WAMBO COAL PTY LIMITED

SOUTH BATES EXTENSION UNDERGROUND MINE

EXTRACTION PLAN LONGWALLS 21 TO 24

REPORT 1

SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

Peabody

REPORT: SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

msec
mine subsidence
ENGINEERING CONSULTANTS

Peabody

WAMBO COAL:

South Bates Extension Subsidence Assessment

Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan Application for WYLW21 to WYLW24 at the South Bates Extension Underground Mine

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01	Draft Issue	JB	BM	9 Jan 20
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Report produced to: Support the Extraction Plan Application for the South Bates Extension Underground Mine WYLW21 to WYLW24 in the Whybrow Seam.

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

Wambo Coal Pty Limited (WCPL) operates the Wambo Coal Mine, which is located in the Hunter Coalfield of New South Wales. The mine was approved under Part 4 of the *Environmental Planning and Assessment Act 1979*, in February 2004, which included the extraction of longwalls in the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams.

WCPL previously submitted a Modification Application for the extraction of Longwalls 17 to 25 in the Whybrow Seam (WYLW17 to WYLW25) at the *South Bates Extension Underground Mine*, part of the Wambo Coal Mine. The extraction of these longwalls was approved on the 20 December 2017.

WCPL is preparing an Extraction Plan Application for WYLW21 to WYLW24 at the South Bates Extension Underground Mine. Mine Subsidence Engineering Consultants has been engaged by WCPL to prepare a subsidence prediction and assessment report to support this application. The layout of these longwalls is the same as that adopted in the Modification Application, except that the finishing (i.e. north-eastern) ends have been shortened by distances of 215 m for WYLW21 and WYLW22, 145 m for WYLW23 and 35 m for WYLW24. There has also been a reorientation of the main headings associated with WYLW23 and WYLW24.

The predicted subsidence effects for WYLW21 to WYLW24 have been determined using the Incremental Profile Method. The maximum predicted vertical subsidence, tilt and curvatures for these longwalls are the same as those presented in the Modification Application.

The maximum predicted subsidence effects for WYLW21 to WYLW24 are 1950 mm vertical subsidence (i.e. 65 % of the maximum extraction height of 3.0 m), 85 mm/m tilt (i.e. 8.5 % or 1 in 12) and greater than 3.0 km^{-1} curvature (i.e. a minimum radius of curvature less than 0.3 km). The maximum predicted subsidence effects occur above the north-eastern ends of the longwalls, where the depths of cover are the shallowest.

The Study Area has been defined as the surface area enclosed by the greater of the 26.5° angle of draw line from the extents of WYLW21 to WYLW24 and the predicted additional 20 mm subsidence contour due to mining these longwalls. Other features which could be subjected to far-field or valley related movements and could be sensitive to such effects have also been assessed in this report.

A number of natural and built features have been identified within or in the vicinity of the Study Area including: North Wambo Creek, ephemeral drainage lines, the Wollemi Escarpment and other cliffs, minor cliffs and pagodas, steep slopes, Wollemi National Park, unsealed tracks and trails, farm dams, the Montrose Open Cut Pit (part of the Wambo Coal Mine), Aboriginal heritage sites, survey control marks and unused building structures.

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

- North Wambo Creek is located directly above the proposed WYLW23 and WYLW24. There are also ephemeral drainage lines located across the Study Area. The North Wambo Creek Diversion is located outside the Study Area and it is not anticipated to experience adverse impacts due to the mining of the proposed longwalls.

  Ponding areas are predicted to develop along North Wambo Creek and the ephemeral drainage lines having depths up to approximately 1.4 m and overall lengths up to approximately 300 m. If adverse impacts were to develop as the result of increased ponding, these could be remediated by locally regrading the stream beds, so as to re-establish the natural gradients.

  Fracturing and compression heaving are expected to develop along the sections of the streams located directly above the proposed longwalls. The impacts are expected to be similar to those observed along the streams above the previously extracted Wambo Seam longwalls at the North Wambo Underground Mine, WYLW11 to WYLW13 at the *South Bates Underground Mine* and WYLW17 at the South Bates Extension Underground Mine. It may be necessary to remediate the larger surface deformations by infilling with surface soil or other suitable materials, or by locally regrading and recompacting the surface.
- Cliffs have been identified within the Study Area which have been categorised into three groups, being: *Cliffs Associated with the Wollemi Escarpment*; *Intermediate Level Cliffs* (i.e. located beneath the escarpment); and *Low Level Cliffs* (i.e. near the base of the steep slopes directly above the south-western ends of the proposed longwalls).

The Cliffs Associated with the Wollemi Escarpment are located outside the 26.5° angle of draw line and the Intermediate Level Cliffs are located near to or outside the angle of draw line. These cliffs are predicted to experience less than 20 mm vertical subsidence. While the Cliffs Associated with the Wollemi Escarpment and the Intermediate Level Cliffs could experience very low levels of vertical subsidence, they are unlikely to experience measurable conventional tilts, curvatures or strains. It is unlikely, therefore, that these cliffs would experience adverse impacts due to the mining of the proposed longwalls.

The Low Level Cliffs are located directly above the proposed longwalls. It has been assessed that 7 % to 10 % of the total length, or approximately 3 % to 5 % of the total face area, of the cliffs located directly above the mining area could be impacted. This equates to a length of disturbance of approximately 15 m, or a face area of approximately 100 m^2. This represents a very small percentage (i.e. less than 1 %) of the total length and face area of the cliffs located within the Study Area.

- Steep slopes are located above the south-western ends of the proposed longwalls. Surface cracking and compression heaving could develop along the areas of the steep slopes that are located directly above the mining area. Impacts are not anticipated along the steep slopes located outside and to the south-west of the mining area. Surface remediation might be required, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface.
- The Wollemi National Park is located to the south and to the west of the proposed longwalls, at minimum distances of 150 m. The land within the National Park is predicted to experience less than 20 mm vertical subsidence and it is not expected to experience measurable conventional tilts, curvatures or strains. The National Park could experience far-field horizontal movements up to 150 mm, based on the 95 % confidence level, but these bodily movements are not expected to be associated with any measurable strains. It is unlikely, therefore, that the Wollemi National Park would be adversely impacted by the vertical or far-field horizontal movements.
- There are unsealed tracks and trails located across the Study Area which are used for the mining operations and for firefighting activities. It is expected that these roads could be maintained in safe and serviceable conditions using normal road maintenance techniques.
- There are four farm dams located within the Study Area. Fracturing and buckling could occur in the uppermost bedrock beneath the farm dams, which could adversely affect the water holding capacities of the farm dams. It may be necessary to remediate some of the farm dams, at the completion of mining, by excavating and re-establishing cohesive material in the beds of the farm dams to reduce permeability.
- The WCPL mining related infrastructure within the Study Area includes the Montrose Open Cut Pit, exploration drill holes, a proposed 11 kV powerline and proposed ventilation shaft. It is recommended that a geotechnical assessment of the highwall be undertaken based on the effects of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24. It is also recommended that the exploration drill holes are capped (if not already done) prior to being directly mined beneath.
- There are 14 Aboriginal heritage sites located within the Study Area, comprising ten open artefact sites, three rock shelters with Potential Archaeological Deposits and one scarred tree. It is unlikely that the artefact scatters and the scarred tree would be adversely impacted by mining-induced surface cracking.

  The rock shelters located directly above the proposed longwalls could be affected by fracturing and spalling of the bedrock. It has been assessed that impacts are possible (i.e. greater than 25 %) for Wambo Site 499, very unlikely (i.e. less than 10 %) for Wambo Site 504 and rare (i.e. less than 5 %) for Wambo Site 503.
- The Whynot Homestead and associated sheds are located above the proposed WYLW21. The building structures are all unused and are in poor conditions. WCPL completed an archival recording of the Whynot Homestead in 2017. It is recommended that the building structures are visually monitored during active subsidence. If any structure is identified as unstable or unsafe during mining, then measures should be undertaken to prevent access (i.e. install temporary fencing) until such time it is made safe, or the structure is removed.

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 the appropriate management strategies. It should be noted, however, that more detailed assessments of some natural and built features have been undertaken by other specialist consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

CONTENTS

Tables

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

Figures

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

Drawings

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

Drawing No.	*Description*	*Revision*
MSEC1080-01	Overall layout	B
MSEC1080-02	General layout	B
MSEC1080-03	Surface level contours	B
MSEC1080-04	Whybrow Seam floor contours	B
MSEC1080-05	Whybrow Seam thickness contours	B
MSEC1080-06	Whybrow Seam depth of cover contours	B
MSEC1080-07	Geological structures at seam level	B
MSEC1080-08	Natural features	B
MSEC1080-09	Built features	B
MSEC1080-10	Predicted total subsidence contours after WYLW21	B
MSEC1080-11	Predicted total subsidence contours after WYLW22	B
MSEC1080-12	Predicted total subsidence contours after WYLW23	B
MSEC1080-13	Predicted total subsidence contours after WYLW24	B

1.1. Background

Wambo Coal Pty Limited (WCPL) operates the Wambo Coal Mine, which is located in the Hunter Coalfield of New South Wales (NSW). The mine was approved under Part 4 of the *Environmental Planning and Assessment Act 1979*, in February 2004, and through subsequent modifications. WCPL has approval to extract longwalls in the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams.

WCPL has completed the extraction of Longwalls 11 to 13 in the Whybrow Seam (WYLW11 to WYLW13) and Longwalls 14 to 16 in the Wambo Seam (WMLW14 to WMLW16) at the *South Bates Underground Mine* mining area of the Wambo Coal Mine. Mine Subsidence Engineering Consultants (MSEC) prepared the subsidence predictions and impact assessments for WYLW11 to WYLW13 and WMLW14 to WMLW16 (Reports Nos. MSEC855 and MSEC899), which supported the Extraction Plan and Modification Applications for these longwalls.

WCPL previously prepared a Modification Application for Longwalls 17 to 25 in the Whybrow Seam (WYLW17 to WYLW25) at the *South Bates Extension Underground Mine* (SBEUM) mining area of the Wambo Coal Mine. These longwalls are located to the north-west of the completed longwalls at the South Bates Underground Mine. MSEC prepared Report No. MSEC848 in support of the SBEUM Modification Application.

WCPL has an approved Extraction Plan for WYLW17 to WYLW20. The finishing ends of WYLW17 to WYLW20 and the commencing ends of WYLW19 and WYLW20 have been shortened from the extents originally adopted in the SBEUM Modification Application and Report No. MSEC848. The subsidence predictions and impact assessments for WYLW17 to WYLW20 are provided in Reports Nos. MSEC935, MSEC1012 and MSEC1069, which supported the Extraction Plan and subsequent Extraction Plan updates for these longwalls.

WCPL is now preparing an Extraction Plan for WYLW21 to WYLW24. The finishing (i.e. north-eastern) ends of these longwalls are proposed to be shortened from the extents adopted in the SBEUM Modification Application and Report No. MSEC848 by 215 m for WYLW21 and WYLW22, 145 m for WYLW23 and 35 m for WYLW24. The commencing ends, void widths and chain pillar widths for these longwalls have not been modified. The comparison between the longwall layouts is provided in Fig. 1.1.

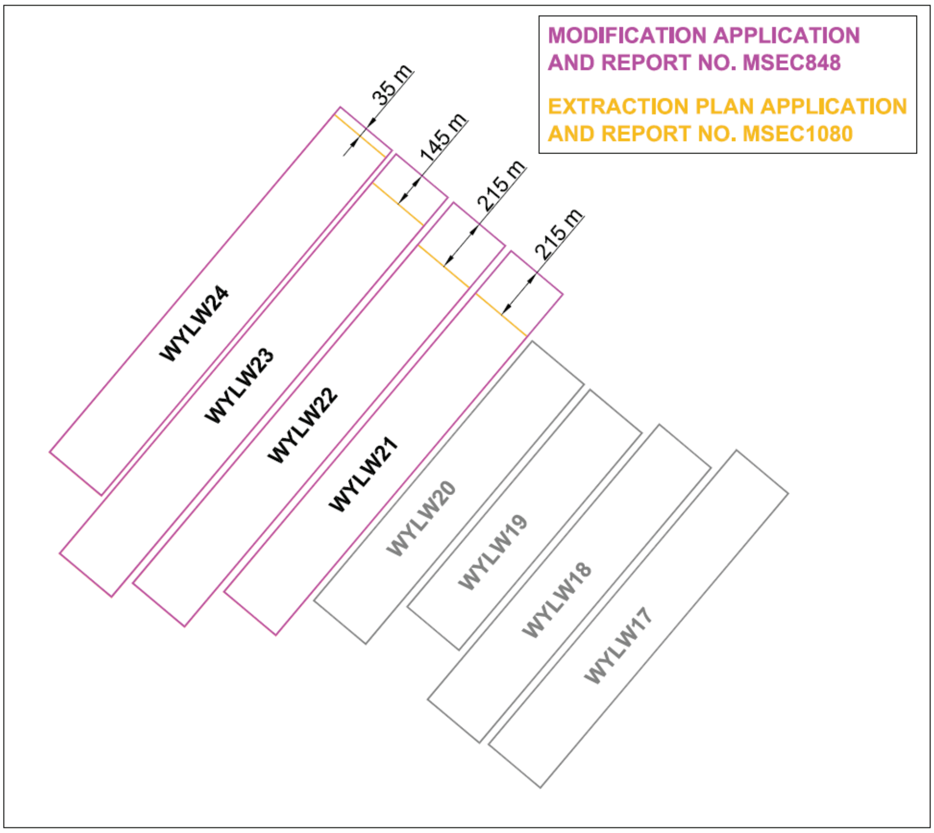
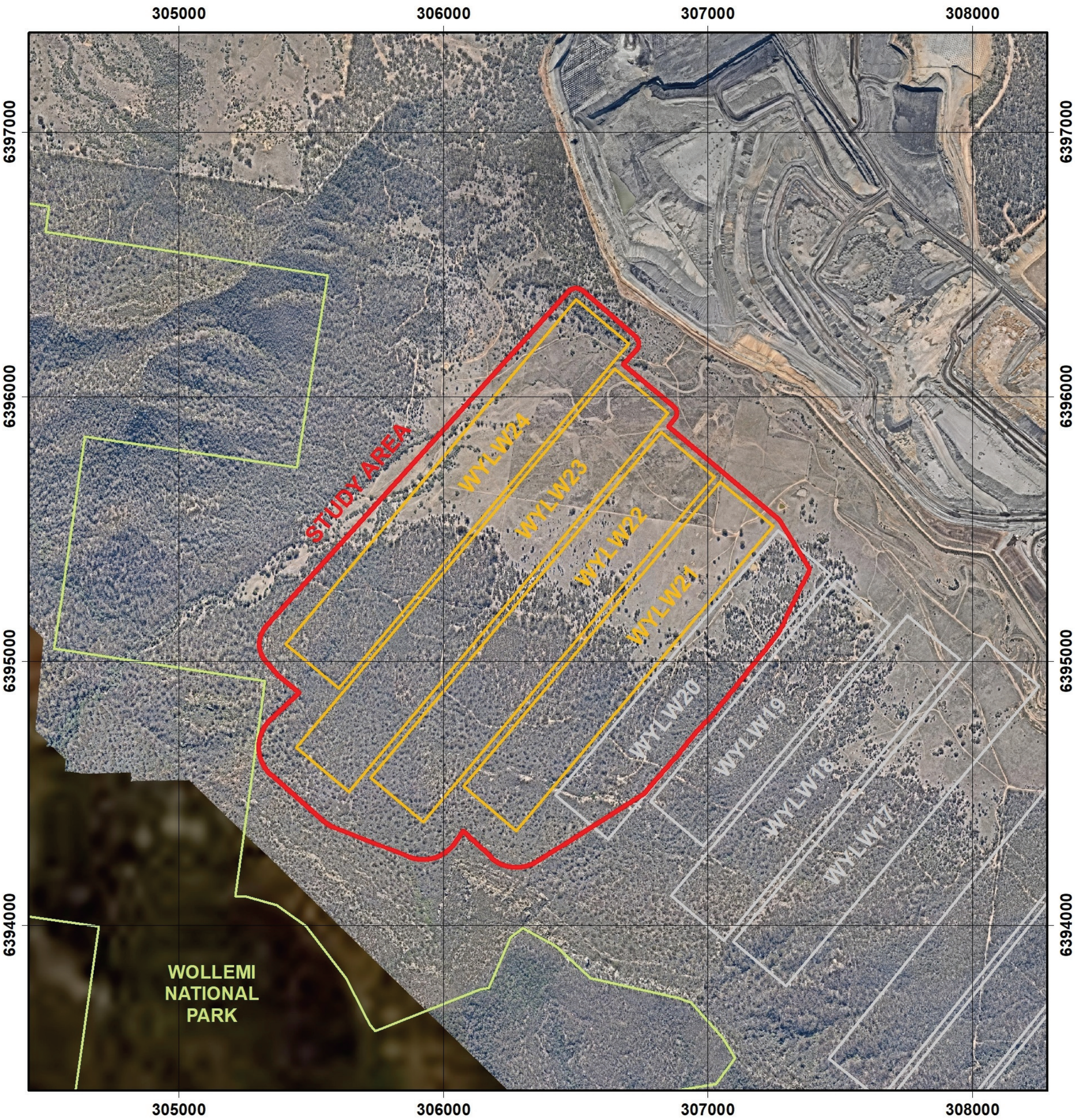


Fig. 1.1 Comparison of the longwall layouts

The locations of the existing, approved and proposed longwalls are shown in Drawings Nos. MSEC1080-01 and MSEC1080-02, in Appendix D. In the context of this report, “existing” refers to completed longwalls, “approved” refers to longwalls with an approved Extraction Plan, “proposed” refers to the longwalls that are the subject of this Extraction Plan application (i.e. WYLW21 to WYLW24) and “future” refers to longwalls that will be the subject of a future Extraction Plan application (i.e. WYLW25).

The proposed WYLW21 to WYLW24 and the Study Area, as defined in Section 2.1, have been overlaid on an orthophoto of the area, which is shown in Fig. 1.2. The boundary of the Wollemi National Park has also been shown in this figure.



Source: Nearmap

Fig. 1.2 WYLW21 to WYLW24 and the Study Area

MSEC has been engaged by WCPL to:

- provide subsidence predictions for WYLW21 to WYLW24, including the cumulative subsidence due to the adjacent existing and approved longwalls;
- compare the predictions with the values presented in the SBEUM Modification Application and Report No. MSEC848;
- update the subsidence predictions for the natural and built features in the mining area;
- review and update the impact assessments, in conjunction with other specialist consultants, for each of these natural and built features; and
- recommend management strategies and monitoring for WYLW21 to WYLW24.

This report has been prepared to support the Extraction Plan Application for WYLW21 to WYLW24 at the SBEUM which will be submitted to the Department of Planning, Infrastructure and Environment (DPIE).

Chapter 2 defines the Study Area and provides a summary of the natural and built features located 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 existing, approved and proposed longwalls.

Chapter 4 provides the maximum predicted subsidence effects due to the mining of the proposed WYLW21 to WYLW24.

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

1.2. Mining geometry

The layout of WYLW21 to WYLW24 is shown in Drawings Nos. MSEC1080-01 and MSEC1080-02. A summary of the dimensions for these longwalls is provided in Table 1.1.

Table 1.1 Mining geometry of WYLW21 to WYLW24

Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
WYLW21	1505	261	26
WYLW22	1705	261	30
WYLW23	1870	261	29
WYLW24	1705	261	21

The widths of the longwall extraction faces (i.e. excluding the first workings) are 250 m. The lengths of extraction (i.e. excluding the installation heading) are approximately 8.5 m less than the overall void lengths provided in the above table. The longwalls will be extracted from the south-west towards the north-east (i.e. towards the Montrose Open Cut Pit).

1.3. Surface and seam levels

The natural surface and the levels of the Whybrow Seam are illustrated along Cross-sections 1 to 3 in Fig. 1.3 to Fig. 1.5 below. The locations of these sections are shown in Drawings Nos. MSEC1080-03 to MSEC1080-06. The existing and approved longwalls in the Whybrow and Wambo Seams are shown as the cyan outlines and the proposed WYLW21 to WYLW24 are shown as the blue outlines.

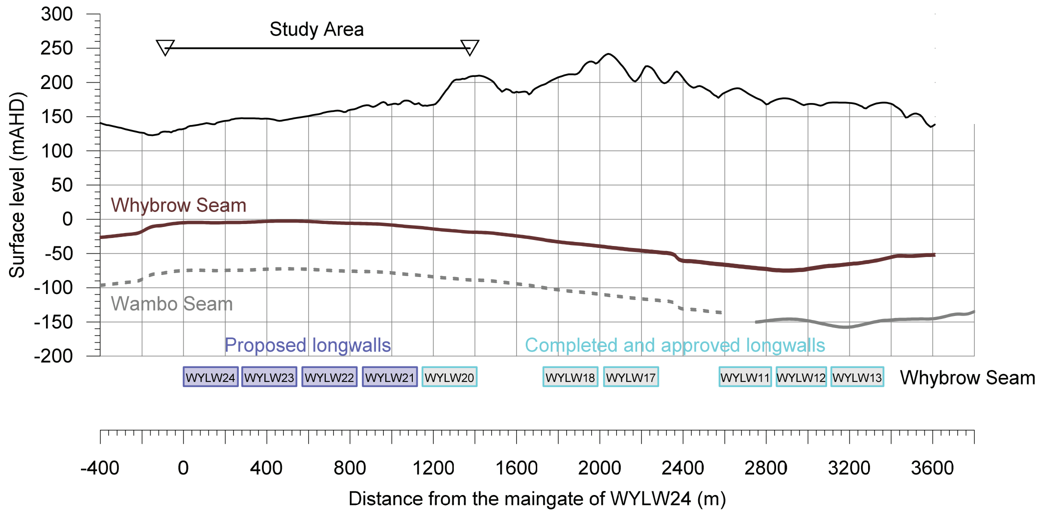


Fig. 1.3 Surface and seam levels along Cross-section 1 near the longwall commencing ends

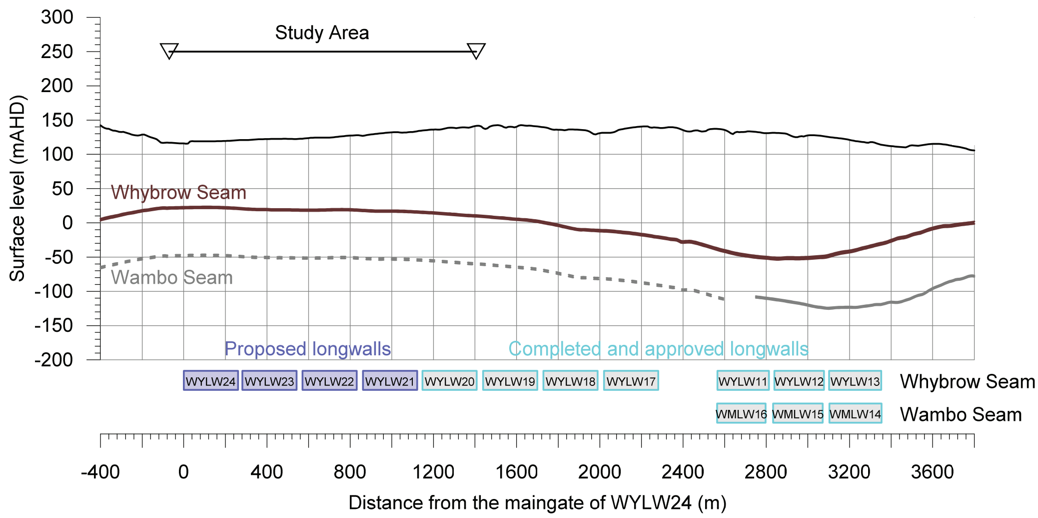


Fig. 1.4 Surface and seam levels along Cross-section 2 near the mid-points of the longwalls

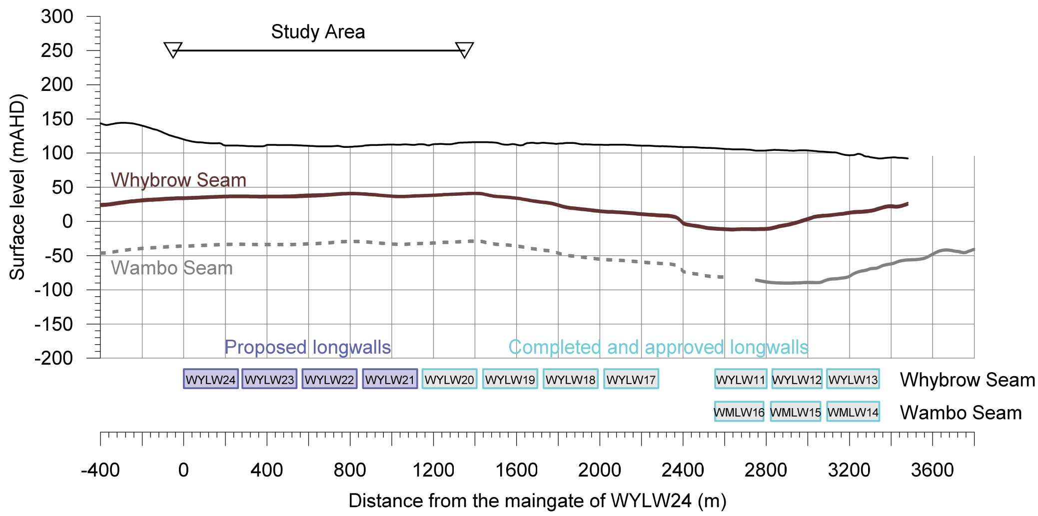


Fig. 1.5 Surface and seam levels along Cross-section 3 near the longwall finishing ends

The surface level contours are shown in Drawing No. MSEC1080-03. The major natural topographical feature in the area is the Wollemi Escarpment, which is located to the south-west and to the west of the proposed longwalls. The Montrose Open Cut Pit is located to the north-east of the longwalls.

The surface levels directly above the proposed longwalls vary from a high point of 255 m above Australian Height Datum (mAHD) above the commencing (i.e. south-western) end of WYLW22, to a low point of 110 mAHD above the finishing (i.e. north-eastern) end of WYLW21.

The seam floor contours, seam thickness contours and depth of cover contours for the Whybrow Seam are shown in Drawings Nos. MSEC1080-04, MSEC1080-05, and MSEC1080-06, respectively. The contours are based on the latest seam information provided by WCPL.

The depths of cover to the Whybrow Seam directly above the proposed longwalls vary between a minimum of 60 m above the finishing (i.e. north-eastern) ends of WYLW21 and WYLW22 and a maximum of 290 m above the commencing (i.e. south-western) ends of WYLW22 and WYLW23.

The seam floor within the mining area generally dips from the north-east towards the south-west, with the seam being shallowest at the Montrose Open Cut Pit and deepest beneath the escarpment. The average dip of the seam within the extents of the proposed longwalls is around 6 %, or 1 in 17.

The thickness of the Whybrow Seam within the extents of the proposed longwalls varies between 2.4 m and 3.6 m. The proposed mining heights for the longwalls are illustrated in Drawing No. MSEC1080-05 and vary from less than 2.8 up to 3.0 m.

1.4. Geological details

The South Bates Underground Mine lies in the Hunter Coalfield, within the Northern Sydney Basin. A typical stratigraphic section of the Hunter Coalfield, reproduced from the Department of Mineral Resources (DMR) *Hunter Coalfield Regional 1:100 000 Geology Map*, is shown in Table 1.2 (DMR, 1993).

The Whybrow Seam lies within the Jerrys Plains Subgroup of the Wittingham Coal Measures. The rocks of the Wittingham Coal Measures mainly comprise frequently bedded sandstones and siltstones, but also include isolated thinner beds of conglomerate and tuff. The formations are generally less than 10 m in thickness.

The Denman Formation marks the top of the Wittingham Coal Measures, which is overlain by the Newcastle Coal Measures. The Newcastle Coal Measures comprise the Watts Sandstone and the Apple Tree Flat, Horseshoe Creek, Doyles Creek and Glen Gallic Subgroups.

Table 1.2 Stratigraphy of the Hunter Coalfield (DMR, 1993)

<table>
<tr><th>Supergroup</th><th>Group</th><th>Subgroup</th><th>Formation</th><th>Seam</th></tr>
<tr><td rowspan="36">Singleton Supergroup</td><td>Narrabeen Group</td><td colspan="3">Widden Brook Conglomerate</td></tr>
<tr><td rowspan="12">Newcastle Coal Measures</td><td rowspan="3">Glen Gallic Subgroup</td><td colspan="2">Greigs Creek Coal</td></tr>
<tr><td colspan="2">Redmanvale Creek Formation</td></tr>
<tr><td colspan="2">Dights Creek Coal</td></tr>
<tr><td rowspan="2">Doyles Creek Subgroup</td><td colspan="2">Waterfall Gully Formation</td></tr>
<tr><td colspan="2">Pinegrove Formation</td></tr>
<tr><td rowspan="4">Horseshoe Creek Subgroup</td><td colspan="2">Lucernia Coal</td></tr>
<tr><td colspan="2">Strathmore Formation</td></tr>
<tr><td colspan="2">Alcheringa Coal</td></tr>
<tr><td colspan="2">Clifford Formation</td></tr>
<tr><td rowspan="2">Appletree Flat Subgroup</td><td colspan="2">Charlton Formation</td></tr>
<tr><td colspan="2">Abbey Green Coal</td></tr>
<tr><td colspan="3">Watts Sandstone</td></tr>
<tr><td rowspan="23">Wittingham Coal Measures</td><td colspan="3">Denman Formation</td></tr>
<tr><td rowspan="18">Jerrys Plains Subgroup</td><td>Mount Leonard Formation</td><td>Whybrow Seam</td></tr>
<tr><td colspan="2">Althorpe Formation</td></tr>
<tr><td rowspan="4">Malabar Formation</td><td>Redbank Creek Seam</td></tr>
<tr><td>Wambo Seam</td></tr>
<tr><td>Whynot Seam</td></tr>
<tr><td>Blakefield Seam</td></tr>
<tr><td rowspan="2">Mount Ogilvie Formation</td><td>Glen Munro Seam</td></tr>
<tr><td>Woodlands Hill Seam</td></tr>
<tr><td colspan="2">Milbrodale Formation</td></tr>
<tr><td rowspan="3">Mount Thorley Formation</td><td>Arrowfield Seam</td></tr>
<tr><td>Bowfield Seam</td></tr>
<tr><td>Warkworth Seam</td></tr>
<tr><td colspan="2">Fairford Formation</td></tr>
<tr><td rowspan="5">Burnamwood Formation</td><td>Mount Arthur Seam</td></tr>
<tr><td>Piercefield Seam</td></tr>
<tr><td>Vaux Seam</td></tr>
<tr><td>Broonie Seam</td></tr>
<tr><td>Bayswater Seam</td></tr>
<tr><td colspan="3">Archerfield Sandstone</td></tr>
<tr><td rowspan="3">Vane Subgroup</td><td colspan="2">Bulga Formation</td></tr>
<tr><td colspan="2">Foybrook Formation</td></tr>
<tr><td colspan="2">Saltwater Creek Formation</td></tr>
</table>

WCPL provided the logs for typical drill holes located within the proposed mining area, which are shown in Drawing No. MSEC1080-09. The geological section for drill hole UG139 is provided in Table 1.3.

The overburden of the Whybrow Seam predominately comprises of interbedded sandstone and siltstone layers, with minor claystone, mudstone, shale, tuffaceous and coal layers. The immediate roof of the Whybrow Seam comprises a 22 m thick claystone layer. The immediate floor of the seam comprises interbedded claystone, sandstone, siderite and siltstone.

There are no massive sandstone or conglomerate units within the overburden. The largest is a 17 m thick sandstone layer located approximately 30 m above the Whybrow Seam. Otherwise, the thicknesses of the formations within the overburden are typically less than 10 m. Other boreholes in the vicinity of the proposed mining area indicate the presence of other larger sandstone units with thicknesses up to 20 m in the lower part of the overburden.

No adjustment factors have been applied in the subsidence prediction model for any massive strata units or for softer floor conditions, as the proposed longwalls are supercritical in width and therefore are predicted to achieve the maximum subsidence for single-seam mining conditions.

Table 1.3 Geological section of Drill Hole UG139

Depth (m)	Thickness (m)	Lithology
0 ~ 0.5	0.5	Soil
0.5 ~ 9	8.5	Clay
9 ~ 15.5	6.5	Sandstone
15.5 ~ 17	1.5	Siltstone
17 ~ 18	1	Sandstone
18 ~ 20	2	Sandstone (70 %) and Siltstone (30 %)
20 ~ 21	1	Sandstone (70 %) and Claystone (30 %)
21 ~ 22.5	1.5	Claystone
22.5 ~ 24	1.5	Sandstone (70 %) and Siltstone (30 %)
24 ~ 25	1	Sandstone
25 ~ 26	1	Claystone
26 ~ 49	23	Sandstone
49 ~ 54	5	Sandstone (80 %) and Siltstone (20 %)
54 ~ 57	3	Sandstone
57 ~ 62	5	Siltstone (70 %) and Sandstone (30 %)
62 ~ 64	2	Siltstone
64 ~ 81	17	Sandstone
81 ~ 82	1	Siltstone
82 ~ 87	5	Siltstone (80 %) and Sandstone (20 %)
87 ~ 88.5	1.5	Siltstone
88.5 ~ 110.5	22	Claystone
110.5 ~ 113	2.5	Coal (Whybrow Seam)
113 ~ 114	1	Claystone
114 ~ 115	1	Sandstone (70 %) and Claystone (30 %)
115 ~ 116	1	Sandstone (50 %) and Siderite (50 %)
116 ~ 117	1	Sandstone
117 ~ 122	5	Sandstone (70 %) and Siltstone (30 %)
122 ~ 127	5	Sandstone

The geological features that have been identified at seam level are shown in Drawing No. MSEC1080-07. The largest structure in the area is the *Redmanvale Fault* which is located south-west of the proposed longwalls. This normal fault has a strike of approximately 325° and dips towards the north-east. The dip angle of normal faults is typically in the range of 70° and 85°. The throw of the Redmanvale Fault is greater than 20 m.

The distances of the Redmanvale Fault (at seam level) from the commencing ends of the proposed longwalls are 540 m for WYLW21, 270 m for WYLW22, 110 m for WYLW23 and 310 m for WYLW24. Two sections have been taken through the Redmanvale Fault and the commencing (i.e. south-western) ends of WYLW21 and WYLW23 and these are shown in Fig. 1.6 and Fig. 1.7, respectively. The assumed fault plane is based on a dip angle of 70°.

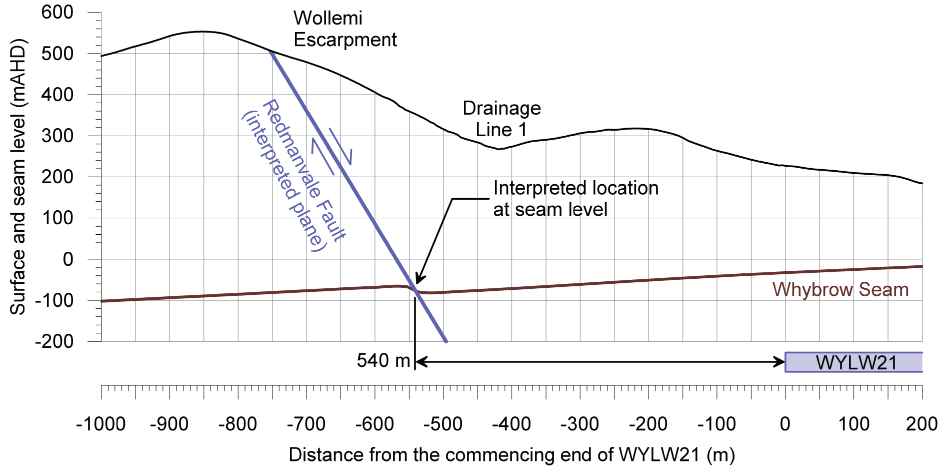


Fig. 1.6 Section through the Redmanvale Fault and the commencing end of WYLW21

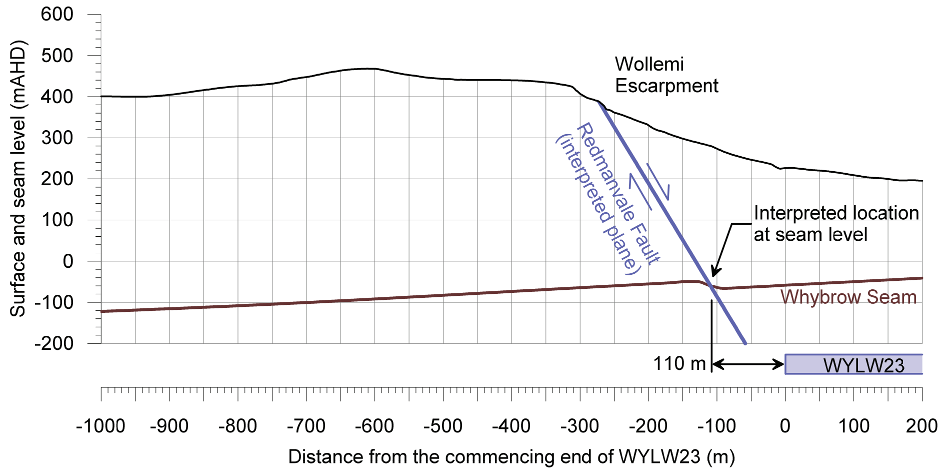


Fig. 1.7 Section through the Redmanvale Fault and the commencing end of WYLW23

The surface expression of the Redmanvale Fault appears to be associated with the Wollemi Escarpment adjacent to the proposed WYLW21 to WYLW24. Further to the south, the surface expression adjacent to the earlier WYLW17 to WYLW20 appears to be associated with a tributary to Stony Creek further to the west of the escarpment.

The assumed surface expression of the Redmanvale Fault, based on a 70° dip, is located at a horizontal distance varying between 270 m and 750 m from the proposed WYLW21 to WYLW24. The component of vertical subsidence at the assumed surface expression of the fault is expected to be negligible (i.e. not measurable) due to the extraction of the proposed longwalls. The potential for differential vertical subsidence to develop at the assumed surface expression of the fault is considered to be very low, due to the footwall block restraining the vertical movement of the hanging block and due to the low levels of predicted vertical subsidence.

The absolute horizontal movements at the assumed surface expression of the fault are predicted to be in the order of 50 mm to 100 mm due to the extraction of the proposed WYLW21 to WYLW24. These far-field horizontal movements are due to the redistribution of horizontal stress and are directed towards the mining area.

The potential for far-field horizontal movements has been reduced as the horizontal in situ stress has already been redistributed due to the mining in the Montrose Open Cut Pit on the north-eastern side of the longwalls. Also, normal faults are formed through tension in the strata and, therefore, there is likely to be a reduced compressive stress across this fault plane.

The potential for mining-induced shear movements across the fault is expected to be very low due to the fault being located outside of the mining area, the dip direction of the fault (i.e. towards the mining area), the dip angle of the fault (i.e. greater than 70°) and the direction of the far-field horizontal movements, with the footwall block pushing against the hanging block, with the resultant vertical action opposing gravity. The potential for irregular ground movements at the surface, therefore, is considered to be very low.

The differential movement at the assumed surface expression of the fault due to the far-field horizontal movements is expected to be negligible (i.e. not measurable) due to the extraction of the proposed WYLW21 to WYLW24. The potential for impacts on the Wollemi Escarpment, therefore, is considered to be very low as it is parallel to the alignment of the fault and there is low potential for differential movements.

No major faults have been identified within the extents of the proposed WYLW21 to WYLW24. Minor faults have been identified within the mining area with throws typically up to 1 m. A series of faults cross the commencing (i.e. south-western) ends of WYLW19 and WYLW20 and the finishing (i.e. north-eastern) ends of WYLW18 to WYLW21. These faults could extend through the proposed WYLW21 to WYLW24. The faults within the proposed mining area will be better defined through ongoing investigations and the development of first workings.

No adjustment factors have been applied in the subsidence prediction model for the minor faults within the mining area, as the proposed longwalls are generally supercritical in width and, therefore, they are predicted to achieve the maximum subsidence for single-seam mining conditions. Increased subsidence has not been observed in the locations of similar minor faults during the mining of longwalls at the South Bates Underground Mine and the SBEUM.

The surface lithology in the area can be seen in Fig. 1.8, which shows the longwalls and the Study Area overlaid on *Geological Map of Doyles Creek 9032-1-N*, which was published by the DMR (1988).

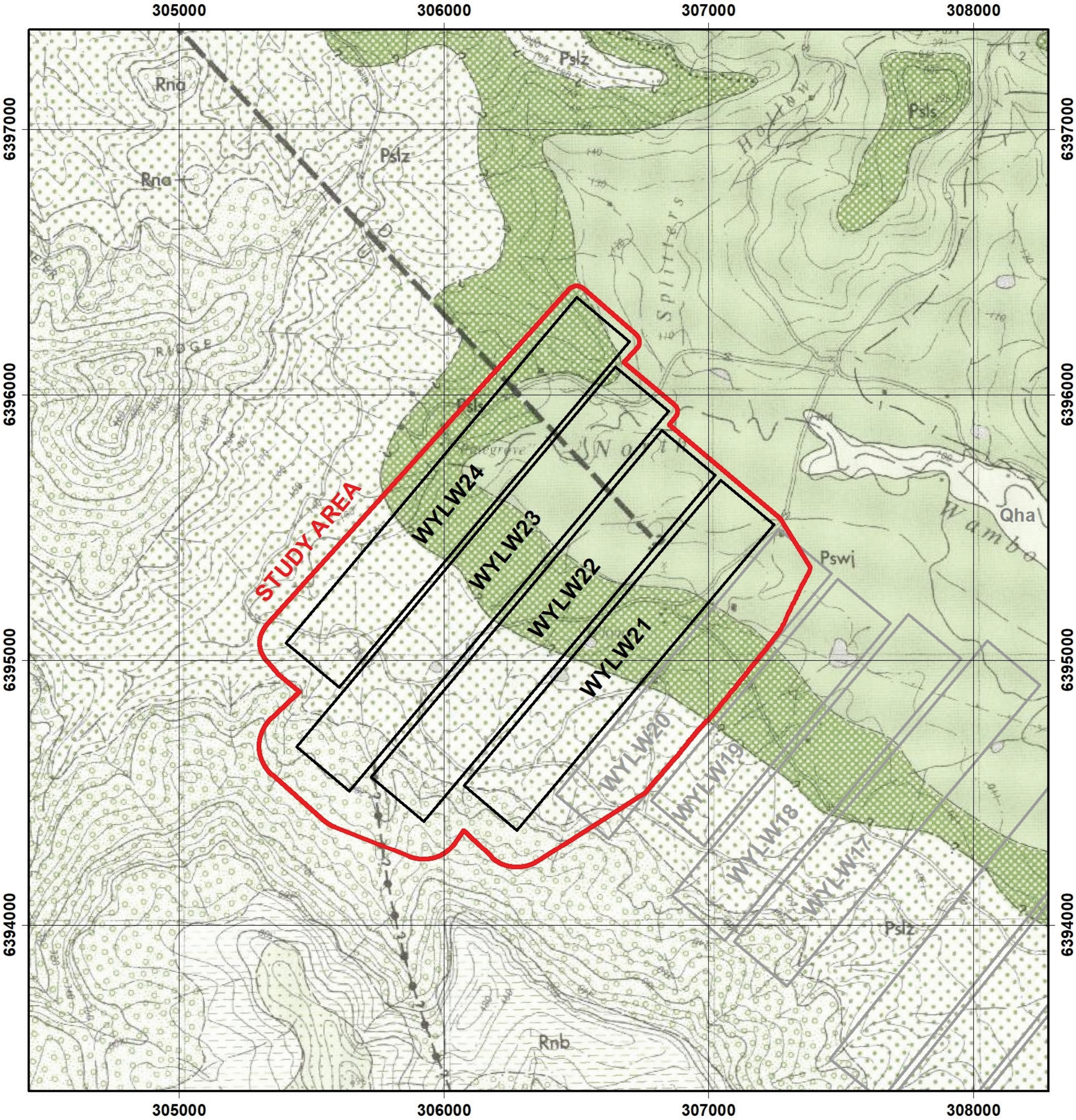


Fig. 1.8 WYLW21 to WYLW24 overlaid on Geological Map Doyles Creek 9032-1-N

It can be seen from Fig. 1.8, that the surface lithology generally comprises the Jerrys Plains Subgroup of the Wittingham Coal Measures (Pswj) above the north-eastern ends of the proposed WYLW21 to WYLW24, the Watts Sandstone (Psls) above the middle parts of the proposed longwalls and the Newcastle Coal Measures (Pslz) and the Widden Brook Conglomerate (Rna) above the south-western ends of the proposed longwalls.

The surface lithology adjacent to the north-eastern ends of the proposed longwalls has been modified by the construction of the North Wambo Creek Diversion, which included excavation and the placement of backfill. It is not expected that the predicted subsidence movements in this location would be affected by these surface earthworks.

2.1. Definition of the Study Area

The Study Area for this assessment is defined as the surface area that is likely to be affected by the mining of the proposed WYLW21 to WYLW24 in the Whybrow Seam. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:

- the 26.5° angle of draw line from the extents of the proposed WYLW21 to WYLW24; and
- the predicted limit of vertical subsidence, taken as the 20 mm subsidence contour resulting from the extraction of the proposed WYLW21 to WYLW24.

The 26.5° angle of draw line is described as the "*surface area defined by the cover depths, angle of draw of 26.5 degrees and the limit of the proposed extraction area in mining leases for all other NSW Coalfields*" (i.e. other than the Southern Coalfield), as stated in Section 6.2 of the Guideline for Applications for Subsidence Management Approvals (DMR, 2003).

The depths of cover contours for the Whybrow Seam are shown in Drawing No. MSEC1080-06. As shown in this drawing, the depths of cover directly above the proposed longwalls vary between 60 m and 290 m. The 26.5° angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 30 m and 145 m around the limits of the extraction areas, based on the depths of cover around the perimeters of the proposed longwalls.

The predicted limit of vertical subsidence, taken as the predicted 20 mm subsidence contour due to the extraction of the proposed WYLW21 to WYLW24, has been determined using the Incremental Profile Method (IPM), which is described in Chapter 3. The predicted 20 mm subsidence contour is located outside the 26.5° angle of draw above the approved WYLW20, but elsewhere it is located inside the angle of draw.

A line has therefore been drawn defining the Study Area, based upon the 26.5° angle of draw line and the predicted 20 mm subsidence contour, whichever is furthest from the proposed WYLW21 to WYLW24, and is shown in Drawings Nos. MSEC1080-01 to MSEC1080-09.

There are areas that lie outside the Study Area that are expected to experience either far-field movements, or valley related movements. The surface features which could be sensitive to such movements have been identified and have been included in the assessments provided in this report.

2.2. Overview of the natural and built features within the Study Area

A number of the natural and built features within the Study Area can be seen in the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA), numbered Doyles Creek 9032-1-N. The proposed longwalls and the Study Area have been overlaid on an extract of this CMA map in Fig. 2.1.

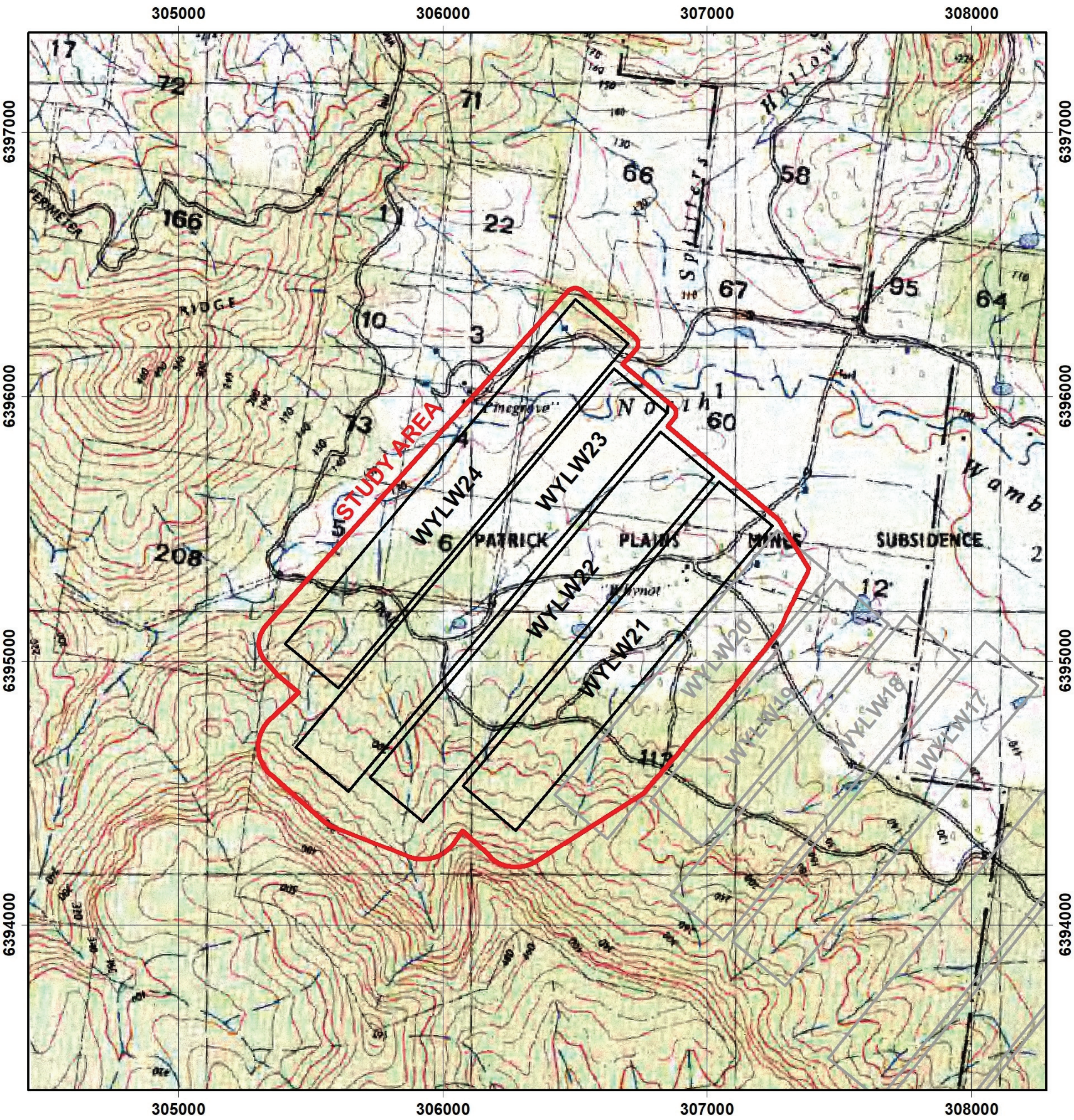


Fig. 2.1 WYLW21 to WYLW24 overlaid on CMA Map No. Doyles Creek 9032-1-N

A summary of the natural and built features within the Study Area is provided in Table 2.1. The locations of these features are shown in Drawings Nos. MSEC1080-08 and MSEC1080-09. The descriptions, predictions and impact assessments for each of the natural and built features are provided in Chapters 5 and 6.

Table 2.1 Natural and Built Features within the Study Area

Item	Within Study Area	Section Number
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	×	
Streams	✓	5.2
Aquifers or Known Groundwater Resources	×	
Springs or Groundwater Seeps	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.5 & 5.6
Steep Slopes	✓	5.7
Escarpments	✓	5.4
Land Prone to Flooding or Inundation	×	5.8
Swamps or Wetlands	×	
Water Related Ecosystems	✓	5.9
Threatened or Protected Species	✓	5.10
Lands Defined as Critical Habitat	×	
National Parks	✓	5.11
State Forests	×	
State Recreation or Conservation Areas	×	
Natural Vegetation	✓	5.12
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	×	
Roads (All Types)	✓	6.1.1
Bridges	×	
Tunnels	×	
Culverts	✓	6.1.1
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	×	
Telecommunication Lines or Associated Plants	×	
Water Tanks, Water or Sewage Treatment Works	×	
Dams, Reservoirs or Associated Works	×	
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	×	
Shopping Centres	×	
Community Centres	×	
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

Item	Within Study Area	Section Number
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	×	6.3.1
Farm Buildings or Sheds	✓	6.7
Tanks	✓	6.7
Gas or Fuel Storages	×	
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	✓	6.3.2
Farm Dams	✓	6.3.3
Wells or Bores	✓	6.3.4
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	✓	6.4.1
Mine Related Infrastructure Including Exploration Bores and Gas Wells	✓	6.4.2
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL SIGNIFICANCE	✓	6.5
AREAS OF HISTORICAL SIGNIFICANCE	×	
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.6
RESIDENTIAL ESTABLISHMENTS		
Houses	✓	6.7
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

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

3.1. Introduction

The following sections provide overviews of conventional and non-conventional mine subsidence effects and the methods that have been used to predict these movements. Further information is also provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

3.2. Overview of conventional subsidence 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 4.5.

3.4. Overview of non-conventional subsidence movements

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

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

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

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

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

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

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

Even though it may be possible to explain most observed non-conventional ground movements, there remains 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, but less so in the Hunter and Newcastle Coalfields. 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.

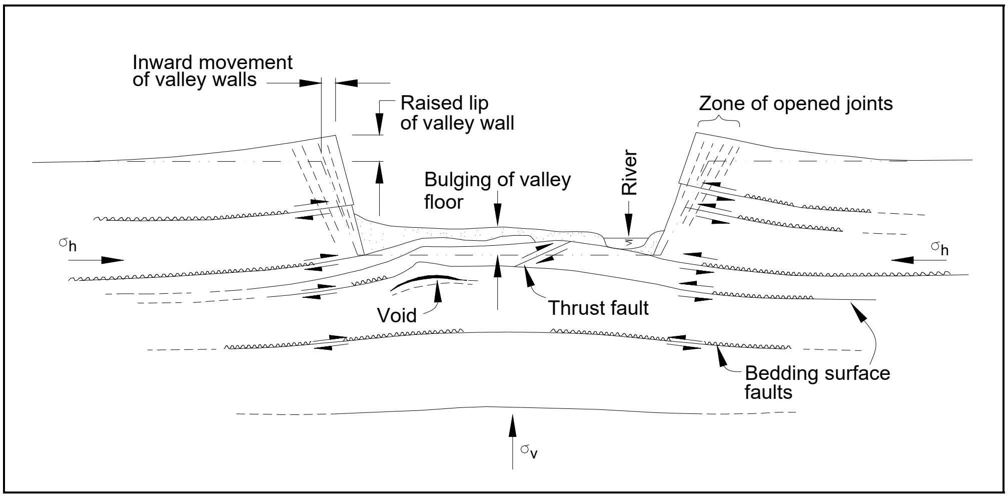


Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

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 effects for the streams have been determined using the empirical method outlined in Australian Coal Association Research Program (ACARP) Research Project No. C9067 (Waddington and Kay, 2002), referred to as the 2002 ACARP method. The predicted compressive strains due to these valley related effects have been determined from the analysis of ground monitoring data from the NSW coalfields.

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 Incremental Profile Method (IPM) was initially developed by Waddington Kay and Associates, now known as MSEC, as part of a study, in 1994 to assess the impacts of subsidence on particular surface infrastructure over a proposed series of longwall panels at Appin Colliery. The method evolved following detailed analyses of subsidence monitoring data from the Southern Coalfield, which was then extended to include detailed subsidence monitoring data from the Newcastle, Hunter and Western Coalfields.

The review of the detailed ground monitoring data from the NSW coalfields showed that whilst the final subsidence profiles measured over a series of longwalls were irregular, the observed incremental subsidence profiles due to the extraction of individual longwalls were consistent in both magnitude and shape and varied according to local geology, depth of cover, panel width, seam thickness, the extent of adjacent previous mining, the pillar width and stability of the chain pillar and a time-related subsidence component.

MSEC developed a series of subsidence prediction curves for the Newcastle and Hunter Coalfields, between 1996 and 1998, after receiving extensive subsidence monitoring data from Centennial Coal for the Cooranbong Life Extension Project (Waddington and Kay, 1998). The subsidence monitoring data from many collieries in the Newcastle and Hunter Coalfields were reviewed and it was found that the incremental subsidence profiles resulting from the extraction of individual longwalls were consistent in shape and magnitude where the mining geometries and overburden geologies were similar.

Since this time, extensive monitoring data has been gathered from mines in the Southern, Newcastle, Hunter and Western Coalfields of NSW and from the Bowen Basin in Queensland, including: Angus Place, Appin, Awaba, Baal Bone, Bellambi, Beltana, Blakefield South, Bulga, Bulli, Burwood, Carborough Downs, Chain Valley, Clarence, Coalcliff, Cook, Cooranbong, Cordeaux, Corrimal, Cumnock, Dartbrook, Delta, Dendrobium, Donaldson, Eastern Main, Ellalong, Elouera, Fernbrook, Glennies Creek, Grasstree, Gretley, Invincible, John Darling, Kemira, Kestrel, Lambton, Liddell, Mandalong, Metropolitan, Moranbah North, Mt. Kembla, Munmorah, Nardell, Newpac, Newstan, Newvale, Newvale 2, NRE Wongawilli, Oaky Creek, Ravensworth, South Bulga, South Bulli, Springvale, Stockton Borehole, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, United, West Cliff, West Wallsend, and Wyee.

Based on the extensive empirical data, MSEC has developed standard subsidence prediction curves for the Southern, Newcastle and Hunter Coalfields. The prediction curves can then be further refined, for the local geology and local conditions, based on the available monitoring data from the area. Discussions on the calibration of the IPM for the proposed longwalls are provided in Section 3.6.

The prediction of subsidence is a three stage process where, first, the magnitude of each increment is calculated, then, the shape of each incremental profile is determined and, finally, the total subsidence profile is derived by adding the incremental profiles from each longwall in the series. In this way, subsidence predictions can be made anywhere above or outside the extracted longwalls, based on the local surface and seam information.

For longwalls in the Newcastle and Hunter Coalfields, the maximum predicted incremental subsidence is initially determined, using the IPM subsidence prediction curves for a single isolated panel, based on the longwall void width (W) and the depth of cover (H). The incremental subsidence is then increased, using the IPM subsidence prediction curves for multiple panels, based on the longwall series, panel width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H). In this way, the influence of the panel width (W), depth of cover (H), as well as panel width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H) are each considered.

The shapes of the incremental subsidence profiles are then determined using the large empirical database of observed incremental subsidence profiles from the Hunter Coalfield. The profile shapes are derived from the normalised subsidence profiles for monitoring lines where the mining geometry and overburden geology are similar to that for the proposed longwalls. The profile shapes can be further refined, based on local monitoring data, which is discussed further in Section 3.6.

Finally, the total subsidence profiles resulting from the series of longwalls are derived by adding the predicted incremental profiles from each of the longwalls. Comparisons of the predicted total subsidence profiles, obtained using the IPM, with observed profiles indicates that the method provides reasonable, if not slightly conservative, predictions where the mining geometry and overburden geology are within the range of the empirical database. The method can also be further tailored to local conditions where observed monitoring data is available close to the mining area.

3.6. Calibration of the IPM

There are no existing workings located above or below the proposed WYLW21 to WYLW24 (i.e. single-seam mining conditions). The depths of cover to the Whybrow Seam directly above these longwalls vary between 60 m and 290 m. The depths of cover are shallowest above the finishing (i.e. north-eastern) ends and are greatest above the commencing (i.e. south-western) ends of the proposed longwalls.

The longwall width-to-depth ratios vary between 0.9 at the longwall commencing ends and greater than 4.0 at the longwall finishing ends. The magnitudes of subsidence and the shapes of the subsidence profiles, therefore, will vary considerably over the lengths of these longwalls.

In the north-eastern part of the mining area, the width-to-depth ratios are greater than 1.4 and, therefore, the longwalls are supercritical in width. The maximum predicted subsidence is expected to be the maximum achievable in the Hunter Coalfield for single-seam mining conditions, which has been found to be 60 % to 65 % of the extracted seam thickness. It has been identified, however, that the measured subsidence varies greatly from point to point, at these very shallow depths of cover, as the result of variations in the overburden geology.

In the south-western part of the mining area, the width-to-depth ratios are less than 1.4 and, therefore, the longwalls are subcritical in width. As a result, the predicted subsidence is expected to be less than the maximum achievable in the Hunter Coalfield and, hence, less than that predicted in the north-eastern part of the mining area. Similarly, the predicted tilts, curvatures and strains in the south-western part of the mining area are less than those predicted in the north-eastern part of the mining area.

The IPM was previously calibrated to local conditions using ground monitoring data from the Wambo Coal Mine and from other nearby collieries. The available monitoring data included that from WYLW11 at the South Bates Underground Mine, Wambo Longwalls 1 to 6 at the North Wambo Underground Mine and above longwalls with width-to-depth ratios ranging between 0.7 and 3.0 from the Hunter Coalfield. The discussions on the calibration of the IPM are provided in Section 3.3 of Report No. MSEC848.

Since that time, further ground monitoring data have been gathered during the extraction of WYLW11 to WYLW13 (i.e. single-seam mining conditions) at the South Bates Underground Mine. The monitoring comprised three ground survey lines (7XL-Line, CL11B-Line and CL13B-Line) and LiDAR surveys. Comparisons between the measured and predicted movements for WYLW11 to WYLW13 are provided in the subsidence summary reviews in Reports Nos. MSEC866, MSEC886 and MSEC916.

Ground monitoring data have also been gathered during the extraction of WYLW17 at the SBEUM. The monitoring comprises two ground survey lines (8XL-Line and CL17B-Line) and Light Detecting and Ranging (LiDAR) surveys. Comparisons between the measured and predicted movements for WYLW17 are provided in the subsidence summary review in Report No. MSEC1007.

The measured and predicted vertical subsidence for the combined 7XL-Line and 8XL-Line, due to the extraction of WYLW11 to WYLW13 and WYLW17, are illustrated in Fig. 3.2. The measured profile of vertical subsidence (i.e. green line) reasonably matches the predicted profile (i.e. red line).

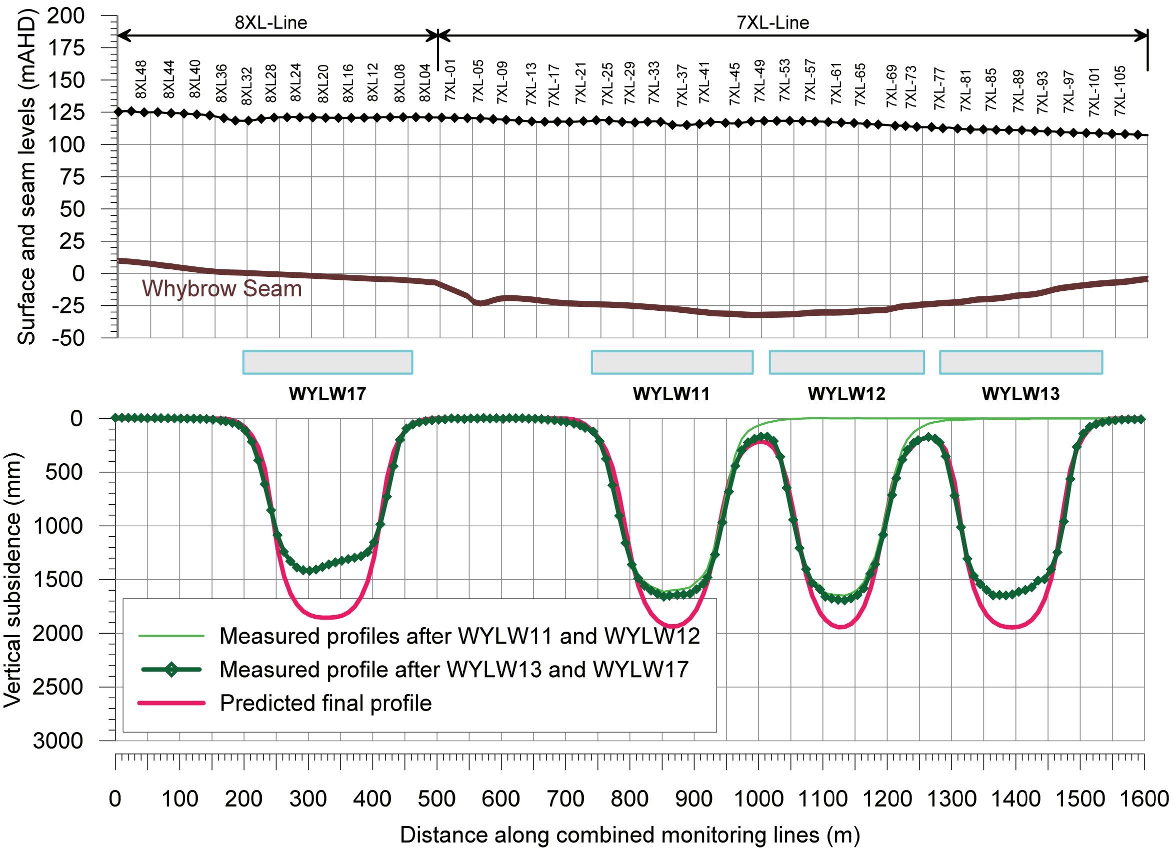


Fig. 3.2 Measured and predicted vertical subsidence along the 7XL-Line and 8XL-Line due to the extraction of WYLW11 to WYLW13 at the South Bates Underground Mine and WYLW17 at the South Bates Extension Underground Mine

The maximum measured values of vertical subsidence along the 7XL-Line and 8XL-Line are less than the maximum predicted values. The ratio of the maximum measured to maximum predicted vertical subsidence are 0.86 above WYLW11, 0.87 above WYLW12, 0.85 above WYLW13 and 0.77 above WYLW17. The values of the measured vertical subsidence above the chain pillars are similar to the predicted values.

The measured profile of tilt (not shown) reasonably matches the predicted profile. The measured profile of curvature (also not shown) is irregular (i.e. more erratic) due to survey tolerance, localised irregular ground movements and possibly due to disturbed survey marks. The measured zones of hogging curvature and sagging curvature reasonably matched the predicted zones. The maximum measured tilt and curvatures are similar to the maximum predicted values.

The observations for the other ground monitoring lines above WYLW11 to WYLW13 and WYLW17 are similar to that described above for the 7XL-Line and 8XL-Line. It is considered, therefore, that the IPM provides predictions that are consistent with the measurements and that it is not necessary to re-calibrate the model based on the monitoring data for the Whybrow Seam.

4.1. Introduction

This chapter provides the maximum predicted conventional subsidence effects due to the mining of the proposed WYLW21 to WYLW24 in the Whybrow Seam. The predicted subsidence effects and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

The predicted values of vertical subsidence, tilt and curvature have been obtained using the standard IPM for the Hunter Coalfield, which is described in Section 3.6. The predicted strains have been determined by analysing the strains measured at the Wambo Coal Mine, and other NSW collieries, where the longwall width-to-depth ratios and extraction heights are similar to those for the proposed WYLW21 to WYLW24.

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 mining of WYLW21 to WYLW24 is provided in Table 4.1. The incremental values represent the maximum predicted additional movements due to the mining of each of the proposed longwalls.

Table 4.1 Maximum predicted incremental vertical subsidence, tilt and curvature due to the mining of each of WYLW21 to WYLW24

Due to longwall	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
WYLW21	1750	70	> 3.0	> 3.0
WYLW22	1850	80	> 3.0	> 3.0
WYLW23	1850	75	> 3.0	> 3.0
WYLW24	1850	80	> 3.0	> 3.0

The magnitudes of the predicted subsidence effects vary considerably across the mining area due to the wide range of depths of cover above the Whybrow Seam. The maximum predicted subsidence effects occur at the finishing (i.e. north-eastern) ends of WYLW21 to WYLW24, where the depths of cover are the shallowest.

The maximum predicted incremental curvatures for each of the proposed longwalls are greater than 3.0 km^{-1} (i.e. minimum radius of curvature of less than 0.3 km). These curvatures are very localised and therefore do not necessarily represent the overall (i.e. macro) ground movements. The magnitudes of the localised curvatures greater than 3.0 km^{-1} become less meaningful and, therefore, the specific values have not been presented.

The predicted total vertical subsidence after the extraction of each of WYLW21 to WYLW24 are shown in Drawings Nos. MSEC1082-10 to MSEC1080-13, respectively. The contours include the accumulated movements due to the mining of the approved WYLW17 to WYLW20.

A summary of the maximum predicted values of total conventional vertical subsidence, tilt and curvature is provided in Table 4.2. The total values represent the maximum predicted accumulated movements within the Study Area due to the extraction of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24.

Table 4.2 Maximum predicted total vertical subsidence, tilt and curvature within the Study Area due to the mining of WYLW17 to WYLW24

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})
WYLW21	1750	70	> 3.0	> 3.0
WYLW22	1850	80	> 3.0	> 3.0
WYLW23	1950	80	> 3.0	> 3.0
WYLW24	1950	85	> 3.0	> 3.0

The maximum predicted total vertical subsidence due to the mining of the proposed WYLW21 to WYLW24 is 1950 mm and it represents 65 % of the maximum extraction height of 3.0 m. The maximum predicted subsidence occurs above the finishing (i.e. north-eastern) ends of the proposed WYLW22 to WYLW24.

The maximum predicted total tilt is 85 mm/m (i.e. 8.5 %, or 1 in 12). The maximum predicted total conventional curvature is greater than 3.0 km^{-1} and it represents a minimum radius of curvature of less than 0.3 km. The maximum curvatures are localised and therefore they do not necessarily represent the overall (i.e. macro) ground movements. The magnitudes of the localised curvatures greater than 3.0 km^{-1} become less meaningful and, therefore, the specific values have not been presented.

The predicted conventional subsidence parameters vary across the Study Area as the result of, amongst other factors, variations in the depths of cover and seam thickness. The predicted vertical subsidence varies between the commencing (i.e. south-western) ends and the finishing (i.e. north-eastern) ends of the proposed longwalls, as shown in Drawings Nos. MSEC1080-10 to MSEC1080-13. It can also be inferred from the spacing of the contours shown in these drawings, that the predicted tilts and curvatures also vary over the lengths of the longwalls.

To illustrate this variation, the predicted profiles of vertical subsidence, tilt and curvature have been determined along three prediction lines. The predicted subsidence effects along Prediction Lines 1, 2 and 3 are shown in Figs. C.01, C.02 and C.03, respectively, in Appendix C. The locations of these prediction lines are shown in Drawings Nos. MSEC1080-10 to MSEC1080-13. The predicted profiles after the completion of the existing and approved longwalls are shown as the cyan lines. The predicted profiles after the extraction of each of the proposed longwalls are shown as the blue lines.

4.3. Comparison of the maximum predicted subsidence effects

The predicted subsidence effects for WYLW17 to WYLW25 were originally provided in Report No. MSEC848, which supported the SBEUM Modification Application. The finishing (i.e. north-eastern) ends of WYLW17 to WYLW24 have since been shortened.

A comparison of the maximum predicted total subsidence effects after the extraction of WYLW17 to WYLW24, based on the layouts adopted in Report No. MSEC848 and MSEC1080, is provided in Table 4.3. The values represent the maximum predicted accumulated movements within the Study Area due to the extraction of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24.

Table 4.3 Comparison of maximum predicted total subsidence effects

Layout	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})
SBEUM Modification (Report No. MSEC848)	1950	90	> 3.0	> 3.0
Extraction Plan (Report No. MSEC1080)	1950	85	> 3.0	> 3.0

The maximum predicted total vertical subsidence is 1950 mm, based on each of the layouts, and it represents 65 % of the maximum extraction height of 3.0 m. The maximum predicted vertical subsidence does not change as the longwalls are supercritical in width.

The maximum predicted total tilt, based on the current longwall layout (i.e. Report No. MSEC1080), is slightly less than the maximum predicted value based on the layout adopted in the SBEUM Modification and Report No. MSEC848. The predicted tilt reduces due to the shortened finishing (i.e. north-eastern) ends of WYLW21 to WYLW24, as this increases the minimum depth of cover directly above the proposed longwalls from 50 m to 60 m.

The maximum predicted total hogging and sagging curvatures are greater than 3.0 km^{-1} (i.e. minimum radius of curvature less than 0.3 km) based on both the original and current layouts. While specific values have not been presented, the maximum predicted curvatures reduce due to the shortened finishing ends of WYLW21 to WYLW24 and the associated increased in the minimum depth of cover directly above the proposed longwalls (i.e. from 50 m to 60 m).

The surface area located directly above the proposed WYLW21 to WYLW24 is approximately 190 hectares (ha) based on the current longwall layout (i.e. Report No. MSEC1080) and is approximately 207 ha based on the layout adopted in the SBEUM Modification and Report No. MSEC848. The surface area above the proposed longwalls reduces by approximately 17 ha due to the shortened finishing ends.

The overall levels of potential impact for the natural and built features, based on the current longwall layout (i.e. Report No. MSEC1080), therefore, are similar to but slightly less than those assessed based on the layout adopted in the SBEUM Modification and Report No. MSEC848. The detailed predictions and impact assessments for the natural and built features are provided in Chapters 5 and 6.

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.

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

In the Hunter Coalfield, it has been found that a factor of 10 provides a reasonable relationship between the predicted maximum curvatures and the predicted maximum conventional strains for single-seam conditions. The maximum predicted strains, therefore, are greater than 30 mm/m above the longwall finishing ends.

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

The range of strains above the proposed WYLW21 to WYLW24 has been determined using monitoring data from the previously extracted longwalls in the Hunter and Newcastle Coalfields, where the mining geometry is reasonably similar to those for the proposed longwalls. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains for these proposed longwalls.

The data used in the analysis of measured strains included those resulting from both conventional and non-conventional anomalous movements, but does not include those resulting from valley related effects, which are addressed separately in this report. The strains resulting from damaged or disturbed survey marks have also been excluded.

4.4.1. Distribution of strain at the longwall commencing ends

The depths of cover near the commencing (i.e. south-western) ends of the proposed WYLW21 to WYLW24 typically vary between 200 m and 290 m. The width-to-depth ratios at the longwall commencing ends, therefore, typically range between 0.9 and 1.3.

The measured ground strains have been analysed for monitoring lines from the Hunter and Newcastle Coalfields, where the longwall width-to-depth ratios are between 0.9 and 1.3. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains above the commencing ends of the proposed WYLW21 to WYLW24.

The available monitoring lines have been analysed to extract the maximum tensile and compressive strains that have been measured at any time during mining, for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls. 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.

Histograms of the maximum measured tensile and compressive strains for the survey bays located directly above goaf, for previously extracted longwalls in the Hunter and Newcastle Coalfields having width-to-depth ratios between 0.9 and 1.3, are provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

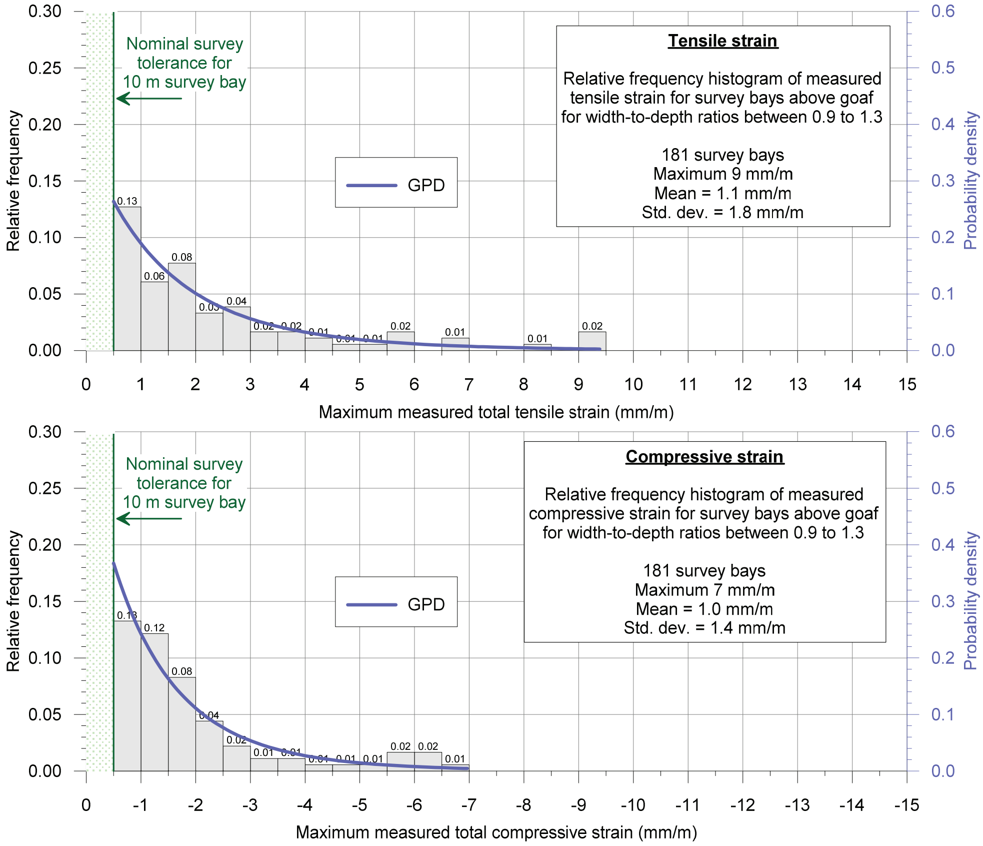


Fig. 4.1 Distributions of the measured maximum tensile and compressive strains for survey bays located above longwalls with width-to-depth ratios between 0.9 and 1.3

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 the 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 strains that the individual survey bays experienced at any time during mining are 5 mm/m tensile and 4 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 10 mm/m tensile and 7 mm/m compressive.

4.4.2. Distribution of strain at the longwall finishing ends

The depths of cover near the longwall finishing (i.e. north-eastern) ends typically vary between 60 m and 100 m. The longwall width-to-depth ratios near the longwall finishing ends, therefore, typically range between 2.6 and greater than 4.0 and, therefore, are supercritical in width.

The measured ground strains have been analysed for monitoring lines from the Hunter and Newcastle Coalfields, where the longwalls have been supercritical in width and where the depths of cover are less than 100 m. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains at the finishing ends of the proposed WYLW21 to WYLW24.

The available monitoring lines have been analysed to extract the maximum tensile and compressive strains that have been measured at any time during mining, for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls. A number of probability distribution functions were fitted to the empirical data. It was found that a GPD provided a good fit to the raw strain data.

Histograms of the maximum measured tensile and compressive strains for the survey bays located directly above goaf, for previously extracted supercritical longwalls in the Hunter and Newcastle Coalfields at depths of cover less than 100 m, are provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

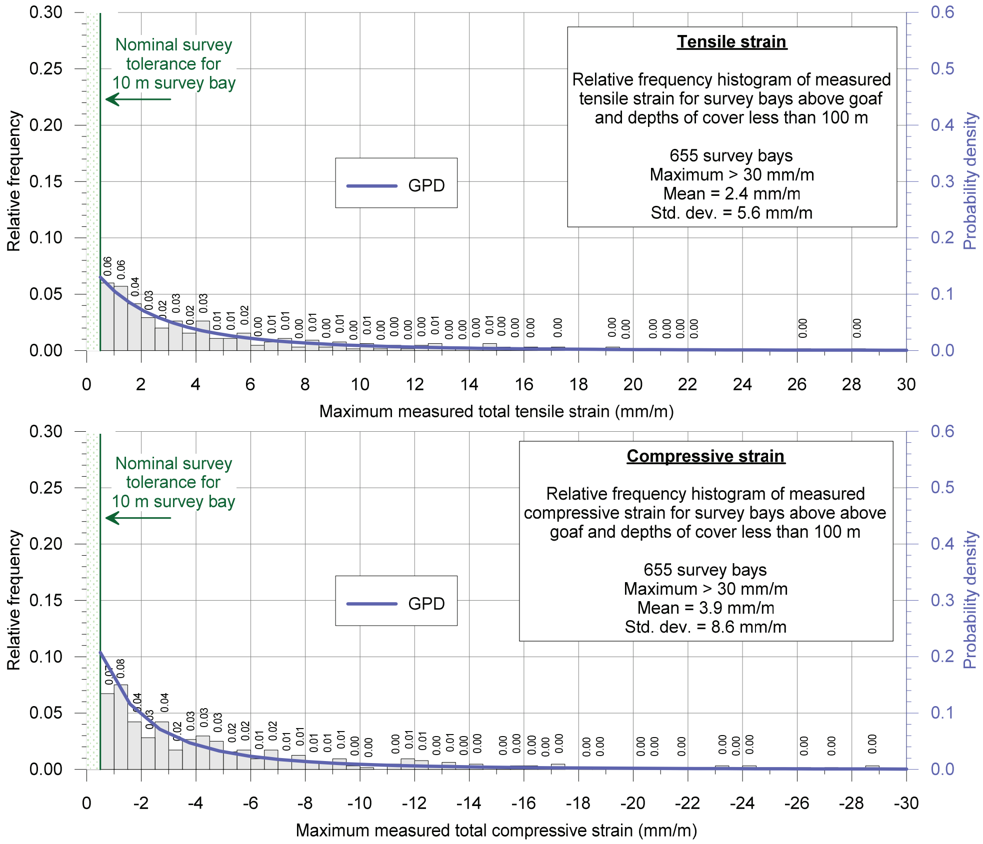


Fig. 4.2 Distributions of the measured maximum tensile and compressive strains for survey bays located above supercritical longwalls at depths of cover less than 100 m

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 the 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 strains that the individual survey bays experienced at any time during mining are 12 mm/m tensile and 17 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are greater than 28 mm/m tensile and greater than 30 mm/m compressive.

4.5. 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 effects along the streams, it is also likely that far-field horizontal movements will occur outside of the mining area.

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data from the Southern and Western Coalfields. The far-field horizontal movements resulting from mining were generally orientated towards the extracted panels. At very low levels of far-field horizontal movements, however, there was a high scatter in the orientation of the observed movements.

There is considerably less 3D monitoring data in the Hunter and Newcastle Coalfields that have stable base points and that extend well beyond the mining areas. Based on the available data, the extents of far-field horizontal movements measured in the Hunter Coalfield are less than those measured in the Southern and Western Coalfields. The reason is that the shallower depths of cover in the Hunter Coalfield result in greater movements above the mining areas but lesser movements outside the mining areas. The data from the Southern and Western Coalfields should therefore provide conservative predictions of the far-field horizontal movements for the proposed longwalls.

The measured total far-field horizontal movements due to longwall mining in the Southern and Western Coalfields are shown in Fig. 4.3. The measured values (y-axis) are the accumulated movements due to the mining in each mining domain. The distances (x-axis) are those of the survey marks from the nearest longwall (active or completed) in the mining domain.

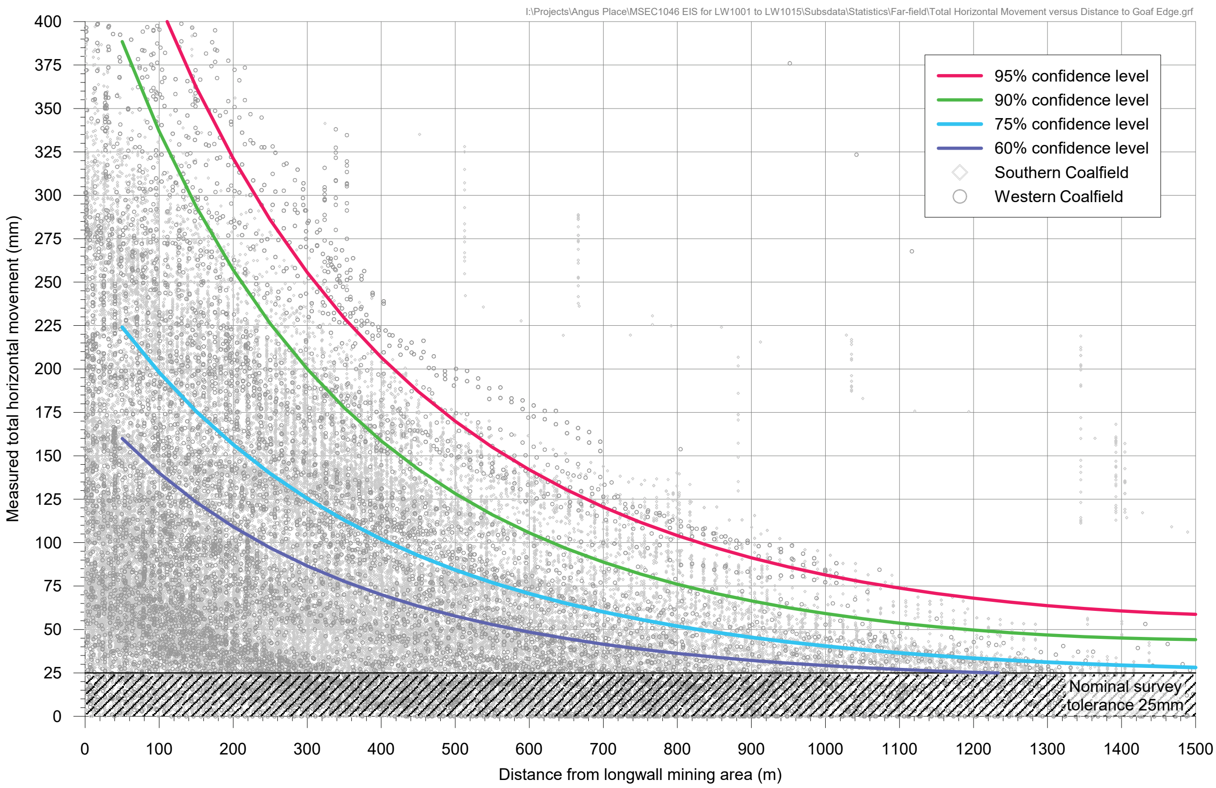


Fig. 4.3 Measured total far-field horizontal movements in the Southern and Western Coalfields

The distributions of far-field horizontal movements in the Southern and Western Coalfields are similar. Confidence levels have therefore been fitted to the data from both these coalfields, as illustrated in Fig. 4.3. The predicted far-field horizontal movement at a distance of 1 km outside the mining area is 80 mm based on the 95 % confidence level.

The Montrose Open Cut Pit is located to the north-east of the proposed longwalls as shown in Drawing No. MSEC1080-01. The open cut pit has extracted the overburden material above the Whybrow Seam. The removal of this material would have relieved and redistributed much of the horizontal in situ stress in the overburden strata adjacent to the pit. The potential for far-field horizontal movements in the vicinity of the Montrose Open Cut Pit, therefore, is reduced.

The predicted far-field horizontal movements due to the mining of the proposed longwalls are expected to be small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the mining area and are accompanied by very low levels of strain, generally in the order of survey tolerance (i.e. less than 0.3 mm/m). The potential impacts of far-field horizontal movements on the natural and built features within the vicinity of the proposed longwalls are not expected to be significant.

4.6. Non-conventional ground movements

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

Specific predictions of upsidence, closure and compressive strain due to the valley related effects are provided for the streams in Section 5.2. The impact assessments for the streams are based on both the conventional and valley related effects. The potential for non-conventional movements associated with steep topography is discussed in Section 5.7.

There are no major geological structures identified within the extents of the proposed WYLW21 to WYLW24. The Redmanvale Fault is located to the south-west of the proposed longwalls. Discussions on the potential effects of this fault on the predicted subsidence are provided in Section 1.4.

In most cases, it is not possible to predict the exact locations or magnitudes of the non-conventional anomalous movements due to near-surface geological conditions. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains, including both conventional and non-conventional anomalous strains, which are discussed in Section 4.4.

4.7. 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 related upsidence and closure effects. The impact assessments for valley related movements are provided in Section 5.2.

The surface deformations due to the mining of WYLW11 to WYLW13 and WYLW17 were recorded by WCPL and these were described in Reports Nos. MSEC866, MSEC886, MSEC916 and MSEC1007. The locations of the mapped surface cracking due to the mining of the longwalls in the Whybrow Seam are shown in Fig. 4.4 (Source: WCPL). Cracking recorded due to the minng in the Wambo Seam (i.e. multi-seam mining conditions) has not been shown for clarity.

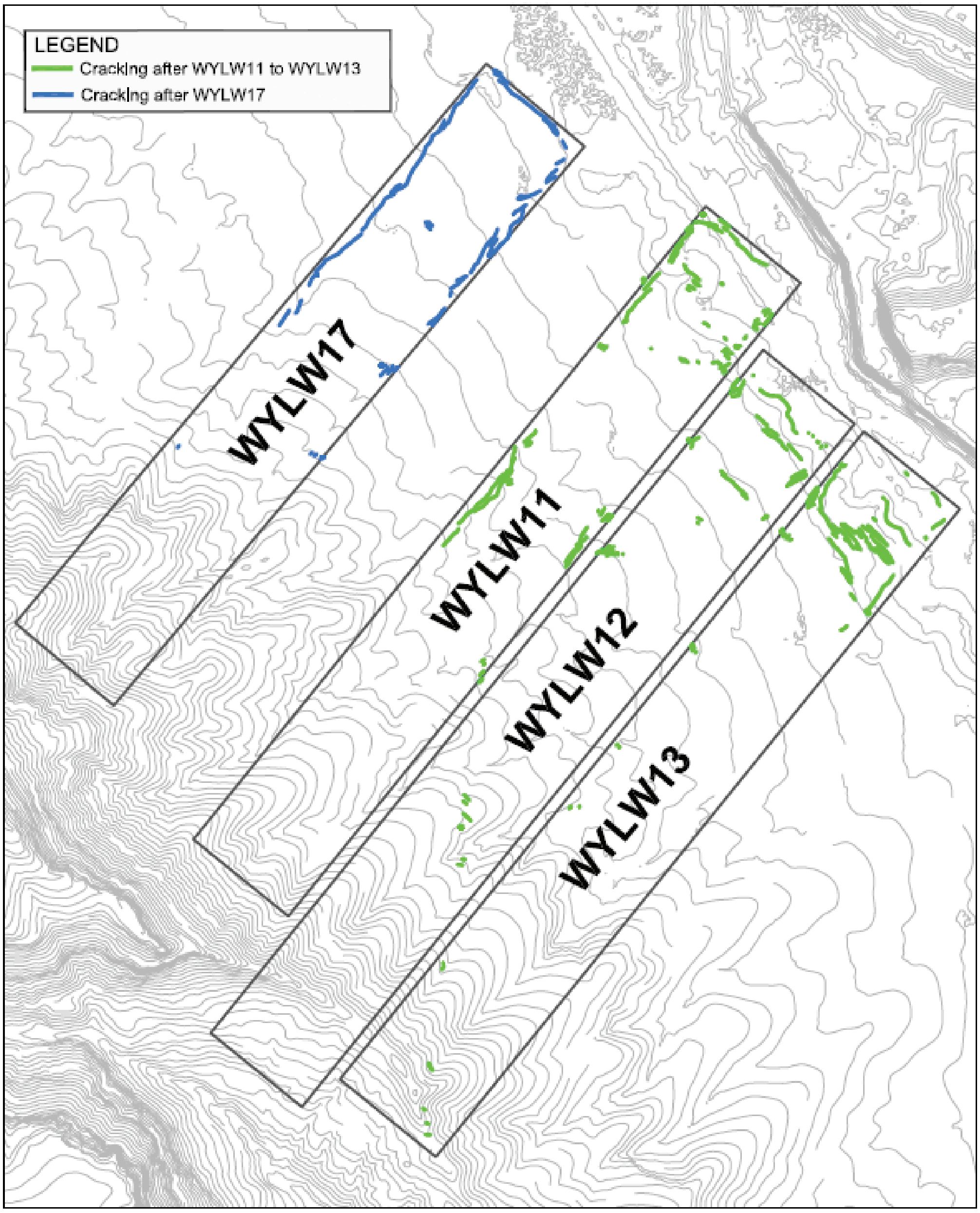


Fig. 4.4 Mapped surface cracking above WYLW11 to WYLW13 and WYLW17

The largest surface deformations occurred towards the finishing (i.e. north-eastern) ends of WYLW11 to WYLW13 and WYLW17 due to the shallower depths of cover. More isolated cracking was recorded towards the commencing (i.e. south-western) ends of the longwalls due to the higher depths of cover and less accessible terrain.

The surface crack widths towards the finishing ends of WYLW11 to WYLW13 and WYLW17 were typically between 25 mm and 50 mm, with localised crack widths up to approximately 400 mm. Compression heaving also developed with heights up to approximately 300 mm. Fracturing and spalling of the exposed bedrock developed within the North Wambo Creek Diversion.

More isolated surface cracking developed above the central and south-western ends of WYLW11 to WYLW13 and WYLW17. The crack widths were typically between 10 mm and 50 mm, with localised crack widths up to approximately 100 mm. Minor potholes were also observed along the steep slopes near the access tracks.

The total length of the mapped surface cracking directly above WYLW11 to WYLW13 and WYLW17 was approximately 3.3 km. The recorded crack widths were generally less than 50 mm (i.e. 91 % of cases). The crack widths were between 50 mm and 100 mm in 8 % of cases and greater than 100 mm in the remaining 1 % of cases. The maximum crack width was approximately 400 mm.

Photographs of the surface deformations that developed above WYLW11 to WYLW13 and WYLW17 are provided in Fig. 4.5 to Fig. 4.17.

Fig. 4.5 Surface cracking above WYLW11 near the 7XL-Line (Source: WCPL)

Fig. 4.6 Surface cracking above south-western end of WYLW11 (Source: WCPL)

Fig. 4.7 Cracking along the fire trails above WYLW12 (Source: WCPL)

Fig. 4.8 Cracking and compression heaving along the tracks above WYLW12 (Source: WCPL)

Fig. 4.9 Cracking along spur adjacent to the tailgate of WYLW12 (Source: WCPL)

Fig. 4.10 Cracking along spur adjacent to the maingate of WYLW12 (Source: WCPL)

Fig. 4.11 Cracking above the north-eastern end of WYLW13 (Source: WCPL)

Fig. 4.12 Cracking along the access tracks above the central part of WYLW13 (Source: WCPL)

Fig. 4.13 Surface cracking above north-eastern end of WYLW17

Fig. 4.14 Compression heaving above north-eastern end of WYLW17

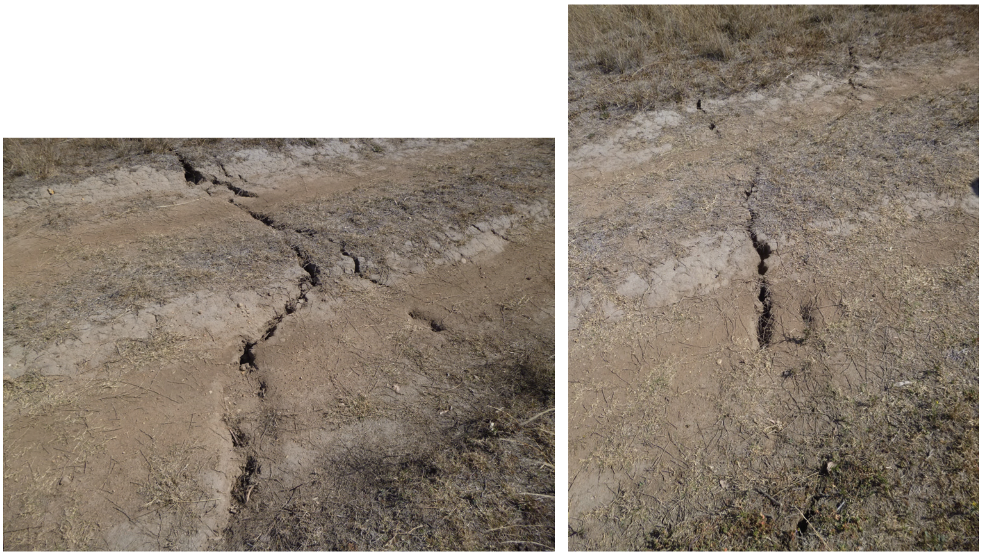


Fig. 4.15 Surface cracking along the access tracks above WYLW17

Fig. 4.16 Surface cracking above the middle of WYLW17

Fig. 4.17 Surface cracking on the steep slopes above the south-western end of WYLW17

Further discussion on surface cracking is provided in the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

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

5.1. Natural features

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

- drinking water catchment areas or declared special areas;
- known springs or groundwater seeps;
- seas or lakes;
- shorelines;
- natural dams;
- swamps or wetlands;
- lands declared as critical habitat under the *Threatened Species Conservation Act 1995*;
- State Recreation Areas or State Conservation Areas;
- State Forests;
- areas of significant geological interest; and
- other significant natural features not described below.

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

5.2. Streams

5.2.1. Description of the streams

The streams are shown in Drawing No. MSEC1080-08. The natural streams within the Study Area include North Wambo Creek and its associated tributaries. The diverted section of North Wambo Creek is located outside the Study Area.

North Wambo Creek commences along the Wollemi Escarpment to the west of the proposed longwalls. The upper section of the creek located outside of the proposed longwalls is formed within an incised valley at the base of the escarpment. The creek bed comprises a rounded gravel to sandy base. In some locations there is exposed bedrock that has formed into small cascades with isolated pools. There is also significant debris along this section of the creek, including boulders, tree branches and other vegetation.

North Wambo Creek crosses directly above the proposed WYLW23 and WYLW24. This section of creek is a fifth order ephemeral stream with a shallow incision into the natural surface soils. The total length of North Wambo Creek located directly above the proposed longwalls is 1.2 km. The natural surface level along the creek falls from a high point of 117 mAHD to a low point of 109 mAHD above the proposed mining area, representing an average natural grade of approximately 6 mm/m (i.e. 0.6 %, or 1 in 167).

The natural section of North Wambo Creek joins the constructed North Wambo Creek Diversion outside and downstream of the Study Area. The creek diversion is located 330 m north-east of WYLW22, at its closest point to the proposed longwalls.

Photographs of the upper and lower sections of North Wambo Creek are provided in Fig. 5.1 and Fig. 5.2, respectively. The locations of the photographs are shown in Drawing No. MSEC1080-08.


Fig. 5.1 Upper section of North Wambo Creek (P0649 and P0595)


Fig. 5.2 Lower section of North Wambo Creek (P0730 and P0745)

Ephemeral drainage lines are located across the Study Area. These drainage lines commence on the Wollemi Escarpment and flow in a north to north-easterly direction to where they join North Wambo Creek and the creek diversion. The drainage lines have shallow incisions into the natural surface soils, with some isolated bedrock outcropping along the upper reaches.

A photograph of the upper reaches of a typical drainage line is provided on the left side of Fig. 5.3. The natural surface between the Wollemi Escarpment and the North Wambo Creek Diversion is shown on the right side of this figure.


Fig. 5.3 Upper reaches of a typical drainage line (left side, P0689) and the natural surface between the Wollemi Escarpment and the North Wambo Creek Diversion (right side, P0723)

The natural grades of the drainage lines within the Study Area typically vary between 5 mm/m (i.e. 0.5 % or 1 in 200) and 100 mm/m (i.e. 10 %, or 1 in 10), with average natural grades of approximately 30 mm/m to 60 mm/m (i.e. 3 % to 6 %, or 1 in 33 to 1 in 17).

5.2.2. Predictions for the streams

The predicted profiles of vertical subsidence, tilt and curvature along North Wambo Creek are shown in Fig. C.04, in Appendix C. The predicted total profiles along the creek, based on the current layout of WYLW17 to WYLW24, are shown as blue lines. The predicted profiles based on the layout adopted in the SBEUM Modification Application and Report No. MSEC848 are shown as the red dashed lines for comparison.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for North Wambo Creek is provided in Table 5.1. The values are the maximum predicted subsidence effects for the section of creek within the Study Area due to the extraction of WYLW17 to WYLW24.

Table 5.1 Maximum predicted total vertical subsidence, tilt and curvature for North Wambo Creek

Location	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})
North Wambo Creek	After WYLW21	< 20	< 0.5	< 0.01	< 0.01
	After WYLW22	< 20	< 0.5	< 0.01	< 0.01
	After WYLW23	1850	70	> 3.0	> 3.0
	After WYLW24	1950	70	> 3.0	> 3.0

The maximum predicted total tilt for North Wambo Creek is 70 mm/m (i.e. 7.0 %, or 1 in 14). The maximum predicted total conventional curvature is greater than 3.0 km^{-1}, which represents a minimum radius of curvature of less than 0.3 km.

The maximum predicted conventional strains for North Wambo Creek, based on applying a factor of 10 to the maximum predicted curvatures, are greater than 30 mm/m tensile and compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The maximum predicted strains for the section of creek near the finishing (i.e. north-eastern) end of WYLW22 are 12 mm/m tensile and 17 mm/m compressive based on the 95 % confidence levels. Lesser strains are predicted further upstream as the depth of cover increases.

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 section of North Wambo Creek located directly above the proposed longwalls has a shallow incision into the natural surface soils. The predicted valley related effects for the creek, therefore, are not significant when compared with the predicted conventional movements.

The upper reach of North Wambo Creek located outside of the proposed longwalls is formed within an incised valley and, therefore, this section of creek could experience valley related effects. The maximum predicted valley related effects for the upper reaches of the creek are 50 mm upsidence and 100 mm closure.

The North Wambo Creek Diversion is located at a distance of 330 m north-east of WYLW22, at its closest point to the proposed longwalls. At this distance, the creek diversion is predicted to experience less than 20 mm vertical subsidence due to the mining of WYLW21 to WYLW24. While the North Wambo Creek Diversion could experience very low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains.

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

5.2.3. Comparison of the predicted subsidence effects for the streams

Comparisons of the maximum predicted total subsidence effects for North Wambo Creek and the drainage lines, based on the layouts adopted in Report No. MSEC848 and MSEC1080, are provided in Table 5.2 and Table 5.3, respectively. The values represent the maximum predicted accumulated movements for the sections of the streams within the Study Area due to the extraction of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24.

Table 5.2 Comparison of maximum predicted total subsidence effects for North Wambo Creek

Layout	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})
SBEUM Modification (Report No. MSEC848)	1950	80	> 3.0	> 3.0
Extraction Plan (Report No. MSEC1080)	1950	70	> 3.0	> 3.0

Table 5.3 Comparison of maximum predicted total subsidence effects for the drainage lines

Layout	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})
SBEUM Modification (Report No. MSEC848)	1950	90	> 3.0	> 3.0
Extraction Plan (Report No. MSEC1080)	1950	85	> 3.0	> 3.0

The maximum predicted total vertical subsidence for North Wambo Creek and the drainage lines is 1950 mm based on both the original and current layouts. The maximum predicted vertical subsidence does not change as the longwalls are supercritical in width.

The maximum predicted total tilt for North Wambo Creek and the drainage lines, based on the current longwall layout (i.e. Report No. MSEC1080), are slightly less than the maximum predicted values based on the layout adopted in the SBEUM Modification and Report No. MSEC848. The predicted tilts reduce due to the shortened finishing (i.e. north-eastern) ends of WYLW21 to WYLW24, as this increases the minimum depth of cover along the alignments of the streams.

The maximum predicted total hogging and sagging curvatures for North Wambo Creek and the drainage lines are greater than 3.0 km^{-1} (i.e. minimum radius of curvature less than 0.3 km) based on both the original and current layouts. While specific values have not been presented, the maximum predicted curvatures reduce due to the shortened finishing ends of WYLW21 to WYLW24, which increases the minimum depth of cover along the alignments of the streams.

The length of North Wambo Creek located directly above the proposed WYLW21 to WYLW24 is 1.2 km based on the current longwall layout (i.e. Report No. MSEC1080) and is 1.5 km based on the layout adopted in the SBEUM Modification and Report No. MSEC848. The length of creek above the proposed longwalls reduces by approximately 0.3 km due to the shortened finishing ends. Similarly, the total length of drainage lines located above the proposed longwalls reduces.

5.2.4. Impact assessments for the streams

Impact assessments for the streams 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.

The North Wambo Creek Diversion is predicted to experience less than 20 mm vertical subsidence due to the mining of the proposed WYLW21 to WYLW24. It is considered unlikely, therefore, that the creek diversion would experience adverse impacts due to the mining of the proposed longwalls.

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 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 gradients that exist before mining.

The maximum predicted tilt for North Wambo Creek is 70 mm/m (i.e. 7.0 % or 1 in 14). The predicted mining-induced tilts are greater than the average natural gradient of the creek above the mining area of 6 mm/m (i.e. less than 1 %). Similarly, the maximum predicted tilt for the drainage lines of 85 mm/m (i.e. 8.5 %) is greater than the average natural gradients of these streams which vary between 30 mm/m to 60 mm/m (i.e. 3 % to 6 %).

The natural and the predicted post-mining surface levels and grades along North Wambo Creek and two typical drainage lines, referred to as Drainage Lines 1 and 2, are illustrated in Fig. 5.4 to Fig. 5.6. The locations of the drainage lines are shown in Drawing No. MSEC1080-08. The profiles shown in these figures are after the completion of all proposed longwalls.

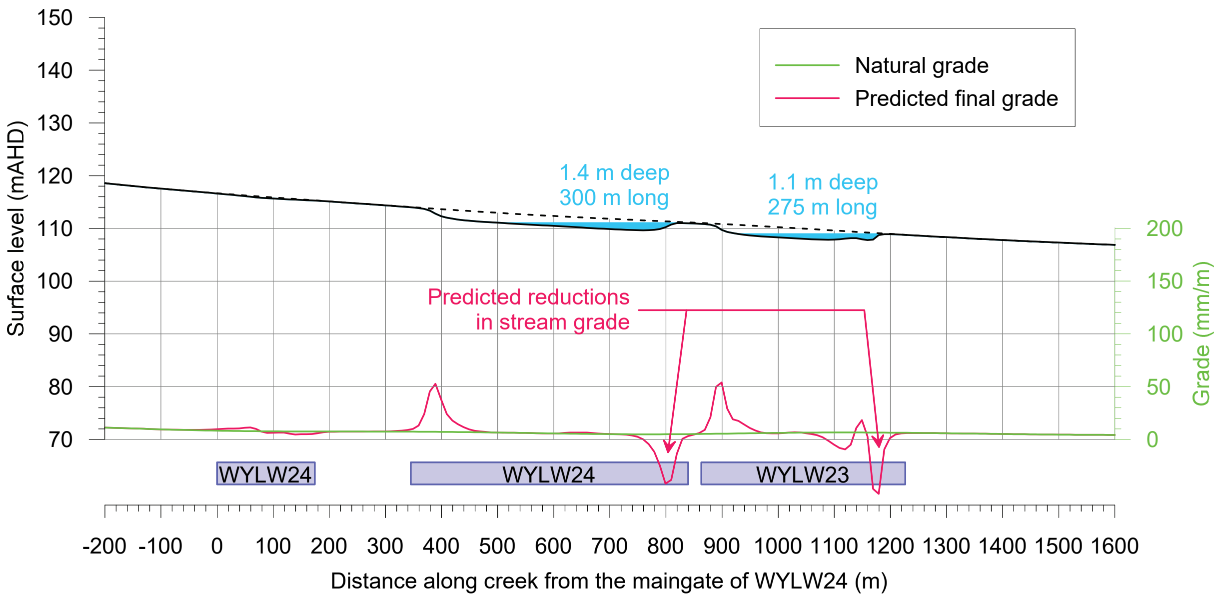


Fig. 5.4 Natural and predicted post-mining surface levels and grades along North Wambo Creek

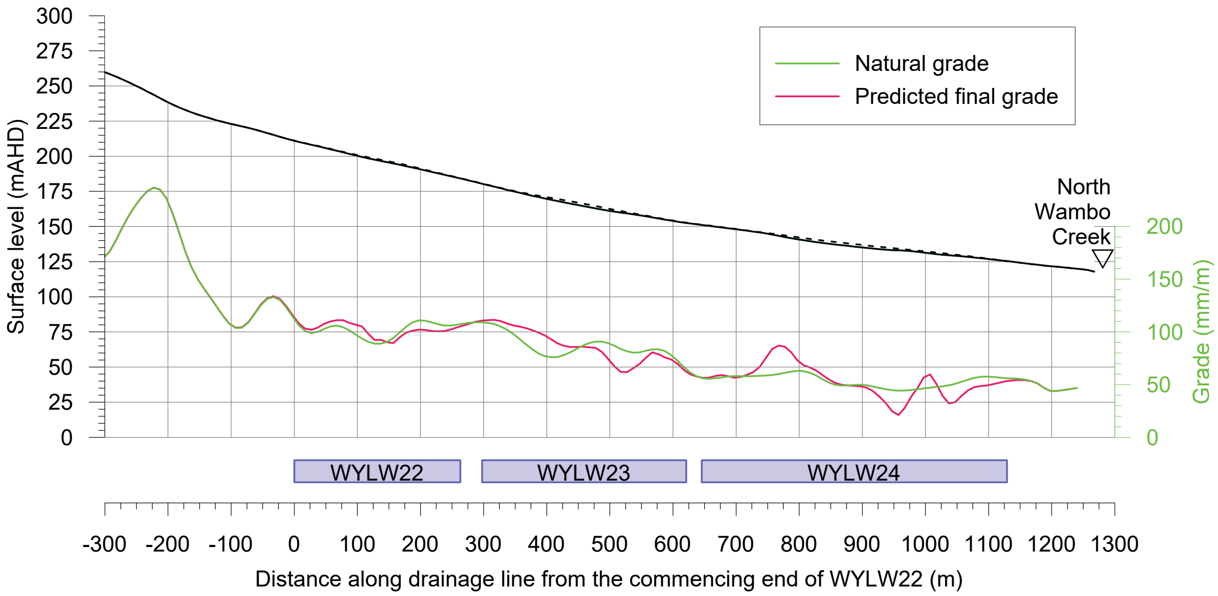


Fig. 5.5 Natural and predicted post-mining surface levels and grades along Drainage Line 1

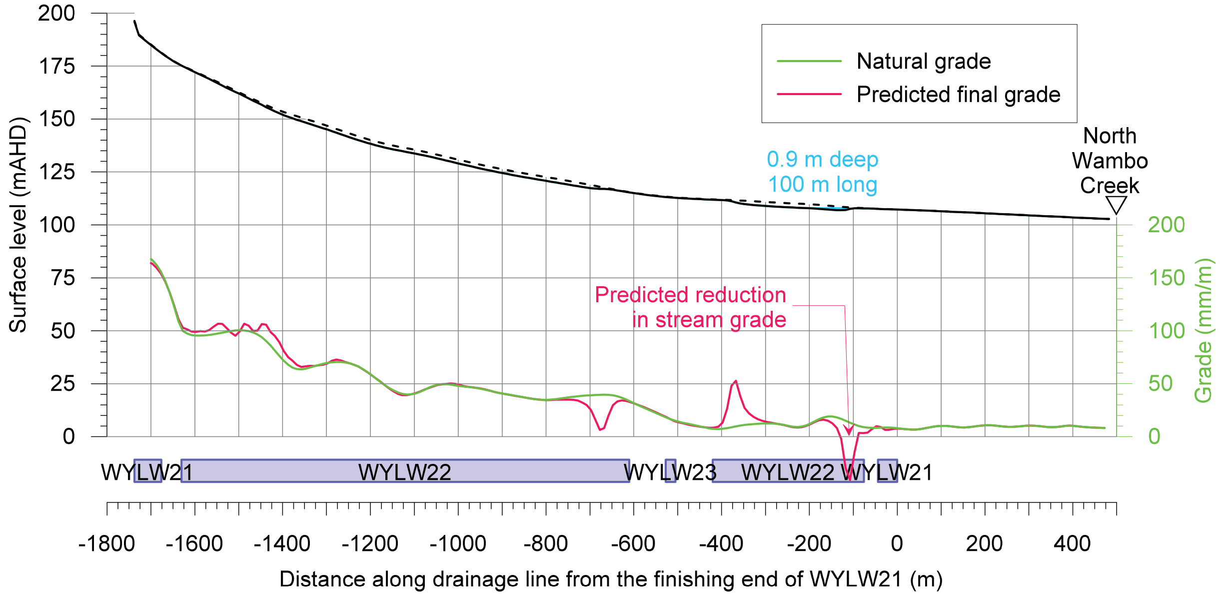


Fig. 5.6 Natural and predicted post-mining surface levels and grades along Drainage Line 2

There are predicted reversals of grade along North Wambo Creek and Drainage Line 2. Ponding areas are predicted to develop upstream of the chain pillars along these streams. There are no predicted reversals of grade along Drainage Line 1 due to the higher natural gradients.

The predicted ponding areas along North Wambo Creek and Drainage Line 2 are illustrated in Fig. 5.4 and Fig. 5.6, respectively. It is noted, that these ponding areas can differ from the topographical depressions discussed in Section 5.8 and indicated in Fig. 5.19, as they have been based on the predicted changes in surface levels along the original alignments of the streams, i.e. they do not consider the natural grades across the alignments of the streams.

The extraction of the proposed longwalls will result in some changes in the stream alignments, due to the natural and mining-induced cross-grades and, in consequence, the actual ponding areas are expected to be less than those illustrated in Fig. 5.4 and Fig. 5.6. The actual extents and depths of the ponding areas are also dependent on a number of other factors, including rainfall, catchment sizes, surface water runoff, infiltration and evaporation and, therefore, are expected to be smaller than the topographical depressions.

There are two ponding areas predicted to develop along North Wambo Creek, due to the mining of the proposed longwalls, having maximum depths up to 1.4 m and overall lengths up to 300 m. Five ponding areas were predicted along this creek, based on the original layout adopted in the SBEUM Modification Application and Report No. MSEC848, due to the greater length of WYLW23 and due to the future WYLW25.

There is one ponding area predicted to develop along Drainage Line 2, due to the mining of the proposed longwalls, having maximum depth of 0.9 m and overall length 100 m. Two ponding areas were predicted along this drainage line, based on the original layout adopted in the SBEUM Modification Application and Report No. MSEC848, due to the greater lengths of WYLW21 and WYLW22. Ponding areas are also likely to develop along other drainage lines within the Study Area.

If adverse impacts were to develop due to increased ponding along the streams, these could be remediated by locally regrading the beds, so as to re-establish the natural gradients. The streams have shallow incisions in the natural surface soils and, therefore, it is expected that the mining-induced ponding areas could be reduced by locally excavating the channels downstream of these areas. The larger ponding areas may require excavation into the topmost bedrock, depending on the thickness of the overlaying surface soils.

Potential for cracking in the stream beds and fracturing of bedrock

It is expected that fracturing of the topmost bedrock would develop along the sections of the streams located directly above the proposed longwalls. North Wambo Creek and the drainage lines have shallow incisions into the natural surface soils. Cracking in the beds of the streams would be visible at the surface where the depths of the surface soils are shallow, or where the bedrock is exposed.

The mining-induced compression can also result in dilation and the development of bed separation in the topmost bedrock. The 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.

North Wambo Creek has been previously mined beneath by Longwalls 1 to 8A in the Wambo Seam (WMLW1 to WMLW8A) at the North Wambo Underground Mine. Surface cracking observed along the creek had widths typically ranging between 10 mm to 50 mm, with localised crack widths up to approximately 100 mm (WCPL, 2014). The North Wambo Creek Diversion has also been previously mined beneath by WYLW11 to WYLW13 and WYLW17. Surface cracking along the creek diversion had widths ranging between 25 mm and 50 mm, with localised crack widths up to approximately 400 mm.

The surface impacts along North Wambo Creek and the drainage lines, due to the mining of the proposed WYLW21 to WYLW24, are expected to be similar to those previously observed at the Wambo Coal Mine. Photographs of the surface deformations above the previously extracted WYLW11 to WYLW13 and WYLW17 are provided in Section 4.7.

The streams are ephemeral and, therefore, surface water flows only occur during and for short periods after rainfall events. In times of heavy rainfall, the majority of the runoff would flow over the natural surface soil beds and would not be diverted into the dilated strata below. In times of low flow and prior to remediation, however, surface water flows could be diverted into the dilated strata below the beds.

It is expected that fracturing in the underlying bedrock would gradually be filled with surface soils during subsequent flow events, especially during times of heavy rainfall. If the surface cracks were found not to fill naturally, some remedial measures may be required at the completion of mining. Where necessary, any significant surface cracks in the stream beds could be remediated by infilling with surface soil or other suitable materials, or by locally regrading and recompacting the surface.

It is not expected that there would be a direct hydraulic connection between the surface and proposed longwalls, as this has not been previously observed at the Wambo Coal Mine. This includes the extraction of the Homestead/Wollemi workings in the Whybrow Seam directly beneath Stony Creek, WMLW1 to WMLW8A directly beneath North Wambo and Stony Creeks and WYLW11 to WYLW13 and WYLW17 beneath the North Wambo Creek Diversion.

Similar experiences have been found elsewhere in the Hunter and Newcastle Coalfields indicating that mining-induced fracturing and dilation do not have long term adverse impacts on ephemeral streams comprising natural soil beds. For example, the ephemeral drainage lines at South Bulga and the Beltana No. 1 Underground Mine were previously mined beneath by longwalls in the Whybrow Seam, where the depths of cover varied between 40 m and 200 m. Although surface cracking was observed across the mining area, there were no observable surface water flow diversions in the drainage lines, after the remediation of the larger surface cracks had been completed.

It will be necessary to remediate some sections of the streams after the extraction of the proposed longwalls directly beneath them. This would include regrading the beds and infilling the larger surface cracking. It is expected that there would be no long-term adverse impacts on these streams after the completion of the necessary surface remediation.

Management strategies have previously been developed for the sections of the streams that have already been directly mined beneath at the Wambo Coal Mine. It is recommended that the existing management strategies for the streams be reviewed and, where required, are revised to include the effects of the proposed longwalls.

5.3. Aquifers and known ground water resources

Descriptions, predictions and the assessment of potential impacts on the aquifers and groundwater resources within the Study Area are provided in the Groundwater Assessment report prepared by HydroSimulations (2017).

There are no Ground Water Management Areas, as defined by the DPIE, within the Study Area. WCPL owns two monitoring bores (Refs. GW200831 and GW200832) which are located near the finishing (i.e. north-eastern) ends of the proposed WYLW23 and WYLW24. These monitoring bores could be affected due to the mining of the proposed longwalls. There were no other registered groundwater bores identified within the Study Area.

5.4. Escarpments

The *Wollemi Escarpment* is located to the south and to the west of the proposed longwalls.

The Macquarie Dictionary defines an *escarpment* as *"a long, cliff-like ridge of rock, or the like, commonly formed by faulting or fracturing of the earth's crust*". The Collins Dictionary of Geology defines an *escarpment* as *"a high, more or less continuous, cliff or long steep slope situated between a lower more gently inclined surface and a higher surface*". It appears, from these examples, that some definitions of an escarpment include only the cliffs and rock formations, whilst other definitions also include the steep slopes.

In this report, the escarpment has been defined as the continuous sections of high level cliffline along the boundary of the Wollemi National Park. The lower levels of cliffs and minor cliffs, the isolated rock outcrops and the steep slopes have not been included as part of the escarpment.

The extent of the escarpment was determined from detailed site investigations by MSEC and WCPL on the 21 July 2016, as well as from an orthophotograph and surface level contours which were generated from a LiDAR survey of the area. The extents of the cliffs associated with the Wollemi Escarpment are shown in Fig. 5.7. All the cliffs within the Study Area, including those not associated with the escarpment, are shown in Drawing No. MSEC1080-08.

The impact assessments for the cliffs associated with the Wollemi Escarpment are included in Section 5.5. The impact assessments for the Wollemi National Park are provided in Section 5.11.

5.5. Cliffs

5.5.1. Descriptions of the cliffs

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

"Cliff	*Continuous rock face, including overhangs, having a minimum length of 20 metres, a minimum height of 10 metres and a minimum slope of 2 to 1 (>63.4º)*
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 were identified using 1 m surface level contours generated from a LiDAR survey and from detailed site investigations. The locations of the cliffs in the vicinity of the proposed WYLW21 to WYLW24 are shown in Drawing No. MSEC1080-08. The cliffs have also been shown in more detail in Fig. 5.7.

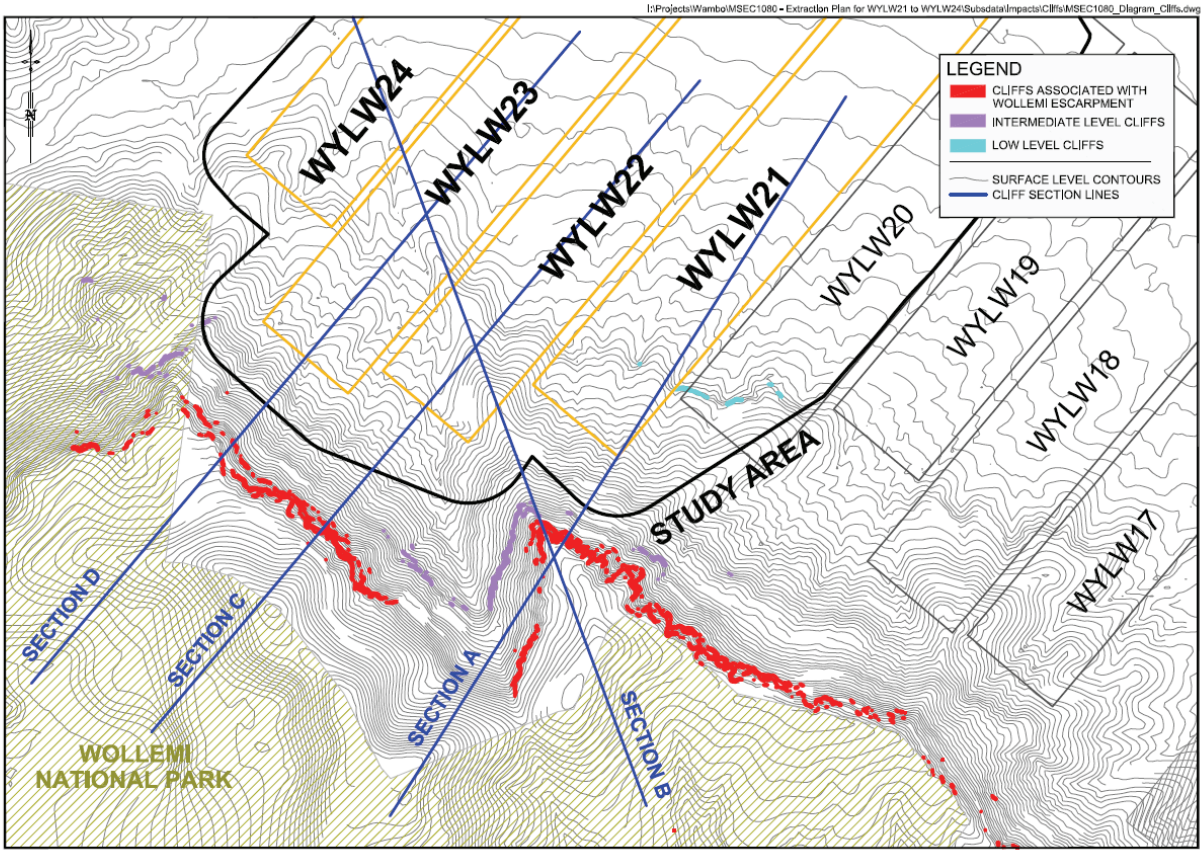


Fig. 5.7 Cliffs located adjacent to the commencing ends of WYLW21 to WYLW24

The cliffs have been categorised into three groups:

- *Cliffs Associated with the Wollemi Escarpment* (red hatch in Fig. 5.7*)* – are the higher level cliffs located along the boundary of the Wollemi National Park to the south-west of the proposed longwalls. These higher level cliffs outcrop at one or two horizons each having overall heights ranging between 10 m and 40 m. The cliff lines are discontinuous and are separated with sections of minor cliffs and rock outcrops;
- *Intermediate Level Cliffs* (purple hatch in Fig. 5.7*)* – are located part way down the steep slopes beneath the Wollemi Escarpment to the south-west of the proposed longwalls. These cliffs have not been considered part of the Wollemi Escarpment. The intermediate level cliffs have heights varying between 10 m and 20 m and continuous lengths up to approximately 50 m; and
- *Low Level Cliffs* (cyan hatch in Fig. 5.7*)* – are located near the bottom of the steep slopes above the south-western ends of the proposed longwalls. The larger low level cliffs are located partially above the proposed WYLW21 having heights varying between 10 m and 15 m and continuous lengths up to approximately 50 m. These cliffs are discontinuous and are separated with sections of minor cliffs and rock outcrops.

Sections A to D have been taken through the commencing (i.e. south-western) ends of the proposed longwalls, showing the relative locations of the cliffs, in Fig. 5.8 to Fig. 5.11. The locations of these sections are shown in Fig. 5.7.

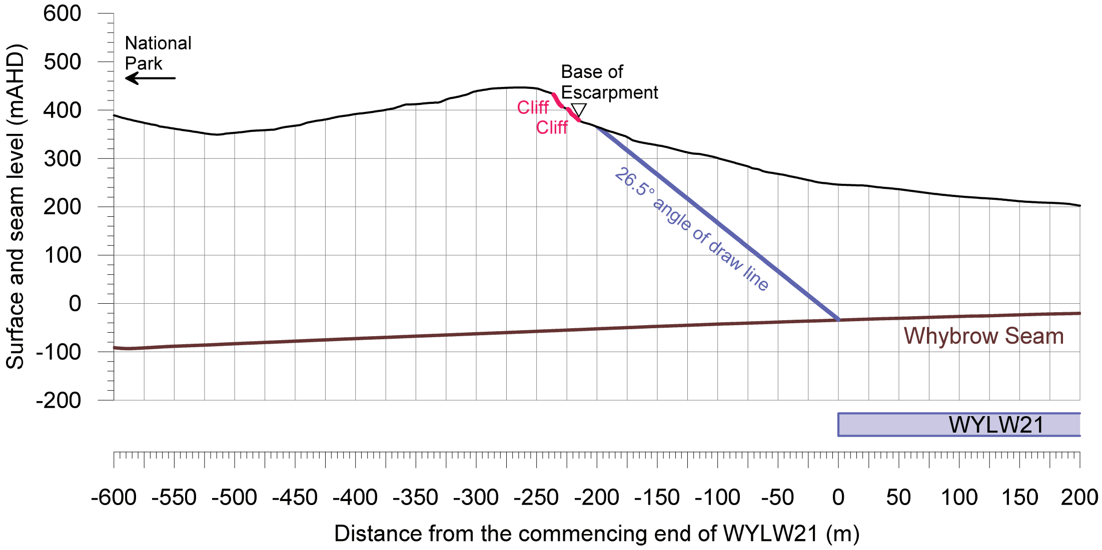


Fig. 5.8 Section A through the Wollemi Escarpment and the commencing end of WYLW21

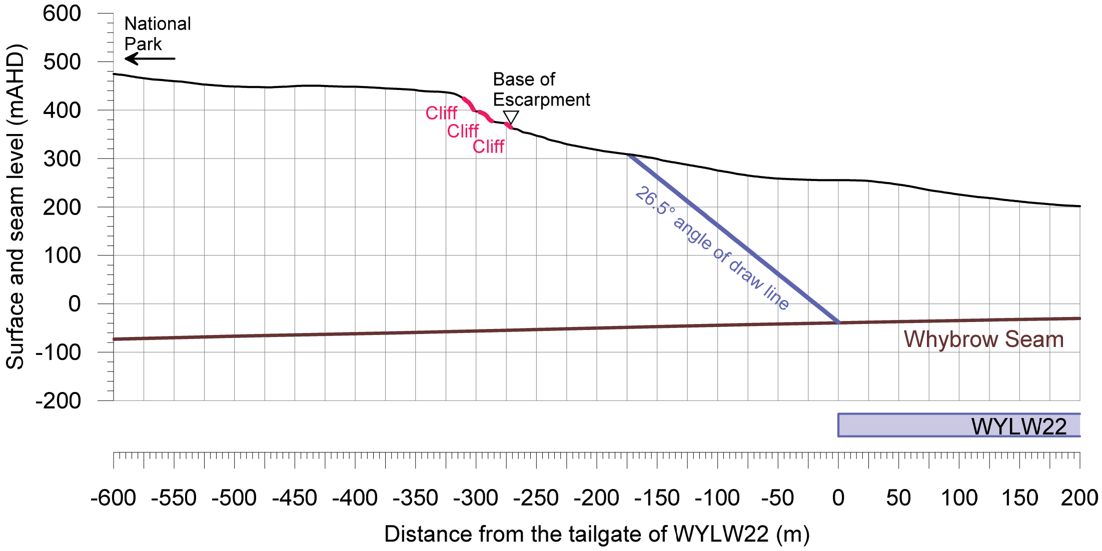


Fig. 5.9 Section B through the Wollemi Escarpment and the tailgate of WYLW22

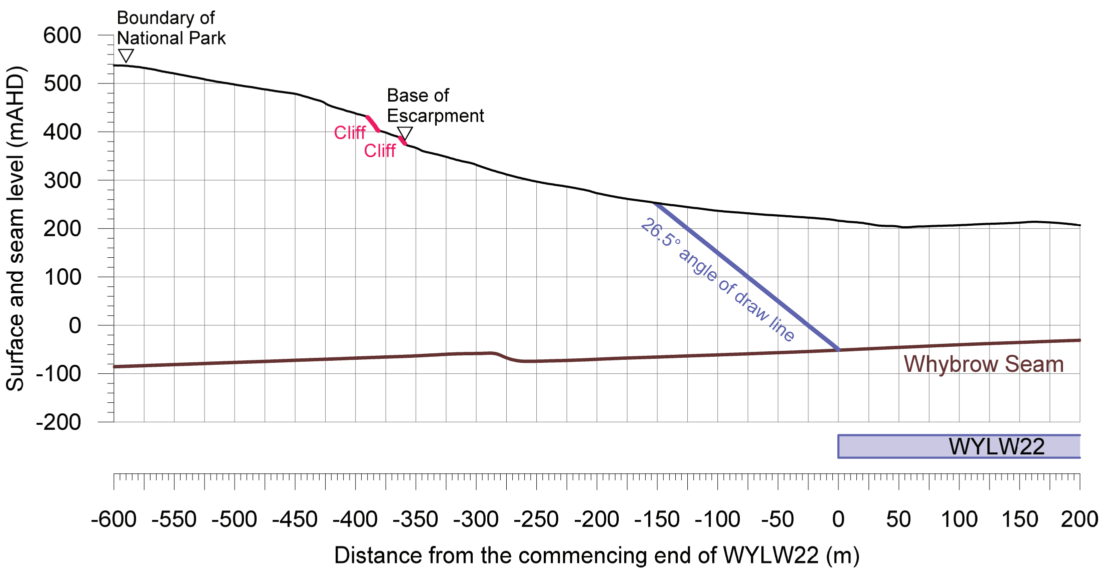


Fig. 5.10 Section C through the Wollemi Escarpment and the commencing end of WYLW22

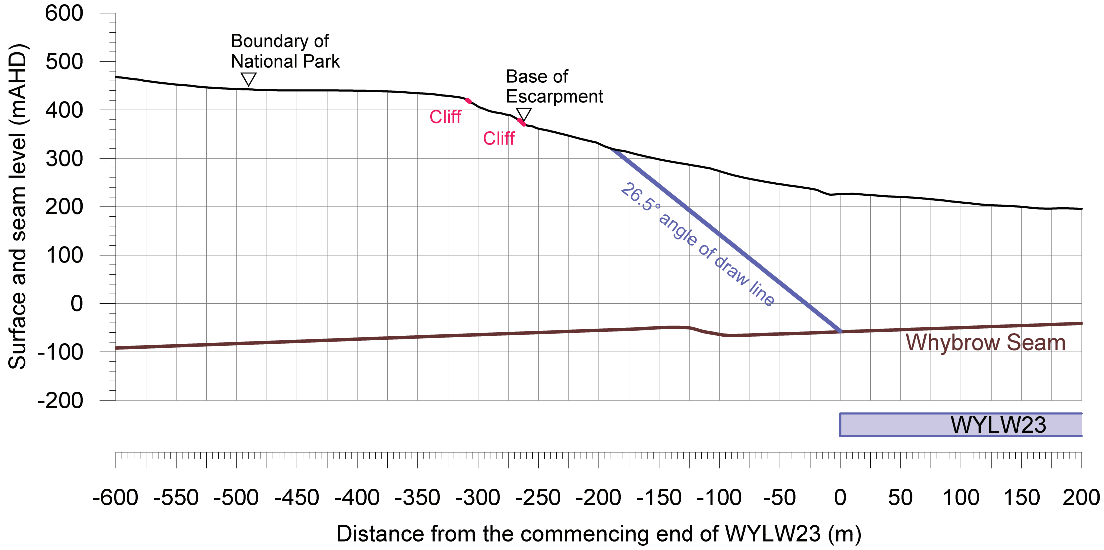


Fig. 5.11 Section D through the Wollemi Escarpment and the commencing end of WYLW23

The Cliffs Associated with the Wollemi Escarpment are located outside of the 26.5° angle of draw line from the proposed WYLW21 to WYLW24. It is noted that the Study Area differs from the 26.5° angle of draw line, as the Study Area is based on an angle of draw using the depth of cover above the longwall commencing ends and, therefore, does not consider the increasing surface elevation to the south-west of the proposed longwalls. For this reason, all the Cliffs Associated with the Wollemi Escarpment, immediately to the south-west of the longwalls, have been included as part of the Study Area and, hence, have been included in the impact assessments provided in this report.

A summary of the minimum distances of the Cliffs Associated with the Wollemi Escarpment from each of the proposed longwalls is provided in Table 5.4.

Table 5.4 Distances of the Cliffs Associated with the Wollemi Escarpment from each of the proposed longwalls

Feature	Longwall	Minimum distance (m)
Cliffs Associated with the Wollemi Escarpment	WYLW21	210
	WYLW22	190
	WYLW23	250
	WYLW24	520

The Intermediate Level Cliffs are located at distances of 210 m and 190 m from WYLW21 and WYLW22, respectively, at their closest point to the proposed longwalls. The Low Level Cliffs are partially located directly above the proposed WYLW21.

The cliffs, minor cliffs and rock outcrops have formed from the Widden Brook Conglomerate of the Narrabeen Group, as can be seen in Fig. 1.8. Photographs of the Cliffs Associated with the Wollemi Escarpment are provided in Fig. 5.12 to Fig. 5.15. The locations and directions of the photographs are indicated in Drawing No. MSEC1080-08.

Fig. 5.12 Overall view of cliffs located south-west of the proposed longwalls (P2846 and P2847)

Fig. 5.13 Cliffs located south-west of the proposed WYLW21 to WYLW23 (P2929, P2930 and P2927)

Fig. 5.14 Cliffs located south-west of the proposed WYLW21 to WYLW24 (P0648, P0647 and P0646)

Fig. 5.15 Discontinuous cliffs located north-west of the proposed WYLW24 (P0655 and P0731)

5.5.2. Predictions for the cliffs

A summary of the maximum predicted total vertical subsidence, tilts and curvatures for the cliffs is provided in Table 5.5. The values represent the maximum predicted accumulated movements within 20 m of the mapped extents of the cliffs due to the extraction of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24.

Table 5.5 Maximum predicted total vertical subsidence, tilts and curvatures 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})
Cliffs Associated with the Wollemi Escarpment	< 20	< 0.5	< 0.01	< 0.01
Intermediate Level Cliffs	< 20	< 0.5	< 0.01	< 0.01
Low Level Cliffs	1750	25	0.7	0.7

The Cliffs Associated with the Wollemi Escarpment and the Intermediate Level Cliffs are predicted to experience less than 20 mm vertical subsidence. While these cliffs could experience very low level vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

The higher level cliffs could experience far-field horizontal movements. There is no 3D ground monitoring data available at the North Wambo Underground Mine along the steep slopes beneath the Wollemi Escarpment. The predicted far-field horizontal movements, therefore, have been based on the observations at Dendrobium Mine, which has similar or shallower depths of cover and similar natural surface gradients.

Fourteen longwalls have been extracted in Areas 1, 2, 3A and 3B at Dendrobium Mine. The depths of cover vary between 170 m and 320 m in Area 1, 150 m and 310 m in Area 2, 275 m and 385 m in Area 3A and 290 m and 410 m in Area 3B. The longwalls were extracted in the Wongawilli Seam and had width-to-depth ratios typically ranging between 0.7 and 1.4. Escarpments were located directly above the longwalls in Areas 1 and 2 and the surface was highly undulating in Areas 3A and 3B, with the natural gradients varying between 1 in 3 and 1 in 2 directly above the longwalls.

The measured total 3D horizontal movements at Dendrobium Mine for survey marks located outside the extents of the longwalls (i.e. above solid coal only) are illustrated in Fig. 5.16. The 95 % confidence level for the measured total horizontal movements has been shown as the blue line in this figure.

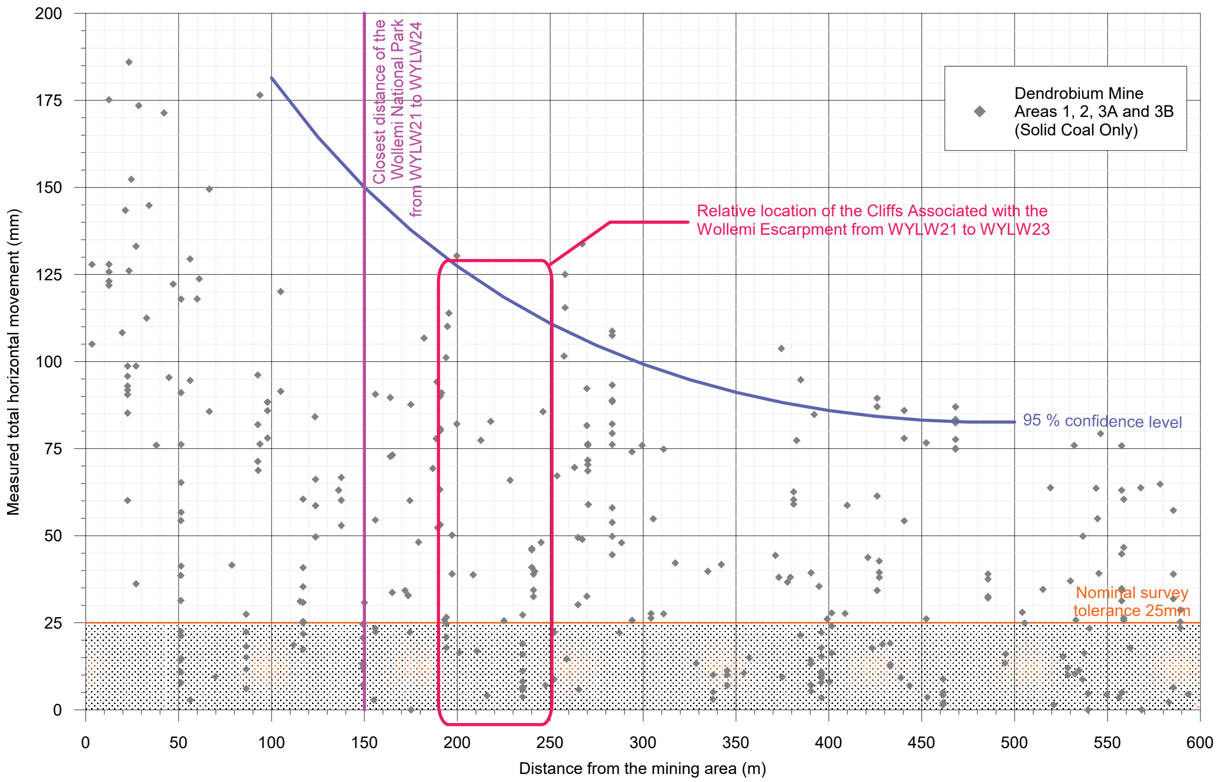


Fig. 5.16 Measured total 3D horizontal movements in Areas 1, 2, 3A and 3B at Dendrobium Mine

The predicted total far-field horizontal movements for the Cliffs Associated with the Wollemi Escarpment and the Intermediate Level Cliffs are in the order of 110 mm to 130 mm based on the 95 % confidence level. These movements tend to be bodily movements, towards the extracted longwalls, which are accompanied by very low levels of strain, typically less than the order of survey tolerance.

The Low Level Cliffs are partially located above the proposed WYLW21 and they are predicted to experience tilts up to 25 mm/m (i.e. 2.5 % or 1 in 40). The maximum predicted curvature for these cliffs is 0.7 km^{-1}, which represents a minimum radius of curvature of 1.4 km.

The maximum predicted conventional strains for the Low Level Cliffs, based on applying a factor of 10 to the maximum predicted curvatures, are 7 mm/m tensile and compressive. An analysis of strain measured above previously extracted longwalls in the Hunter and Newcastle Coalfields having similar width-to-depth ratios as the south-western ends of the proposed longwalls is provided in Section 4.4.1. The 95 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 5 mm/m tensile and 4 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.

5.5.3. Comparison of the predicted subsidence effects for the cliffs

The maximum predicted subsidence effects for the Cliffs Associated with the Wollemi Escarpment, Intermediate Level Cliffs and Low Level Cliffs, based on the current longwall layout (i.e. Report No. MSEC1080), are the same as the maximum predicted values based on the layout adopted in the SBEUM Modification and Report No. MSEC848. The predicted subsidence effects for the cliffs have not changed as the longwall commencing ends have remained the same.

5.5.4. Impact assessments for the Cliffs Associated with the Wollemi Escarpment and the Intermediate Level Cliffs

The Cliffs Associated with the Wollemi Escarpment and the Intermediate Level Cliffs are predicted to experience vertical subsidence of less than 20 mm. While these cliffs could experience very low levels of vertical subsidence, they are not expected to experience measurable conventional tilts, curvatures or strains, even if the predicted vertical subsidence was exceeded by a factor of two times.

These higher level cliffs could also experience far-field horizontal movements in the order of 110 mm to 130 mm based on the 95 % confidence level. These movements are expected to be bodily movements towards the extracted longwalls and are not expected to be associated with any measurable strains. It is unlikely, therefore, that the Cliffs Associated with the Wollemi Escarpment and the Intermediate Level Cliffs would experience adverse impacts due to far-field horizontal movements, even if these predictions were exceeded by a factor of two times.

The existing Wollemi/Homestead workings in the Whybrow Seam were extracted adjacent to the Wollemi Escarpment to the south-east of the Study Area. An east-west cross-section through Homestead Longwall 13 and the escarpment is provided in Fig. 5.17.

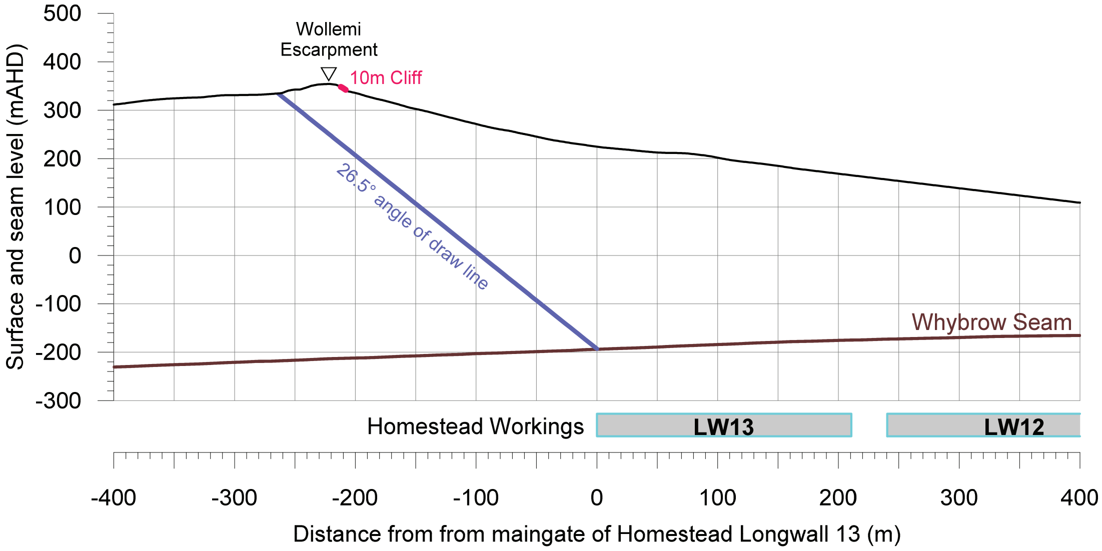


Fig. 5.17 Cross-section through the Wollemi Escarpment and the Homestead Workings

The Homestead workings were extracted to within a distance of 210 m from the Cliffs Associated with the Wollemi Escarpment, which is equivalent to a 21° angle of draw. There were no reported impacts for the Cliffs Associated with the Wollemi Escarpment resulting from the extraction of the Wollemi/Homestead workings.

WYLW11 to WYLW13 at the South Bates Underground Mine and WYLW17 at the SBEUM have also been extracted adjacent to the Wollemi Escarpment. The Cliffs Associated with the Wollemi Escarpment are located at minimum distances of 290 m from WYLW12 and 230 m from WYLW17, at their closest points to the mining areas. There have been no reported impacts to these cliffs due to the mining at the South Bates Underground Mine and the SBEUM.

It is not expected, therefore, that there would be adverse impacts on the Cliffs Associated with the Wollemi Escarpment or the Intermediate Level Cliffs due to the mining of the proposed WYLW21 to WYLW24.

It is recommended that monitoring is undertaken to measure the actual angle of draw to the limit of vertical subsidence. The monitoring could include continuous Global Navigation Satellite System (GNSS) survey monitoring points that provide high accuracy 3D survey data (approximately 3 mm at the first standard deviation) based on continuous GPS reception. It is also recommended that the cliffs are periodically visually inspected during and after the extraction of the proposed longwalls.

5.5.5. Impact assessments for the Low Level Cliffs

The Low Level Cliffs are partially located above the south-western end of the proposed WYLW21. These cliffs are predicted to experience up to 1750 mm vertical subsidence, 25 mm/m tilt (i.e. 2.5 %, or 1 in 40) and 0.7 km^{-1} curvature (i.e. a minimum radius of curvature of 1.4 km).

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

The likelihood of instabilities for the Low Level Cliffs has been assessed based on the experience at Dendrobium Mine, as the maximum predicted subsidence parameters are similar orders of magnitude. Longwalls 1 and 2 at Dendrobium 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. The maximum predicted conventional curvatures due to 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 width of disturbance resulting from the extraction of Dendrobium Longwalls 1 and 2 was approximately 135 m to 175 m. The total plan length of ridgeline located directly above the longwalls was between approximately 1.8 km to 2.0 km. 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 width of ridgeline disturbed as a result of the extraction of Dendrobium Longwalls 1 and 2 was, therefore, estimated to be between 7 % and 10 % of the total plan length of ridgeline directly above the longwalls. The width of rockfalls which occurred as a result of the extraction of Longwalls 1 and 2, however, was less than the width of disturbed ridgeline.

Based on this case study, it has been estimated that approximately 7 % to 10 % of the total length, or approximately 3 % to 5 % of the total face area, of the Low Level Cliffs located directly above the existing and proposed longwalls could be impacted. The total length of the Low Level Cliffs located above the longwalls is approximately 150 m based on the LiDAR surface level contours. This equates to a length of disturbance of approximately 15 m, or a face area of disturbance of approximately 100 m^2. This represents a very small percentage (i.e. less than 1 %) of the total length and face area of the cliffs located within the Study Area.

It is recommended that the Low Level Cliffs are periodically visually inspected during and after the extraction of the longwalls directly beneath them.

5.6. Pagodas

There are no pagoda complexes identified within the Study Area. There are isolated pagodas associated with the Wollemi Escarpment that are located outside of the proposed longwalls. The pagodas have formed from the Widden Brook Conglomerate and have heights typically up to around 3 m to 5 m.

The pagodas are predicted to typically experience vertical subsidence less than 20 mm. While the pagodas could experience very low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains. It is unlikely, therefore, that the isolated pagodas would experience adverse impacts as a result of the extraction of the proposed WYLW21 to WYLW24.

5.7. Steep slopes

5.7.1. Descriptions of the steep slopes

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

Steep slopes have been identified above the commencing (i.e. south-western) ends of the proposed WYLW21 to WYLW24. These steep slopes extend up to the Wollemi Escarpment which is located outside the 26.5° angle of draw line from the proposed longwalls. The natural surface gradients directly above the proposed longwalls typically range between 1 in 3 and 1 in 2. The slopes are locally steeper at the base of the Low Level Cliffs, above the proposed longwalls, with gradients up to approximately 1 in 1.5.

The natural slopes along Section A through the commencing end of the proposed WYLW21 are illustrated in Fig. 5.18. The location of this cross-section is shown in Fig. 5.7.

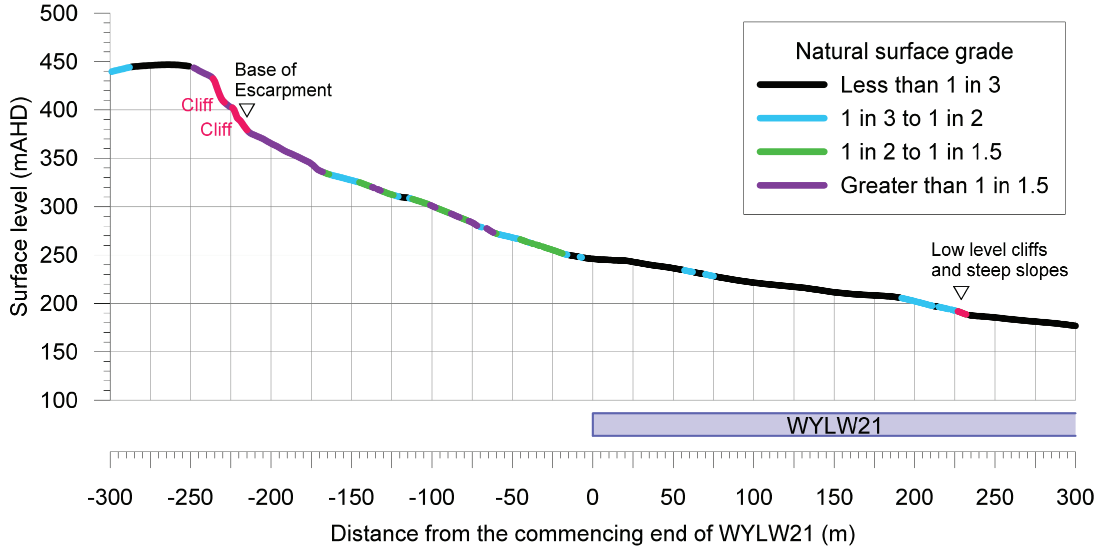


Fig. 5.18 Section A through the steep slopes and the commencing end of WYLW21

The surface soils along the steep slopes above the commencing ends of the proposed longwalls are generally derived from the Widden Brook Conglomerate (Rna), as can be inferred from Fig. 1.8. The slopes are stabilised by the natural vegetation, which can be seen in Fig. 1.2.

There are also isolated steep slopes elsewhere above the proposed longwalls which are generally associated with the banks of the streams. An example is provided in Fig. 5.2 showing the banks along North Wambo Creek near the finishing end of the proposed WYLW23.

5.7.2. Predictions for the steep slopes

A summary of the maximum predicted total subsidence, tilts and curvatures for the steep slopes is provided in Table 5.6. The values represent the maximum predicted accumulated movements for the steep slopes within the Study Area due to the extraction of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24.

Table 5.6 Maximum predicted total vertical subsidence, tilts and curvatures for the steep slopes

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})
Steep slopes	1800	30	1.0	1.0

The steep slopes are predicted to experience tilts up to 30 mm/m (i.e. 3 %, or 1 in 33). The maximum predicted curvature for the steep slopes is 1.0 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 1 km.

The maximum predicted conventional strains for the steep slopes, based on applying a factor of 10 to the maximum predicted curvatures, are 10 mm/m tensile and compressive. An analysis of strain measured above previously extracted longwalls in the Hunter and Newcastle Coalfields having similar width-to-depth ratios as the south-western ends of the proposed longwalls is provided in Section 4.4.1. The 95 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 5 mm/m tensile and 4 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.

5.7.3. Comparison of the predicted subsidence effects for the steep slopes

The maximum predicted subsidence effects for the steep slopes, based on the current longwall layout (i.e. Report No. MSEC1080), are the same as the maximum predicted values based on the layout adopted in the SBEUM Modification and Report No. MSEC848. The predicted subsidence effects for the steep slopes have not changed as the longwall commencing ends have remained the same.

5.7.4. Impact assessments for the steep slopes

The maximum predicted tilt for the steep slopes of 30 mm/m (i.e. 3.0 % or 1 in 33) is 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 steep slopes.

The steep slopes are more likely to be impacted by curvature and ground strain, rather than tilt. The potential impacts would generally result from the movement of the natural surface in the downslope direction, resulting in tension cracks appearing at the tops and on the sides of the steep slopes and compression ridges forming at the bottoms of the steep slopes.

The south-western ends of WYLW11 to WYLW13 at the South Bates Underground Mine and WYLW17 at the SBEUM have been mined beneath the steep slopes. Surface cracking recorded due to the mining of these longwalls is described in Section 4.7. It is noted, however, that the visual inspections above the south-western ends of these longwalls were limited due to the steep terrain and heavy vegetation.

Surface cracking recorded on the steep slopes had widths typically ranging between 25 mm and 50 mm, with localised crack widths up to approximately 400 mm. Photographs of cracking on the steep slopes are provided in Fig. 4.9 and Fig. 4.10. Similar surface deformations are expected where the south-western ends of the proposed WYLW21 to WYLW24 mine beneath the steep slopes.

The steep slopes are heavily vegetated and natural erosion due to soil instability (i.e. natural downslope movements) was not readily apparent from the site investigations undertaken. If tension cracks were to develop, due to the mining of the proposed longwalls, it is possible that soil erosion could occur if these cracks were left untreated.

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.

5.8. Land prone to flooding or inundation

The land within the Study Area generally falls in a north-easterly direction from the Wollemi Escarpment to the North Wambo Creek and the creek diversion. The natural surface level contours (grey lines) and the predicted post-mining surface level contours (green lines) above the proposed WYLW21 to WYLW24 are illustrated in Fig. 5.19. The alignment of North Wambo Creek and the creek diversion is shown as the blue line in this figure.

The predicted extents of the mining-induced topographical depressions are also illustrated in Fig. 5.19, as the cyan hatching, based on the predicted post mining surface level contours. The actual extents and depths of increased ponding in these locations are dependent on a number of other factors, including rainfall, catchment sizes, surface water runoff, infiltration and evaporation and, therefore, these are expected to be smaller than the topographical depressions.

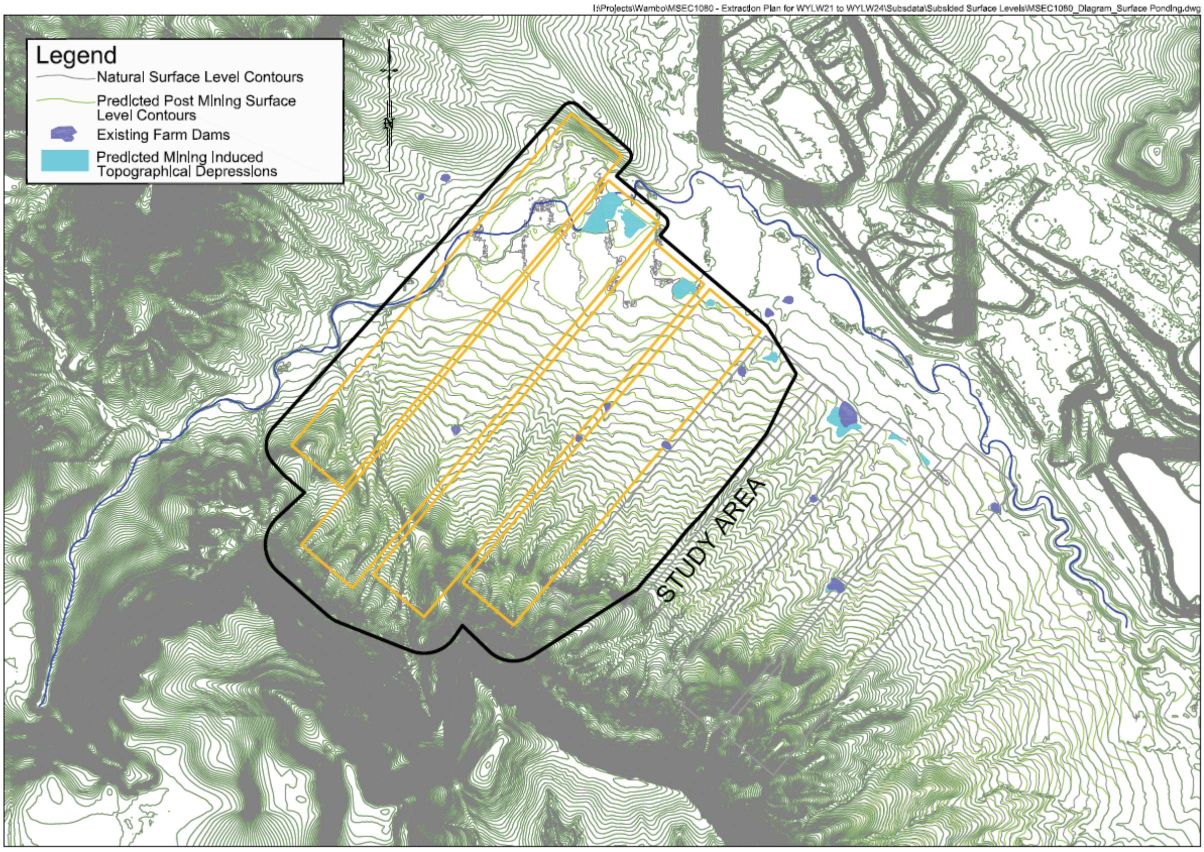


Fig. 5.19 Natural and predicted subsided surface levels and predicted mining-induced topographical depressions

Mining-induced topographical depressions are predicted to develop above the finishing (i.e. north-eastern) ends of the proposed WYLW21 to WYLW24, as indicated by the cyan hatching. The topographical depressions are predicted to have depths up to approximately 1.6 m and surface areas up to approximately 1.8 ha.

The actual depths and extents of increased ponding in these locations are expected to be less than the predicted topographical depressions due to the various other factors described previously. The potential for increased ponding along the alignments of North Wambo Creek and typical drainage lines are discussed further in Section 5.2.4.

There are no predicted topographical depressions (i.e. areas of increased ponding) away from the finishing ends of the proposed longwalls, apart from the isolated locations along the drainage lines. It is not considered, therefore, that the land across the Study Area is naturally susceptible to flooding or inundation.

5.9. Water related ecosystems

There are water related ecosystems associated with the drainage within the Study Area, which are described and assessed in the report prepared by FloraSearch (2017).

5.10. Threatened or protected species

An investigation of the flora and fauna within the Study Area has been undertaken, which is described and assessed in the reports prepared by FloraSearch (2017) and Eco Logical Australia (2017).

5.11. National Parks or wilderness areas

The *Wollemi National Park* is located to the south and to the west of the proposed longwalls. The boundary of the National Park is located at a distance of 150 m from the commencing (i.e. south-western) ends of WYLW23 and WYLW24, at its closest points. The location of the National Park is shown in Drawings Nos. MSEC1080-01, MSEC1080-02, MSEC1080-08 and MSEC1080-09.

The land within the National Park is predicted to experience less than 20 mm vertical subsidence due to the mining of the proposed WYLW21 to WYLW24, i.e. the boundary is located outside of the limit of vertical subsidence. The magnitude of the predicted vertical subsidence is similar to the natural movements that occur due to the wetting and drying of the surface soils. Whilst the National Park could experience very low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains.

The Wollemi National Park could experience low level far-field horizontal movements. It can be seen from Fig. 5.16, that the National Park could experience total far-field horizontal movements up to 150 mm, based on the 95 % confidence level. These movements are expected to be bodily movements towards the extracted longwalls and are not expected to be associated with measurable strains.

It is unlikely, therefore, that the Wollemi National Park would experience adverse impacts due to the vertical or far-field horizontal movements, even if these predictions were exceeded by a factor of two times. The predictions and impact assessments for the Wollemi Escarpment (i.e. the cliffs along the boundary of the National Park) are provided in Section 5.5.

The drainage lines within the National Park are generally located at distances greater than 400 m from the proposed longwalls. There are small sections of drainage lines (total length of approximately 0.3 km) that are located at distances less than 400 m from the commencing ends of WYLW23 and WYLW24.

While minor and isolated fracturing have been observed up to around 400 m from longwall mining in the NSW coalfields, these have occurred within very incised river valleys within the Southern Coalfield and have had no adverse impacts on the streams. The drainage lines within the National Park are on top of the escarpment (i.e. small valley heights) and, therefore, it is unlikely that mining-induced fracturing would occur at these distances from the proposed longwalls.

It is unlikely that there would be any adverse impacts to the Wollemi National Park, even if the predictions were exceeded by a factor of two times.

5.12. Natural vegetation

There is natural vegetation located above the south-western ends of the proposed longwalls, as can be seen from the aerial photograph in Fig. 1.2. The land has been largely cleared above the north-eastern ends of the proposed longwalls. A detailed survey of the natural vegetation has been undertaken and is described and assessed in the report prepared by FloraSearch (2017).

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

6.1. Public utilities

As listed in Table 2.1, there were no public utilities identified within the Study Area, apart from the unsealed roads and the associated drainage culverts, which are described below.

6.1.1. Unsealed roads

There are unsealed tracks and fire trails located within the Study Area. The locations of these roads are shown in Drawing No. MSEC1080-09. The unsealed roads are used for the mining operations and for firefighting activities. Circular concrete culverts have been constructed, in some locations, where the roads cross the drainage lines.

The unsealed tracks and trails are located across the proposed mining area and, therefore, could 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.

It is expected that cracking, rippling and stepping of the unsealed road surfaces would occur as each of the longwalls mine beneath them. The largest impacts will occur in the north-eastern part of the Study Area, where the depths of cover are the shallowest. Examples of impacts observed along the tracks located above WYLW11 to WYLW13 and WYLW17 are provided in Section 4.7. The crack widths above these longwalls typically varied between 25 mm and 50 mm, with localised crack widths up to approximately 400 mm.

The impacts on the unsealed tracks and fire trails due to the proposed longwalls are expected to be similar to those observed due to WYLW11 to WYLW13 and WYLW17. It is expected that the roads could be maintained in safe and serviceable condition throughout the mining period using normal road maintenance techniques.

The drainage culverts could experience the full range of predicted subsidence movements. The predicted tilts could result in a reduction or, in some cases, a reversal of grade of the drainage culverts. In these cases, the culverts would need to be re-established to provide the minimum required grades. The predicted curvatures and ground strains could result in cracking of the concrete culverts. It may be necessary to repair, or in some cases, replace the affected culverts.

There are existing management strategies for maintaining the unsealed roads that are located above the previously extracted longwalls at the Wambo Coal Mine. It is expected that these same strategies could be used to maintain the unsealed roads which are located directly above the proposed WYLW21 to WYLW24. It is recommended that these roads are periodically visually inspected during active subsidence.

6.2. Public amenities

As listed in Table 2.1, there were no public amenities identified within the Study Area.

6.3. Farm land and facilities

6.3.1. Agricultural utilisation

There is no major farm land or agricultural utilisation identified within the Study Area. The land above the north-eastern ends of the proposed longwalls has been cleared and is used for light grazing. There are also some farm features located within the Study Area, which are described in the following sections.

6.3.2. Fences

Fences are located across the Study Area and, therefore, they are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence parameters within the Study Area is provided in Chapter 4.

Wire fences can be affected by tilting of the fence posts and by changes of tension in the fence wires due to strain as mining occurs. These types of fences are generally flexible in construction and can usually tolerate tilts of up to 10 mm/m and strains of up to 5 mm/m without significant impacts.

It is likely, therefore, that some of the wire fences within the Study Area would be impacted as the result of the extraction of the proposed longwalls. Any impacts on the wire fences could be remediated by re-tensioning the fencing wire, straightening the fence posts, and if necessary, replacing some sections of fencing.

The management strategies for the fences should be incorporated into the Built Features Management Plan.

6.3.3. Farm dams

There are four farm dams (Refs. d07, d08, d09 and d10) that have been identified within the Study Area and their locations are shown in Drawing No. MSEC1080-09. The proposed Montrose Water Storage Dam is located outside the Study Area and it is not predicted to experience measurable subsidence effects due to the mining of the proposed longwalls.

The farm dams are typically of earthen construction and have been established by localised cut and fill operations within the natural drainage lines. The surface areas of the dams vary between 460 m^2 and 870 m^2 and the maximum lengths vary between 37 m and 53 m. The dams within the Study Area are all located on WCPL owned land.

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the farm dams is provided in Table 6.1. The values represent the maximum predicted accumulated movements within 20 m of the perimeters of the dams due to the extraction of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24.

Table 6.1 Maximum predicted total vertical subsidence, tilt and curvatures for the farm dams

Location	Ref.	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Farm dams	d07	1700	65	> 3.0	> 3.0
	d08	550	35	2.5	1.0
	d09	250	10	0.6	0.5
	d10	250	7	0.7	0.3

The maximum predicted conventional strains for Dam d07, based on applying a factor of 10 to the maximum predicted curvatures, are greater than 30 mm/m tensile and compressive. The maximum predicted conventional strains for Dam d08 are 25 mm/m tensile and 10 mm/m compressive and for Dams d09 and d10 are 7 mm/m tensile and 5 mm/m compressive.

The farm dams within the Study Area are generally located between the mid-lengths and the finishing (i.e. north-eastern) ends of the longwalls. The depths of cover in the locations of these dams vary between 80 m and 120 m. The distribution of strain therefore is similar to but slightly less than that predicted above the longwall finishing ends, as described in Section 4.4.2. The predicted strains for the farm dams based on the 95 % confidence levels are 12 mm/m tensile and 17 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 maximum predicted subsidence effects for the farm dams, based on the current longwall layout (i.e. Report No. MSEC1080), are similar to the maximum predicted values based on the layout adopted in the SBEUM Modification and Report No. MSEC848. The predicted subsidence effects for the dams are similar as they are located away from the modified longwall finishing ends.

The predicted final tilts for the farm dams vary between 7 mm/m (i.e. 0.7 % or 1 in 143) and 65 mm/m (i.e. 6.5 % or 1 in 15). Mining-induced tilts can affect the water levels around the perimeters of farm dams, with the freeboard increasing on one side and decreasing on the other. The predicted final changes in freeboard for the farm dams vary from less than 0.1 m to 0.5 m.

The maximum predicted change in freeboard of 0.5 m occurs at Dam d07. The direction of tilt at this dam is transverse to the longwalls (i.e. north-west to south-east) and, therefore, it is orientated parallel to the dam wall. The predicted changes in freeboard for the remaining dams within the Study Area are less than 0.1 m. It is unlikely, therefore, that the predicted tilts would adversely impact on the water storage capacities of the farm dams.

It is expected, at the magnitudes of predicted curvatures and strains, that fracturing and buckling would occur in the uppermost bedrock beneath the natural surface soils. Surface cracking could also occur in the cohesive soils forming the bases and walls of the dams, especially where the depths to bedrock are relatively shallow. It may be necessary to remediate some of the farm dams, at the completion of mining, by excavating and re-establishing cohesive material in the beds of the farm dams to reduce permeability.

It is recommended that the farm dams are visually inspected during active subsidence.

6.3.4. Registered groundwater bores

The registered groundwater bores within the Study Area are shown in Drawing No. MSEC1080-09. The locations and details of these bores were obtained from the Australian Groundwater Explorer, which is publicly available online (BoM, 2020).

WCPL owns two monitoring bores (Refs. GW200831 and GW200832) that are located above and near to the finishing (i.e. north-eastern) ends of the proposed WYLW23 and WYLW24. These two bores could be adversely impacted due to the mining of the proposed longwalls. Impacts could include temporary lowering of the piezometric surface, blockage of the bore due to differential horizontal displacements at different horizons within the strata and changes to groundwater quality.

There were no other registered groundwater bores identified within the Study Area.

6.4. Industrial, commercial or business establishments

As listed in Table 2.1, there were no Industrial, Commercial or Business Establishments identified within the Study Area, apart from the mine related infrastructure, which are described below.

6.4.1. Montrose Open Cut Pit

The Montrose Open Cut Pit, part of the Wambo Coal Mine, is located to the north-east of the proposed WYLW21 to WYLW24. The current extent of the pit is shown in Drawing No. MSEC1080-01. It is recommended that a geotechnical assessment of the highwall be undertaken based on the effects of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24.

6.4.2. Exploration drill holes

The locations of the exploration drill holes within the Study Area are shown in Drawing No. MSEC1080-09. The drill holes are located directly above and adjacent to the proposed longwalls and, therefore, could experience the full range of predicted subsidence movements, which were described in Chapter 4. It is likely, therefore, that fracturing and shearing would occur in the drill holes as the result of mining. It is recommended that the exploration drill holes are capped (if not already completed) prior to being directly mined beneath.

6.4.3. 11 kV powerline

An 11 kV powerline is proposed to be constructed by WCPL on the north-eastern side of the mining area, as shown in Drawing No. MSEC1080-09. The powerline is located at a distance of 85 m from the finishing end of WYLW21, at its closest point to the proposed longwalls.

The 11 kV powerline is predicted to experience less than 20 mm vertical subsidence due to the proposed mining. While the powerline could experience very low level vertical subsidence, it is not predicted to experience measurable tilts, curvatures or strains. No adverse impacts on the 11 kV powerline are anticipated due to the mining of the proposed WYLW21 to WYLW24.

6.4.4. Ventilation shaft

A ventilation shaft is being constructed by WCPL on the north-eastern side of the proposed WYLW21, as shown in Drawing No. MSEC1080-09. The shaft is located 70 m from the finishing end of the proposed longwall and it is located outside the 26.5° angle of draw. The predicted vertical subsidence at the surface is less than 20 mm. While the top of the shaft could experience very low level vertical subsidence, it is not predicted to experience measurable tilts, curvatures or strains.

The fans associated with the shaft could be sensitive to the low level tilt. Also, the shaft could experience differential horizontal shear over its height. It is recommended that WCPL develop monitoring and management strategies to maintain the shaft and the associated infrastructure in serviceable conditions during the mining period.

6.5. Aboriginal heritage sites

6.5.1. Descriptions of the Aboriginal heritage sites

There are no lands within the Study Area declared as an Aboriginal Place under the *National Parks and Wildlife Act 1974*. There are 14 Aboriginal heritage sites that have been identified within the Study Area, comprising ten open artefact sites, three rock shelters with Potential Archaeological Deposits (PADs) and one scarred tree.

The locations of the Aboriginal heritage sites are shown in Drawing No. MSEC1080-09. The site types are shown in Table 6.2. Further details on the Aboriginal heritage sites are provided in the report by South East Archaeology (2017).

6.5.2. Predictions for the Aboriginal heritage sites

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for each of the Aboriginal heritage sites located within the Study Area is provided in Table 6.2. The values represent the maximum predicted accumulated movements within 20 m of the locations of the sites due to the extraction of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24.

Table 6.2 Maximum predicted total vertical subsidence, tilt and curvatures for the Aboriginal heritage sites within the Study Area

Site reference	Site type	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})
Wambo Site 240	Open artefact site	1900	10	> 3.0	> 3.0
Wambo Site 241	Open artefact site	1300	75	> 3.0	> 3.0
Wambo Site 308	Open artefact site	< 20	< 0.5	< 0.01	< 0.01
Wambo Site 311	Open artefact site	1600	70	> 3.0	> 3.0
Wambo Site 324	Scarred tree	1700	60	> 3.0	> 3.0
Wambo Site 488	Open artefact site	1900	75	> 3.0	> 3.0
Wambo Site 489	Open artefact site	75	5	0.5	0.5
Wambo Site 491	Open artefact site	1700	45	> 3.0	> 3.0
Wambo Site 493	Open artefact site	1600	20	0.4	0.5
Wambo Site 496	Open artefact site	< 20	< 0.5	< 0.01	< 0.01
Wambo Site 498	Open artefact site	< 20	< 0.5	< 0.01	< 0.01
Wambo Site 499	Rock shelter with PAD	400	10	0.3	0.1
Wambo Site 503	Rock shelter with PAD	25	1	< 0.01	< 0.01
Wambo Site 504	Rock shelter with PAD	1500	20	0.5	0.5

A summary of the maximum predicted total subsidence effects for each site type of Aboriginal heritage site is provided in Table 6.3. The values represent the maximum predicted accumulated movements within 20 m of the locations of the sites due to the extraction of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24.

Table 6.3 Maximum predicted total vertical subsidence, tilts and curvatures for the Aboriginal heritage sites

Site type	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})
Open artefact sites	1900	75	> 3.0	> 3.0
Rock shelters with PADs	1500	20	0.5	0.5
Scarred tree	1700	60	> 3.0	> 3.0

The maximum predicted conventional strains for the Aboriginal heritage sites, based on applying a factor of 10 to the maximum predicted curvatures, are greater than 30 mm/m tensile and compressive for the open artefact sites and scarred tree, and 5 mm/m tensile and compressive for the rock shelters with PADs.

The range of strains will vary considerably across the extents of the proposed longwalls due to, amongst other factors, the variation in the depth of cover. The greatest strains are predicted to occur near the longwall finishing (i.e. north-eastern) ends where the depths of cover are shallowest. Lower strains are predicted to occur towards the longwall commencing (i.e. south-western) ends where the depths of cover are higher.

The distributions of strain above the proposed longwalls are described in Section 4.4. The predicted strains for the Aboriginal heritage sites located near the longwall commencing ends (refer to Section 4.4.1) are 5 mm/m tensile and 4 mm/m compressive based on the 95 % confidence levels. The predicted strains for the sites located near the longwall finishing ends (refer to Section 4.4.2) are 12 mm/m tensile and 17 mm/m compressive based on the 95 % confidence levels.

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

6.5.3. Comparison of the predicted subsidence effects for the Aboriginal heritage sites

The maximum predicted subsidence effects for the Aboriginal heritage sites, based on the current longwall layout (i.e. Report No. MSEC1080), are similar to or less than the maximum predicted values based on the layout adopted in the SBEUM Modification and Report No. MSEC848. The predicted subsidence effects do not change where the sites are located directly above the mining area. The predicted subsidence effects reduce where the sites are located outside the mining area due to the modified longwall finishing ends.

6.5.4. Impact assessments for the open artefact sites

There are ten sites within the Study Area comprising open artefact sites, being Wambo Sites 240, 241, 308, 311, 488, 489, 491, 493, 496 and 498.

The maximum predicted total tilt for the open artefact sites is 75 mm/m (i.e. 7.5 %, or 1 in 13). It is unlikely that these sites would experience adverse impacts resulting from the mining-induced tilts.

The maximum predicted total curvatures for the open artefact sites are greater than 3.0 km^{-1} hogging and sagging, which represents a minimum radius of curvature of less than 0.3 km. The maximum predicted strains for these sites are 12 mm/m tensile and 17 mm/m compressive based on the 95 % confidence levels.

The mining-induced curvatures and strains could result in surface cracking near the sites that are located directly above the mining area. It is unlikely, however, that the artefacts themselves would be adversely impacted by the surface cracking. It is possible, however, that if remediation of the surface was required after mining, that these works could potentially impact these sites.

It is recommended that WCPL seek the required approvals from the appropriate authorities, in the event that remediation of the surface is required in the locations of the open artefact sites. Further discussions on the potential impacts on the open artefact sites are provided in the report by South East Archaeology (2017).

6.5.5. Impact assessments for the rock shelters

Wambo Sites 499 and 504 are located directly above the proposed WYLW21 and WYLW22, respectively, towards the commencing (i.e. south-western) ends of these longwalls. The rock shelter at Wambo Site 499 is up to approximately 20 m wide, 17 m deep and 6 m high and it has formed within a conglomerate minor cliff. The rock shelter at Wambo Site 504 is up to approximately 3.5 m wide, 2.3 m deep and 1.8 m high at it has formed within a rock outcrop. Wambo Sites 499 and 504 are predicted to experience maximum curvatures of 0.5 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 2 km.

The predicted curvatures and strains in the locations of Wambo Sites 499 and 504 are likely to be sufficient to result in the fracturing of the conglomerate minor cliff and rock outcrop. It is extremely difficult to assess the likelihood of instabilities for the rock shelters based upon predicted ground movements. The likelihood of the shelters becoming unstable is dependent on a number of factors which are difficult to fully quantify. These factors include jointing, inclusions, weaknesses within the rockmass, groundwater pressure and seepage flow behind the rockface. Even if these factors could be determined, it would still be difficult to quantify the extent to which these factors may influence the stability of the shelter naturally or when it is exposed to mine subsidence effects.

It has been estimated that approximately 7 % to 10 % of the total length, or approximately 3 % to 5 % of the total face area, of the Low Level Cliffs located directly above the mining area could be impacted (refer to Section 5.5.5). The potential impacts on the rock outcrops are considerably less due to their discontinuous nature.

Wambo Site 499 is up to approximately 20 m wide and it represents a large proportion of the length of the discontinuous minor cliff. The potential for adverse impacts at this rock shelter, therefore, has been assessed as possible (i.e. greater than 25 %). It is noted that this assessment represents the likelihood of adverse fracturing and spalling being coincident with the rock shelter.

Wambo Site 504 is a considerably smaller rock shelter that has formed within an isolated rock outcrop. The potential for adverse impacts (i.e. fracturing and spalling) at this rock shelter, therefore, has been assessed as very unlikely (i.e. less than 10 %).

Wambo Site 503 is located outside the mining area at a distance of approximately 70 m from the commencing (i.e. south-western) end of the proposed WYLW23. At this distance, the site is predicted to experience 25 mm of vertical subsidence. While this site could experience very low levels of vertical subsidence, it is unlikely to experience measurable conventional tilts, curvatures or strains.

Wambo Site 503 is a small rock shelter (up to approximately 2.4 m wide, 3.6 m deep and 1.5 m high) and it has formed within a conglomerate rock outcrop. The isolated rock feature is not expected to be sensitive to the predicted low level of vertical subsidence in this location. The potential for adverse impacts (i.e. fracturing and spalling) at this rock shelter, therefore, has been assessed as rare (i.e. less than 5 %).

Further discussions on the potential impacts on the Rock Shelters with PADs are provided in the report prepared by South East Archaeology (2017).

6.5.6. Impact assessments for the scarred tree

The scarred tree (Wambo Site 324 St 1) is located directly above the proposed WYLW21 towards the finishing (i.e. north-eastern) end of this longwall.

It has been found, from past longwall mining experience, that the incidence of impacts on trees is extremely rare. Impacts in the Hunter and Newcastle Coalfields have been observed where the depths of cover are shallow and/or where the surface terrain is very steep. The depth of cover to the Whybrow Seam in the location of the scarred tree is 75 m. The natural surface in the location of the scarred tree is relatively flat, with a natural gradient of approximately 1 in 30 (i.e. 3 % or 2°).

The size and extent of surface cracking in the vicinity of the scarred tree is expected to be similar to that observed near the finishing ends of WYLW11 to WYLW13 and WYLW17 (refer to Section 4.7). The likelihood that surface cracking would be coincident with the tree is considered low. It is considered very unlikely (i.e. less than 10 %), therefore, that the scarred tree would experience adverse impacts due to the mining of the proposed longwalls.

Further discussions on the potential impacts on the scarred tree are provided in the report prepared by South East Archaeology (2017).

6.6. State survey control marks

The locations and details of the state survey control marks were obtained from *Spatial Services* using the *SCIMS Online* website (SCIMS, 2020). There are two state survey control marks identified within the Study Area (Refs. SS119671 and TS12077), the locations of which are shown in Drawing No. MSEC1080-09. There are additional state survey control marks identified further afield, including within the Montrose Open Cut Pit.

The survey control marks located in the area could be affected by far-field horizontal movements, up to 3 km outside the extents of the longwalls. Far-field horizontal movements and the methods used to predict such movements are described further in Sections 3.3 and 4.5.

It will be necessary on the completion of the longwalls, when the ground has stabilised, to re-establish any survey control marks that are required for future use. Consultation between WCPL and Spatial Services will be required to ensure that these survey control marks are reinstated at the appropriate time, as required.

6.7. Building structures

6.7.1. Description of the building structures

The Whynot Homestead is located above the proposed WYLW21. The homestead is a single storey timber framed structure, supported on timber piers, with timber and fibro wall claddings and a metal sheeted roof. An external brick chimney is located on the southern façade of the homestead. The structure is in poor condition and is currently unoccupied. Photographs of the Whynot Homestead are provided in Fig. 6.1. WCPL completed an archival recording of the Whynot Homestead in 2017.

Fig. 6.1 Whynot Homestead

There are other building structures associated with the Whynot Homestead, including timber framed sheds with metal sheet cladding and water storage tanks.

6.7.2. Predictions for the building structures

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the building structures is provided in Table 6.4. The values represent the maximum predicted accumulated movements within 20 m of the mapped extents of the perimeters of the structures due to the extraction of the approved WYLW17 to WYLW20 and the proposed WYLW21 to WYLW24.

Table 6.4 **Maximum predicted total vertical subsidence, tilt and curvatures for the building structures**

Location	Description	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})
Building structures above WYLW21	Whynot Homestead	1800	5	> 3.0	> 3.0
	Sheds and tanks	1800	60	> 3.0	> 3.0

The maximum predicted conventional strains for the building structures, based on applying a factor of 10 to the maximum predicted curvatures, are greater than 30 mm/m tensile and compressive. The depths of cover in the locations of these building structures vary between 90 m and 100 m. The distribution of strain therefore is similar to but slightly less than that predicted above the longwall finishing ends, as described in Section 4.4.2. The predicted strains for the building structures based on the 95 % confidence levels are 12 mm/m tensile and 17 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.

6.7.3. Comparison of the predicted subsidence effects for the building structures

The maximum predicted subsidence effects for the building structures, based on the current longwall layout (i.e. Report No. MSEC1080), are the same as the maximum predicted values based on the layout adopted in the SBEUM Modification and Report No. MSEC848. The predicted subsidence effects for the building structures have not changed as they are located away from the modified longwall finishing ends.

6.7.4. Impact assessments for the building structures

The Whynot Homestead is predicted to experience a final tilt of 5 mm/m (i.e. 0.5 % or 1 in 200) at the completion of mining. The homestead is also predicted to experience a transient tilt of approximately 30 mm/m (i.e. 3 % or 1 in 33) as the extraction face of WYLW21 mines directly beneath it. The homestead is a single storey timber framed structure with lightweight cladding. It is unlikely, therefore, that the main structure would become unstable or unsafe as a result of the mining-induced tilt. It is recommended, however, that the brick chimney is visually monitored during active subsidence to identify if the mining-induced tilt adversely effects its integrity.

The homestead could experience curvatures greater than 3.0 km^{-1} (i.e. minimum radius of curvature less than 0.3 km) and strains greater than 30 mm/m. The structure is supported above the natural ground on timber piers. The predicted ground movements could result in the distortion of the timber frames and it is possible that the structure could become unsafe due to its poor existing condition. The mining-induced impacts could be minimised by packing between the main structure and the piers during active subsidence so as to maintain the floor as planar.

The sheds and tanks associated with the Whynot Homestead could experience tilts up to 60 mm/m (i.e. 6.0 % or 1 in 17), curvatures greater than 3.0 km^{-1} (i.e. minimum radius of curvature less than 0.3 km) and strains greater than 30 mm/m. The predicted ground movements could result in the distortion of the timber frames and it is also possible that some structures become unsafe due to their poor existing conditions.

It is recommended that the Whynot Homestead and associated structures are visually monitored during active subsidence as WYLW21 mines directly beneath them. If any structure is identified as unstable or unsafe during mining, then measures should be undertaken to prevent access (i.e. install temporary fencing) until such time it is made safe, or the structure is removed.

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

Glossary of terms and definitions

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

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

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

APPENDIX B. REFERENCES

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APPENDIX C. FIGURES

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to WYLW17 to WYLW24

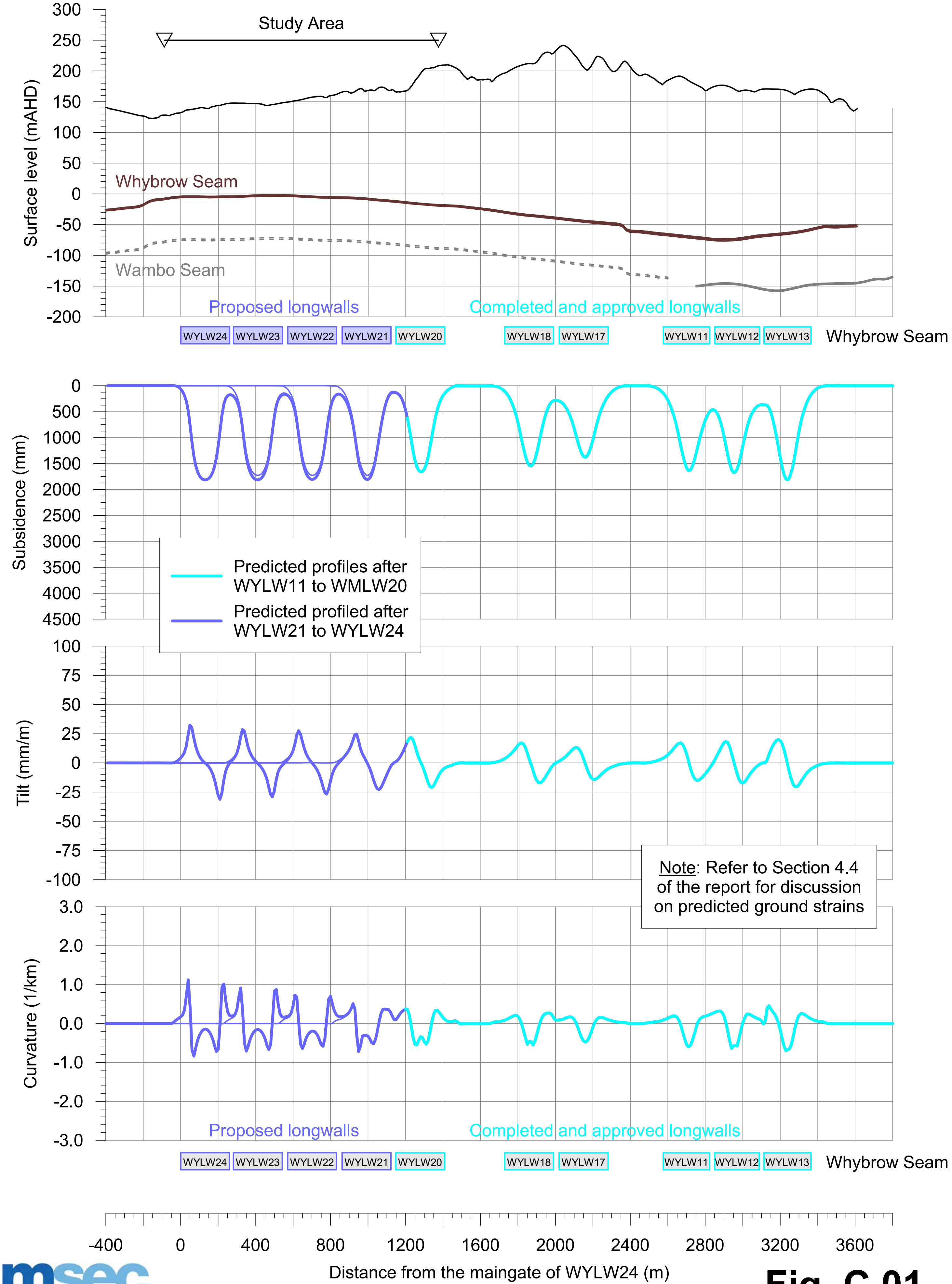

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Fig. C.01

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to WYLW17 to WYLW25

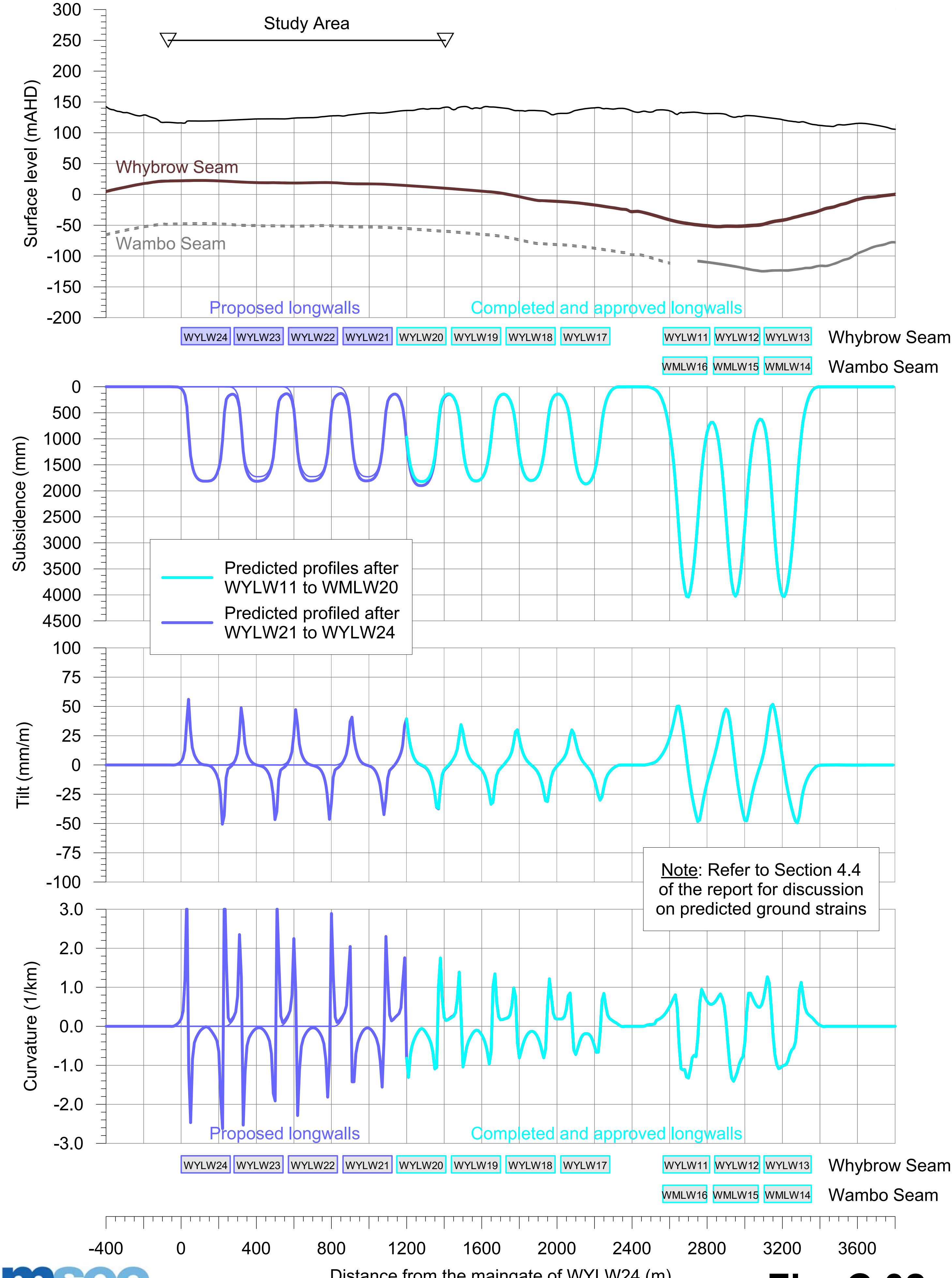

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Fig. C.02

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 3 due to WYLW17 to WYLW25

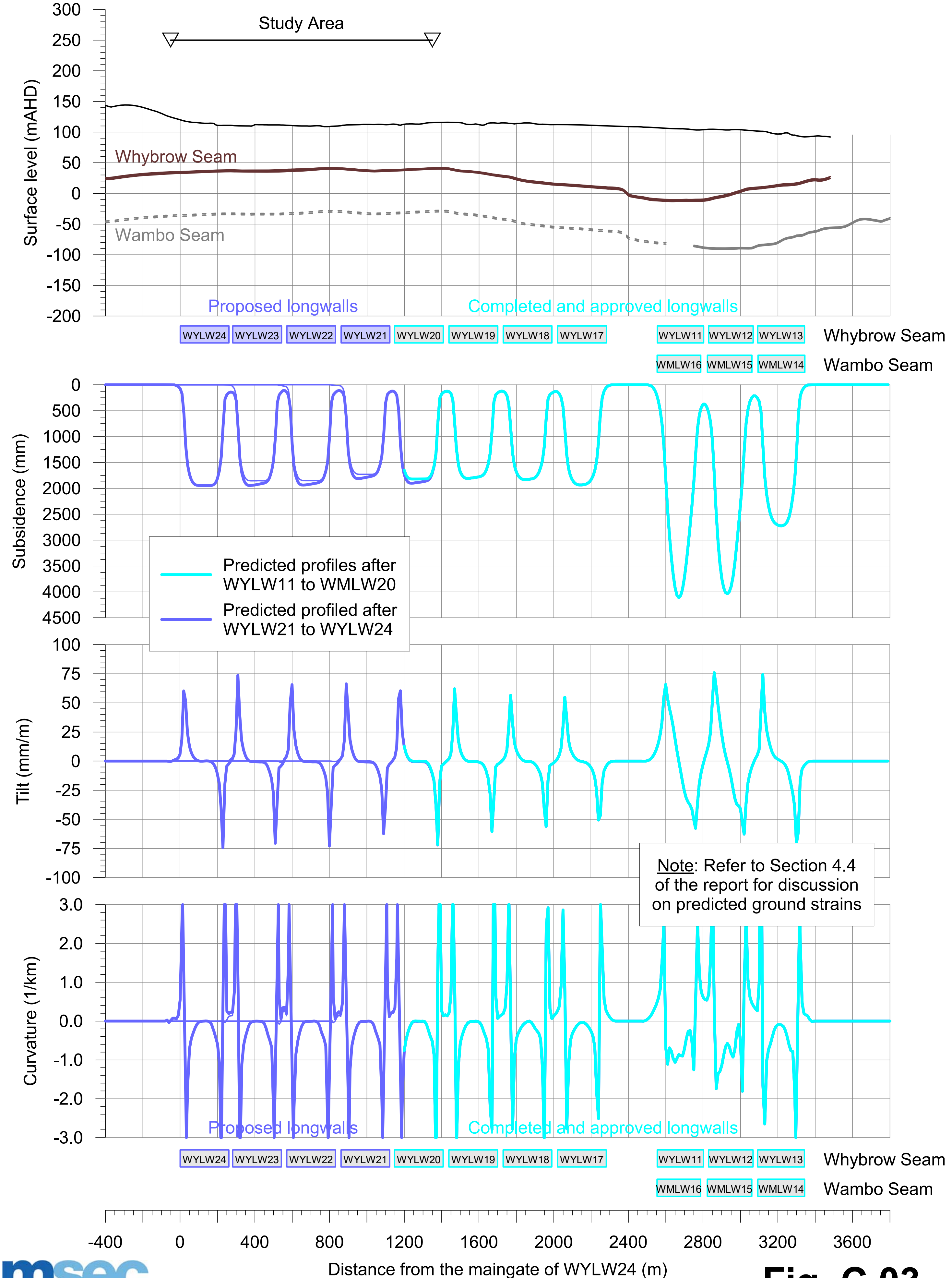

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Fig. C.03

Predicted profiles of vertical subsidence, tilt and curvature along North Wambo Creek due to WYLW17 to WYLW24

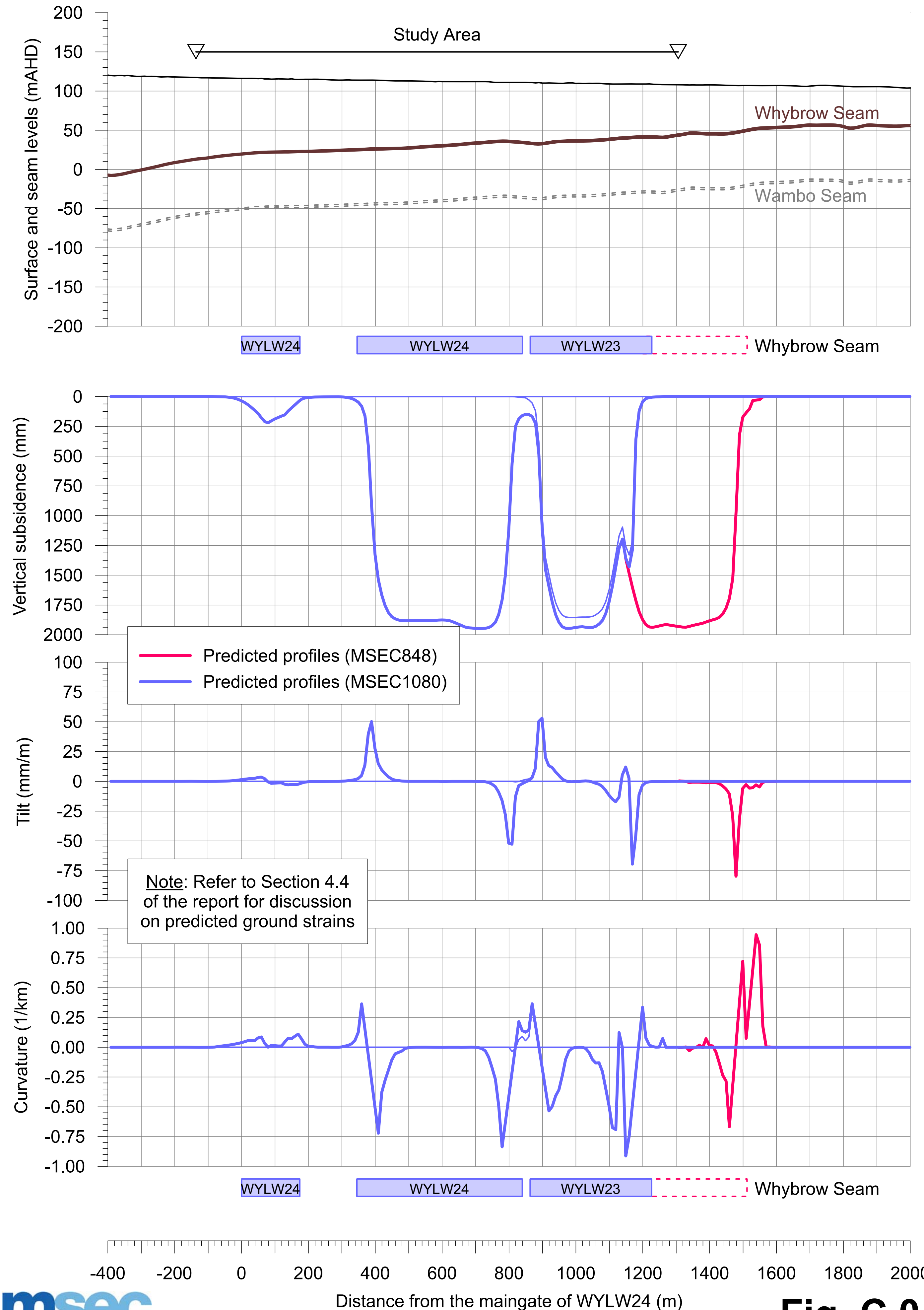

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Fig. C.04

APPENDIX D. DRAWINGS

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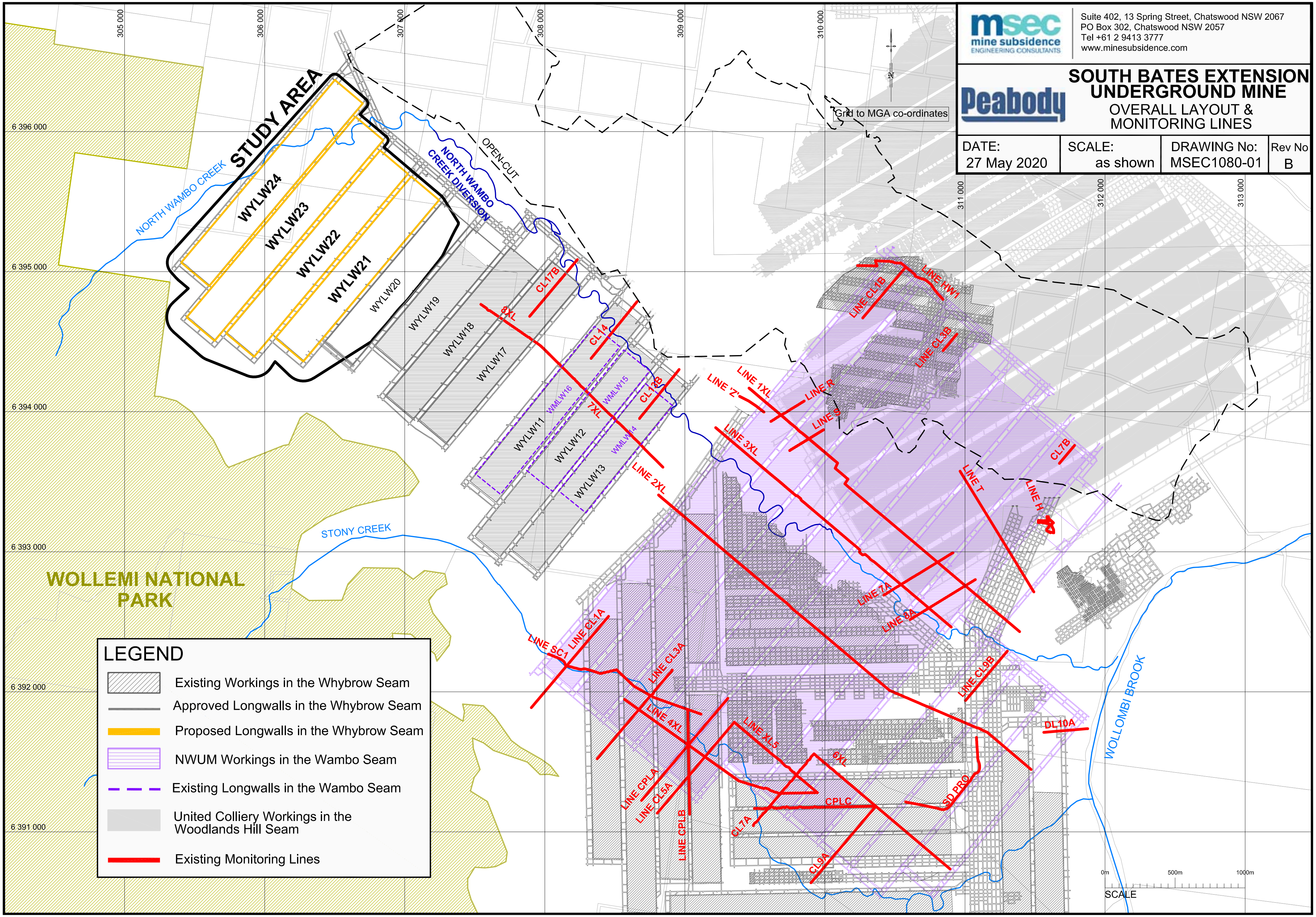

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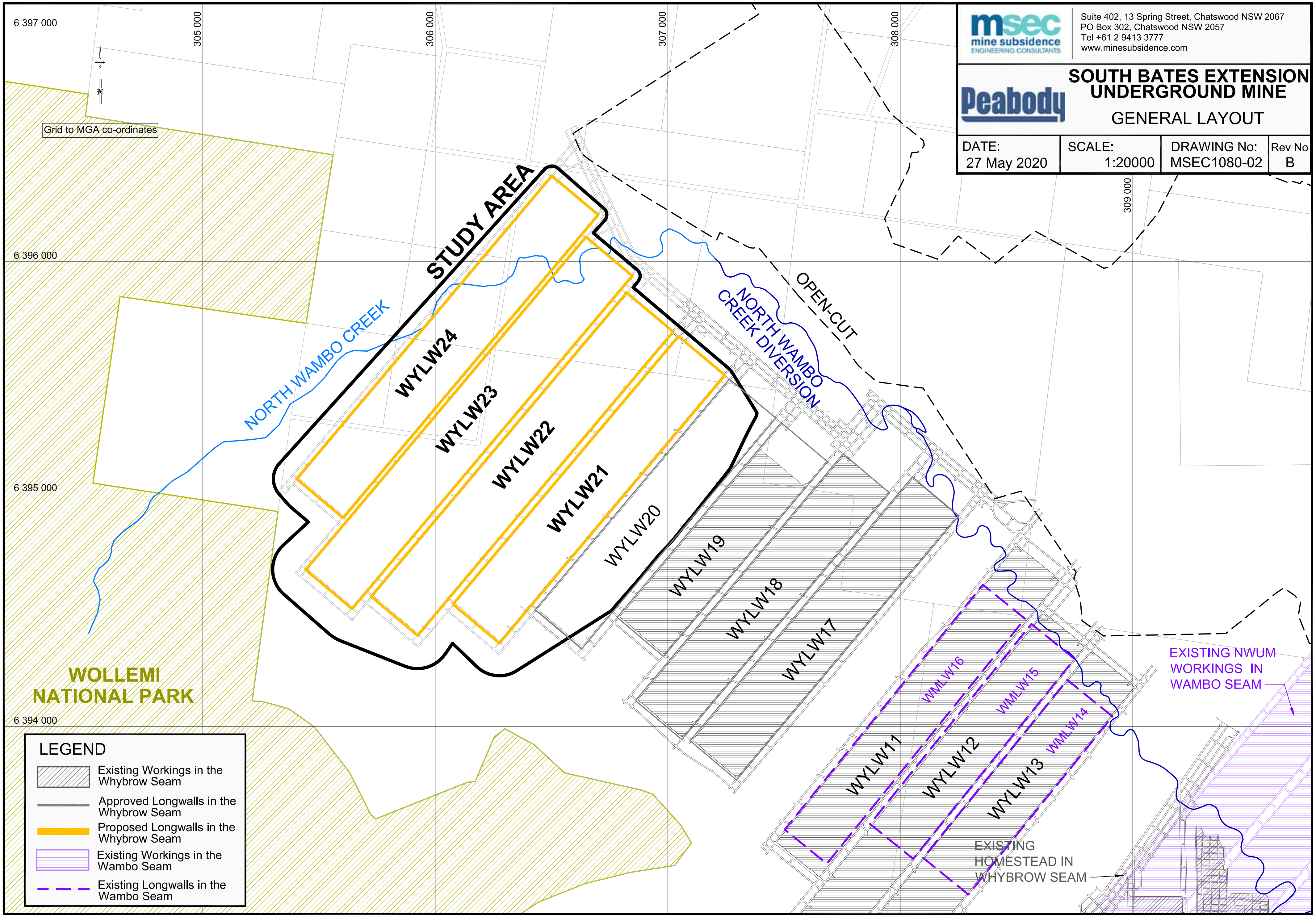

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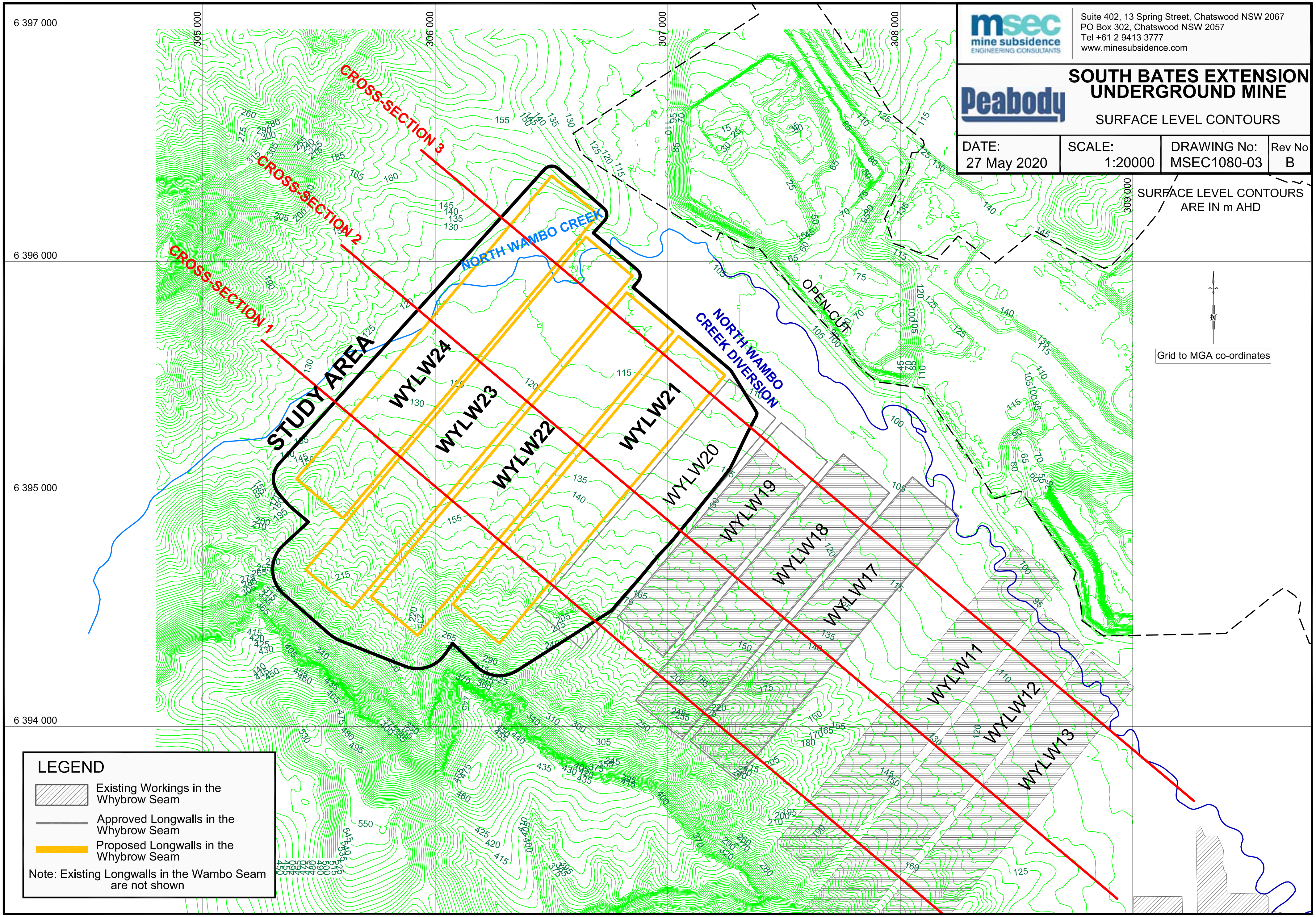

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PO Box 302, Chatswood NSW 2057
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SOUTH BATES EXTENSION UNDERGROUND MINE

SURFACE LEVEL CONTOURS

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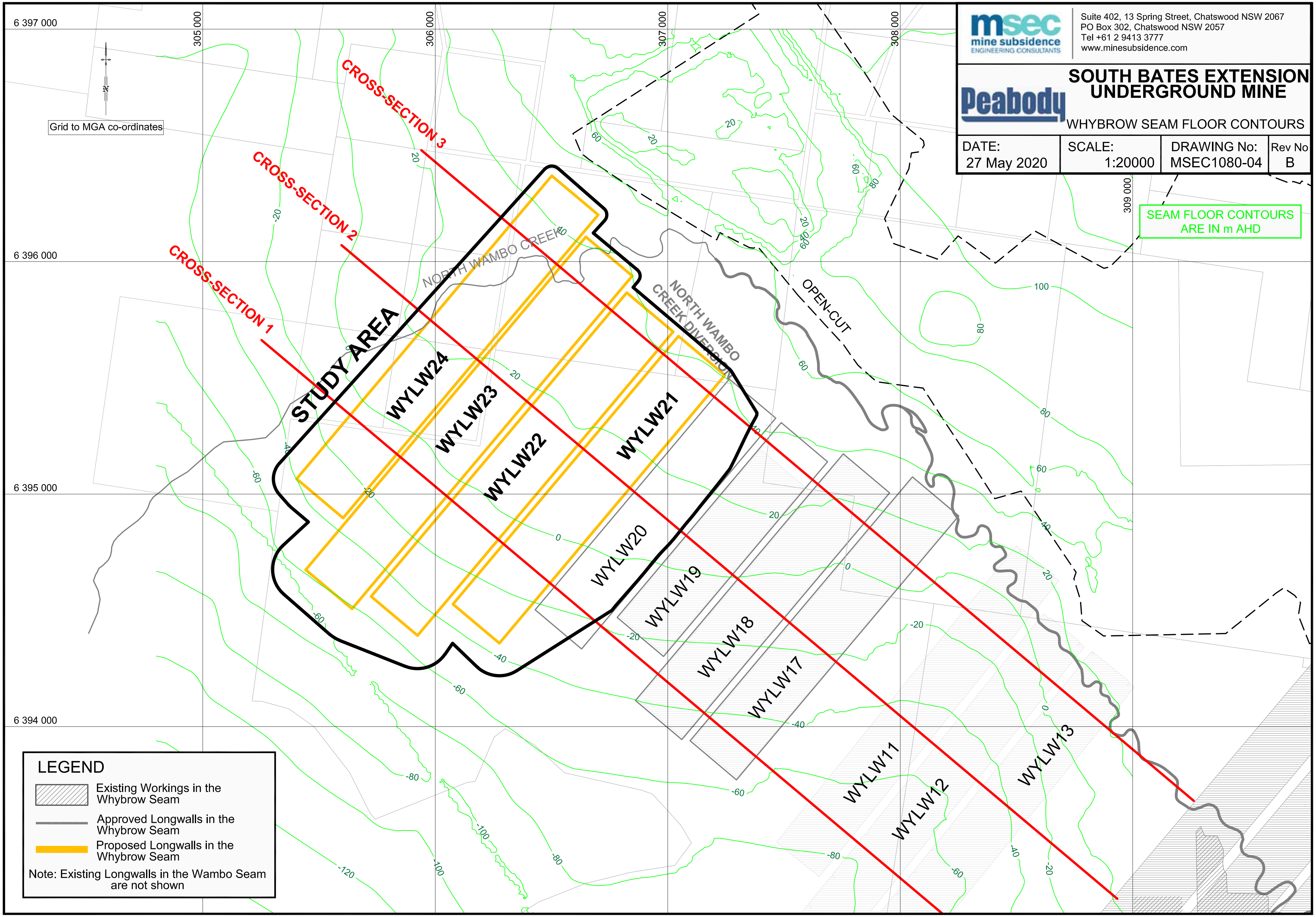

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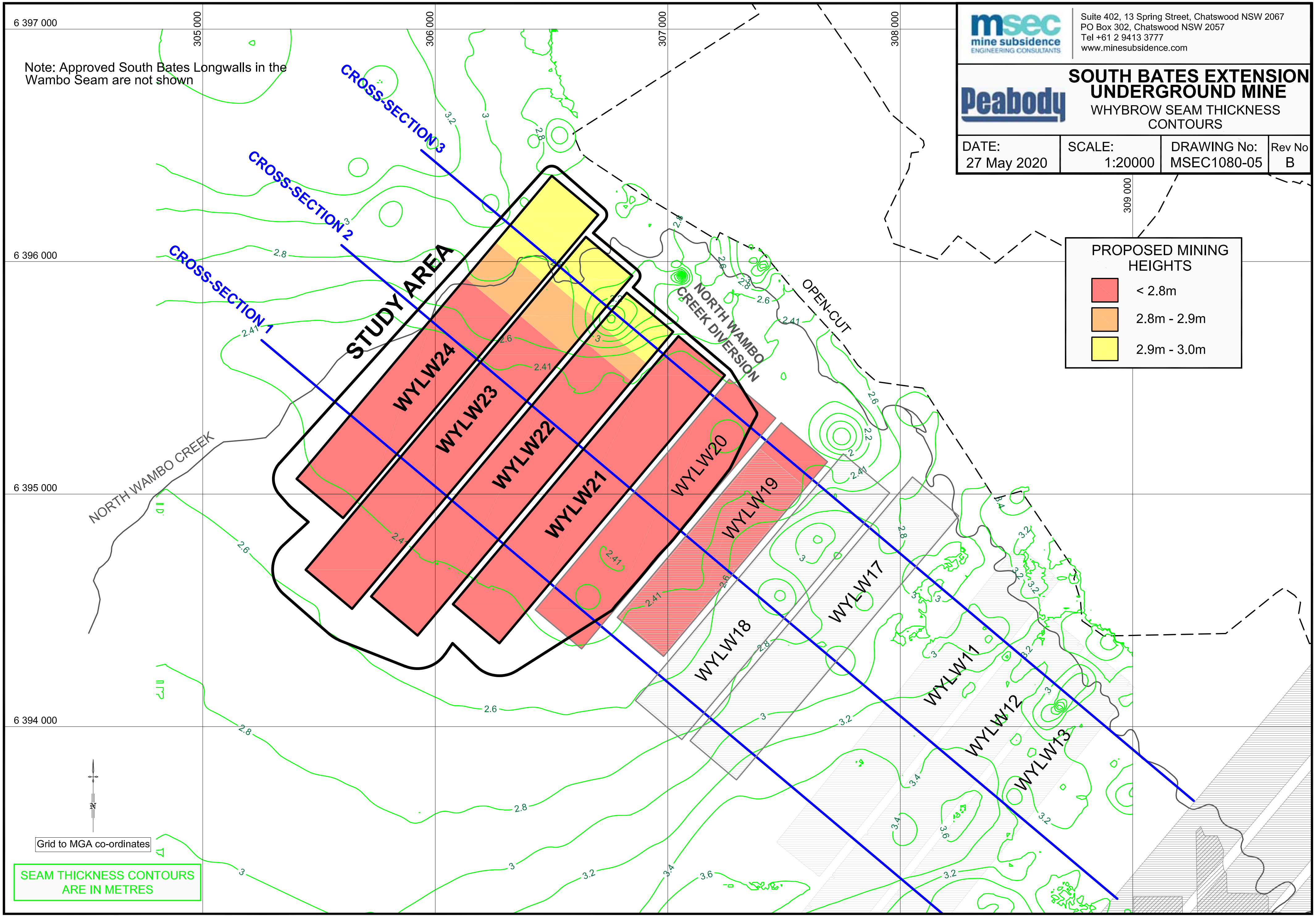

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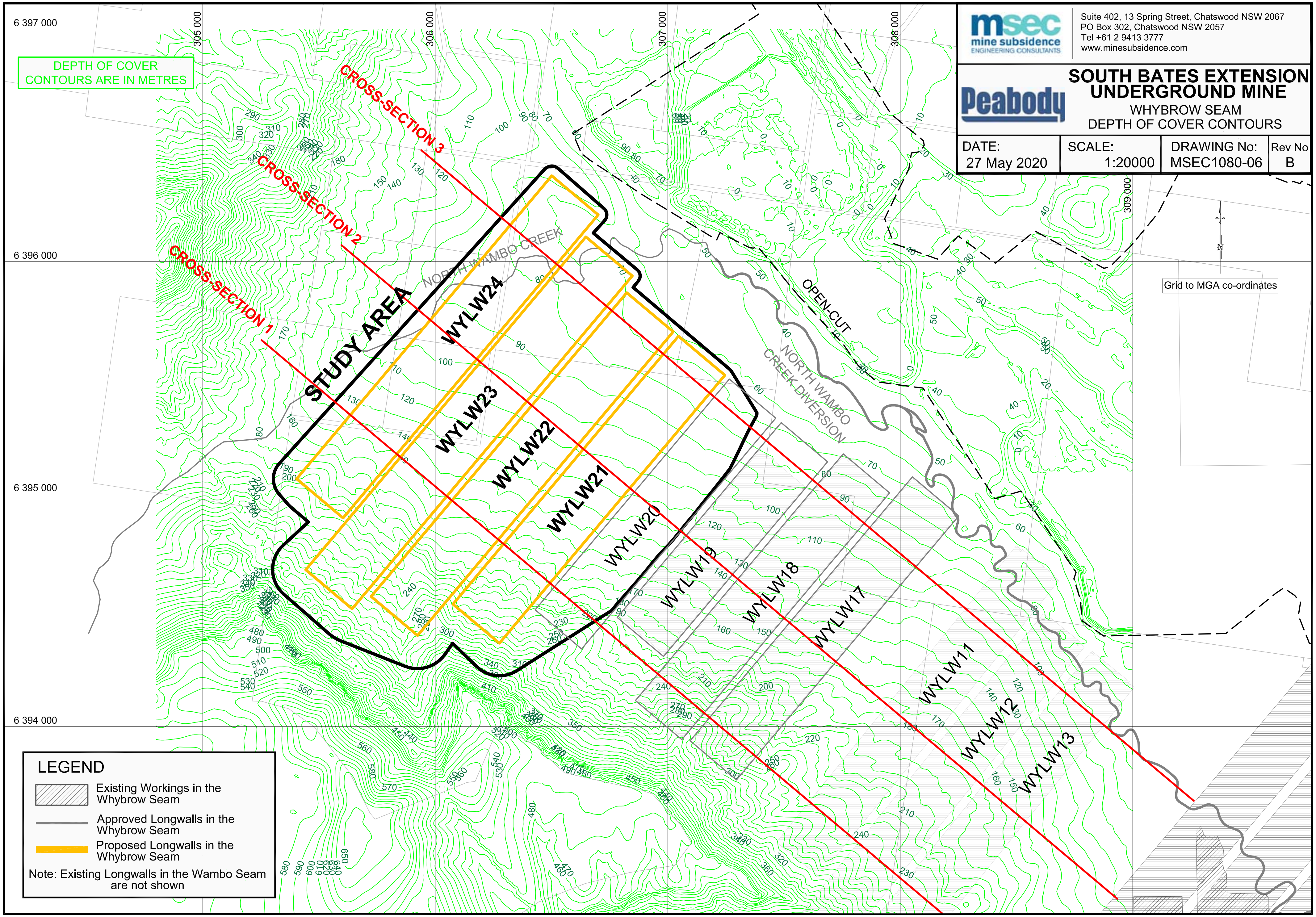

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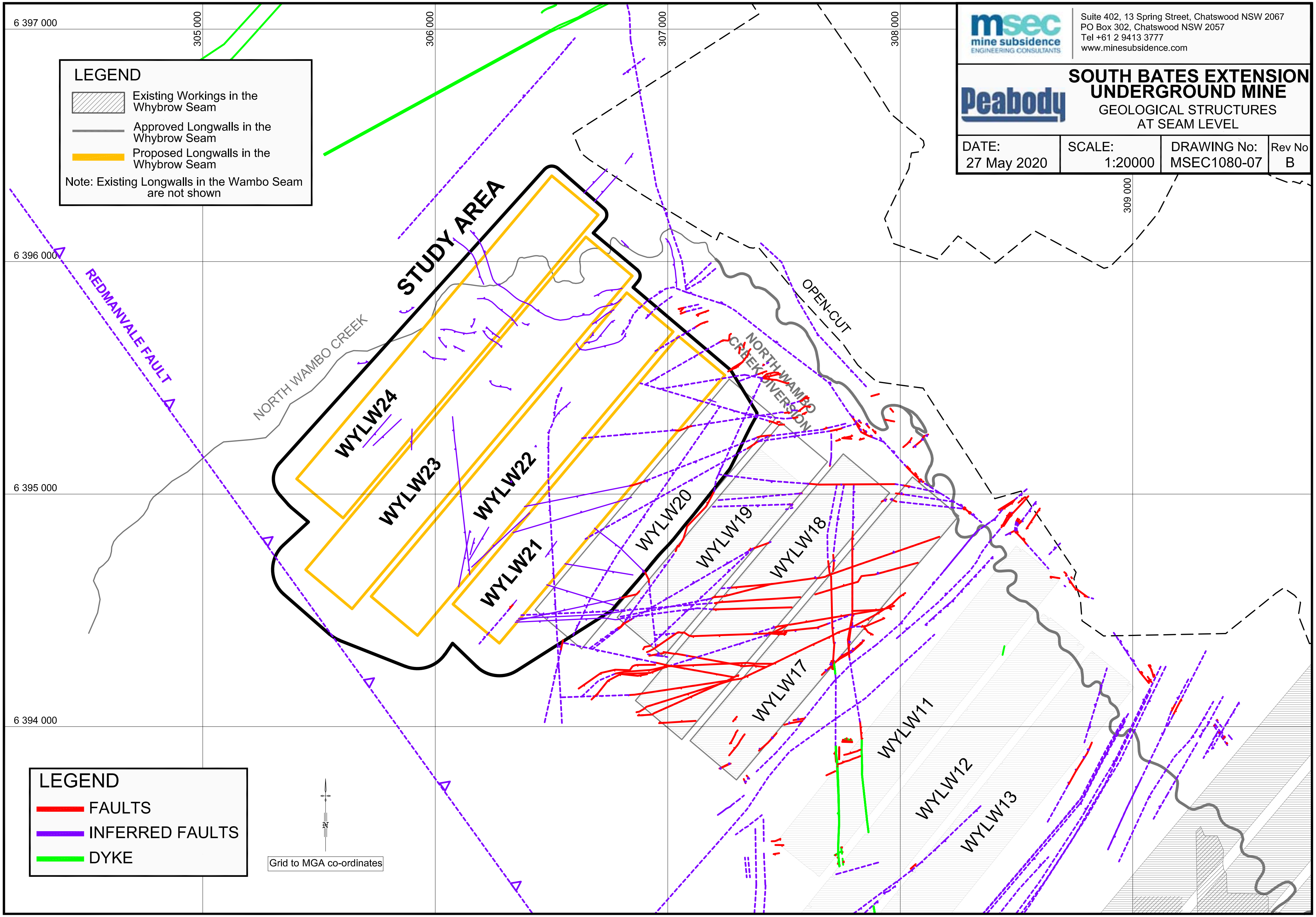

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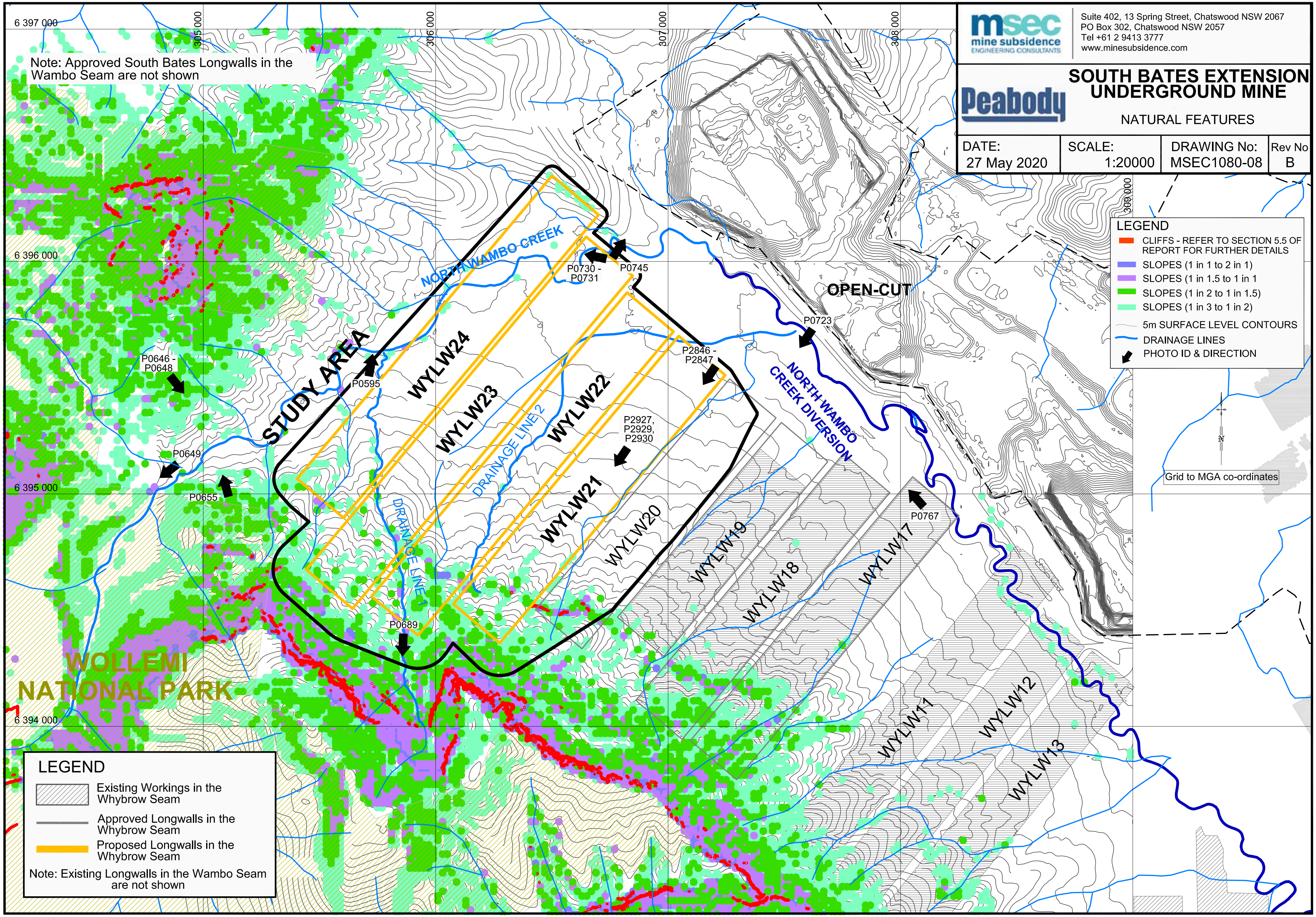

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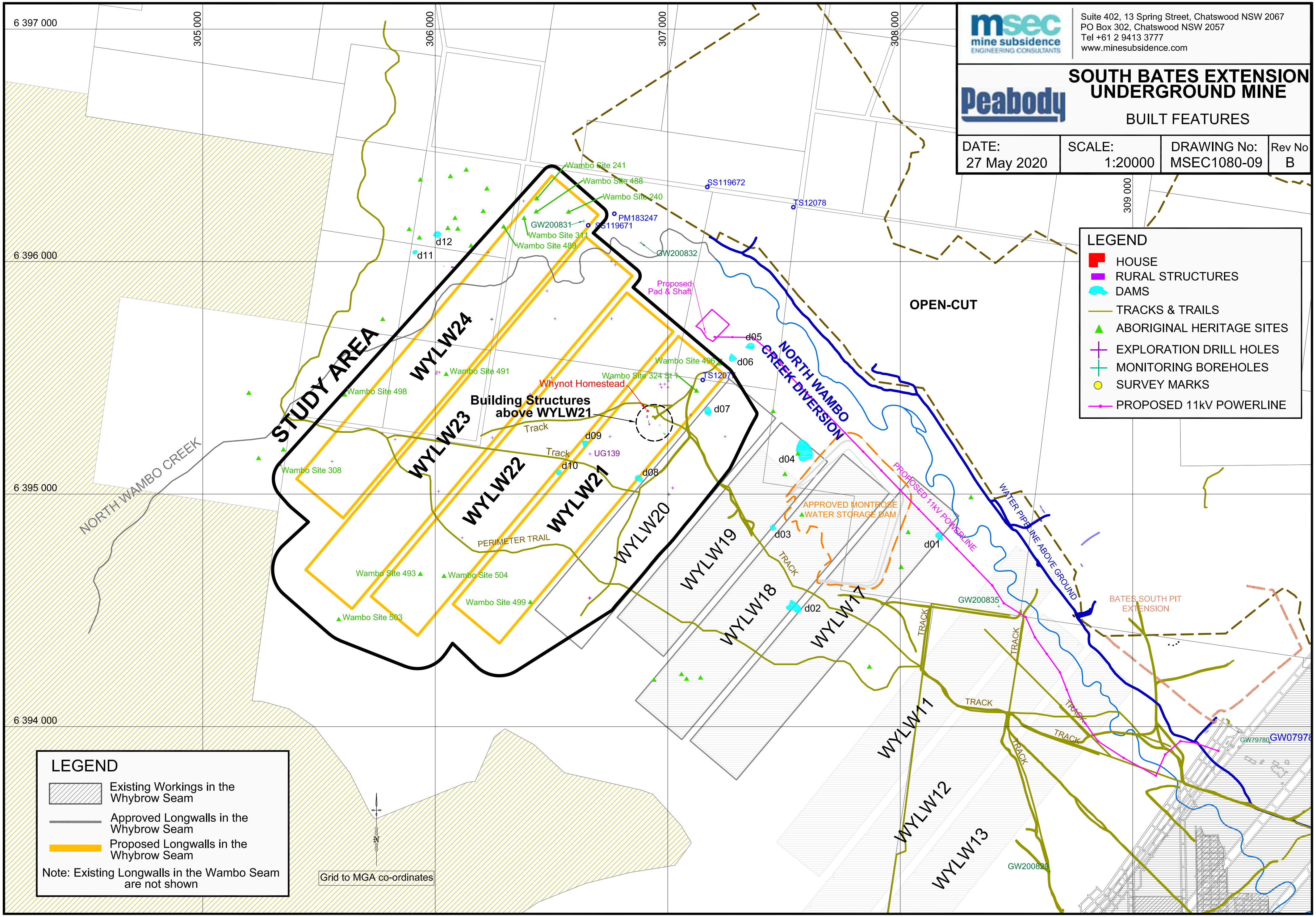

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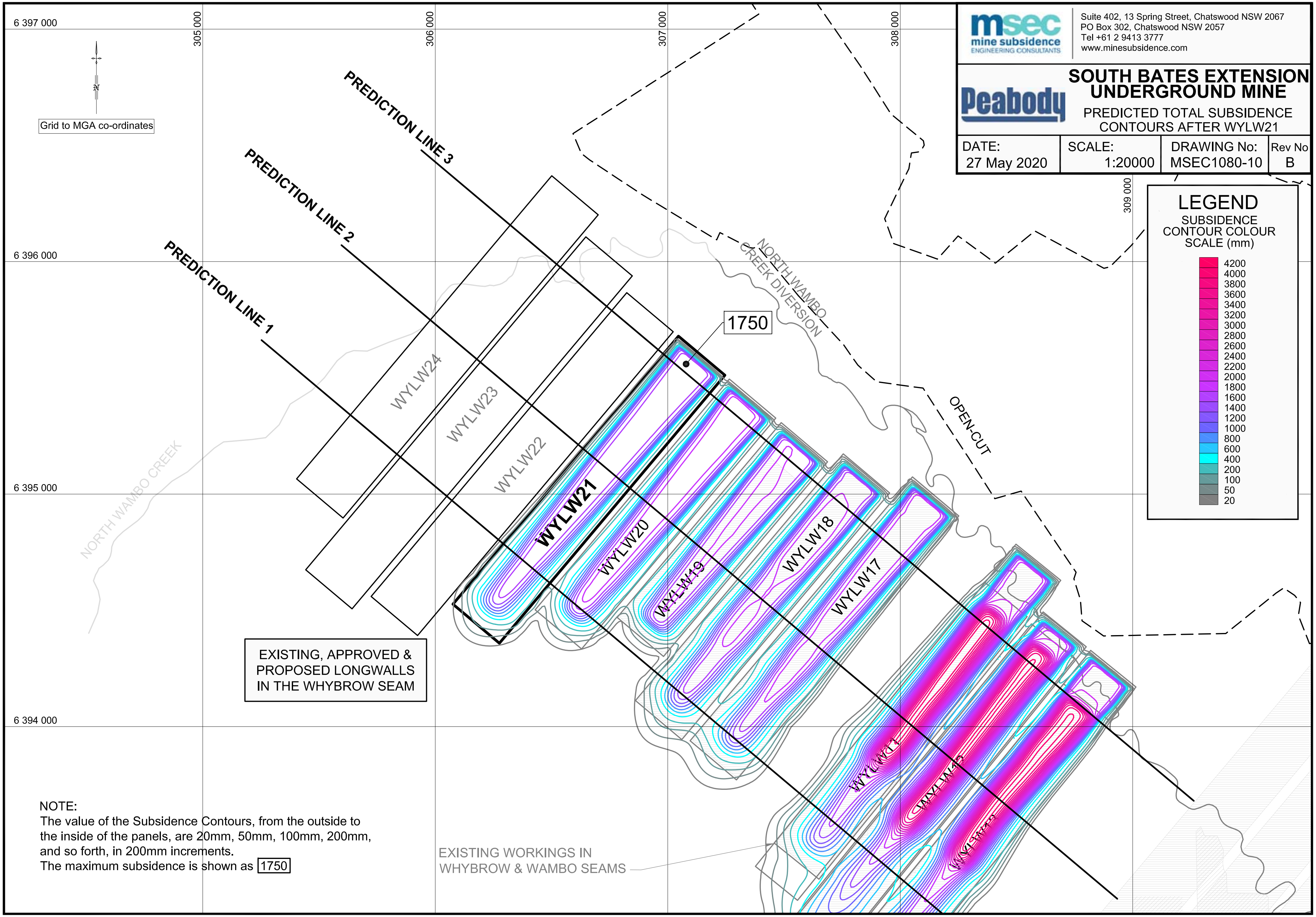

NOTE:
The value of the Subsidence Contours, from the outside to the inside of the panels, are 20mm, 50mm, 100mm, 200mm, and so forth, in 200mm increments.
The maximum subsidence is shown as $\boxed{1750}$

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PO Box 302, Chatswood NSW 2057
Tel +61 2 9413 3777
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SOUTH BATES EXTENSION UNDERGROUND MINE

PREDICTED TOTAL SUBSIDENCE CONTOURS AFTER WYLW22

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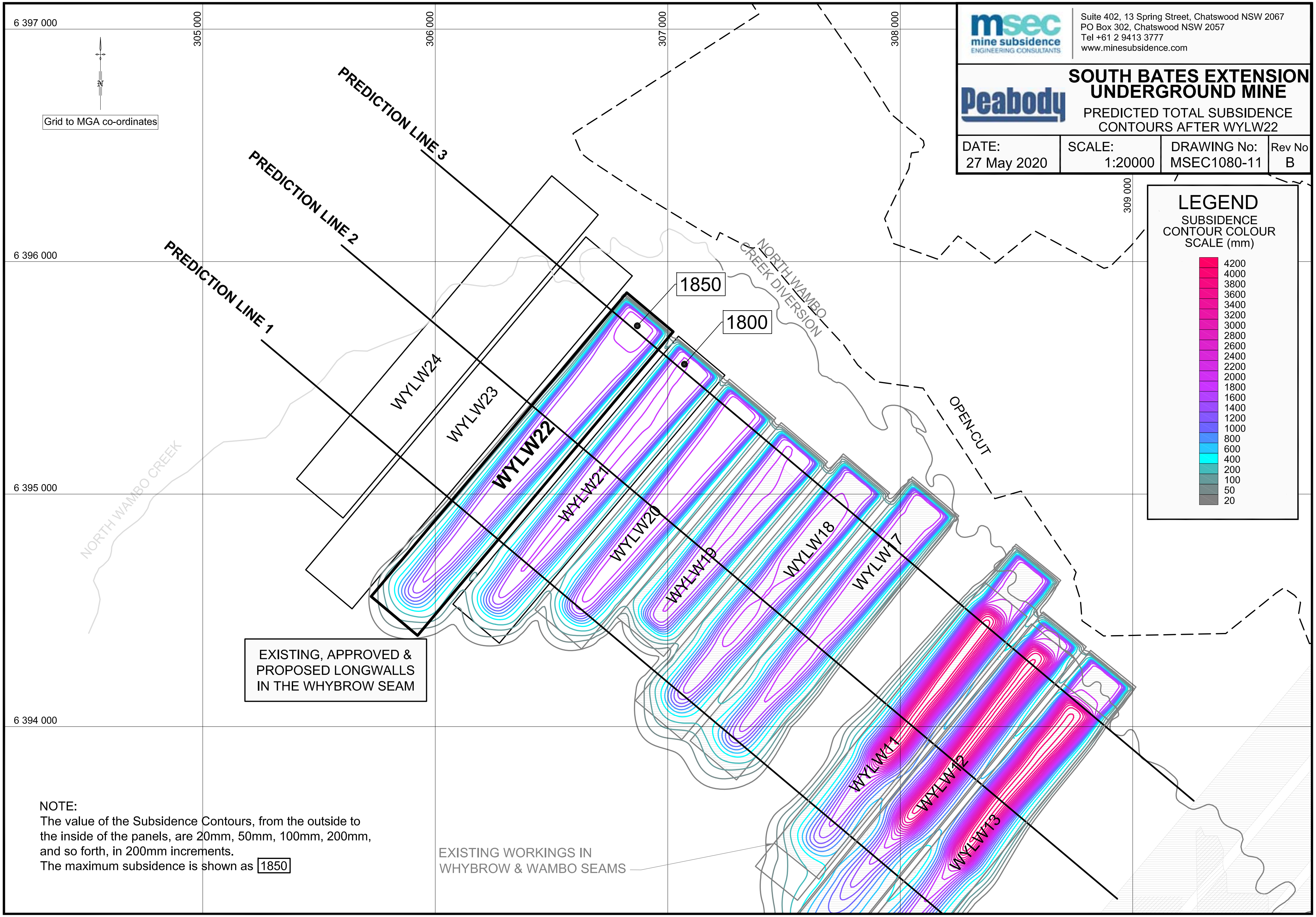

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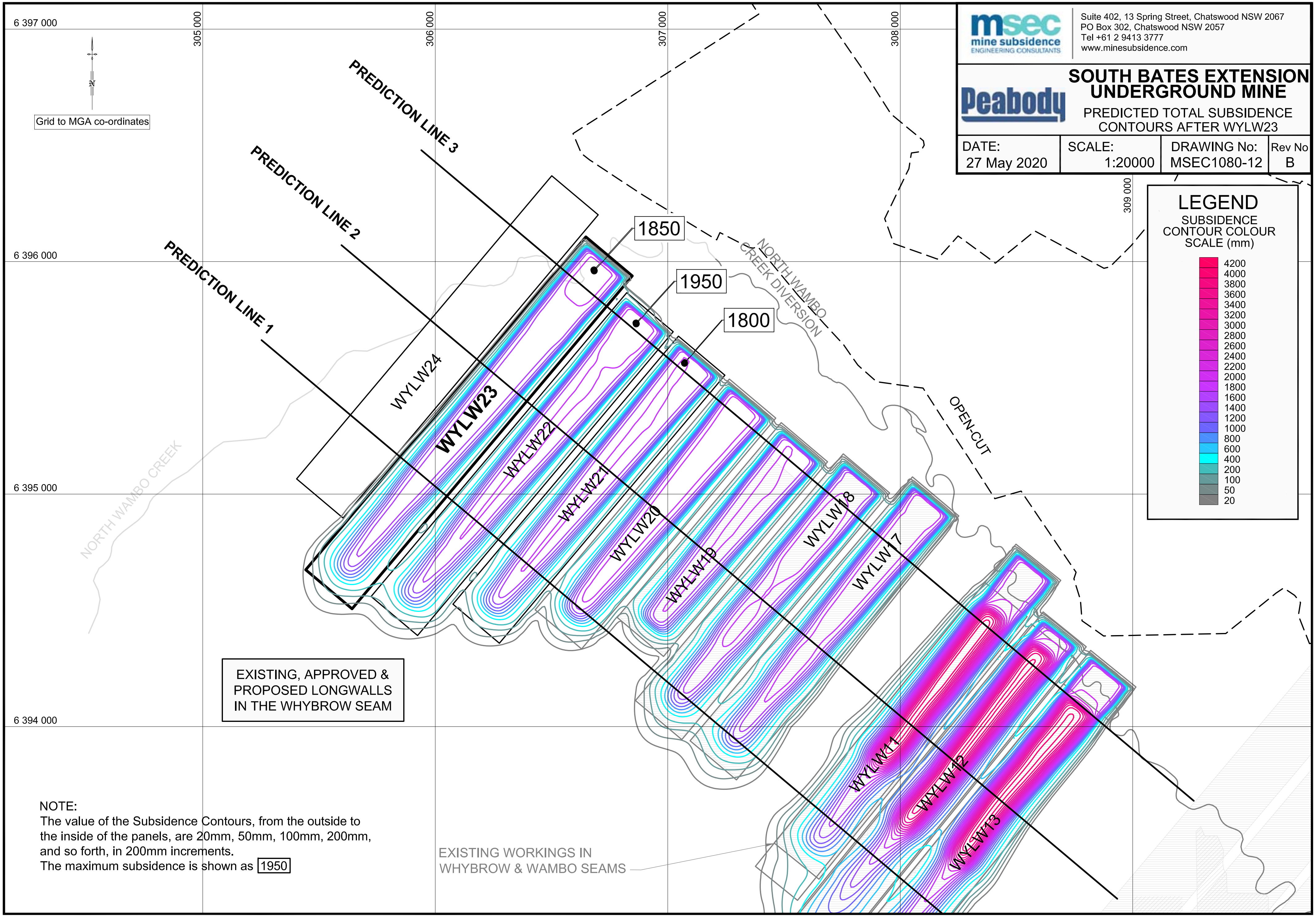

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