.9	0.9

The predicted total vertical subsidence contours due to the mining of LW6 to LW8, LW19 and LW19A are shown in Drawing No. MSEC1234-12, 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 values represent the accumulated movements within the Study Area due to the extraction of the existing, future and proposed longwalls.

Table 4.2 Maximum predicted total vertical subsidence, tilt and curvature due to the mining of LW6 to LW8, LW19 and LW19A

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})
LW6 to LW8 and LW19	3000	40	1.0	1.0
LW19A	3250	40	1.0	1.0

The maximum predicted total vertical subsidence of 3000 mm represents 83 % 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 is 40 mm/m (i.e. 4.0 %, or 1 in 25), which occurs adjacent to the maingate of LW19A. The maximum predicted total conventional curvatures are 1.0 km^{-1} hogging and sagging, which represent 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 Drawings Nos. MSEC1234-11 and MSEC1234-12.

4.3. Comparison of the maximum predicted subsidence effects for Areas 3A and 3B

A comparison of the maximum predicted total conventional subsidence effects for 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 vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 3A (LW6 to LW8, LW19 and LW19A)	3250	40	1.0	1.0
Area 3B (LW9 to LW18)	3600	50	1.4	1.4

The maximum predicted subsidence effects due to the mining of LW6 to LW8, LW19 and LW19A in Area 3A are less than the maximum predicted values for LW9 to LW18 in Area 3B. The predicted subsidence effects are less as the maximum mining height for Area 3A of 3.9 m is less than the maximum mining height for Area 3B of 4.6 m.

It is noted that the maximum predicted vertical subsidence for LW6 to LW8 in Area 3A was originally provided in Report No. MSEC437 as 2500 mm. Subsequent to that report, the subsidence model was recalibrated based on the LiDAR monitoring data for LW7 and LW8 in Area 3A and LW9 and LW10 in Area 3B. The maximum predicted subsidence for LW6 to LW8 in Area 3A based on the calibrated model was then revised to 3000 mm.

The calibrated model was designed to provide reasonable but slightly conservative predictions for the active longwalls in Area 3B. However, the calibrated model provides overly conservative predictions for Area 3A, based on the review of the LiDAR monitoring data at the completion of LW6 to LW8, as described in Section 3.6.

The predicted subsidence due to LW8 has been refined based on the LiDAR monitoring data at the completion of that longwall. No adjustments have been made for LW6, LW7, LW19 and LW19A based on this monitoring data. The maximum predicted subsidence due to the mining of LW6 to LW18, LW19 and LW19A is 3250 mm, as presented in this current report.

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 due to the mining of LW19A, 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, on steep slopes or within 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, rather than 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 locations of these monitoring lines are shown on Drawing No. MSEC1234-01 in Appendix D. The ranges of potential strains due to LW19A, 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 those at the Mine.

A comparison of the mining geometry for LW19A 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 LW19A with the longwalls from the NSW coalfields used in the strain analysis

Parameter	Dendrobium LW19A		Longwalls used in strain analysis	
	Range	Average	Range	Average
Longwall width	275	275	120 ~ 410	190
Depth of cover	290 ~ 360	330	100 ~ 360	180
W/H ratio	0.76 ~ 1.0	0.83	0.8 ~ 1.2	1.06
Mining height	3.9	3.9	3.0 ~ 4.8	4.2

The range of width-to-depth ratios and mining heights for the longwalls used in the strain analysis are similar to but greater, on average, than the width-to-depth ratio and mining height of the proposed LW19A. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains resulting from the mining of LW19A.

The data used in the analysis of observed strains included those resulting from both conventional and non-conventional anomalous movements but did not include those resulting from valley-related movements, 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 the longwalls or the chain pillars between the longwalls, referred to as *above goaf*. 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.

A histogram of the maximum observed tensile and compressive strains measured in survey bays located 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.

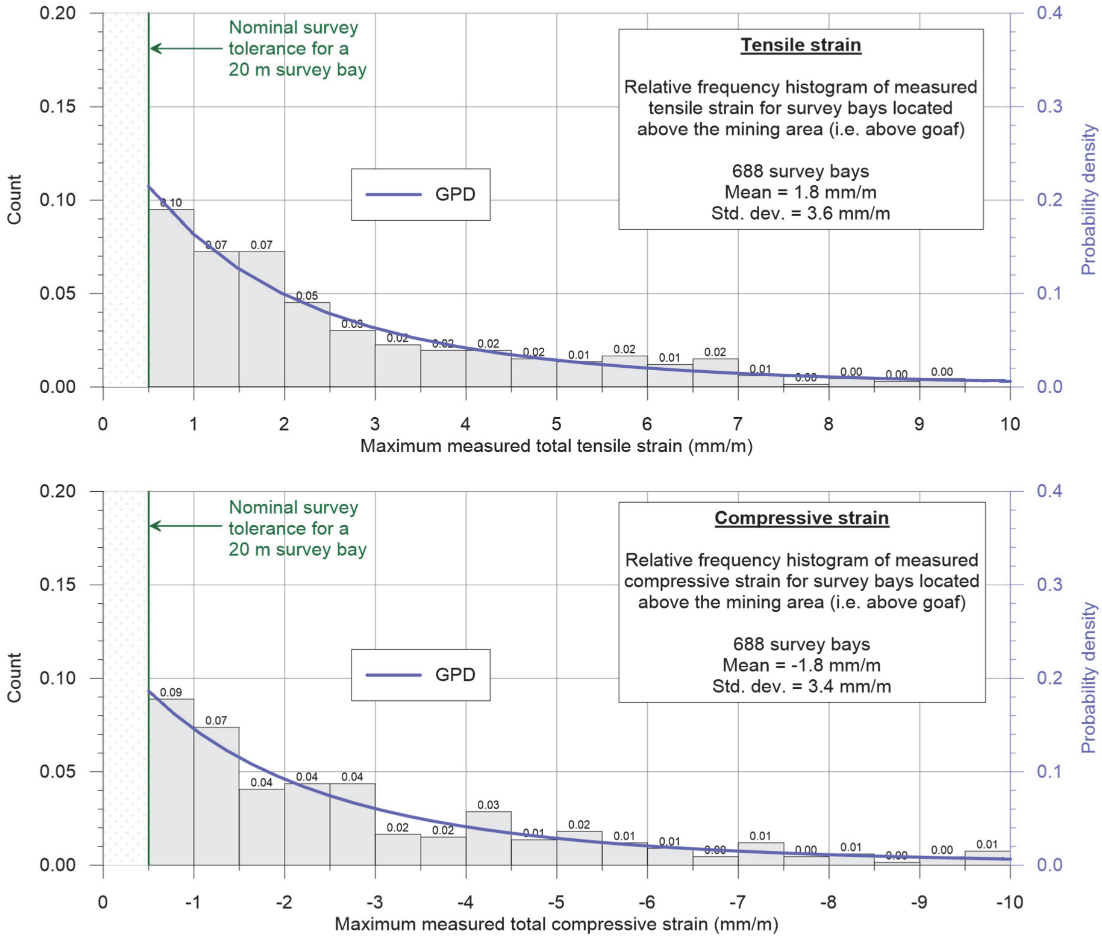

Fig. 4.1 Distributions of the measured maximum tensile and compressive strains during the mining of previous longwalls in the NSW coalfields for bays located above goaf

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 above the existing, future 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 LW19A 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 of up to 700 mm have been measured at the Mine, with an average measured value of approximately 310 mm.

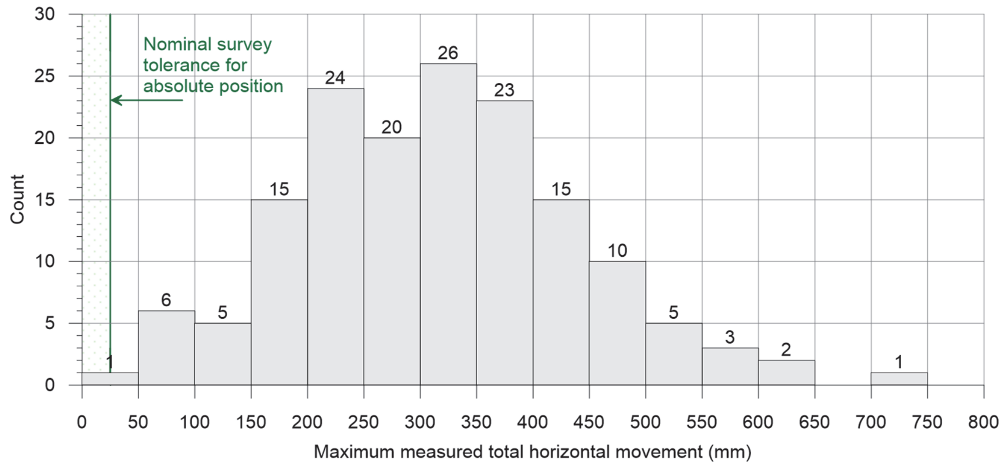

Fig. 4.2 Distribution of the maximum measured horizontal movements for the 3D marks located directly above the longwalls in Dendrobium Areas 1, 2, 3A and 3B

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 and built features 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, future and proposed longwalls, and the predicted valley-related movements along the streams, it is also likely that far-field horizontal movements will be experienced during mining.

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 active longwall or skewed towards the downslope direction. 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 empirical mean and the 95 % confidence level for the 3D monitoring data at Dendrobium Mine are also shown in this figure.

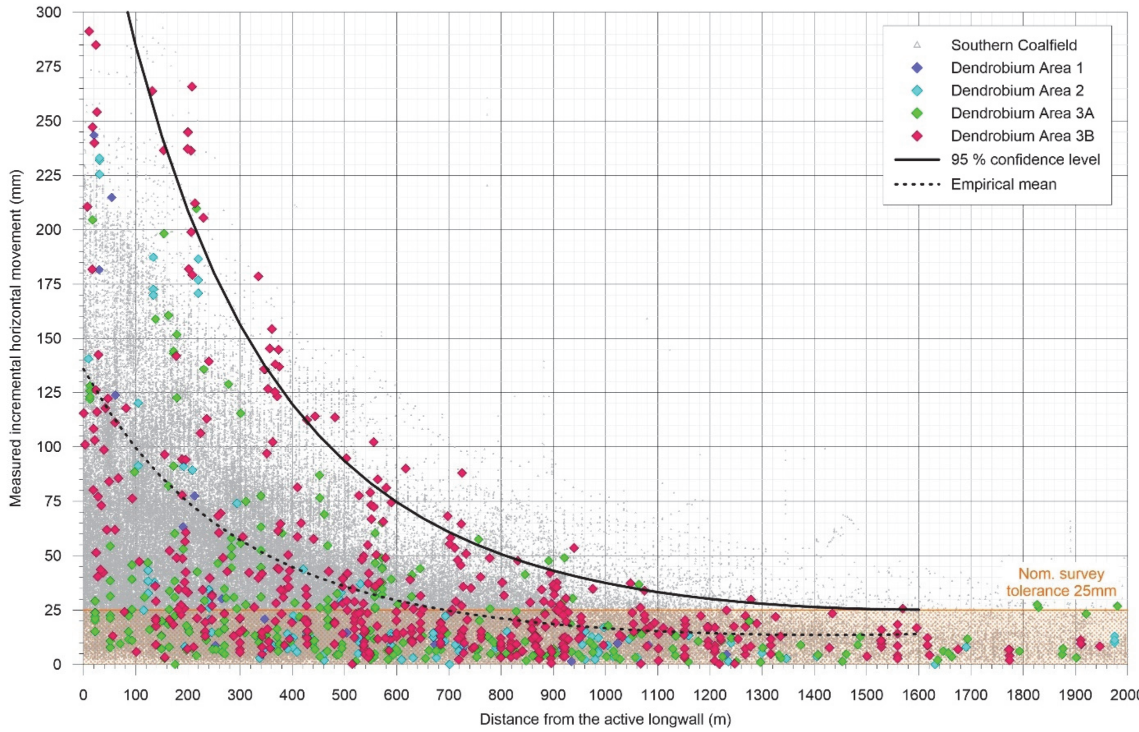

Fig. 4.3 Measured incremental far-field horizontal movements at Dendrobium Mine and elsewhere in the Southern Coalfield

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 due to the mining of 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 and built features in the vicinity of the Study Area are not expected to be significant, except where they occur at large structures which may be 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 movements, 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 5.4. 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 5.7.

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 statistical analyses of measured strains in the NSW coalfields, including both conventional and non-conventional anomalous strains, and they are discussed in Section 4.4. In addition to this, 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.

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 due to increased horizontal movements in the downslope direction where longwalls are mined 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 5.7.

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 effects are provided in Sections 5.2 to 5.4.

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 LW17 in Area 3B. The distribution of the measured widths of these surface deformations is illustrated in Fig. 4.4.

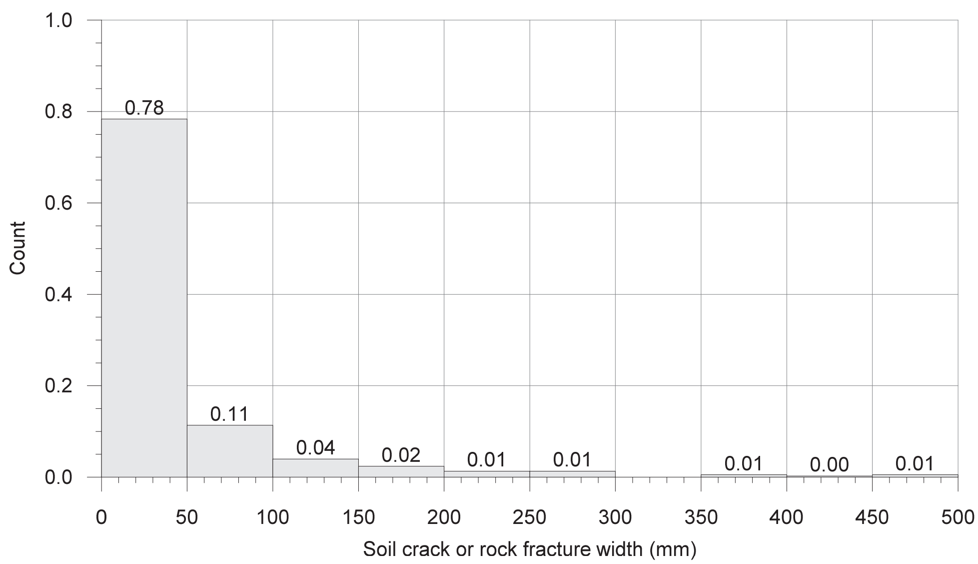

Fig. 4.4 Distribution of measured soil crack and rock fracture widths in Areas 2, 3A and 3B

The soil crack and rock fracture widths were generally observed to be less than 50 mm (i.e. 78 % 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 approximately 2 % of cases.

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 750 m (not shown in the above figure for clarity).

The predicted subsidence effects for the proposed LW19A are less than those 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 longwall, therefore, are expected to be similar or less than those previously measured in Areas 3A and 3B.

5.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE NATURAL FEATURES

The following sections provide the descriptions, predictions and impact assessments for the natural features located within the Study Area. The 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 proposed LW19A is located outside the Dams Safety NSW Notification Areas for Cordeaux and Avon Reservoirs. The Study Area based on both the 35° angle of draw and predicted 20 mm subsidence contour and the Study Area based on the 600 m boundary are also located outside the Notification Areas.

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.

5.2. Wongawilli Creek

5.2.1. Description of Wongawilli Creek

The location of Wongawilli Creek is shown in Drawing No. MSEC1234-09.

Wongawilli Creek is situated on the western side of the longwalls in Area 3A. The currently active longwalls in Area 3B are being mined on the western side of the creek. The longwalls in both Areas 3A and 3B have been set back from Wongawilli Creek so that they do not directly mine beneath it.

The thalweg (i.e. base or centreline) of Wongawilli Creek is located at a minimum distance of 390 m west of the finishing end of LW19A, at its closest point. The minimum distances between the thalweg of the creek and the completed longwalls are 110 m for LW6 in Area 3A and 290 m for LW9 in Area 3B.

Wongawilli Creek is located outside the Study Area based on the 35° angle of draw line and predicted 20 mm subsidence contour. The total length of creek within the Study Area based on the 600 m boundary is approximately 1.1 km.

Wongawilli Creek is a third order perennial stream with a small base flow and increased flows for short periods of time after each significant rain event. The creek generally flows in a northerly direction and drains into the Cordeaux River more than 5 km north of LW19A.

The locations of the mapped stream features along Wongawilli Creek are shown in Drawing No. MSEC1234-09. Summaries of the mapped stream features along the section of creek located within the Study Area based on the 600 m boundary are provided in Table 5.1 to Table 5.4. It is noted that some of the stream features in Wongawilli Creek shown in the drawing and the tables are temporary (i.e. they change with time) and are re-mapped as required.

Table 5.1 Pools mapped along Wongawilli Creek

Label	Approximate size	Distance at closest point
Pool R	100 m long x 8 m wide	500 m west of LW19A
Pool S	30 m long x 6 m wide	440 m west of LW19A
Pool T	15 m long x 4 m wide	430 m west of LW19A
Pool U	160 m long x 10 m wide	390 m west of LW19A
Pool V	30 m long x 6 m wide	450 m west of LW19A
Pool W	90 m long x 8 m wide	400 m west of LW19A
Pool X	60 m long x 8 m wide	390 m west of LW19A
Pool Y	15 m long x 5 m wide	390 m west of LW19A
Pool Z	30 m long x 6 m wide	400 m west of LW19A
Pool AA	20 m long x 4 m wide	400 m south-west of LW19A
Pool AB	20 m long x 6 m wide	420 m south-west of LW19A
Pool AC	30 m long x 5 m wide	400 m south-west of LW19A
Pool AD	40 m long x 10 m wide	400 m south-west of LW19A
Pool AE	15 m long x 8 m wide	430 m south-west of LW19A
Pool AF	20 m long x 6 m wide	440 m south-west of LW19A
Pool AG	210 m long x 6 m wide	460 m south-west of LW19A
Pool AH	80 m long x 6 m wide	590 m south-west of LW19A

Table 5.2 Channels mapped along Wongawilli Creek

Label	Approximate size	Distance at closest point
Channel E	12 m long x 3 m wide	590 m west of LW19A
Channel F	25 m long x 4 m wide	470 m west of LW19A
Channel G	7 m long x 2 m wide	440 m west of LW19A
Channel H	4 m long x 4 m wide	400 m south-west of LW19A
Channel I	8 m long x 3 m wide	450 m south-west of LW19A

Table 5.3 Riffles mapped along Wongawilli Creek

Label	Approximate size	Distance at closest point
Riffle Zone F	30 m long x 5 m wide	480 m west of LW19A
Riffle Zone G	4 m long x 1 m wide	450 m west of LW19A
Riffle Zone H	22 m long x 4 m wide	450 m west of LW19A
Riffle Zone I	3 m long x 5 m wide	400 m west of LW19A
Riffle Zone J	9 m long x 6 m wide	390 m west of LW19A
Riffle Zone K	9 m long x 3 m wide	400 m west of LW19A
Riffle Zone L	11 m long x 4 m wide	420 m south-west of LW19A
Riffle Zone M	57m long x 3 m wide	410 m south-west of LW19A
Riffle Zone N	15 m long x 2 m wide	410 m south-west of LW19A
Riffle Zone O	17 m long x 6 m wide	410 m south-west of LW19A
Riffle Zone P	5 m long x 4 m wide	590 m south-west of LW19A

Table 5.4 Log Jams mapped along Wongawilli Creek

Label	Approximate size	Distance at closest point
Log Jam G	6 m long x 5 m wide	410 m west of LW19A
Log Jam H	2 m long x 1 m wide	420 m west of LW19A
Log Jam I	2 m long x 4 m wide	420 m south-west of LW19A

In particular, the locations of riffles are known to change over time, as a result of flooding events and, therefore, the actual locations during the mining period could differ from those shown.

The surface mapping and geological modelling undertaken by IMC indicate that the base of the creek cuts through the stratigraphy as it runs from the south to the north. The creek bed is formed in the Hawkesbury Sandstone to the south of LW19A. The creek bed transitions through the Newport Formation and Bald Hill Claystone, adjacent to the longwalls in Area 3A, and is then formed in the Bulgo Sandstone further to the north.

Photographs of Wongawilli Creek are provided in Fig. 5.1.

Fig. 5.1 Wongawilli Creek (Source: IMC)

The natural surface level along Wongawilli Creek, within the extents of the Study Area based on the 600 m boundary, varies from 290 mAHD at the upstream end to 287 mAHD at the downstream end. The average natural grade over the 1.1 km length, therefore, is approximately 3 mm/m (i.e. 0.3 %, or 1 in 333).

The valley of Wongawilli Creek has an overall height of approximately 100 m to 160 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 5.6 and 5.7.

Section A has been taken through the valley of Wongawilli Creek and LW19A and it is shown in Fig. 5.2. The location of this section is shown in Drawing No. MSEC1234-09.

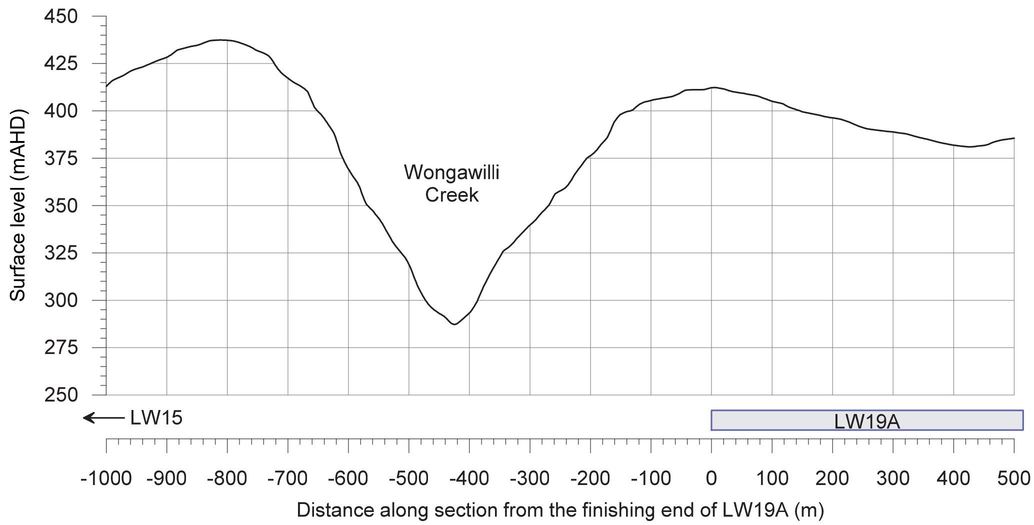

Fig. 5.2 Section A through Wongawilli Creek and LW19A

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 mining of the existing and future longwalls in Area 3A (LW6 to LW8 and LW19), Area 3B (LW9 to LW18) and Area 3C (LW20 and LW21) are shown as cyan lines. The predicted total profiles after the mining of the proposed LW19A are shown as the blue lines.

A summary of the maximum predicted values of incremental vertical subsidence, upsidence and closure for Wongawilli Creek is provided in Table 5.5. The values are the maximum predicted additional subsidence effects along the creek due to the mining of LW19A only.

Table 5.5 Maximum predicted incremental vertical subsidence, upsidence and closure for Wongawilli Creek due to the mining of LW19A only

Location	Due to longwall	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental upsidence (mm)	Maximum predicted incremental closure (mm)
Wongawilli Creek	LW19A	< 20	40	40

Wongawilli Creek is predicted to experience less than 20 mm vertical subsidence due to the mining of LW19A only. 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 incremental valley-related effects due to the mining of the proposed LW19A only are 40 mm upsidence and 40 mm closure. The maximum predicted incremental valley-related effects occur where Wongawilli Creek is located closest to the proposed LW19A.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for Wongawilli Creek is provided in Table 5.6. The values are the maximum predicted subsidence effects within the Study Area based on the 600 m boundary due to the mining in Areas 3A, 3B and 3C.

Table 5.6 Maximum predicted total vertical subsidence, upsidence and closure for Wongawilli Creek within the Study Area based on the 600 m boundary

Location	After longwalls	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Wongawilli Creek	LW6 to LW8, LW9 to LW18, LW19, LW20 and LW21	< 20	70	180
	LW19A	< 20	120	200

Wongawilli Creek is predicted to experience less than 20 mm vertical subsidence due to the mining in Areas 3A, 3B and 3C. 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 Wongawilli Creek within the Study Area based on the 600 m boundary are 120 mm upsidence and 200 mm closure. The maximum predicted valley-related effects within the Study Area occur to the west of the proposed LW19A.

The maximum predicted total valley closure anywhere along Wongawilli Creek is 210 mm which occurs outside and to the north of the Study Area based on the 600 m boundary. The predicted closure in that location is due to the mining of the existing longwalls in Areas 3A and 3B and there is negligible additional closure due to the mining of the proposed LW19A.

Wongawilli Creek could experience compressive strains due to the valley closure effects. The predicted strains have been determined based on analyses of ground monitoring lines for valleys with similar heights located at similar distances from extracted longwalls in the Southern Coalfield, as for Wongawilli Creek from the proposed LW19A.

The maximum predicted incremental compressive strain for Wongawilli Creek due to the mining of the proposed LW19A only is 2 mm/m based on the 95 % confidence level. The maximum predicted total compressive strain anywhere along the creek within the Study Area based on the 600 m boundary due to the mining in Areas 3A, 3B and 3C is 7 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 5.7 to Table 5.10. The locations of these features are shown in Drawing No. MSEC1234-09. The values are the total accumulated effects due to the existing and future longwalls in Areas 3A, 3B and 3C. The stream feature labels for Wongawilli Creek are temporary and these labels will be updated once re-mapping of the creek is completed.

Table 5.7 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	Pool R	< 20	90	200
	Pool S	< 20	110	200
	Pool T	< 20	120	200
	Pool U	< 20	120	210
	Pool V	< 20	75	160
	Pool W	< 20	65	160
	Pool X	< 20	60	140
	Pool Y	< 20	55	120
	Pool Z	< 20	50	120
	Pool AA	< 20	50	110
	Pool AB	< 20	50	110
	Pool AC	< 20	45	95
	Pool AD	< 20	45	90
	Pool AE	< 20	40	85
	Pool AF	< 20	40	80
	Pool AG	< 20	35	80
	Pool AH	< 20	35	70

Table 5.8 Maximum predicted total vertical subsidence, upsidence and closure at the mapped riffles 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	Channel E	< 20	90	200
	Channel F	< 20	100	200
	Channel G	< 20	120	200
	Channel H	< 20	45	90
	Channel I	< 20	35	80

Table 5.9 Maximum predicted total vertical subsidence, upsidence and closure at the mapped riffles along Wongawilli Creek

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Riffles along Wongawilli Creek	Riffle Zone F	< 20	95	200
	Riffle Zone G	< 20	75	160
	Riffle Zone H	< 20	70	160
	Riffle Zone I	< 20	60	140
	Riffle Zone J	< 20	55	120
	Riffle Zone K	< 20	50	120
	Riffle Zone L	< 20	50	110
	Riffle Zone M	< 20	45	110
	Riffle Zone N	< 20	45	100
	Riffle Zone O	< 20	40	85
	Riffle Zone P	< 20	35	70

Table 5.10 Maximum predicted total vertical subsidence, upsidence and closure at the mapped log jams along Wongawilli Creek

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Log jams along Wongawilli Creek	Log Jam G	< 20	50	110
	Log Jam H	< 20	50	110
	Log Jam I	< 20	45	100

5.2.3. Comparison between measured and predicted subsidence effects for Wongawilli Creek due to the mining of LW6 to LW8 and LW9 to LW17

The closure movements across Wongawilli Creek have been measured using the Wong X A-Line, Wong X B-Line, Wong X C-Line, Wong X D-Line and Wong X E-Line. The locations of these monitoring lines are shown in Drawing No. MSEC1234-01.

A review of the Wongawilli Creek closure lines was carried out as part of the End of Panel Report for LW17 (MSEC, 2022). The measured and predicted total closures along Wongawilli Creek after the completion of LW17 are illustrated in Fig. 5.3.

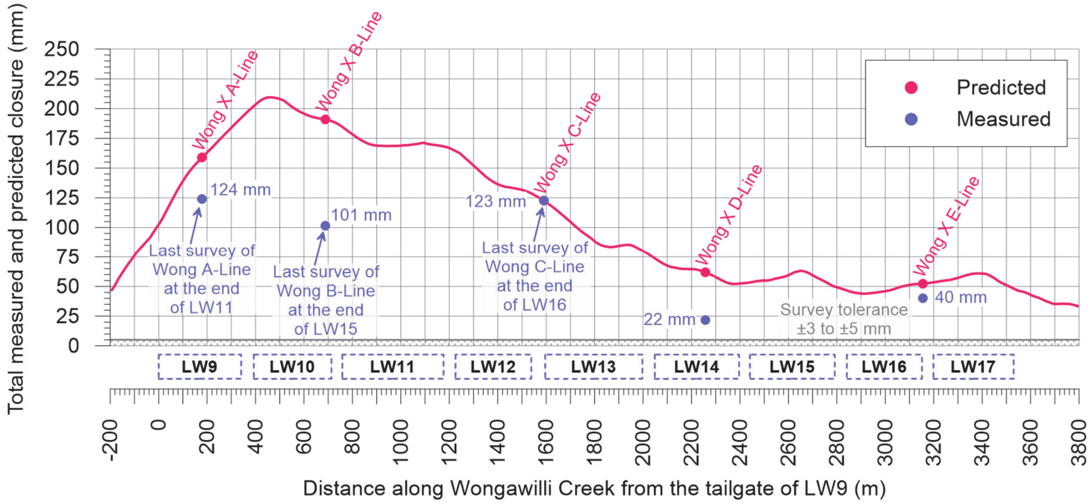

Fig. 5.3 Measured and predicted closure along Wongawilli Creek

The measured closures at the Wong X Creek A-Line to E-Line are similar to or less than the predicted closures in the locations of these monitoring lines.

5.2.4. Observed impacts along Wongawilli Creek due to LW9 to LW17

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 LW17 in Area 3B. The minimum distances between the thalweg of the creek and the completed longwalls are 110 m for Area 3A and 290 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 LW17 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 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 set back from Wongawilli Creek so that the predicted closure is less than 200 mm at the mapped rockbars and other stream controlling features. 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 for 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 mining of the proposed LW19A. 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 incremental upsidence along Wongawilli Creek due to the mining of the proposed LW19A only is 40 mm. The maximum predicted total upsidence along the creek within the Study Area based on the 600 m boundary is 120 mm. While the magnitudes of the predicted upsidence movements 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 3 mm/m (i.e. 0.3 %, or 1 in 333). The predicted changes in grade due to the mining of LW19A, 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.

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 effects 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 flows 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 110 m and 290 m from the existing longwalls in Areas 3A and 3B, respectively, and a minimum distance of 390 m from the proposed LW19A. 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 incremental closure along Wongawilli Creek due to the mining of the proposed LW19A only is 40 mm. The maximum predicted incremental compressive strain for the creek due to the valley closure effects is 2 mm/m based on the 95 % confidence level.

The maximum predicted total closure along the creek within the Study Area based on the 600 m boundary is 200 mm. The maximum predicted total compressive strain for the creek due to the valley closure effects is 7 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 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. 5.4.

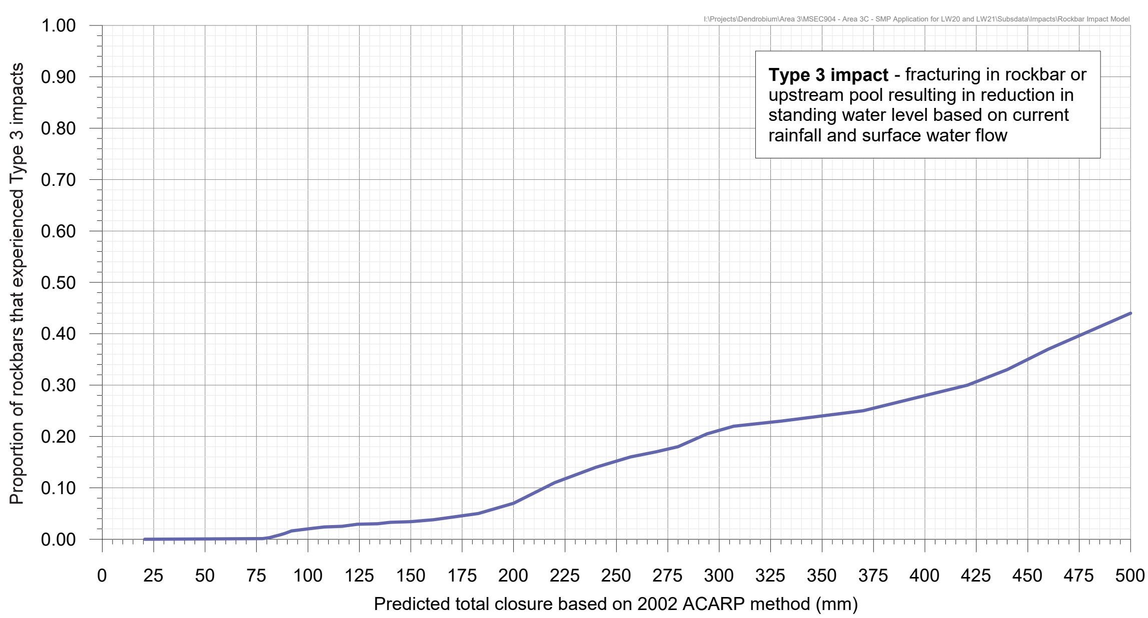

Fig. 5.4 Rockbar impact model based on predicted valley closure

The maximum predicted total closure along Wongawilli Creek within the Study Area based on the 600 m boundary, due to the mining of the existing, future and proposed longwalls in Areas 3A, 3B and 3C is 200 mm. The predicted rate of impact for the rockbars and other stream controlling features along the creek after the extraction of the existing and future longwalls, therefore, is in the order of 7 % 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 LW19A, is low, i.e. affecting less than 10 % of rockbars and other stream controlling features located within the Study Area. However, minor fracturing could still occur along the creek, at distances up to approximately 400 m from the proposed longwall.

Further assessments of the potential impacts on surface water are provided in the report by HGeo (2022).

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 Area 3A Watercourse Impact Management Monitoring and Contingency Plan be revised to include the proposed LW19A.

5.3. Sandy Creek and Sandy Creek Waterfall

The location of Sandy Creek is shown in Drawing No. MSEC1234-09.

Sandy Creek is situated on the eastern side of Area 3A. The thalweg of the creek is located approximately 1200 m from the commencing end of LW19A, at its closest point. Sandy Creek is therefore located well outside the Study Area based on the 600 m boundary.

The maximum predicted incremental vertical subsidence, upsidence and closure for Sandy Creek, due to the mining of LW19A, are all less than 5 mm. While the creek could experience very low levels of these subsidence effects, it is not expected to experience measurable tilts, curvatures or strains.

It is unlikely, therefore, that adverse impacts would occur along Sandy Creek due to the mining of LW19A.

Sandy Creek Waterfall (SC-WF1) is situated where Sandy Creek flows into the Cordeaux Reservoir. The centre of the waterfall is located more than 1400 m north-east of the commencing end of LW19A. At this distance, the predicted incremental vertical subsidence, upsidence and closure for Sandy Creek Waterfall are negligible.

The valley closure effects across Sandy Creek Waterfall due to the mining of LW6 to LW8 were measured using the SCW High Resolution Survey (HRS) H1, H2, H3, G1, G2 and AA Lines. The locations of these monitoring lines are shown in Drawing No. MSEC1234-01. The measured total closures for SCW HRS lines are illustrated in Fig. 5.5. The survey accuracy for these high-resolution monitoring lines is in the order of ±0.5 mm to ±1 mm. The measured movements also include a component due to environmental effects (i.e. changes in temperature and rainfall) in the order of ±1 mm to ±2 mm.

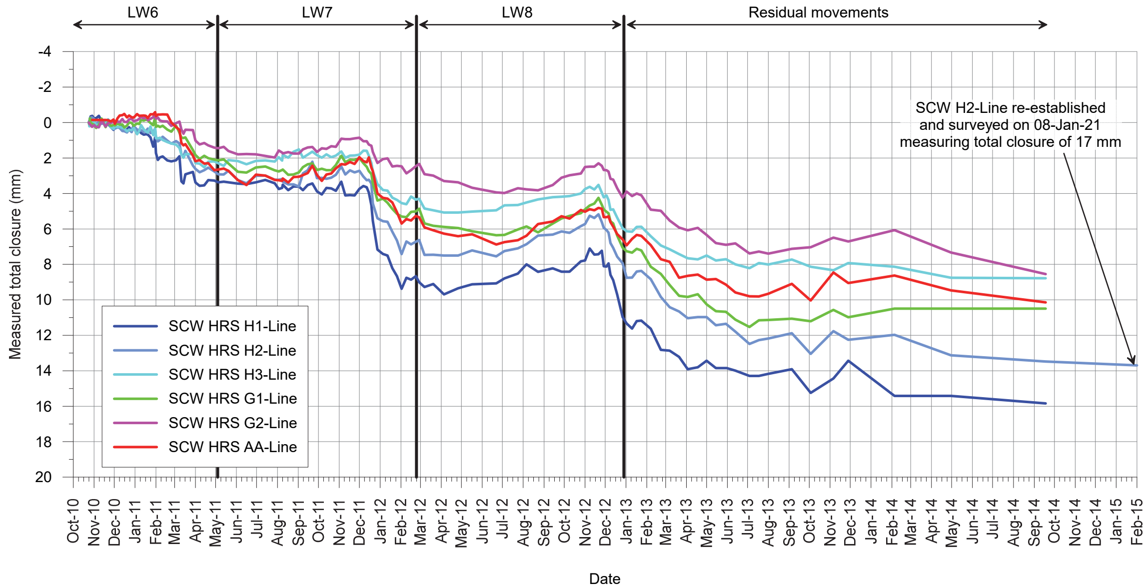

Fig. 5.5 Measured total closure for the SCW HRS monitoring lines for LW6 to LW8

On 18 September 2014, the maximum measured total closure across Sandy Creek Waterfall due to the mining of LW6 to LW8 was approximately 16 mm. The greatest closure was measured across the SCW HRS H1-Line located downstream of the waterfall and across the valley of Lake Cordeaux.

The monitoring of the SCW closure lines ceased in September 2014 and the survey marks were either destroyed by erosional processes or obscured by vegetation. Subsequently, the SCW H2-Line was re-established and surveyed again on 8 January 2021 and the measured total closure was 17 mm. However, the reliability of that survey is considerably reduced sine the survey marks had to be re-established more than five years after the previous survey. It is therefore considered that the SCW H1-Line provides the most reliable measure of the maximum closure across Sandy Creek Waterfall.

A summary of the measured incremental closure movements for the SCW HRS H1-Line, due to the mining of each of LW6 to LW8, is provided in Table 5.11. The distances of the longwalls from the centreline of the waterfall are also provided in the table.

Table 5.11 Measured incremental closure for the SCW HRS H1-Line due to LW6 to LW8

Monitoring line	Longwall	Distance from the centreline of Sandy Creek Waterfall (m)	Measured incremental closure (mm)
SCW HRS H1-Line	LW6	390	4
	LW7	430	6
	LW8	500	7

The future LW19 and the proposed LW19A are located 900 m and 1200 m, respectively, from the centreline of Sandy Creek Waterfall. These longwalls are between 1.8 to 3.1 times the distances of LW6 to LW8 from the centreline of the waterfall. Also, the eastern end of LW8 extends beyond the eastern ends of both LW19 and LW19A and, therefore, it provides shadowing effects. On this basis, the predicted incremental closure for Sandy Creek Waterfall due to the mining of LW19 and LW19A are less than 2 mm each. The predicted incremental movements therefore are in the order of the survey tolerance and environmental effects.

It is unlikely that Sandy Creek Waterfall would experience adverse impacts due to the mining of the future LW19 and the proposed LW19A.

It is recommended that the closure across the waterfall is measured monthly during the first 1000 m of mining of the future LW19 and the proposed LW19A. A Trigger Action Response Plan (TARP) should also be established based on the measured movements.

5.4. Drainage lines

5.4.1. Descriptions of the drainage lines

The locations of the drainage lines are shown in Drawing No. MSEC1234-09. The unnamed drainage lines have been labelled in this report for reference.

The drainage lines located within the Study Area based on the 600 m boundary are SC10, SC10C, WC13(A) and WC14. The upper reaches of WC13(A) and WC14 are partially located above the proposed LW19A and SC10, SC10C and WC14 are partially located above the future LW19. The drainage lines in the western part of the Study Area flow into Wongawilli Creek and the drainage lines in the eastern part of the Study Area flow into Sandy Creek.

The drainage lines are first and second order streams. The beds 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 loose rocks and tree branches. The waterfall along SC10 (Ref. SC10-WF15) is located outside the Study Area based on the 600 m boundary.

The natural gradients of the drainage lines typically vary between 50 mm/m (i.e. 5.0 %, or 1 in 20) and 200 mm/m (i.e. 20 %, or 1 in 5), with average natural gradients in the order of 100 mm/m (i.e. 10 %, or 1 in 10). The drainage lines have localised areas with natural grades greater than 500 mm/m where there are steps and cascades.

5.4.2. Predictions for the drainage lines

The drainage lines are located above the mining 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 SC10, WC13(A) and WC14 are shown in Figs. C.04 to C.06, respectively, in Appendix C. The predicted total profiles after the mining of the existing LW6 to LW8 and the future LW19 are shown as cyan lines. The predicted total profiles after the mining of the proposed LW19A are shown as the blue lines.

A summary of the maximum predicted values of incremental vertical subsidence, upsidence and closure for the drainage lines located within the Study Area is provided in Table 5.12. The values are the maximum predicted additional subsidence effects due to the mining of LW19A only.

Table 5.12 Maximum predicted incremental subsidence, upsidence and closure for the drainage lines due to the mining of LW19A only

Type	Reference	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental upsidence (mm)	Maximum predicted incremental closure (mm)
Drainage lines	SC10	< 20	50	50
	SC10C	275	60	70
	WC13(A)	375	80	170
	WC14	2150	225	140

The maximum predicted incremental subsidence effects due to the mining of LW19A only occur along WC14 as the upper reaches are located directly above LW19A and further downstream it is located directly above the future LW19. The predicted incremental subsidence effects for SC10, SC10C and WC13(A) are less as they are located outside the extents of LW19A apart from the very upper reaches of WC13(A).

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the drainage lines located within the Study Area is provided in Table 5.13. The values are the maximum predicted accumulated subsidence effects due to the mining of LW6 to LW8, LW19 and LW19A.

Table 5.13 Maximum predicted total subsidence, tilt and curvature for the drainage lines

Type	Reference	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Drainage lines	SC10	40	160	250
	SC10C	2750	375	650
	WC13(A)	400	130	275
	WC14	2300	425	575

The maximum predicted vertical subsidence and valley-related effects occur along SC10C and WC14 since they are located directly above the mining area. The valleys of these streams are also incised downstream of the mining area.

The maximum predicted total tilt for the drainage lines located above the mining area is 30 mm/m (i.e. 3.0 %, or 1 in 33). The maximum predicted total conventional curvatures are 0.9 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 1.1 km.

The maximum predicted conventional strains for the drainage lines, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 14 mm/m tensile and compressive. The distribution of the predicted strains due to the mining 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 maximum predicted valley-related effects are 425 mm upsidence and 650 mm closure. The range of closure movements for the drainage lines within the Study Area are expected to be similar to those measured across the streams above the existing longwalls in Area 3B. The data includes monitoring lines across Donalds Castle Creek, tributary cross-lines and swamp cross-lines. The maximum measured closure for the streams in Area 3B due to the mining of LW9 to LW17 is 880 mm. The average measured values for the streams above the mining area is 240 mm and the 95-percentile is 670 mm.

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

Summaries of the maximum predicted values of total vertical subsidence, upsidence and closure at the mapped rockbars along SC10, WC13(A) and WC14 are provided in Table 5.14, Table 5.15 and Table 5.16, respectively. The locations of these features are shown in Drawing No. MSEC1234-09. The rockbars along SC10C are located outside the Study Area based on the 600 m boundary.

Table 5.14 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along drainage line SC10

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Rockbars along drainage line SC10	SC10-RB17	< 20	100	150
	SC10-RB18	< 20	100	150
	SC10-RB19	< 20	100	150
	SC10-RB20	< 20	125	175
	SC10-RB21	20	125	200
	SC10-RB22	30	125	225
	SC10-RB23	< 20	150	250
	SC10-RB24	< 20	150	250
	SC10-RB25	< 20	150	225
	SC10-RB26	< 20	125	225
	SC10-RB27	< 20	60	80

Table 5.15 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along drainage line WC13(A)

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Rockbars along drainage line WC13(A)	WC13-RB01	< 20	60	100
	WC13-RB02	< 20	60	100
	WC13-RB03	< 20	60	100

Table 5.16 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along drainage line WC14

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Rockbars along drainage line WC14	WC14-RB1	< 20	200	325
	WC14-RB2	< 20	250	425
	WC14-RB3	< 20	250	450
	WC14-RB4	< 20	250	450
	WC14-RB5	< 20	275	500
	WC14-RB6	< 20	275	525
	WC14-RB7	125	375	575
	WC14-RB8	150	375	575
	WC14-RB9	225	375	550
	WC14-RB10	275	375	550
	WC14-RB11	325	375	550
	WC14-RB12	675	350	525

The mapped rockbars along WC13(A) are located outside the mining area. Some of the mapped rockbars along SC10 and WC14 are located above the mining area; however, none are located directly above the proposed LW19A.

Rockbars SC10-RB22, WC14-RB7 to WC14-RB12 are located above the future LW19 to the north of the proposed LW19A. These rockbars along SC10 and WC14 are predicted to experience up to 675 mm vertical subsidence, 375 mm upsidence and 4575 mm closure.

5.4.3. Observed impacts to the drainage lines due to previous mining in Area 3B

First and second-order streams are located above the previously extracted LW9 to LW17 in Area 3B. The impact assessments for these streams 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 unnamed streams due to LW9 are described in the End of Panel Report (IMC, 2014) and these have been summarised below:

> *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.
>
> *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 unnamed streams due to LW10 are described in the End of Panel Report (IMC, 2015) and these have been summarised below:

> *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 unnamed streams 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 unnamed streams 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 unnamed streams 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 unnamed streams 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 unnamed streams 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 was 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 unnamed streams due to LW16 are described in the End of Panel Report (IMC, 2021a) 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 impacts observed along the unnamed streams due to LW17 are described in the End of Panel Report (IMC, 2021b) and these have been summarised below:

> Rock fracturing was observed along LA2 causing likely loss of surface water flow (Type 3 impact) in three locations and possible loss of surface water flow in another seven locations. The fracturing occurred predominately above LW17 with only one physical impact site (i.e. fracturing or cracking) occurring outside the mining area and adjacent to the longwall commencing end.

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

5.4.4. 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 30 mm/m (i.e. 3.0 % or 1 in 33). 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 drainage lines SC10, WC13(A) and WC14 are illustrated in Fig. 5.6 to Fig. 5.8, respectively. The locations of these drainage lines are shown in Drawing No. MSEC1234-09.

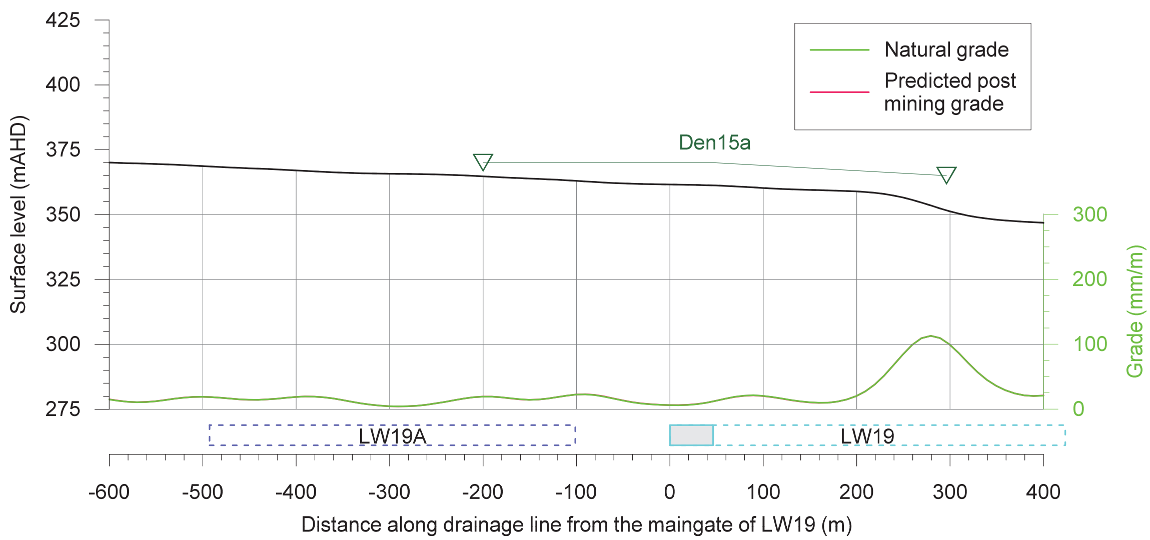

Fig. 5.6 Natural and predicted post-mining surface levels along SC10

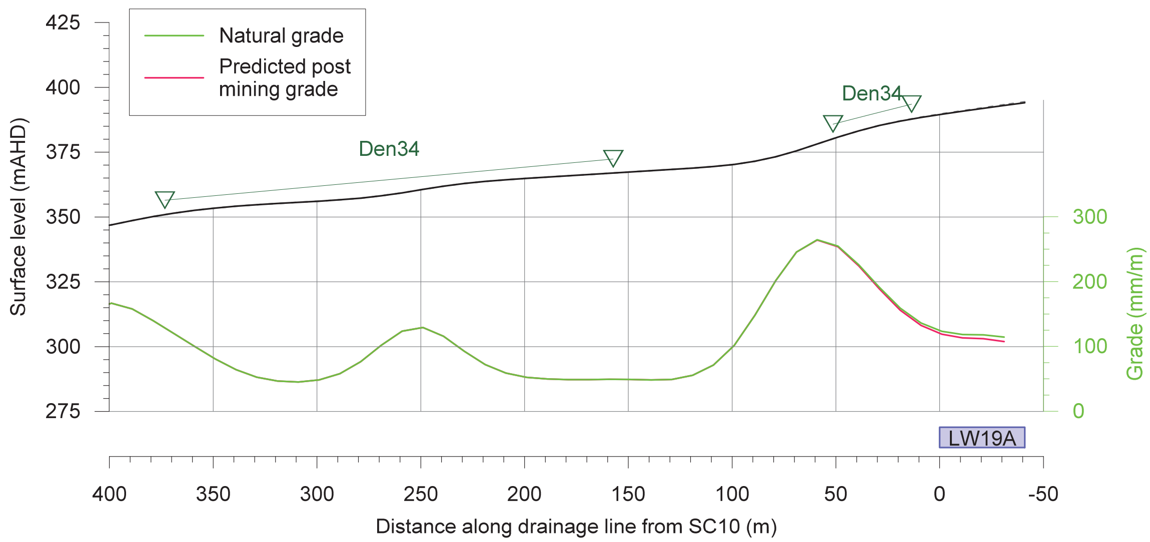

Fig. 5.7 Natural and predicted post-mining surface levels along WC13(A)

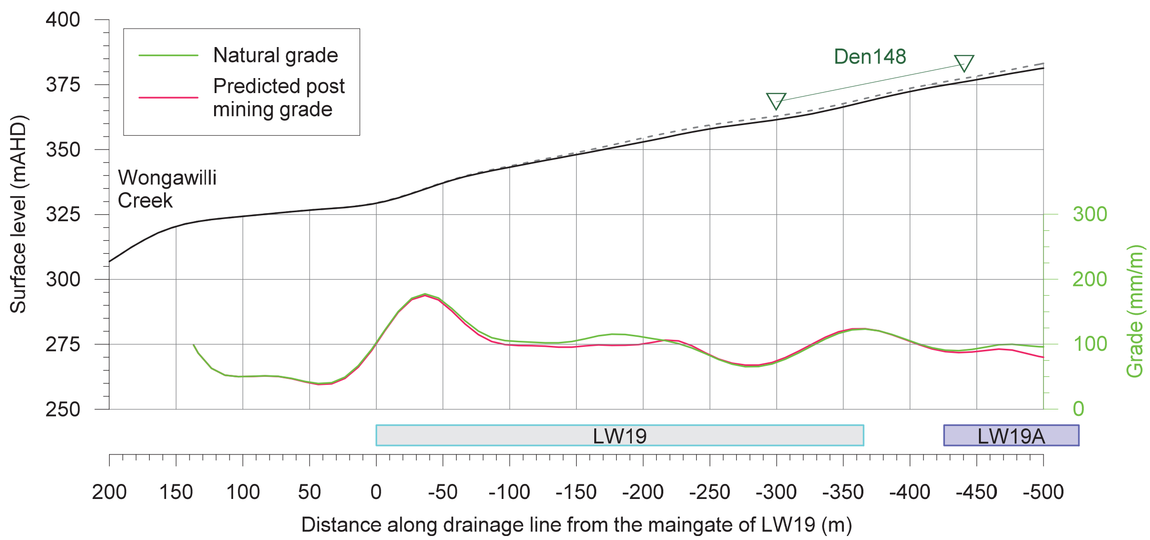

Fig. 5.8 Natural and predicted post-mining surface levels along WC14

There are no predicted reversals of stream grade along drainage lines SC10, WC13(A) and WC14. There are slight reductions in grades along drainage lines WC13(A) and WC14, upstream of the chain pillars and the edges of the mining area. There is potential for minor and localised increased ponding upstream of these locations.

Elsewhere, the predicted post-mining grades are similar to the natural grades. It is unlikely, therefore, 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 upstream of the chain pillars and the edges of the mining area.

The potential impacts of increased ponding and scouring of the drainage lines, therefore, are expected to be minor and localised. Impacts resulting from changes in surface water flows 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 LW17 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 300 m from the extracted longwalls in Area 3B and up to 400 m from extracted longwalls elsewhere in the Southern Coalfield.

The maximum predicted subsidence effects due to the mining of the proposed LW19A are similar to but less than the maximum predicted values for the existing longwalls in Area 3B. The potential impacts for the drainage lines within the Study Area, therefore, are expected to be similar to those observed above and adjacent to the existing 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 LW19A and the adjacent future LW19. Fracturing can also occur outside the extents of the longwalls, with minor and isolated fracturing occurring 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 dilation associated with the valley-related closure 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 longwalls.

Further assessments of the potential impacts on surface water are provided in the report by HGeo (2022).

5.4.5. 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 LW19A. It is also recommended that periodic inspections are carried out along the drainage lines during active subsidence.

5.5. 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.

5.6. Cliffs

5.6.1. Descriptions of the cliffs

The definitions of cliffs and minor cliffs provided in the NSW DPIE *Standard and Model Conditions for Underground Mining* (DPIE, 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 (>63.4°)*
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 (>63.4°); 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 LiDAR surface level contours and field investigations. The locations of these features are shown in Drawing No. MSEC1234-08.

There are no cliffs identified within the Study Area based on the 35° angle of draw line and the predicted 20 mm subsidence contour. There are six cliffs located within the Study Area based on the 600 m boundary, with DA3-CF7 and DA3-CF8 located on a ridgeline above the eastern end of the future LW19 and DA3-CF16 to DA3-CF18 and DA3-CF24 situated within the valley of Wongawilli Creek.

A summary of the cliffs identified within the Study Area based on the 600 m boundary is provided in Table 5.17.

Table 5.17 Cliffs located within the Study Area based on the 600 m boundary

Reference	Location	Overall length (m)	Maximum height (m)
DA3-CF7	Directly above LW19 and 240 m east of the LW19A commencing end	20	15
DA3-CF8	Directly above LW19 and 420 m east of the LW19A commencing end	25	10
DA3-CF16	540 m north-west of the LW19A finishing end	70	10
DA3-CF17	Partially above LW19 and 210 m west of the LW19A finishing end	280	10
DA3-CF18	220 m west of LW19A finishing end	180	15
DA3-CF24	330 m south-west of LW19A finishing end	20	20

The cliffs have formed predominantly 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. A photograph of the Wongawilli Creek valley is provided in Fig. 5.9 (Source: IMC). The cliffs on the western side of the creek (i.e. near the longwalls in Area 3B) are partially visible on the left side of this photograph. The cliffs of the eastern side of the creek (i.e. near the longwalls in Area 3A) are obscured by the trees on the right side of this photograph.

Fig. 5.9 Wongawilli Creek valley (Source: IMC)

The minor cliffs within the Study Area are located within the valleys of Wongawilli Creek and the drainage lines. 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.

5.6.2. Predictions for the cliffs

The cliffs are all predicted to experience incremental vertical subsidence of less than 20 mm due to the mining of LW19A only. While the cliffs could experience very low levels of vertical subsidence due to the mining of LW19A, they are not expected to experience measurable tilts, curvatures or strains.

Cliffs DA3-CF16 to DA3-CF18 and DA3-CF24 are situated within the valley of Wongawilli Creek. While the valleys where the cliffs are located could experience valley-related effects, the cliffs themselves are unlikely to experience upsidence or compressive strain due to valley closure, as they are located along the valley sides.

5.6.3. Impact assessments for the cliffs

It is difficult to assess the likelihood of cliff instabilities based upon predicted subsidence effects. 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 cliffs are located at distances ranging between 210 m and 540 m from the proposed LW19A. At these distances, the cliffs are predicted to experience very low levels of vertical subsidence, upsidence and compressive strain due to valley closure due to the mining of LW19A.

Cliff DA3-CF7 is located above the eastern end of LW19 and DA3-CF17 is partially located above the western end of that longwall. While the mining of the proposed LW19A will result in very low subsidence effects at these cliffs, higher levels of subsidence will develop further along the ridgelines on which these cliffs have formed. It is therefore possible that isolated rock falls could occur at DA3-CF7 and DA3-CF17, due to the mining of LW19A, where they are located above the previously mined area.

Cliffs DA3-CF16 to DA3-CF18 and DA3-CF24 are located outside the mining area. It is unlikely that these cliffs would experience adverse impacts due to the mining of LW19A based on their distances from the longwall and the very low levels of predicted subsidence effects. 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 rock falls could occur due to mining, natural processes, or both.

5.6.4. 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.

5.7. Rock outcrops and steep slopes

5.7.1. Descriptions of the rock outcrops and steep slopes

The definition of a steep slope provided in the NSW DPIE *Standard and Model Conditions for Underground Mining* (DPIE, 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 a LiDAR survey of the area.

The areas identified as having steep slopes are shown in Drawing No. MSEC1234-08.

The steep slopes within the Study Area have been identified within the valleys of Wongawilli Creek and its tributaries and along the ridgelines located directly above the mining area. 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 Wongawilli Creek and its tributaries and along the ridgelines directly above the mining area. 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

5.7.2. Predictions for the rock outcrops and steep slopes

The rock outcrops and steep slopes 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 values of total vertical subsidence, tilt and curvatures for the rock outcrops and steep slopes is provided in Table 5.18. The values in this table are the maximum predicted subsidence effects due to the mining of LW6 to LW8, LW19 and LW19A.

Table 5.18 Maximum predicted total vertical subsidence, tilt and curvatures for the rock outcrops and steep slopes

Location	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})
Rock outcrops and steep slopes	LW6 to LW8, LW19 and LW19A	3250	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 represent 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 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.

5.7.3. 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 25). 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 affected by curvature and strain, rather than tilt. The potential impacts would generally occur 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 surface topography above LW19A is similar to that above the existing LW6 to LW8 in Area 3A and similar to that in Area 3B. Also, the predicted total subsidence effects due to mining in Area 3A are similar to but less than the predicted values in Area 3B. The surface deformations observed due to mining in Areas 3A and 3B should, therefore, provide a reasonable indication of the potential impacts due to the mining of the proposed LW19A.

The surface deformations due to mining in Areas 2, 3A and 3B are discussed in Section 4.8. The soil crack and rock fracture widths were generally observed to be less than 50 mm (i.e. 78 % of the cases); however, cracking up to 300 mm also typically occurred. Localised erosion also occurred at several sites causing surface deformations with widths up to 750 mm.

Photographs of the surface cracking at Dendrobium Mine are provided in Fig. 5.11.

Fig. 5.11 Surface tension cracking due to downslope movements at Dendrobium Mine

It is expected, therefore, that the increased horizontal movements in the downslope direction would also occur along rock outcrops and steep slopes due to the mining of LW19A. 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 longwall, 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.

5.7.4. 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 longwall are undertaken during or after active subsidence and that any remedial measures required to prevent erosion are implemented in consultation with WaterNSW.

5.8. Escarpments

There are no escarpments located within the Study Area. The *Illawarra Escarpment* is located more than 12 km to the east of LW19A. At this distance, the escarpment is not expected to experience measurable mine subsidence movements or adverse impacts due to the extraction of the proposed longwall.

5.9. 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 Wongawilli Creek and Sandy Creek. There are no major flood prone areas identified within the Study Area. The predicted changes in the surface levels of the streams, resulting from the extraction of the proposed longwall, will have only a marginal effect on their natural gradients, and hence, on their discharge characteristics.

5.10. Swamps, wetlands and water related ecosystems

5.10.1. Descriptions of the swamps

The swamps are shown in Drawing No. MSEC1234-09. The locations and extents of the upland swamps have been interpreted from detailed aerial photogrammetry and site inspections.

There are five swamps (Refs. Den15a, Den15b, Den15c, Den34 and Den148) that have been identified partially or wholly within the Study Area based on the 35° angle of draw line and predicted 20 mm subsidence contour. There are two additional swamps (Refs. Den12 and Den96) that are partly or wholly located within the Study Area based on the 600 m boundary.

Parts of Den15c and Den148 are partially located above the tailgate of the proposed LW19A and part of Den34 is partially located above the maingate of this longwall. The remaining swamps are located outside the extents of the proposed LW19A. A summary of the swamps located within the Study Area based on the 600 m boundary is provided in Table 5.19.

Table 5.19 Swamps located within the Study Area based on the 600 m boundary

Reference	Location	Description
Den12	Directly above LW7 and LW8, 580 m north-west of LW19A	Base and side of valley for Stream WC17
Den15a	Outside the mining area, 60 m south-east of LW19A	Base and side of valley for Stream SC10
Den15b	Directly above LW7 and LW8, 430 m north-east of LW19A	Base and side of valley for Stream SC10C
Den15c	Directly above the tailgate of LW19A near the eastern end	Base and side of valley for tributary to Stream SC10
Den34	Generally outside the mining area but the northern extent above the maingate of LW19A	Base and side of valley for Stream WC13
Den96	Outside the mining area, 400 m east of LW19A	Side of valley for Stream SC10
Den148	Directly above LW19 and LW19A	Base and side of valley for Stream WC14

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. 5.12. Photographs of a typical headwater swamp are provided in Fig. 5.13.

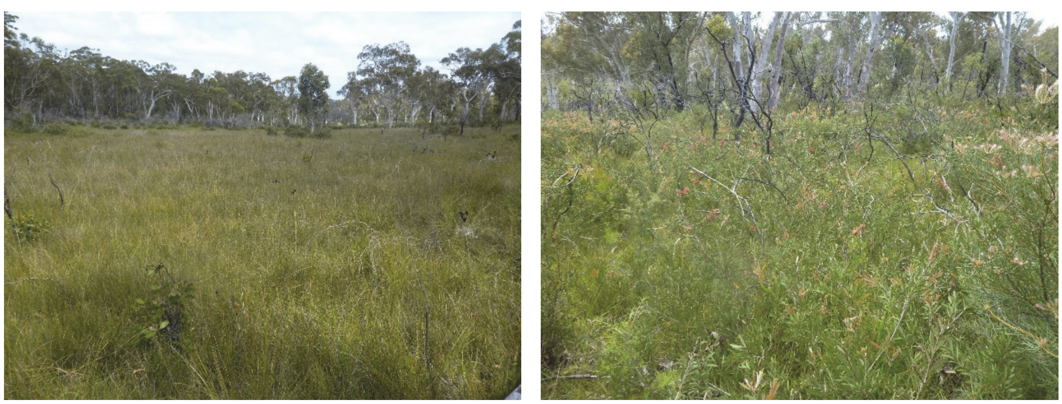

Fig. 5.12 Typical valley infill swamps

Fig. 5.13 Typical headwater swamp

Further descriptions of the swamps are provided in the report by Niche (2022a).

5.10.2. Predictions for the swamps

A summary of the maximum predicted incremental vertical subsidence, tilt and curvatures for the swamps located within the Study Area is provided in Table 5.20. The values are the maximum predicted additional subsidence effects within 20 m of the mapped extents of each of the swamps due to the mining of LW19A only.

Table 5.20 Maximum predicted incremental vertical subsidence, tilt and curvatures for the swamps

Reference	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
Den12	< 20	< 0.5	< 0.01	< 0.01
Den15a	30	< 0.5	0.01	< 0.01
Den15b	30	< 0.5	0.01	< 0.01
Den15c	1300	25	0.50	0.45
Den34	325	11	0.25	0.03
Den96	< 20	< 0.5	< 0.01	< 0.01
Den148	1650	16	0.35	0.13

The maximum predicted incremental vertical subsidence for Den12, Den15a, Den15b and Den96 are 30 mm or less. While these swamps could experience very low levels of vertical subsidence due to the mining of LW19A only, they are not expected to experience measurable tilts, curvatures or strains.

The maximum predicted incremental subsidence effects occur at Den15c and Den148 as they are partially located above the tailgate of LW19A. The predicted incremental subsidence effects for Den34 are lower since this swamp is generally located outside the mining area apart from its northern extent.

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the swamps located within the Study Area is provided in Table 5.21. The values are the maximum predicted cumulative subsidence effects within 20 m of the mapped extents of each of the swamps due to the mining of LW6 to LW8, LW19 and LW19A.

Table 5.21 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})
Den12	2750	25	0.50	0.70
Den15a	30	< 0.5	0.01	< 0.01
Den15b	2750	35	0.90	0.80
Den15c	1400	25	0.50	0.45
Den34	350	11	0.25	0.03
Den96	< 20	< 0.5	< 0.01	< 0.01
Den148	3250	35	0.90	0.70

The maximum predicted total tilt for the swamps is 35 mm/m (i.e. 3.5 %, or 1 in 29). The maximum predicted total conventional curvatures are 0.90 km^{-1} hogging and 0.80 km^{-1} sagging, which represent minimum radii of curvatures of 1.1 km and 1.3 km, respectively. The maximum predicted tilt and curvatures occur at Den15b (located above the existing LW7 and LW8) and Den148 (located above the future LW19 and the proposed LW19A).

The maximum predicted conventional strains for the swamps, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 14 mm/m tensile and 12 mm/m 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.

Den12, Den15a, Den15b, Den15c, Den34 and Den148 are located near the bases of drainage lines WC17, SC10, SC10C, tributary to SC10, WC13 and WC14, respectively. These swamps could experience valley-related effects due to the mining of the existing, future and proposed longwalls in Area 3A. The remaining swamps within the Study Area are located on the valley sides and, therefore, they are unlikely to experience upsidence or compressive strain due to the valley closure effects.

A summary of the maximum predicted incremental upsidence and closure for the swamps within the Study Area is provided in Table 5.22. The values are the maximum predicted valley-related effects for each of the swamps due to the mining of LW19A only.

Table 5.22 Maximum predicted incremental upsidence and closure for the swamps

Location	Maximum predicted incremental upsidence (mm)	Maximum predicted incremental closure (mm)
Den12	< 20	30
Den15a	60	100
Den15b	40	90
Den15c	80	125
Den34	70	150
Den148	100	150

Only very low levels of incremental upsidence and closure are predicted for Den12 as it is located at a minimum distance of 580 m from the proposed LW19A and the valley base is located 850 m this longwall. The maximum predicted incremental valley-related effects occur at Den15a, Den15c, Den34 and Den148 as they are adjacent to or partially above the proposed LW19A.

A summary of the maximum predicted total upsidence and closure for the swamps within the Study Area is provided in Table 5.23. The values are the maximum predicted valley-related effects for each of the swamps due to the mining of LW6 to LW8, LW19 and LW19A.

Table 5.23 Maximum predicted total upsidence and closure for the swamps

Location	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Den12	350	550
Den15a	125	225
Den15b	275	425
Den15c	175	250
Den34	125	225
Den148	225	325

The swamps will also experience compressive strains due to the valley-related effects where they are located near the valley bases. The predicted total compressive strains due to the valley-related effects for the swamps located directly above the mining area are in the order of 10 mm/m to 20 mm/m.

Den15a and most of Den34 are located outside the mining area and they will experience smaller compressive strains due to the valley-related effects. The predicted total compressive strains based on the 95 % confidence levels are 5 mm/m for Den15a and 8 mm/m for Den34.

5.10.3. Previous experience of mining beneath swamps

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.

- *Area 2*

  LW4 and LW5 in Area 2 were extracted directly beneath Den01, which is both a headwater and valley infill swamp located along stream 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. 5.14.

Fig. 5.14 Fracturing in the rockbar downstream of Den01 (Source: IMC)

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

- *Area 3A*

  LW7 in Area 3A was extracted directly beneath Den12, which is a headwater swamp located on the valley side of stream 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 physical changes in the swamp have been observed. Four piezometers have been installed in and around the swamp to measure 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.

- *Area 3B*

  LW9 in Area 3B was extracted directly beneath 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 LW17 which were described in each of the End of Panel Reports (IMC, 2015, 2016, 2017, 2018, 2019, 2020 and 2021a and 2021b). The groundwater levels were lower than baseline and recession rates greater than baseline for Den03, Den05, Den10, Den11, Den13, Den14 and Den23. Soil moisture levels below baseline were also reported in Den05, Den11 and Den23.

5.10.4. 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 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 flows 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.

The maximum predicted total tilt for the swamps is 35 mm/m (i.e. 3.5 %, or 1 in 29). The greatest tilts (i.e. 25 mm/m to 35 mm/m) occur at Den12, Den15b, Den15c and Den148 as they are located directly above the mining area. Den15a, Den34 and Den96 are predicted to experience tilts of less than 0.5 mm/m (i.e. < 0.05 %, or 1 in 2000), 11 mm/m (i.e. 1.1 %, or 1 in 91) and less than 0.5 mm/m (i.e. < 0.05 %, or 1 in 2000), respectively, as they are predominately located outside the mining area.

Den12, Den15a, Den15b, Den15c, Den34 and Den148 are located near the bases of drainage lines WC17, SC10, SC10C, tributary of SC10, WC13 and WC14, respectively. The predicted changes in grade for the drainage lines SC10, WC13(A) and WC14 are illustrated in Fig. 5.6 to Fig. 5.8. There are no predicted substantial reductions or reversals of stream grade along these drainage lines nor within the extents of the swamps. Similarly, there are no substantial changes for the other swamps within the Study Area.

There are small reductions in grades along drainage lines WC13(C) and WC14, upstream of the chain pillars and the edges of the mining area. There is potential for minor and localised increased ponding in these locations, due to the mining-induced tilt, and therefore upstream of Den34 and Den148.

The remaining swamps are located on the valley sides where the natural grades are greater than 100 mm/m (i.e. 10 %, or 1 in 10). These swamps are also located outside the extents of the proposed LW19A and, therefore, are predicted to experience lower mining-induced tilts. It is unlikely, therefore that increased ponding would occur within the extents of these swamps due to mining-induced tilt.

It is considered unlikely, therefore, that there would be adverse changes in the levels of ponding or scouring for the swamps within the Study Area 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.

Den15c, Den34 and Den148 are partially located above the proposed LW19A and Den12, Den15b and Den148 are partially located above the existing LW7 and LW8. The maximum predicted total compressive strains for these swamps due to the valley-related effects are in the order of 10 mm/m to 20 mm/m. However, the valley-related effects for Den12 and Den15b occur predominately due to the existing LW7 and LW8, rather than the proposed LW19A. It is likely, therefore, that fracturing would occur in the bedrock beneath these swamps, predominately in areas located above and adjacent to the mining area.

The typical fracture widths in the bedrock beneath Den12, Den15b, Den15c and Den148 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. 78 % 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.

Den15a is located outside and adjacent to the mining area and Den34 is generally located outside the mining area apart from its northern extent. The maximum predicted total compressive strains for these swamps due to the valley-related effects are between 5 mm/m and 8 mm/m based on the 95 % confidence levels. Fracture widths in the order of 20 mm to 50 mm have been observed due to valley closure effects at similar distances from longwall mining. It is possible that a series of smaller fractures, rather than one single fracture, could develop in the bedrock.

Den96 is located 400 m from the proposed LW19A and it is situated on a valley-side. This swamp is not predicted to experience measurable conventional or valley-related effects. Fracturing or surface cracking due to mine subsidence are therefore not anticipated at Den96 due to the mining of LW19A.

Den12, Den15b, Den15c and Den148 are located above the mining area and are predicted to experience upsidence of 175 mm to 350 mm. These valley-related effects could result in the dilation of the strata beneath these swamps. It has been previously observed that the depth of fracturing and dilation of the uppermost bedrock, resulting from valley-related movements, 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 upstream of Den12, Den15b, Den15c and Den148 could result in the diversion of some surface water flows beneath parts of these swamps where they are located directly above the mining area. 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. Den12 and Den15b are located directly above LW7 and LW8 and, therefore, the potential impacts predominately occur due to these existing longwalls, rather than the proposed LW19A. Only a small area of Den148 are located directly above the proposed LW19A.

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.

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

5.10.5. 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.

5.11. Flora and fauna

The land above the longwalls in Area 3A largely consists of undisturbed native bush, as shown in Fig. 1.1. 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 longwall are provided in Sections 5.2 to 5.10. Assessments of the environmental consequences have been provided by the other specialist consultants on the project.

Assessments for the aquatic and terrestrial ecology are provided by Cardno (2022) and Niche (2022a).

The following sections provide the descriptions, predictions and impact assessments for the built features within the Study Area. The 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. MSEC1234-10.

Fire Road 6F crosses directly above the existing LW6 to LW8, the future LW19 and proposed LW19A. 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

Fire Road 6F and other unsealed roads and tracks are located directly above the mining area and, therefore, they 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 fire roads is provided in Table 6.1. The values in this table are the maximum predicted subsidence effects due to the mining of LW6 to LW8, LW19 and LW19A.

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

Location	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})
Fire roads	LW6 to LW8, LW19 and LW19A	3250	40	1.0	1.0

The maximum predicted total tilt for the fire roads 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 represent a minimum radius of curvature of 1 km.

The maximum predicted conventional strains for the fire roads, 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.

6.1.3. Impact assessments for the unsealed roads and tracks

Fire Road 6F and other unsealed roads and tracks are located directly above the proposed LW19A. It is possible that cracking, rippling and stepping of the unsealed road surfaces could occur due to the mining of this longwall. The estimated crack widths in the fire roads, 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.

The typical fracture widths 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. 78 % 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.

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. Similar impacts are anticipated for Fire Road 6F and other unsealed roads and tracks due to the mining of the proposed LW19A.

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 Road 6F and the other unsealed roads and tracks 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 affected by subsidence at Dendrobium Mine. It is recommended that these management strategies are reviewed and updated to incorporate the proposed LW19A. 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 existing LW6 to LW8, the future LW19 and proposed LW19A in Area 3A. The location of the 330 kV transmission line is shown in Drawing No. MSEC1234-10.

There are two transmission towers (Refs. 14 and 15) that are located within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. A summary of the transmission towers within the Study Area is provided in Table 6.2.

Table 6.2 Transmission towers located within the Study Area

Feature	Tower ref.	Type	Footing	Distance from LW19
330 kV transmission line	14	Suspension	Piles	Directly above LW19A, 80 m north of maingate
	15	Suspension	Cruciform	Directly above LW8 and 430 m north of LW19A

Photographs of a typical transmission tower are 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.07, in Appendix C. The predicted total profiles after the mining of the existing LW6 to LW8 and the future LW19 are shown as cyan lines. The predicted total profiles after the mining of the proposed LW19A are shown as the blue lines.

A summary of the maximum predicted values of incremental 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 additional subsidence effects anywhere along the transmission line (i.e. not necessarily at the tower locations) due to the mining of LW19A only.

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

Due to longwall	Maximum predicted total incremental subsidence (mm)	Maximum predicted incremental tilt along alignment (mm/m)	Maximum predicted incremental tilt across alignment (mm/m)
LW19A	2400	30	9

The maximum predicted incremental tilts for the 330 kV transmission line due to the mining of LW19A only are 30 mm/m (i.e. 3.0 % or 1 in 33) along the alignment and 9 mm/m (0.9 % or 111) across the alignment.

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 6.4. The values are the maximum predicted accumulated 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 and the predicted incremental 20 mm subsidence contour, due to the mining of LW6 to LW8, LW19 and LW19A.

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

After longwalls	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)
LW6 to LW8 and LW19	2700	30	9
LW19A	3100	30	9

The predicted subsidence effects at the tower locations are similar to or less than the maximum predicted values anywhere along the transmission line provided in Table 6.3 and Table 6.4 above.

A summary of the maximum predicted incremental vertical subsidence, tilt and curvature at each of the tower locations is provided in Table 6.5. The values are the maximum predicted additional subsidence effects within a distance of 20 m from the centre of each tower due to the mining of LW19A only.

Table 6.5 Maximum predicted incremental subsidence and tilt for the transmission towers

Tower ref.	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
14	2000	30	0.50	0.80
15	70	0.5	< 0.01	< 0.01

The maximum predicted incremental tilt for Tower 14 due to the mining of LW19A only is 30 mm/m (i.e. 3.0 % or 1 in 33). This tilt is orientated perpendicular to the main axis of the proposed LW19A (i.e. approximately 11° clockwise from true north) and, therefore, it is slightly oblique to the alignment of the transmission line. The maximum predicted incremental curvatures for Tower 14 are 0.50 km^{-1} hogging and 0.80 km^{-1} sagging, which represent minimum radii of curvatures of 2.0 km and 1.3 km, respectively.

The maximum predicted incremental vertical subsidence for Tower 15 due to the mining of LW19A only is 70 mm. While this tower could experience low level vertical subsidence, it is not predicted to experience measurable tilts, curvatures or strains. Only low level subsidence effects are predicted at Tower 15 since it is located 430 m from LW19A.

A summary of the maximum predicted total vertical subsidence, tilt and curvature at each of the tower locations is provided in Table 6.6. The values are the maximum predicted accumulated subsidence effects within a distance of 20 m from the centre of each tower due to the mining of LW6 to LW8, LW19 and LW19A.

Table 6.6 Maximum predicted total subsidence and tilt for the transmission towers

Tower ref.	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})
14	2150	35	0.60	0.80
15	1700	12	0.35	0.09

The maximum predicted total tilt at Tower 14 is 35 mm/m (i.e. 3.5 % or 1 in 29). This tilt is orientated perpendicular to the main axis of the proposed LW19A (i.e. approximately 11° clockwise from true north) and, therefore, it is slightly oblique to the alignment of the transmission line. The components of tilt at Tower 14 are 30 mm/m (i.e. 3.0 % or 1 in 33) along the alignment (i.e. towards north) and 9 mm/m (0.9 % or 111) across the alignment (towards east) of the transmission line.

The predicted total tilt at Tower 15 is 12 mm/m (i.e. 1.2 % or 1 in 83). The components of tilt at this tower are 11 mm/m (i.e. 1.1 % or 1 in 91) along the alignment (i.e. towards north) and 3.5 mm/m (0.35 % or 286) across the alignment (i.e. towards east) of the transmission line. The tilt at Tower 15 occurs predominately due to the mining of the existing LW6 to LW8 and the future LW19, and the additional effects due to the mining of the proposed LW19A are not expected to be measurable.

The maximum predicted total horizontal movement of the ground at Tower 14 is 525 mm. The components of horizontal movement at this tower are 450 mm along the alignment (i.e. towards north) and 135 mm across the alignment (towards east) of the transmission line. The maximum predicted total horizontal movement at the top of Tower 14 (assuming a height of 50 m) therefore is approximately 2 m.

The maximum predicted conventional strains for the transmission towers, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 9 mm/m tensile and 12 mm/m compressive. The distribution of the predicted strains due to the mining 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.

A summary of the maximum predicted values of incremental extension and contraction between the tops of the transmission towers is provided in Table 6.7. The values are the maximum predicted changes in the spans due to the mining of LW19A only.

Table 6.7 Maximum predicted incremental extension and contraction between the tops of the towers along the 330 kV transmission line

Span	Maximum predicted incremental extension (+ve) or contraction (-ve) due to LW19A only (mm)
12 to 13	< ±20
13 to 14	+1900
14 to 15	-1900
15 to 16	< ±20

The mining of LW19A is predicted to cause an extension of 1900 mm between the tops of Towers 13 and 14 and a contraction of -1900 mm between the tops of Towers 14 and 15. Very small changes are predicted for other spans along the transmission line.

A summary of the maximum predicted values of total extension and contraction between the tops of the transmission towers is provided in Table 6.8. The values are the maximum predicted changes in the spans at any time during the mining of LW6 to LW8, LW19 and LW19A.

Table 6.8 Maximum predicted total extension and contraction between the tops of the towers along the 330 kV transmission line

Span	Maximum predicted transient or total extension (mm)	Maximum predicted transient or total contraction (mm)	Final predicted extension (+ve) or contraction (-ve) after the completion of LW19A (mm)
13 to 14	1950	< 20	1950
14 to 15	425	-1600	-1600

The maximum predicted total differential movements between the tops of the transmission towers are 1950 mm extension between Towers 13 and 14 and -1600 mm contraction between Towers 14 and 15.

6.2.3. Impact assessments for the 330 kV transmission line

The maximum predicted total differential movements between the tops of the transmission towers are 1950 mm extension and 1600 mm contraction. These values represent the total effects due to the mining of the existing LW6 to LW8, the future LW19 and proposed LW19A.

It is recommended that the predicted subsidence effects for 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.

The predicted total strains at Towers 14 and 15 are 8 mm/m tensile and compressive based on the 95 % confidence levels. These values represent the total effects due to the mining of the existing LW6 to LW8, the future LW19 and proposed LW19A. Tower 15 has a cruciform base and, therefore, it will not experience the mining-induced strains.

The measured changes in k-point distances for Towers 15 and 16, due to the mining of LW6 to LW8, were in the order of ±1 mm. Only very small movements were measured between the tower legs as they were constrained by the cruciform bases. The transmission towers did not experience adverse impacts due to the mining of LW6 to LW8 in Area 3A. It is unlikely, therefore, that Tower 15 would experience adverse impacts, due to the mining of the proposed LW19A, due to its cruciform base.

Tower 14 does not have a cruciform base and, therefore, it will experience the predicted ground strains. The predicted changes in the k-point distances for this tower based on an 8 m span, therefore, are 64 mm extension and contraction. It is noted that the predicted strains have been derived from ground monitoring data and it likely to include a component of survey tolerance.

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 Tower 14 are anticipated, then these could be managed with the installation of a cruciform base, as previously carried out on Towers 15 and 16.

With the implementation of the appropriate 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 previous extraction of LW6 to LW8 in Area 3A.

6.2.4. 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 management strategies are developed, in consultation with TransGrid, which could include the installation of cable rollers, the construction of an additional cruciform base, the provision of monitoring points on the tower bases and tops, and the development of a TARP.

6.3. Dams, reservoirs or associated works

6.3.1. Descriptions of the reservoirs

Dendrobium Mine is located within the Metropolitan Special Area. There are two reservoirs located in the vicinity of the mining area, as shown in Drawing No. MSEC1234-01.

The Cordeaux Reservoir, also known as Lake Cordeaux, is located 1.4 km north-east of the proposed LW19A, at its closest point. The Cordeaux Dam Wall is located more than 5 km north of this longwall. The Upper Cordeaux No. 1 and No. 2 Dams are located more than 3 km south-east of the proposed LW19A.

The Avon Reservoir, also known as Lake Avon, is located more than 3 km west of the proposed LW19A. The existing longwalls in Area 3B are located between LW19A and the reservoir. The Avon Dam Wall is located more than 5 km north-west of the proposed LW19A.

6.3.2. Predictions for the reservoirs

The Cordeaux and Avon Reservoirs are located at minimum distances of 1.4 km and more than 3 km, respectively, from the proposed LW19A. At these distances, the reservoirs are not predicted to experience measurable conventional or valley-related effects.

The dam walls associated with the Cordeaux and Avon Reservoirs are located more than 3 km from the proposed LW19A. At these distances, the dam walls are not predicted to experience measurable conventional, valley-related or far-field effects.

6.3.3. 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 Upper Cordeaux No. 2 reservoir is shown in Drawing No. MSEC1234-01.

The mine subsidence movements 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 SCA monitoring report entitled *Upper Cordeaux No. 2 – Dam Wall & Ground Monitoring – Survey No 9a Report – April 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.

6.3.4. Impact assessments for the reservoirs

The predicted vertical and horizontal movements at the Cordeaux and Avon Reservoirs and their associated dam walls are very small and are unlikely to be measurable. Previous experience of mining in Areas 1, 2, 3A and 3B has not resulted in adverse impacts on these structures.

The dam walls associated with the Cordeaux and Avon Reservoirs are located more than 3 km from the proposed LW19A. It is unlikely, therefore, that the reservoirs and dam walls would experience adverse impacts due to the extraction of the proposed LW19A.

6.3.5. Recommendations for the reservoirs

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

6.4. Aboriginal heritage sites

6.4.1. Descriptions of the Aboriginal heritage sites

The locations of the Aboriginal heritage sites are shown in Drawing No. MSEC1234-10. The details of the heritage sites have been provided by Niche (2022b).

There are four Aboriginal heritage sites that have been identified within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. There are also five additional sites that are located within 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 they have therefore been included in the assessments.

Details of the Aboriginal heritage sites located within Study Area based on the 600 m boundary are provided in Table 6.9.

Table 6.9 Aboriginal heritage sites identified within the Study Area

Reference	Type	Location
52-2-1643	Shelter with Art and Deposit	Outside the mining area, 590 m south of LW19A
52-2-1644	Shelter with Art	Outside the mining area, 350 m south of LW19A
52-2-1645	Shelter with Art	Outside the mining area, 390 m south of LW19A
52-2-1646	Shelter with Art	Outside the mining area, 200 m west of LW19A
52-2-3639	Shelter with Art	Directly above LW19, 200 m north-west of LW19A
52-2-3644	Shelter with Art	Directly above pillar for LW19, 350 m north-west of LW19A
52-5-0271	Shelter with Art	Outside the mining area, 560 m south of LW19A
52-5-0272	Shelter with Art	Outside the mining area, 320 m south of LW19A
52-5-0273	Shelter with Art	Directly above LW19, 60 m north of LW19A

Site 52-2-1646 is located 200 m west of the finishing end of the proposed LW19A. A longitudinal section through this site and the longwall is provided in Fig. 6.4. Site 52-2-1646 is located coincident with the 35° angle of draw line. It is noted that Drawings Nos. MSEC1234-01 and 02 show Site 52-2-1646 located within the Study Area based on the 35° angle of draw as that boundary is based on the depth of cover above the perimeter of the mining area and, therefore, it does not consider the reducing surface level outside the mining area.

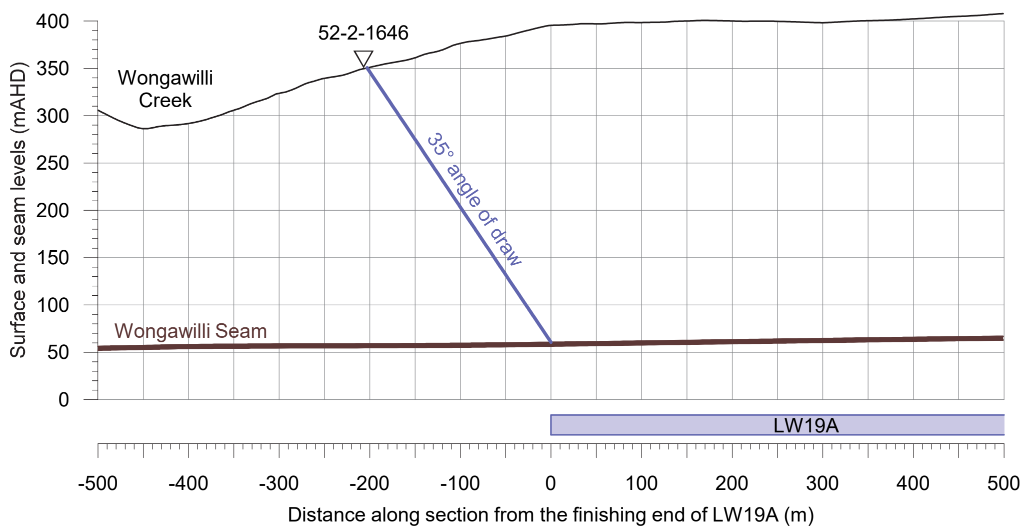

Fig. 6.4 Longitudinal section through Site 52-2-1646 and the proposed LW19A

Further details on the Aboriginal heritage sites are provided in the report by Niche (2022b).

6.4.2. Predictions for the Aboriginal heritage sites

A summary of the maximum predicted incremental vertical subsidence, tilt and curvatures for the Aboriginal heritage sites located within the Study Area based on the 600 m boundary is provided in Table 6.10. The values are the maximum predicted additional subsidence effects within 20 m of the identified locations of each of the sites due to the mining of LW19A only.

Table 6.10 Maximum predicted incremental vertical subsidence, tilt and curvatures for the Aboriginal heritage sites

Reference	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
52-2-1643	< 20	< 0.5	< 0.01	< 0.01
52-2-1644	< 20	< 0.5	< 0.01	< 0.01
52-2-1645	< 20	< 0.5	< 0.01	< 0.01
52-2-1646	< 20	< 0.5	< 0.01	< 0.01
52-2-3639	< 20	< 0.5	< 0.01	< 0.01
52-2-3644	150	1.5	0.01	0.01
52-5-0271	< 20	< 0.5	< 0.01	< 0.01
52-5-0272	< 20	< 0.5	< 0.01	< 0.01
52-5-0273	950	4.5	0.15	0.06

The maximum predicted incremental vertical subsidence for Sites 52-2-3644 and 52-5-0273 are 150 mm and 950 mm, respectively. The remaining sites are predicted to experience incremental subsidence of less than 20 mm due to the mining of LW19A.

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the Aboriginal heritage sites located within the Study Area based on the 600 m boundary is provided in Table 6.11. The values are the maximum predicted subsidence effects within 20 m of the identified locations of each of the sites due to the mining of LW6 to LW8, LW19 and LW19A.

Table 6.11 Maximum predicted total vertical subsidence, tilt and curvatures for the Aboriginal heritage sites

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})
52-2-1643	< 20	< 0.5	< 0.01	< 0.01
52-2-1644	< 20	< 0.5	< 0.01	< 0.01
52-2-1645	< 20	< 0.5	< 0.01	< 0.01
52-2-1646	< 20	< 0.5	< 0.01	< 0.01
52-2-3639	2350	30	0.05	0.65
52-2-3644	1450	5.5	0.15	0.09
52-5-0271	< 20	< 0.5	< 0.01	< 0.01
52-5-0272	< 20	< 0.5	< 0.01	< 0.01
52-5-0273	1400	10	0.35	0.06

Sites 52-2-3639 and 52-2-3644 are located above the future LW19 and they are at distances of 200 m and 350 m, respectively, from the proposed LW19A. The predicted total subsidence effects at these sites are predominately due to the mining of the future LW19 rather than the proposed LW19A. The predicted additional subsidence for Site 52-2-3639 due to the mining of LW19A only is less than 20 mm. While this site could experience very low levels of vertical subsidence due to the mining of the proposed LW19A only, it is not predicted to experience measurable additional tilts, curvatures or strains.

Site 52-5-0273 is also located directly above the future LW19 and it is 60 m north of the proposed LW19A. The predicted total subsidence effects at this site are due to the mining of both these longwalls. The maximum predicted total tilt is 10 mm/m (i.e. 1 % or 1 in 100). The maximum predicted total conventional curvatures are 0.35 km^{-1} hogging and 0.06 km^{-1} sagging, which represent minimum radii of curvature of 2.9 km and 17 km, respectively.

The remaining sites are predicted to experience total vertical subsidence of less than 20 mm. While the sites located closest to the mining area could experience very low levels of vertical subsidence, they are not predicted to experience measurable tilts, curvature or strains.

The Aboriginal heritage sites within the Study Area based on the 600 m boundary are located on the sides of ridgelines where there are no significant surface incisions. These sites are therefore not expected to experience measurable valley-related upsidence or compressive strain due to valley closure.

Site 52-2-1646 is located on the eastern valley side of Wongawilli Creek approximately 200 m west of the finishing end of the proposed LW19A. The mining of LW19A could result in increased horizontal movements in the downslope direction on the eastern valley side. However, the longwall does not mine directly beneath the valley side and therefore there is reduced potential for the development of both the valley-related and conventional components of horizontal movement.

The predicted strain at Site 52-2-1646 has been determined based on statistical analyses of monitoring lines from the NSW coalfields where the mining geometry (i.e. width-to-depth ratio and mining height) are similar to those for the proposed LW19A.

The analysis initially considered the strains measured in survey bays located at distances between 100 m and 300 m from longwall mining regardless of the surface terrain (i.e. flat, steep slopes or incised). The measured total tensile strains from this analysis (366 cases) have a mean of 0.23 mm/m and a standard deviation of 0.31 mm/m. The measured movements are therefore similar to the order of survey tolerance of ±0.25 mm/m.

The analysis then considered the strains for survey bays located at distances between 100 m and 300 m from longwall mining for steep slopes only (i.e. grades greater than 1 in 3). The measured total tensile strains from this analysis (51 cases) have a mean of 0.21 mm/m and a standard deviation of 0.22 mm/m. While the measured strains for steep slopes are less than that for the initial analysis, this is likely due to the smaller sample size and the influence of survey tolerance. An analysis of variance shows that there is no statistical difference between the two data sets. This is not unexpected based on the distance from the mining area where strains are predominately governed by survey tolerance.

On this basis, the predicted tensile strain at Site 52-2-1646 therefore is less than 0.5 mm/m.

6.4.3. Impact assessments for the Aboriginal heritage sites

The impact assessments for the Aboriginal heritage sites are provided below. These assessments should be read in conjunction with the assessments by Niche (2022b) and SCT (2022).

Sites 52-2-3639, 52-2-3644 and 52-5-0273

There are three rock shelters located directly above the mining area, being Sites 52-2-3639, 52-2-3644 and 52-5-0273. These site are above the future LW19 or its chain pillar and they are located at distances ranging between 65 m and 350 m from the proposed LW19A.

The predicted subsidence for Sites 52-2-3639, 52-2-3644 and 52-5-0273 varies between 1400 mm and 2350 mm. The subsidence effects for Sites 52-2-3639 and 52-2-3644 predominately occur due to the mining of the future LW19 and only low-level additional movements are predicted due to the mining of the proposed LW19A. The predicted subsidence effects for Site 52-5-0273 are due to the mining of both LW19 and LW19A.

It is extremely difficult to assess the likelihood of impacts on rock shelters based upon predicted subsidence effects. The likelihood of a rock fall 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 effects.

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 mining of the existing, future and 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.

The potential for adverse physical impacts (i.e. rock fracturing, spalling, etc.) for Sites 52-2-3639, 52-2-3644 and 52-5-0273 has therefore been assessed as *unlikely* (i.e. less than 10 %) for each of these sites. Hence, it is possible that at least one of these sites could experience fracturing that could potentially cause spalling or rock falls.

The predicted subsidence effects and, hence, the potential for adverse impacts for Sites 52-2-3639 and 52-2-3644 are predominately due to the future LW19 rather than the proposed LW19A. The potential for adverse impacts for Site 52-5-0273 is due to the combination of both LW19 and LW19A.

Further discussions on Sites 52-2-3639, 52-2-3644 and 52-5-0273 are provided by Niche (2022b).

Site 52-2-1646

Site 52-2-1646 is a significant rock shelter located approximately 200 m west of the finishing end of the proposed LW19A. At this distance, this site is predicted to experience vertical subsidence of less than 20 mm. While Site 52-2-1646 could experience very low-levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains.

The site is located on the eastern valley side of Wongawilli Creek. The mining of the proposed LW19A could cause increased horizontal movements in the downslope direction. However, the longwall does not mine directly beneath the valley side and therefore there is reduced potential for both the development of the valley-related and conventional components of horizontal movement.

The predicted tensile strain at Site 52-2-1646 is less than 0.5 mm/m. Based on the predicted subsidence effects and the distance of the site from the proposed LW19A, the likelihood of adverse physical impacts (i.e. rock fracturing, spalling, etc.) for Site 52-2-1646 is considered to be very rare (i.e. less than 1 %).

Further discussions on Site 52-2-1646 are provided by Niche (2022b) and SCT (2022).

Remaining sites

The remaining sites (Refs. 52-2-1643, 52-2-1644, 52-2-1645, 52-5-0271 and 52-5-0272) are rock shelters located outside the mining area at distances ranging between 320 m and 590 m from the proposed LW19A.

These sites are all predicted to experience vertical subsidence of less than 20 mm. While they could experience very low-levels of vertical subsidence, they are not expected to experience measurable conventional tilts, curvatures or strains.

Based on the predicted subsidence effects and the distances of the sites from the proposed LW19A, the likelihood of adverse physical impacts (i.e. rock fracturing, spalling, etc.) for Sites 52-2-1643, 52-2-1644, 52-2-1645, 52-5-0271 and 52-5-0272 is considered to be very rare (i.e. less than 1 %).

Further discussions on Sites 52-2-1643, 52-2-1644, 52-2-1645, 52-5-0271 and 52-5-0272 are provided by Niche (2022b).

6.4.4. 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.

6.5. Survey control marks

The locations of the survey control marks are shown in Drawing No. MSEC1234-10. The locations and details of the survey control marks were obtained from *Spatial Services* using the *SCIMS Online* website (SCIMS, 2022).

There are no survey control marks located within the Study Area based on the 600 m boundary. The nearest mark is SS 66043 located 560 m north of the existing LW6. There are also other survey control marks located further afield.

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 proposed longwall. 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 mining of LW6 to LW8, LW19 and LW19A

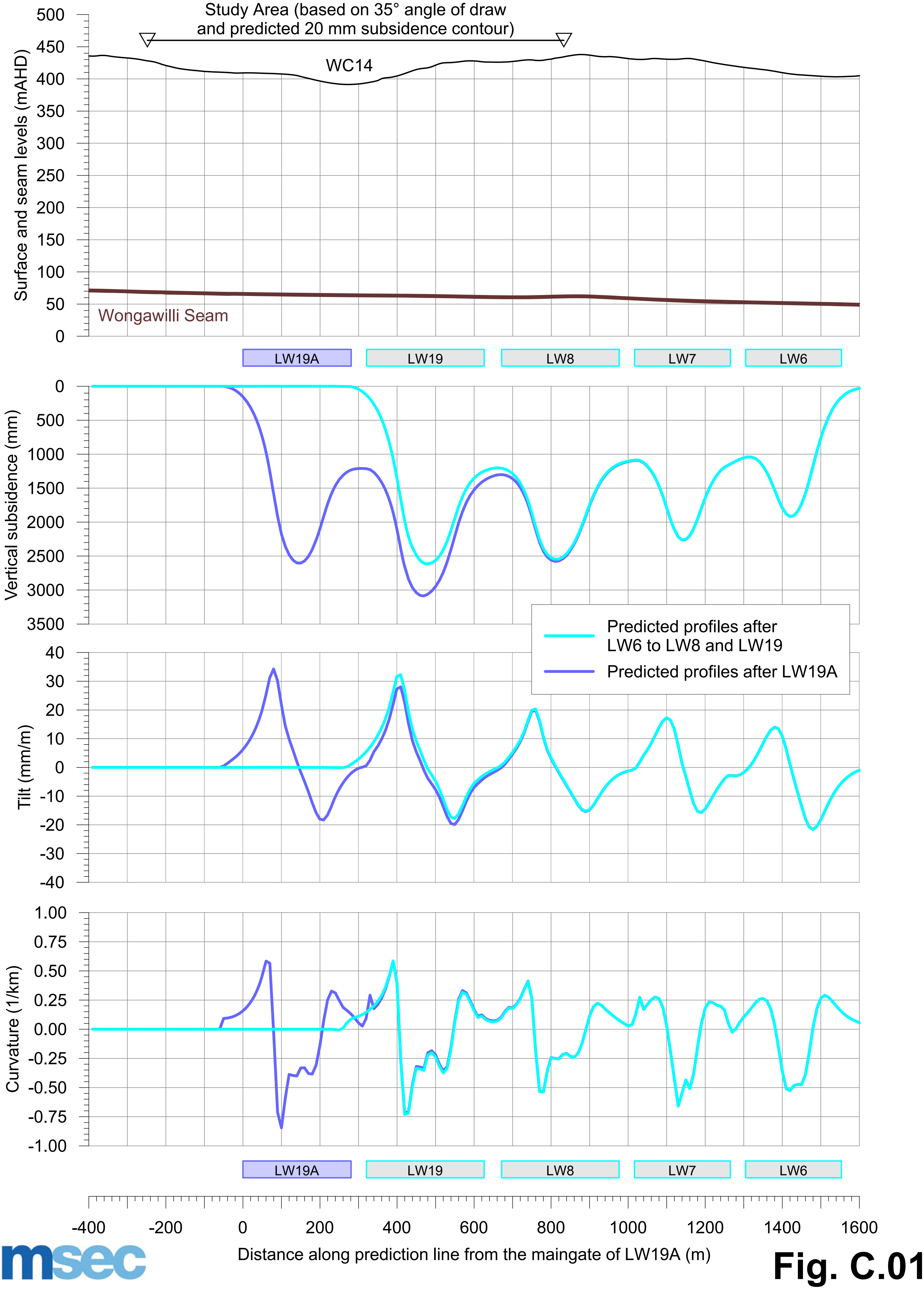

Fig. C.01

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to the mining of LW6 to LW8, LW19 and LW19A

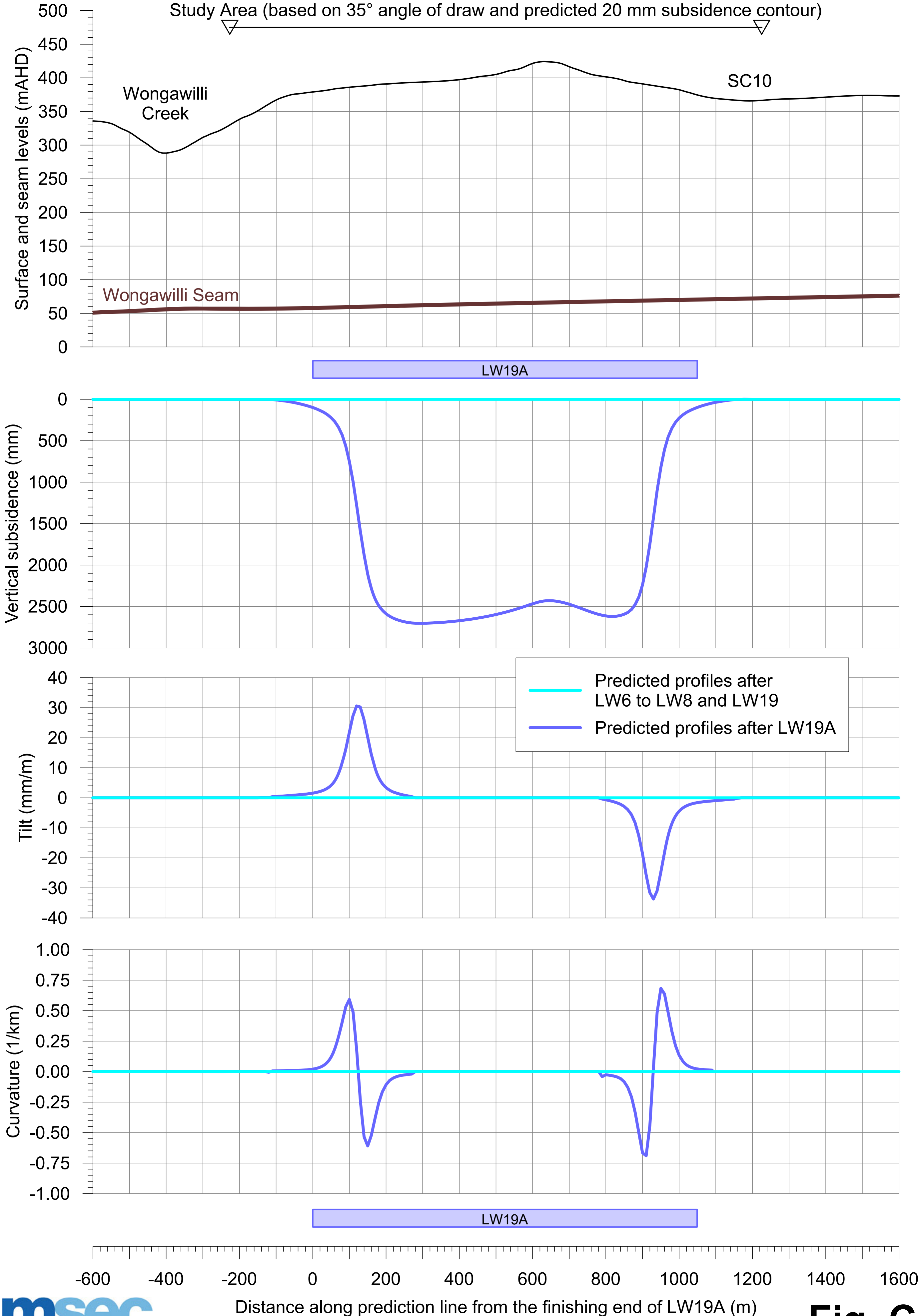

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Fig. C.02

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

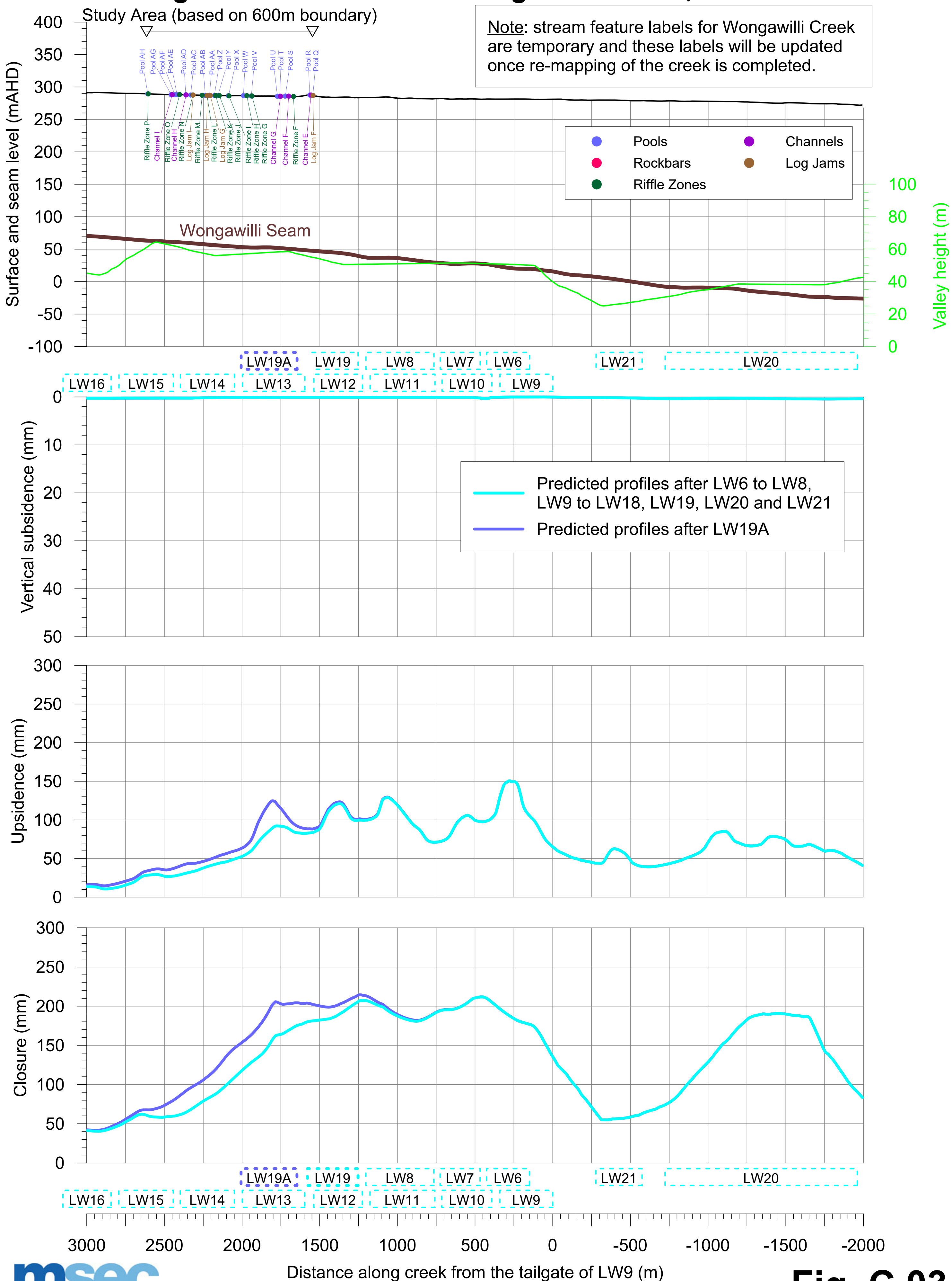

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Fig. C.03

Predicted profiles of vertical subsidence, upsidence and closure along Stream SC10 due to the mining of LW6 to LW8, LW19 and LW19A

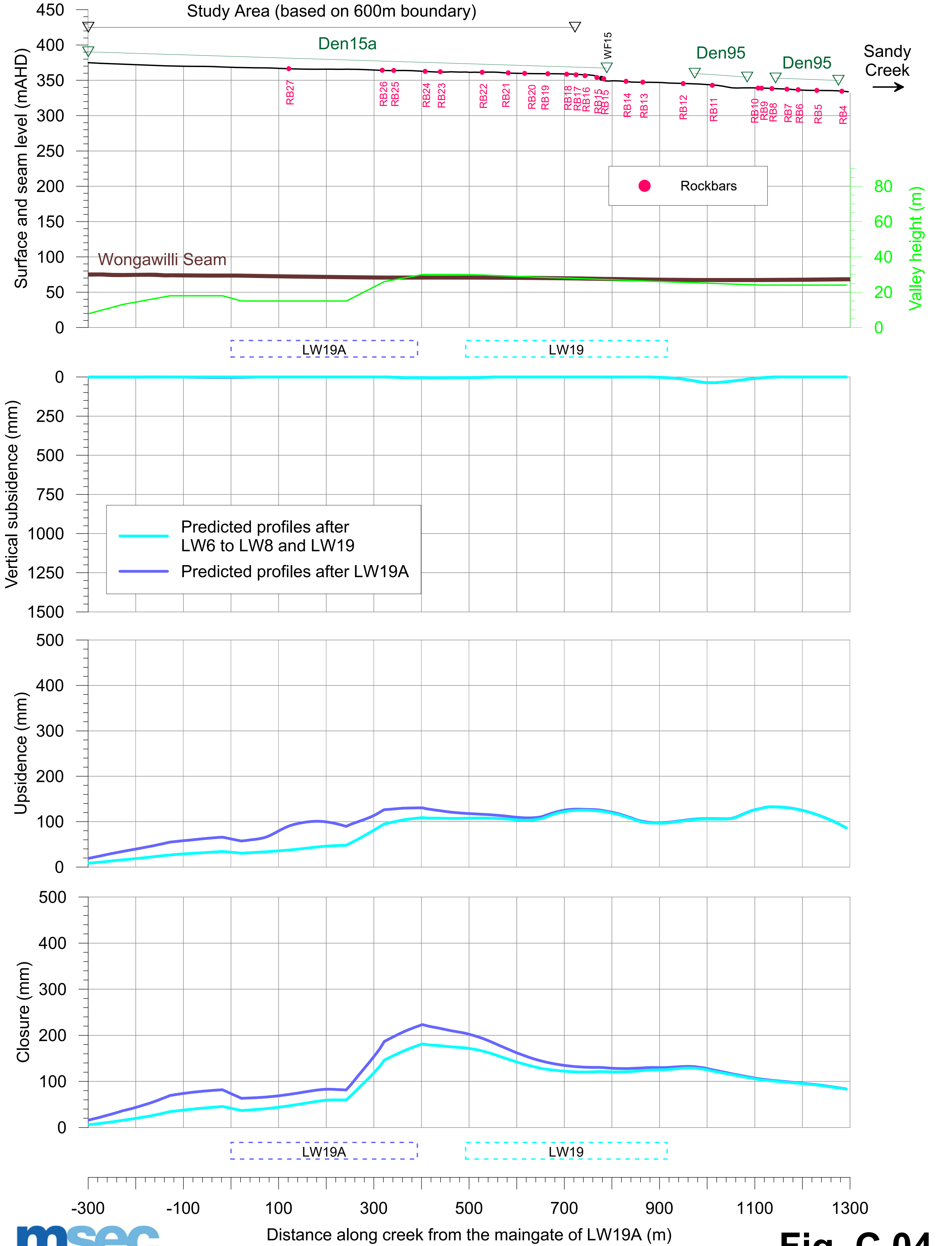

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Fig. C.04

Predicted profiles of vertical subsidence, upsidence and closure along Stream WC13(A) due to the mining of LW6 to LW8, LW19 and LW19A

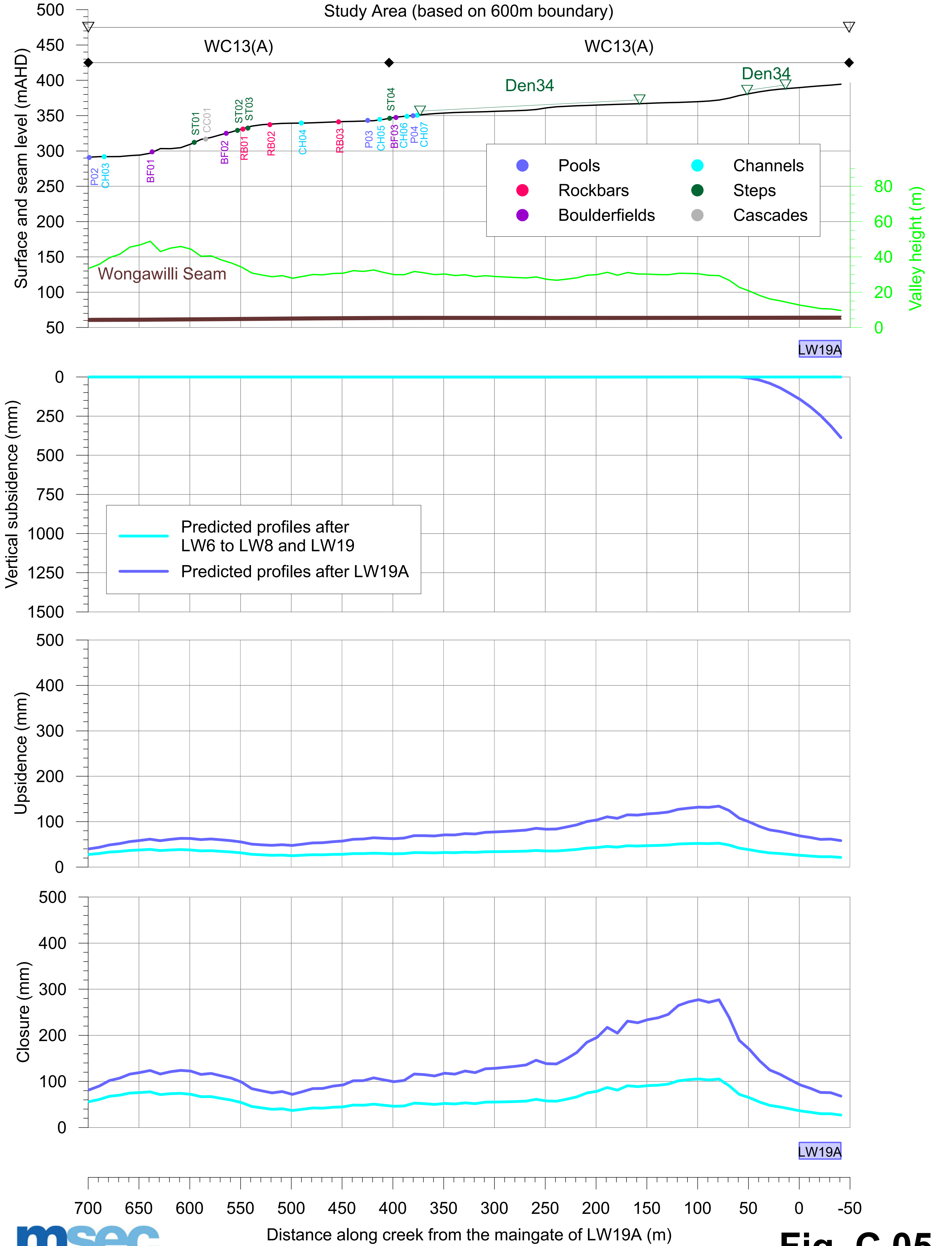

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Fig. C.05

Predicted profiles of vertical subsidence, upsidence and closure along Stream WC14 due to the mining of LW6 to LW8, LW19 and LW19A

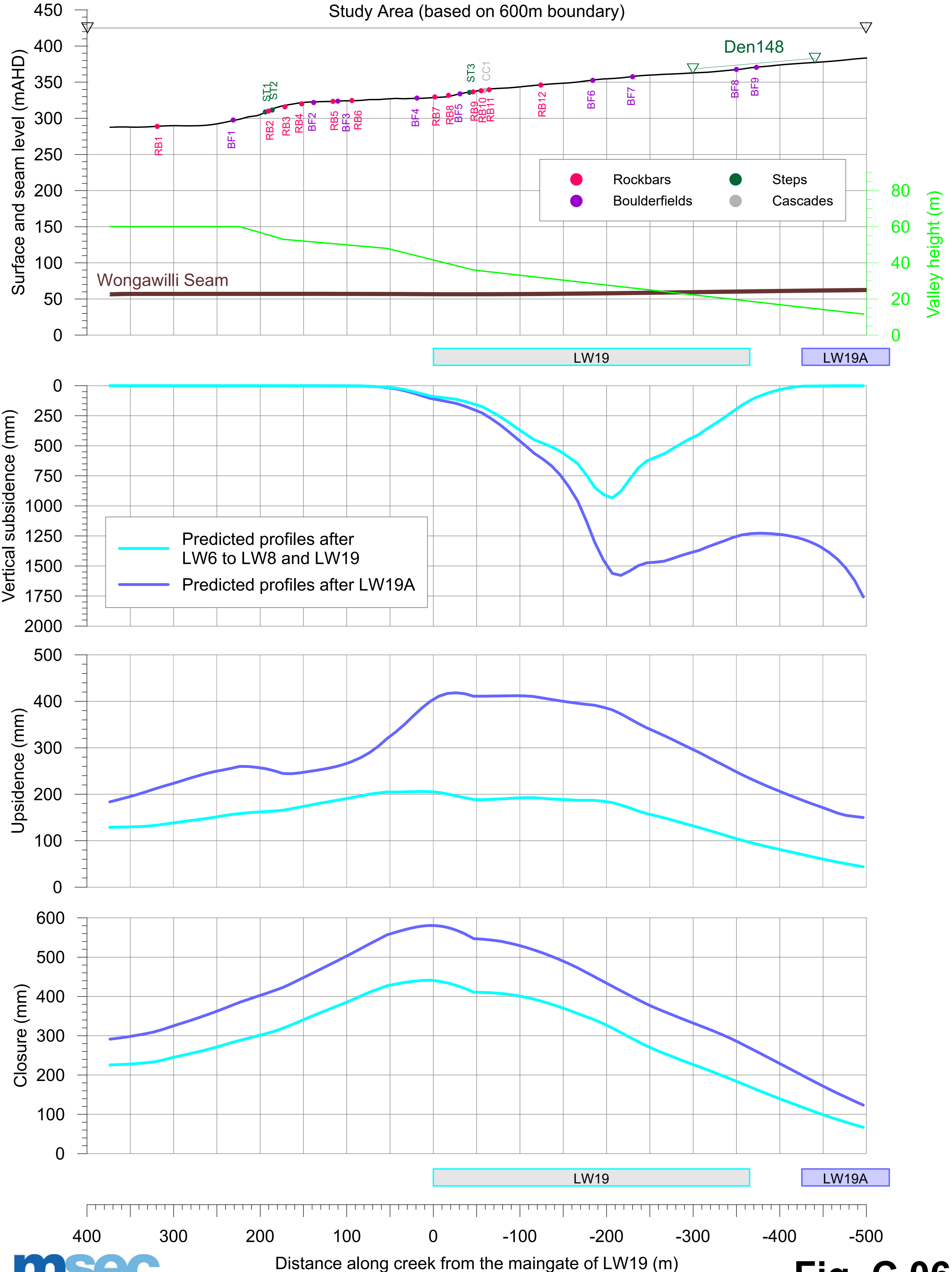

Fig. C.06

Predicted profiles of vertical subsidence, tilt along and tilt across the 330 kV transmission line due to the mining of LW6 to LW8, LW19 and LW19A

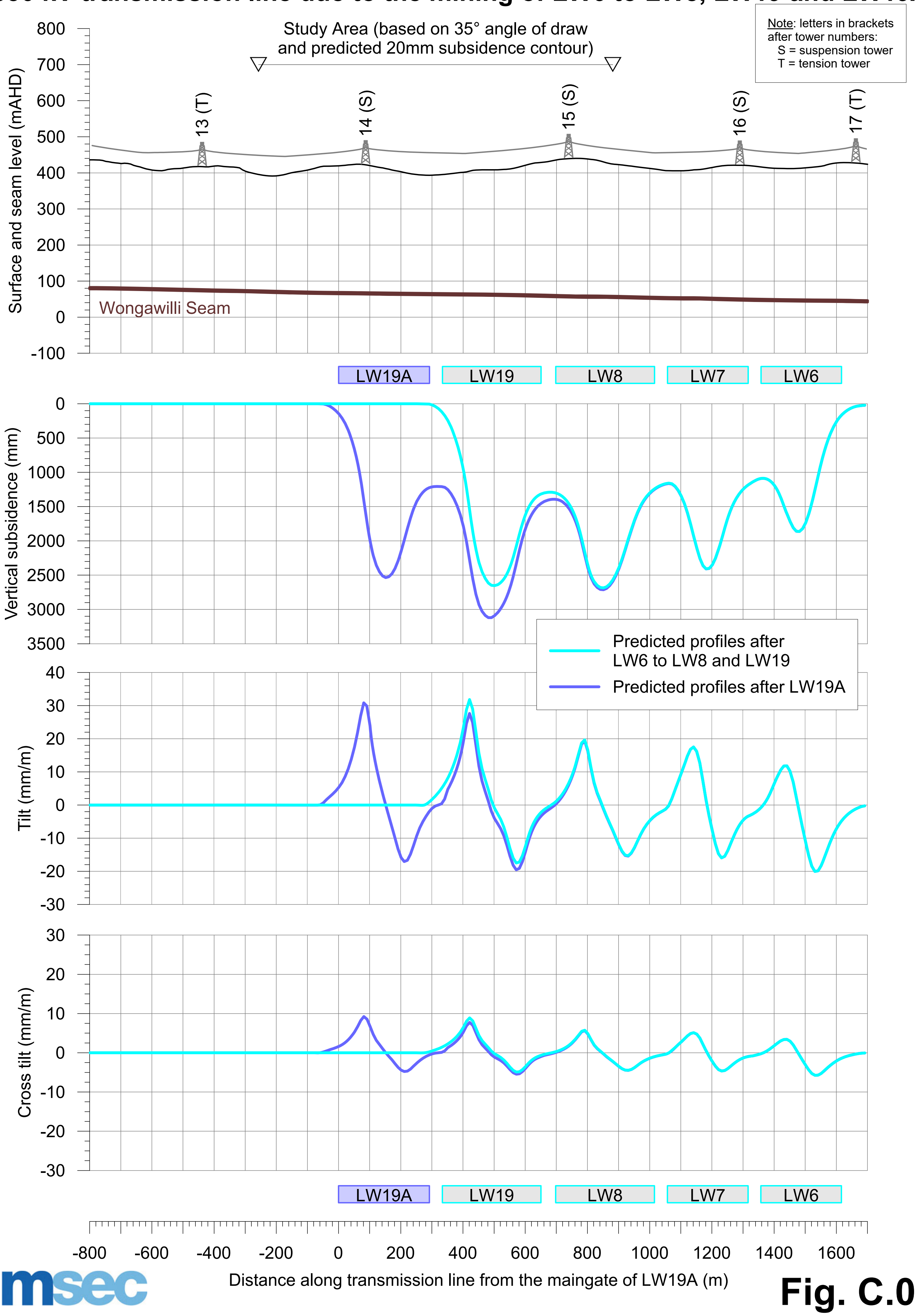

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Fig. C.07

APPENDIX D. DRAWINGS

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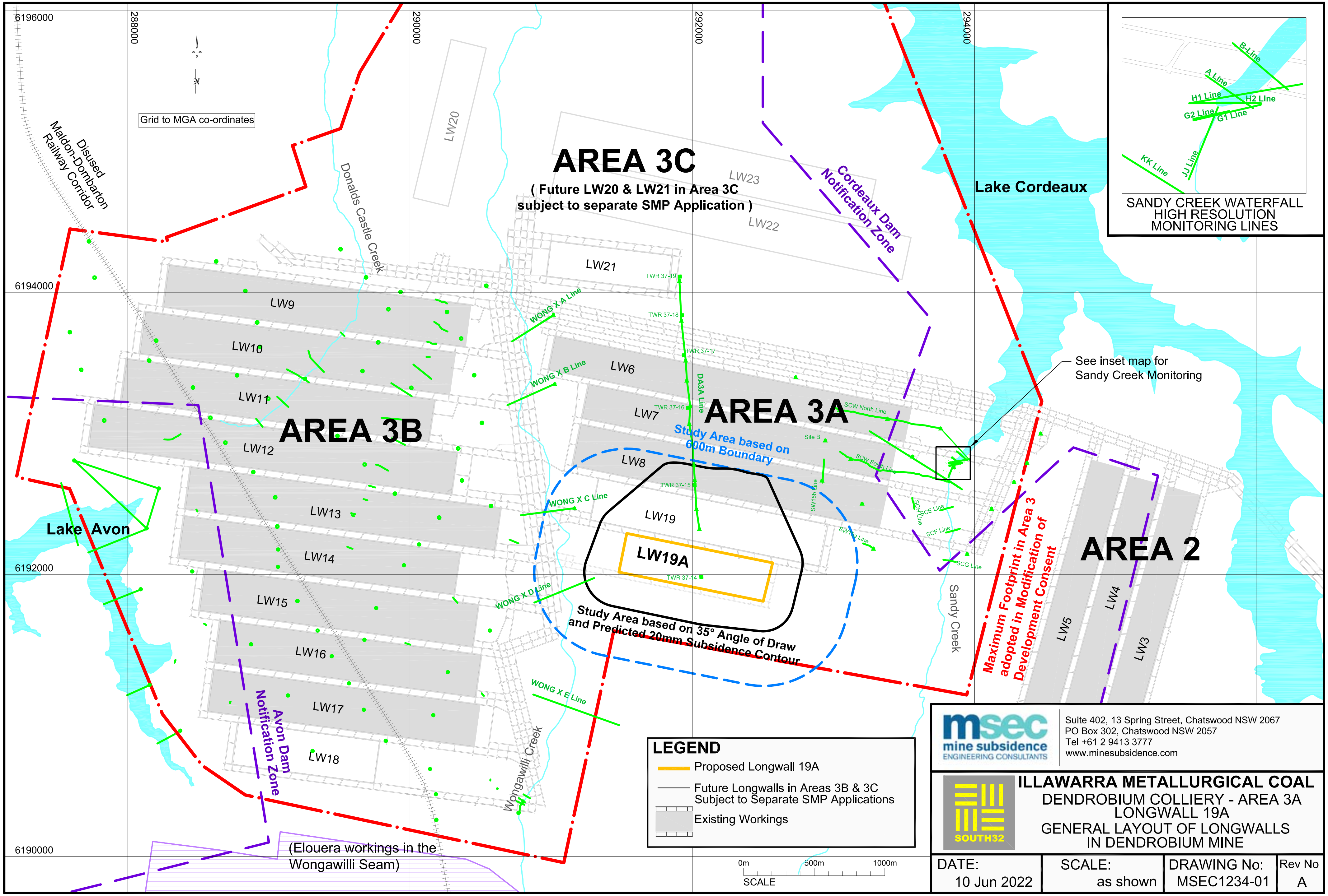

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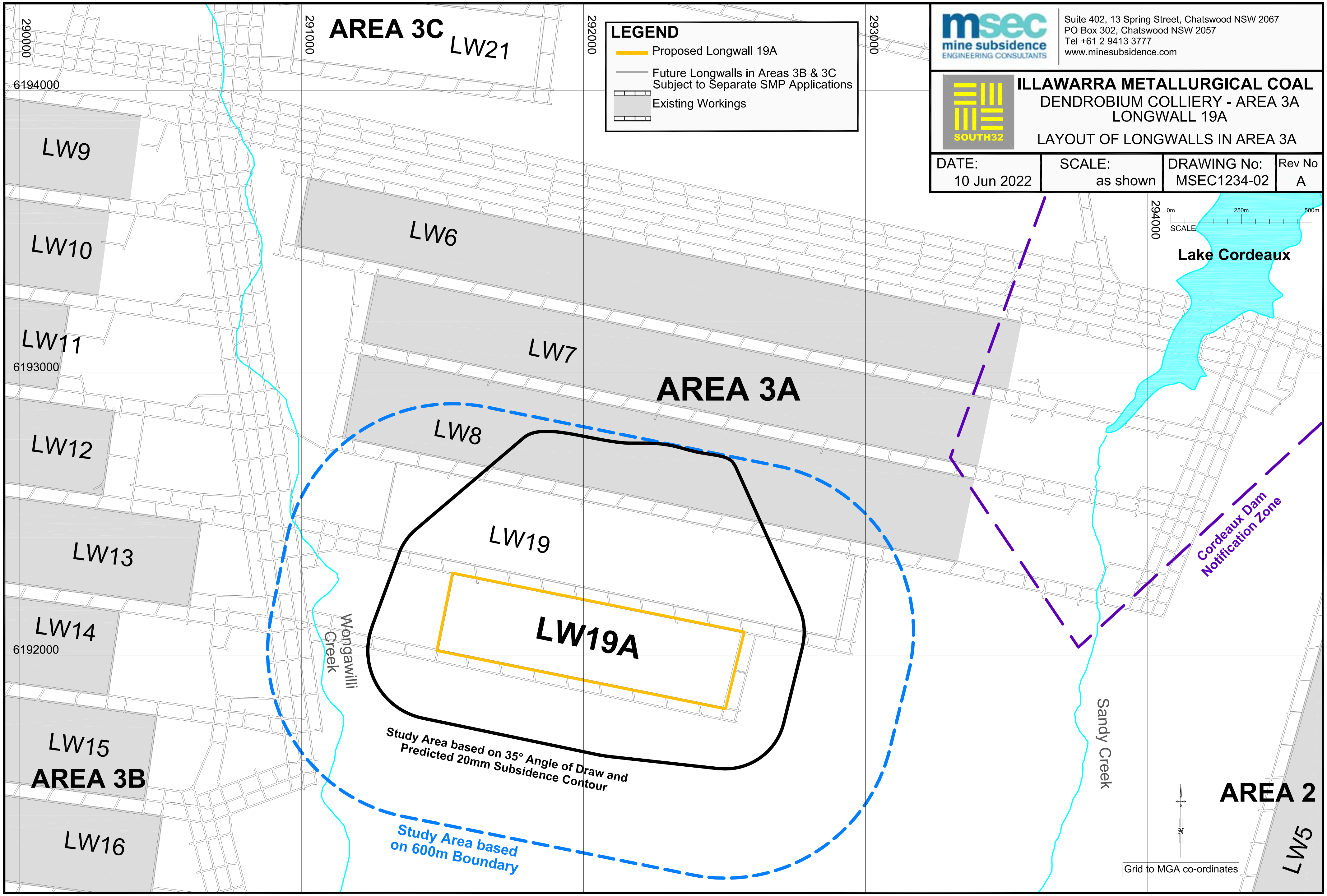

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LAYOUT OF LONGWALLS IN AREA 3A

DATE:	SCALE:	DRAWING No:	Rev No
10 Jun 2022	as shown	MSEC1234-02	A

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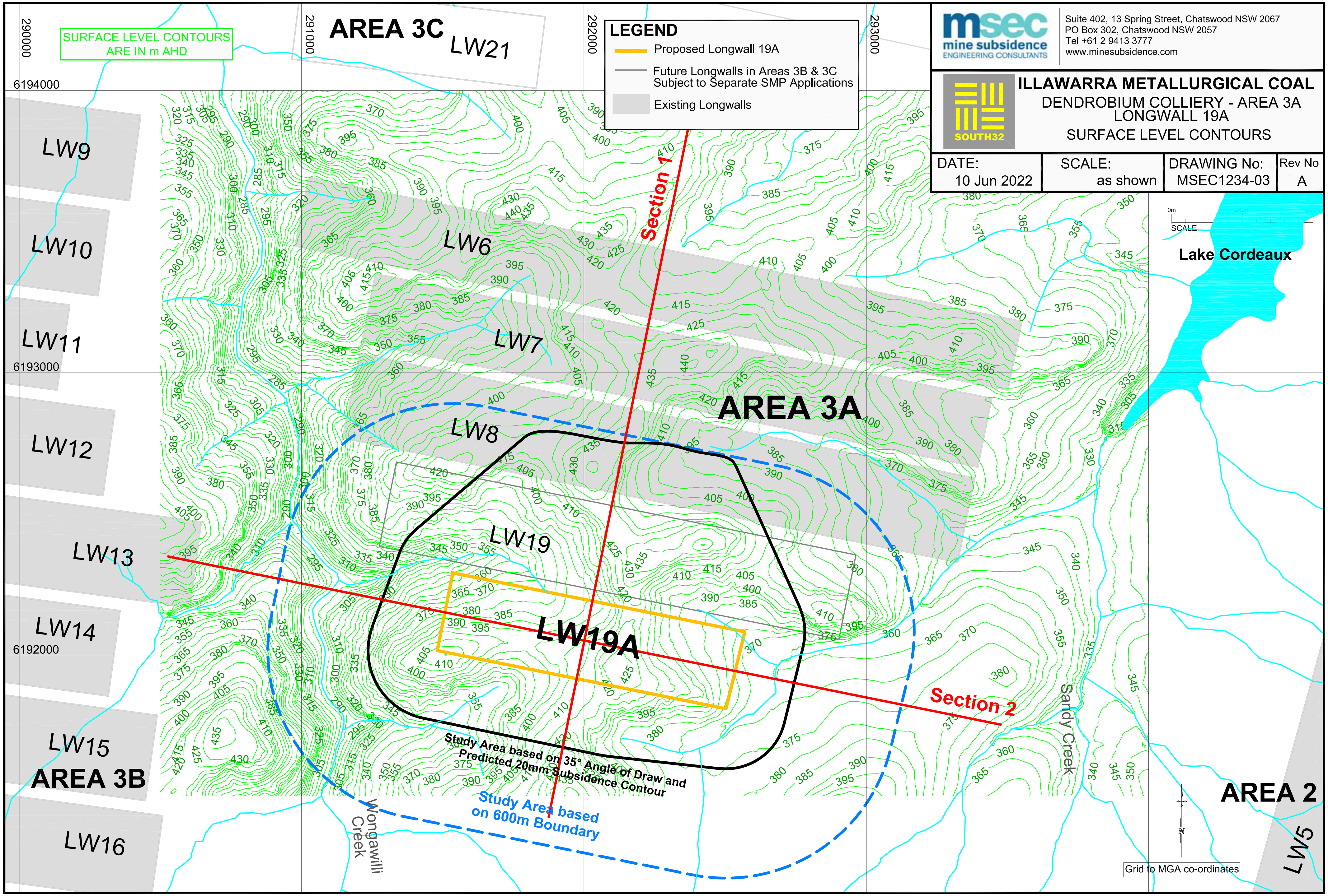

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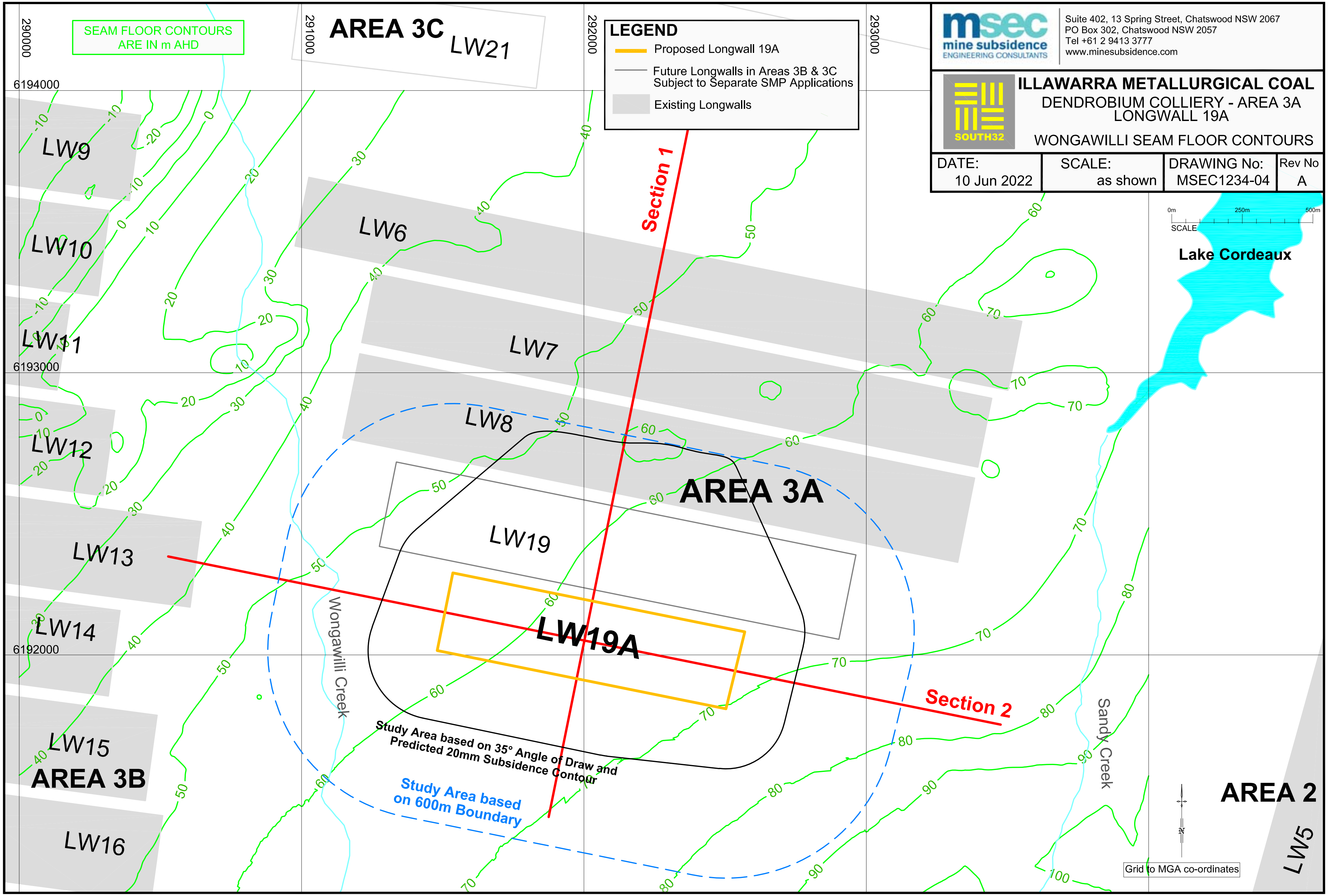

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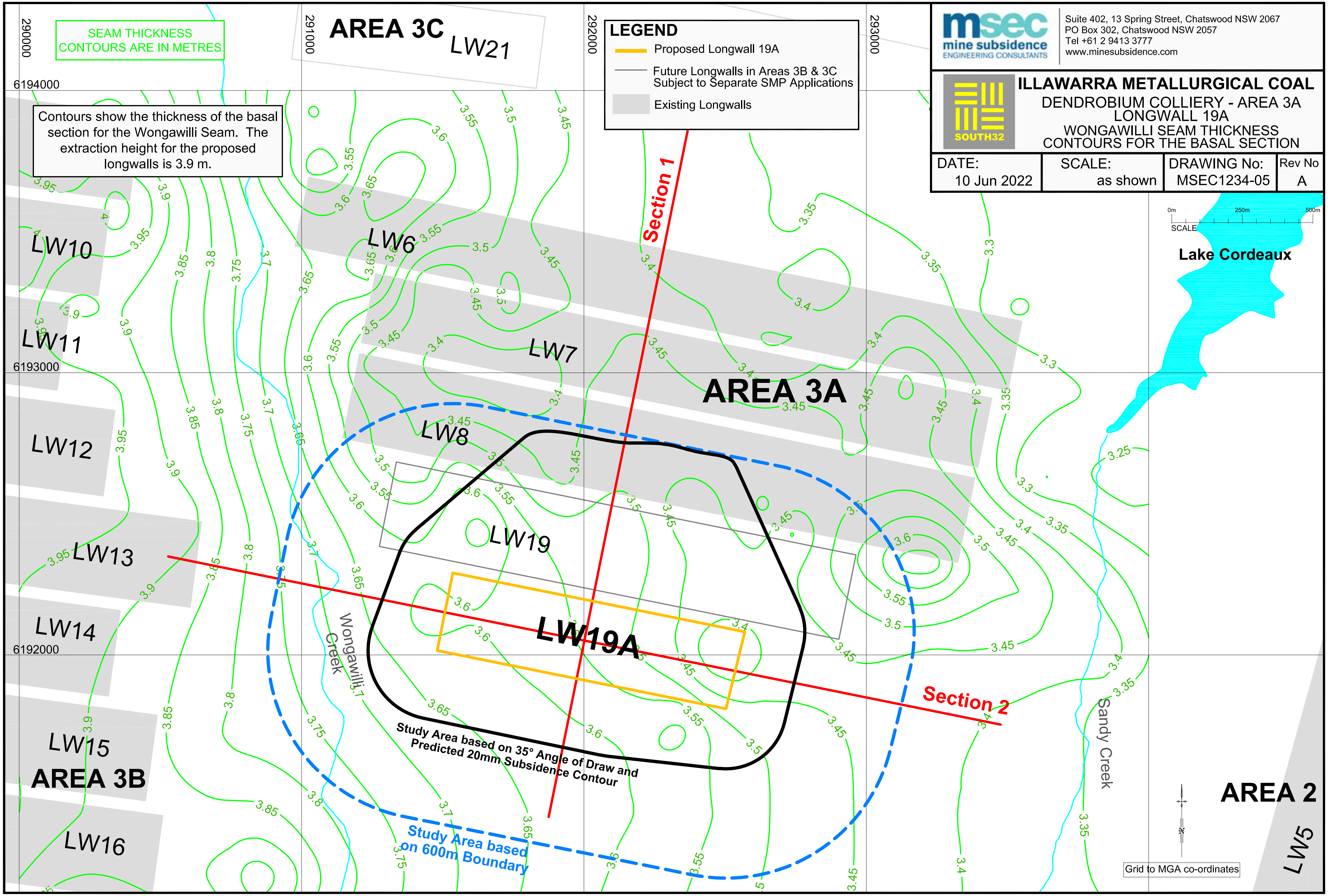
ILLAWARRA METALLURGICAL COAL
DENDROBIUM COLLIERY - AREA 3A
LONGWALL 19A
WONGAWILLI SEAM THICKNESS
CONTOURS FOR THE BASAL SECTION

DATE:	SCALE:	DRAWING No:	Rev No
10 Jun 2022	as shown	MSEC1234-05	A



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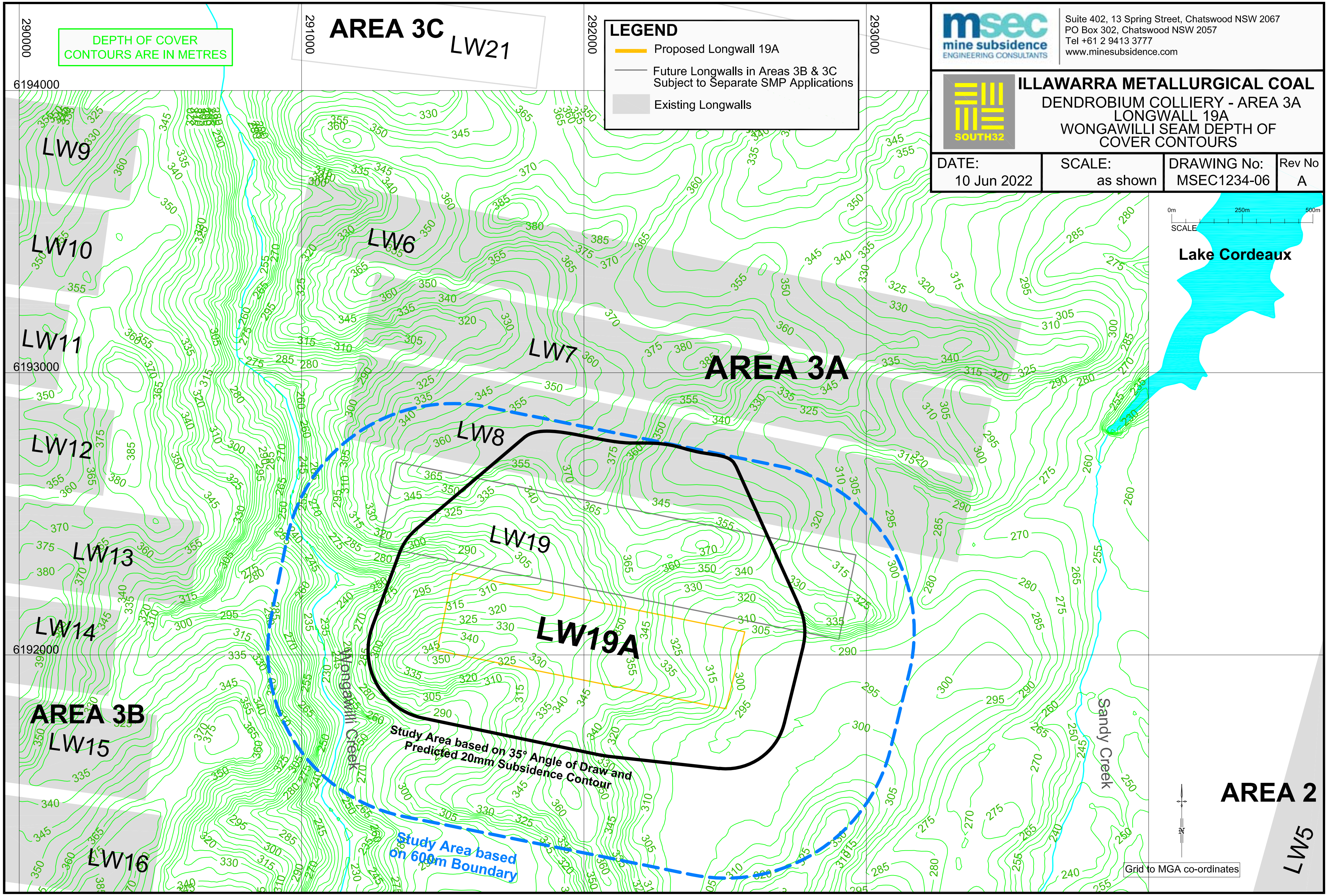

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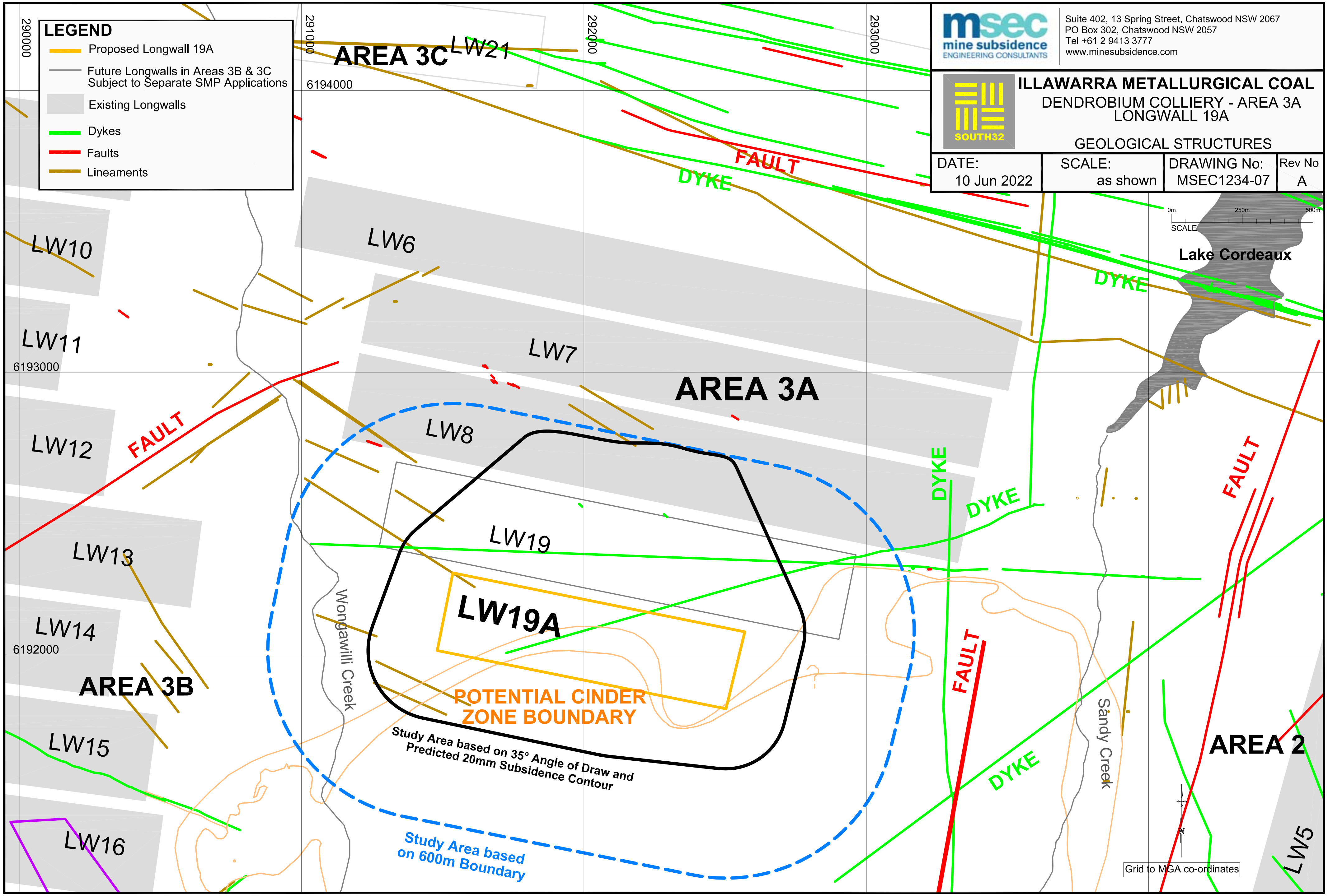

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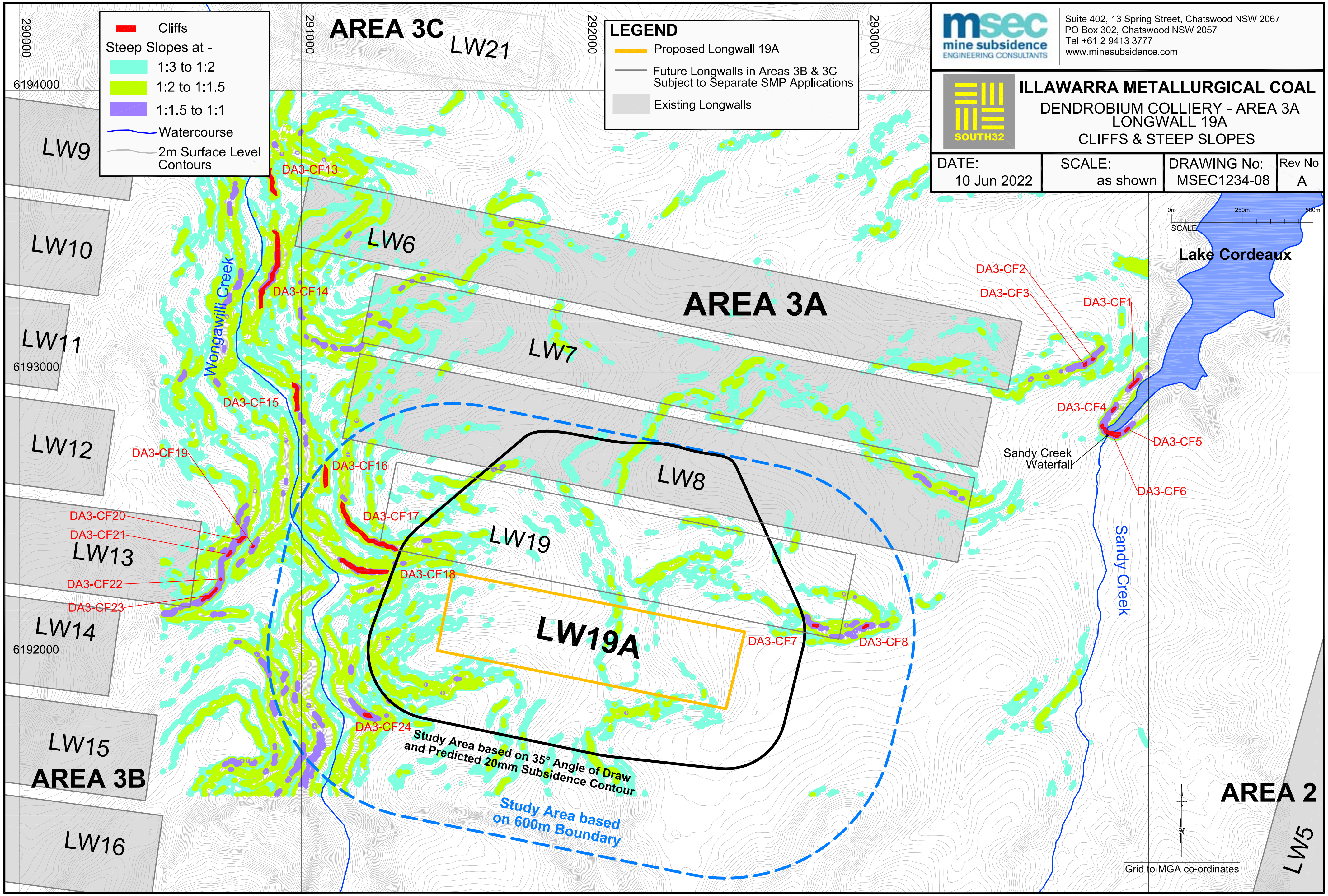
ILLAWARRA METALLURGICAL COAL
DENDROBIUM COLLIERY - AREA 3A
LONGWALL 19A

GEOLOGICAL STRUCTURES

DATE:	SCALE:	DRAWING No:	Rev No
10 Jun 2022	as shown	MSEC1234-07	A

I:\Projects\Dendrobium\Area 3\MSEC1234 - Area 3A - SMP Application for Longwall 19A\AcadData\MSEC1234-08 Cliffs & Steep Slopes.dwg



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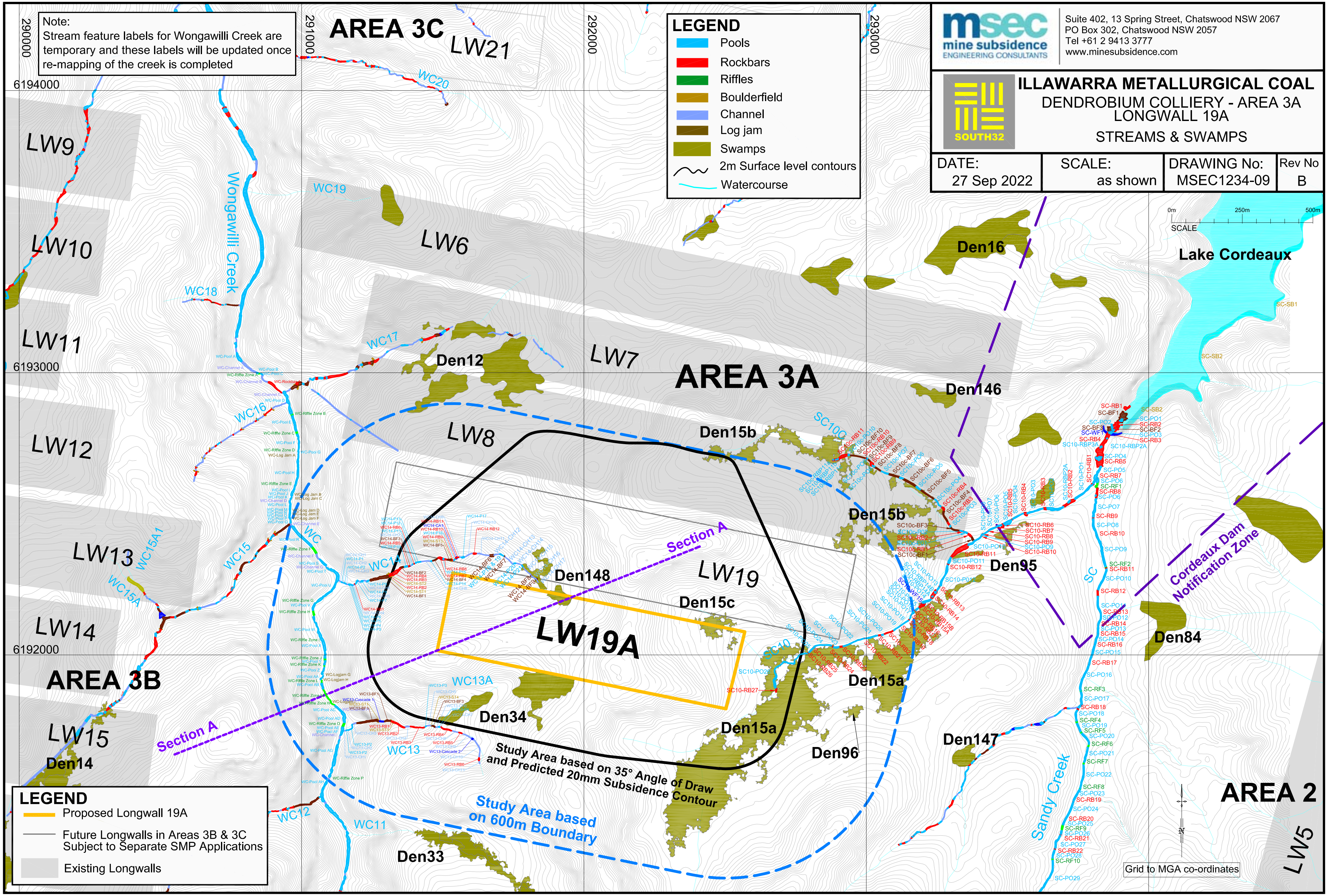
ILLAWARRA METALLURGICAL COAL
DENDROBIUM COLLIERY - AREA 3A
LONGWALL 19A
CLIFFS & STEEP SLOPES

DATE:	SCALE:	DRAWING No:	Rev No
10 Jun 2022	as shown	MSEC1234-08	A

I:\Projects\Dendrobium\Area 3\MSEC1234 - Area 3A - SMP Application for Longwall 19A\AcadData\MSEC1234-09 Stream & Swamps.dwg



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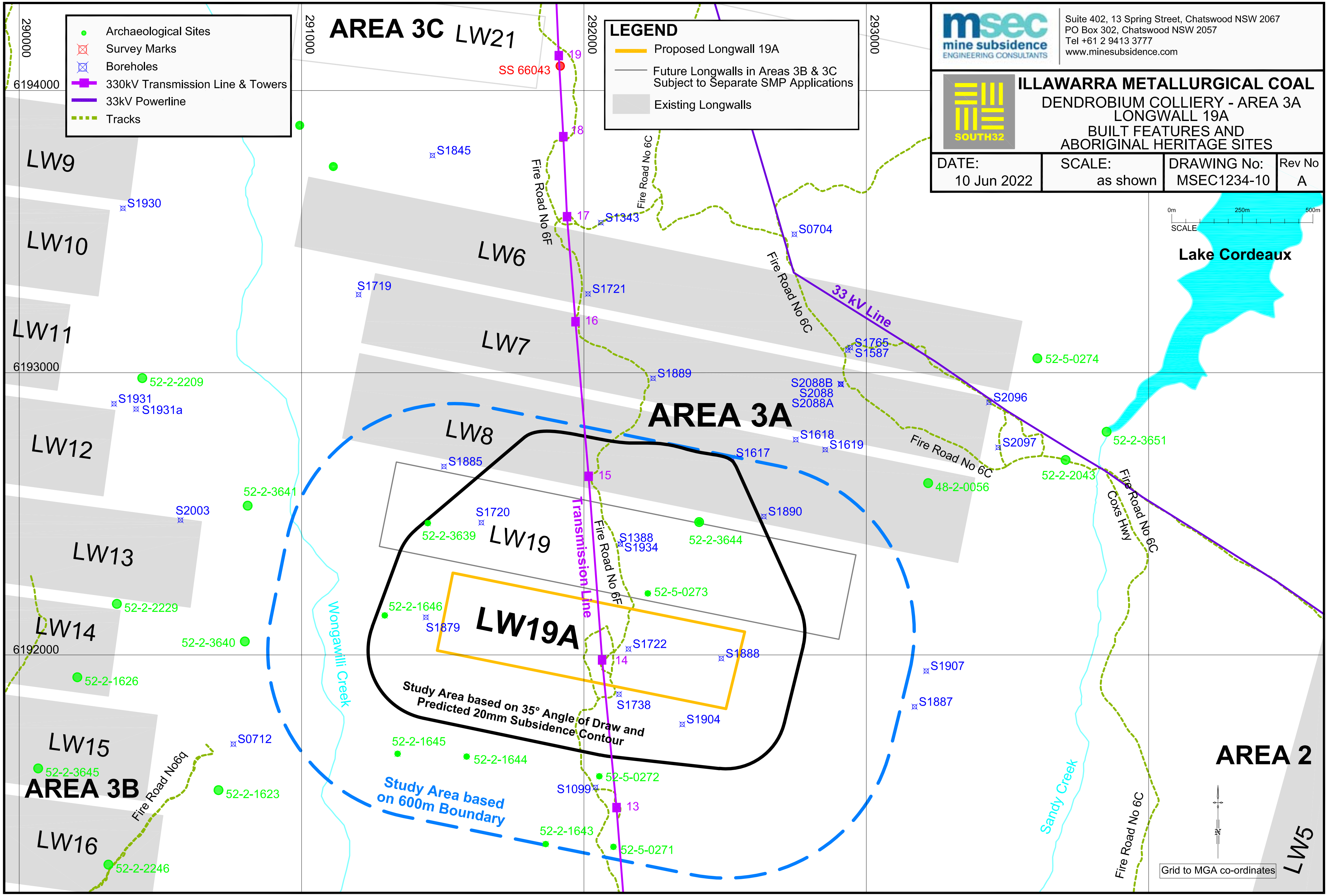

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ILLAWARRA METALLURGICAL COAL
DENDROBIUM COLLIERY - AREA 3A
LONGWALL 19A
BUILT FEATURES AND
ABORIGINAL HERITAGE SITES

DATE:	SCALE:	DRAWING No:	Rev No
10 Jun 2022	as shown	MSEC1234-10	A

I:\Projects\Dendrobium\Area 3\MSEC1234 - Area 3A - SMP Application for Longwall 19A\AcadData\MSEC1234-11 Pred Inc Subs Contours.dwg

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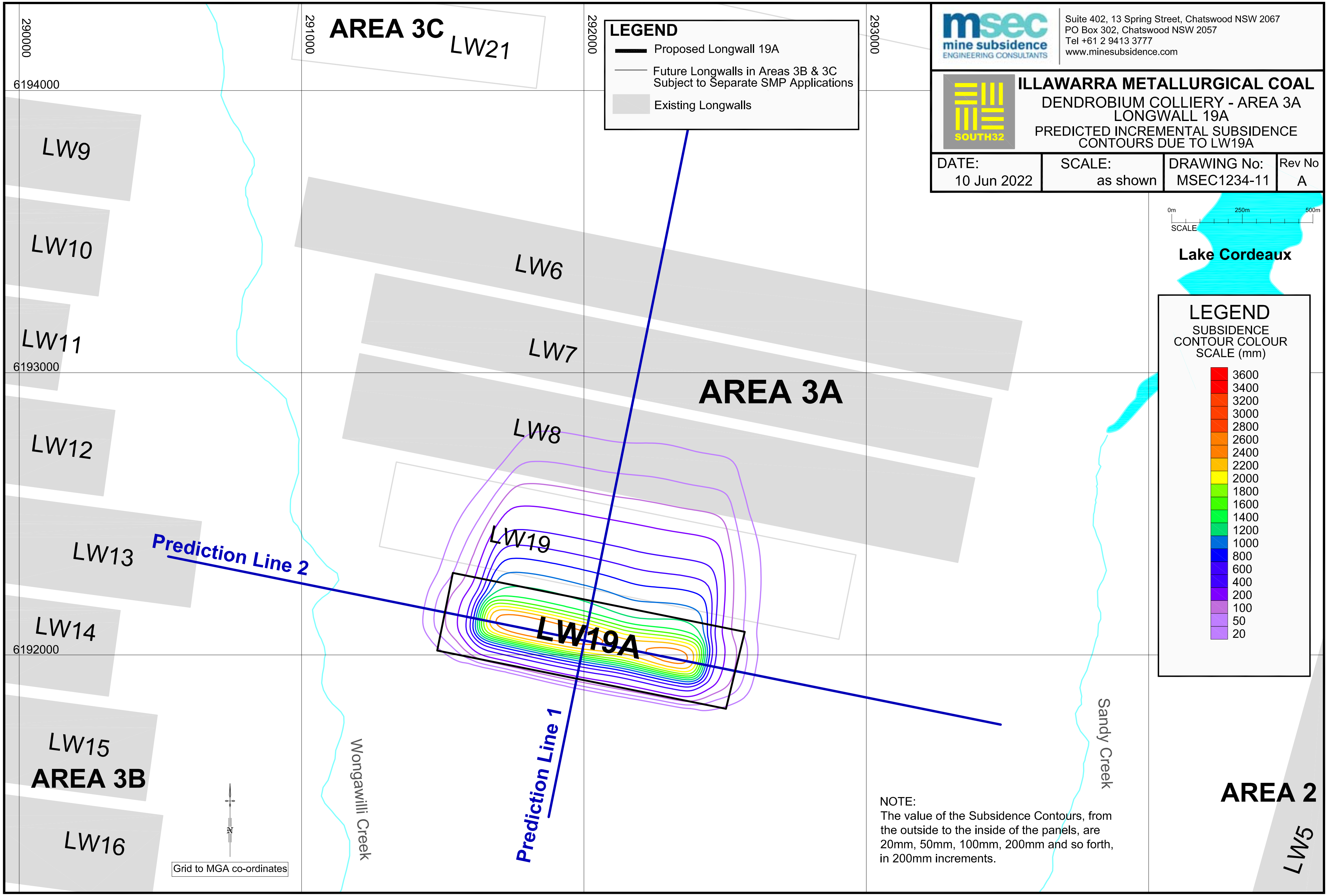
ILLAWARRA METALLURGICAL COAL
DENDROBIUM COLLIERY - AREA 3A
LONGWALL 19A
PREDICTED INCREMENTAL SUBSIDENCE CONTOURS DUE TO LW19A

DATE:	SCALE:	DRAWING No:	Rev No
10 Jun 2022	as shown	MSEC1234-11	A



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

I:\Projects\Dendrobium\Area 3\MSEC1234 - Area 3A - SMP Application for Longwall 19A\AcadData\MSEC1234-12 Pred Total Subs Contours.dwg