ILLAWARRA COAL:

Dendrobium – Longwalls 20 and 21

Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwalls 20 and 21 in Area 3C at Dendrobium Mine

 | REPORT NUMBER: MSEC978 | REVISION D

DOCUMENT REGISTER

Revision	Description	Author	Checker	Date
01	Draft Issue	JB	-	06 Sep 18
02	Draft Issue	JB	-	18 Sep 18
A	Final Issue	JB	BM	19 Nov 18
B	Minor Updates	JB	BM	11 Dec 18
C	Minor Updates	JB	BM	17 Apr 19
D	Modified Longwall Layout	JB	BM	3 May 19

Report produced to: Support the Subsidence Management Plan Application for the proposed Longwalls 20 and 21 at Dendrobium Mine to be issued to the Department of Planning and Environment.

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

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

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

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

MSEC888 (Rev. A) - Dendrobium - Area 3B - Longwall 12 – End of Panel Subsidence Monitoring Review Report for Dendrobium Longwall 12 (May 2017)

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 Coal (IC) has approval to mine longwalls in Area 3C at Dendrobium Mine. IC proposes to extract Longwalls 20 and 21 (LW20 and LW21) within the Wongawilli Seam. There are also additional longwalls in Area 3C that are proposed to be mined, but these will be the subject of separate Subsidence Management Plan (SMP) Applications.

The predicted subsidence parameters for the proposed LW20 and LW21 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 parameters are 2050 mm vertical subsidence, 30 mm/m tilt (i.e. 3 %, or 1 in 33), 0.50 km^{-1} hogging curvature (2 km minimum radius) and 0.75 km^{-1} sagging curvature (1.3 km minimum radius).

The maximum predicted subsidence parameters for the proposed LW20 and LW21 are less than the maximum predicted values for the existing and approved longwalls in Areas 3A and 3B. The reasons are the longwall void widths are narrower (255 m rather than 305 m), LW20 and LW21 are single isolated panels and the extraction heights are less (3.9 m rather than up to 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 LW20 and LW21; the predicted total 20 mm subsidence contour due to the extraction of the proposed longwalls; natural features located within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d) of the Development Consent; and features that are expected to experience either far-field horizontal movements, or valley related movements, 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, Donalds Castle Creek, drainage lines, cliffs, minor cliffs, rock outcrops, steep slopes, swamps, unsealed roads and tracks, a 330 kV transmission line, Aboriginal heritage sites, the Cordeaux and Avon Reservoirs and associated dam walls, and survey control marks.

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

- Wongawilli Creek is located between LW20 and LW21. The thalweg (i.e. base or centreline) of the creek is 125 m east of the tailgate of LW20 and 240 m west of the finishing end of LW21, at its closest points to the proposed longwalls.

  The maximum predicted additional movements along Wongawilli Creek, due to the extraction of LW20 and LW21 only, are less than 20 mm vertical subsidence, 60 mm upsidence and 150 mm closure. The maximum predicted total movements along the section of creek within the Study Area, including the movements from the existing longwalls in Area 3B, are less than 20 mm vertical subsidence, 150 mm upsidence and 210 mm closure.

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

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

- Donalds Castle Creek is located to the west of LW20, at a minimum distance of 470 m at its closest point. The creek crosses directly above the existing LW9 and LW10 in Area 3B further upstream.

  The maximum predicted additional parameters for Donalds Castle Creek, due to the extraction of LW20 and LW21 only, are less than 20 mm vertical subsidence, less than 20 mm upsidence and less than 20 mm. The maximum predicted total movements along the section of creek within the Study Area, including the movements from the existing longwalls in Area 3B, are less than 20 mm vertical subsidence, 90 mm upsidence and 180 mm closure.

  The creek experienced fracturing and surface water flow diversion (i.e. Type 3 impact) at Rockbar DC-RB33 due to the previous extraction of LW9 in Area 3B. This rockbar is located between LW9 and the proposed LW20. However, only low level additional movements are predicted along Donalds Castle Creek due to the extraction of LW20 and LW21.

  It is considered unlikely, therefore, that fracturing would occur along Donalds Castle Creek due to the extraction of LW20 and LW21 due to the low levels of predicted movements and its distance from the proposed longwalls.

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

  It is expected that fracturing would occur along the sections of the drainage lines that are located directly above the proposed LW20 and LW21. Fracturing can also occur outside the extents of the proposed longwalls at distances up to approximately 400 m. Surface water flow diversions are also likely to occur along the sections of drainage lines that are located directly above and adjacent to the proposed longwalls.

- There are three cliffs that have been identified within the Study Area. One cliff is located above LW20 and the other two cliffs are located outside the extents of the proposed longwalls at minimum distances of 30 m and 230 m. The cliffs have overall lengths ranging between 30 m and 65 m and heights ranging between 10 m and 15 m.

  The cliff located directly above LW20 could experience adverse impacts including rockfalls and cliff instabilities. Only low levels of vertical subsidence (50 mm or less) are predicted for the other two cliffs within the Study Area. It is possible that isolated rock falls could occur at the two cliffs located outside the extents of the proposed longwalls.

- Rock outcrops and steep slopes are located across the Study Area. These features could experience the full range of predicted subsidence movements. It is likely that fracturing and cracking would occur where these features are located directly above the proposed longwalls. The crack widths could be similar to those previously observed at the mine, which were up to approximately 400 mm in width, but typically in the order of 100 mm to 150 mm in width.

- There are three swamps that have been identified wholly or partially within the Study Area based on the 35° angle of draw line. There are also seven additional swamps that are located within the Study Area based on the 600 m boundary. The swamps are all located outside the proposed longwalls at minimum distances ranging between 50 m and 600 m.

  The predicted post-mining grades within the swamps are similar to the natural grades and, therefore, it is not expected that there would be adverse changes in ponding or scouring within the swamps. It is also not anticipated that there would be significant changes in the distribution of the stored surface waters within the swamps as a result of the mining-induced tilt or vertical subsidence.

  Fracturing of the bedrock could occur beneath Swamps Den142 and Den144 due to conventional and valley related effects. These swamps have layers of organic soil and, in most cases, cracking would not be visible at the surface within these swamps, except where the depths of bedrock are shallow or exposed.

  The dilated strata beneath the drainage lines, upstream of Swamps Den142 and Den144, could result in the diversion of some surface water flows beneath parts of these swamps. The drainage lines upstream of these swamps flow during and shortly after rainfall events. On the basis that there is no connective fracturing to any deeper storage, it is likely that the diverted surface water flows will re-emerge at the limits of fracturing and dilation.

  The remaining swamps are located outside the proposed longwalls at minimum distances ranging between 230 m and 600 m. These swamps are predicted to only experience very low levels of vertical subsidence and valley related effects.

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

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

- A 330 kV transmission line is located immediately to the east of LW21. There are three transmission towers located within the Study Area at distances ranging between 60 m and 230 m from the longwall. The closest tower (Ref. T8) is predicted to experience 50 mm vertical subsidence, 0.5 mm/m tilt and 0.01 km^{-1} hogging curvature. The other two towers are predicted to experience less than 20 mm vertical subsidence.

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

- The Cordeaux and Avon Reservoirs are located at minimum distances of 1.6 km and 2.8 km, respectively, from the proposed LW20 and LW21. The Cordeaux Dam Wall and Avon Dam Wall are located at distances of more than 3 km and 7 km, respectively, from the proposed longwalls.

  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 LW20 and LW21.

- There are no Aboriginal heritage sites that have been identified within the Study Area based on the 35° angle of draw. There are seven Aboriginal heritage sites that are located within the Study Area based on the 600 m boundary.

  The sites within the combined Study Area comprise five rock shelters with art, one rock shelter with art and grinding grooves, and one artefact with PAD. These sites are all located at distances between 230 m and 530 m outside the proposed longwalls.

  The Aboriginal heritage sites are predicted to experience less than 20 mm vertical subsidence due to the extraction of LW20 and LW21. The sites are not expected to experience measurable upsidence or compressive strain due to valley closure effects as they are located on the sides of the ridgelines away from the valley bases.

  It is unlikely, therefore, that the Aboriginal heritage sites located within the Study Area would experience adverse impacts due to the extraction of LW20 and LW21.

- 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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Drawings

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

Drawing No.	***Description***	***Rev.***
MSEC978-01	Overall layout of longwalls at Dendrobium Mine	D
MSEC978-02	Layout of LW20 and LW21	D
MSEC978-03	Surface level contours	D
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MSEC978-08	Cliffs and steep slopes	D
MSEC978-09	Streams and swamps	D
MSEC978-10	Stream features – Map 1	D
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1.1. Background

Illawarra Coal Holdings Pty Ltd (IC), 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.

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

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

IC now propose to extract the first two longwalls in Area 3C, referred to as Longwalls 20 and 21 (LW20 and LW21), within the Wongawilli Seam. There are also additional longwalls in Area 3C that are proposed to be mined, but these will be the subject of separate Subsidence Management Plan (SMP) Applications.

The locations of the existing and approved longwalls in Areas 3A and 3B and the proposed LW20 and LW21 in Area 3C are shown in Fig. 1.1. The Area 3 approval boundary is also shown in this figure.

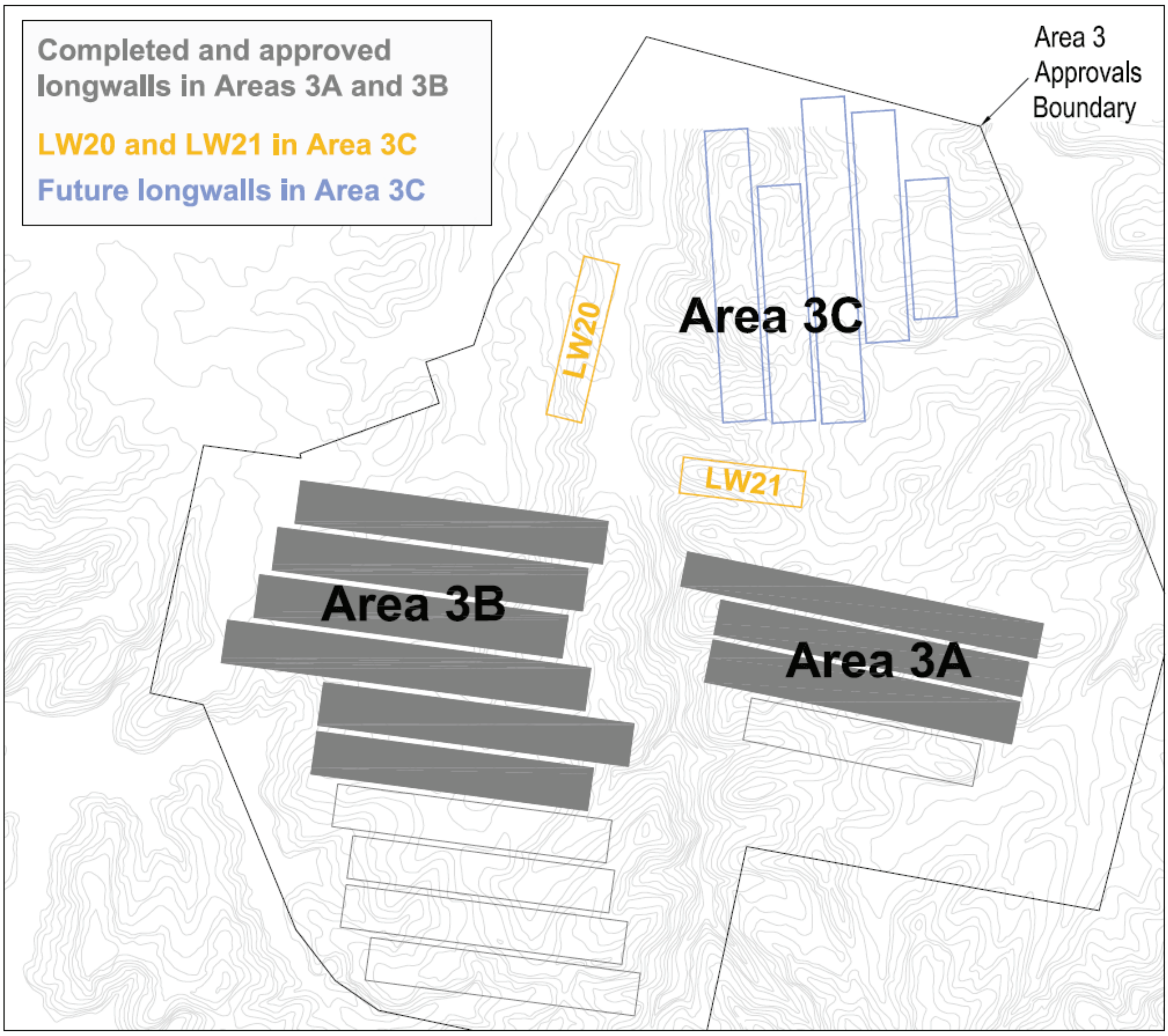

Fig. 1.1 Existing and approved longwalls in Areas 3A, 3B and 3C

The existing and approved longwalls at the Mine and the proposed LW20 and LW21 are shown in Drawings Nos. MSEC978-01 and MSEC978-02, respectively, in Appendix D. The proposed longwalls and the Study Area, as defined in Section 2.1, have been overlaid on an orthophoto of the area, and is shown in Fig. 1.2.

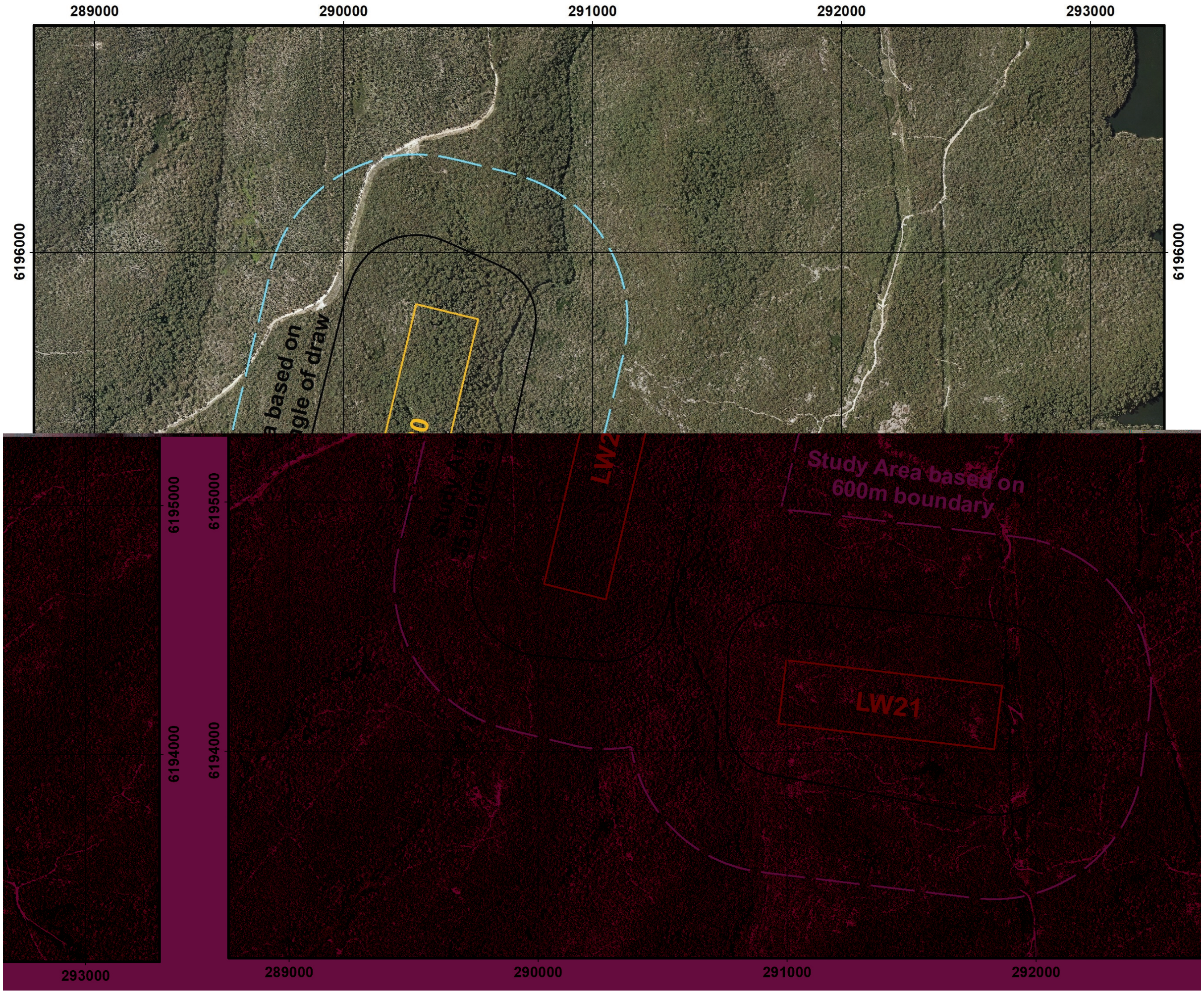

Fig. 1.2 Aerial photograph showing the proposed longwalls and the Study Area

IC is preparing an SMP Application for the proposed LW20 and LW21 in Area 3C. MSEC has been commissioned by IC to:

- prepare subsidence predictions for the proposed LW20 and LW21, including the cumulative movements due to the previously extracted and approved longwalls in Areas 3A and 3B;
- identify the natural and built features in the vicinity of the proposed longwalls;
- provide subsidence predictions for each of these features;
- prepare impact assessments, in conjunction with other specialist consultants, for each of the natural and built features; and
- recommend management strategies and monitoring.

This report has been prepared to support the SMP Application for the proposed LW20 and LW21 which will be submitted to the Department of Planning and Environment. In some cases, this report will refer to other sources of information on specific natural and built features. This report, therefore, should be read in conjunction with the other relevant reports associated with this application.

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

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

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

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

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

1.2. Mining geometry

The layouts of the proposed LW20 and LW21 are shown in Drawings Nos. MSEC978-01 and MSEC978-02, in Appendix D. A summary of the dimensions of these longwalls is provided in Table 1.1. The longwalls are proposed to be extracted from the Wongawilli Seam.

Table 1.1 Geometry of the proposed longwalls

Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
LW20	1154	256	-
LW21	872	256	-

The lengths of longwall extraction excluding the installation headings are approximately 9 m less than the overall void lengths provided in the above table, i.e. 1145 m for LW20 and 863 m for LW21. The longwall face widths excluding the first workings are 246 m for both LW20 and LW21. The proposed longwalls are single isolated longwalls, i.e. no tailgate chain pillars.

The longwalls will be extracted towards the main headings (i.e. retreat mining) within the Wongawilli Seam. LW20 will be extracted first from the north towards the south and then LW21 will be extracted from the east towards the west.

1.3. Surface and seam levels

The levels of the natural surface and the Wongawilli Seam are illustrated along the centrelines of LW20 and LW21 in Fig. 1.3 and Fig. 1.4, respectively. The definition of the Study Area is provided in Section 2.2.

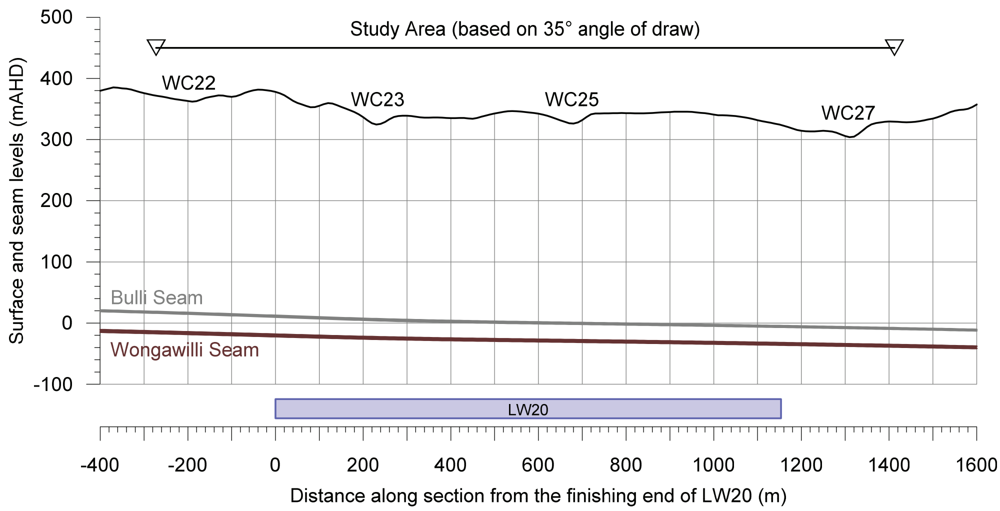

Fig. 1.3 Surface and seam levels along the centreline of LW20

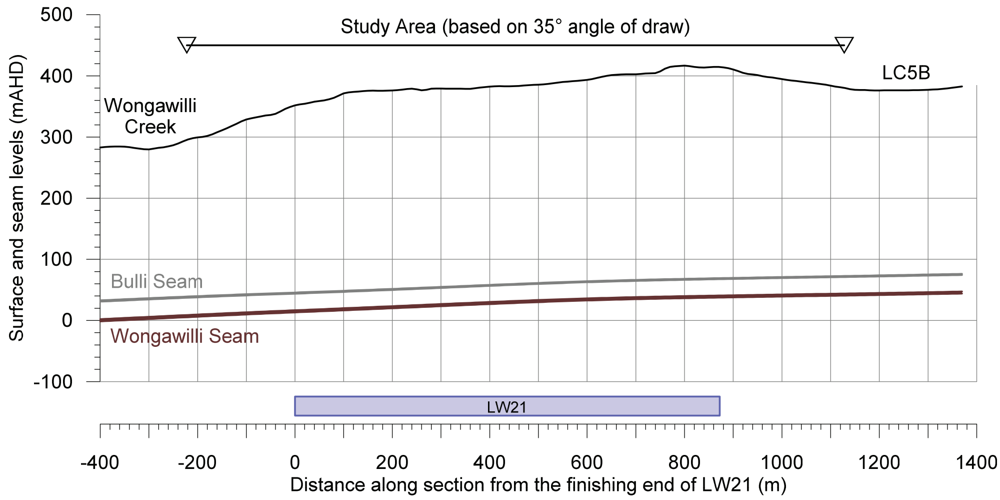

Fig. 1.4 Surface and seam levels along the centreline of LW21

The surface level contours are shown in Drawing No. MSEC978-03, in Appendix D. The proposed longwalls are located beneath two ridgelines on either side of Wongawilli Creek. The natural ground falls towards Wongawilli Creek and its tributaries.

The surface levels directly above the proposed LW20 vary between 300 metres above Australian Height Datum (mAHD) on the eastern side and 390 mAHD at the south-western corner of the longwall. The surface levels directly above the proposed LW21 vary between 310 mAHD at the south-western corner and 430 mAHD above the eastern end of the longwall.

The seam floor contours, seam thickness contours and depth of cover contours for the Wongawilli Seam are shown in Drawings Nos. MSEC978-04, MSEC978-05 and MSEC978-06, respectively. The contours are based on the latest information provided by the Mine.

The proposed LW20 is located on the eastern side of a north-south trending syncline. The floor of the Wongawilli Seam dips towards the syncline from the east towards the west. The average gradient of the seam within the extents of the two proposed longwalls is approximately 3 % or 1 in 33.

The depths of cover to the Wongawilli Seam vary between 320 m and 410 m directly above the proposed LW20 and between 290 m and 390 m directly above the proposed LW21.

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

1.4. Geological details

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

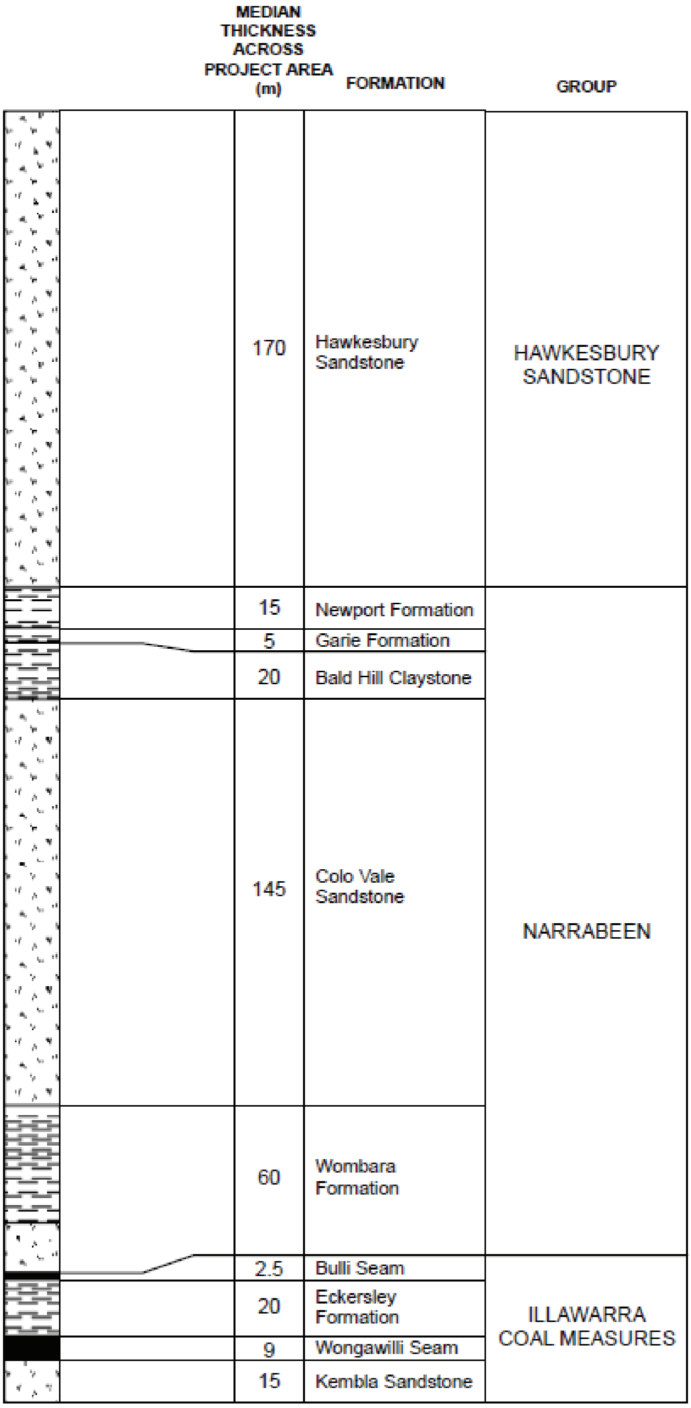

Fig. 1.5 Typical stratigraphic section for the Mine (Source: IC)

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 LW20 and LW21 will be extracted from the Wongawilli Seam.

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

The Mine sits at the southern end of the Nepean/Kurrajong Fault and Lapstone Monocline system. The area is therefore imprinted with the north-westerly trending structures that connect to these large scale geological features to the north. The large north-west and north-north-west displacement faults are the primary deformational set in the area. However, those faults trend north-east in the coastal fault zone. The geological structures identified or inferred at the Mine are shown in Drawing No. MSEC978-07.

Igneous sills have intruded into the coal seams in parts of the Mine. A sill has intruded into the Wongawilli Seam north-west of the proposed LW20. A sill has also intruded into the overlying Bulli Seam directly above the proposed longwalls. This sill will be located within the collapsed zone above the proposed longwalls and, therefore, is unlikely to affect the mine subsidence movements at the surface.

A series of east-west orientated dykes and associated minor faulting cross through the southern end of the proposed LW20 and partially extend into the proposed LW21. The locations and sizes of these structures will be better defined through ongoing investigations and the development of the first workings.

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

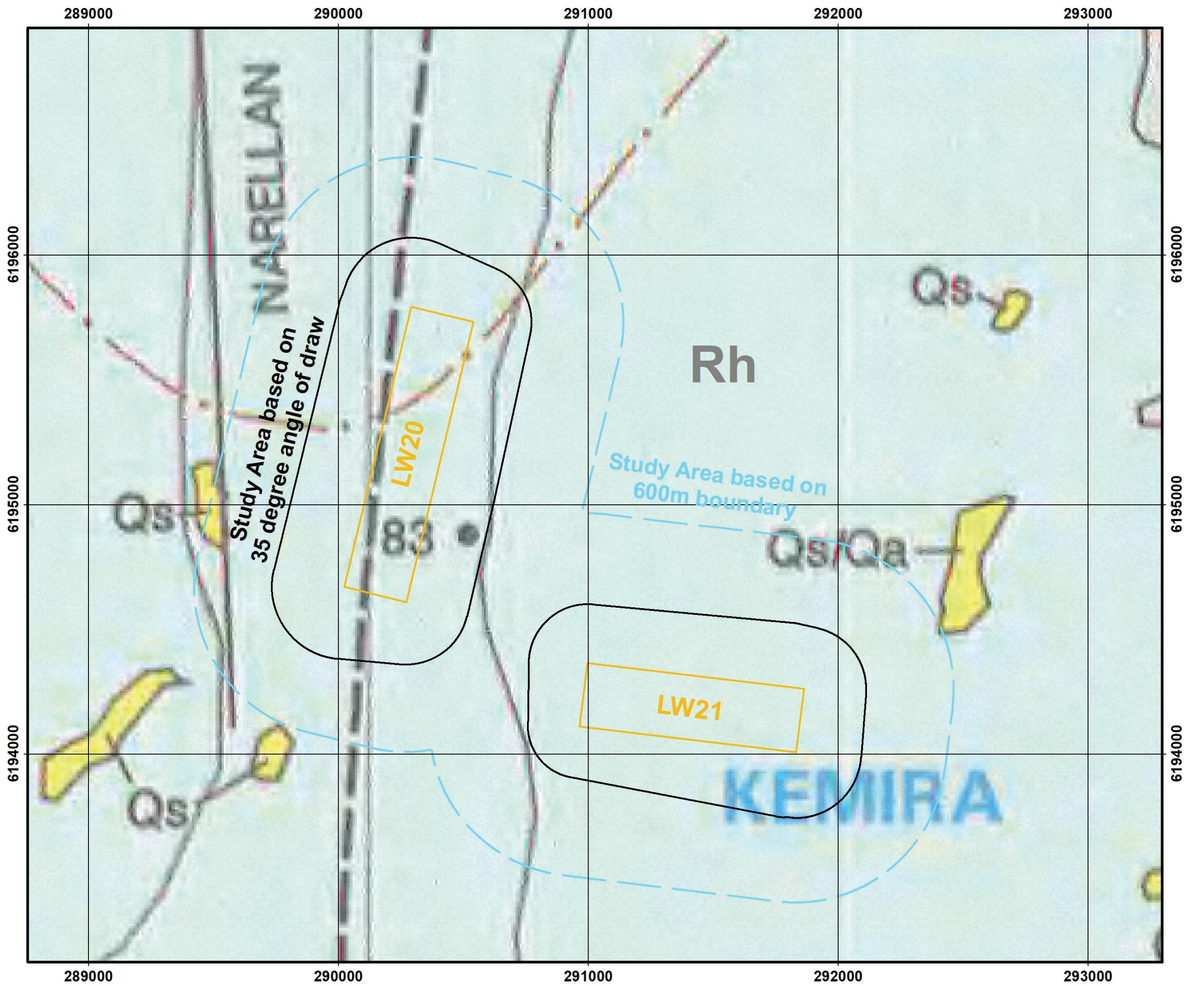

Fig. 1.6 The proposed longwalls overlaid on Geological Map *Bargo 9029-3-N* (DMR, 1988)

2.1. Definition of the Extent of the Longwall Mining Area

The *Extent of the Longwall Mining Area* is defined as the overall void area for the proposed LW20 and LW21 (i.e. second workings plus the immediately adjacent roadways), indicated by the orange outlines shown in Drawings Nos. MSEC978-01 and MSEC978-02.

2.2. Definition of the Study Area

The *Study Area* is defined as the surface area that could be affected by the mining of the proposed LW20 and LW21. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:

- The 35° angle of draw line from the extents of the proposed LW20 and LW21;
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, resulting from the extraction of the proposed longwalls; and
- The natural features located within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d) of the Development Consent.

The depths of cover contours are shown in Drawing No. MSEC978-06. The depth of cover varies between 290 m and 410 m directly above the proposed LW20 and LW21. The 35° angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 200 m and 290 m around the extents of the longwall voids.

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, has been determined using the calibrated Incremental Profile Method (IPM), which is described in Chapter 3. The predicted total subsidence contours, including the 20 mm subsidence contour, are shown in Drawing No. MSEC978-13, in Appendix D. The predicted 20 mm subsidence contour is located entirely within the 35° angle of draw line.

The Study Area based on the 35° angle of draw line is shown in Drawings Nos. MSEC978-01 and MSEC978-02, in Appendix D. The Study Area based on a 600 m boundary around the extents of the proposed longwalls is also shown in those drawings. The features that are located within the 600 m boundary that are predicted to experience valley related movements and could be sensitive to these movements have been included in the assessments provided in this report. These features include the streams and upland swamps.

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

2.3. Natural and built features within the Study Area

A summary of the natural and built features located within the Study Area is provided in Table 2.1. The locations of these features are shown in Drawings Nos. MSEC978-08 to MSEC978-12, 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	✓	6.4
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	×	
Shopping Centres	×	
Community Centres	×	
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

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

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

3.1. Introduction

The following sections provide overviews of conventional and non-conventional mine subsidence parameters 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 parameters

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

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.
- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/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, higher levels of far-field horizontal movements have been observed where steep slopes or surface incisions exist nearby, as these features influence both the magnitude and the direction of ground movement patterns. Similarly, increased horizontal movements are often observed around sudden changes in geology or where blocks of coal are left between longwalls or near other previously extracted series of longwalls. In these cases, the levels of observed subsidence can be slightly higher than normally predicted, but these increased movements are generally accompanied by very low levels of tilt and strain.

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

3.4. Overview of non-conventional subsidence movements

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

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

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

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

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

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

In this report, non-conventional ground movements are being included statistically in the predictions and impact assessments, by basing these on the frequency of past occurrence of both the conventional and non-conventional ground movements and impacts. The analysis of strains provided in Section 4.4 includes those resulting from both conventional and non-conventional anomalous movements. The impact assessments for the natural and built features, which are provided in Chapters 5 and 6, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

3.4.2. Non-conventional subsidence movements due to steep topography

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

Further discussions on the potential for downslope movements for the steep slopes within the Study Area are provided in Section 5.7.

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.

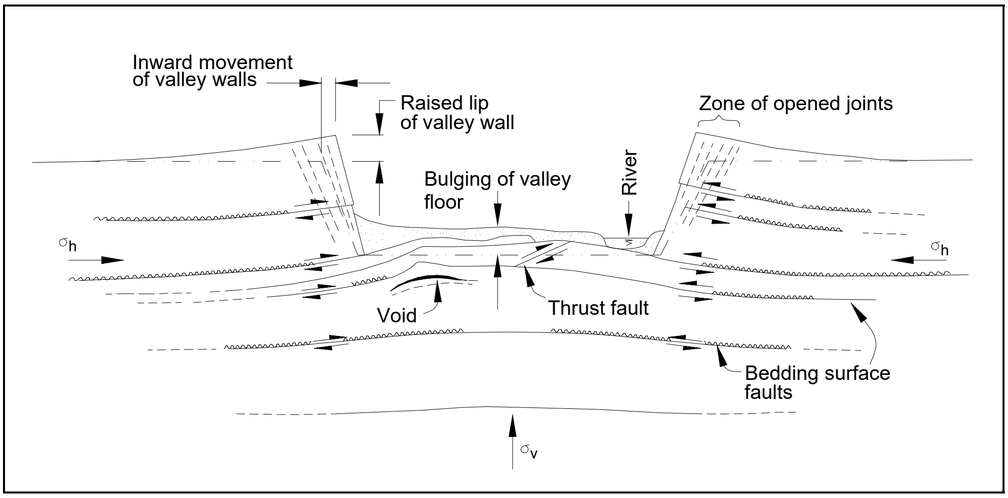

Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

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

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

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

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

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

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

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

3.6. Calibration of the IPM

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

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

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

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

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

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

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

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

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

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

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

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

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

The changes in surface level due to the current mining in Area 3B at the Mine are being measured using ALS and LiDAR surveys. The measured changes in surface level due to the extraction of LW9 to LW13 are shown in Fig. 3.2.

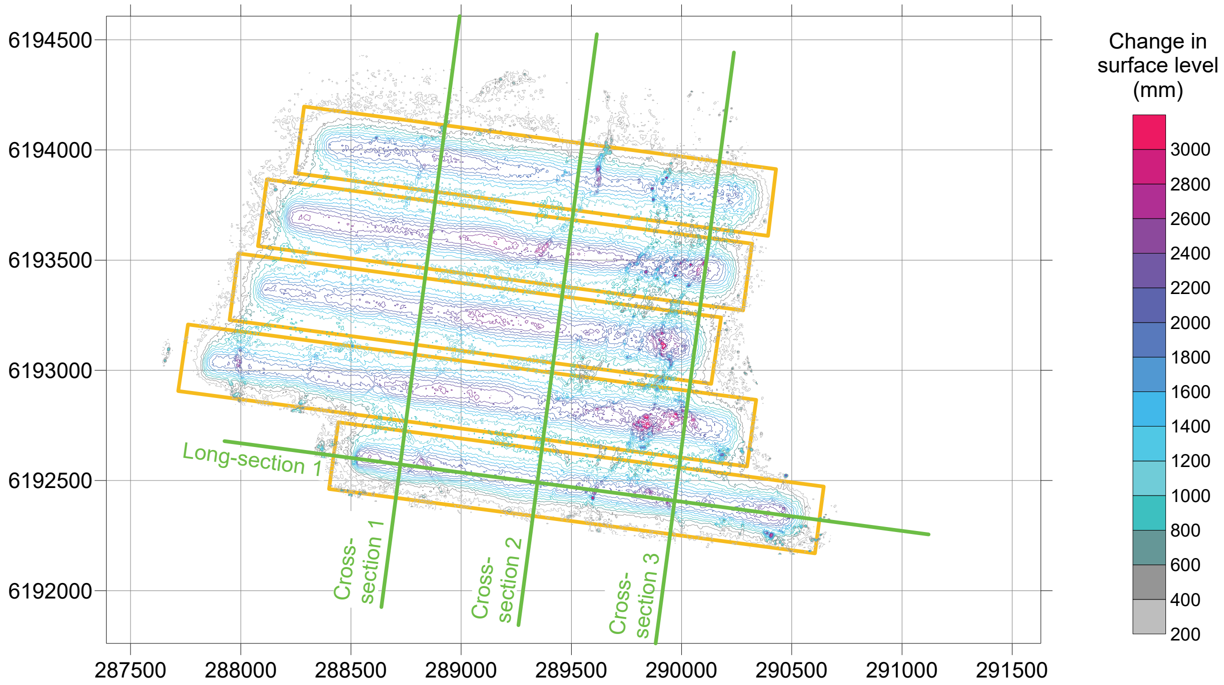

Fig. 3.2 Measured changes in surface level due to LW9 to LW13 in Area 3B

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

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

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

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

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

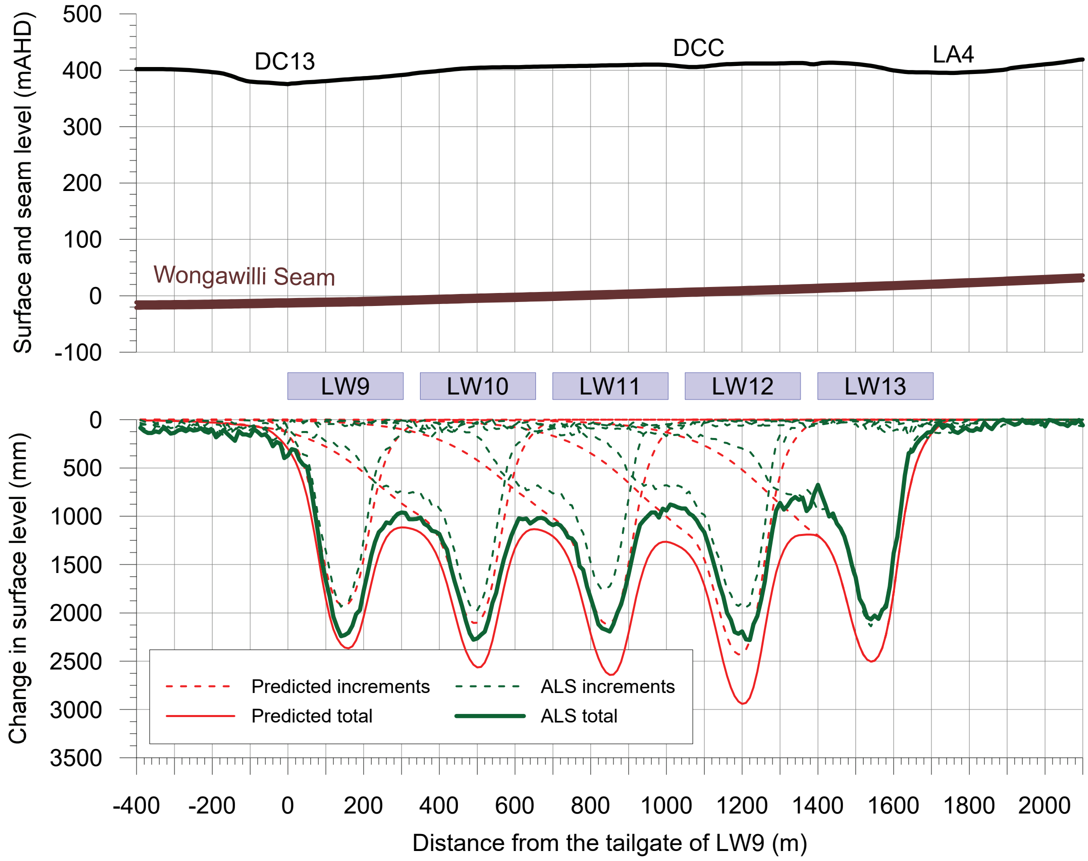

Fig. 3.3 Measured and predicted changes in surface level along Cross-section 1

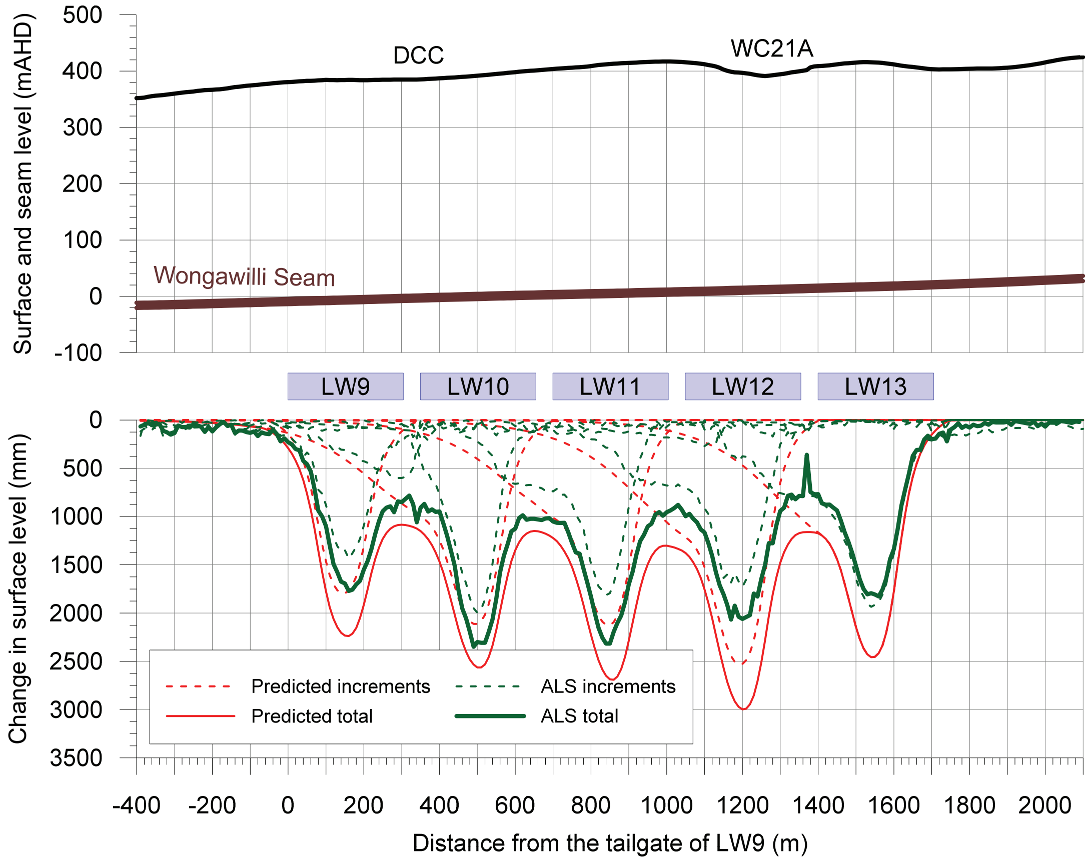

Fig. 3.4 Measured and predicted changes in surface level along Cross-section 2

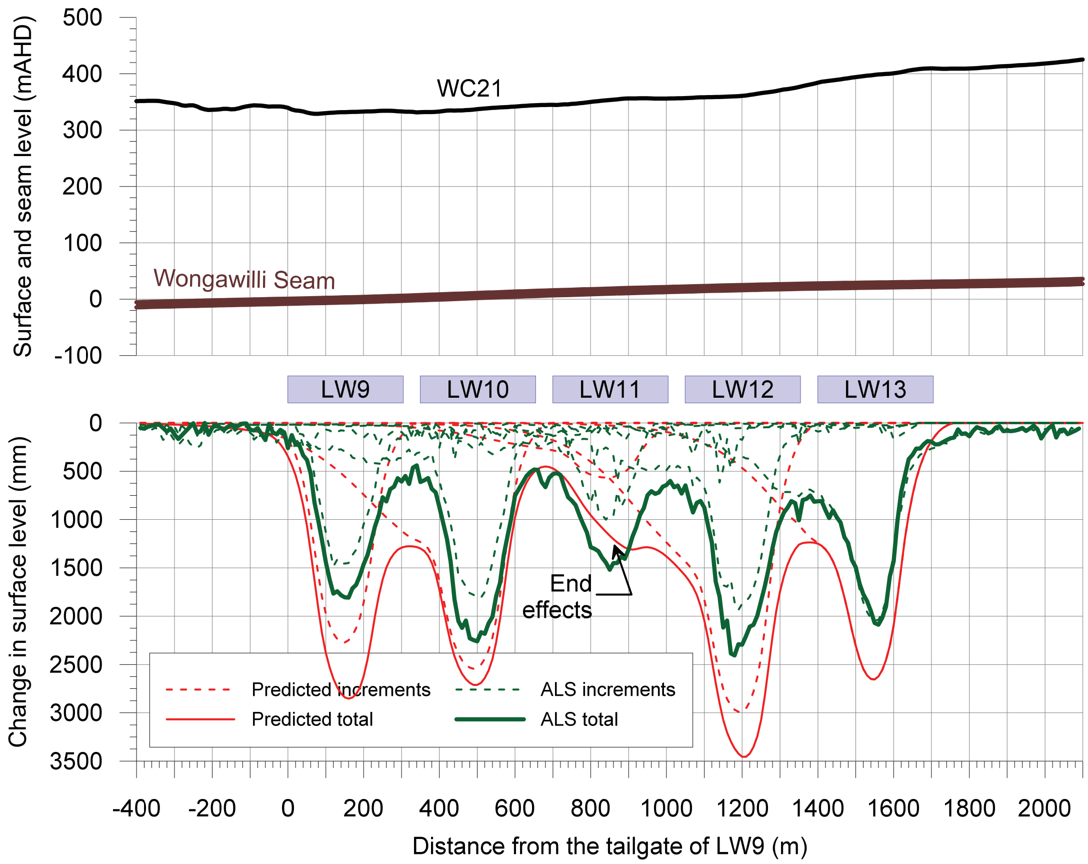

Fig. 3.5 Measured and predicted changes in surface level along Cross-section 3

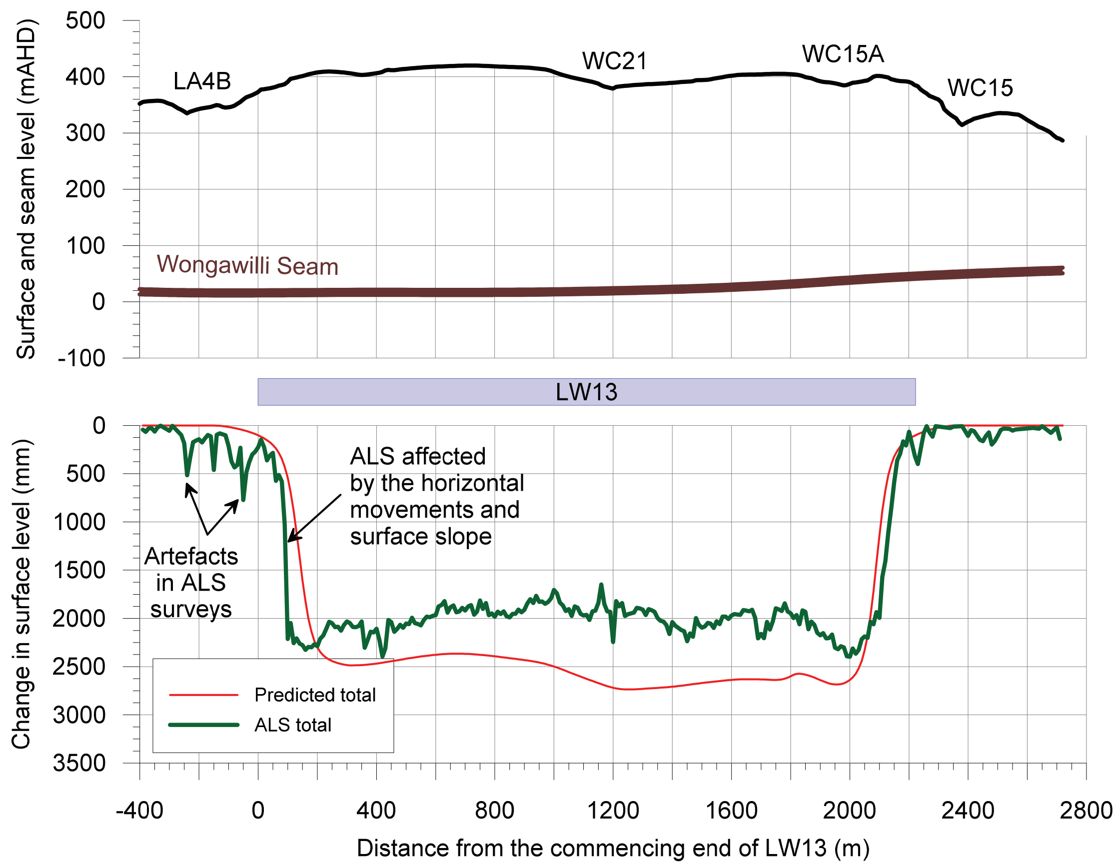

Fig. 3.6 Measured and predicted changes in surface level along Long-section 1

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

The measured change in surface level along Cross-section 3 (refer to Fig. 3.5) is slightly greater than the predicted vertical subsidence above LW11. This cross-section is located close to the finishing end of LW11 and, therefore, the predictions are influenced by the longwall end effects. The difference between the measured and predicted movements are in the order of accuracy of the measurement method.

The measured change in surface level along Long-section 1 (refer to Fig. 3.6) is greater than the predicted vertical subsidence above the commencing end of LW13 (i.e. left side of figure). However, this may be partly due to the effects of the horizontal movements on the LiDAR surveys. The ground directly above the commencing end of LW13 has moved towards the ends (i.e. following the extraction face). The natural surface dips towards the west in this location (i.e. towards the thalweg of LA4B). The mining-induced horizontal movement, therefore, results in the measured changes in level at a fixed position to be greater than the true vertical subsidence above the commencing end of LW13.

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.

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

The vertical subsidence and valley closure were monitored during the extraction of LW9 to LW13 in Area 3B using the Wongawilli Creek Closure Lines, Tributary Cross Lines, Donalds Castle Creek Cross Lines and Swamp Cross Lines.

The comparisons of the measured and predicted total vertical subsidence for the traditional ground monitoring lines at the completion of LW13 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.

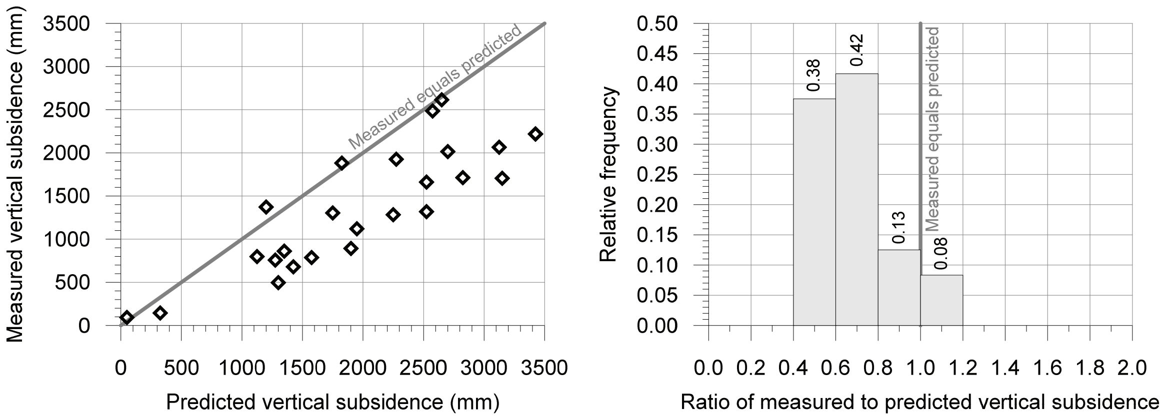

Fig. 3.7 Comparison of measured and predicted subsidence for the ground monitoring lines

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 0.70.

The measured total vertical subsidence movements exceed the predicted values in three of the 24 cases (i.e. 13 % 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 maxima that occur directly above the longwalls. The ratios of the measured to predicted total vertical subsidence for these three monitoring lines range between 1.05 to 1.17 and, therefore, are within the order of accuracy of the predictive method for vertical subsidence of ±15 % to ±25 %.

The comparisons of the measured and predicted total closure for the traditional ground monitoring lines are at the completion of LW13 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.

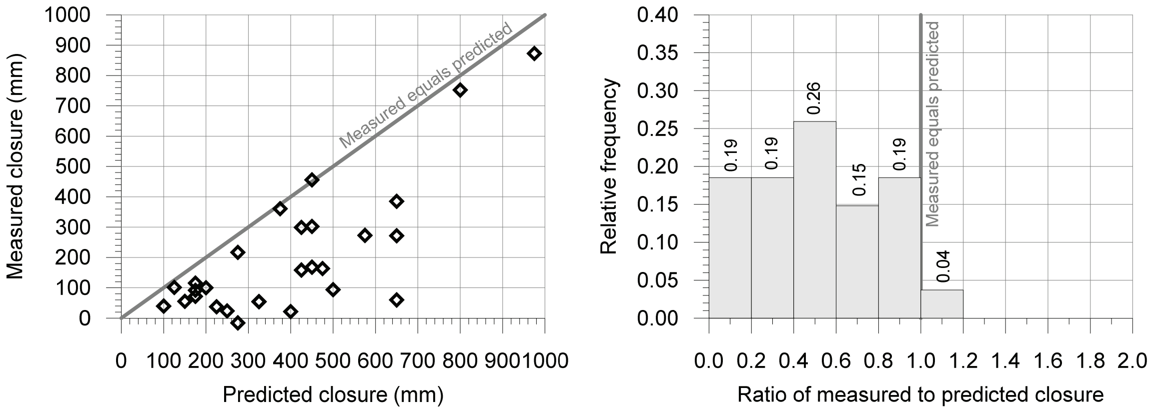

Fig. 3.8 Comparison of measured and predicted closure for the ground monitoring lines

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 0.50, i.e. the measured closures are, on average, around half of those predicted.

The measured total closure movements exceed the predicted values in one of the 28 cases (i.e. 4 % of the monitoring lines). It is noted that there were two additional cases where the measured closures exceeded the predicted values at the completion of LW12. However, the measured closures for these two cases were less than the predicted values after the completion of LW13. The ratio of the measured to predicted total closure for the remaining monitoring 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 lines. The measured movements can be greater than the predicted values, in some cases, but these exceedances are expected to be within the orders of accuracy of the predictive methods of ±15 % to ±25 %.

3.6.3. Use of the calibrated IPM for the proposed longwalls

The calibrated IPM based on the MSEC792 prediction curves has been reviewed based on the ground movement monitoring data from LW9 to LW13 in Area 3B. A comparison of the mining geometry for the proposed LW20 and LW21 with that for the completed longwalls in Area 3B is provided in Table 3.1.

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

Parameter	Proposed LW20 and LW21 (Area 3C)		Completed LW9 to LW13 (Area 3B)	
	Range	Average	Range	Average
Longwall widths	256	256	305	305
Depth of cover	290 ~ 410	360	310 ~ 410	390
W/H ratio	0.62 ~ 0.88	0.71	0.74 ~ 0.98	0.78
Extraction height	3.9	3.9	3.4 ~ 4.5	3.8

The range of depths of cover above the proposed LW20 and LW21 is similar to the range for the completed LW9 to LW13. However, the width-to-depth ratios for LW20 and LW21 are less than those for LW9 to LW13 due to the narrower void widths. The extraction height for the proposed LW20 and LW21 is similar to the average extraction height for the completed LW9 to LW13. The longwalls in Areas 3B and 3C are all within the Wongawilli Seam.

It is considered appropriate, therefore, to adopt the MSEC792 prediction curves for the proposed LW20 and LW21. These prediction curves provide an additional 30 % to the maximum incremental vertical subsidence for each of the longwalls, when compared with that predicted using the standard IPM model.

3.7. Numerical model

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

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

3.7.1. Calibration of the UDEC model for Dendrobium Mine

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

The widths of LW9 to LW13 in Area 3B are 305 m. The average depth of cover to the Wongawilli Seam is 390 m. The average width-to-depth ratio for these longwalls therefore is 0.78. The average mining heights at the cross-section considered were 3.5 m for LW9, 4.5 m for LW10 and 4.0 m for LW11 to LW13.

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

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

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

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

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

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

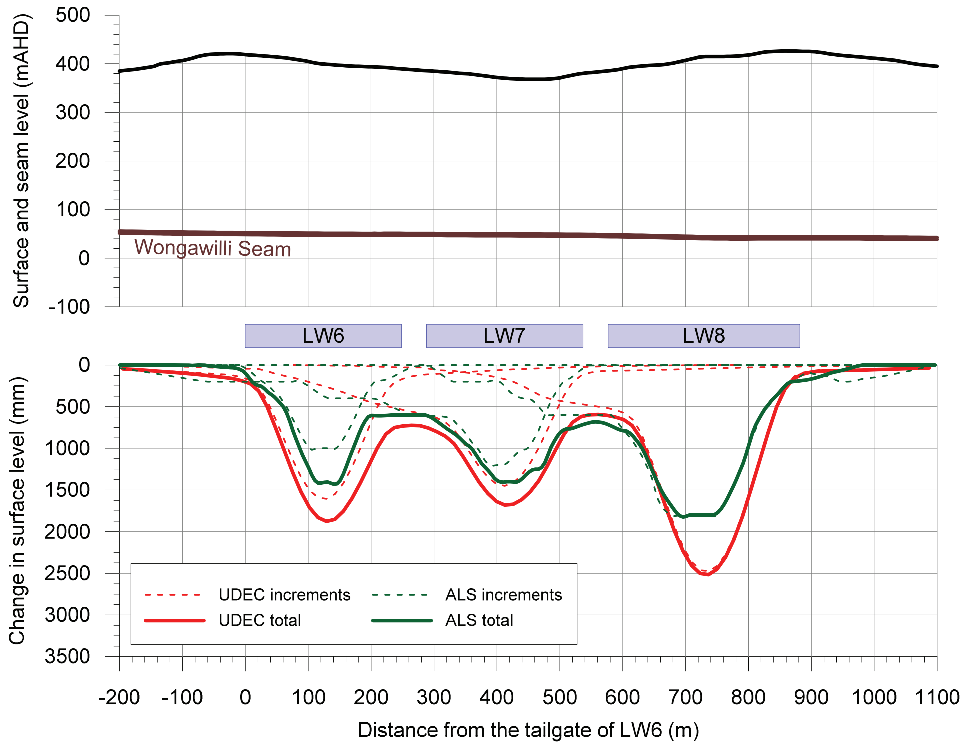

Fig. 3.9 Comparison of modelled and measured subsidence for Dendrobium Area 3A

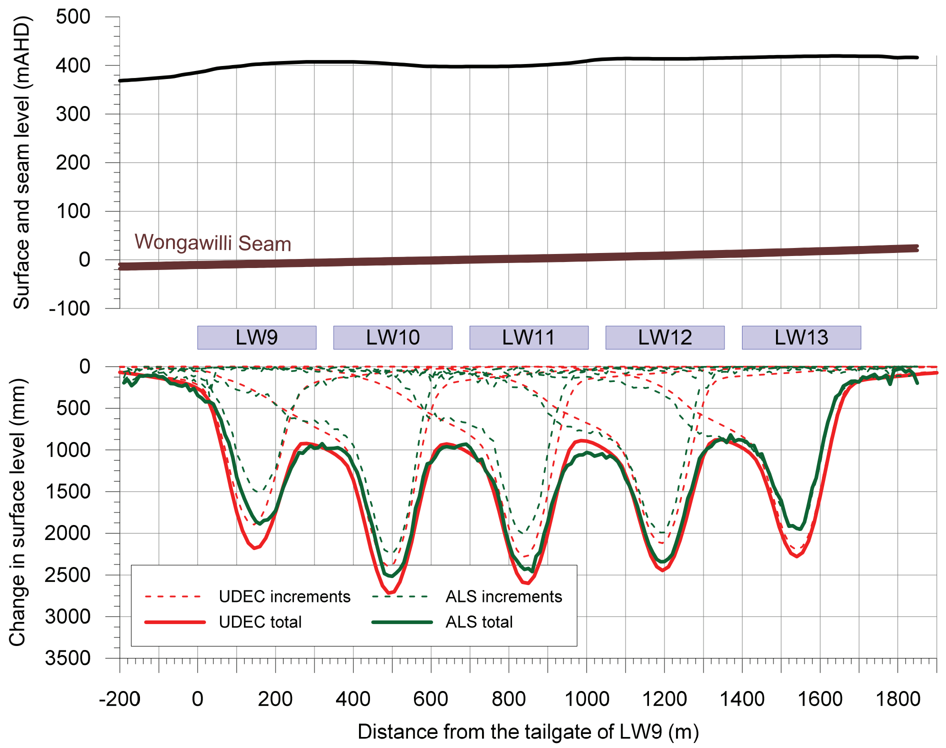

Fig. 3.10 Comparison of modelled and measured subsidence for Dendrobium Area 3B

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

The mining geometries for the proposed LW20 and LW21 are similar to that for LW6 in Area 3A. The overall void width of LW6 was 250 m and it was extracted from the Wongawilli Seam at an average depth of cover of 350 m. The average width-to-depth ratio of LW6 of 0.71 is the same as that for the proposed LW20 and LW21. The average mining height for LW6 of 3.9 m is also the same as that for the proposed longwalls. The numerical model should therefore provide reasonable, if not, slightly conservative predictions of vertical subsidence for the proposed LW20 and LW21.

3.7.2. UDEC model for the proposed longwalls

The void widths for LW20 and LW21 are 256 m. The average depth of cover to the Wongawilli Seam is 370 m for LW20 and 350 m for LW21. The longwalls are proposed to extract a thickness of 3.9 m in the basal section of the Wongawilli Seam which is approximately 10 m thick. The mining geometries of the two proposed longwalls are similar. A single UDEC model has therefore been developed that is representative of both LW20 and LW21.

The edges of the numerical model have been taken as the greater of two times the longwall widths and 600 m from the longwall maingate and tailgate. The overall width of the model therefore is 1456 m. The average depth of cover to the Wongawilli Seam for LW20 and LW21 is 360 m. The modelled width-to-depth ratio therefore is 0.71.

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

Table 3.2 Stratigraphy adopted in the UDEC model

Unit	Thickness (m)	Depth to base on unit (m)	Block size (H x V, m x m)
Hawkesbury Sandstone	130	130	15 x 10
Newport/Garie Formation	20	150	6 x 4
Bald Hill Claystone	20	170	6 x 4
Bulgo Sandstone	130	300	15 x 10
Wombarra Claystone	37	337	6 x 4
Bulli Coal	3	340	4.5 x 3
Eckersley Formation	20	360	7.5 x 5
Wongawilli Coal	10	370	2 x 1
Sub-Wongawilli	100	470	15 x 10

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

Table 3.3 Material properties adopted in the UDEC model

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

Table 3.4 Joint properties adopted in the UDEC model

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

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

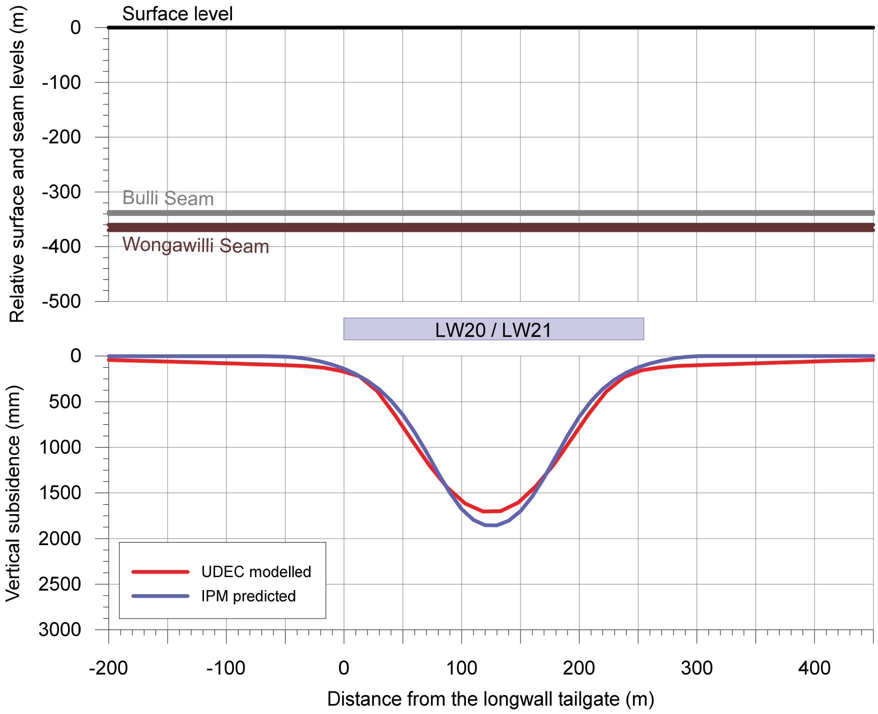

Fig. 3.11 UDEC modelled and IPM predicted profiles of vertical subsidence

The profile of vertical subsidence obtained from the UDEC model reasonably matches that predicted using the IPM. The values of maximum predicted vertical subsidence directly above the proposed longwall are within ±10 %. The numerical model predicts slightly higher vertical subsidence outside the extents of the proposed longwall; however, the differences in magnitude are 100 mm or less.

The maximum predicted tilts and curvatures obtained from the UDEC model are slightly less than the maximum predicted values based on the IPM. This is due to the UDEC model predicting a broader (i.e. flatter) subsidence profile above and adjacent to the longwall edges compared to that for the IPM.

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

In addition, the potential for impacts on the natural and built features result from the differential movements (i.e. tilt and curvature) rather than from the absolute vertical subsidence. The impact assessments based on the predictions obtained from the UDEC model, therefore, are similar to or slightly less than the assessments based on the predictions obtained from the IPM.

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

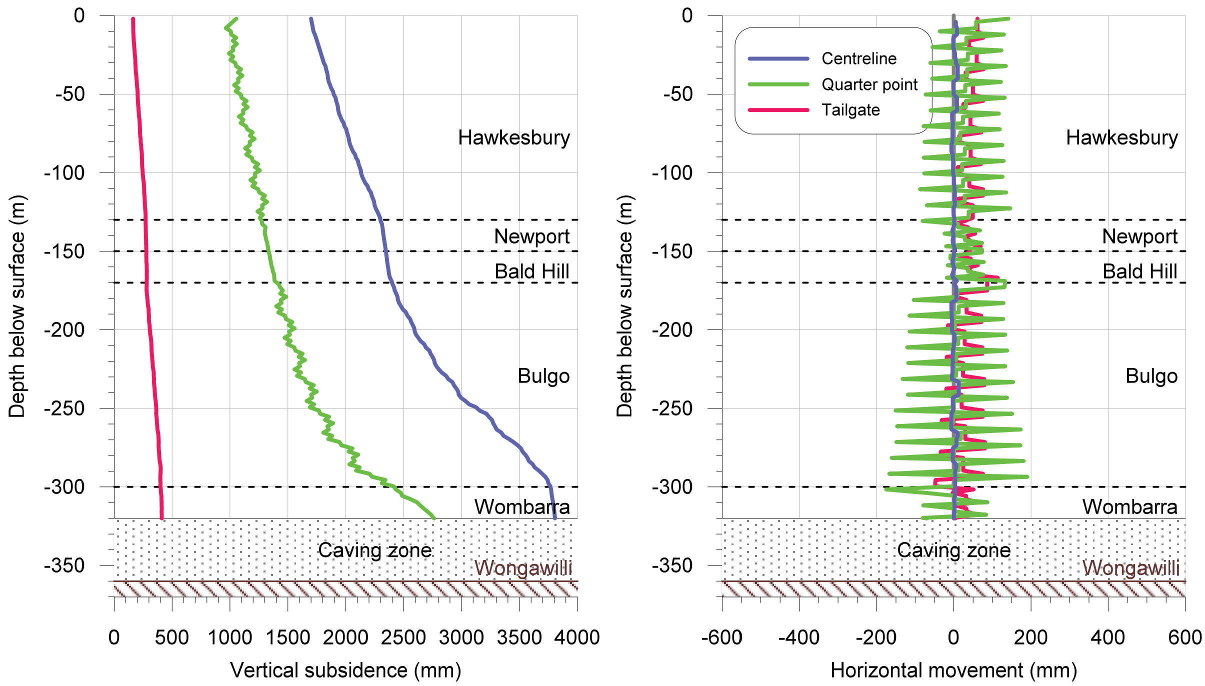

Fig. 3.12 Modelled profiles of vertical subsidence and horizontal movement through the overburden at the longwall centreline, quarter point and longwall tailgate

The vertical subsidence at the longwall centreline varies between 44 % 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 4 % of the mining height at the surface through to 11 % 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, at the longwall centreline, varies between approximately 4 mm/m at the top, 16 mm/m near mid-height and 4 mm/m at the base of the unit. The vertical strain at the quarter-point of the longwall varies between approximately 4 mm/m at the top and 24 mm/m at the base of the Bulgo Sandstone.

The vertical strain within the Wombarra Claystone varies between 12 mm/m and 24 mm/m. The maximum vertical strain occurs at the longwall quarter-points, with the strains reducing towards the longwall centreline, maingate and tailgate. The vertical strains within the Newport Formation and the Bald Hill Claystone are typically 5 mm/m or less.

The horizontal shear on the bedding plane partings varies between approximately 150 mm and 250 mm within the Hawkesbury Sandstone and varies between approximately 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 parameters resulting from the extraction of the proposed LW20 and LW21 in Area 3C. The predicted subsidence parameters and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

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

The maximum predicted subsidence parameters and the predicted subsidence contours provided in this report describe and show the conventional movements and do not include the valley related upsidence and closure movements, nor the effects of faults and other geological structures. Such effects have been addressed separately in the impact assessments for each feature provided in Chapters 5 and 6.

4.2. Maximum predicted conventional subsidence, tilt and curvature

A summary of the maximum predicted values of incremental conventional vertical subsidence, tilt and curvature due to the extraction of each of LW20 and LW21 is provided in Table 4.1. The incremental values are the additional movements due to each proposed longwall.

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

Due to longwall	Maximum predicted incremental subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
LW20	1800	20	0.30	0.60
LW21	2050	30	0.50	0.75

The predicted total vertical subsidence contours after the extraction of LW20 and LW21 are shown in Drawing No. MSEC978-13, 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 parameters represent the accumulated movements within the Study Area due to the extraction of the existing and proposed longwalls.

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

After longwalls	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
LW20 and LW21	2050	30	0.50	0.75

The maximum predicted total vertical subsidence of 2050 mm represents 53 % of the proposed extraction height of 3.9 m. The maximum predicted vertical subsidence occurs above the western end of LW21, where the depth of cover is shallowest.

The maximum predicted total tilt is 20 mm/m (i.e. 2.0 %, or 1 in 50) above LW20 and 30 mm/m (i.e. 3.0 %, or 1 in 33) above LW21. The maximum predicted total conventional curvatures for the proposed longwalls are 0.50 km^{-1} hogging and 0.75 km^{-1} sagging, which represent minimum radii of curvatures of 2 km and 1.3 km, respectively.

The predicted conventional subsidence parameters vary across the Study Area as the result of, amongst other factors, variations in the longwall geometry, depths of cover, seam thickness and overburden geology. To illustrate this variation, the predicted profiles of vertical subsidence, tilt and curvature have been determined along two prediction lines. The predicted profiles of total vertical subsidence, tilt and curvature along Prediction Lines 1 and 2 are shown in Figs. C.01 and C.02, respectively, in Appendix C. The locations of these prediction lines are shown in Drawing No. MSEC978-13.

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

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

Table 4.3 Comparison of maximum predicted total subsidence parameters

Area (Longwalls)	Maximum predicted total conventional subsidence (mm)	Maximum predicted total conventional tilt (mm/m)	Maximum predicted total conventional hogging curvature (km^{-1})	Maximum predicted total conventional sagging curvature (km^{-1})
Area 3A (LW6 to LW8 and LW19)	3600	50	1.4	1.4
Area 3B (LW9 to LW18)	3600	50	1.4	1.4
Area 3C (LW20 and LW21)	2050	30	0.50	0.75

The maximum predicted subsidence parameters for the proposed LW20 and LW21 are less than the maximum predicted values for the existing and approved longwalls in Areas 3A and 3B at the Mine. The predicted subsidence parameters are less due to the:

- narrower void widths (i.e. 256 m) compared with a typical void width of 305 m in Areas 3A and 3B, except for LW6 and LW7 at widths of 255 m;
- proposed LW20 and LW21 are single isolated longwalls, whereas the longwalls in Areas 3A and 3B comprise a series of four and ten longwalls, respectively. The vertical subsidence due to the first longwall in a series is less than that for the subsequent longwalls; and
- extraction height for the proposed LW20 and LW21 of 3.9 m is less than the extraction height for LW10 to LW13 in Area 3B of up to 4.6 m.

It is noted that the maximum measured vertical subsidence in Areas 3A and 3B, to date, are less than the maximum predicted value as provided in Table 4.3. The maximum measured vertical subsidence movements based on the LiDAR surveys are approximately 2000 mm due to LW6 to LW8 in Area 3A and approximately 2700 mm due to LW9 to LW13 in Area 3C.

Whilst not all longwalls have been extracted in Areas 3A and 3B, it is expected that the maximum measured vertical subsidence will be less than the maximum predicted values at the completion of mining in these areas. It is expected, therefore, that the actual measured vertical subsidence for the proposed LW20 and LW21 will also be less than the maximum predicted values obtained using the calibrated IPM model.

4.4. Predicted strains

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

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

Adopting a linear relationship between curvature and strain provides a reasonable prediction for the conventional tensile and compressive strains. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones. In the Southern Coalfield, it has been found that a factor of 15 provides a reasonable relationship between the predicted maximum curvatures and the predicted maximum conventional strains.

The maximum predicted conventional strains resulting from the extraction of proposed LW20 and LW21, based on applying a factor of 15 to the maximum predicted curvatures, are 8 mm/m tensile and 11 mm/m compressive. These strains represent typical values when the ground subsides regularly with no localised or elevated strains due to near-surface geological structures or valley closure effects. The maximum strains can be much greater than these typical values, especially in the locations of near-surface geological structures and in the bases of valleys.

At a point, however, there can be considerable variation from the linear relationship, resulting from non-conventional movements or from the normal scatters which are observed in strain profiles. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strain for low magnitudes of curvature. In this report, therefore, we have provided a statistical approach to account for the variability, instead of just providing a single predicted conventional strain.

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

A comparison of the mining geometry for the proposed LW20 and LW21 with that for the previously extracted longwalls used in the strain analysis is provided in Table 4.4. There is a total of 21 ground monitoring lines located above 54 previously extracted longwalls in the Hunter and Newcastle Coalfields.

Table 4.4 Comparison of the mine geometry for the proposed LW20 and LW21 with the longwalls from the NSW coalfields used in the strain analysis

Parameter	Proposed LW20 and LW21 (Area 3C)		Longwalls used in strain analysis	
	Range	Average	Range	Average
Longwall width	256	256	140 ~ 230	180
Depth of cover	290 ~ 410	360	160 ~ 370	210
W/H ratio	0.62 ~ 0.88	0.71	0.6 ~ 1.0	0.87
Extraction height	3.9	3.9	3.1 ~ 4.8	4.2

The range of width-to-depth ratios and extraction heights for the longwalls used in the strain analysis are similar to but greater, on average, than the width-to-depth ratios and extraction heights of the proposed LW20 and LW21. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains resulting from the extraction of the proposed longwalls.

The data used in the analysis of observed strains included those resulting from both conventional and non-conventional anomalous movements but did not include those resulting from valley related 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 goaf or the chain pillars that are located between the extracted longwalls. A number of probability distribution functions were fitted to the empirical data. It was found that a *Generalised Pareto Distribution (GPD)* provided a good fit to the raw strain data.

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

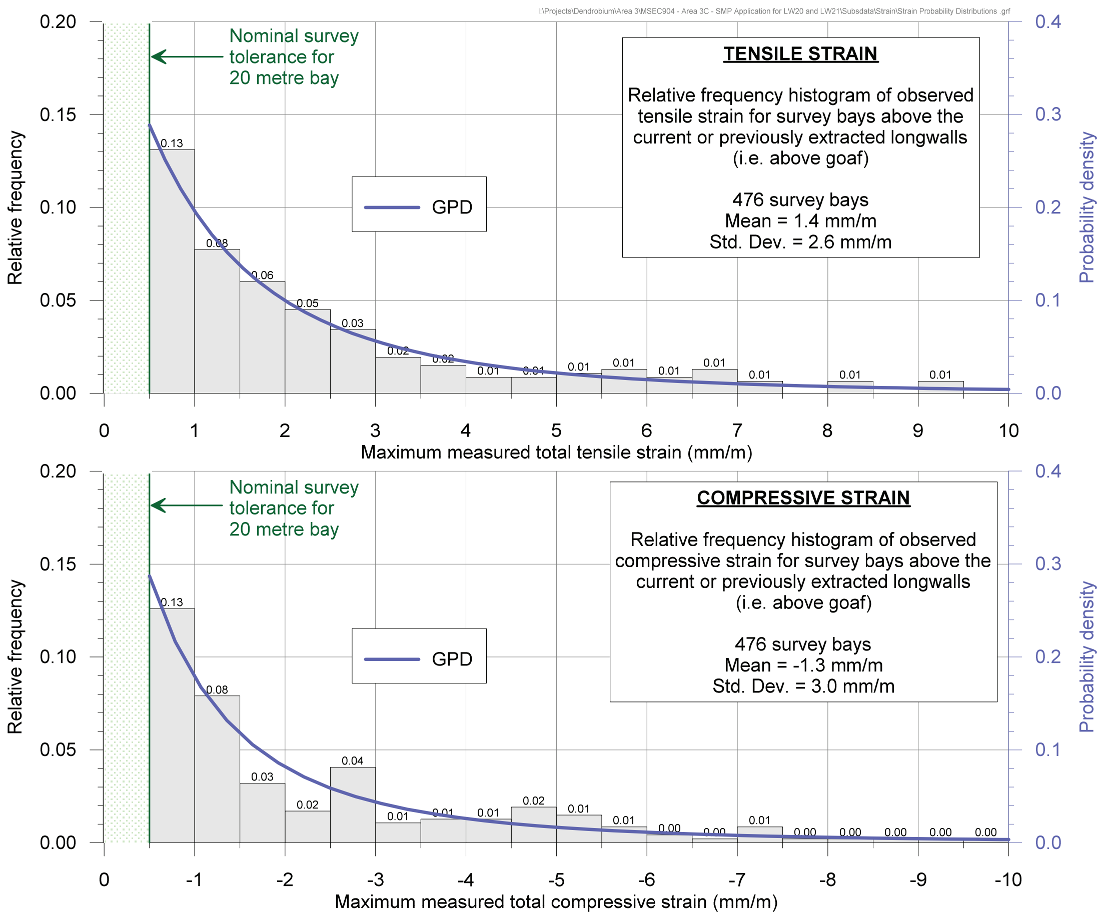

Fig. 4.1 Distributions of the measured maximum tensile and compressive strains during the extraction of previous longwalls in the NSW coalfields for bays located above goaf

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

The 95 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining are 6 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 14 mm/m tensile and 15 mm/m compressive.

4.5. Predicted conventional horizontal movements

The predicted conventional horizontal movements over the 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 LW20 and LW21 is 30 mm/m. The maximum predicted conventional horizontal movement, therefore, is approximately 450 mm, i.e. 30 mm/m multiplied by a factor of 15. Greater movements can develop in incised terrain, due to the increased horizontal movements that develop in the downslope direction.

The distribution of the maximum observed horizontal movements for the 3D survey marks located directly above the longwalls in Dendrobium Areas 1, 2, 3A and 3B is provided in Fig. 4.2. It can be seen from this figure, that horizontal movements have been measured up to 600 mm at the Mine, with an average measured value of approximately 300 mm.

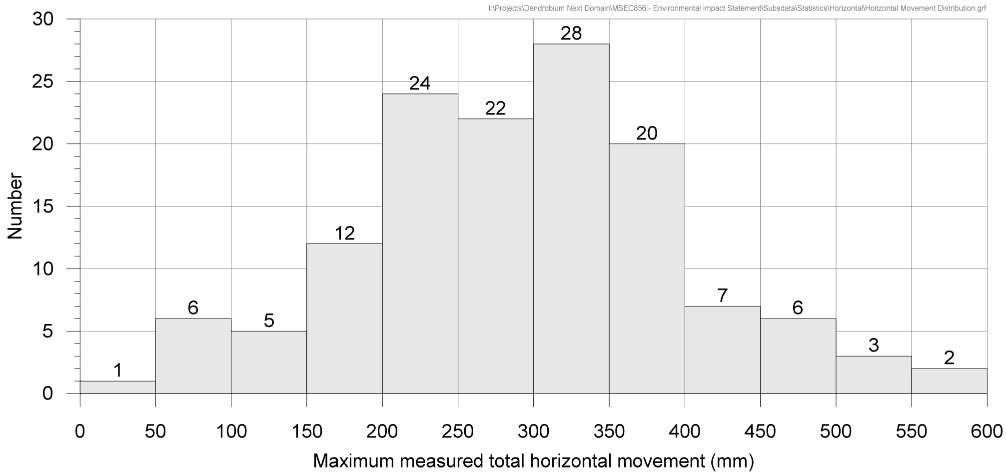

Fig. 4.2 Distributions of the maximum observed horizontal movements for the 3D marks located directly above the longwalls in Dendrobium Areas 1, 2, 3A and 3B

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

4.6. Predicted far-field horizontal movements

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

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

The observed incremental far-field horizontal movements, resulting from the extraction of longwalls at Dendrobium Areas 1, 2, 3A and 3B, are provided in Fig. 4.3. The observed far-field movements for other collieries in the Southern Coalfield, including the confidence levels based on fitted GPDs, have also been shown in this figure for comparison.

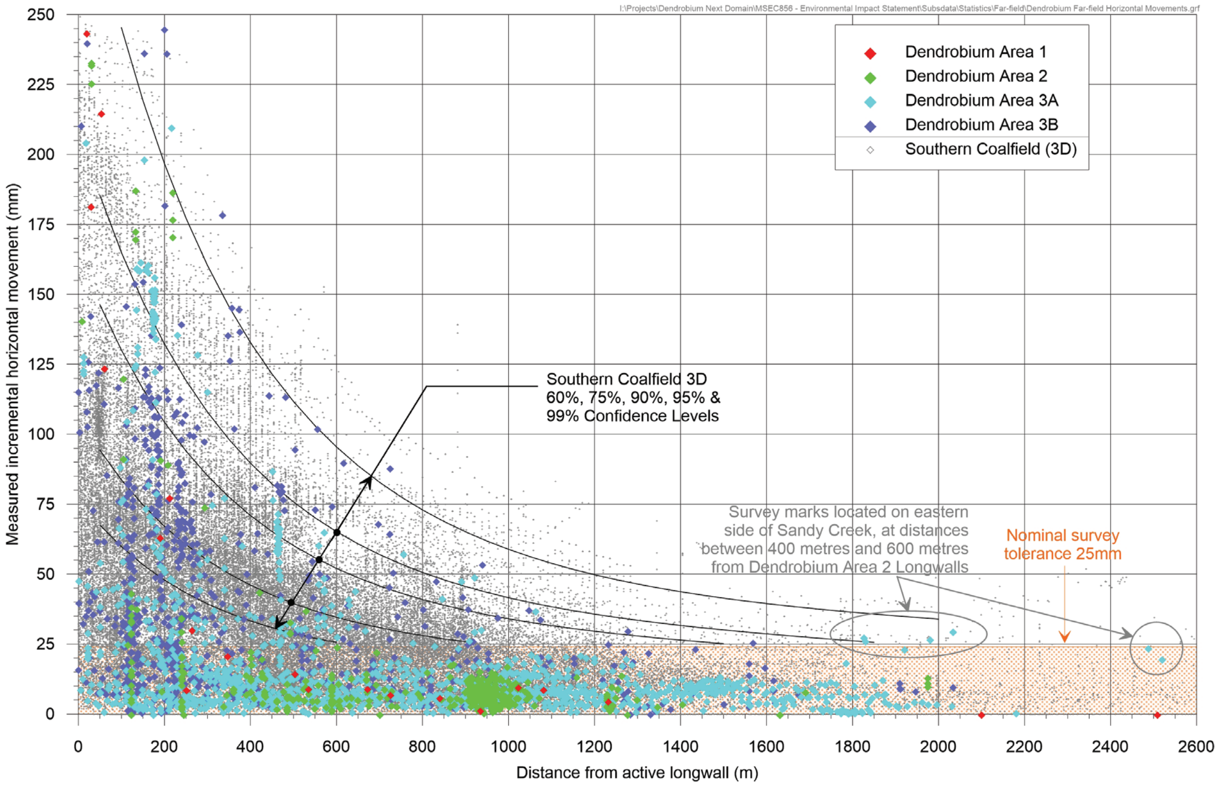

Fig. 4.3 Measured incremental far-field horizontal movements at Dendrobium Mine and elsewhere in the Southern Coalfield

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

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

4.7. Non-conventional ground movements

It is likely non-conventional ground movements will occur within the Study Area, due to near surface geological conditions, steep topography and valley related 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 movements 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 movements. 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 a statistical analysis of measured strains in the NSW coalfields, including both conventional and non-conventional anomalous strains and are discussed in Section 4.4. In addition to this, the impact assessments for the natural features and items of surface infrastructure, which are provided in Chapters 5 and 6, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

4.8. Surface deformations

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

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

Surface deformations can also develop as the result of downslope movements where longwalls are extracted beneath steep slopes. In these cases, the downslope movements can result in the development of tension cracks at the tops and on the sides of the steep slopes and compression ridges at the bottoms of the steep slopes. The impact assessments for downslope movements are provided in Section 5.7.

Fracturing of bedrock can also occur in the bases of stream valleys due to the compressive strains associated with valley upsidence and closure movements. The impact assessments for valley related movements are provided in Sections 5.2 to 5.4.

The soil crack and rock fracture widths were measured at the impact sites located above LW3 to LW5 in Area 2, LW6 to LW8 in Area 3A and LW9 and LW13 in Area 3B. The distribution of the measured widths of these surface deformations is illustrated in Fig. 4.4.

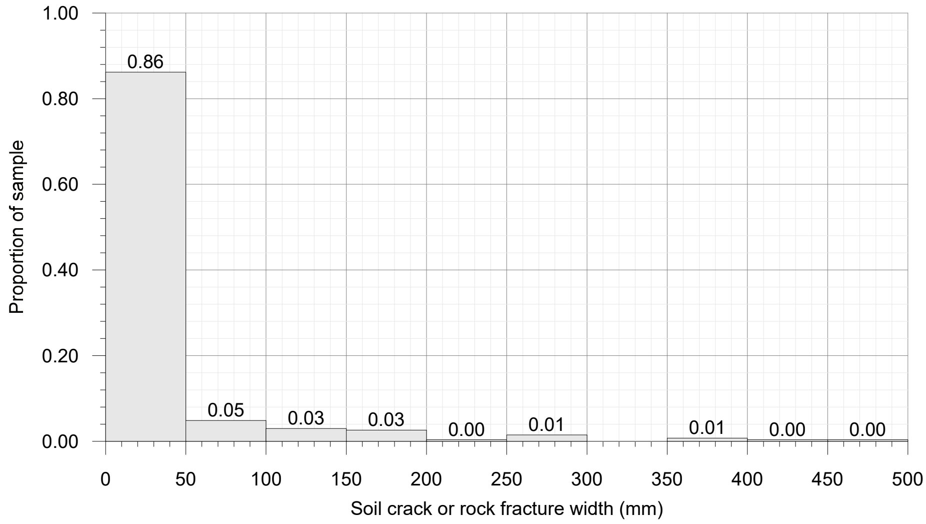

Fig. 4.4 Distribution of measured soil crack and rock fracture widths in Areas 2, 3A and 3B

The soil crack and rock fracture widths were generally less than 50 mm (i.e. 86 % of the cases). However, the widths of the surface deformations were between 50 mm and 150 mm in 8 % of cases, between 150 mm and 300 mm in 4 % of cases and greater than 300 mm in 2 % of cases. The maximum measured crack width was approximately 500 mm.

It is noted, that there was a series of cracks up to 1.5 m wide located above the commencing end of LW3 (not shown in the above figure for clarity) that developed due to downslope movement on the steep slopes, the shallower depth of cover (less than 200 m at that location) and fretting of the crack edges.

The predicted mine subsidence parameters for the proposed LW20 and LW21 are less than those for the previously extracted longwalls in Areas 3A and 3B at the Mine, as shown in Table 4.3. The soil crack and rock fracture widths due to the extraction of the proposed longwalls, therefore, are expected to be less, on average, that those measured in Areas 3A and 3B.

The following sections provide the descriptions, predictions and impact assessments for the natural features located within the Study Area. All significant natural features located outside the Study Area, which may be subjected to far-field movements or valley related movements 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 LW20 and LW21 are located outside the Dams Safety Committee (DSC) Notification Areas for Lake Cordeaux and Lake Avon. The Study Areas based on both the 35° angle of draw and the 600 m boundary are also located outside the DSC 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. MSEC978-09.

Wongawilli Creek is located between the proposed LW20 and LW21. The thalweg (i.e. base or centreline) of the creek is 125 m east of the tailgate of LW20 and 240 m west of the finishing end of LW21, at the closest points to the proposed longwalls. Further upstream, the creek is located between the completed longwalls in Areas 3A and 3B. The minimum distances between the thalweg of the creek and the completed longwalls are 110 m for Area 3A and 260 m for Area 3B.

The total length of Wongawilli Creek located within the Study Area based on the 35° angle of draw line is approximately 0.8 km. The length of the creek located within the Study Area based on the 600 m boundary is approximately 3.0 km.

Wongawilli Creek is a third order perennial stream with a small base flow and increased flows for short periods of time after significant rain events. The creek generally flows in a northerly direction and drains into the Cordeaux River approximately 2.3 km to the north of the proposed longwalls.

Pools in the creek naturally develop behind the rockbars and at the sediment and debris accumulations. The locations of the mapped stream features along Wongawilli Creek are shown in Drawings Nos. MSEC978-10 and MSEC978-11. Summaries of the features mapped along the section of creek located within the Study Area based on the 600 m boundary are provided in Table 5.1 to Table 5.4.

Table 5.1 Rockbars mapped along Wongawilli Creek

Label	Approximate size	Location at closest point to mining
WC-RB18	40 m long x 15 m wide	440 m north-east of LW20
WC-RB19	30 m long x 15 m wide	430 m north-east of LW20
WC-RB20	15 m long x 15 m wide	350 m north-east of LW20
WC-RB21	50 m long x 10 m wide	170 m east of LW20
WC-RB22	5 m long x 10 m wide	140 m east of LW20
WC-RB23	10 m long x 8 m wide	140 m east of LW20
WC-RB24	3 m long x 6 m wide	130 m east of LW20
WC-RB25	25 m long x 10 m wide	220 m east of LW20
WC-RB26	15 m long x 10 m wide	240 m east of LW20
WC-RB27	100 m long x 20 m wide	260 m east of LW20
WC-RB29	20 m long x 8 m wide	330 m east of LW20
WC-RB30	8 m long x 5 m wide	270 m east of LW20
WC-RB31	8 m long x 5 m wide	270 m east of LW20
WC-RB32	5 m long x 5 m wide	330 m west of LW21
WC-RB33	8 m long x 5 m wide	260 m west of LW21
WC-RB34	8 m long x 5 m wide	240 m west of LW21
WC-RB35	15 m long x 10 m wide	430 m south of LW21

Table 5.2 Riffles mapped along Wongawilli Creek

Label	Approximate size	Location at closest point to mining
WC-RF25a	25 m long x 10 m wide	120 m east of LW20
WC-RF25b	3 m long x 8 m wide	140 m east of LW20
WC-RF27	6 m long x 10 m wide	250 m east of LW20
WC-RF30	30 m long x 8 m wide	300 m east of LW20
WC-RF32	10 m long x 5 m wide	360 m south-east of LW20
WC-RF33	8 m long x 5 m wide	270 m west of LW21
WC-RF35a	3 m long x 3 m wide	270 m south-west of LW21
WC-RF35b	3 m long x 5 m wide	300 m south-west of LW21
WC-RF35c	5 m long x 5 m wide	310 m south-west of LW21
WC-RF35d	5 m long x 5 m wide	420 m south of LW21

Table 5.3 Islands mapped along Wongawilli Creek

Label	Approximate size	Location at closest point to mining
WC-IS30	40 m long x 15 m wide	280 m east of LW20
WC-IS32	20 m long x 3 m wide	330 m west of LW21
WC-IS35a	20 m long x 5 m wide	270 m south-west of LW21
WC-IS35b	60 m long x 5 m wide	280 m south-west of LW21

Table 5.4 Sandbars mapped along Wongawilli Creek

Label	Approximate size	Location at closest point to mining
WC-SB25a	40 m long x 8 m wide	140 m east of LW20
WC-SB25b	10 m long x 8 m wide	220 m east of LW20

It is noted that the riffle and sandbar locations are based on those mapped by IC using GPS during the field surveys carried out in 2011. The locations of these features 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 IC indicate that the base of the creek rises up through the stratigraphy as it runs from the south to the north. The section of Wongawilli Creek located within the Study Area is founded in Bulgo Sandstone.

Photographs of Wongawilli Creek at the crossing with Fire Road 6 are provided in Fig. 5.1. This crossing is located approximately 1 km to the north of the proposed LW21.

Fig. 5.1 Wongawilli Creek at crossing with Fire Road 6

The natural surface level along Wongawilli Creek, within the extents of the Study Area based on the 600 m boundary, varies from 282 mAHD at the upstream end to 271 mAHD at the downstream end. The average natural grade over the 3.0 km length, therefore, is approximately 3.7 mm/m (i.e. 0.37 %, or 1 in 270).

The valley of Wongawilli Creek has an overall height of approximately 100 m to 120 m within the Study Area. The valley is steeply sided, comprising cliffs, minor cliffs and talus slopes in a number of locations. The descriptions of the cliffs, minor cliffs, rock outcrops and steep slopes within the valley are included in Sections 5.6 and 5.7.

A section through the valley of Wongawilli Creek, where the creek is located closest to the proposed longwalls, is provided in Fig. 5.2. Another section through the valley, further upstream where the creek is located closest to the proposed LW21, is provided in Fig. 5.3. The locations of these sections are shown in Drawing No. MSEC978-08.

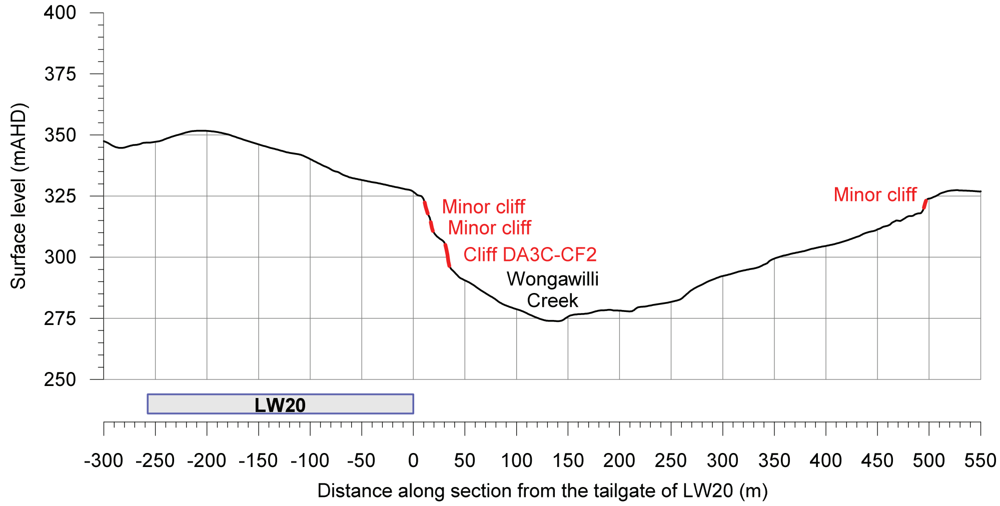

Fig. 5.2 Section A through Wongawilli Creek and the proposed LW20

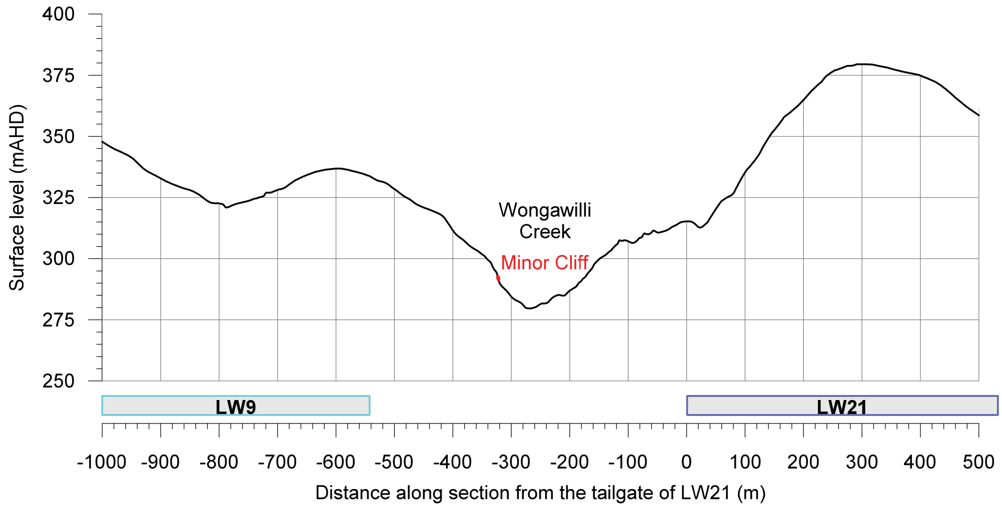

Fig. 5.3 Section B through Wongawilli Creek and the proposed LW21

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

5.2.2. Predictions for Wongawilli Creek

The predicted profiles of total vertical subsidence, upsidence and closure along Wongawilli Creek are shown in Fig. C.03, in Appendix C. The predicted total profiles after the completion of the existing and approved longwalls in Areas 3A and 3B are shown as cyan lines. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for Wongawilli Creek is provided in Table 5.5. The values are the maxima anywhere along the section of the creek located within the Study Area based on the 600 m boundary.

Table 5.5 Maximum predicted total vertical subsidence, upsidence and closure for Wongawilli Creek

Location	Area or Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Wongawilli Creek	Areas 3A and 3B	< 20	140	200
	LW20	< 20	140	200
	LW21	< 20	150	210

The section of Wongawilli Creek located within the Study Area is predicted to experience less than 20 mm vertical subsidence. Whilst 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 movements for the section of creek located within the Study Area are 150 mm upsidence and 210 mm closure. The maximum predicted valley related effects within the Study Area occur adjacent to the completed LW9 and LW10 in Area 3B.

The maximum predicted additional valley related effects due to the extraction of the proposed LW20 and LW21 only are 60 mm upsidence and 150 mm closure. The maximum additional valley related effects occur where Wongawilli Creek is located closes to the proposed LW20.

Wongawilli Creek could experience compressive strains due to the valley closure movements. The predicted strains have been determined based on an analysis of ground monitoring lines for valleys with similar heights located at similar distances from previously extracted longwalls in the Southern Coalfield, as for Wongawilli Creek. The maximum predicted compressive strain for Wongawilli Creek due to the extraction of the proposed LW20 and LW21 is 8 mm/m based on the 95 % confidence level.

Summaries of the maximum predicted values of total vertical subsidence, upsidence and closure at the mapped stream features along Wongawilli Creek are provided in Table 5.6 to Table 5.9. The locations of these features are shown in Drawings Nos. MSEC978-10 and MSEC978-11.

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

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Rockbars along Wongawilli Creek	WC-RB18	< 20	< 20	20
	WC-RB19	< 20	< 20	20
	WC-RB20	< 20	< 20	30
	WC-RB21	< 20	30	70
	WC-RB22	< 20	40	80
	WC-RB23	< 20	50	90
	WC-RB24	< 20	50	90
	WC-RB25	< 20	50	140
	WC-RB26	< 20	50	130
	WC-RB27	< 20	40	120
	WC-RB29	< 20	40	80
	WC-RB30	< 20	40	60
	WC-RB31	< 20	40	60
	WC-RB32	< 20	50	50
	WC-RB33	< 20	40	50
	WC-RB34	< 20	40	70
	WC-RB34	< 20	130	180

Table 5.7 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	WC-RF25a	< 20	60	150
	WC-RF25b	< 20	60	150
	WC-RF27	< 20	50	130
	WC-RF30	< 20	40	70
	WC-RF32	< 20	30	50
	WC-RF33	< 20	50	50
	WC-RF35a	< 20	50	100
	WC-RF35b	< 20	60	130
	WC-RF35c	< 20	60	140
	WC-RF35d	< 20	120	180

Table 5.8 Maximum predicted total vertical subsidence, upsidence and closure at the mapped islands along Wongawilli Creek

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Islands along Wongawilli Creek	WC-IS30	< 20	40	70
	WC-IS32	< 20	50	50
	WC-IS35a	< 20	50	100
	WC-IS35b	< 20	50	120

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

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Sandbars along Wongawilli Creek	WC-SB25a	< 20	60	130
	WC-SB25b	< 20	50	140

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

5.2.3. Comparison between measured and predicted movements for Wongawilli Creek due to the extraction of LW9 to LW13

The closure movements across Wongawilli Creek have been measured using the Wong X A-Line, Wong X B-Line, Wong X C-Line and Wong X D-Line. The locations of these monitoring lines are shown in Drawing No. MSEC978-01.

A review of the ground monitoring data was carried out as part of the End of Panel Report for LW13 and is summarised in Report MSEC965. The measured and predicted total closures along Wongawilli Creek after the completion of LW13 are illustrated in Fig. 5.4.

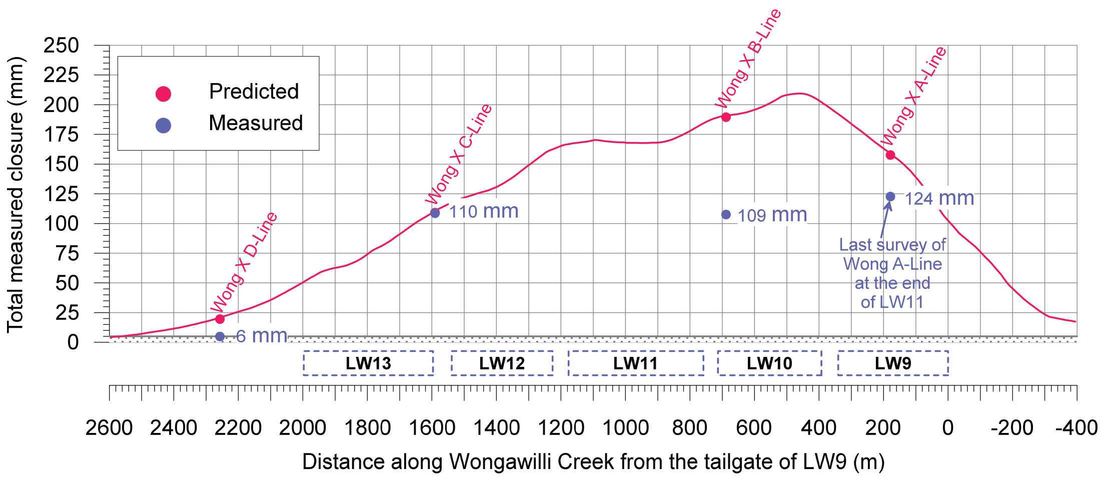

Fig. 5.4 Measured and predicted closure along Wongawilli Creek

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

5.2.4. Observed impacts along Wongawilli Creek due to LW9 to LW13

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 LW13 in Area 3B. The minimum distances between the thalweg of the creek and the completed longwalls are 110 m for Area 3A and 260 m for Area 3B.

The reported impacts for Wongawilli Creek have been summarised in the End of Panel reports for each of the extracted longwalls. The extraction of LW6 to LW13 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 setback from Wongawilli Creek so that the predicted closure is less than 200 mm at the mapped rockbars. It was assessed that the likelihood of significant fracturing resulting in surface water flow diversions along Wongawilli Creek would be low, i.e. affecting less than 10 % of the pools and channels. It is considered that the observed rate of impact (i.e. one Type 3 impact along the 2 km length of Wongawilli Creek) is similar to the MSEC assessments.

5.2.5. Impact assessments of Wongawilli Creek

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

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

Wongawilli Creek is predicted to experience less than 20 mm vertical subsidence due to the extraction of the proposed LW20 and LW21. Whilst 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 additional upsidence along Wongawilli Creek due to the extraction of the proposed LW20 and LW21 is 60 mm. The maximum predicted total upsidence along the creek within the Study Area is 150 mm which occurs adjacent to the completed LW9 and LW10 in Area 3B. Whilst 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 3.7 mm/m (i.e. 0.37 %, or 1 in 270). The predicted changes in grade due to the extraction of LW20 and LW21, therefore, are considerably less than the average natural grade. It is unlikely, therefore, that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilt.

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

Potential for fracturing of bedrock and surface water flow diversions

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

Diversions of surface water 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 a minimum distance of 125 m from the proposed LW20 and LW21. Whilst 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 additional closure along Wongawilli Creek due to the extraction of the proposed LW20 and LW21 is 150 mm. The maximum predicted total closure along the creek within the Study Area is 210 mm which occurs adjacent to the completed LW9 and LW10 in Area 3B. The maximum predicted compressive strain for the creek due to the valley closure effects is 8 mm/m based on the 95 % confidence level.

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

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

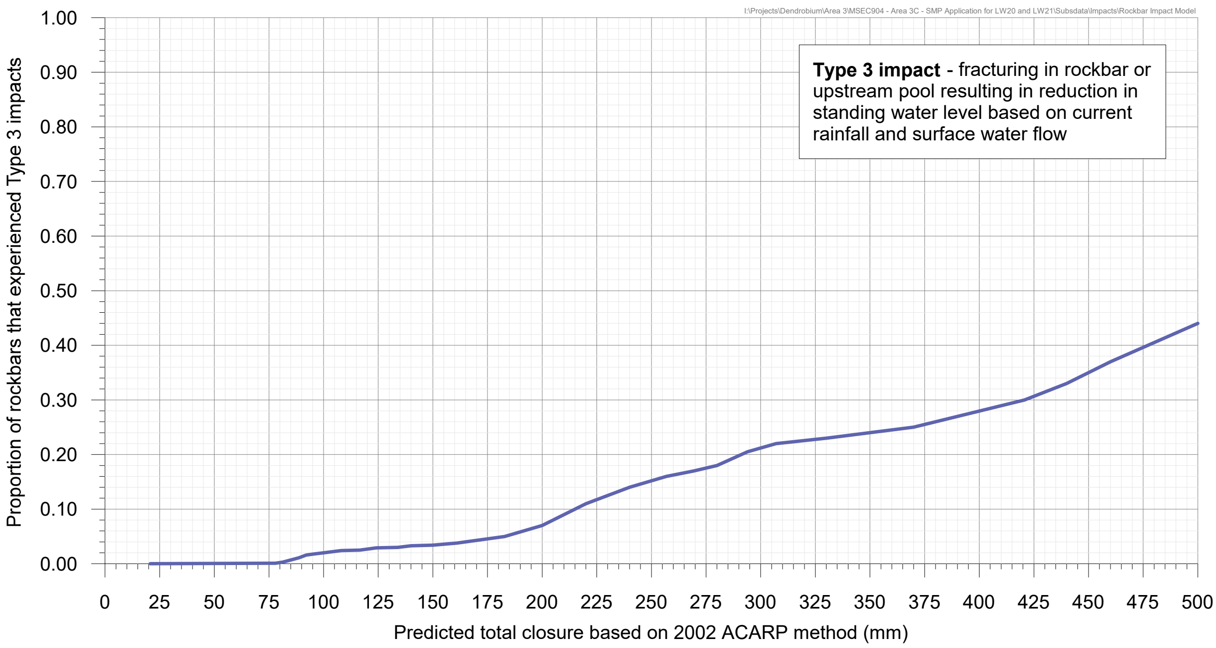

Fig. 5.5 Rockbar impact model based on predicted valley closure

The maximum predicted total closure along Wongawilli Creek within the Study Area, after the extraction of the proposed LW20 and LW21, is 210 mm. The predicted rate of impact for the rockbars along this creek after the extraction of the proposed longwalls, therefore, is in the order of 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 LW20 and LW21, is low, i.e. affecting less than 10 % of rockbars located within the Study Area. However, minor fracturing could still occur along the creek, at distances up to approximately 400 m from the proposed longwalls.

Further assessments of the potential impacts on surface water is provided in the report by HGeo (2019).

5.2.6. Recommendations for Wongawilli Creek

It is recommended that the closure movements are measured and that inspections are carried out along Wongawilli Creek during active subsidence. It is also recommended that the Dendrobium Watercourse Impact Management Monitoring and Contingency Plan be revised to take into account the extraction of the proposed LW20 and LW21.

5.3. Donalds Castle Creek

5.3.1. Description of Donalds Castle Creek

The location of Donalds Castle Creek is shown in Drawing No. MSEC978-09.

Donalds Castle Creek is located to the west of the proposed longwalls. The thalweg of the creek is 470 m from the maingate and finishing end of LW20, at its closest point. Donalds Castle Creek is located outside the Study Area based on the 35° angle of draw. The total length of the creek located within the Study Area based on the 600 m boundary is approximately 0.8 km.

Donalds Castle Creek crosses directly above the completed LW9 to LW12 in Area 3B upstream of the proposed longwalls. The total length of creek that has been directly mined beneath in Area 3B is approximately 1.5 km.

The section of Donalds Castle Creek located within the Study Area is a second order perennial stream with a small base flow and increased flows for short periods after significant rain events. The creek generally flows in a northerly direction and drains into the Cordeaux River more than 4 km to the north of the proposed longwalls.

The bed of the creek comprises exposed bedrock containing rockbars with standing pools. There are also other controlling features including channels, steps and debris accumulations. The locations of the mapped stream features are shown in Drawings Nos. MSEC978-10 and MSEC978-11. Summaries of the features mapped along the section of creek located within the Study Area based on the 600 m boundary are provided in Table 5.10 and Table 5.11.

Table 5.10 Rockbars mapped along Donalds Castle Creek

Label	Approximate size	Minimum distance from the proposed longwalls (m)
DC-RB15	6 m long x 6 m wide	540 m west of LW20
DC-RB16	3 m long x 3 m wide	550 m west of LW20
DC-RB18	5 m long x 3 m wide	550 m west of LW20
DC-RB21	30 m long x 5 m wide	500 m south-west of LW20
DC-RB22	3 m long x 3 m wide	490 m south-west of LW20
DC-RB25	5 m long x 3 m wide	470 m south-west of LW20
DC-RB29	8 m long x 15 m wide	500 m south-west of LW20

Table 5.11 Steps mapped along Donalds Castle Creek

Label	Approximate size	Minimum distance from the proposed longwalls (m)
DC-ST19	8 m long x 5 m wide	530 m south-west of LW20
DC-ST20	5 m long x 10 m wide	520 m south-west of LW20

Photographs of Donalds Castle Creek at the Fire Road 6 crossing are provided in Fig. 5.6. This crossing is located approximately 0.8 km to the west of the proposed LW20.

Fig. 5.6 Donalds Castle Creek at the Fire Road 6 Crossing

The natural surface level along Donalds Castle Creek, within the extents of the Study Area based on the 600 m boundary, varies from 360 mAHD at the upstream end to 335 mAHD at the downstream end. The average natural grade over the 0.8 km length, therefore, is approximately 35 mm/m (i.e. 3.5 %, or 1 in 30).

The valley of Donalds Castle Creek has an overall height up to approximately 40 m, where it is located closest to the proposed longwalls, and increases up to approximately 70 m further downstream. The valley is steeply sided, comprising minor cliffs, rock outcrops and talus slopes in a number of locations. The descriptions of the minor cliffs, rock outcrops and steep slopes within the valley are included in Sections 5.6 and 5.7.

A section through Donalds Castle Creek, where the creek is located closest to the proposed longwalls, is provided in Fig. 5.7. The location of this section is shown in Drawing No. MSEC978-08.

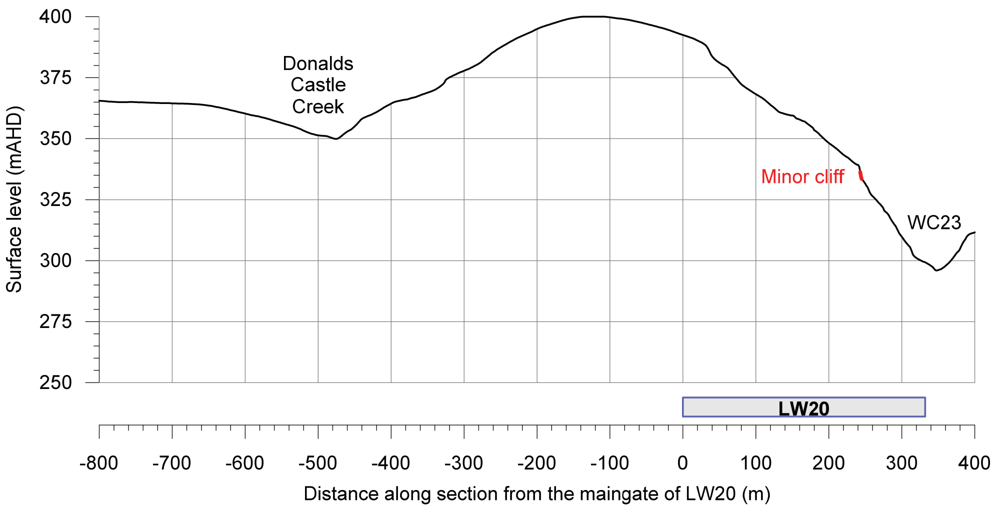

Fig. 5.7 Section C through Donalds Castle Creek and the proposed longwalls

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

5.3.2. Predictions for Donalds Castle Creek

The predicted profiles of total vertical subsidence, upsidence and closure along Donalds Castle Creek are shown in Fig. C.04, in Appendix C. The predicted total profiles after the completion of the existing and approved longwalls in Area 3B are shown as cyan lines. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for Donalds Castle Creek is provided in Table 5.12. The values are the maxima anywhere along the section of the creek located within the Study Area based on the 600 m boundary and include the predicted movements due to the previously extracted longwalls in Area 3B.

Table 5.12 Maximum predicted total vertical subsidence, upsidence and closure for Donalds Castle Creek

Location	Area or Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Donalds Castle Creek	Area 3B	< 20	90	170
	LW20	< 20	90	180
	LW21	< 20	90	180

The section of Donalds Castle Creek located within the Study Area is predicted to experience less than 20 mm vertical subsidence after the extraction of the proposed LW20 and LW21. Whilst 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 upsidence and closure provided in Table 5.12 occur adjacent to the existing longwalls in Area 3B. Only very small additional movements are predicted to occur in this location due to the extraction of the proposed LW20 and LW21.

The section of Donalds Castle Creek located downstream of the previously extracted longwalls in Area 3B could experience additional valley related effects, where it is located closest to the proposed LW20. A summary of the maximum predicted values of additional vertical subsidence, upsidence and closure for the creek, due to the extraction of the proposed longwalls only, is provided in Table 5.13.

Table 5.13 Maximum predicted additional vertical subsidence, upsidence and closure for Donalds Castle Creek

Location	Longwall	Maximum predicted additional vertical subsidence (mm)	Maximum predicted additional upsidence (mm)	Maximum predicted additional closure (mm)
Donalds Castle Creek	LW20	< 20	< 20	< 20
	LW21	< 20	< 20	< 20

The maximum predicted additional valley related movements for the section of creek located within the Study Area are less than 20 mm upsidence and less than 20 mm closure. Only low levels of additional valley related effects are predicted due to the distance of Donalds Castle Creek from the proposed longwalls.

Donalds Castle Creek could experience compressive strains due to the low level valley closure movements. The predicted strains have been determined based on an analysis of ground monitoring lines for valleys with similar heights located at similar distances from previously extracted longwalls in the Southern Coalfield, as for Donalds Castle Creek. The maximum predicted compressive strain for Donalds Castle Creek due to the extraction of the proposed LW20 and LW21 is 1 mm/m based on the 95 % confidence level.

5.3.3. Comparison between measured and predicted movements for Donalds Castle Creek due to LW9 to LW13

The closure movements across Donalds Castle Creek have been measured using the DCC X A-Line to F-Line. The locations of the monitoring lines are shown in Drawing No. MSEC978-01. A review of the ground monitoring data was carried out as part of the End of Panel Report for LW12 and is summarised in Report No. MSEC888. The report stated that:

> "*The total measured closures for the DCCX C-Line and E-Line of 464 mm and 385 mm are greater than the predicted values of 450 mm and 350 mm, respectively. The exceedances of 14 mm and 35 mm represent 3 % and 10 % of the predicted values and, therefore, are within the order of accuracy of the predictive method for valley closure of ±15 % to ±25 %.*"

The DCC X E-Line and F-Line were also monitored during the extraction of LW13. A review of the ground monitoring data was carried out as part of the End of Panel Report for LW13 and is summarised in Report No. MSEC965. The report stated that:

> *"The measured total vertical subsidence and closure for the DCCXE-Line and DCCXF-Line are less than the predicted values at the end of LW13. The measured vertical subsidence movements range between 66 % and 98 % of the predicted values. The measured closures range between 58 % and 98 % of the predicted values.*
>
> *The maximum closure measured along the DCCE-Line, at any time during mining, was 490 mm on the 11 August 2016 (i.e. during LW12), which exceeded the predicted value. However, the closure decreased after that survey with a final measured value of 369 mm at the completion of LW13. The final closure is less than the predicted closure of 375 mm at the completion of this longwall.*
>
> *The maximum closure measured along the DCCF-Line, at any time during mining, was 163 mm on the 11 August 2016 (i.e. during LW12). The closure reduced to 133 mm at the completion of LW12, which is less than the predicted value of 150 mm at that time. The closure reduced again to 101 mm at the completion of LW13, which is also less than the final predicted value of 175 mm."*

It is considered that the valley closure movements measured along Donalds Castle Creek are similar to those predicted using the 2002 ACARP method. The exceedances during LW12 were within the order of accuracy of the predictive methods. The measured closures at the end of LW13 were less than predicted values.

5.3.4. Observed impacts for Donalds Castle Creek due to LW9 to LW13

The upper reaches of Donalds Castle Creek are located above the previously extracted LW9 and LW10 in Area 3B. The impact assessments for this creek were provided in Report No. MSEC459 which stated:

> "*…it is expected that fracturing will occur in the bedrock along the section of Donalds Castle Creek which is located directly above the proposed longwalls…"* and that "*…there may be some diversion of surface water flows into the dilated strata beneath the bed.*"

Impacts were observed in Donalds Castle Creek due to the extraction of LW9, which were described in the End of Panel Report (IC, 2014) and have been summarised below:

> "*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"*
>
> "*Site DA3B_LW9_007: Change in water appearance in DC_Pool33. Yellow/orange colour and increase in turbidity*"; and
>
> "*Reduction in pool water levels were observed in watercourses Donalds Castle Creek*"

There was no observable fracturing along the creek due to the extraction of LW10, as Swamp 5 overlays the creek above the extent of this longwall. There were increased rates of water level recession compared to baseline conditions within this swamp. There were no observable impacts to Donalds Castle Creek due to the subsequent extraction of LW11 to LW13.

5.3.5. Impact assessments for Donalds Castle Creek

The impact assessments for Donalds Castle 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

Donalds Castle Creek is predicted to experience less than 20 mm additional vertical subsidence due to the extraction of the proposed LW20 and LW21. Whilst the creek could experience very low levels of additional 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 average natural grade of the section of Donalds Castle Creek within the Study Area is approximately 35 mm/m (i.e. 3.5 %, or 1 in 30). The predicted changes in grade due to the extraction of the proposed LW20 and LW21, 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 tilts.

Potential for fracturing of bedrock and surface water flow diversions

Fracturing occurred in Rockbar DC-RB33 along Donalds Castle Creek, due to the extraction of LW9, which resulted in the diversion of surface water flows in that location (i.e. Type 3 impact). This rock bar is located outside the Study Area at a distance of more than 600 m from the finishing end of the proposed LW20.

At this distance, Rockbar DC-RB33 is not predicted to experience measurable additional upsidence or closure movements due to the extraction of LW20 and LW21. It is unlikely that additional fracturing would occur at this rockbar due to these proposed longwalls.

The remaining rockbars along Donalds Castle Creek downstream of Rockbar DC-RB33 are predicted to experience additional closure movements of less than 20 mm. The maximum predicted compressive strain for the creek due to the valley closure effects is 1 mm/m based on the 95 % confidence level.

Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield. Donalds Castle Creek is located 470 m from the maingate and finishing end of LW20, at its closest point to the proposed longwalls.

It is considered unlikely, therefore, that fracturing would occur along Donalds Castle Creek due to the extraction of LW20 and LW21 due to the low levels of predicted movements and its distance from the proposed longwalls.

Further assessments of the potential impacts on surface water is provided in the report by HGeo (2019).

5.3.6. Recommendations for Donalds Castle Creek

It is recommended that the closure movements are measured and that inspections are carried out along Donalds Castle Creek during active subsidence. It is also recommended that the Dendrobium Watercourse Impact Management Monitoring and Contingency Plan be revised to take into account the extraction of the proposed LW20 and LW21.

5.4. Drainage lines

5.4.1. Descriptions of the drainage lines

The locations of the drainage lines are shown in Drawing No. MSEC978-09. The unnamed drainage lines are located above and adjacent to LW20 and LW21. These drainage lines are first and second order streams that form tributaries to Wongawilli Creek.

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

The natural gradients of the drainage lines vary between 20 mm/m (i.e. 2.0 %, or 1 in 50) and 500 mm/m (i.e. 50 %, or 1 in 2), with average natural gradients typically ranging between 100 mm/m (i.e. 10 %, or 1 in 10) and 200 mm/m (i.e. 20 %, or 1 in 5). The drainage lines have localised areas with natural grades greater than 500 mm/m where there are steps and cascades.

5.4.2. Predictions for the drainage lines

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

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the drainage lines is provided in Table 5.14. The total parameters represent the accumulated movements within the Study Area due to the extraction of the existing and proposed longwalls.

Table 5.14 Maximum predicted total subsidence, tilt and curvature for the drainage lines

Location	After longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Drainage Lines	LW20 and LW21	2050	30	0.50	0.75

The maximum predicted total tilt for the drainage lines is 30 mm/m (i.e. 3.0 %, or 1 in 33). The maximum predicted total conventional curvatures are 0.50 km^{-1} hogging and 0.75 km^{-1} sagging, which represent minimum radii of curvatures of 2 km and 1.3 km, respectively.

The drainage lines have shallow incisions into the natural surface. The predicted valley related movements, therefore, are small and not considered significant when compared with the predicted conventional movements provided in the above table.

The maximum predicted conventional strains for the drainage lines, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 8 mm/m tensile and 11 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted strains directly above the proposed longwalls are 6 mm/m tensile and compressive based on the 95 % confidence level.

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.

5.4.3. Review of the assessed and observed impacts for the drainage lines due to LW9 to LW13

First and second order drainage lines are located above the previously extracted LW9 to LW13 in Area 3B. The impact assessments for these drainage lines were provided in Report No. MSEC459, which related to the physical impacts, i.e. cracking, fracturing and deformation of the bedrock and surface soils as the result of mining. The assessments of the environmental consequences were provided in the other specialist consultants' reports and, therefore, the discussions below should be read in conjunction with those provided by the other specialist consultants.

The impact assessments for the drainage lines provided in Report No. MSEC459 state that:

> *"… fracturing would occur in the uppermost bedrock"* and that *"where the bases of the drainage lines have exposed bedrock, there may be some diversion of surface water flows into the dilated strata beneath the beds and the draining of pooled water within their alignments."*; and
>
> *"It is possible that there could be localised areas along the drainage lines which could experience small increases in the levels of ponding and flooding, in the locations of predicted maximum decreasing tilts, such as upstream of the longwall chain pillars and goaf edges. It is also possible, that there could be localised areas which experience increased scouring of the banks, in the locations of the predicted maximum increasing tilts, such as downstream of the longwall chain pillars."*

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

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

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

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

The impacts observed in the drainage lines due to LW11 were described in the End of Panel Report (IC, 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 flow along Watercourse WC21 in Pool 30.

The impacts observed along the drainage lines due to LW12 were described in the End of Panel Report (IC, 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 flow along stream LA4 and possible diversion along stream LA4B. Fracturing observed outside of mining along LA4B and WC21 at distances of 290 m and 110 m, respectively.

The impacts observed along the drainage lines due to LW13 were described in the End of Panel Report (IC, 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 flow 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 environmental consequences due to the abovementioned physical impacts are described by the specialist consultants' reports attached to each of the End of Panel reports.

5.4.4. 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 100 mm/m and 200 mm/m (i.e. 10 % to 20 %).

The natural grades and the predicted post-mining grades along Drainage Lines WC20 and WC25 are illustrated in Fig. 5.8 and Fig. 5.9, respectively. The locations of these drainage lines are shown in Drawing No. MSEC978-09.

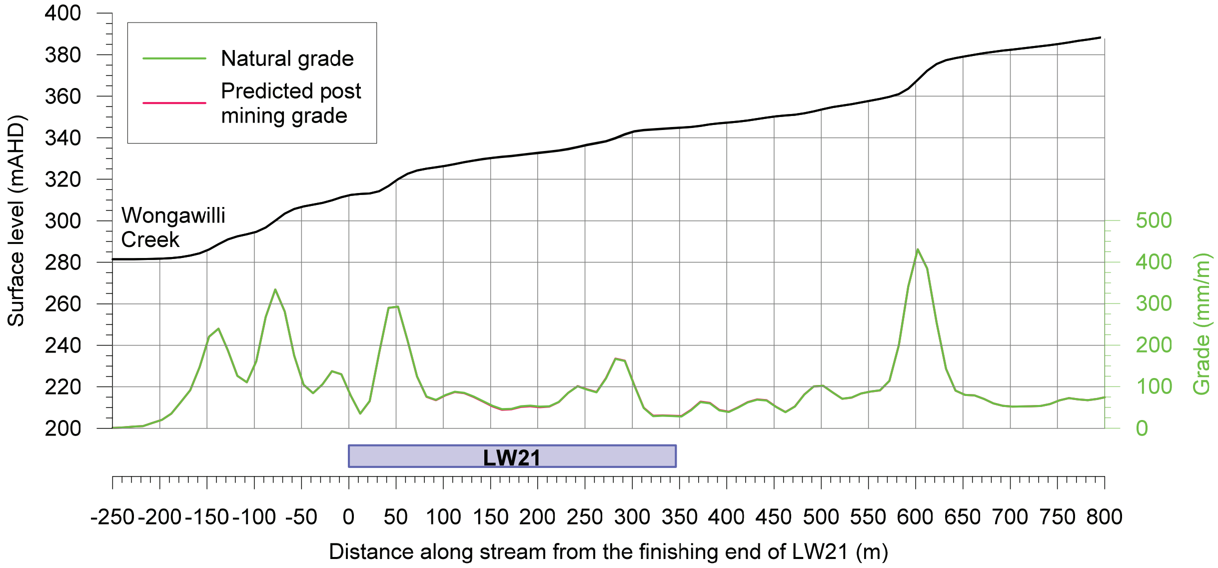

Fig. 5.8 Natural and predicted post-mining surface levels along drainage line WC20

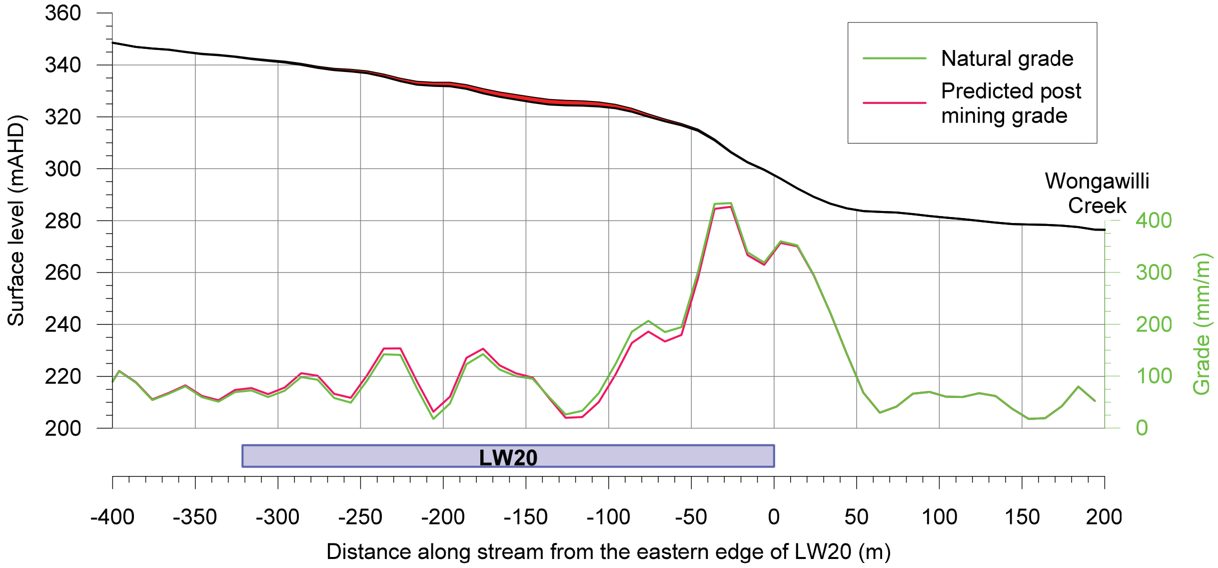

Fig. 5.9 Natural and predicted post-mining surface levels along drainage line WC25

It can be seen from Fig. 5.8 and Fig. 5.9, that the predicted post-mining grades (i.e. red lines) are similar to the natural grades (i.e. green lines). There are no predicted reversals in grade along these drainage lines.

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 where the drainage lines exit the mining area.

The potential impacts of increased ponding and scouring of the drainage lines, therefore, are expected to be minor and localised. The impacts resulting from the changes in surface water flows 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 LW13 in Area 3B, including fracturing in the rockbars and exposed bedrock, dilation and uplift of the bedrock, iron staining, surface water flow diversions and reduction in pool water levels. These impacts predominately occurred directly above the extracted longwalls. However, fracturing was also observed up to 290 m from the extracted longwalls in Area 3B.

A comparison of the maximum predicted subsidence parameters for the proposed LW20 and LW21 in Area 3C with the maxima predicted for the longwalls in Area 3B is provided in Table 4.3. The predicted subsidence parameters for the proposed longwalls are less than the maxima predicted for the existing and approved longwalls due to their narrower longwall void widths.

It is expected that fracturing of the bedrock would occur along the sections of the drainage lines that are located directly above the proposed LW20 and LW21. Fracturing can also occur outside the extents of the proposed 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 valley closure related dilation is expected to develop predominately within the top 10 m to 20 m of the bedrock. Compression can also result in buckling of the topmost bedrock resulting in heaving in the overlying surface soils.

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

Further assessments of the potential impacts on surface water is provided in the report by HGeo (2019).

5.4.5. Recommendations for the drainage lines

IC has developed management strategies for drainage lines that have been directly mined beneath by previously extracted longwalls at Dendrobium Mine. It is recommended that these management strategies are reviewed and updated to incorporate the proposed LW20 and LW21. 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 DP&E *Standard and Model Conditions for Underground Mining* (DP&E, 2012) are:

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

The cliffs and minor cliffs within the Study Area have been identified from the LiDAR surface level contours and field investigations. The locations of these features are shown in Drawing No. MSEC978-08.

There are three cliffs that have been identified within the Study Area based on the 35° angle of draw line. There is also one additional cliff located within the Study Area based on the 600 m boundary. Whilst the valleys along which the cliffs are located could experience valley related movements, the cliffs themselves are unlikely to experience upsidence and compressive strain due to valley closure, as they are located along the valley sides. The cliffs located outside the Study Area based on the 35° angle of draw, therefore, have not been assessed further.

A summary of the three cliffs that were identified within the Study Area based on the 35° angle of draw is provided in Table 5.15.

Table 5.15 Cliffs located within the Study Area

Reference	Location	Overall length (m)	Maximum height (m)
DA3C-CF1	Directly above the eastern edge of LW20	65	15
DA3C-CF2	30 m east of LW20	30	10
DA3C-CF3	230 m north of LW20	30	10

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 from the top of Cliff DA3C-CF1 is provided in Fig. 5.10 (Source: IC).

Fig. 5.10 View from the top of Cliff DA3C-CF1 (Source: IC)

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

5.6.2. Predictions for the cliffs

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the cliffs located within the Study Area is provided in Table 5.16. The values are the maxima within 20 m of the mapped extents of each of the cliffs.

Table 5.16 Maximum predicted total vertical subsidence, tilt and curvatures for the cliffs

Reference	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
DA3C-CF1	425	15	0.30	0.01
DA3C-CF2	50	2	0.10	< 0.01
DA3C-CF3	< 20	< 0.5	< 0.01	< 0.01

Cliff DA3C-CF1 is located directly above LW20. The maximum predicted tilt for this cliff is 15 mm/m (i.e. 1.5 %, or 1 in 67). The maximum predicted curvatures for DA3C-CF1 are 0.30 km^{-1} hogging and 0.01 km^{-1} sagging, which represent minimum radii of curvatures of 3.3 km and 100 km, respectively.

The maximum predicted conventional strains for DA3C-CF1, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 4.5 mm/m tensile and less than 0.5 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted tensile strain directly above the proposed longwalls is 6 mm/m tensile based on the 95 % confidence level.

Cliffs DA3C-CF2 and DA3C-CF3 are located outside the extents of the proposed longwalls. The predicted conventional strains for these cliffs, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 1.5 mm/m tensile and less than 0.5 mm/m compressive.

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

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

5.6.3. Comparison of the predictions for the cliffs

Cliffs are located directly or partially above the previously extracted longwalls in Areas 1, 2 and 3A at the Mine. Cliffs are also located outside the extents of the previously extracted and approved longwalls in Area 3B. A comparison of the maximum predicted total subsidence parameters for the cliffs at the Mine is provided in Table 5.17.

Table 5.17 Comparison of the maximum predicted subsidence parameters for the cliffs

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 1	2800	20	0.35	0.75
Area 2	1275	17	0.50	0.60
Area 3A	700	13	0.20	0.06
Area 3B	25	1	0.09	< 0.01
LW20 and LW21	425	15	0.30	0.01

The maximum predicted vertical subsidence for the cliffs located within the Study Area are less than those predicted for the cliffs in Areas 1, 2 and 3A. However, the potential for impacts on cliffs is not directly affected by absolute vertical subsidence, but rather by the differential movements. The maximum predicted tilt, curvature and strain for the cliffs within the Study Area are similar orders of magnitude as those predicted for the cliffs located in Areas 1, 2 and 3A.

The predicted subsidence parameters are greater than those predicted for the cliffs in Area 3B. The reason is the cliffs in Area 3B are located outside the extents of these existing and approved longwalls.

5.6.4. Impact assessments for the cliffs

Cliff DA3C-CF1 is located directly above LW20. The maximum predicted subsidence parameters for this cliff are: 425 mm vertical subsidence, 15 mm/m tilt and 0.30 km^{-1} hogging curvature.

It is difficult to assess the likelihood of cliff instabilities based upon predicted ground movements. The likelihood of a cliff becoming unstable is dependent on many factors that are difficult to quantify. Some of these factors include jointing, inclusions, weaknesses within the rockmass, groundwater pressure and seepage flow behind the rockface. Even if these factors could be determined, it would still be difficult to quantify the extent to which these factors may influence the stability of a cliff naturally or when it is exposed to mine subsidence movements. It is therefore possible that cliff instabilities may occur during mining that may be attributable to either natural causes, mine subsidence, or both.

The likelihood of instability for Cliff DA3C-CF1 has been assessed using the previous experience of mining beneath cliffs at the Mine. The cliffs that were located above the previously extracted longwalls in Area 1 are the most relevant case study.

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

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

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

Based on the experience in Area 1 at the Mine, it has been assessed that Cliff DA3C-CF1 could be impacted due to the extraction of LW20 directly beneath it. Cliffs DA3C-CF2 and DA3C-CF3 are located outside the extents of the proposed longwalls and are predicted to experience vertical subsidence of 50 mm or less. These cliffs are predicted to experience only low levels of tilt, curvature and strain. Isolated rock falls could occur at some of the cliffs located outside the extents of the proposed longwalls.

It is unlikely that other cliffs located outside the 35° angle of draw would experience adverse impacts due to their distances outside of the mining areas. 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.

5.6.5. Recommendations for the cliffs

It is recommended that periodic inspections of the cliffs and minor cliffs located within the Study Area are undertaken during active subsidence and at the completion of mining.

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

The areas identified as having steep slopes are shown in Drawing No. MSEC978-08.

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

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

Photographs of typical rock outcropping at the Mine are provided in Fig. 5.11.

Fig. 5.11 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, are expected to experience the full range of predicted subsidence movements. 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.

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

Location	After longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Rock outcrops and steep slopes	LW20 and LW21	2050	30	0.50	0.75

The maximum predicted total tilt for the rock outcrops and steep slopes is 30 mm/m (i.e. 3.0 %, or 1 in 33). The maximum predicted total conventional curvatures are 0.50 km^{-1} hogging and 0.75 km^{-1} sagging, which represent minimum radii of curvatures of 2 km and 1.3 km, respectively.

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 8 mm/m tensile and 11 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted strains directly above the proposed longwalls are 6 mm/m tensile and compressive based on the 95 % confidence level.

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 30 mm/m (i.e. 3.0 %, or 1 in 67). The predicted changes in grade are very small when compared to the natural surface grades, which are greater than 1 in 3. It is unlikely, therefore, that the mining-induced tilts themselves would result in any adverse impact on the stability of the rock outcrops or steep slopes.

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

The maximum predicted total curvatures for the rock outcrops and steep slopes within the Study Area are 0.50 km^{-1} hogging and 0.75 km^{-1} sagging. The maximum predicted curvatures and strains for these features are similar to those predicted to have occurred for Dendrobium LW1 and LW2, which mined directly beneath a ridgeline comprising cliffs, rock outcrops and steep slopes. The impacts observed from this case study, therefore, can be used to provide an indication of the potential impacts on the rock outcrops and steep slopes located within the Study Area.

Dendrobium LW1 and LW2 mined directly beneath a ridgeline where steep slopes had natural surface gradients of up to 1 in 1 (i.e. 100 %, or an angle to the horizontal of 45°). A number of surface cracks were observed along the steep slopes located directly above Dendrobium LW1 and LW2 which are shown in Fig. 5.12.

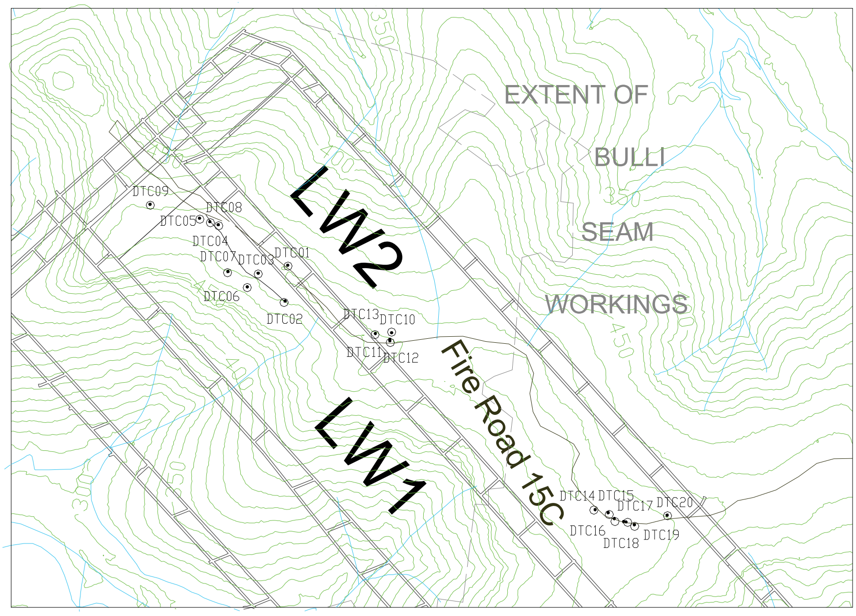

Fig. 5.12 Locations of observed surface cracking above Dendrobium LW1 and LW2

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

Photographs of the surface cracking at Dendrobium Mine are provided in Fig. 5.13.

Fig. 5.13 Surface tension cracking due to downslope movements at Dendrobium Mine

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

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

5.7.4. 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 longwalls 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 the proposed longwalls. At this distance, the escarpment is not expected to experience measurable mine subsidence movements or adverse impacts due to the extraction of the proposed longwalls.

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 Donalds Castle 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 longwalls, 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 locations of the swamps are shown in Drawing No. MSEC978-09. The locations and extents of the upland swamps have been interpreted from detailed aerial photogrammetry and site inspections.

There are three swamps that have been identified wholly or partially within the Study Area based on the 35° angle of draw line. There are seven additional swamps that are located wholly or partially within the Study Area based on the 600 m boundary.

There are no swamps that are located directly above LW20 and LW21. The swamps are located outside the proposed longwalls at distances ranging between 50 m and 600 m. A summary of the swamps that are 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
Den02	600 m west of LW20	Near the valley base of Donalds Castle Creek
Den05	520 m south-west of LW20	Partially located above the existing LW9 in Area 3B
Den07	590 m north-east of LW21	Near the valley base of Stream LC5B
Den09	290 m east of LW21	Near the valley base of Stream LC5B
Den124	590 m north-west of LW20	On the valley side of Donalds Castle Creek
Den140	320 m north-east of LW20	On the valley side of Wongawilli Creek
Den141	230 m east of LW20	On the valley side of Wongawilli Creek
Den142	70 m west of LW20	Near the valley base of upper reaches of WC25
Den144	50 m south of LW21	Near the valley based of Stream WC20
Den145	330 m south-east of LW21	At the headwaters of Steam LC5B

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. 5.14. Photographs of a typical headwater swamp are provided in Fig. 5.15.

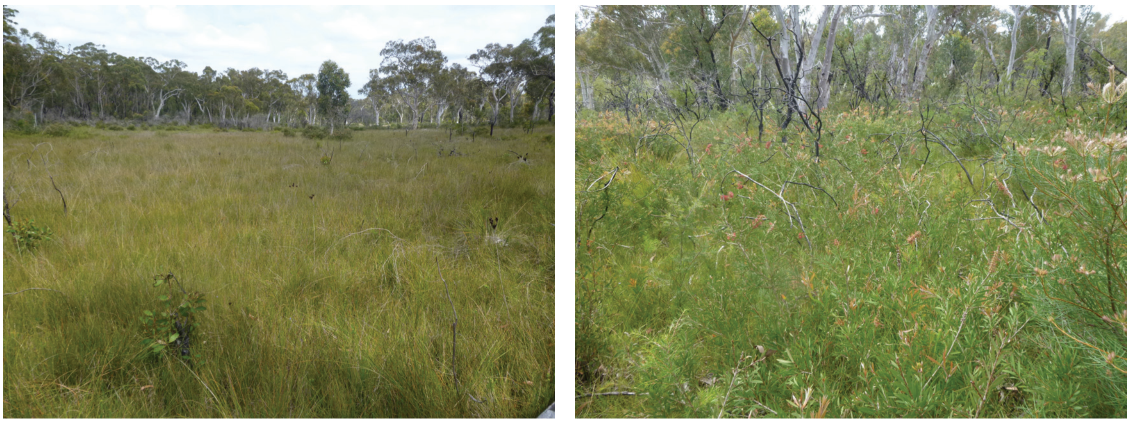

Fig. 5.14 Typical valley infill swamps

Fig. 5.15 Typical headwater swamp

Further descriptions of the swamps are provided in the report by *Niche Environment and Heritage* (Niche, 2019a).

5.10.2. Predictions for the swamps

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the swamps located within the Study Area is provided in Table 5.20. The values are the maxima within 20 m of the mapped extents of each of the swamps within the Study Area due to the extraction of the existing longwalls in Area 3B and the proposed LW20 and LW21. The section of Swamp Den05 that is located above the previously extracted LW9 in Area 3B has not been included in this table as it is located outside the Study Area.

Table 5.20 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})
Den02	< 20	< 0.5	< 0.01	< 0.01
Den05	< 20	< 0.5	< 0.01	< 0.01
Den07	< 20	< 0.5	< 0.01	< 0.01
Den09	< 20	< 0.5	< 0.01	< 0.01
Den124	< 20	< 0.5	< 0.01	< 0.01
Den140	< 20	< 0.5	< 0.01	< 0.01
Den141	< 20	< 0.5	< 0.01	< 0.01
Den142	30	1.0	0.05	< 0.01
Den144	30	1.0	0.05	< 0.01
Den145	< 20	< 0.5	< 0.01	< 0.01

Swamps Den142 and Den144 are predicted to experience 30 mm vertical subsidence due to the extraction of LW20 and LW21. The maximum predicted tilt is 1 mm/m (i.e. 0.1 % or 1 in 1000). The maximum predicted curvature is 0.05 km^{-1} hogging, which represents a minimum radius of curvature of 20 km. The maximum predicted conventional strains for Swamps Den142 and Den144, based on applying a factor of 15 to the maximum predicted curvatures, are 1 mm/m tensile and less than 0.5 mm/m compressive.

The remaining swamps within the Study Area are predicted to experience less than 20 mm vertical subsidence due to the extraction of LW20 and LW21. Whilst these swamps could experience very low levels of vertical subsidence, they are not expected to experience measurable conventional tilts, curvatures or strains.

It is noted that Swamp Den05 is partially located above LW9 in Area 3B. However, the section of swamp that has been previously mined beneath is located outside of the Study Area based on the 600 m boundary for LW20 and LW21. The section of swamp within the Study Area is predicted to experience less than 20 mm vertical subsidence.

Swamps Den02 and Den05 are located near the base of the valley for Donalds Castle Creek. Swamps Den07 and Den09 are located along Stream LC5B. Swamp Den142 is located at the upper reaches of Stream WC21 and Swamp Den144 is located along Stream WC20. These swamps could experience valley related effects due to the extraction of the proposed longwalls. The remaining swamps within the Study Area are located further up the valley sides and, therefore, are unlikely to experience upsidence or compressive strain due to valley closure effects.

A summary of the maximum predicted total upsidence and closure for the swamps within the Study Area is provided in Table 5.21. The values are the maxima within 20 m of the mapped extents of each of the swamps within the Study Area due to the extraction of the existing longwalls in Areas 3A and 3B and the proposed LW20 and LW21.

Table 5.21 Maximum predicted total upsidence and closure for the swamps

Location	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Den02	< 20	< 20
Den05	100	200
Den07	< 20	< 20
Den09	< 20	20
Den142	40	80
Den144	50	100

Swamp Den05 is predicted to experience total valley related effects of 100 mm upsidence and 200 mm closure. The majority of these movements are due to the previous extraction of the longwalls in Area 3B and only low level additional movements are expected to due LW20 and LW21.

A summary of the maximum predicted additional upsidence and closure for the swamps within the Study Area is provided in Table 5.22. The values are the maxima within 20 m of the mapped extents of each of the swamps due to the extraction of the proposed LW20 and LW21 only.

Table 5.22 Maximum predicted additional upsidence and closure for the swamps

Location	Maximum predicted additional upsidence (mm)	Maximum predicted additional closure (mm)
Den02	< 20	< 20
Den05	< 20	< 20
Den07	< 20	< 20
Den09	< 20	20
Den142	40	80
Den144	50	100

Swamps Den09, Den142 and Den144 are predicted to experience additional closure movements of between 20 mm and 100 mm due to the extraction of LW20 and LW21. These swamps could experience compressive strains due to the valley closure effects.

The predicted strains have been determined based on an analysis of ground monitoring lines for valleys with similar heights located at similar distances from previously extracted longwalls in the Southern Coalfield. The maximum predicted compressive strain for Swamp Den09, due to the extraction of the proposed LW20 and LW21, is 1 mm/m based on the 95 % confidence level. The maximum predicted compressive strain for Swamps Den142 and Den144 is 3 mm/m based on the 95 % confidence level.

The remaining swamps are predicted to experience valley closure effects of less than 20 mm due to the extraction of LW20 and LW21. These swamps could still experience compressive strains due to the low level valley closure effects. The maximum predicted compressive strain for Swamps Den02, Den05 and Den07, due to the extraction of the proposed LW20 and LW21, is 1 mm/m based on the 95 % confidence level.

Swamp Den05 is located directly above the previously extracted LW9 in Area 3B and, therefore, could have already experienced compressive strains in the order of 10 mm/m to 20 mm/m. The additional closure strain at Swamp Den05, due to the extraction of LW20 and LW21, is small when compared with the total strain due to the previous longwall mining in Area 3B.

5.10.3. Previous experience of mining beneath swamps at Dendrobium Mine

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

- *Dendrobium Area 2*

  LW4 and LW5 in Area 2 were extracted directly beneath Swamp Den01, which is both a headwater and valley infill swamp located along Drainage Line A2-14. Cracking was observed within the extent of the swamp in three locations and fracturing was observed in the downstream rockbar. A photograph of the fracturing in the downstream rockbar is provided in Fig. 5.16.

Fig. 5.16 Fracturing in the rockbar downstream of Swamp Den01 (Source: IC)

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

- *Dendrobium Area 3A*

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

- *Dendrobium Area 3B*

  LW9 in Area 3B was extracted directly beneath Swamp Den05, which is a valley infill swamp located along the alignment of Donalds Castle Creek. The impacts to this swamp were described in the End of Panel Report (IC, 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 LW13 which were described in each of the End of Panel Reports (IC, 2015, 2016, 2017 and 2018). The groundwater levels were lower than baseline and recession rates greater than baseline for Swamps Den03, Den05, Den10 and Den11. Soil moisture levels below baseline were also reported in Swamps Den05 and Den11.

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 mine subsidence movements 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.

Swamps Den142 and Den144 are located at minimum distances of 70 m and 50 m, respectively, from the proposed longwalls. The maximum predicted tilt for these swamps is 1 mm/m (i.e. 0.1 %, or 1 in 1000). Swamps Den142 and Den144 are located along the upper reaches of Streams WC25 and WC20, respectively, where the natural grades are in the order of 100 mm/m (i.e. 10 %, or 1 in 10). The mining-induced tilts at Swamps Den142 and Den144, therefore, are small when compared to the natural surface gradients along the alignments of the drainage lines.

There are no topographical depressions or reversals in grade predicted to develop within the extents of Swamps Den142 and Den144 due to the extraction of LW20 and LW21. It is unlikely, therefore, that there would be adverse changes in the levels of ponding or scouring in these swamps based on the predicted vertical subsidence and tilt.

The remaining swamps within the Study Area are located on or outside the Study Area based on the 35° angle of draw. These swamps are predicted to experience tilts of less than 0.5 mm/m (i.e. less than 0.5 %, or 1 in 2000). It is unlikely, therefore, that these swamps would experience adverse changes in the levels of ponding or scouring based on the predicted vertical subsidence and tilt.

Potential for cracking in the swamps and fracturing of bedrock

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

Swamps Den142 and Den144 are located along the upper reaches of Streams WC25 and WC20, respectively, at distances of 70 m and 50 m from the proposed longwalls. These swamps are predicted to experience conventional tensile strains of 1 mm/m and compressive strains due to valley closure effects of 3 mm/m. Fracturing could therefore occur in the bedrock beneath these swamps.

The estimated fracture widths in the bedrock beneath the Swamps Den142 and Den144, based on the maximum predicted conventional tensile strain of 1 mm/m and a typical joint spacing of 10 m, is in the order of 10 mm. Wider fractures could develop if the compressive strains due to the valley closure effects result in localised failure of the bedrock. Fracture widths in the order of 20 mm to 50 mm have been observed due to valley closure effects at similar distances from previous longwall mining. It is possible that a series of smaller fractures, rather than one single fracture, could develop in the bedrock. Fracturing would only be visible at the surface where the bedrock is exposed, or where the thickness of the overlying soil is relatively shallow

Swamps Den142 and Den144 are predicted to experience upsidence movements of 40 mm and 50 mm, respectively. These valley related upsidence movements 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 Swamps Den142 and Den144, could result in the diversion of some surface water flows beneath parts of these swamps. The drainage lines upstream of these swamps flow during and shortly after rainfall events. On the basis that there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation.

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.

The remaining swamps are located outside the proposed longwalls at minimum distances ranging between 230 m and 600 m. These swamps are predicted to experience additional movements due to LW20 and LW21 of less than 20 mm vertical subsidence, less than 20 mm upsidence and up to 20 mm closure. These swamps are predicted to experience tensile strains less than 0.5 mm/m and compressive strains less than 2 mm/m due to the extraction of the proposed LW20 and LW21. It is unlikely, therefore, that the bedrock beneath these swamps would experience significant fracturing.

Fracturing has been observed in streams located outside the extents of previously extracted longwalls in the NSW coalfields. Fracturing has been observed in the drainage lines at the Mine at distances of up to 290 m from the previously extracted longwalls in Area 3B. Minor and isolated fracturing has also been observed up to 400 m outside of longwalls extracted elsewhere in the Southern Coalfield.

Swamps Den02 and Den05 are located along Donalds Castle Creek at distances of 600 m to 520 m, respectively, from LW20. Swamp Den07 is located along Stream LC5B at a distance of 590 m from LW21. The remaining swamps are located further up the valley sides. It is unlikely, therefore, that significant fracturing would occur at the swamps located on or outside the Study Area based on the 35° angle of draw.

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

The potential for impacts on the vegetation in the mining area is dependent on the surface cracking, changes in surface water and changes in groundwater. Assessments of the physical impacts due to the proposed longwalls are provided in Sections 5.2 to 5.10. Assessments of the environmental consequences have been provided by the other specialist consultants on the project.

Assessments for the terrestrial and aquatic ecology are provided by Cardno (2019) and Niche (2019a).

The following sections provide the descriptions, predictions and impact assessments for the built features within the Study Area. All significant features located outside the Study Area, which may be subjected to far-field movements or valley related movements 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. MSEC978-12.

Fire Road 6F crosses directly above the commencing (i.e. eastern) end of LW21. Fire Road 6AA is located to the west of LW20 at a minimum distance of 90 m. 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 crosses directly above the commencing (i.e. eastern) end of LW21. The maximum predicted vertical subsidence for this road is 50 mm. The maximum predicted conventional strains for this fire road, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 1 mm/m tensile and less than 1 mm/m compressive.

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 remaining unsealed roads and tracks are located outside the extents of LW20 and LW21. Only low levels of vertical subsidence are predicted for the roads and tracks located outside of the mining areas.

6.1.3. Impact assessments for the unsealed roads and tracks

Fire Road 6F crosses directly above the commencing (i.e. eastern) end of LW21. It is possible that cracking, rippling and stepping of the unsealed road surface could occur due to the mining of this longwall.

The estimated crack widths in Fire Road 6F, based on the maximum predicted conventional tensile strain of 1 mm/m and a typical bedrock joint spacing of 10 m, is in the order of 10 mm. However, wider cracks could develop along the road due topographic effects. Surface cracking in the order of 20 mm to 50 mm could occur along the alignment of Fire Road 6F due to topographic effects. It is possible that a series of smaller cracks, rather than one single crack, could develop in the road surface.

The predicted subsidence parameters for Fire Road 6F are less than the values predicted for the previously extracted longwalls in Areas 3A and 3B. The potential impacts on this fire road, therefore, are expected to be less than the levels of impacts that occurred for the roads and tracks previously mined beneath at the Mine. Examples of the impacts on unsealed roads and tracks in Areas 3A and 3B are provided in Fig. 6.2 (Source: IC). The impacts on the unsealed roads and tracks were repaired by regrading and recompacting the road surfaces.

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

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

6.1.4. Recommendations for the unsealed roads and tracks

IC has developed management strategies for unsealed roads and tracks that have been impacted by subsidence at Dendrobium Mine. It is recommended that these management strategies are reviewed and updated to incorporate the proposed LW20 and LW21. 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. Descriptions of the 330 kV transmission line

The Avon-to-Macarthur 330 kV transmission line (Line 17) owned by TransGrid is located immediately to the east of LW21. This transmission line crosses directly above the completed LW6 to LW8 in Area 3A. The location of the 330 kV transmission line is shown in Drawing No. MSEC978-12.

There are three transmission towers (Refs. T7 to T9) that are located within the Study Area based on the 35° angle of draw. The distances of the towers from LW21 are 190 m for Tower T7, 60 m for Tower T8 and 230 m for Tower T9. Towers T7 to T9 are suspension towers with pile footings. Photographs of a typical transmission tower is provided in Fig. 6.3.

Fig. 6.3 330 kV transmission tower

6.2.2. Predictions for the 330 kV transmission line

The predicted profiles of vertical subsidence, tilt along and tilt across the alignment of the 330 kV transmission line are shown in Fig. C.05, in Appendix C. The predicted total profiles after the completion of the existing longwalls in Area 3A are shown as cyan lines. The predicted total profiles after the extraction of LW21 are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, tilt along the alignment and tilt across the alignment of the 330 kV transmission line is provided in Table 6.1. The values are the maxima anywhere along the transmission line (i.e. not necessarily at the tower locations) within the Study Area based on the 35° angle of draw.

Table 6.1 Maximum predicted total subsidence and tilt for the 330 kV transmission line

Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)
LW21	50	< 0.5	0.5

There are three transmission towers that are located within the Study Area based on the 35° angle of draw. A summary of the maximum predicted vertical subsidence, tilt and curvature at each of the tower locations is provided in Table 6.2. The values are the maxima within a distance of 20 m from the centre of each tower resulting from the extraction of the proposed longwalls.

Table 6.2 Maximum predicted total subsidence and tilt for the 330 kV transmission line

Tower	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
T7	< 20	< 0.5	< 0.01	< 0.01
T8	50	0.5	0.01	< 0.01
T9	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted total tilt at Tower T8 is 0.5 mm/m (i.e. 0.05 %, or 1 in 2000). The tilt is orientated towards the west, i.e. in the direction of LW21. The predicted tilts for the remaining towers are less than 0.5 mm/m and these are unlikely to be measurable.

Tower T8 is located 60 m from the commencing (i.e. eastern) end of LW21. The base of this tower could experience a horizontal movement of 100 mm to 200 mm towards the proposed longwall, as illustrated in Fig. 4.3. The maximum predicted horizontal movement at the top of Tower T8, due to both the horizontal movement and tilt (assuming a height of 50 m) is therefore 150 mm to 250 mm.

Towers T7 and T9 are located at distances of 190 m and 230 m, respectively, from LW21. The bases of these towers could experience horizontal movements of 50 mm to 150 mm towards the proposed longwall, as illustrated in Fig. 4.3. The predicted horizontal movements at the tops of Towers T7 and T9 also range between 50 mm and 150 mm, as these towers are predicted to experience negligible tilts.

The differential horizontal movements between the tops of the towers due to the mining of LW21 could result in opening or closure over the intermediate spans. The predicted changes in the spans between Towers T7 and T8 and between Towers T8 and T9 are both +20 mm opening. The predicted changes in the spans between the other towers are less than 20 mm opening and these are unlikely to be measurable.

The maximum predicted strains for Tower T8 have been determined based on an analysis of ground monitoring data from the NSW coalfields, at similar distances from the longwalls, where the mining geometries are reasonably similar to that at the Mine. The maximum predicted strains are 1 mm/m tensile and 0.5 mm/m compressive based on the 95 % confidence levels.

The maximum predicted strains for Towers T7 and T9 are less than 0.5 mm/m tensile and compressive. The strains are not expected to be measurable at these towers due to their distances from the proposed longwalls.

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

The 330 kV transmission line crosses above the completed LW6 to LW8 and the approved LW19 in Area 3A at the Mine. A comparison of the maximum predicted total conventional subsidence parameters for the 330 kV transmission line is provided in Table 6.3. The values are the maxima anywhere along the transmission line (i.e. not just at the tower locations).

Table 6.3 Comparison of the maximum predicted total subsidence parameters for the 330 kV transmission line

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 3A	2150	18	5	0.17	0.50
LW20 and LW21	50	< 0.5	0.5	0.01	< 0.01

The maximum predicted subsidence parameters for the section of the 330 kV transmission line within the Study Area are considerably less than the maximum predicted values in Area 3A. The reason is that the transmission line is located outside the extents of the proposed LW20 and LW21, whereas the transmission line is located directly above the previously extracted longwalls in Area 3A.

6.2.4. Impact assessments for the 330 kV powerline

The predicted changes in the spans between Towers T7 and T8 and between Towers T8 and T9 are both +20 mm opening. The differential movements between the tops of the transmission towers are very small and are unlikely to be measurable.

The predicted strains at Tower T8 are 1 mm/m tensile and 0.5 mm/m compressive based on the 95 % confidence levels. The predicted changes in the k-point distances (i.e. spacing between the tower legs at the pile connections) based on an 8 m span, therefore, are 8 mm opening and 4 mm closure. These predicted changes in k-point distances could induce loads into the transmission tower frames and into the pile foundations.

The predicted strains at Towers T7 and T9 are less than 0.5 mm/m tensile and compressive based on the 95 % confidence levels. The predicted changes in the k-point distances based on an 8 m span, therefore, are less than 4 mm opening and closure. It is noted that the predicted strains have been derived from ground monitoring data and these low level movements are likely to largely comprise the survey tolerance. The changes in the k-point distances for Towers T7 and T9 are not expected to be measurable due to the distances of these towers from the proposed longwalls.

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

It is recommended that TransGrid undertake a structural analysis of the transmission towers within the Study Area (with a focus on Tower T8) based on the predicted ground movements. If adverse impacts on the transmission tower frames or pile foundations are anticipated, then these could be managed with the installation of cruciform bases, as undertaken for the transmission towers in Area 3A.

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 extraction of the completed longwalls in Area 3A.

6.2.5. Recommendations for the electrical infrastructure

It is recommended that the predicted subsidence parameters 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 cruciform bases, the provision of monitoring points on the tower bases and tops, and the development of a Trigger Action Response Plan (TARP).

6.3. 33 kV powerline

A 33 kV powerline is located outside of the Study Area at a minimum distance of 590 m east of LW21. At this distance, the powerline is not predicted to experience measurable vertical subsidence, tilts, curvatures or strains. It is unlikely, therefore, that the 33 kV powerline would experience adverse impacts due to the extraction of LW20 and LW21.

6.4. Dams, reservoirs or associated works

6.4.1. Descriptions of the reservoirs

Dendrobium Mine is located within the Metropolitan Special Area. There are two reservoirs located in the vicinity of the proposed longwalls, as shown in Drawing No. MSEC978-01.

The Cordeaux Reservoir, also known as Lake Cordeaux, is located to the east of the proposed longwalls. The reservoir is at a distance of 1.6 km east of LW21, at its closest point. The Cordeaux Dam Wall is located more than 3 km north of LW20. The Upper Cordeaux No. 1 and No.2 Dams are located more than 5 km south-east of LW21.

The Avon Reservoir, also known as Lake Avon, is located to the south-west of the proposed longwalls. The reservoir is at a distance of 2.8 km from LW20, at its closest point. The existing longwalls in Area 3B are located between the proposed longwalls and the reservoir, where it is located closest to the proposed longwalls. The Avon Dam Wall is located more than 7 km west of LW20.

6.4.2. Predictions for the reservoirs

The Cordeaux and Avon Reservoirs and their associated dam walls are located more than 1.6 km from the proposed LW20 and LW21. At these distances, the reservoirs and dam walls are not predicted to experience measurable conventional vertical subsidence, tilt or curvatures.

The reservoirs and dam walls could experience very low levels of absolute horizontal movement, in the order of 20 mm. However, these features are not expected to experience measurable strains.

6.4.3. Previous experience of mining near the reservoirs

The longwalls at Dendrobium Mine have been extracted near the Upper Cordeaux No. 2 reservoir. The dam wall is located approximately 1.5 km from LW1 in Area 1 and approximately 0.9 km from LW3 in Area 2 at the mine. The Upper Cordeaux No. 2 reservoir is shown in Drawing No. MSEC978-01.

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.

6.4.4. 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.

It is unlikely, therefore, that the reservoirs and dam walls would experience adverse impacts due to the extraction of the proposed LW20 and LW21.

6.4.5. Recommendations for the reservoirs

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

6.5. Aboriginal heritage sites

6.5.1. Descriptions of the Aboriginal heritage sites

The locations of the Aboriginal heritage sites are shown in Drawing No. MSEC978-12. The details of the heritage sites have been provided by *Niche Environment and Heritage* (Niche, 2019b).

There are no Aboriginal heritage sites that have been identified within the Study Area based on the 35° angle of draw. There are seven Aboriginal heritage 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 movements and could be sensitive to these movements and they have therefore been included in the assessments.

The details of the Aboriginal heritage sites located within the Study Area is provided in Table 6.4.

Table 6.4 Aboriginal heritage sites identified within the Study Area based on the 600 m boundary

Reference	Type	Location relative to the longwalls
52-2-1632	Shelter with Art	520 m east of LW20
52-2-1633	Shelter with Art	310 m east of LW20
52-2-1634	Shelter with Art and Grinding Grooves	530 m east of LW20
52-2-1647	Shelter with Art	230 m south of LW21
52-2-3642	Shelter with Art	330 m north-east of LW20
52-2-3643	Artefact and PAD	360 m north-east of LW20
Dendrobium 3C Shelter 1	Shelter with Art	360 m south of LW21

Further details on the Aboriginal cultural heritage sites are provided in the report by Niche (2019b).

6.5.2. Predictions for the Aboriginal heritage sites

The Aboriginal heritage sites are located outside the Study Area based on the 35° angle of draw line. The sites are all predicted to experience less than 20 mm vertical subsidence due to the extraction of LW20 and LW21. Whilst these sites could experience very low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or conventional strains.

The sites located within the Study Area are located on the sides of the ridgelines where there are no significant valleys. These sites are therefore not expected to experience measurable valley related effects.

6.5.3. Impact assessments for the Aboriginal heritage sites

The Aboriginal heritage sites are all located outside the extents of the proposed LW20 and LW21 at distances ranging between 230 m and 530 m. These sites are predicted to experience less than 20 mm vertical subsidence due to the extraction of LW20 and LW21. The sites are also not expected to experience measurable upsidence or compressive strain due to valley closure effects as they are located on the sides of the ridgelines away from the valley bases.

It is unlikely, therefore, that the Aboriginal heritage sites within the Study Area would experience adverse impacts due to the extraction of LW20 and LW21.

6.5.4. Recommendations for the Aboriginal heritage sites

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

6.6. Survey control marks

The locations of the survey control marks are shown in Drawing No. MSEC978-12. The locations and details of the survey control marks were obtained from *Spatial Services* using the *SCIMS Online* website (SCIMS, 2017).

Survey control mark SS 66043 is located 70 m east of LW21. This mark could experience a horizontal movement of 100 mm to 200 mm towards the proposed longwall, as illustrated in Fig. 4.3. It could also experience vertical subsidence in the order of 50 mm due to the extraction of LW21.

The remaining survey control marks are located outside the Study Area based on the 35° angle of draw. The marks that are located closest to the proposed mining area could experience small amounts of subsidence and small far-field horizontal movements. It is possible that the survey control marks could be affected by far-field horizontal movements at distances of 1 km to 2 km outside the proposed longwalls. 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 IC 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 thickness	The thickness of coal that is extracted. The extracted seam thickness is normally given as an average over the area of the panel.
Effective extracted seam thickness (T)	The extracted seam thickness modified to account for the percentage of coal left as pillars within the panel.
Face length	The width of the coalface measured across the longwall panel.
Far-field movements	The measured horizontal movements at pegs that are located beyond the longwall panel edges and over solid unmined coal areas. Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain.
Goaf	The void created by the extraction of the coal into which the immediate roof layers collapse.
Goaf end factor	A factor applied to reduce the predicted incremental subsidence at points lying close to the commencing or finishing ribs of a panel.
Horizontal displacement	The horizontal movement of a point on the surface of the ground as it settles above an extracted panel.
Inflection point	The point on the subsidence profile where the profile changes from a convex curvature to a concave curvature. At this point the strain changes sign and subsidence is approximately one half of S max.
Incremental subsidence	The difference between the subsidence at a point before and after a panel is mined. It is therefore the additional subsidence at a point resulting from the excavation of a panel.
Panel	The plan area of coal extraction.
Panel length (L)	The longitudinal distance along a panel measured in the direction of mining from the commencing rib to the finishing rib.
Panel width (Wv)	The transverse distance across a panel, usually equal to the face length plus the widths of the roadways on each side.
Panel centre line	An imaginary line drawn down the middle of the panel.
Pillar	A block of coal left unmined.
Pillar width (Wpi)	The shortest dimension of a pillar measured from the vertical edges of the coal pillar, i.e. from rib to rib.

Shear deformations The horizontal displacements that are measured across monitoring lines and these can be described by various parameters including; horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.

Strain The change in the horizontal distance between two points divided by the original horizontal distance between the points, i.e. strain is the relative differential displacement of the ground along or across a subsidence monitoring line. Strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation.

Tensile Strains are measured where the distance between two points or survey pegs increases and **Compressive Strains** where the distance between two points decreases. Whilst mining induced **strains** are measured **along** monitoring lines, ground **shearing** can occur both vertically, and horizontally **across** the directions of the monitoring lines.

Sub-critical area An area of panel smaller than the critical area.

Subsidence The vertical movement of a point on the surface of the ground as it settles above an extracted panel, but, 'subsidence of the ground' in some references can include both a vertical and horizontal movement component. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of *millimetres (mm)*. Sometimes the horizontal component of a peg's movement is not measured, but in these cases, the horizontal distances between a particular peg and the adjacent pegs are measured.

Super-critical area An area of panel greater than the critical area.

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

Uplift An increase in the level of a point relative to its original position.

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

APPENDIX B. REFERENCES

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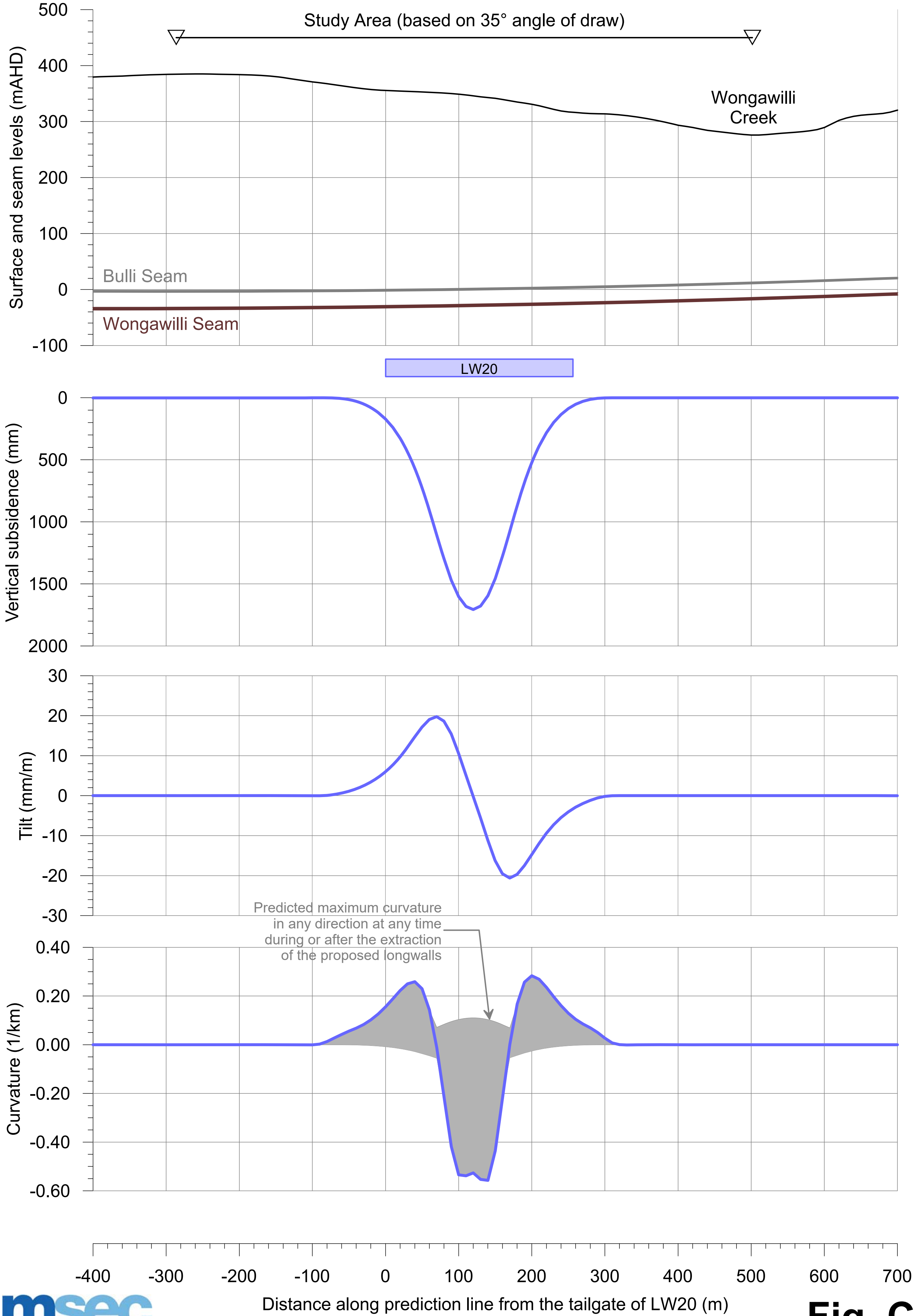
APPENDIX C. FIGURES

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to the extraction of LW20



msec

Fig. C.01

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to the extraction of LW21

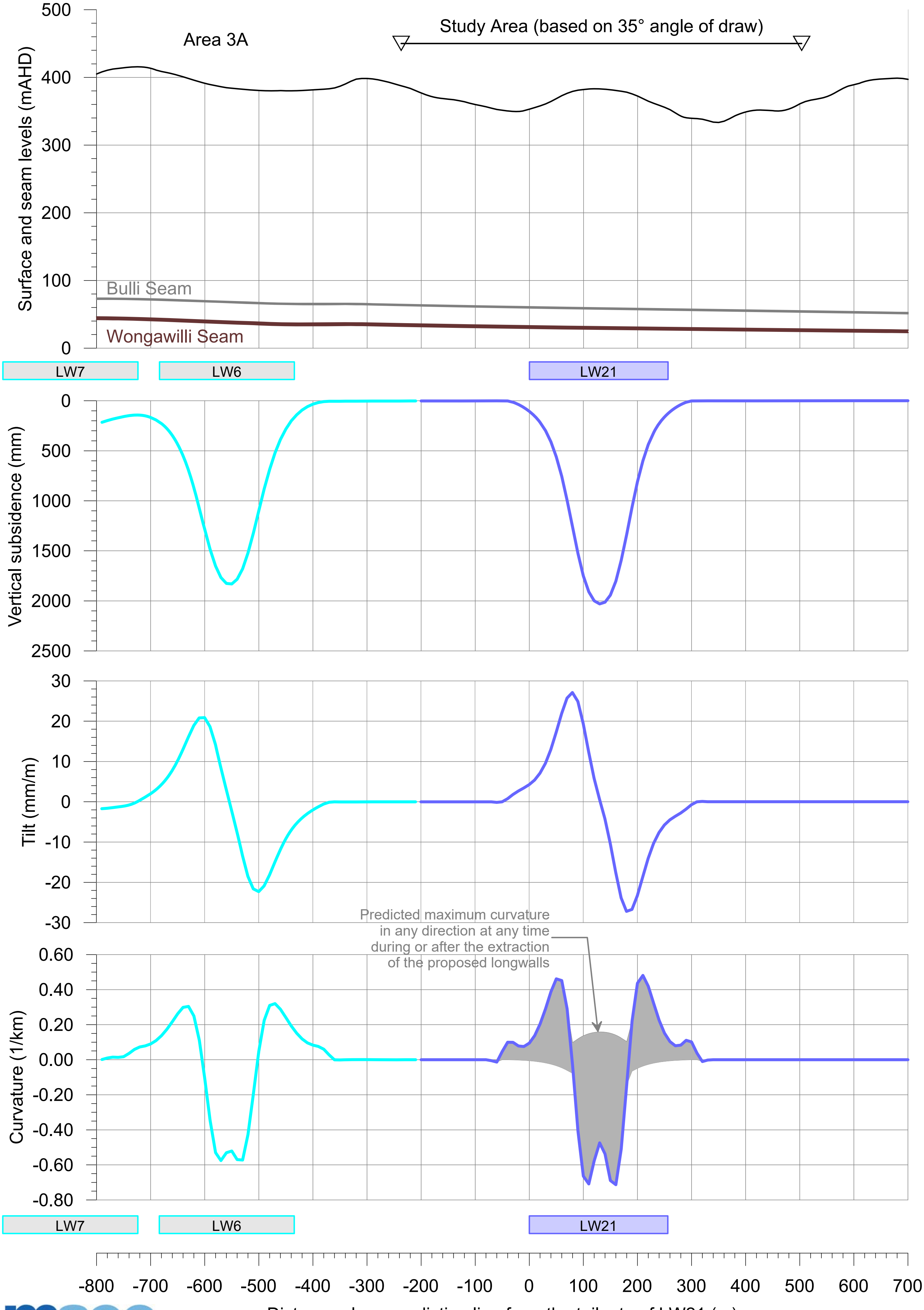


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Fig. C.02

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

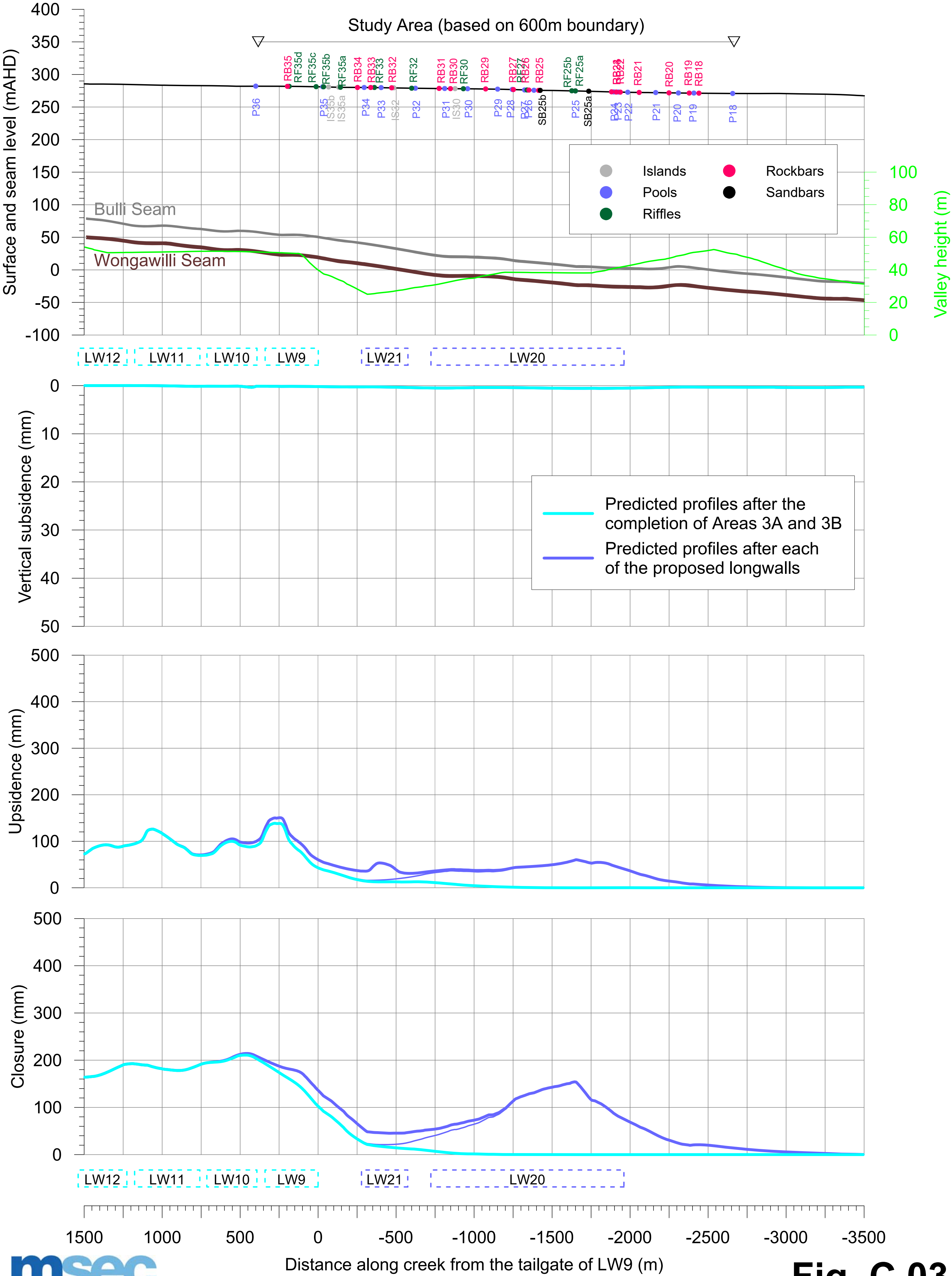

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Fig. C.03

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

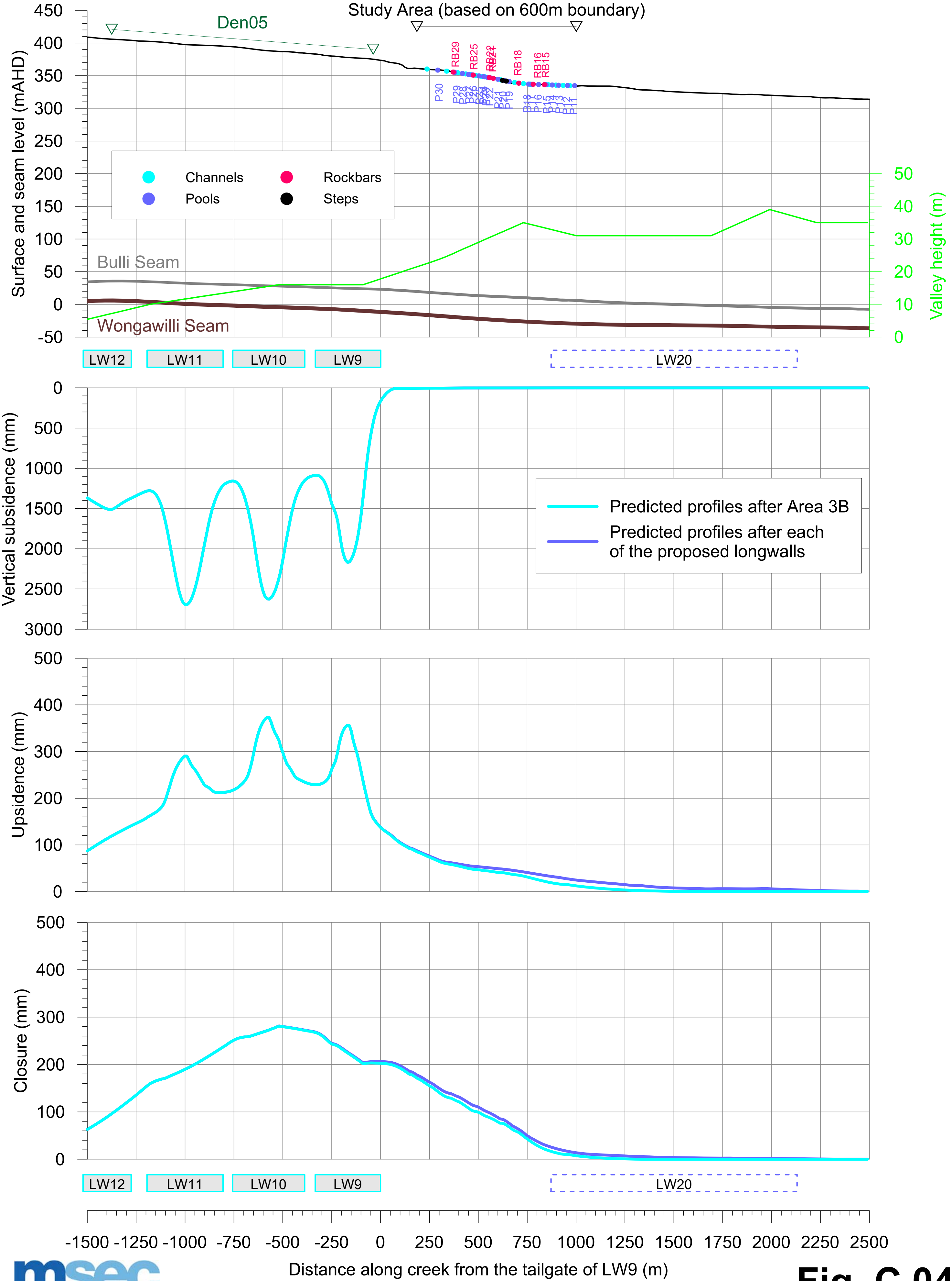

Fig. C.04

Predicted profiles of vertical subsidence, tilt along and tilt across the 330 kV transmission line due to mining in Areas3A and 3C

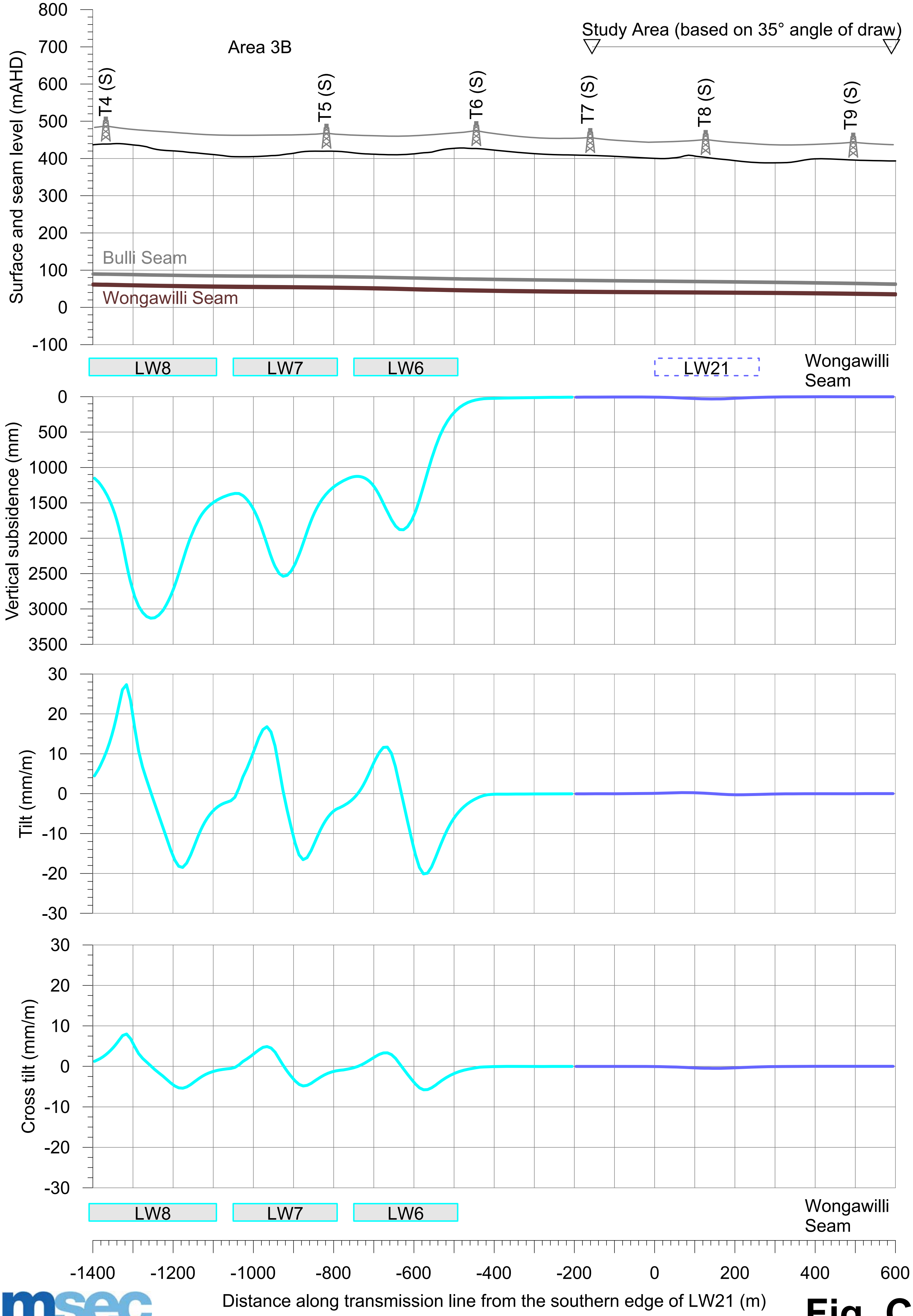

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Fig. C.05

APPENDIX D. DRAWINGS

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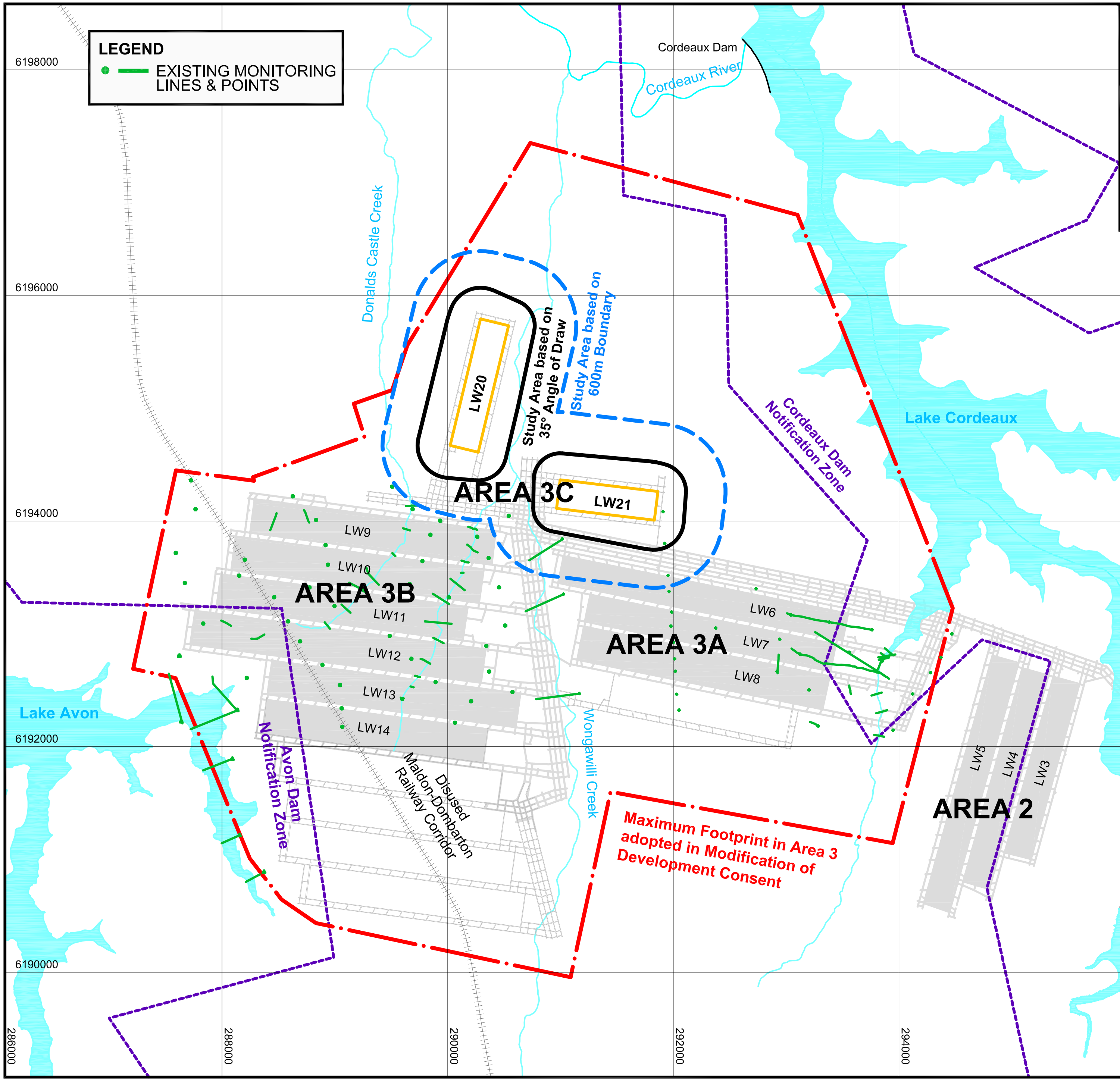

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ILLAWARRA COAL
DENDROBIUM COLLIERY - AREA 3C
OVERALL LAYOUT

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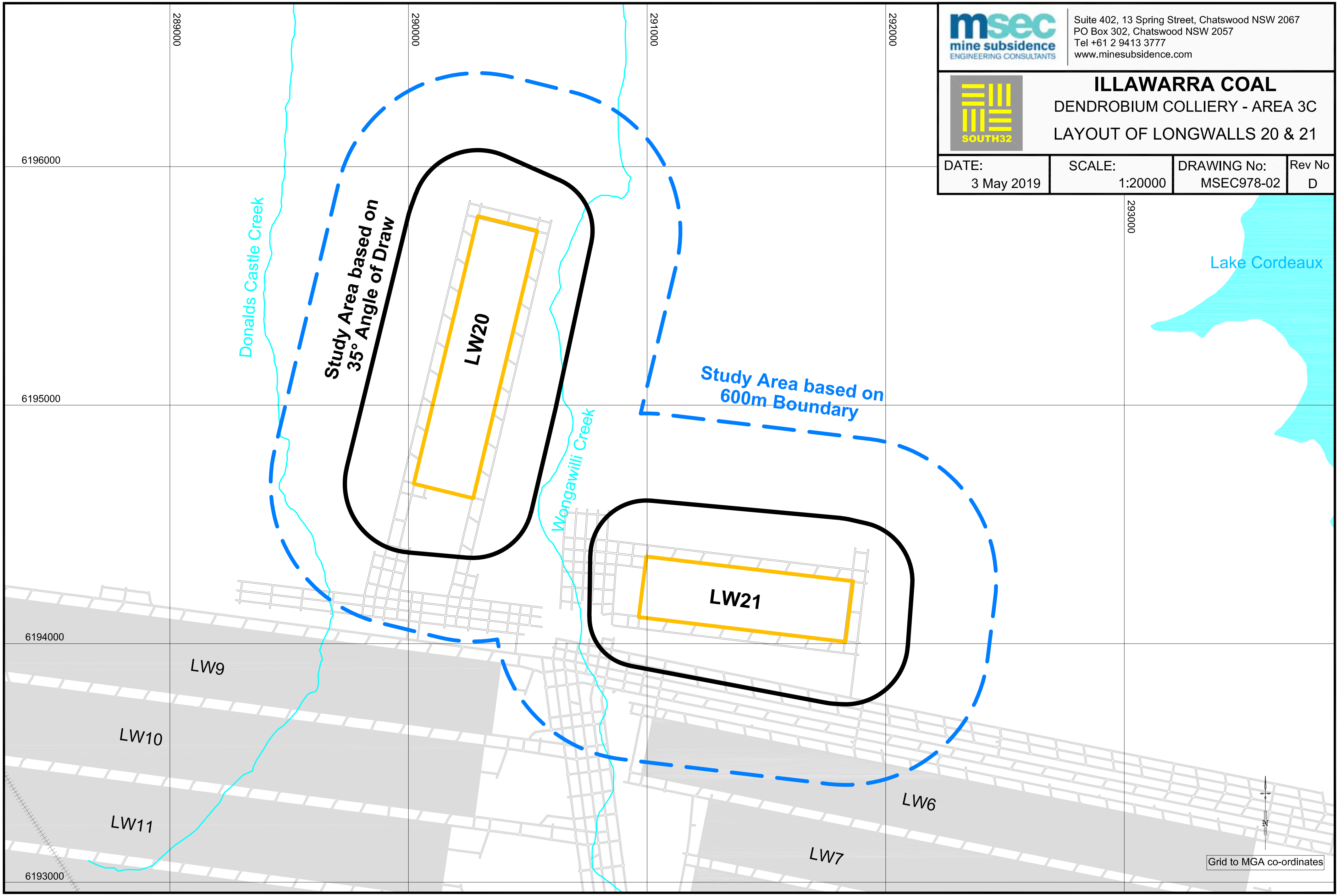

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DENDROBIUM COLLIERY - AREA 3C

LAYOUT OF LONGWALLS 20 & 21

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3 May 2019	1:20000	MSEC978-02	D

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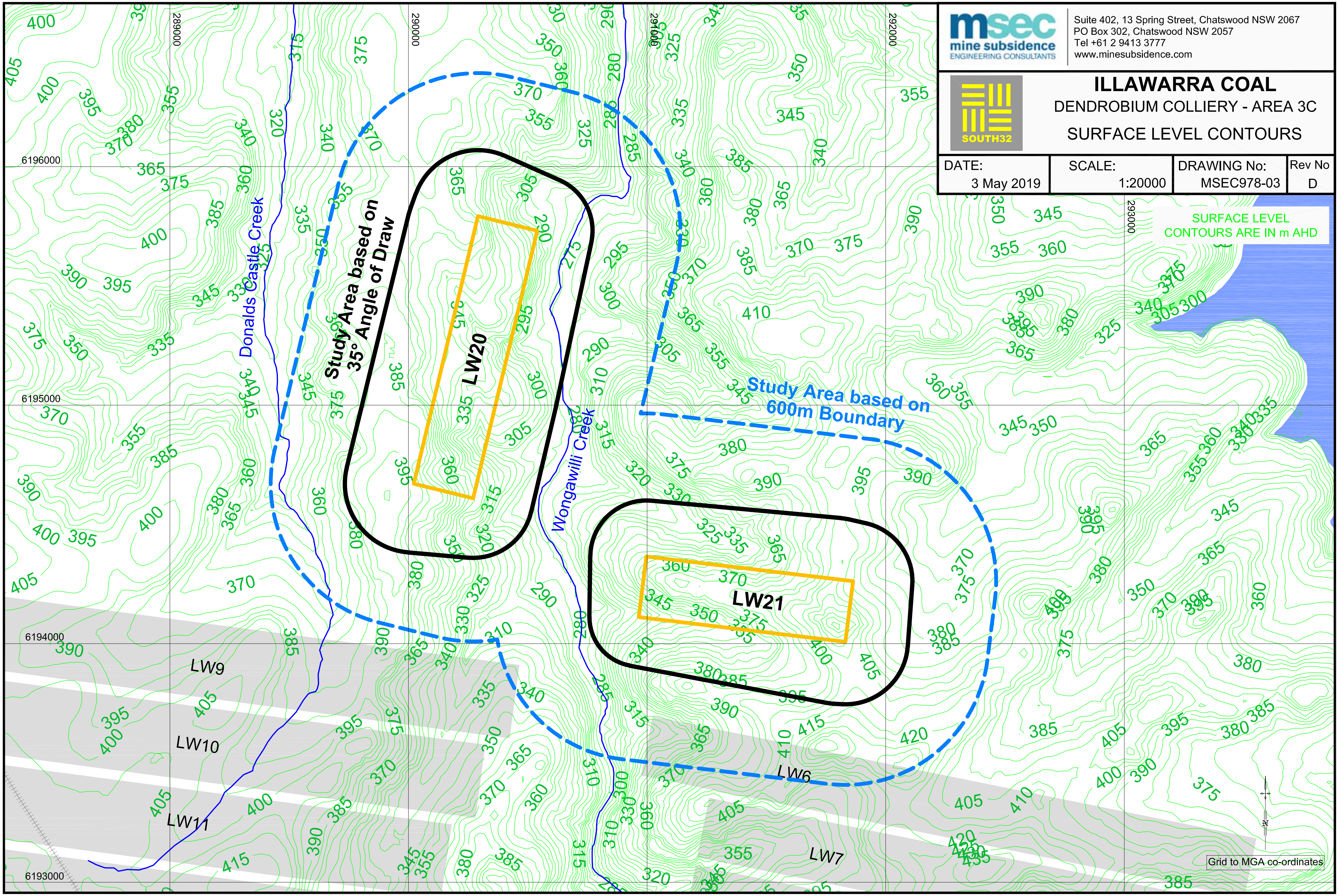

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DENDROBIUM COLLIERY - AREA 3C

SURFACE LEVEL CONTOURS

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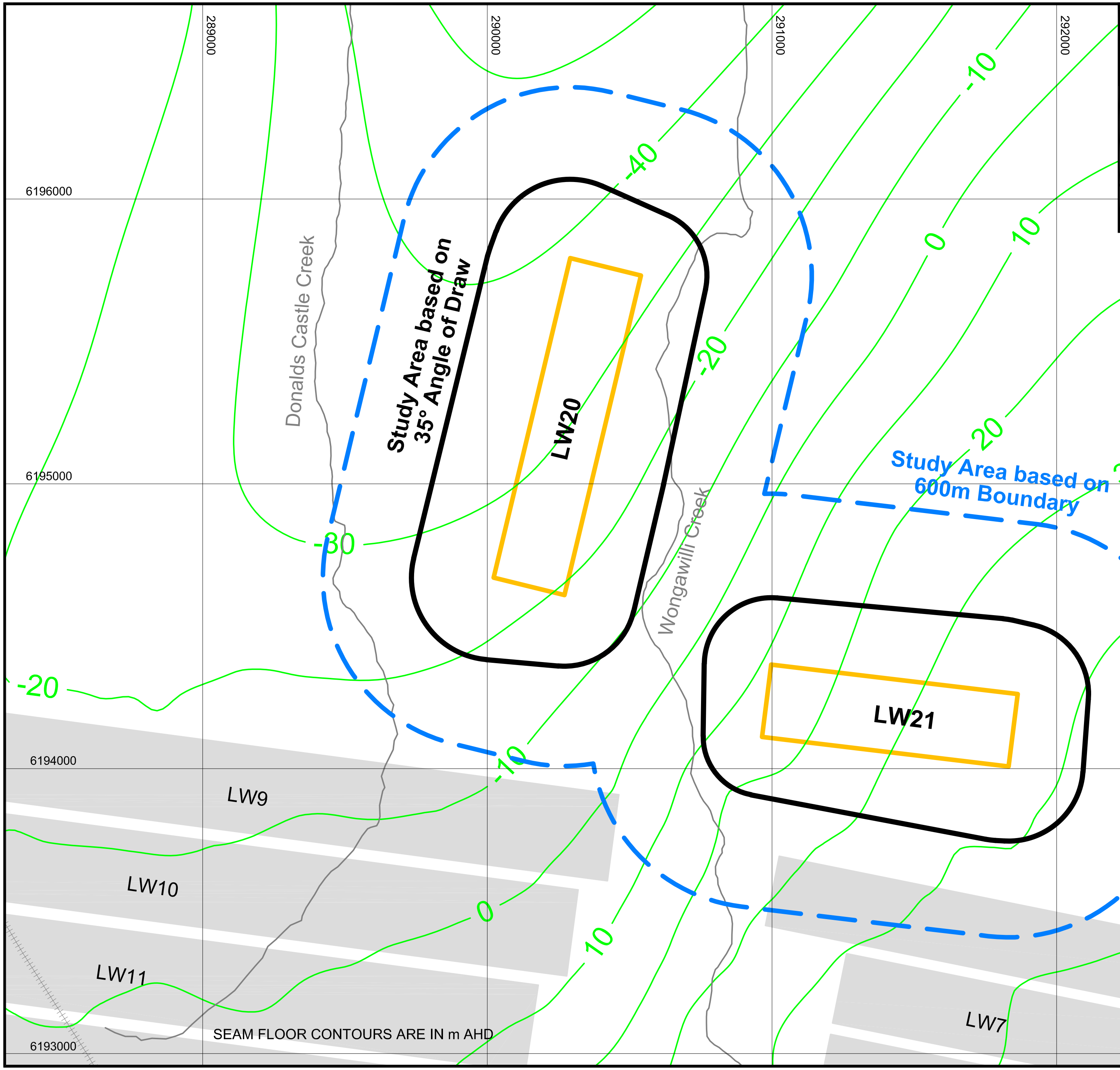

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DENDROBIUM COLLIERY - AREA 3C

WONGAWILLI SEAM FLOOR CONTOURS

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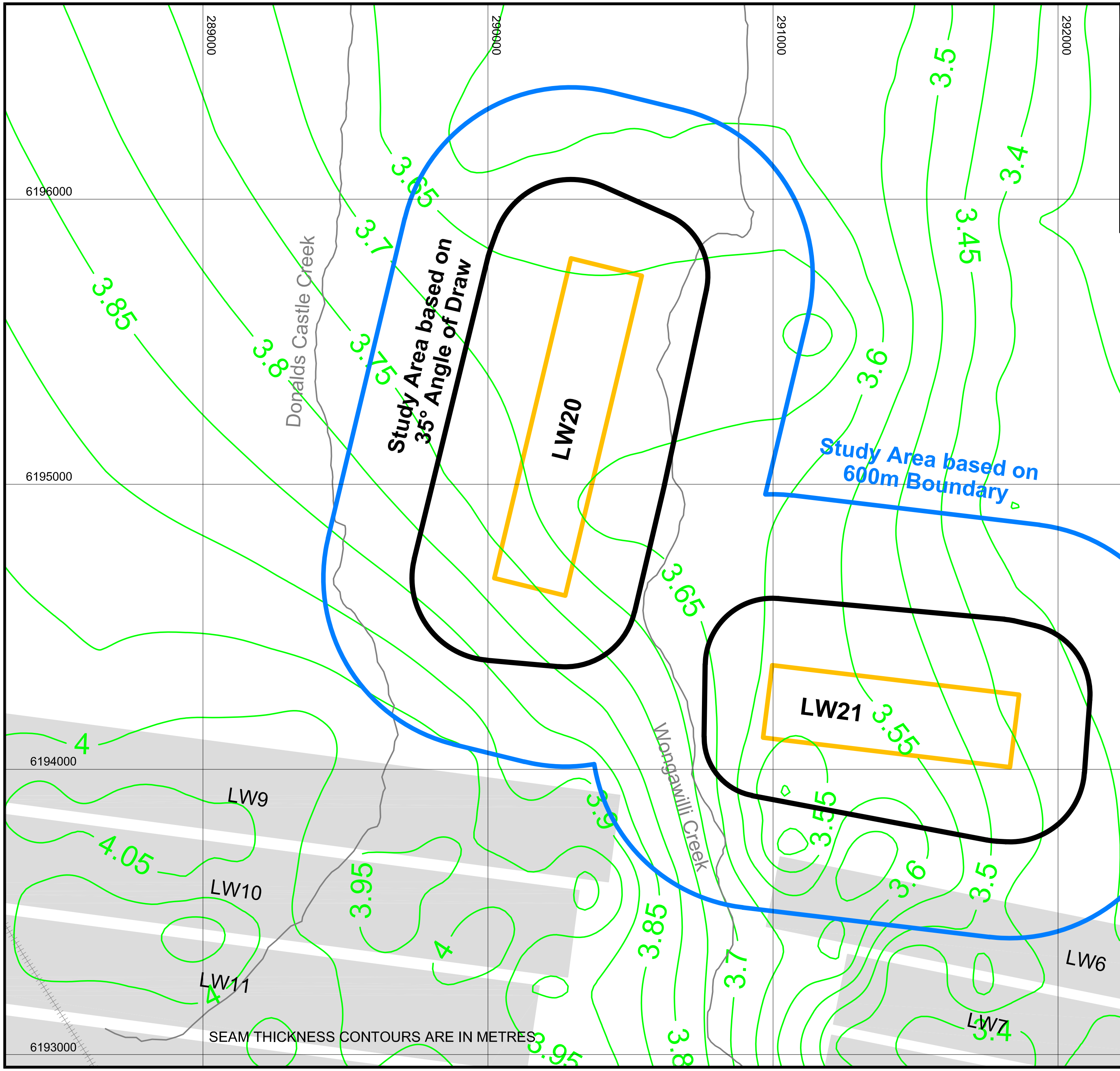

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DENDROBIUM COLLIERY - AREA 3C

WONGAWILLI SEAM THICKNESS CONTOURS FOR THE BASL SECTION

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

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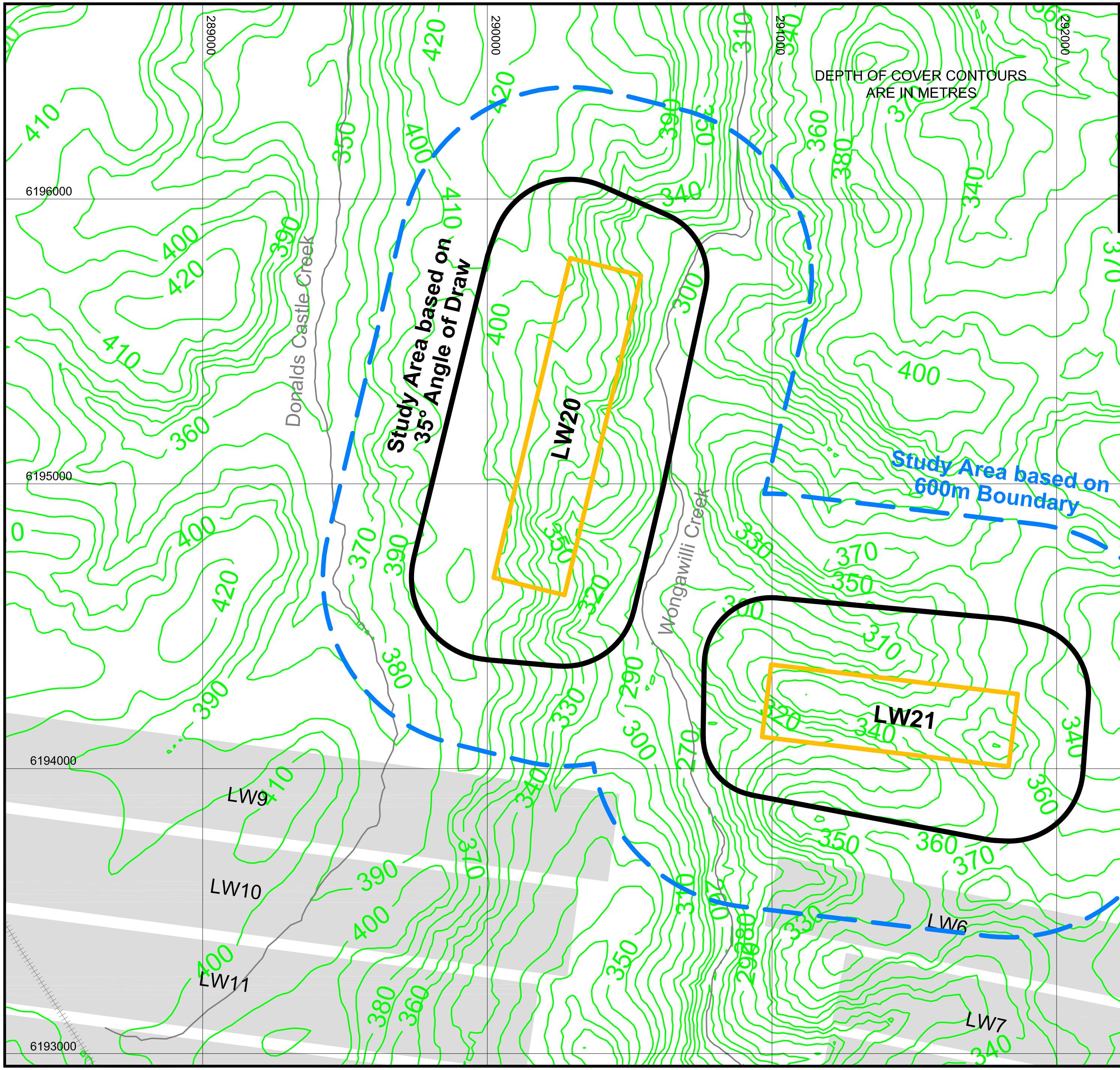

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DENDROBIUM COLLIERY - AREA 3C
WONGAWILLI SEAM
DEPTH OF COVER CONTOURS

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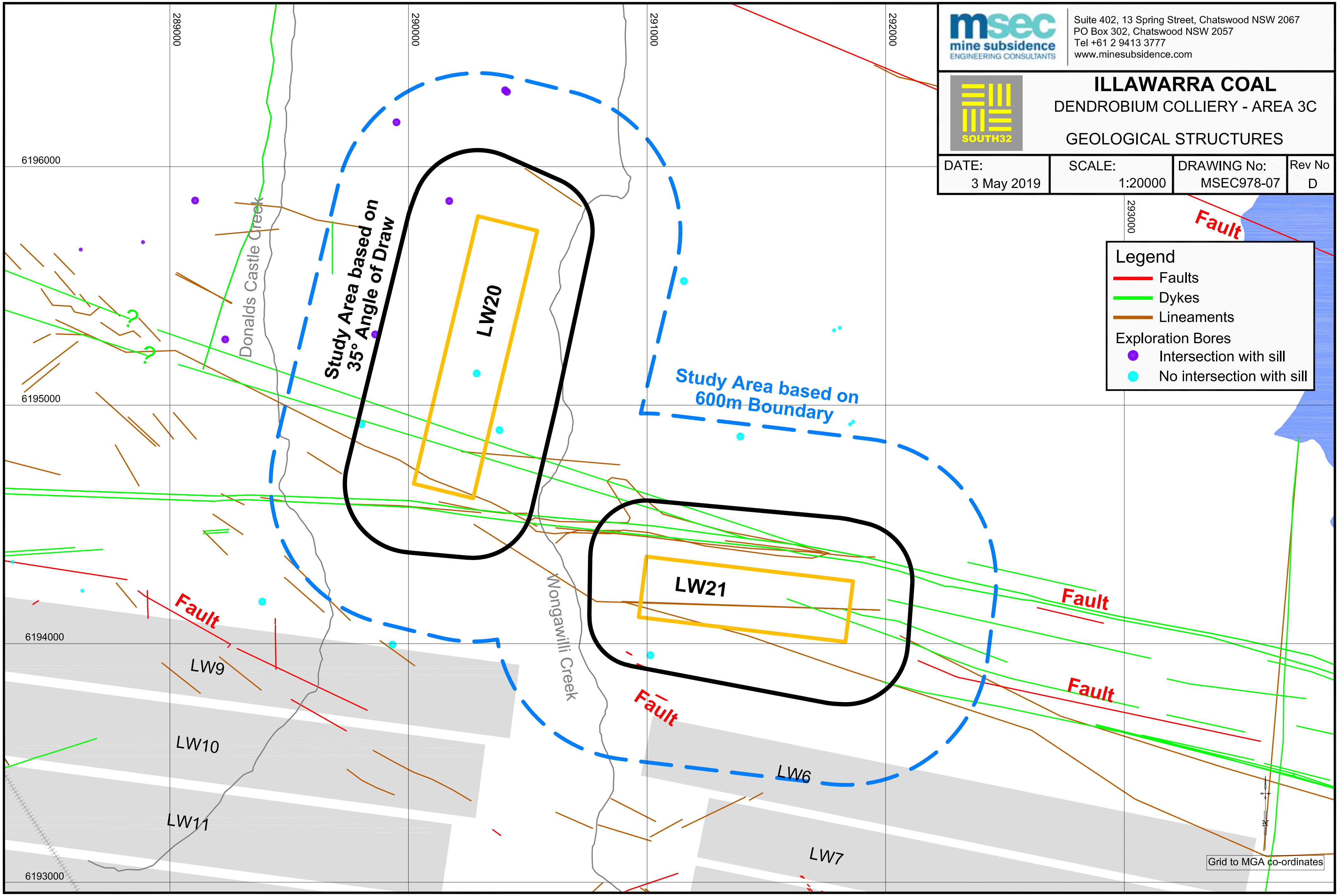

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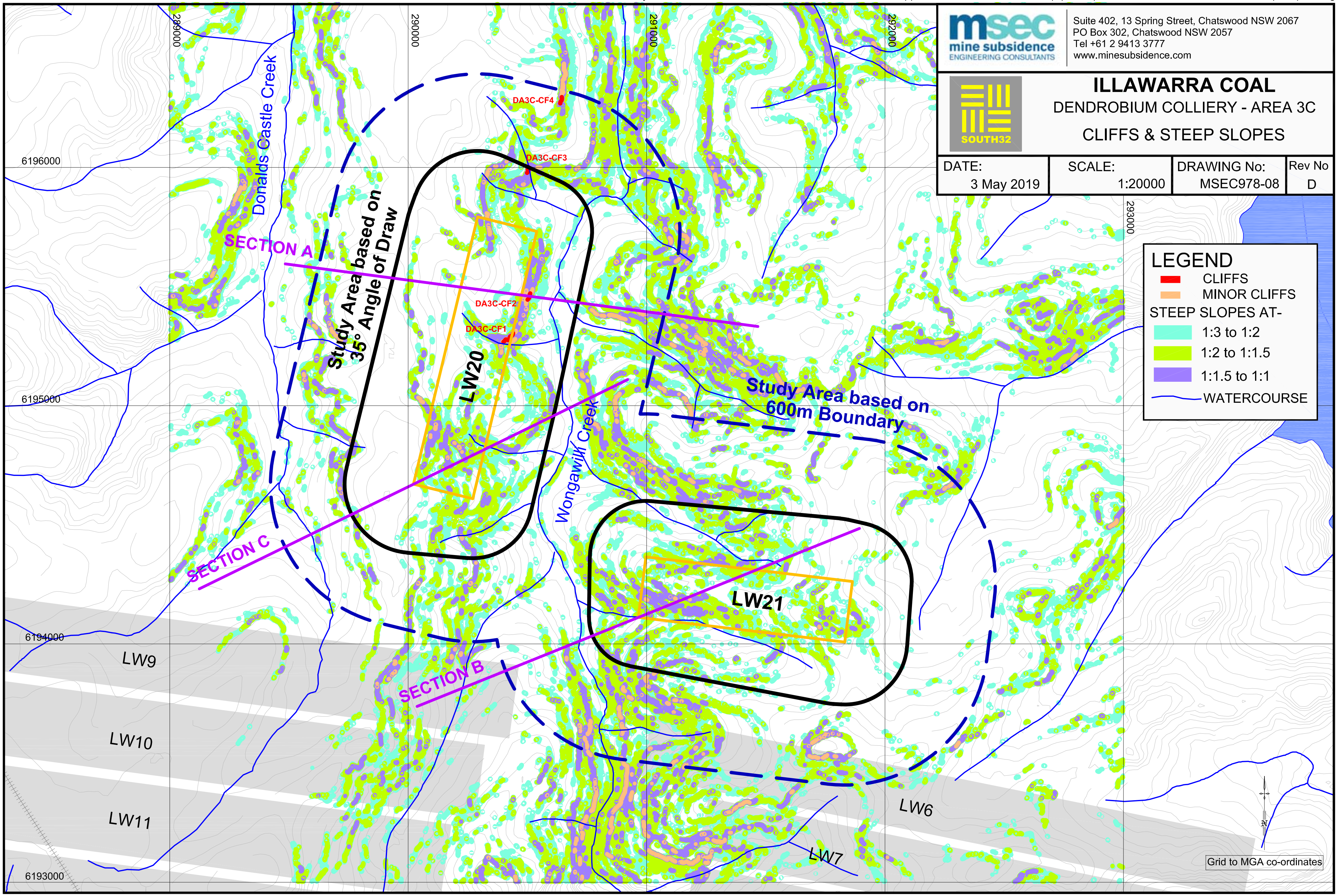

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DENDROBIUM COLLIERY - AREA 3C

CLIFFS & STEEP SLOPES

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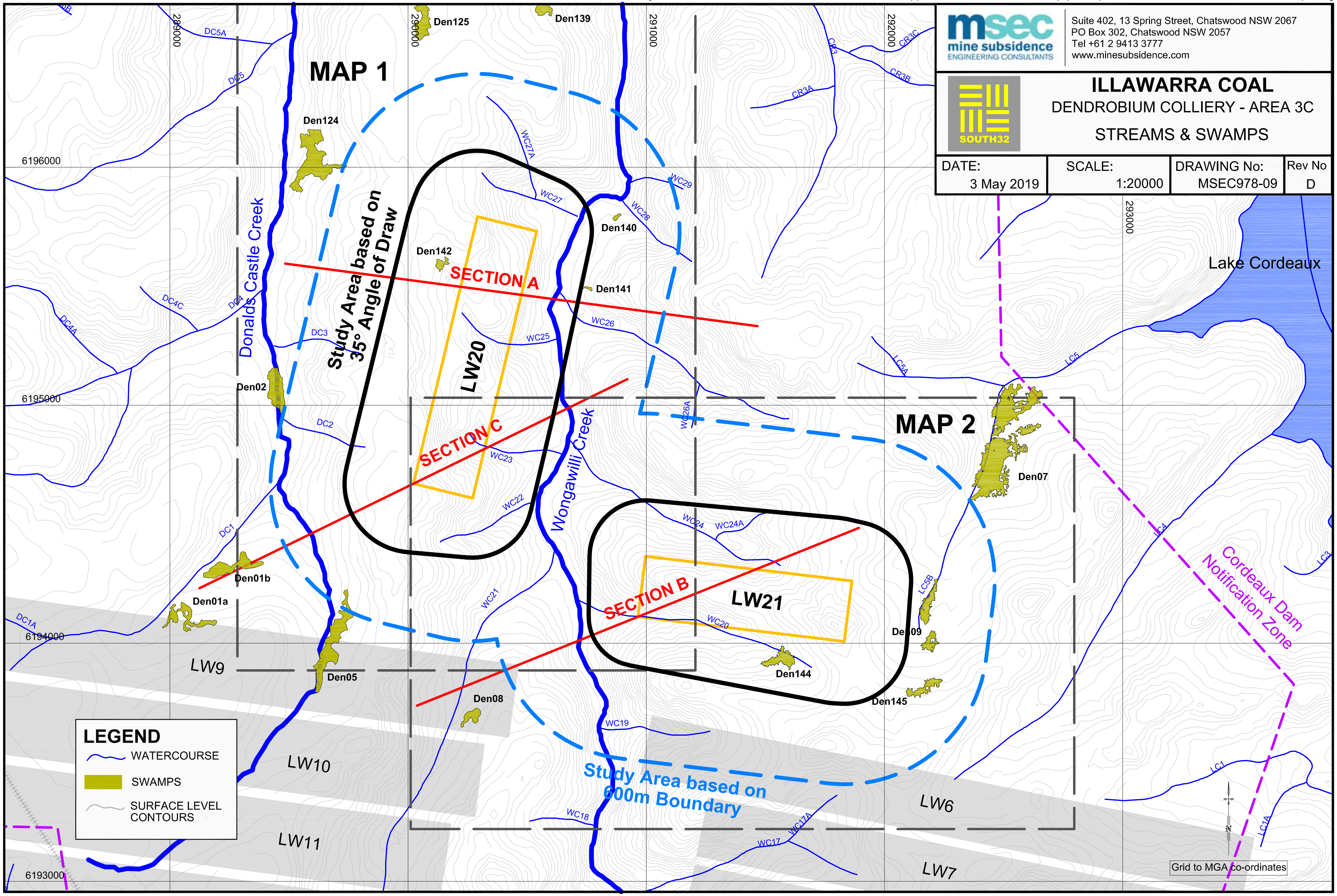

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DENDROBIUM COLLIERY - AREA 3C

STREAMS & SWAMPS

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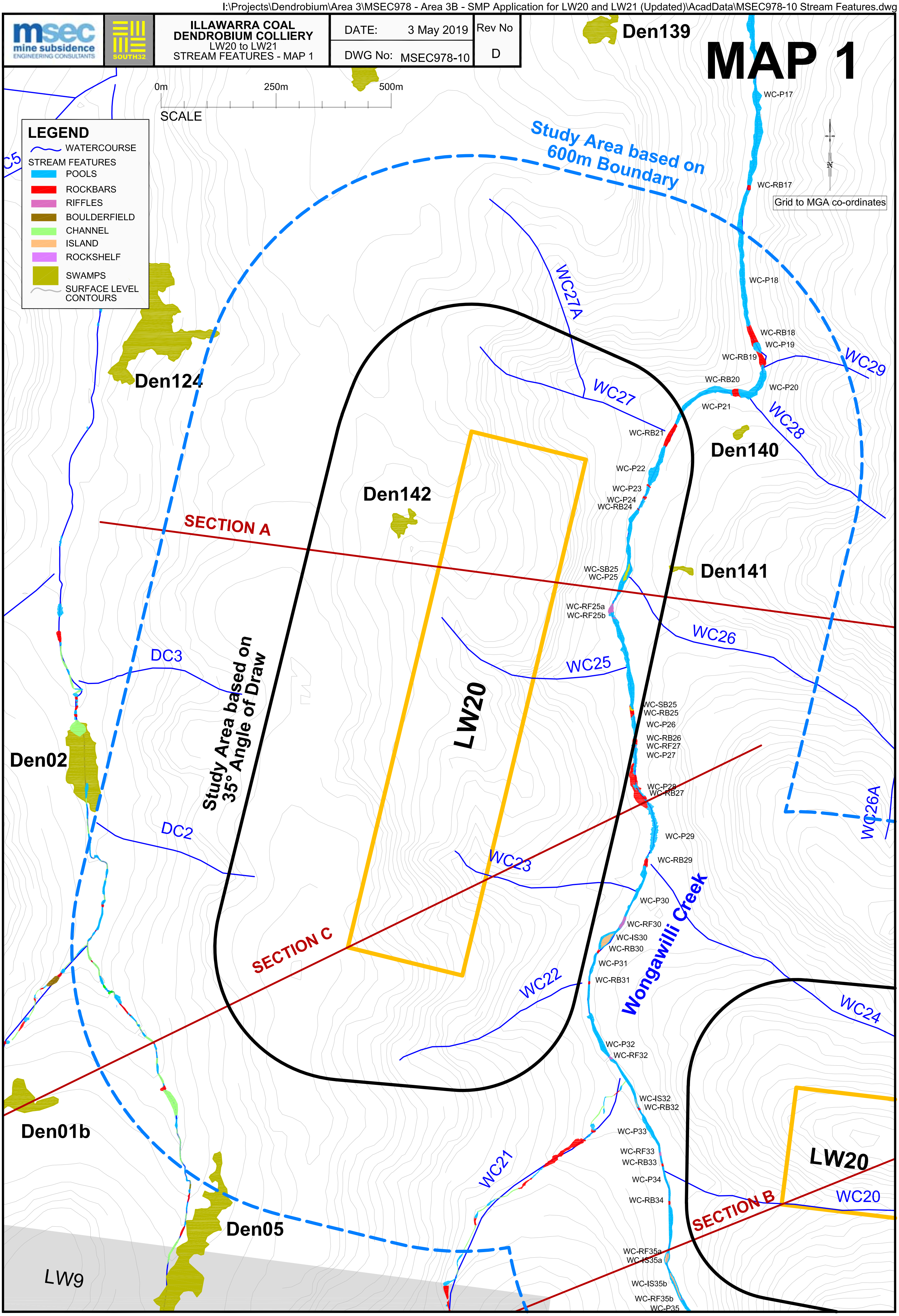

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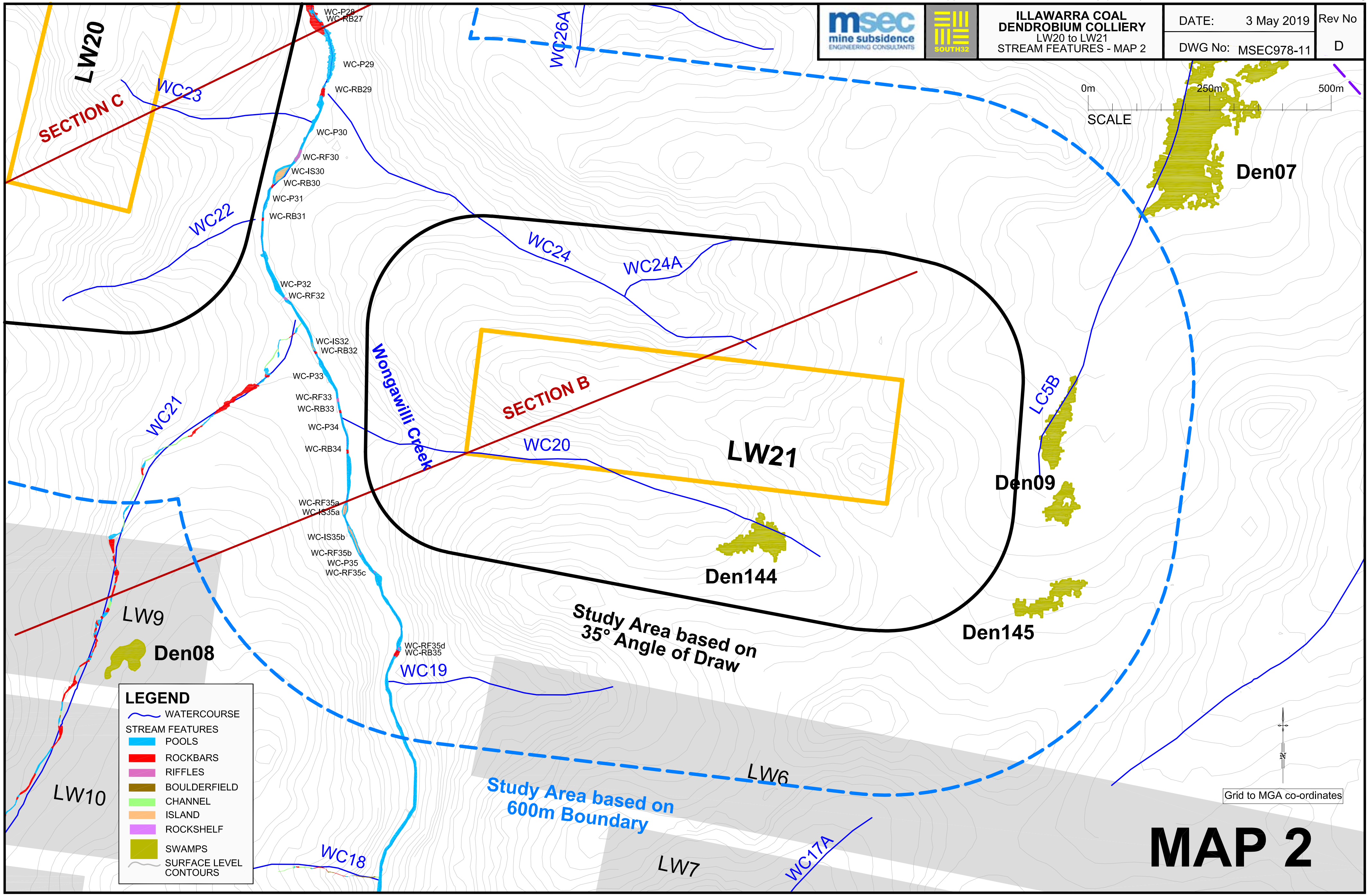

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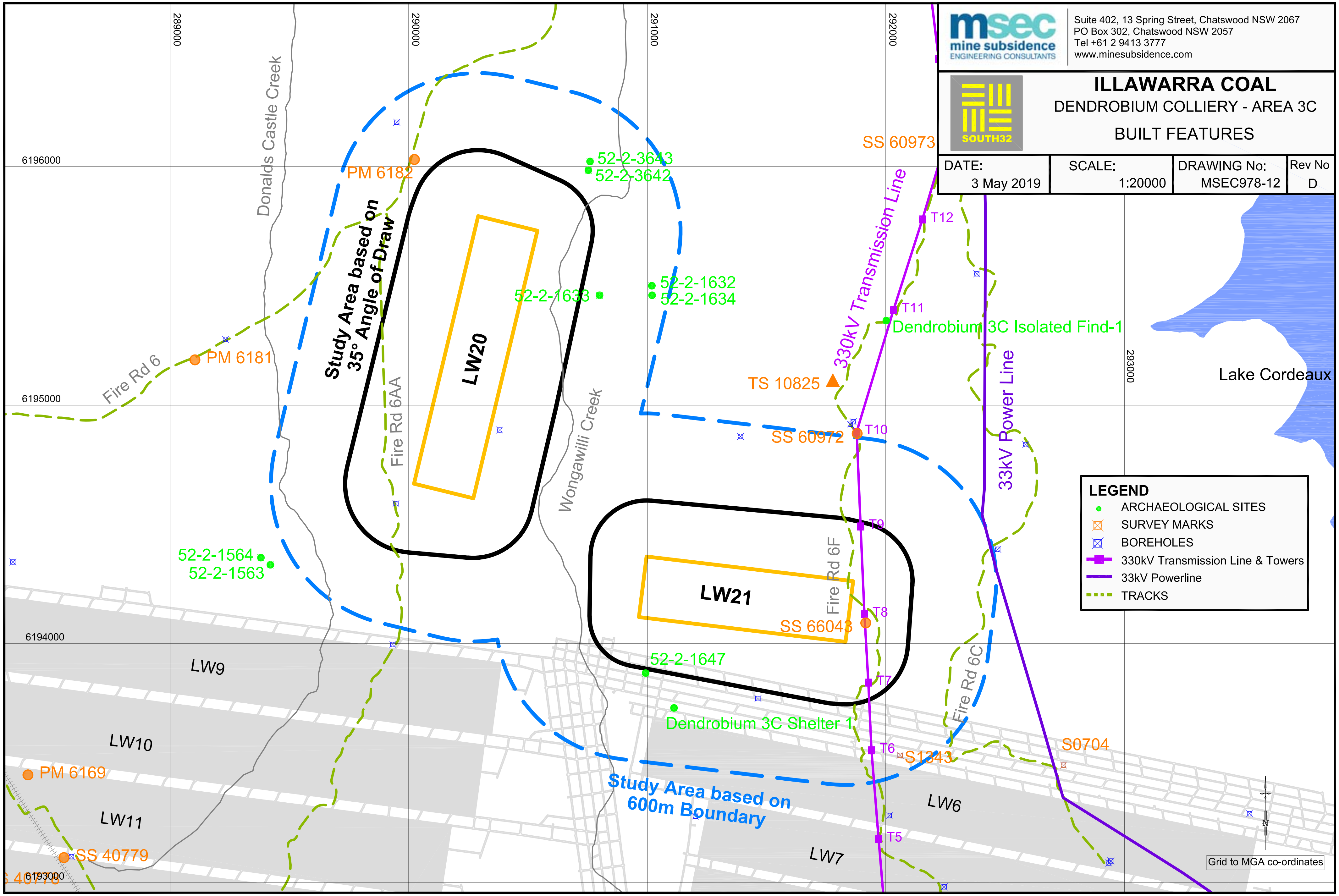

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BUILT FEATURES

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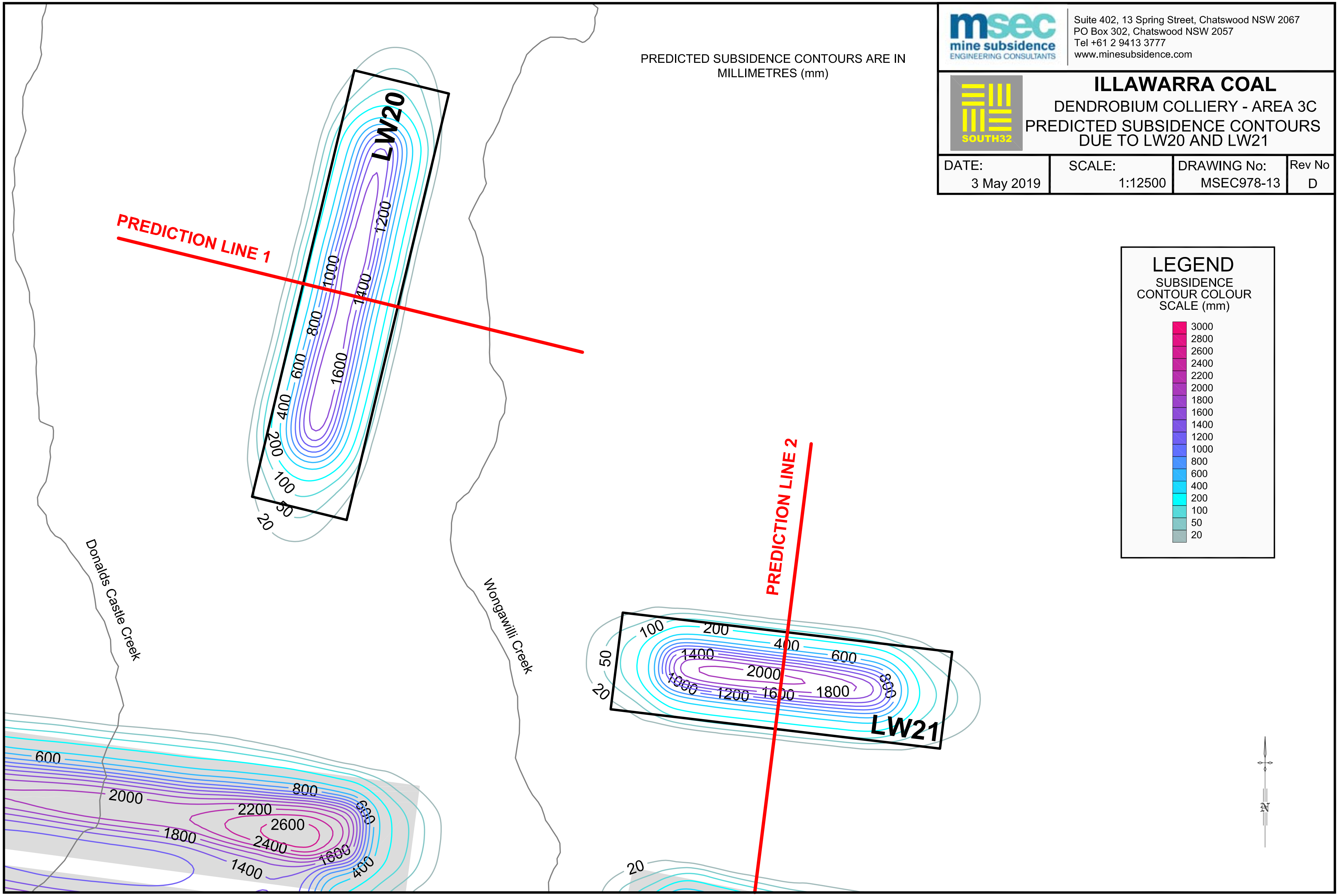

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PREDICTED SUBSIDENCE CONTOURS DUE TO LW20 AND LW21

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