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MALABAR COAL

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MAXWELL PROJECT:

Environmental Impact Statement – Subsidence Assessment

Subsidence Predictions and Impact Assessments for Natural and Built Features
due to Multi-seam Mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams,
in Support of the Environmental Impact Statement

DOCUMENT REGISTER

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06	Draft Issue	JB	BM	27 Jun 19
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Report produced to:	support the Environmental Impact Statement for the Maxwell Project.

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)

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

EXECUTIVE SUMMARY

Maxwell Ventures (Management) Pty Ltd, a wholly owned subsidiary of Malabar Coal Limited (Malabar), is seeking consent to develop an underground coal mining operation, referred to as the Maxwell Project (the Project). Malabar proposes to utilise bord and pillar panels (with partial pillar extraction) in the Whynot Seam and longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams within Exploration Licence 5460.

The layouts of the proposed mining operations are shown in Drawings Nos. MSEC986-01 to MSEC986-05, in Appendix E. This subsidence report has been prepared to support the Environmental Impact Statement (EIS) for the proposed mining.

The subsidence predictions for the proposed underground mining operations have been obtained using the Incremental Profile Method. This method has been calibrated using the available single-seam and multi-seam monitoring data from the New South Wales coalfields. The maximum predicted subsidence effects due to the proposed mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are:

- vertical subsidence of 5600 mm (58 % of the total mining height in all seams);
- tilt of 50 mm/m (i.e. 5 %, or 1 in 20);
- hogging and sagging curvatures of 2.0 per kilometre (km^{-1}, i.e. minimum radius of curvature of 0.5 km); and
- strains typically between 10 mm/m and 20 mm/m, with localised strains greater than 20 mm/m.

The proposed underground mining includes both first and second workings. The first workings comprise a network of access roadways (i.e. drifts and main headings) that will be designed to remain stable for the life of the mine. The secondary workings associated with the partial pillar extraction and longwalls will result in subsidence that develops predominately above the area of secondary extraction.

The *Study Area* is defined as the surface area that is likely to be affected by the secondary extraction of the proposed panels and longwalls in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams. The extent of the Study Area has been calculated, as a minimum, as the surface area enclosed by the greater of the 26.5° angles of draw from the limits of secondary extraction in each seam and by the predicted total 20 mm subsidence contour. Natural and built features that could be subjected to far-field or valley related movements and could be sensitive to such effects have also been assessed in this report.

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

- The Hunter River is located to the south of the proposed mining area. The thalweg (i.e. centreline) of the river channel is at a minimum distance of 525 m from the proposed panels and longwalls and a minimum distance of 375 m outside the 26.5° angle of draw. At these distances, the river channel itself is expected to experience negligible vertical subsidence. The river channel could experience low levels of far-field or valley related effects. However, it is highly unlikely that these low-level movements would result in adverse impacts on the river channel itself.

  The mapped limit of alluvium for the Hunter River within the relevant Water Sharing Plan is located more than 50 m outside the 26.5° angle of draw lines from the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. The alluvium is predicted to experience less than 20 mm vertical subsidence and is not expected to experience measurable tilts, curvatures or strains. The potential impacts on the alluvium and associated aquifer are discussed by the specialist surface water and groundwater consultants for the EIS.

- Saddlers Creek is located to the north of the proposed mining area. The thalweg of the creek channel is at a minimum distance of 240 m from the proposed panels and longwalls and a minimum distance of 170 m outside the 26.5° angle of draw. At these distances, the creek channel is not expected to experience adverse surface impacts due to the proposed mining. Further discussions are provided by the specialist surface water and groundwater consultants for the EIS.

- The ephemeral[2] drainage lines above the southern part of the proposed mining area are tributaries to Saltwater Creek and the Hunter River and the ephemeral drainage lines above the northern part of the proposed mining area are tributaries to Saddlers Creek. The upper reaches are first and second order streams and some parts of the lower reaches are third order streams.

  The potential for topographic depressions to develop that may result in ponding has been modelled by Fluvial Systems (2019) based on the subsidence predictions outlined in this report. Based on this assessment, additional ponding as a result of subsidence is expected to be restricted to existing drainage lines.

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[2] Drainage lines where surface water only flows during and for short periods after rainfall events.

It is also expected that surface cracking would occur in the soil beds or the exposed bedrock along the drainage lines due to the proposed mining. The larger surface cracks along the drainage line beds could be remediated by infilling with the surface soils or other suitable materials, or by locally regrading and recompacting the surface.

- Steep slopes have been identified along the ridgelines predominately in the south-eastern part of the Study Area. The natural grades of the steep slopes are typically between 1 in 3 (i.e. 33 % or 18.3°) and 1 in 2 (i.e. 50 % or 26.6°), with isolated areas with natural grades up to approximately 1 in 1 (i.e. 100 % or 45°).

  The extraction of the longwalls beneath the steep slopes will result in increased mining-induced horizontal movements in the downslope direction. This will result in tension cracks appearing at the tops and on the sides of the slopes and compression ridges forming at the bottoms of the slopes.

  The surface cracking is expected to be typically between 50 mm and 100 mm, with widths greater than 300 mm in some locations. Multiple cracks resulting in deformations over greater widths can also occur in more isolated locations. Compression heaving is expected to be typically less than 100 mm but vertical shear greater than 300 mm could also occur.

  It is considered unlikely that the proposed mining would result in adverse impacts on the stability of the steep slopes based on the experience from the NSW coalfields. The Land Management Plan component of the Extraction Plan should include more detailed consideration of slope stability, including input from a specialist geotechnical expert.

  The steep slopes should be visually monitored during mining. The larger surface cracking that could result in increased erosion or restrict access to areas should be remediated by infilling with soil or other suitable materials, or by locally regrading and compacting the surface.

- The Golden Highway crosses the south-western boundary of the Study Area. The highway is at a minimum distance of 160 m from the proposed panels and longwalls and it is located just inside the 26.5° angle of draw, at its closest point. At this distance, the highway is predicted to experience less than 20 mm vertical subsidence. It is unlikely that these low-level movements would result in adverse impacts on the highway.

- The Golden Highway crosses the Hunter River approximately 800 m to the south of the proposed mining area. A bridge crosses the river and the adjacent floodplain comprising a suspended concrete deck supported on concrete abutment wingwalls and nine intermediate concrete headstocks on dual concrete columns.

  The bridge is predicted to experience negligible vertical subsidence, tilt, curvature and strain. It could experience small far-field horizontal movements due to the proposed mining. The predicted differential horizontal movements between the intermediate supports are between ±5 mm and ±7 mm based on the 95 % confidence levels.

  The predicted movements should be provided to the bridge engineers so that its design can be reviewed based on the predicted mining-induced movements. The bridge should also be monitored during active subsidence.

- Edderton Road crosses directly above the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. If the road were to be maintained in its current alignment, cracking, heaving and stepping of the road pavement would occur as each of the proposed longwalls are mined directly beneath it. Alternatively, the potential impacts on the road could be avoided by realigning the road around the proposed mining area. Malabar is liaising with Muswellbrook Shire Council to develop suitable management methods.

- There are unsealed tracks across the Study Area that are located on Malabar-owned land. It is expected that cracking, rippling and stepping of the unsealed tracks would occur as each of the proposed panels and longwalls mine beneath them. The unsealed tracks can be maintained in safe and serviceable conditions using normal road maintenance techniques.

- An 11 kilovolt powerline follows the alignment of Edderton Road and it is located directly above the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. The powerline comprises aerial copper conductors supported by timber poles.

  The powerline could experience impacts due to the extraction of the proposed longwalls directly beneath it. These impacts can be managed with the implementation of preventive measures, such as realignment of the powerline or the provision of cable rollers, guy wires or additional poles.

- Plashett Reservoir and dam wall are located more than 2 km east of the proposed mining area. At this distance, the vertical subsidence at the reservoir and dam wall are expected to be negligible.

  The reservoir and dam wall could experience very small far-field horizontal movements due to the proposed mining, typically less than 25 mm, which is in the order of survey tolerance for absolute position. It is unlikely that the differential horizontal movements (i.e. strains) at the dam wall would be measurable.

  Longwall mining has been previously carried out near other prescribed dams in the NSW coalfields at distances of less than 1 km. This previous underground mining has not resulted in adverse impacts on these structures.
- The land above the proposed mining area is owned by Malabar and it is used for cattle grazing. The agricultural improvements include fences, farm dams, land contours and cattle yards. Management strategies can be developed for the mining-induced surface cracking, to manage the potential impacts on these cattle grazing operations. It may be necessary to install temporary fencing or to temporarily relocate stock to areas outside the active subsidence zone.
- There are four rural structures and three tanks on Malabar-owned land that are located just inside the southern boundary of the Study Area. These structures are at distances between 85 m and 170 m from the proposed mining area, at their closest points. There are no houses located within the Study Area.

  The rural structures and tanks are predicted to experience very low levels of vertical subsidence and are not expected to experience measurable tilts, curvatures or strains. It is unlikely that the rural structures and tanks would experience adverse impacts due to the proposed mining. All structures are expected to remain in safe and serviceable conditions throughout the mining period.
- There are 18 farm dams within the Study Area, all on Malabar-owned land. The dams are of earthen construction and have been established by localised cut and fill operations within the natural drainage lines.

  The mining-induced tilts could reduce the storage capacities of the larger dams that are located above the proposed mining area. It is also likely, that the farm dams would be affected by cracking, heaving or stepping in the bases or dam walls. Surface cracking or leakages in the dams could be identified by visual inspections and repaired as required.
- There are 17 groundwater bores within the Study Area, all on Malabar-owned land. These bores could experience impacts including 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 are other privately-owned groundwater bores located outside and near to the Study Area. The potential impacts on these bores and the groundwater resources are provided by the specialist groundwater consultant for the EIS.
- There are no business or commercial establishments within the Study Area. There are business and commercial establishments located along the Golden Highway to the south of the Study Area, including horse studs and a vineyard.

  The building structures, surface infrastructure and improvements on the properties located outside the Study Area are predicted to experience negligible vertical subsidence, tilts, curvatures and strains. It is unlikely that these features would experience adverse impacts due to the proposed mining. All structures, infrastructure and improvements on the private properties are expected to remain in safe and serviceable conditions throughout the mining period.
- Aboriginal heritage sites located within the Study Area comprise isolated artefacts, artefact scatters and an artefact scatter with an associated potential archaeological deposit. Stone quarry sites are also located outside and near to the Study Area.

  The Aboriginal heritage sites can potentially be affected by cracking and heaving of the surface soils due to the proposed mining. It is unlikely that the finds, artefacts and deposits themselves would be impacted by surface cracking.
- The survey control marks near the proposed longwalls could experience vertical subsidence and far-field horizontal movements. It may be necessary on the completion of the proposed longwalls within each seam, when the ground has stabilised, to re-establish any state survey control marks that are required for future use.

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.

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LIST OF TABLES, FIGURES AND DRAWINGS

Tables

Table numbers are prefixed by the number of the chapter or the letter of the appendix 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 E at the end of this report.

1.0 INTRODUCTION

1.1. Background

Maxwell Ventures (Management) Pty Ltd, a wholly owned subsidiary of Malabar Coal Limited (Malabar), is seeking consent to develop an underground coal mining operation, referred to as the Maxwell Project (the Project). Malabar proposes to extract bord and pillar panels (with partial pillar extraction) in the Whynot Seam and longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams within Exploration Licence (EL) 5460.

EL 5460 is located in the Hunter Coalfield of New South Wales (NSW) east-southeast of Denman and south-southwest of Muswellbrook. The locations of EL 5460 and the proposed underground mining area are shown in Fig. 1.1.

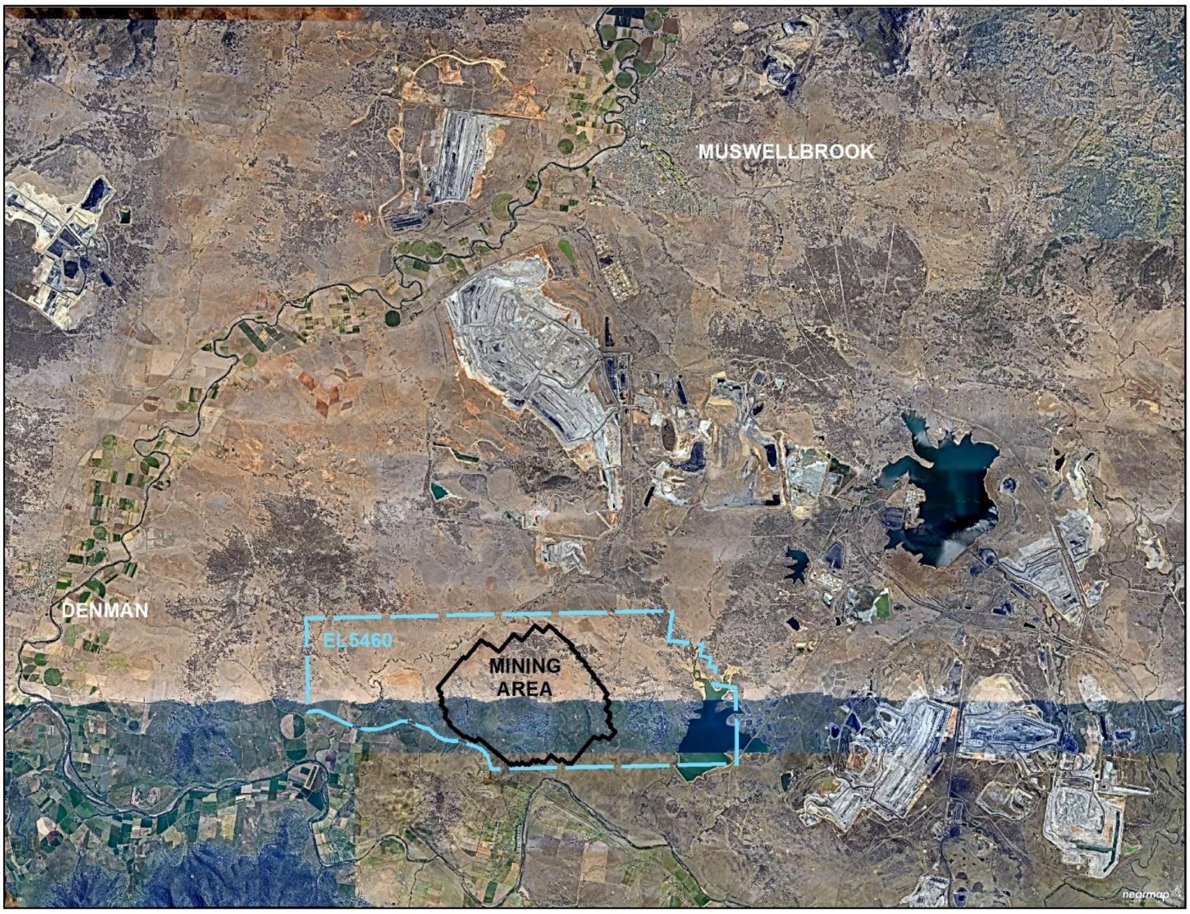

Fig. 1.1 Locations of EL 5460 and the proposed underground mining area

Mine Subsidence Engineering Consultants (MSEC) has been commissioned by Malabar to:

- review the proposed mining layouts in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams to identify mining geometry, surface and seam information and geological details relevant to subsidence predictions and impact assessments;
- prepare predicted subsidence contours after the extraction of the proposed panels and longwalls within each of the seams;
- identify and describe the natural and built features within the proposed mining area;
- provide subsidence predictions and impact assessments for each of these natural and built features; and
- provide recommendations for strategies to manage the potential impacts resulting from mining.

This report has been prepared to support the Environmental Impact Statement (EIS) for the Project that will be submitted to the Department of Planning and Environment (DP&E).

Chapter 1 of this report provides a general introduction to the study, which also includes a description of the mining geometry, seam information and geological details of the area.

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

Chapter 3 includes an overview of conventional and non-conventional subsidence movements and the methods which have been used to predict the multi-seam mine subsidence movements for the Project.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of the proposed panels and longwalls in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams.

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

This report also provides information to satisfy the Secretary's Environmental Assessment Requirements (SEARs) relating to surface subsidence, which has been summarised Table 1.1. The references for the submissions provided by the Dams Safety Committee (DSC) and Muswellbrook Shire Council attached to the SEARs are provided in Table 1.2.

Table 1.1 Secretary's Environmental Assessment Requirements (SEARs) Relating to subsidence

SEARs for subsidence	Section reference
The EIS must address the following key issues: • *Subsidence – including an assessment of the likely conventional and non-conventional subsidence effects and impacts of the development, and the potential consequences of these effects and impacts on the natural and built environment (including Edderton Road), paying particular attention to those features that are considered to have significant economic, social, cultural or environmental value;*	The maximum predicted subsidence, tilt and curvatures are summarised in Chapter 4. The predicted strains based on both conventional and non-conventional movements are summarised in Section 4.3. The assessments of the potential consequences on the natural and built features are provided in the impact assessments for each of the surface features in Chapters 5 and 6.
• *Water – including:* – *an assessment of any likely flooding impacts of the development;*	The assessment of the changes in the surface topography are provided in Sections 5.3 and 5.6. This provides the background information for the more detailed assessments undertaken by the specialist surface water consultant for the EIS.
• *Heritage – including:* – *an assessment of the potential impacts of the development on Aboriginal heritage (cultural and archaeological);* – *an assessment of the likelihood and significance of impacts on heritage items;*	The impact assessments for the Aboriginal and European heritage sites are provided in Sections 6.15 and 6.16, respectively. Further assessments are provided by the specialist heritage consultants for the EIS.
• *Hazards – including:* – *interactions with nearby prescribed dams (including the possibility of far field horizontal movements)*	Refer to Section 4.5 for the predicted far-field horizontal movements and Section 6.8 for the descriptions, predictions and impact assessments for the dam structure.

Table 1.2 Submissions by the Dams Safety Committee and Muswellbrook Shire Council

Submissions for Subsidence	Section Reference
Dams Safety Committee: • *Adjacent to the project area is the Plashett Dam, a 46m high embankment dam which is a prescribed dam under the Dam Safety Act 1978 with a High 'C' consequence if failure were to occur.* • *The dam is surrounded by a Notification Area. The proposed mining may overlap with the Notification Area.* • *The possibility of "far field horizontal movement" on the dam embankment should be addressed in the EIS*	Refer to Section 4.5 for the predicted far-field horizontal movements and Section 6.8 for the descriptions, predictions and impact assessments for the dam structure.
Muswellbrook Shire Council: • *Any EIS should include a thorough geotechnical investigation relating to this subsidence and its anticipated impact on the safety and maintenance of Edderton Road. Where this investigation identifies the project is likely to have considerable implications for the safety or operability of Edderton Road or increase road maintenance requirements it may be necessary for the proponent to investigate the realignment of the road around the mine and a Voluntary Planning Agreement in relation to the long-term maintenance and upkeep of this community asset.*	The impact assessment for Edderton Road is provided in Section 6.3. Recommended management strategies for this road are also provided in this section.

1.2. Mining geometry

Malabar proposes to extract bord and pillar panels (with partial extraction) in the Whynot Seam and longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. The layouts of the proposed panels and longwalls are shown in Drawings Nos. MSEC986-01 to MSEC986-05.

There are 19 proposed panels in the Whynot Seam, referred to as WNP1 to WNP19. A summary of the proposed panel dimensions is provided in Table 1.3. The dimensions represent the maximum extents of first workings for each of the panels.

Table 1.3 Geometry of the proposed bord and pillar panels in the Whynot Seam

Panel	Overall void lengths including roadways (m)	Overall panel widths including first workings (m)	Solid barrier pillar widths (m)
WNP1	2555	185	-
WNP2	2330	185	55
WNP3	1955	185	55
WNP4	1685	185	55
WNP5	1265	185	55
WNP6	185	185	55
WNP7	185	155	55
WNP8	2015	185	55
WNP9	1925	185	55
WNP10	2015	185	55
WNP11	2015	185	55
WNP12	1685	185	55
WNP13	1565	185	55
WNP14	1535	185	55
WNP15	1505	185	55
WNP16	1355	185	55
WNP17	1055	185	55
WNP18	635	185	55
WNP19	365	185	55

The proposed panels each comprise six rows of pillars along their lengths, as shown in Drawing No. MSEC986-02. The pillars have dimensions of 25 m by 25 m and are separated by 5 m wide development roadways.

Malabar proposes to carry out partial extraction of the pillars within each of the proposed panels to achieve approximately 55 % to 70 % coal recovery based on both first and second workings. There are various partial extraction methods that could achieve this level of coal recovery. The final layout in the Whynot Seam would be presented by Malabar in future Extraction Plans, with the subsidence predictions based on the selected pillar extraction method.

The subsidence predictions provided in this report have been based on the extraction of the two rows of pillars adjacent to each of the barrier pillars (i.e. four rows of pillars within each panel) and leaving the two central rows of pillars unmined (i.e. central spine pillar). Small sections of the coal seam will be left as a result of the mining process, known as stooks, representing approximately 15 % of the coal for the rows of mined pillars. The recovery method used for the predictions in this report would result in higher levels of vertical subsidence compared to other recovery methods that would achieve similar coal recovery.

This partial extraction method achieves approximately 71% coal recovery, within each of the proposed panels, based on both first and second workings. The overall coal recovery is approximately 55 % when considering both the panels and the barrier pillars.

The partial extraction within each of the proposed panels results in two voids between each of the barrier pillars and the central spine pillar. These two voids each have a width of 65 m. The overall width of the central spine pillar is 55 m, which is split by a 5 m wide roadway.

There are 14 longwalls proposed in the Woodlands Hill Seam (WHLW1 to WHLW14), 14 longwalls proposed in the Arrowfield Seam (AFLW1 to AFLW14) and 11 longwalls proposed in the Bowfield Seam (BFLW1 to BWLW11). Summaries of the longwall dimensions are provided in Table 1.4 for the Woodlands Hill Seam, Table 1.5 for the Arrowfield Seam and Table 1.6 for the Bowfield Seam.

Table 1.4 Geometry of the proposed longwalls in the Woodlands Hill Seam

Longwall	Overall void lengths including installation headings (m)	Overall void widths including first workings (m)	Overall tailgate chain pillar widths (m)
WHLW1	4095	305	-
WHLW2	3445	305	35
WHLW3	2415	305	35
WHLW4	2095	305	35
WHLW5	4375	305	35
WHLW6	4095	305	35
WHLW7	4095	305	35
WHLW8	4010	305	35
WHLW9	3925	305	35
WHLW10	3840	305	35
WHLW11	3460	305	35
WHLW12	3010	305	35
WHLW13	2475	305	35
WHLW14	1945	305	35

Table 1.5 Geometry of the proposed longwalls in the Arrowfield Seam

Longwall	Overall void lengths including installation headings (m)	Overall void widths including first workings (m)	Overall tailgate chain pillar widths (m)
AFLW1	1295	305	-
AFLW2	2355	305	35
AFLW3	2580	305	35
AFLW4	2625	305	35
AFLW5	2625	305	35
AFLW6	2505	305	35
AFLW7	2340	305	35
AFLW8	2870	305	35
AFLW9	2980	305	35
AFLW10	3090	305	35
AFLW11	2905	305	35
AFLW12	2630	305	35
AFLW13	2370	305	35
AFLW14	2085	305	35

Table 1.6 Geometry of the proposed longwalls in the Bowfield Seam

Longwall	Overall void lengths including installation headings (m)	Overall void widths including first workings (m)	Overall tailgate chain pillar widths (m)
BFLW1	2145	305	-
BFLW2	2370	305	35
BFLW3	2545	305	35
BFLW4	2245	305	35
BFLW5	2245	305	35
BFLW6	1990	305	35
BFLW7	1990	305	35
BFLW8	2170	305	35
BFLW9	2170	305	35
BFLW10	1945	305	35
BFLW11	1465	305	35

The lengths of longwall extraction excluding the installation headings are approximately 10 m less than the overall void lengths provided in Table 1.4 to Table 1.6. The longwall face widths excluding the first workings are 295 m.

The proposed longwalls within each of the seams have been staggered so that the chain pillars are not aligned. The longwalls in the Arrowfield Seam have been offset by approximately 75 m from the longwalls in the overlying Woodlands Hill Seam. The longwalls in the Bowfield Seam have been offset by approximately 100 m from the longwalls in the overlying Arrowfield Seam.

1.3. Surface and seam information

The surface level contours within the proposed mining area are shown in Drawing No. MSEC986-06. The land generally falls towards the Hunter River to the south of the mining area and towards Saddlers Creek to the north of the mining area.

The surface elevations directly above the proposed mining area vary from a low point of 110 metres above Australian Height Datum (mAHD) within a tributary to the Hunter River to a high point of 240 mAHD at the top of a hill in the eastern side of the mining area.

The seam floor contours for the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are shown in Drawings Nos. MSEC986-07, MSEC986-08, MSEC986-09 and MSEC986-10, respectively. The target seams generally dip from the north-north-west towards the south-south-east, with average gradients varying between 3 % and 5 % within the proposed mining area.

The seam thickness contours for the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are shown in Drawings Nos. MSEC986-11, MSEC986-12, MSEC986-13 and MSEC986-14, respectively. The full seam thicknesses are proposed to be extracted, with minimum mining heights of 1.5 m in the Whynot Seam, 2.1 m in the Woodlands Hill and Arrowfield Seams and 2.4 m in the Bowfield Seam. The subsidence predictions provided in this report have been based on the variable seam thicknesses shown in Drawings Nos. MSEC986-11, MSEC986-12, MSEC986-13 and MSEC986-14, with the minimum mining heights applied.

The depth of cover contours for the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are shown in Drawings Nos. MSEC986-15, MSEC986-16, MSEC986-17 and MSEC986-18, respectively. The depths of cover are shallowest in the north-western part of the mining area and generally increase towards the south-eastern part of the mining area. The Whynot Seam outcrops in the northern part of EL 5460.

The interburden thickness contours between the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are shown in Drawings Nos. MSEC986-19, MSEC986-20 and MSEC986-21, respectively. The depth of cover to the Whynot Seam is less than 50 m in the northern part of the mining area. Secondary extraction will only occur within this seam where the depths of cover are greater than 50 m.

A summary of the ranges of depths of cover, interburden thicknesses, working section thicknesses and mining heights is provided in Table 1.7. The values represent the ranges within the proposed mining areas for each of the seams.

Table 1.7 Depths of cover, interburden thicknesses, working sections and proposed mining heights for each of the seams

Seam	Depth of cover (m)	Interburden thickness to the overlying seam (m)	Working section thickness (m)	Mining height (m)
Whynot Seam (WN)	40* ~ 180 (100 average)	N/A (Single-seam)	1.3 ~ 2.3 (2.0 average)	1.5 ~ 2.3
Woodlands Hill (WH)	125 ~ 365 (260 average)	155 ~ 185 (165 average)	1.7 ~ 3.5 (2.7 average)	2.1 ~ 3.5
Arrowfield (AF)	165 ~ 415 (315 average)	40 ~ 75 (50 average)	2.1 ~ 3.7 (2.9 average)	2.1 ~ 3.7
Bowfield (BF)	215 ~ 425 (330 average)	20 ~ 45 (30 average)	2.2 ~ 3.3 (2.8 average)	2.4 ~ 3.3

*Note: * denotes that secondary extraction will only occur at depths of cover greater than 50 m.*

The surface and seam levels are illustrated along Sections 1 and 2 in Fig. 1.2 and Fig. 1.3, respectively. The locations of these sections are shown in Drawings Nos. MSEC986-06 to MSEC986-10. The Study Area is defined in Section 2.2.

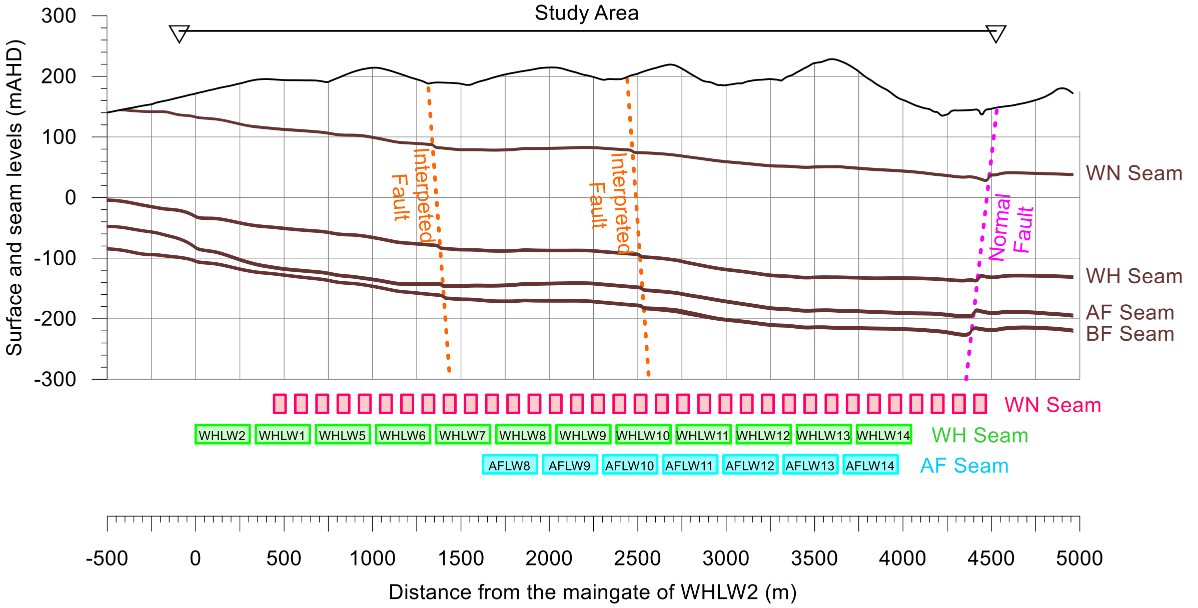

Fig. 1.2 **Surface and seam levels along Section 1**

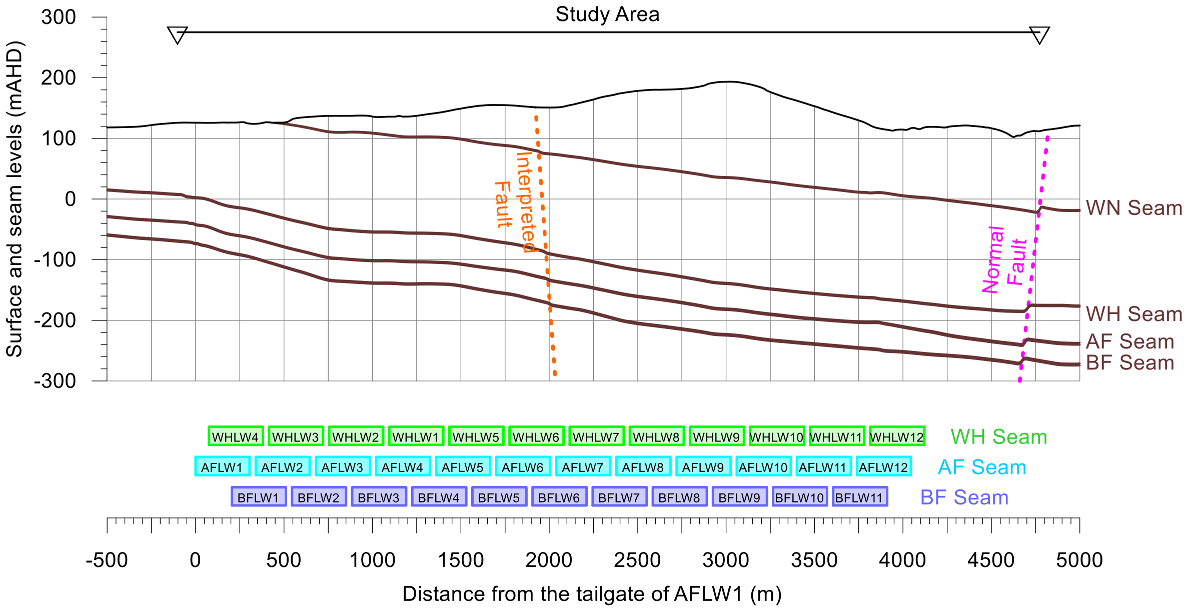

Fig. 1.3 **Surface and seam levels along Section 2**

1.4. Geological details

EL 5460 lies in the Hunter Coalfield within the Northern Sydney Basin. The general stratigraphy of the Hunter Coalfield is shown in Table 1.8 (after Stevenson, et al., 1998). The target seams lie within the Jerrys Plains Subgroup of the Wittingham Coal Measures, which is shown in more detail in Table 1.9. The Newcastle Coal Measures and overlying groups are generally not present in the proposed mining area.

Table 1.8 Middle Permian to Quaternary stratigraphy of the Hunter Coalfield (after Stevenson, et al., 1998)

Period	Stratigraphy			Lithology
Quaternary				silt, sand, gravel
Tertiary				basalt
Jurassic				basalt
Triassic	Hawkesbury Sandstone			massive quartz sandstone with minor siltstone
	Narrabeen Group	Terrigal Formation		sandstone, interbedded sandstone and siltstone, mudstone, claystone
		Clifton Subgroup	Patonga Claystone Tuggerah Formation Widden Brook Conglomerate	sandstone, interbedded sandstone and siltstone, claystone
Permian	Singleton Supergroup	Newcastle Coal Measures	Glen Gallic Subgroup Doyles Creek Subgroup Horseshoe Creek Subgroup Apple Tree Flat Subgroup	coal, claystone, siltstone, shale, sandstone, conglomerate, tuffaceous sediments
			Watts Sandstone	medium to coarse sandstone
		Wittingham Coal Measures	Denman Formation Jerrys Plains Subgroup Archerfield Sandstone Vane Subgroup Saltwater Creek Formation	sandstone, siltstone, laminate coal, claystone, tuff, siltstone, sandstone, conglomerate well-sorted quartz-lithic sandstone coal, siltstone, lithic sandstone, shale, conglomerate sandstone, siltstone, minor coal

Table 1.9 Stratigraphy of the Wittingham Coal Measures

	Stratigraphy		Lithology	
Wittingham Coal Measures	Denman Formation			
	Jerrys Plains Subgroup	Mount Leonard Formation Althorpe Formation	Whybrow seam	
			Redbank Creek seam	
		Malabar Formation	Wambo seam	
			Whynot seam	
			Blakefield seam	
			Saxonvale Member	
		Mount Ogilvie Formation	Glen Munro seam	
			Woodlands Hill seam	
		Millbrodale Formation		
			Arrowfield seam	
		Mount Thorley Formation	**Bowfield seam**	
			Warkworth seam	
		Fairford Formation		
			Mount Arthur seam	
			Piercefield seam	
			Vaux seam	
		Burnamwood Formation	Broonie seam	
			Bayswater seam	
	Archerfield Sandstone			
	Vane Subgroup	Bulga Formation		
		Foy Brook Formation	Lemington seam	Wynn C. M.
			Pikes Gully seam	Edderton C. M.
			Arties seam	Clanricard C. M.
			Liddell seam	Bengalla C. M.
			Barrett seam	Edinglassie C. M.
			Hebden seam	Ramrod Ck. C.M.
	Saltwater Creek Subgroup			

Note: C. M. = Coal Measure

There have been a number of drilling campaigns within EL 5460 from the late 1940's through to the present. Other geological exploration includes: 3D seismic surveys in 2003, 2004, 2005 and 2006; a high-resolution ground magnetic survey in 1998; a low-level aero-magnetic survey in 2002; and a radiometric survey for the purposes of detecting and mapping intrusive bodies (Malabar, pers. comm., April 2018, and MBGS, 2018).

Geophysical logging has been generally carried out on the drillholes since 1998. The testing identified the coal seam floors, coal seam roofs, partings, igneous intrusions and tuff marker bands, lithological boundaries and structural features (Malabar, pers. comm., April 2018). Geotechnical logging to identify natural fractures has been carried out since 2008.

The south-southeast trending Muswellbrook Anticline is located near the eastern boundary of EL 5460 and well outside the proposed mining area. The strata dip steeply along this structure with gradients varying between 35 % and 85 %. On the western side of the anticline, the strata dip gently with gradients varying between 3 % and 5 % within the proposed mining area. The Calool Syncline crosses the proposed mining area. The syncline is sub-parallel to the East Graben Fault and it has a dip between 2° and 5° towards the south (MBGS, 2018).

The mapped geological structures in EL 5460 are shown in Drawing No. MSEC986-22.

The faults have been interpreted from the seismic surveys and from the structure contour plans. The positions and throws of some faults have been confirmed using a series of closely spaced non-core drillholes (MBGS, 2018). These drillholes indicate that the throws of the normal faults are generally consistent through the target coal seams.

A complex north-northwest orientated graben structure crosses the western part of EL 5460, comprising the East Graben Fault (Ref. F4) and the Randwick Park Fault, which is part of a regional graben system. The East Graben Fault has a dip of 70° and a throw of up to 20 m near the proposed mining area. The Randwick Park Fault is sub-vertical and it has and a throw of up to 30 m.

The south-western ends of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams have been set back from the graben structure. The locations of the East Graben Fault and the Randwick Park Fault relative to the proposed longwalls are shown along Section 3 in Fig. 1.4. This section has been taken where the graben structure is located closest to the proposed longwalls, as shown in Drawing No. MSEC986-22.

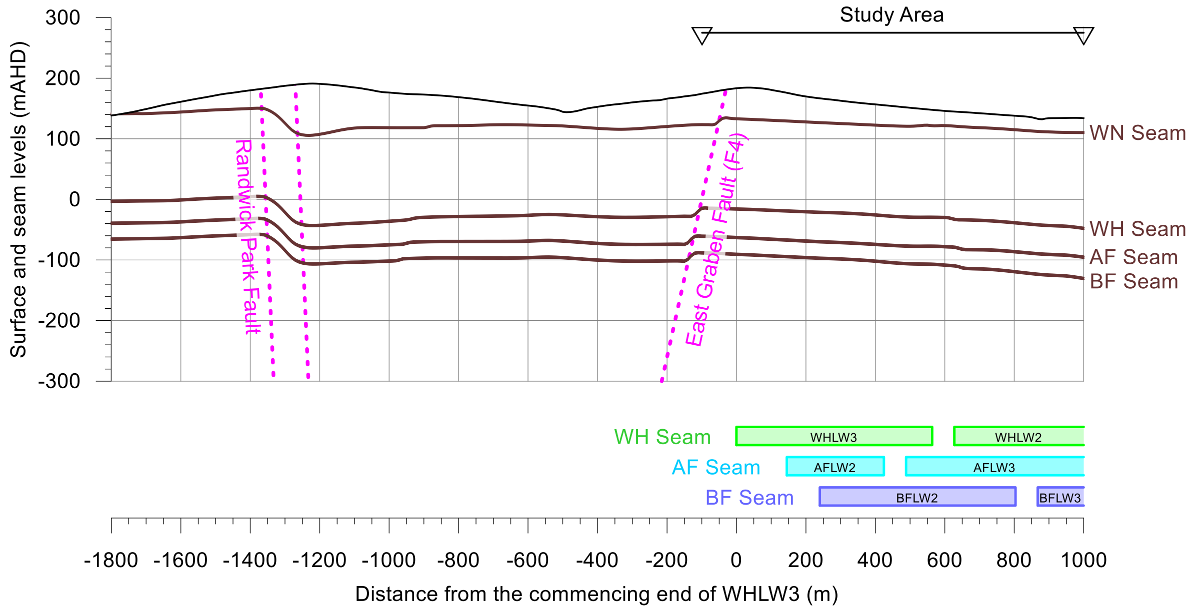

Fig. 1.4 Surface and seam levels along Section 3

The projected surface expression of the East Graben Fault is located approximately 30 m from the corner of the proposed WHLW3. Localised surface deformations could develop at the surface expression of this fault where it is located closest to the proposed longwalls. Further discussions are provided in Section 4.6.

A north-east trending fault (Ref. F3) is located on the south-eastern side of the proposed mining area. This normal fault has a dip of approximately 70° and a throw of 10 m. There are also north-west trending faults and interpreted north-east trending faults within the proposed mining area. These normal faults have dips of approximately 70° to 75° and throws of 2 m to 6 m. The north-east trending faults and interpreted faults are shown in Fig. 1.2 and Fig. 1.3.

There are two parallel north trending dykes in the northern part of the proposed mining area with widths of approximately 1.8 m. There are also two north-east trending interpreted dykes within the proposed mining area. The dykes have been delineated by the magnetic surveys and some have been confirmed by trenching (MBGS, 2018).

Dolerite sills have intruded into the Whynot, Arrowfield and Bowfield Seams within EL 5460. The layouts of the proposed panels and longwalls within these seams have been designed to avoid these igneous intrusions. The mapped extents of the sills within the Whynot, Arrowfield and Bowfield Seams are illustrated in Fig. 1.5 to Fig. 1.7, respectively.

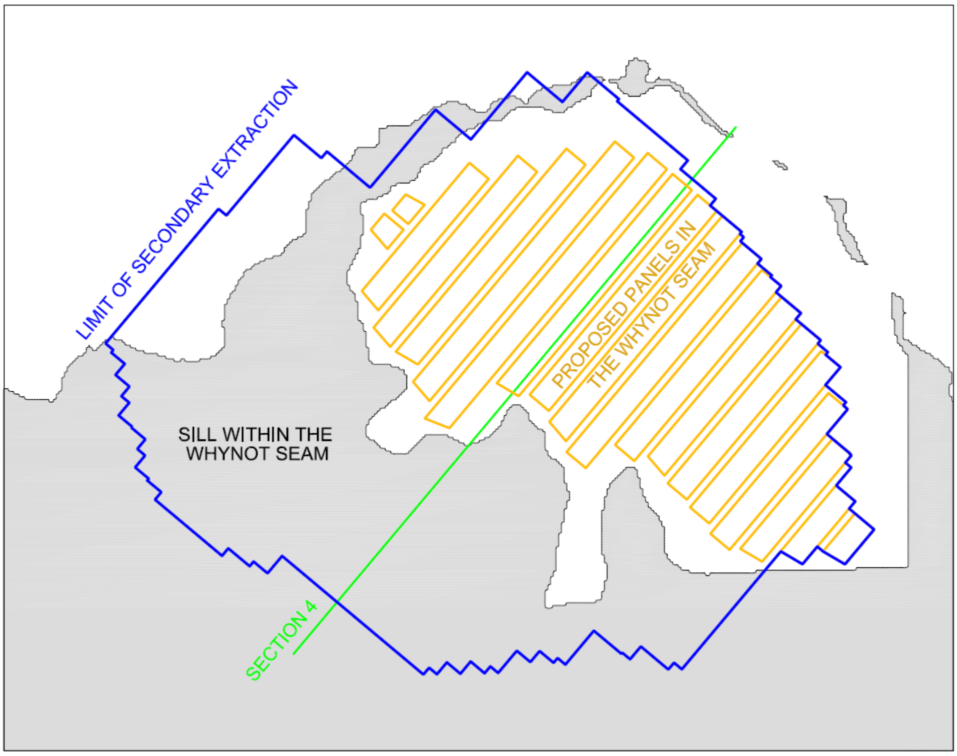

Fig. 1.5 Mapped extent of the sill within the Whynot Seam

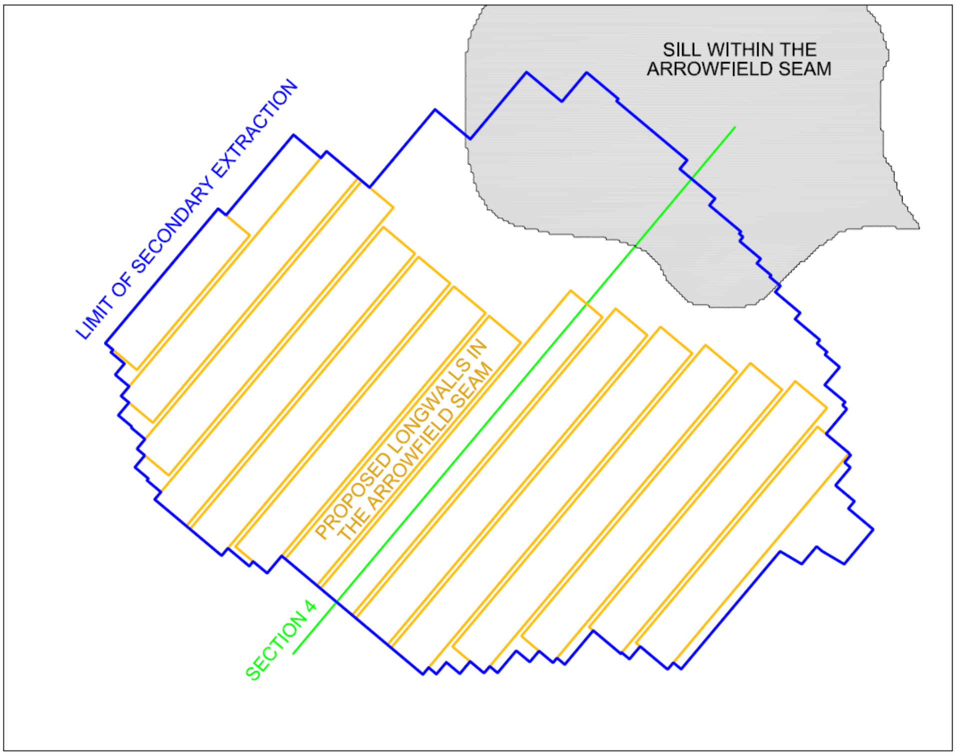

Fig. 1.6 Mapped extent of the sill within the Arrowfield Seam

Fig. 1.7 Mapped extent of the sill within the Bowfield Seam

The Edderton Sill has also intruded into the interburden between the Whynot and Woodlands Hill Seams. This sill extends across the proposed mining area and has a thickness of approximately 20 m for much of its extent (MBGS, 2018). Two samples of the Edderton Sill have been tested and the measured Unconfined Compressive Strength (UCS) was up to 186 megapascals (MPa).

The levels of the Whynot, Arrowfield and Bowfield Seams and the extents of the sills in each of these seams are illustrated along Section 4 in Fig. 1.8. The position of the Edderton Sill is also shown in this figure. The location of Section 4 is shown in Fig. 1.5 to Fig. 1.7.

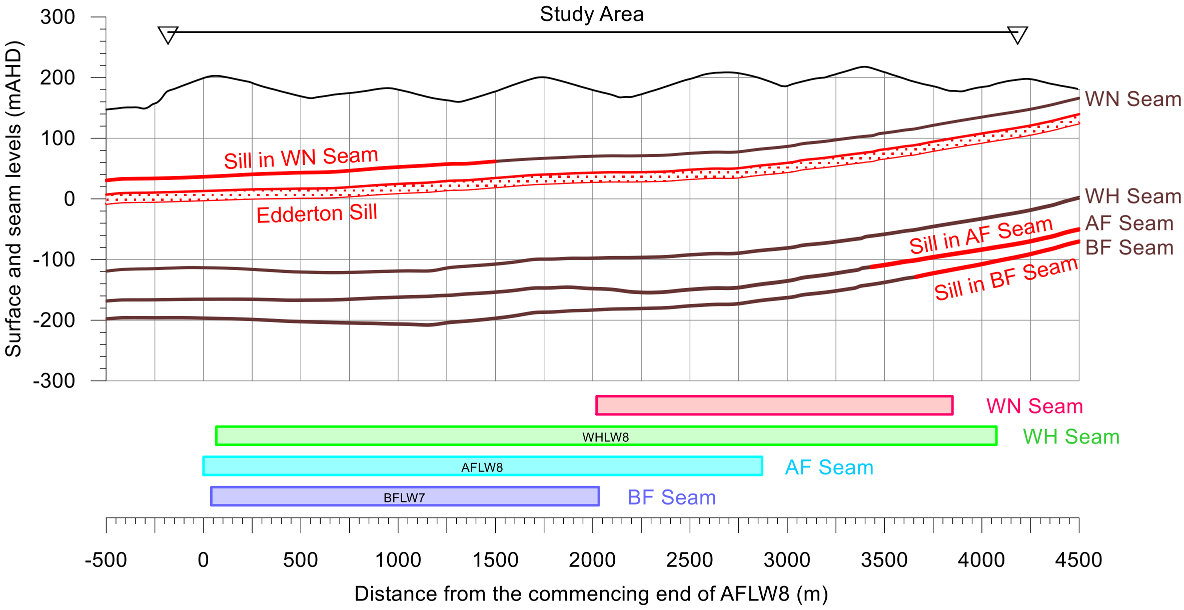

Fig. 1.8 Surface, seam and sill levels along Section 4

The proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams will be extracted beneath the Edderton Sill. This sill is located approximately 110 m to 130 m above the Woodlands Hill Seam.

The south-western ends of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams will also be extracted beneath the sill in the Whynot Seam. This sill has a thickness ranging between 1 m and 10 m within the proposed mining area.

The Whynot and Edderton Sills are located in the upper part of the overburden and their strengths and stiffnesses are greater than those of the sedimentary strata. These sills could therefore result in reduced vertical subsidence (i.e. less than predicted) due to the proposed mining in the Woodlands Hill, Arrowfield and Bowfield Seams.

The potential for subsidence reduction due to the presence of these sills is dependent on the strengths and spanning capabilities of the materials and whether they are massive (i.e. devoid of faults, inclusions and defects), which is not certain at this stage.

The critical span of an igneous sill (i.e. the maximum distance that a sill can span without failure) can be estimated using *Equation 1* (after Galvin, 1981). This equation was developed using empirical results from mining beneath dolerite sills in South Africa. The empirical data comprised of dolerite sills with strengths typically ranging between 250 MPa and 390 MPa. The application of this equation, therefore, could over-estimate the spanning capacities of the sills within the proposed mining area. It is also noted, that the method has yet to be verified for "*sills exceeding a depth (to the base) of 140 m*" (Galvin, 1981).

Equation 1

$$S = \sqrt{1165 t_D - \frac{935 t_D^2}{D_D}} + 2 t_p \tan(\beta - 90)$$

where
t_D = Thickness of sill (m);
D_D = Depth to sill base from surface (m);
t_p = Thickness of parting between sill base and seam (m); and
β = Caving angle of strata between the seam and sill base (degrees).

A summary of the estimated critical spans of the Whynot and Edderton Sills is provided in Table 1.10. The caving angle of the strata (β) has been taken to be 110°, i.e. an angle of break of 20°.

Table 1.10 Estimated critical spans of the Whynot and Edderton Sills

Location	Thickness of sill (t_D, m)	Depth to sill base (D_D, m)	Thickness of the parting between sill base and seam (t_p, m)	Critical span (S, m)
Whynot Sill	1 ~ 10	100 ~ 170	150 ~ 170	140 ~ 230
Edderton Sill	≈ 20	90 ~ 200	110 ~ 130	≈ 230

The critical spans for the Whynot and Edderton Sills range between 140 m and 230 m. The proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams have void widths of 305 m. It is unlikely, therefore, that the Whynot and Edderton Sills could span the void widths of the proposed longwalls.

It is therefore considered that there is low potential for subsidence reduction due to the Whynot and Edderton Sills. The predicted vertical subsidence for the proposed longwalls, therefore, has not been reduced due to the presence of these sills.

It is possible that the sills could partially span across the corners of the proposed longwalls. However, the potential for this spanning is reduced due to the multi-seam mining, with the proposed longwalls staggered so that the longwall corners are not aligned.

The Whynot and Edderton Sills could potentially result in irregular subsidence profiles if they were to partially span the corners of the proposed longwalls, i.e. reduced subsidence in the corners transitioning to full subsidence towards the middle of the goaf. The sills are generally at depths of cover of 100 m or greater and, therefore, the irregular subsidence is expected to be expressed as rolling or heaving at the surface, rather than as stepping, due to the depths of the overburden. However, it is possible that localised surface cracking and/or stepping could develop near the corners of the proposed longwalls where the depths of cover are the shallowest. Further discussions are provided in Section 4.6.

The proposed longwalls in the Bowfield Seam do not extend beneath the sill within the overlying Arrowfield Seam. The sill within the Arrowfield Seam, therefore, will not affect the subsidence that develops due to the mining in the Bowfield Seam.

The surface lithology above the proposed mining area is shown in Fig. 1.9. The surface soils are predominately derived from the Jerrys Plains Subgroup (Pswj) of the Wittingham Coal Measures. There are small areas that are derived from the Newcastle Coal Measures (formerly known as the Wollombi Coal Measures, Psl) and basalt (Jv). Quaternary material is mapped along the alignments of the Hunter River and Saddlers Creek.

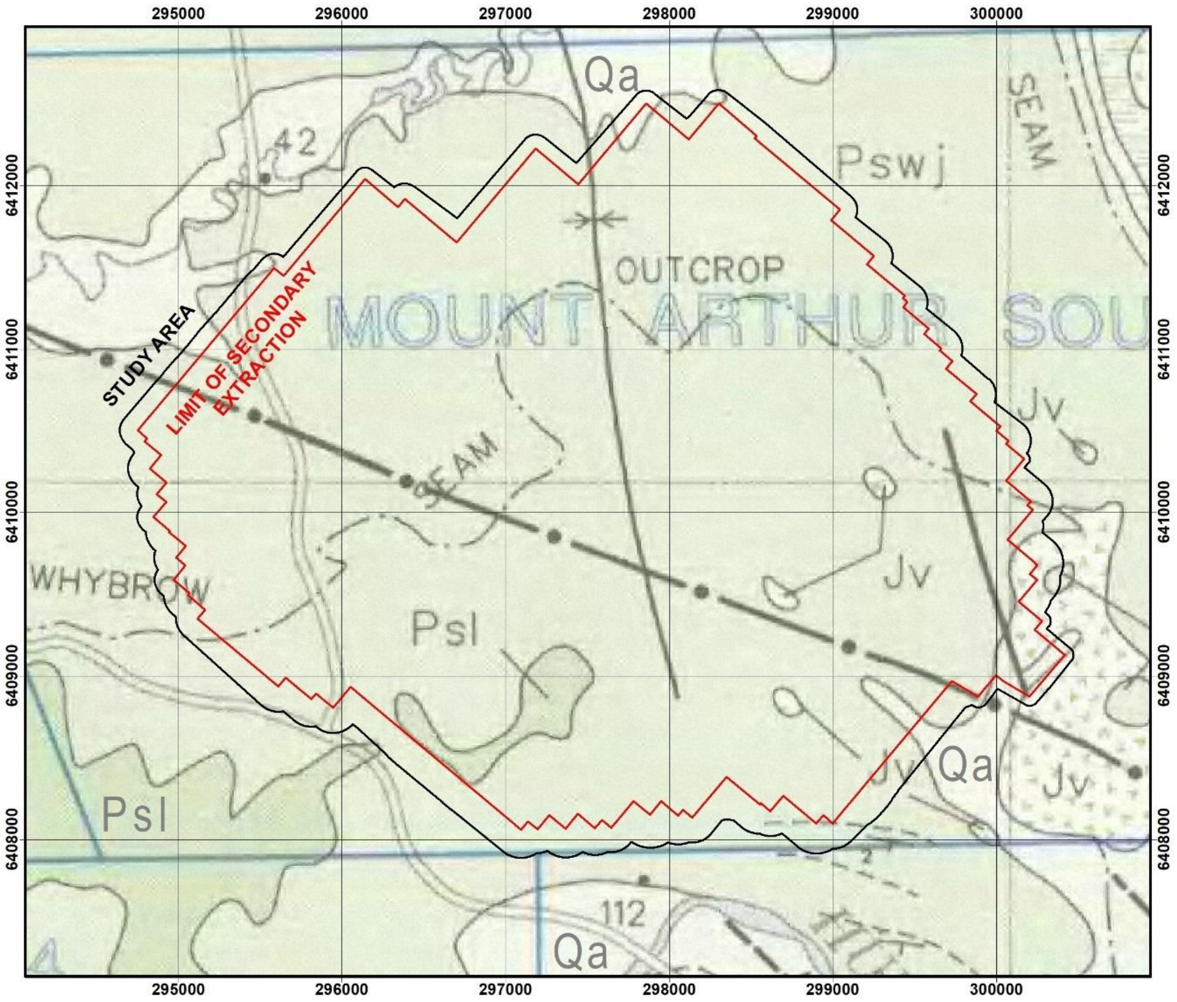

Fig. 1.9 Surface lithology above the proposed mining area

2.1. Definition of the Limit of Secondary Extraction

The *Limit of Secondary Extraction* is defined as the surface area above the secondary workings associated with the proposed panels and longwalls and the pillars between each of the proposed panels and longwalls within the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams. This area is shown in Drawings Nos. MSEC986-02 to MSEC986-29.

2.2. Definition of the Study Area

The *Study Area* is defined as the surface area that could be affected by the mining of the proposed panels and longwalls in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:

- 26.5° angle of draw from the extents of the proposed panels and longwalls in each seam; and
- predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, resulting from the extraction of the proposed panels and longwalls in all seams.

The depths of cover contours are shown in Drawings Nos. MSEC986-15 to MSEC986-18. The depths of cover above the proposed panels in the Whynot Seam vary between 40 m and 180 m. The depths of cover above the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams vary between 125 m and 425 m. The 26.5° angles of draw, therefore, have been determined by drawing a line that is a horizontal distance varying between 20 m and 213 m around the limits of the mining areas.

The 26.5° angles of draw for the proposed panels and longwalls in each of the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are shown in Drawings Nos. MSEC986-02 to MSEC986-05, respectively.

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, has been determined using the Incremental Profile Method (IPM), which is described in Chapter 3. The predicted total subsidence contours after the completion of mining in each of the seams, including the predicted 20 mm subsidence contours, are shown in Drawings Nos. MSEC986-26 to MSEC986-29.

The predicted 20 mm subsidence contour is generally located inside of the 26.5° angle of draw. However, the contour extends slightly outside of the angle of draw near the re-entrant corners of the proposed longwalls, in the south-eastern part of the mining area, where the depths of cover are higher.

The comparison between the combined 26.5° angle of draw (red line) and the predicted total 20 mm subsidence contour (blue line) in the south-eastern part of the proposed mining area is provided in Fig. 2.1. The equivalent angles of draw have been shown in this figure where the predicted total 20 mm subsidence contour extends outside the 26.5° angle of draw.

The equivalent angles of draw to the predicted total 20 mm subsidence contour, where it extends outside the traditional angle of draw, vary between 29° and 32°. These cases are all located near the re-entrant corners of the proposed mining area.

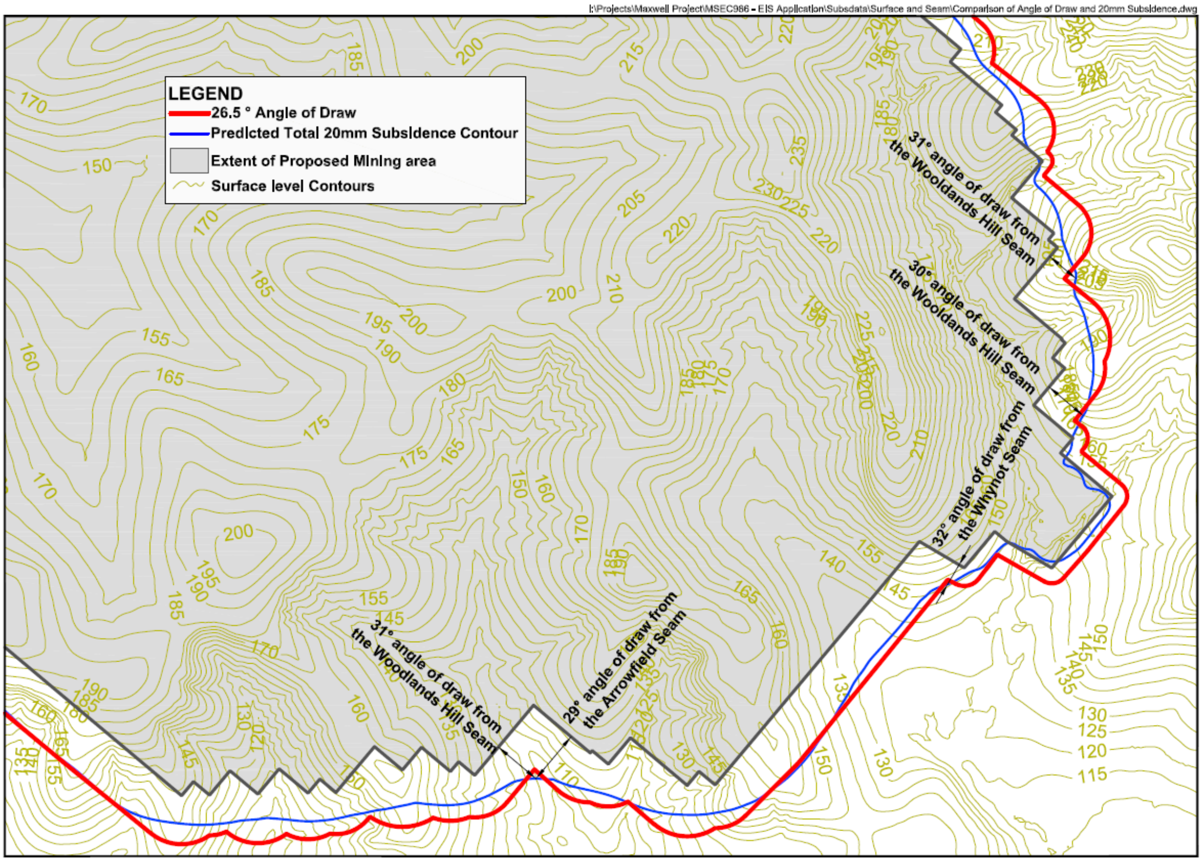

Fig. 2.1 Comparison of the combined 26.5° angle of draw and the predicted total 20 mm subsidence contour

The Study Area based on the greater of the combined 26.5° angle of draw and the predicted 20 mm total subsidence contour is shown in Drawings Nos. MSEC986-01 to MSEC986-25.

There are surface features that are located outside the Study Area that could experience either far-field horizontal movements or valley related movements. The surface features that could be sensitive to such movements have been identified and have also been included in the assessments provided in this report. These features include the Golden Highway road bridge at Bowmans Crossing, Plashett Reservoir (including the dam wall) and survey control marks.

2.3. Natural and built features within the Study Area

The major natural and built features within the Study Area can be seen in the 1:25,000 topographic map of the area from the Central Mapping Authority (CMA) shown in Fig. 2.2. The surface topography and the larger natural and built features can also be seen in an aerial photograph of the area shown in Fig. 2.3.

A summary of the natural and built features located within the Study Area is provided in Table 2.1. The locations of these features are shown in Drawing Nos. MSEC986-23 to MSEC986-25. The descriptions, predictions and impact assessments for the natural and built features are provided in Chapters 5 and 6. The section number references are provided in Table 2.1.

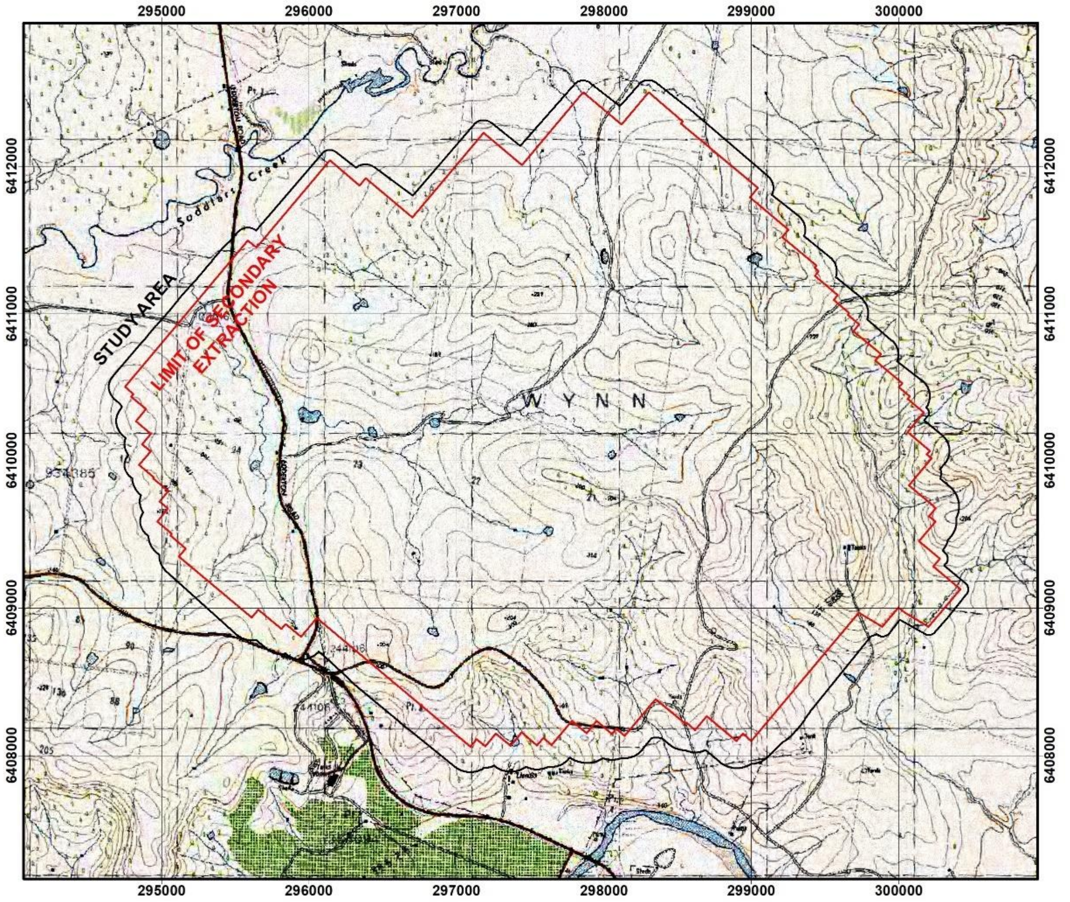

Fig. 2.2 The Study Area overlaid on CMA Map No. 9033-2

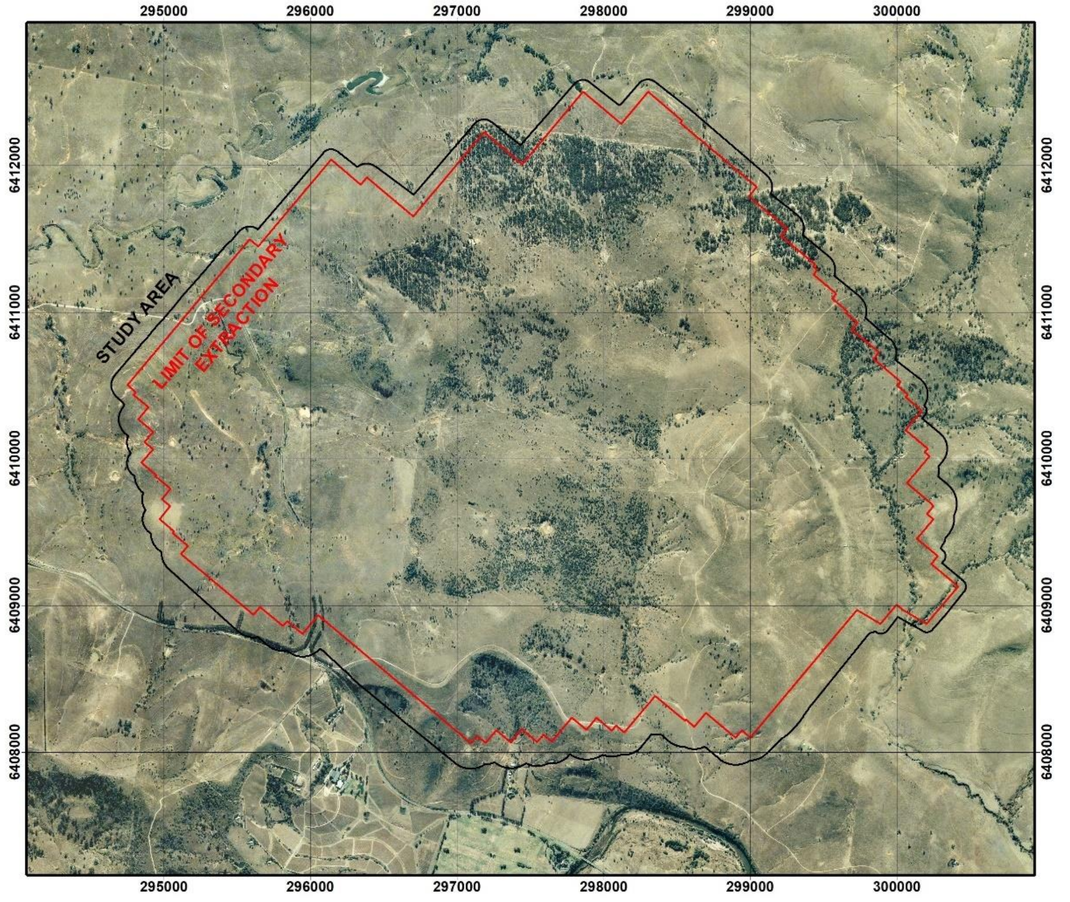

Fig. 2.3 The Study Area overlaid on an aerial photograph

Table 2.1 Natural and built features within the Study Area

Item	Within Study Area	Section number reference
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	×	
Rivers or Creeks	✓	5.1 to 5.3
Aquifers or Known Groundwater Resources	✓	5.4
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	×	
Steep Slopes	✓	5.5
Escarpments	×	
Land Prone to Flooding or Inundation	✓	5.6
Swamps, Wetlands or Water Related Ecosystems	✓	5.7
Threatened or Protected Species	✓	5.8
National Parks	×	
State Forests	×	
State Conservation Areas	×	
Natural Vegetation	✓	5.9
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	×	
Roads (All Types)	✓	6.1 & 6.3
Bridges	×	6.2
Tunnels	×	
Culverts	✓	6.3 & 6.5
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	✓	6.6
Telecommunication Lines or Associated Plants	×	6.7
Water Tanks, Water or Sewage Treatment Works	×	
Dams, Reservoirs or Associated Works	×	6.8
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	×	
Shopping Centres	×	
Community Centres	×	
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

Item	Within Study Area	Section number reference
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	✓	6.9
Farm Buildings or Sheds	✓	6.10
Tanks	✓	6.10
Gas or Fuel Storages	×	
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	✓	6.11
Farm Dams	✓	6.12
Wells or Bores	✓	6.13
Any Other Farm Features	×	
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Factories	×	
Workshops	×	
Business or Commercial Establishments or Improvements	×	6.14
Gas or Fuel Storages or Associated Plants	×	
Waste Storages or Associated Plants	×	
Buildings, Equipment or Operations that are Sensitive to Surface Movements	×	
Surface Mining (Open Cut) Voids or Rehabilitated Areas	×	
Mine Infrastructure Including Tailings Dams or Emplacement Areas	×	
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL OR HERITAGE SIGNIFICANCE	✓	6.15 & 6.16
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.17
RESIDENTIAL ESTABLISHMENTS		
Houses	×	
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

3.0 OVERVIEW OF MINE SUBSIDENCE AND THE METHODS THAT HAVE BEEN USED TO PREDICT THE MINE SUBSIDENCE EFFECTS FOR THE PROPOSED PANELS AND LONGWALLS

3.1. Introduction

Overviews of longwall mining, the development of mine subsidence and the methods of predicting mine subsidence movements are provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

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

3.2. Overview of conventional subsidence effects

The normal ground movements resulting from the extraction of pillars or longwalls are referred to as conventional or systematic subsidence movements. These subsidence effects 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 such as 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 distance between two points increases and **Compressive Strains** occur when the distance between two points decreases. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

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

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

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

The **incremental** subsidence, tilts, curvatures and strains are the additional parameters which result from the extraction of each panel or longwall. The **additional** subsidence, tilts, curvatures and strains are the maximum changes in the parameters due to the extraction of a series of panels or longwalls within a single seam. The **total** subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of panels and longwalls from a number of seams.

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 surface infrastructure, 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.

3.4. Overview of non-conventional subsidence effects

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 there is a high depth of cover, the observed subsidence profiles along monitoring survey 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 and strains at very shallow depths of cover where the collapsed zone above the extracted longwalls extends up to or near to the surface.

Non-conventional ground movements are likely to occur, in this case, due to the multi-seam mining conditions where longwalls are proposed to be extracted below the previously extracted panels and longwalls. Additional subsidence, accompanied by locally elevated tilts, curvatures and strains are expected to occur, particularly in the immediate vicinity of the chain pillars in the overlying seams, where extra voids may have been formed as the overlying strata cantilevered into the overlying goafs.

Non-conventional ground movements also occur at the higher depths of cover and in single-seam mining conditions, although much less frequently than observed at very shallow depths of cover or in multi-seam mining conditions. The irregular movements appear as a localised bump in an otherwise smooth subsidence profile, accompanied by locally elevated tilts, curvatures and strains. 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 the above mechanisms are discussed in the following sections.

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

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

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

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

In this report, non-conventional ground movements have been considered in the statistical analyses of strain, provided in Section 4.3, which have been based on measurements for both conventional and non-conventional anomalous movements. The management strategies developed for the natural and built features should be designed to accommodate movements greater than the predicted conventional movements, so that the potential impacts resulting from non-conventional movements can be adequately managed.

3.4.2. Non-conventional subsidence movements due to steep topography

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

3.4.3. Valley related effects

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

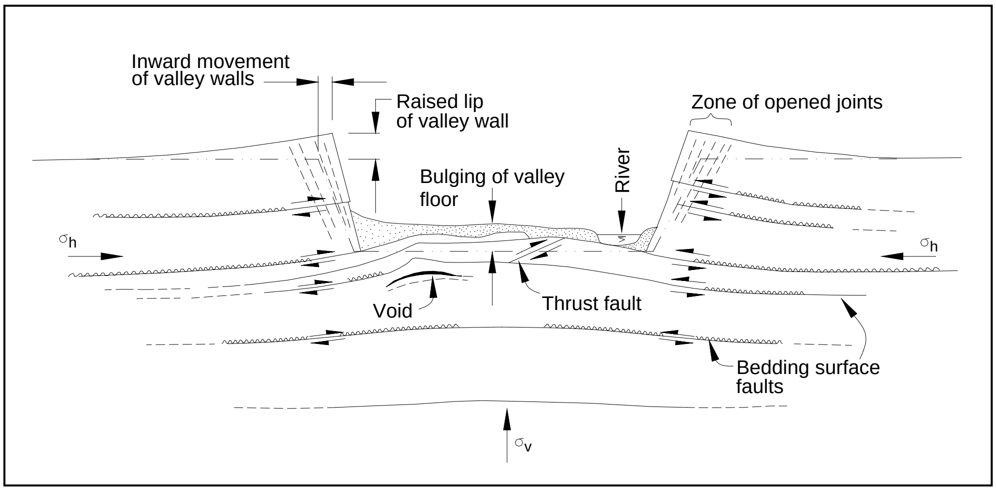

Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

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

- **Upsidence** is the reduced subsidence, or the relative uplift within a valley which results from the dilation or buckling of near-surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain;
- **Closure** is the reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides; and
- **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 resulting from the extraction of the proposed panels and longwalls were made using the empirical method outlined in Australian Coal Association Research Program (ACARP) Project No. C9067 (Waddington and Kay, 2002). Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

3.5. The Incremental Profile Method

The 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 mines in 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 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 local single-seam and multi-seam mining conditions 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), the depth of cover (H) and the extracted seam thickness (T). 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 taken into account.

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.

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 indicate 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.

Further details on the IPM are provided in the background report entitled General Discussion on Mine Subsidence Ground Movements which can be obtained from *www.minesubsidence.com*. The following section describes the calibration of the IPM for local single-seam and multi-seam mining conditions.

3.6. Calibration of the IPM

There are no existing workings within the Study Area and, therefore, the panels extracted in the first seam will be governed by single-seam mining conditions. The calibration of IPM for local single-seam mining conditions is described in Section 3.6.1.

The longwalls in subsequent seams will then be extracted beneath the previously extracted panels and longwalls and, therefore, will be governed by multi-seam mining conditions. The calibration of the IPM for multi-seam mining conditions is described in Section 3.6.2.

3.6.1. Calibration for local single-seam mining conditions

The first seam to be extracted is the Whynot Seam. The proposed bord and pillar panels have overall widths of 185 m and barrier pillar widths of 55 m. Malabar proposes to carry out partial extraction of these panels. The subsidence predictions have been based on the extraction of two rows of pillars adjacent to each of the barrier pillars (i.e. four rows of pillars within each panel) and leaving the two central rows of pillars unmined (i.e. central spine pillar). The void widths between the barrier and spine pillars are 65 m. The overall width of the central spine pillar is 55 m, which is split by a 5 m wide roadway.

The ground monitoring data from the total extraction of bord and pillar workings in the NSW coalfields show that the measured subsidence is similar to that for longwall mining of similar mining geometries. However, the magnitude of subsidence is less due to the remnant coal that remains in the total extraction of bord and pillar workings.

Total extraction of bord and pillar workings can typically recover between 75 % and 85 % of the coal due to both the first and second workings. The total extraction of a bord and pillar panel therefore results in vertical subsidence that is around 75 % to 85 % of that for a longwall with a similar mining geometry (i.e. overall void width, barrier pillar width, depth of cover and mining height). The Project involves the partial extraction of pillars.

The depth of cover to the Whynot Seam above the proposed bord and pillar panels varies between 40 m and 180 m, with an average depth of cover of 100 m. The void width-to-depth ratios for the bord and pillar panels, therefore, vary between 0.36 and 1.6, with an average of 0.65.

The proposed panels are supercritical in width[3] at the shallowest depths of cover in the northern part of the mining area. However, the shallowest depths of cover occur near the edges of the panels and, therefore, the vertical subsidence is reduced due to the panel side and end effects. Spanning of the overburden strata within the Malabar Formation across the narrow voids (i.e. 65 m) would also reduce the vertical subsidence. The component of sag subsidence has been assessed based on previous partial pillar extraction carried out in the NSW coalfields.

The average depth of cover to the Whynot Seam within the extents of the proposed panels is 100 m and the corresponding average void width-to-depth ratio is 0.65. The predicted vertical subsidence as a ratio of the extracted seam thickness is 25 % to 30 % of the extracted seam thickness.

The second seam to be extracted is the Woodlands Hill Seam. The longwalls in this seam extend beyond the bord and pillar panels in the overlying Whynot Seam in southern, western and northern parts of the mining area. The proposed longwalls in the Woodlands Hill Seam are therefore extracted under single-seam mining conditions in the southern, western and northern parts of the mining area.

The depth of cover to the Woodlands Hill Seam within the extent of the proposed longwalls and outside the extents of the overlying bord and pillar panels, varies between 125 m and 345 m, with an average depth of cover of 260 m. The width-to-depth ratios for these longwalls, therefore, vary between 0.88 and 2.4, with an average of 1.2.

The proposed longwalls in the Woodlands Hill Seam are therefore critical to supercritical in width outside the extents of the overlying panels in the Whynot Seam (i.e. single-seam conditions). The maximum achievable subsidence in the Hunter Coalfield, for single-seam supercritical conditions, is generally 60 % to 65 % of the extracted seam thickness.

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[3] Supercritical width is the void width required to develop the maximum achievable vertical subsidence, which is typically for panels having void width-to-depth ratios greater than around 1.4.

The standard IPM for the Hunter Coalfield has been used to predict the mine subsidence movements at a number of nearby collieries in the same or similar coal seams, including Beltana, Blakefield South, Integra Underground, United and Wambo. Comparisons between the measured and predicted movements indicate that the standard subsidence model provides reasonable, if not slightly conservative, predictions of the mine subsidence parameters.

The comparisons between the measured and predicted profiles of vertical subsidence, tilt and curvature for monitoring lines in the Hunter and Newcastle Coalfields, where the longwall width-to-depth ratios are 0.4, 0.7 and greater than 2.0, are shown in Fig. 3.2, Fig. 3.3 and Fig. 3.4, respectively.

The measured profiles of vertical subsidence, tilt and curvature along these monitoring lines reasonably match those predicted using the standard IPM for the Hunter Coalfield. In some locations, there are small lateral shifts between the measured and predicted profiles, which could be the result of surface dip, seam dip, or variations in the overburden geology.

The magnitudes of the maximum measured vertical subsidence along the monitoring lines were similar to or less than the maxima predicted using the standard IPM. In Fig. 3.4, the longwall was supercritical and, in this case, the standard IPM adopted a maximum achievable vertical subsidence of 65 % of the extracted seam thickness, whereas the maximum observed subsidence was around 45 % of the extracted seam thickness.

The magnitudes of the measured tilts and curvatures along the monitoring lines were also reasonably similar to those predicted using the standard IPM. The measured tilts and curvatures, however, were less than those predicted in some locations, whilst the measured tilts and curvatures exceed those predicted in other locations. This demonstrates the difficulty in predicting tilts and curvatures at a point, especially at shallow depths of cover.

It is important then to recognise that there is greater potential for variation between measured and predicted movements at a point, as the depth of cover decreases. For this reason, the predictions for point features provided in Chapters 5 and 6 are based on the maximum values within 20 m of their mapped extents. The impact assessments and recommendations for these features also consider the variability in the predicted tilts, curvatures and strains at a point.

Based on these comparisons, it has been considered that the standard IPM for the Hunter Coalfield provides reasonable predictions of vertical subsidence, tilt and curvature in these cases, where the longwall width-to-depth ratios are 0.4, 0.7 and greater than 2.0. It has not been considered necessary, therefore, to provide any specific calibration of the standard model for the proposed longwalls in the Woodlands Hill Seam based on single-seam mining conditions.

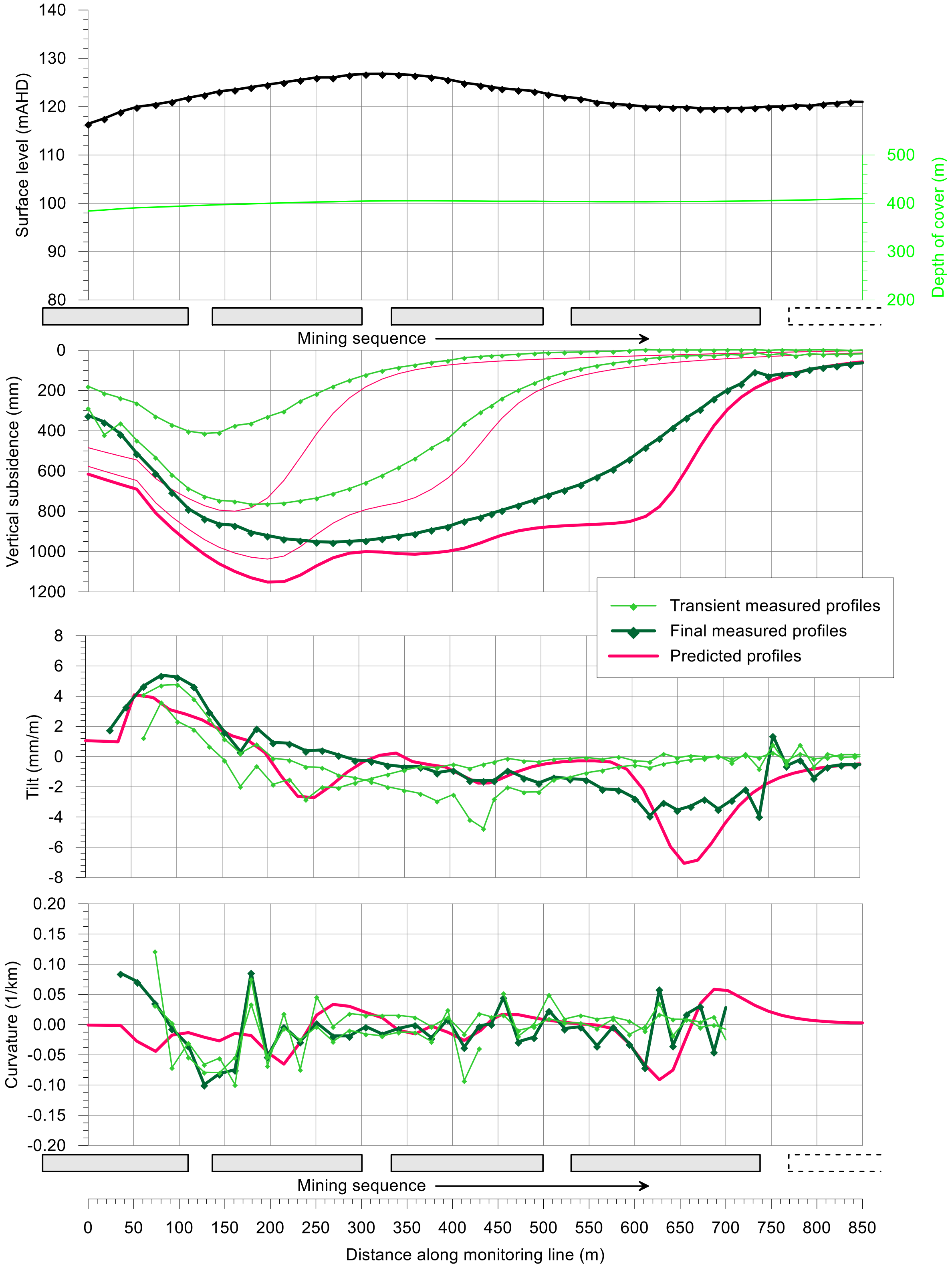


Fig. 3.2 Measured and predicted vertical subsidence, tilt and curvature along a monitoring line in the Newcastle Coalfield with a longwall width-to-depth ratio of around 0.4

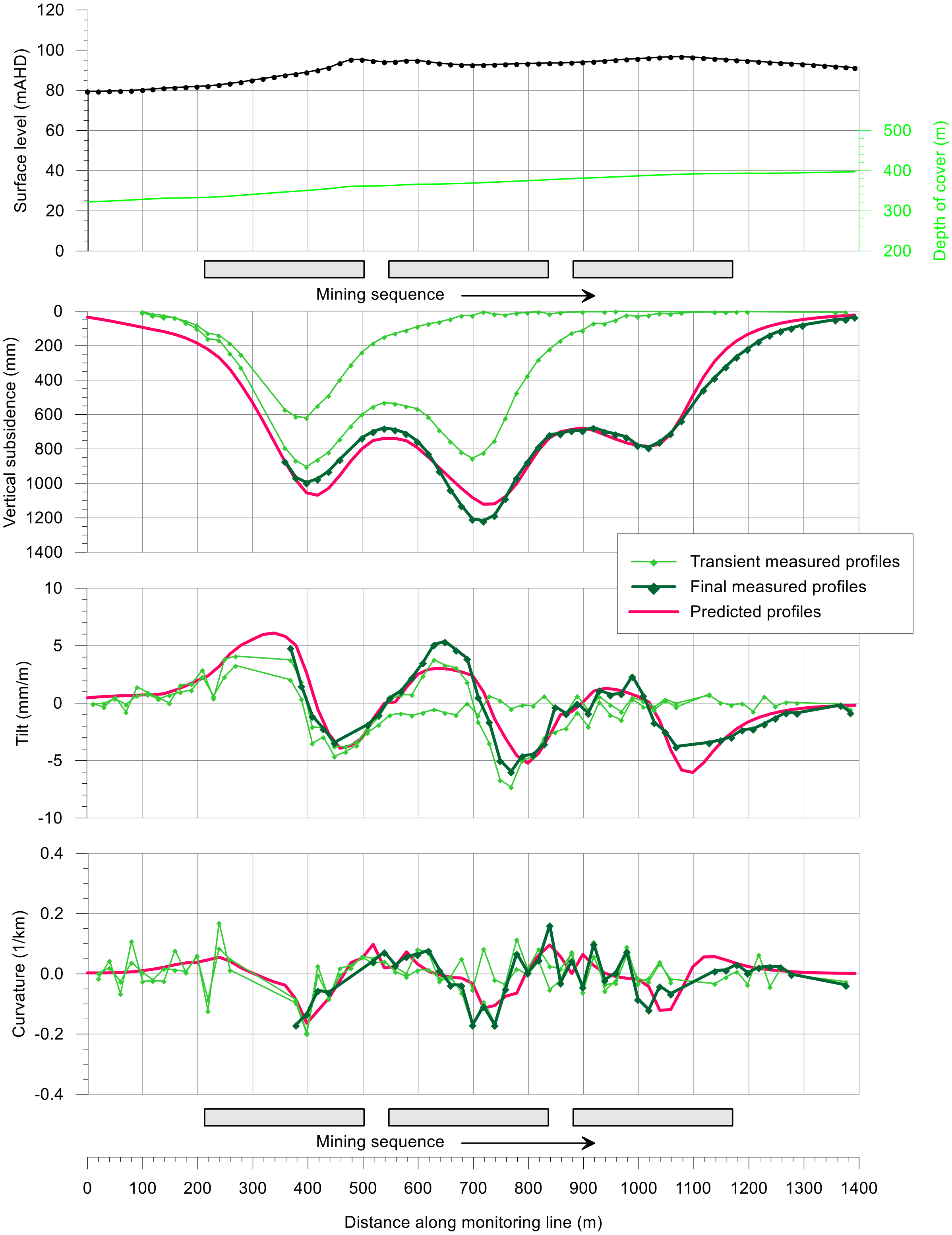


Fig. 3.3 **Measured and predicted vertical subsidence, tilt and curvature along a monitoring line in the Hunter Coalfield with a longwall width-to-depth ratio of around 0.7**

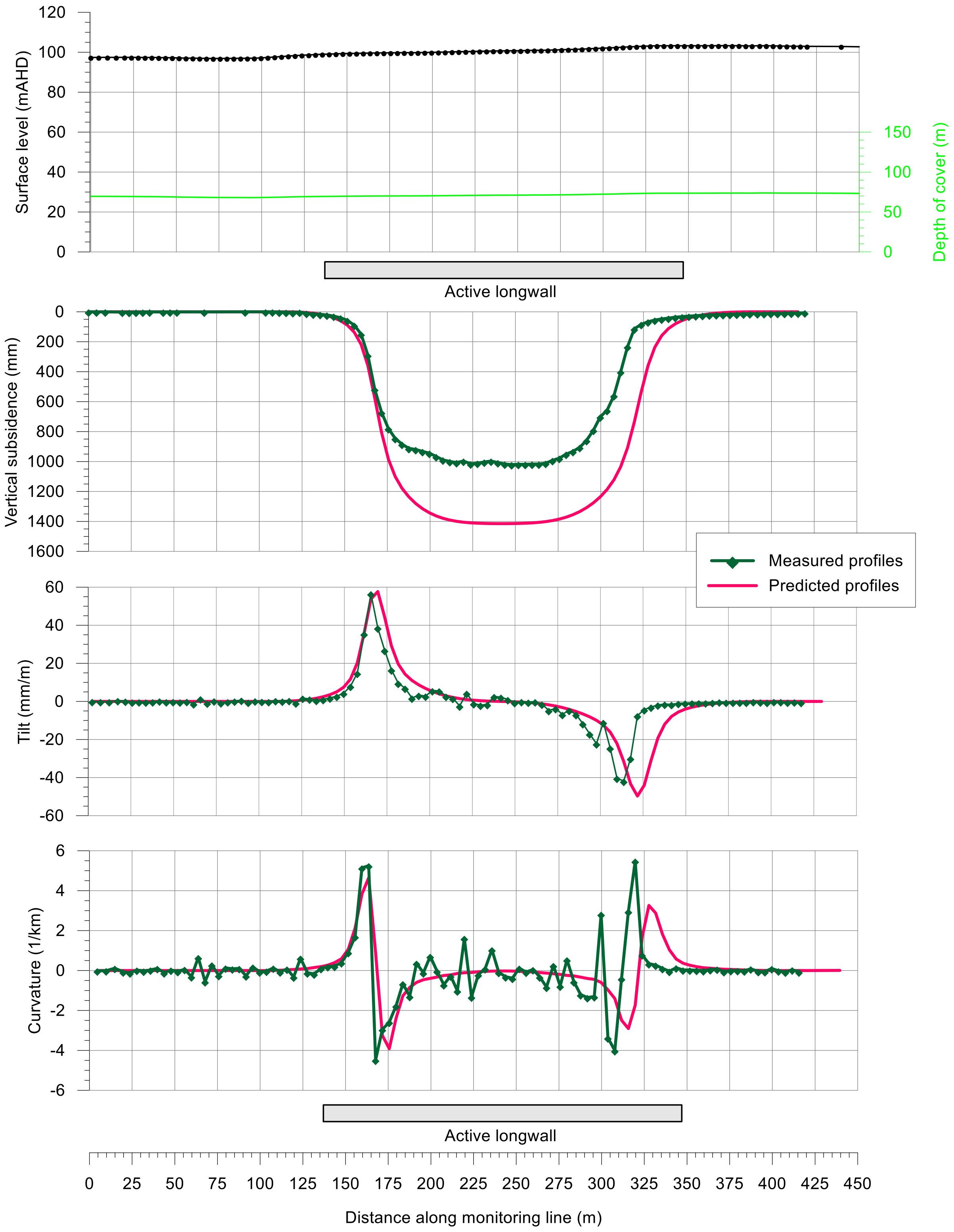


Fig. 3.4 **Measured and predicted vertical subsidence, tilt and curvature along a monitoring line in the Hunter Coalfield with a longwall width-to-depth ratio greater than 2.0**

3.6.2. Calibration for multi-seam mining conditions

The second seam proposed to be extracted is the Woodlands Hill Seam. The north-eastern ends of these longwalls are partially located beneath the bord and pillar panels in the Whynot Seam. The proposed longwalls in the Woodlands Hill Seam are therefore extracted under multi-seam mining conditions in the north-eastern part of the mining area.

Monitoring data from multi-seam longwall mining in the NSW coalfields and overseas show that the maximum values of vertical subsidence, as proportions of the mining heights, are greater than those for equivalent single-seam mining cases. The monitoring data from the multi-seam cases also show that the shapes of the subsidence profiles are affected by the locations and stabilities of the goafs and pillars in the previously extracted seams as the longwalls are extracted beneath the existing workings.

The depth of cover to the Woodlands Hill Seam, beneath the bord and pillar panels in the overlying Whynot Seam, varies between 200 m and 365 m, with an average depth of cover of 280 m. The longwall width-to-depth ratios for these longwalls, therefore, varies between 0.84 and 1.5, with an average of 1.1. The proposed longwalls in the Woodlands Hill Seam are generally critical or supercritical in width where they are located beneath the bord and pillar panels in the overlying Whynot Seam (i.e. multi-seam conditions).

The height of discontinuous fracturing for critical and supercritical longwalls is typically in the range of 1 to 1.5 times the longwall width above the seam roof. The height of discontinuous fracturing for the proposed longwalls in the Woodlands Hill Seam is in the range of 300 m to 450 m above the seam roof. The interburden thickness between the Woodlands Hill and Whynot Seams varies between 155 m and 185 m within the extents of these proposed panels and longwalls.

The discontinuous fracturing due to the extraction of the proposed longwalls in the Woodlands Hill Seam, therefore, will extend up to the previously extracted bord and pillar panels in the overlying Whynot Seam. The extraction of these longwalls will remobilise the goaf and reactivate the spine and barrier pillars in the Whynot Seam. Increased vertical subsidence due to the multi-seam mining conditions is therefore expected.

Multi-seam subsidence factors

As described in the papers by Li, et al. (2007 and 2010), the maximum additional subsidence resulting from the extraction of longwalls beneath existing longwall goaf (i.e. multi-seam mining conditions) can be estimated from the following equation:

Equation 2 $S_2 = a_2 T_2$ (after Li, et al., 2007 and 2010)

where $a_2 = (a_m - a_1)\left(\frac{T_1}{T_2}\right) + a_m$

S_2 = Maximum vertical subsidence resulting from the extraction of the second seam (multi-seam conditions) as a proportion of the extracted seam thickness

a_1 = Maximum vertical subsidence resulting from the extraction of the first seam (single-seam conditions) as a proportion of the extracted seam thickness

a_m = Maximum total subsidence resulting from the extraction of the first seam (single-seam conditions) plus the extraction of the second seam (multi-seam conditions) as a proportion of total extracted seam thickness of both seams

T_1 = Extracted seam thickness in first seam

T_2 = Extracted seam thickness in second seam

The value of 'a_1' can be calculated from the predicted vertical subsidence resulting from the extraction of the existing longwalls or panels in the first seam (i.e. single-seam conditions). The value of "a_m" can be determined from the observations from previous multi-seam longwall mining cases. There is limited multi-seam monitoring data from the NSW coalfields, especially where longwalls have been extracted directly beneath or above existing longwalls or panels.

Multi-seam ground monitoring data for longwall mining beneath existing bord and pillar panels have been considered from John Darling, Kemira, Newstan, Teralba, Wyee and North Wambo Underground. Further multi-seam ground monitoring data for longwall mining beneath existing longwalls have also been considered from Blakefield South, Cumnock, Liddell, Newstan, Sigma and North Wambo Underground.

A summary of the details, measured vertical subsidence and mining heights for the multi-seam mining case studies where longwalls were mined beneath or above previously extracted longwalls or panels is provided in Table 3.1. The maximum vertical subsidence parameters (a_1, a_2 and a_m) are also provided in this table.

Table 3.1 Multi-seam mining cases for longwalls mining beneath or above previous mining

Colliery [Coalfield] (Location)	Seam	Longwall	Depth of cover (m)	Interburden thickness (m)	Vertical subsidence (m)	Seam thickness (m)	a_1 a_2	a_m
Blakefield South [Hunter Coalfield] (BSLW1)	Whybrow	LW3 to LW6	90 ~ 140	75 ~ 80	N/A	2.2 ~ 2.5	$0.65^{\#}$	0.70 ~ 0.81
	Blakefield	BSLW1	165 ~ 215		2.1 ~ 2.7	2.2 ~ 3.0	0.75 ~ 0.96	
Blakefield South [Hunter Coalfield] (BSLW2)	Whybrow	LW1 to LW6	50 ~ 150	75 ~ 90	N/A	2.2 ~ 2.5	$0.65^{\#}$	0.64 ~ 0.82
	Blakefield	BSLW2	150 ~ 240		1.9 ~ 2.7	2.6 ~ 3.4	0.63 ~ 0.96	
Blakefield South [Hunter Coalfield] (BSLW3)	Whybrow	LW1 to LW6	75 ~ 170	70 ~ 95	N/A	2.2 ~ 2.6	$0.65^{\#}$	0.73 ~ 0.86
	Blakefield	BSLW3	170 ~ 270		2.0 ~ 2.8	2.8 ~ 3.1	0.81 ~ 1.04	
Blakefield South [Hunter Coalfield] (BSLW4)	Whybrow	LW1 to LW4	110 ~ 165	70 ~ 95	NA	2.2 ~ 2.6	$0.65^{\#}$	0.69 ~ 0.83
	Blakefield	BSLW4	200 ~ 250		2.2 ~ 2.9	2.9 ~ 3.2	0.72 ~ 0.96	
Blakefield South [Hunter Coalfield] (BSLW5)	Whybrow	LW2 to LW5	150 ~ 215	75 ~ 90	NA	2.0 ~ 2.6	$0.65^{\#}$	0.69 ~ 0.83
	Blakefield	BSLW5	235 ~ 305		2.8 ~ 3.0	3.1 ~ 3.4	0.87 ~ 0.93	
Cumnock Colliery [Hunter Coalfield]	Liddell	LW3	135	43	S_1 = 1.25	T_1 = 2.50	0.50	0.63
	Lower Pikes	LW17	90		S_2 = 1.72	T_2 = 2.20	0.78	
Liddell Colliery [Hunter Coalfield]	Upper Liddell	LW1 & LW2	160	40	S_1 = 1.6	T_1 = 2.72	0.59	0.67*
	Middle Liddell	LW3	200		S_2 = 2.0	T_2 = 2.65	0.76	
Newstan Colliery [Newcastle Coalfield]	Great Northern	Panel 6	55	15	S_1 = 2.03	T_1 = 3.4	0.60	0.80
	Fassifern	Panel 8	70		S_2 = 3.22	T_2 = 3.2	1.01	
Sigma Colliery [South Africa]	No. 3	LW4	135	13	S_1 = 1.1	T_1 = 2.75	0.40	0.69
	No. 2B	LW4A	150		S_2 = 2.92	T_2 = 3.05	0.96	
NWUM [Hunter Coalfield] (XL1-Line)	Woodlands Hill	LW2 to LW7	130 ~ 145	50	N/A	3.0	$0.65^{\#}$	0.63 ~ 0.72
	Wambo	LW2 to LW7	80 ~ 95		1.5 ~ 1.9	2.3	0.60 ~ 0.82	
NWUM [Hunter Coalfield] (XL2-Line)	Whybrow	LW10 / B&P	95 ~ 100	45 ~ 65	N/A	3.0	$0.65^{\#}$	0.68 ~ 0.86
	Wambo	LW1 to LW7	140 ~ 165		1.6 ~ 2.5	2.2	0.71 ~ 1.16	
NWUM [Hunter Coalfield] (XL4-Line)	Whybrow	LW10 to LW12	140 ~ 170	80	N/A	3.0	$0.65^{\#}$	0.70 ~ 0.76
	Wambo	LW3 to LW5	225 ~ 250		1.0 ~ 1.2	2.5	0.76 ~ 0.90	
NWUM [Hunter Coalfield] (XL5-Line)	Whybrow	LW3 / B&P	150 ~ 170	70	N/A	3.0	$0.65^{\#}$	0.65 ~ 0.77
	Wambo	LW6 and LW7	225 ~ 240		1.1 ~ 1.2	2.5	0.65 ~ 0.91	
NWUM [Hunter Coalfield] (SC1-Line)	Whybrow	LW10 to LW13	100 ~ 175	80 ~ 120	N/A	3.0	$0.65^{\#}$	0.71 ~ 0.80
	Wambo	LW2 to LW4	220 ~ 255		2.0 ~ 2.4	2.2 ~ 2.5	0.79 ~ 0.97	

*Note: * denotes that the value of “a_m” of 67 % for Liddell Colliery is based on the most recent seam extraction information provided by the colliery and, hence, is less than that provided in the paper by Li et al (2007) of 83 %. # denotes subsidence due to the extraction of the first seam has been estimated to be 65 % of the mining height based on supercritical conditions. The depths of cover have been rounded to the nearest 5 m, therefore, calculating the interburden thicknesses by taking the difference between in the depths of covers minus the thickness of the top seam provides a slightly different result to the stated interburden thicknesses.*

NWUM = North Wambo Underground Mine

The additional vertical subsidence measured due to the extraction of the second seam varied between 60 % and 116 % of the mining height (i.e. a_2 = 0.60 ~ 1.16). In many of these cases, however, the maximum measured vertical subsidence was localised and the values elsewhere were less than the maxima provided in the table. On average, the additional subsidence observed for these available multi-seam mining cases was around 85 % of the mining height in the second seam (i.e. a_2 = 0.85).

The additional vertical subsidence can be greater than 100 % of the seam thickness adjacent to the chain pillars in the upper seam. The initial extraction of the first seam results in voids adjacent to the chain pillars due to the angle of break over the caving zone. The subsequent extraction in the lower seam can fail the cantilevering strata resulting in locally increased subsidence adjacent to the chain pillars. Whilst the additional subsidence due to the extraction of the lower seam can be greater than 100 % of its thickness, the total subsidence from mining both seams is less than the combined thickness of these seams.

The total vertical subsidence measured due to the extraction of both seams varied between 63 % and 86 % of the total mining height (i.e. $a_m = 0.63 \sim 0.86$). On average, the total vertical subsidence measured for these available multi-seam mining cases was around 75 % of the total mining height in both seams (i.e. $a_m = 0.75$).

Additional vertical subsidence due to the Woodlands Hill Seam

The interburden thickness for the proposed longwalls in the Woodlands Hill Seam beneath the bord and pillar panels in the Whynot Seam varies between 155 m and 185 m. The multi-seam cases provided in Table 3.1 have thinner interburden thicknesses, being less than 50 m at Cumnock, Liddell, Newstan and Sigma, between 70 m and 95 m at Blakefield South and between 45 m and 120 m at the North Wambo Underground Mine.

Whilst the interburden thickness for the proposed longwalls is greater than those for the previous multi-seam cases, these proposed longwalls are mining beneath subcritical bord and pillar panels. There is greater potential for reactivation of these workings when compared with the previous multi-seam cases, which generally comprised supercritical longwalls mining beneath supercritical longwalls and panels.

It is considered that the most relevant case studies are the XL2-Line and SC1-Line at the North Wambo Underground Mine, as well as Liddell, Cumnock and Blakefield South Mines. Based on these case studies, it appears that adopting a value for “a_m” of 75 % would provide reasonable predictions of the multi-seam subsidence for the proposed longwalls in the Woodlands Hill Seam.

The average mining height in the area of multi-seam extraction is 2.0 m for the Whynot Seam (i.e. $a_1 = 2.0$) and 3.0 m for the Woodlands Hill Seam (i.e. $a_2 = 3.0$). The additional vertical subsidence, as a proportion of the mining height, due to the extraction of the proposed longwalls in the Woodlands Hill Seam is as follows:

Equation 3 $$a_2 = (0.75 - 0.30)\left(\frac{2.0}{3.0}\right) + 0.75 = 1.05$$

The maximum predicted additional vertical subsidence due to the extraction of the proposed longwalls in the Woodlands Hill Seam, therefore, has been taken as 100 % of the mining height (i.e. $a_2 = 1.0$) where they are located directly beneath the bord and pillar panels in the overlying Whynot Seam. This is reasonably consistent with the observations along the monitoring lines at the North Wambo Underground Mine, as shown in Table 3.1.

The multi-seam prediction curves are illustrated as the red lines in Fig. 3.5. These have been developed by scaling up the single-seam prediction curves (i.e. grey lines) so as to achieve a maximum predicted vertical subsidence of 100 % of extracted seam thickness based on supercritical conditions. These multi-seam prediction curves provide vertical subsidence that is around 55 % greater than those obtained using the standard single-seam prediction curves.

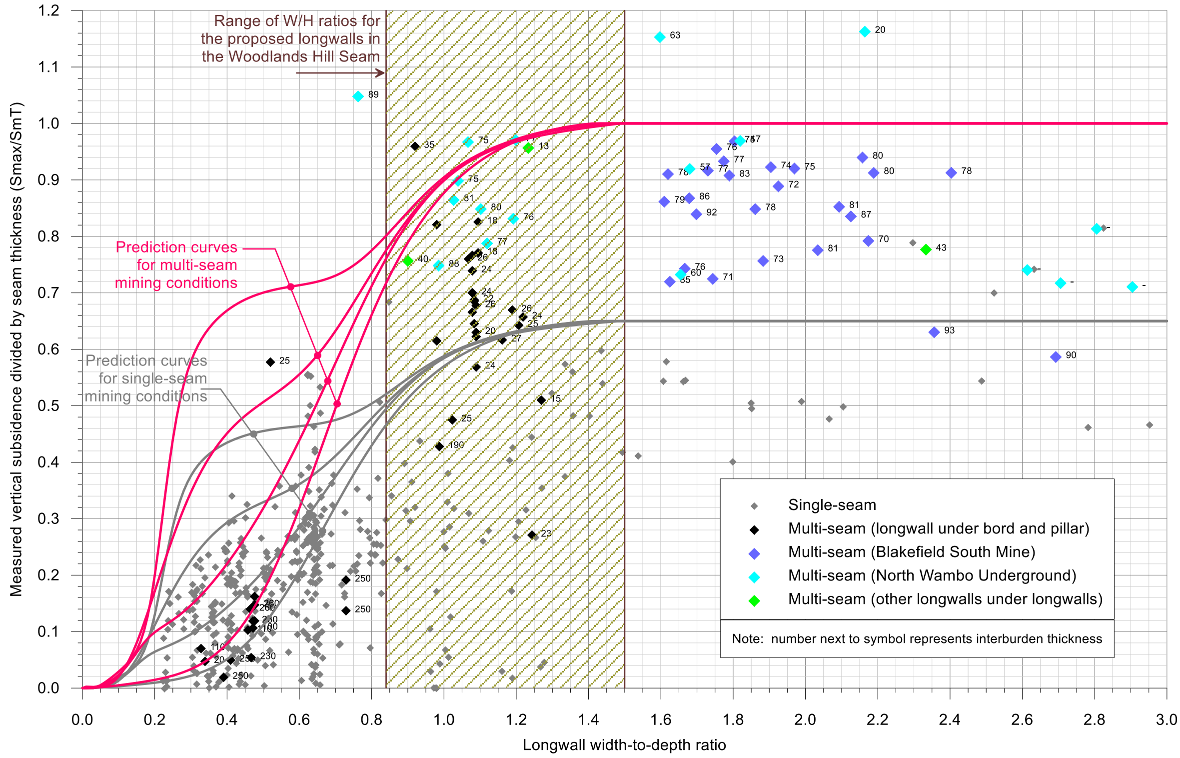


Fig. 3.5 **Maximum measured vertical subsidence versus longwall width-to-depth ratio for previous multi-seam mining cases**

The multi-seam mining cases beneath bord and pillar workings are shown as the black diamonds and beneath longwalls are shown as the blue, cyan and green diamonds in Fig. 3.5. The numbers adjacent to these symbols represent the interburden thicknesses. The single-seam mining cases are also shown in this figure, for comparison, as the light grey diamonds.

The multi-seam prediction curves are above the majority of the multi-seam cases based on mining beneath bord and pillar workings (i.e. black diamonds) and mining beneath longwalls (i.e. blue, cyan and green diamonds). In some cases, the maximum measured vertical subsidence exceeds the prediction curves; however, in many of these cases the maximum subsidence was localised and the subsidence elsewhere was below the prediction curves. Also, in some of these cases, the upper seam was thicker than the lower seam and, therefore, there was greater potential for increased multi-seam subsidence.

The width-to-depth ratios for the proposed longwalls in the Woodlands Hill Seam for multi-seam conditions vary between 0.84 and 1.5. It can be seen from Fig. 3.5, that previous longwall mining beneath bord and pillar workings (i.e. black diamonds) at similar width-to-depth ratios has resulted in vertical subsidence typically between 0.50 and 0.82 times the mining height. The previous longwall mining beneath longwalls (i.e. cyan and green diamonds) has resulted in vertical subsidence typically between 0.74 and 0.96 times the mining height.

The maximum predicted additional vertical subsidence for the proposed longwalls in the Woodlands Hill Seam, as a proportion of the mining height, varies between 0.75 (at a width-to-depth ratio of 0.84) and 1.0 (at a width-to-depth ratio of 1.5) based on the multi-seam prediction curves.

Additional vertical subsidence for the Arrowfield and Bowfield Seams

The third and fourth seams to be extracted are the Arrowfield and Bowfield Seams, respectively. The proposed longwalls in each of the seams are located beneath the previously extracted longwalls in the overlying seams. The interburden thickness between the Arrowfield and Woodlands Hill Seams varies between 40 m and 75 m, with an average of 50 m. The interburden thickness between the Bowfield and Arrowfield Seams varies between 20 m and 45 m, with an average of 30 m.

The discontinuous fracturing due to the extraction of the proposed longwalls in each of the Arrowfield and Bowfield Seams will extend up to the previously extracted longwalls in the overlying seams. The extraction of these longwalls will remobilise the goaf and reactivate the chain pillars in the overlying seams. Increased vertical subsidence due to the multi-seam mining conditions is therefore expected.

The maximum predicted vertical subsidence due to the extraction of the proposed longwalls in the Arrowfield and Bowfield Seams has been based on the multi-seam prediction curves shown in Fig. 3.5.

There is greater uncertainty in the predictions for the Arrowfield and Bowfield Seams since there is limited multi-seam data available for third and fourth seams. However, the proposed longwalls in the Arrowfield and Bowfield Seams are critical to super-critical in width and the maximum predicted additional subsidence represents close to 100 % of their respective seam thicknesses. The predictions of vertical subsidence for these seams are therefore considered to be conservative since the actual subsidence is limited by the available voids defined by the overall seam thicknesses.

Shapes of the multi-seam subsidence profiles

It has been found from past longwall mining experience, that the shapes of multi-seam subsidence profiles depend on, amongst other factors, the depths of cover, interburden thickness, mining heights and the relative locations between the longwalls within each seam.

In the cases where the chain pillars within the lower seam are located directly beneath the chain pillars or panel edges in the overlying seam, which are referred to as *stacked cases*, the measured subsidence profiles are steeper and more localised above the longwalls when compared with those for similar single-seam conditions. In the cases where the chain pillars within the lower seam are offset from the chain pillars or panel edges in the overlying seam, which are referred to as *staggered cases*, the subsidence profiles are flatter and extend further when compared with those for similar single-seam conditions.

The proposed longwalls within each of the seams have been staggered so that the chain pillars are not aligned. The longwalls in the Arrowfield Seam have been offset by approximately 75 m from the longwalls in the overlying Woodlands Hill Seam. The longwalls in the Bowfield Seam have been offset by approximately 100 m from the longwalls in the overlying Arrowfield Seam.

The shapes of the multi-seam subsidence profiles were determined using the available monitoring data from Blakefield South, North Wambo Underground Mine and other available cases outlined previously. It was also observed at Blakefield South, that locally increased subsidence occurred adjacent to the chain pillars in the overlying seam, and that locally reduced subsidence occurred directly above the chain pillars and directly above the middle of the longwalls in the overlying seam.

3.7. Reliability of the predicted conventional subsidence parameters

The IPM is based upon a large database of observed subsidence movements in the NSW coalfields and has been found, in most cases, to give reasonable, if not, slightly conservative predictions of maximum subsidence, tilt and curvature. The predicted profiles obtained using this method also reflect the way in which each parameter varies over the mined area and indicate the movements that are likely to occur at any point on the surface.

In this case, the IPM was calibrated using monitoring data from elsewhere in the Hunter Coalfield. The subsidence model was also calibrated using the available multi-seam monitoring data from the NSW coalfields.

The prediction of the conventional subsidence parameters at specific points is more difficult than the prediction of the maxima anywhere above extracted longwalls. Variations between predicted and observed parameters at a point can occur where there is a lateral shift between the predicted and observed subsidence profiles, which can result from seam dip or variations in topography. In these situations, the lateral shift can result in the observed parameters being greater than those predicted in some locations, whilst the observed parameters are less than those predicted in other locations.

Notwithstanding the above, the IPM provides site specific predictions for each natural and built feature and, hence, provides a more realistic assessment of the subsidence impacts than by applying the maximum predicted parameters at every point, which would be overly conservative and would yield an excessively overstated assessment of the potential subsidence impacts.

The prediction of strain at a point is even more difficult as there tends to be a large scatter in observed strain profiles. It has been found that measured strains can vary considerably from those predicted at a point, not only in magnitude, but also in sign, that is, the tensile strains have been observed where compressive strains were predicted, and vice versa. For this reason, the prediction of strain in this report has been based on a statistical approach, which is discussed in Section 4.3.

It is also likely that some localised irregularities will occur in the subsidence profiles due to near-surface geological features and multi-seam mining conditions. The irregular movements are accompanied by elevated tilts, curvatures and strains, which often exceed the conventional predictions. In most cases, it is not possible to predict the locations or magnitudes of these irregular movements. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains, including both conventional and non-conventional anomalous strains, which is discussed in Section 4.3.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed panels and longwalls in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams. The predicted subsidence parameters and the impact assessments for the natural and built features within the Study Area are provided in Chapter 5.

The predicted subsidence, tilts and curvatures have been obtained using the IPM, which has been calibrated for single-seam and multi-seam conditions, as described in Section 3.6. The predicted strains have been determined by analysing the strains measured in the NSW coalfields, where the mining geometries and overburden geologies are similar to those for the proposed panels and longwalls.

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

4.2. Maximum predicted subsidence, tilt and curvature

The predicted total subsidence contours after the extraction of the proposed panels and longwalls in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are shown in Drawings Nos. MSEC986-26, MSEC986-27, MSEC986-28 and MSEC986-29, respectively.

A summary of the maximum predicted additional conventional subsidence parameters, due to the extraction of the proposed series of panels or longwalls in each of the seams, is provided in Table 4.1. The values in this table represent the maximum additional movements due to mining in each seam.

Table 4.1 Maximum predicted additional conventional subsidence parameters for each seam

Due to each seam	Maximum predicted additional vertical subsidence (mm)	Maximum predicted additional tilt (mm/m)	Maximum predicted additional hogging curvature (km^{-1})	Maximum predicted additional sagging curvature (km^{-1})
Whynot Seam (single-seam conditions)	350	15	0.5	1.0
Woodlands Hill Seam (including reactivation)	3100	45	2.0	1.5
Arrowfield Seam (including reactivation)	2700	20	0.5	0.5
Bowfield Seam (including reactivation)	2500	20	0.5	0.5

A summary of the maximum predicted cumulative (i.e. total) conventional subsidence parameters, after the completion of the proposed series of panels or longwalls in each of the seams, is provided in Table 4.2. The predicted tilts are the maxima after the completion of all panels or longwalls within each of the seams. The predicted curvatures are the maxima at any time during or after the extraction of the panels or longwalls within each of the seams.

Table 4.2 Maximum predicted cumulative conventional subsidence parameters after each seam

After each seam	Maximum predicted cumulative vertical subsidence (mm)	Maximum predicted cumulative tilt (mm/m)	Maximum predicted cumulative hogging curvature (km^{-1})	Maximum predicted cumulative sagging curvature (km^{-1})
Whynot Seam	350	15	0.5	1.0
Woodlands Hill Seam	3200	45	2.0	1.5
Arrowfield Seam	5400	50	2.0	2.0
Bowfield Seam	5600	50	2.0	2.0

The maximum predicted additional vertical subsidence, as percentages of the mining heights, are 17 % for the Whynot Seam, 99 % for the Woodlands Hill Seam, 95 % for the Arrowfield Seam and 94 % for the Bowfield Seam.

The maximum predicted total vertical subsidence, after the extraction of the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams, is 5600 mm and it represents approximately 58 % of the combined mining heights of these seams. It is noted, that the percentage of the total mining height is less than the percentages of the mining heights for individual seams for multi-seam conditions, as the positions of maximum subsidence do not coincide due to the stagger of the longwalls.

The maximum predicted total conventional tilt is 50 mm/m (i.e. 5 %, or 1 in 20). The maximum predicted total conventional curvatures are 2.0 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 0.5 km.

It can be seen from Drawings Nos. MSEC986-26 to MSEC986-29, that the magnitude of the predicted subsidence varies over the proposed mining area, due to the single-seam and multi-seam mining conditions, as well as the variations in the depths of cover and mining heights. It can also be inferred from the spacing of the contours shown in these drawings, that the magnitudes of the predicted tilts and curvatures also vary over the mining area.

To illustrate this variation, the predicted profiles of vertical subsidence, tilt and curvature have been determined along two prediction lines, the locations of which are shown in Drawings Nos. MSEC986-26 to MSEC986-29. The predicted profiles of vertical subsidence, tilt and curvature along Prediction Lines 1 and 2 are shown in Figs. C.01 and C.02, respectively, in Appendix C. The predicted profiles are shown after the completion of the Whynot Seam (red lines), Woodlands Hill Seam (green lines), Arrowfield Seam (cyan lines) and Bowfield Seam (blue lines). The maximum predicted tilts and curvatures after any panel or longwall in any seam are shown as the grey lines.

4.3. Predicted strains

It is more difficult predicting strain compared to predicting vertical 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.

4.3.1. Single-seam mining conditions

It has been found, for single-seam mining conditions, that applying a constant factor to the predicted maximum curvatures provides a reasonable prediction for the maximum conventional or typical 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 mining conditions.

The maximum predicted conventional curvatures due to the extraction of the proposed panels in the Whynot Seam are 0.5 km^{-1} hogging and 1.0 km^{-1} sagging. Adopting a factor of 10, the maximum predicted conventional strains, due to the proposed mining in the Whynot Seam only, are 5 mm/m tensile and 10 mm/m compressive. These maximum strains occur where the depths of cover are shallowest, in the northern part of the proposed mining area.

The proposed longwalls in the Woodlands Hill Seam are located outside the extents of the overlying panels in the Whynot Seam in the southern, western and northern parts of the proposed mining area. These parts of the longwalls will be extracted under single-seam mining conditions.

The maximum predicted conventional curvatures for the proposed longwalls in the Woodlands Hill Seam, outside the extents of the overlying panels in the Whynot Seam (i.e. single-seam conditions), are 2.0 km^{-1} hogging and 1.5 km^{-1} sagging. Adopting a factor of 10, the maximum predicted conventional strains for single-seam mining conditions are 20 mm/m tensile and 15 mm/m compressive.

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 longwalls in the Woodlands Hill Seam has been determined using monitoring data from previously extracted panels in the Hunter and Newcastle Coalfields, for single-seam mining conditions, where the width-to-depth ratios and mining heights were similar to those of the proposed longwalls.

The depth of cover to the proposed longwalls in the Woodlands Hill Seam, outside of the extents of the overlying panels in the Whynot Seam (i.e. single-seam conditions), varies between 125 m in the north-western part of the mining area and 345 m in the south-eastern part of the mining area. The longwall width-to-depth ratios vary between 0.88 and 2.4, i.e. subcritical through to supercritical widths.

The strain distributions for the proposed longwalls in the Woodlands Hill Seam, for single-seam mining conditions, have therefore been determined separately in the north-western and southern parts of the proposed mining area.

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

Woodlands Hill Seam (north-western part of the mining area for single-seam mining conditions)

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 between 100 m and 150 m. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains for the proposed longwalls in the Woodlands Hill Seam, for single-seam mining conditions, in the north-western part of the mining area.

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.

The histograms of the maximum observed tensile and compressive strains measured for the survey bays located directly above goaf, for previously extracted supercritical longwalls in the Hunter and Newcastle Coalfields at depths of cover between 100 m and 150 m, are provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

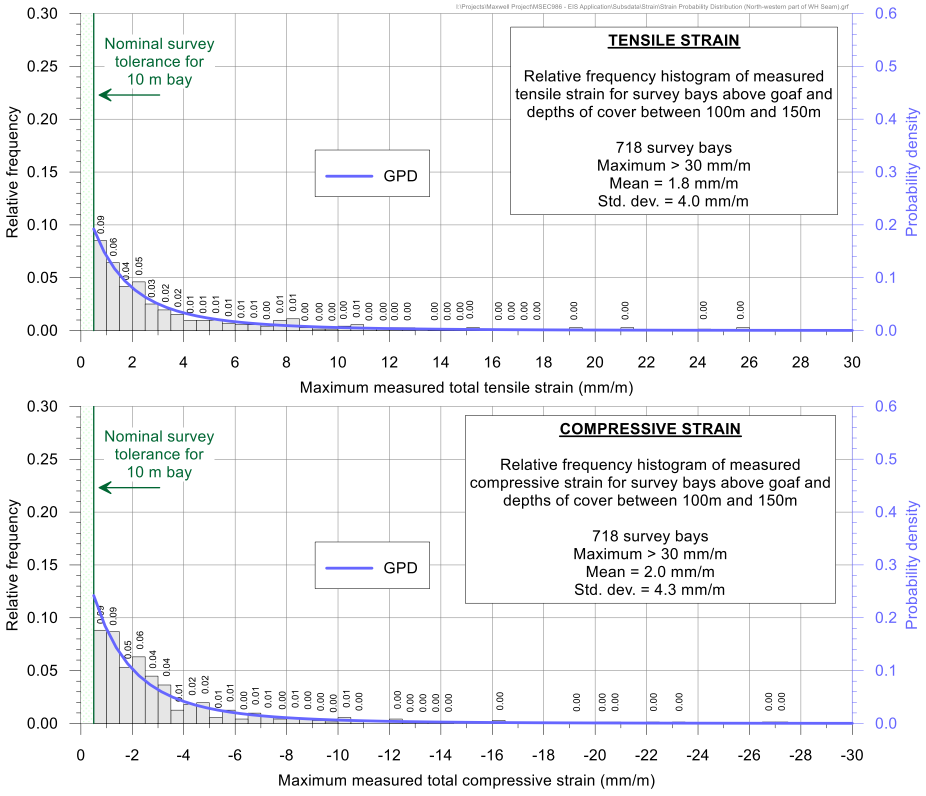


Fig. 4.1 Distributions of the measured tensile and compressive strains for survey bays located above supercritical longwalls at depths of cover between 100 m and 150 m

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 8 mm/m tensile and compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 21 mm/m tensile and 19 mm/m compressive.

Woodlands Hill Seam (southern part of the mining area for single-seam mining conditions)

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 0.8 and 1.2. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains for the proposed longwalls in the Woodlands Hill Seam, for single-seam mining conditions, in the south-eastern part of the mining area.

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.

The histograms of the maximum observed tensile and compressive strains measured for the survey bays located directly above goaf, for previously extracted longwalls in the Hunter and Newcastle Coalfields with width-to-depth ratios between 0.8 and 1.2, are provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

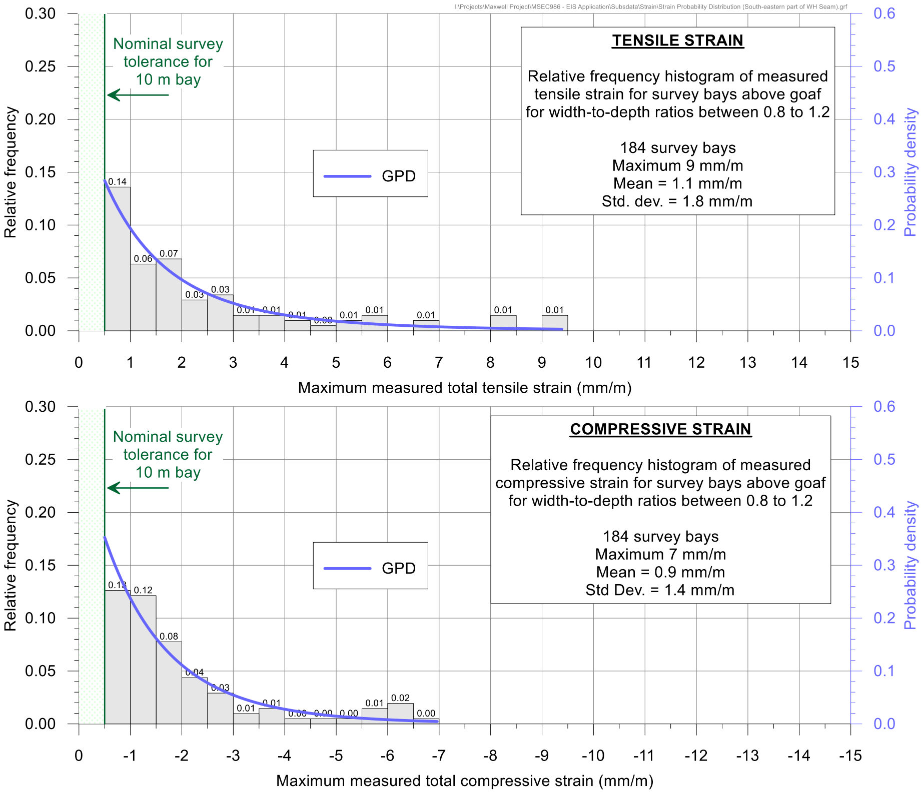


Fig. 4.2 Distributions of the measured tensile and compressive strains for survey bays located above longwalls with width-to-depth ratios between 0.8 and 1.2

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 9 mm/m tensile and 6 mm/m compressive.

4.3.2. Multi-seam mining conditions

It is not possible to provide a simple relationship between conventional curvature and conventional strain for multi-seam mining conditions, since there is limited empirical data to establish this relationship. In addition to this, localised strains also develop in multi-seam mining conditions, as the result of remobilising the existing goaf and chain pillars in the overlying seam, which are not directly related to curvature.

The range of potential strains resulting from the extraction of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams, for multi-seam mining conditions, has been based on the measured strains for multi-seam mining in the Hunter and Newcastle Coalfields. The most extensive multi-seam strain data comes from: Blakefield South Mine where Longwalls 1 to 5 were mined beneath the South Bulga longwalls in the overlying Whybrow Seam (17 monitoring lines); and the North Wambo Underground Mine where Longwalls 1 to 10A in the Wambo Seam were extracted directly beneath the existing Homestead/Wollemi workings in the Whybrow Seam (six transverse monitoring lines).

Comparisons of the void widths, depths of cover, width-to-depth ratios, interburden thicknesses and mining heights of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams, in the multi-seam mining areas, with those at Blakefield South Mine and the North Wambo Underground Mine, are provided in Table 4.3.

Table 4.3 Comparison of the mine geometry for the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams with Blakefield South Mine and the North Wambo Underground Mine

Parameter	Proposed longwalls at the Maxwell Project			Longwalls used in the strain analysis
	Woodlands Hill Seam	Arrowfield Seam	Bowfield Seam	
Void width (m)	305	305	305	260 ~ 410 (325 ave.)
Depth of cover (m)	200 ~ 365 (280 ave.)	170 ~ 415 (315 ave.)	215 ~ 425 (340 ave.)	80 ~ 300 (190 ave.)
W/H ratio	0.84 ~ 1.5 (1.1 ave.)	0.73 ~ 1.8 (0.97 ave.)	0.72 ~ 1.4 (0.90 ave.)	0.9 ~ 3.3 (1.8 ave.)
Interburden (m)	155 ~ 185 (170 ave.)	40 ~ 75 (50 ave.)	20 ~ 45 (30 ave.)	50 ~ 120 (80 ave.)
Mining height (m)	2.6 ~ 3.5 (3.0 ave.)	2.1 ~ 3.7 (2.9 ave.)	2.4 ~ 3.3 (2.8 ave.)	2.1 ~ 3.4 (2.6 ave.)

The void width of the proposed longwalls of 305 m is similar to but slightly less than the average void width of the longwalls used in the strain analysis of 325 m. The width-to-depth ratios for the proposed longwalls of 0.72 to 1.8 are at the lower end of the range of width-to-depth ratios for the longwalls used in the strain analysis of 0.9 to 3.3.

The interburden thicknesses above the proposed longwalls in the Woodlands Hill Seam of 155 m to 185 m are greater than those for the longwalls used in the strain analysis of 50 m to 120 m. The interburden thicknesses above the proposed longwalls in the Arrowfield Seam are reasonably similar to, and the interburden thicknesses above the longwalls in the Bowfield Seam are less than those for the longwalls used in the strain analysis. The average mining heights for the proposed longwalls of 2.8 m to 3.0 m are similar to but slightly greater than the average mining height of the longwalls used in the strain analysis of 2.6 m.

The strain analysis, therefore, should also provide reasonable, if not, slightly conservative indication of the range of potential strains for the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams for multi-seam mining conditions.

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. The frequency distribution of the maximum observed tensile and compressive strains measured in survey bays above goaf is provided in Fig. 4.3. The probability distribution functions, based on the fitted GPDs, are also shown in this figure.

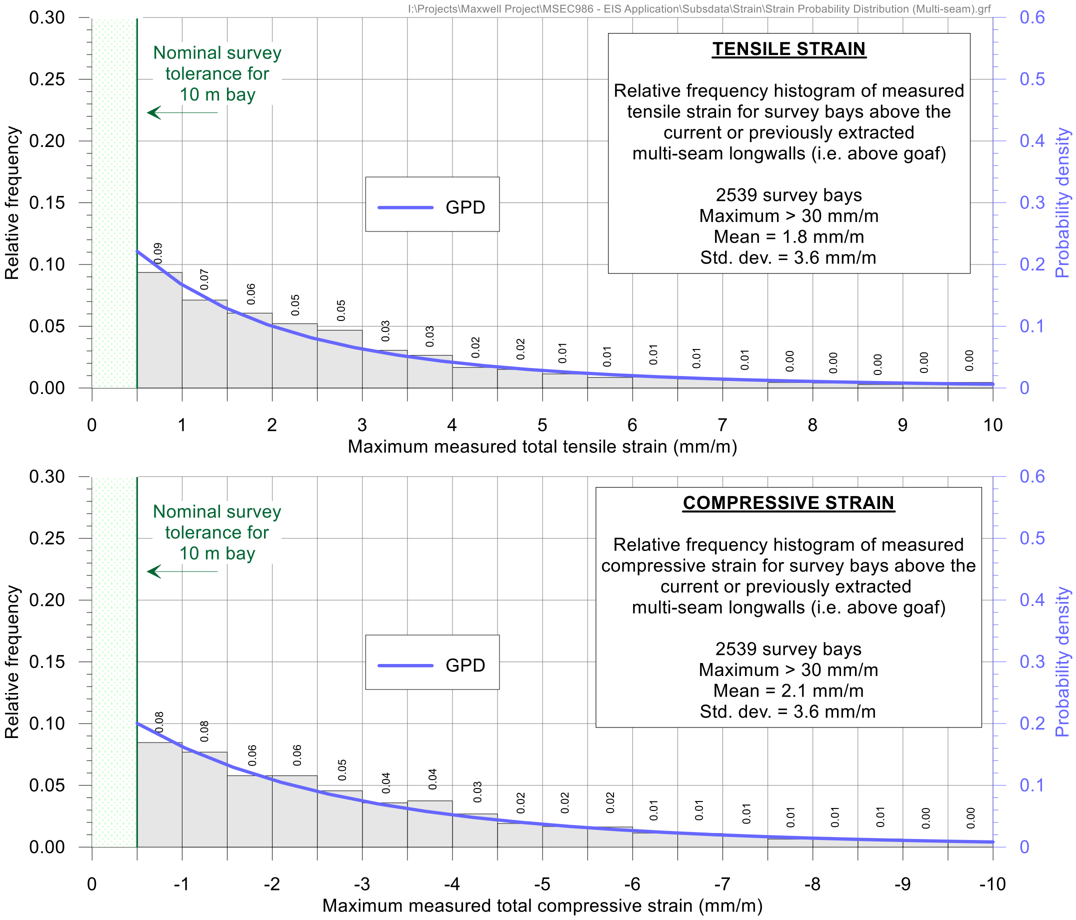


Fig. 4.3 Distributions of the measured tensile and compressive strains for multi-seam longwalls in the Hunter Coalfield

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 8 mm/m tensile and 9 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining are 16 mm/m tensile and compressive.

The predicted range of strains based on multi-seam conditions is similar to but slightly less than that for single-seam conditions in the north-western part of the proposed mining area. The reason is the proposed longwalls in the Woodlands Hill Seam, in the north-western part of the mining area (i.e. single-seam conditions), are supercritical in width and have depths of cover less than 200 m. Whereas the proposed longwalls in the eastern part of the mining area (i.e. multi-seam conditions) are subcritical in width and have depths of cover greater than 200 m.

The experience from Blakefield South Mine found that the highest strains for multi-seam conditions occurred where the chain pillars in the Blakefield Seam were located directly beneath the existing chain pillars in the overlying Whybrow Seam (i.e. stacked case). The proposed longwalls within each of the Woodlands Hill, Arrowfield and Bowfield Seams have been staggered so that the chain pillars are not aligned. The predicted strains for these proposed longwalls, due to the multi-seam conditions, therefore, are expected to be less than those for single-seam conditions due to the overburden being already fractured by the extraction of the earlier seams and due to the increasing depths of cover.

4.4. Development of subsidence

Subsidence will develop gradually at the surface as the panel and longwall extraction faces mine directly beneath or adjacent to a given point. The rate of development of subsidence is dependent on many factors including the longwall width, depth of cover, extraction height, extraction rate and the previously extracted panels and longwalls located adjacent to and above the active panel or longwall.

As the panel or longwall extraction face approaches a feature on the surface, subsidence will start to develop when it is located approximately half a depth of cover away. When the panel or longwall extraction face is directly beneath the feature, approximately 10 % of the subsidence due to that particular panel or longwall (i.e. 10 % of the incremental subsidence) will have developed.

The maximum rate of development of subsidence occurs when the extraction face has mined approximately half a depth of cover beyond a given location. The majority of the immediate subsidence (90 % to 95 % of the incremental subsidence) for that panel or longwall develops after the extraction face has mined approximately one depth of cover beyond that location.

The active subsidence period (i.e. development of the majority of the immediate subsidence) occurs when the extraction face is approaching within half a depth of cover to when it is one depth of cover beyond a given location. Based on an average extraction rate of 50 m per week, the period of active subsidence at a given point is approximately:

- 2 to 6 weeks for the panels in the Whynot Seam;
- 4 to 12 weeks for the longwalls in the Woodlands Hill Seam; and
- 5 to 14 weeks for the longwalls in the Arrowfield and Bowfield Seams.

The active subsidence period is longer for linear surface features (i.e. roads and powerlines) that are oblique to the panels and longwalls and for planar features with larger surface areas. The active subsidence period occurs when the extraction face is half a depth of cover from the nearest point to one depth of cover beyond the further point of the feature above the active longwall.

Long-term residual movements continue to develop over the following 12 months, but predominately over the first three months, after active subsidence as equilibrium in the overburden is re-established. These low-level movements typically represent approximately 5 % to 10 % of the incremental subsidence for the active panel or longwall.

The extraction of subsequent panels or longwalls in the series (i.e. within the same seam), adjacent to a given location, results in the development of additional subsidence due to the chain pillar compression and reactivation of the existing goaf. Similarly, the extraction of subsequent longwalls in lower seams results in the development of additional subsidence due to its extraction and due to the reactivation of the chain pillars and goafs in the overlying seams.

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, it is also likely that far-field horizontal movements will be experienced during the proposed mining.

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data from the NSW coalfields, but predominately from the Southern Coalfield. The far-field horizontal movements resulting from longwall mining were generally observed to be orientated towards the extracted longwall. At very low-levels of far-field horizontal movements, however, there was a high scatter in the orientation of the observed movements.

The observed incremental far-field horizontal movements, resulting from the extraction of a single longwall, are provided in Fig. 4.4. The confidence levels, based on fitted GPDs, have also been shown in this figure to illustrate the spread of the data.

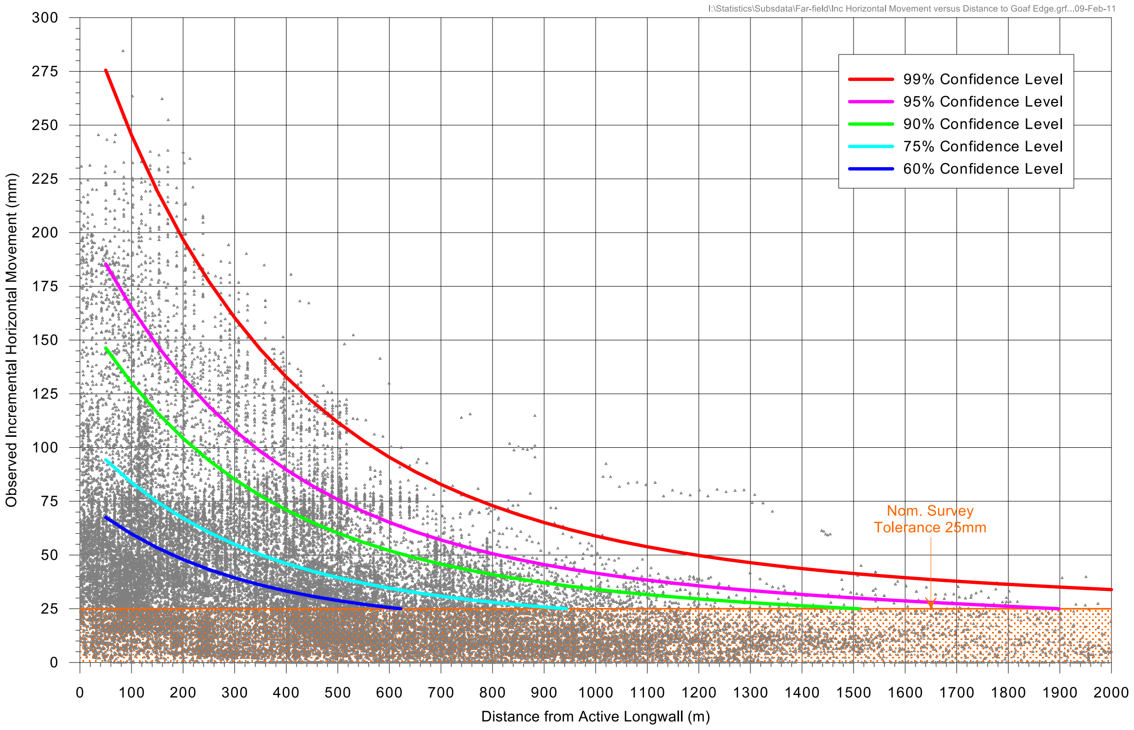


Fig. 4.4 Observed incremental far-field horizontal movements

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

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

4.6. Surface cracking and deformations

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

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

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

At shallow depths of cover, it is also likely that additional surface cracks will occur above and parallel to the moving extraction face, i.e. at right angles to the longitudinal edges of the longwall, as the subsidence trough develops. In multi-seam mining cases, surface cracking and heaving can potentially occur in any location above the extracted longwalls. The larger and more permanent cracks, however, are usually located in the final tensile zones around the perimeters of the longwalls. Open fractures and heaving, however, can also occur due to the buckling of surface beds that are subject to compressive strains.

Surface deformations observed above previous longwall mining

Detailed crack mapping was undertaken above the commencing end of the Beltana No. 1 Underground Mine Longwall 1, which was mined under single-seam conditions. The longwall had a void width of 275 m and was extracted in the Whybrow Seam at a depth of cover around 175 m. The width-to-depth ratio for Beltana Longwall 1 was around 1.6, which is reasonably similar to but slightly greater than that for the proposed longwalls in the Woodlands Hill Seam, for multi-seam conditions, which have width-to-depth ratios varying between 0.84 and 1.5 and an average of 1.1.

The cracking observed above Beltana Longwall 1 should, therefore, provide a reasonable indication of the extent of cracking in the relatively flat terrain above the proposed longwalls in the Woodlands Hill Seam for single-seam mining conditions. It was found from the detailed crack mapping, that 62 % of the cracks had widths less than 25 mm, 26 % had widths between 25 mm and 50 mm, and 12 % had widths between 50 mm and 100 mm. There was a total of 72 cracks recorded having a combined length of 494 m and a combined area of 17.7 m^2. The surveyed area was 112,476 m^2 and, therefore, it is estimated that less than 0.02 % of the surface was affected by cracking.

Several trial pits were excavated above Beltana Longwall 1 to determine the nature and the depths of the cracks. It was found that the cracks up to 25 mm in width were relatively shallow, having depths less than 0.5 m below the surface. The wider cracks were found to extend more than 1 m below the surface. In all cases, the crack widths reduced as the depth increased.

Detailed crack mapping was also undertaken above the Blakefield South Mine Longwalls 1 to 5 (BSLW1 to BSLW5), which were extracted beneath the existing South Bulga longwalls in the Whybrow Seam (i.e. multi-seam conditions). The void width of BSLW1 was 330 m and the void widths of BSLW2 to BSLW5 were 400 m. These longwalls were extracted in the Blakefield Seam at depths of cover ranging between 150 m and 305 m. The interburden thickness between the Whybrow and Blakefield Seams typically varied between 70 m and 95 m.

The cracking observed above BSLW1 to BSLW5 should provide a reasonable indication of the extent of cracking in relatively flat terrain for multi-seam conditions. It was found from the detailed crack mapping, that 79 % of the cracks had widths less than 100 mm, with the majority of these having widths less than 50 mm. The maximum observed crack width was around 500 mm.

There were more than 2390 cracks recorded above BSLW1 to BSLW5 having a combined length of around 62 km. The combined surface area above these longwalls was around 5.1 km^2 and it is estimated, therefore, that less than 0.09 % of this area was affected by cracking. The compression heaving and step heights observed during the extraction of BSLW1 to BSLW5 were typically less than 50 mm. The maximum observed step height was around 800 mm which resulted from a localised vertical ground shear.

Photographs of surface cracking resulting from the extraction of BSLW1 to BSLW5 at the Blakefield South Mine (i.e. multi-seam conditions) are provided in Fig. 4.5.

Fig. 4.5 Surface cracking above Blakefield South Mine (multi-seam conditions)

Larger surface cracking and deformations could also develop along the steeper slopes on the ridgelines. The extraction of the proposed longwalls could result in increased horizontal movements in the downslope direction, resulting in tension cracks appearing at the tops and along the sides of the steep slopes and compression ridges forming at the bottoms of the steep slopes.

Some examples of surface cracking along steep slopes in the Hunter Coalfield are provided in Fig. 4.6. Crack widths greater than 300 mm and depths greater than 3 m have been observed where longwalls have previously been extracted beneath steep slopes.

Fig. 4.6 Examples of surface cracking on steep slopes in the Hunter Coalfield

Detailed crack mapping was undertaken at a mine in the Hunter Coalfield for multi-seam mining conditions and beneath steep slopes with natural grades typically between 1 in 3 and 1 in 2. The depths of cover to the longwalls in the lower seam varied between 130 m and 310 m. The interburden thickness to the overlying longwalls varied between 70 m and 75 m. The surface deformations observed above these longwalls should provide a reasonable indication of the range of cracking for the proposed longwalls for multi-seam conditions and beneath steep slopes.

The detailed mapping identified that 63 % of the cracks had widths less than 100 mm, 19 % had widths between 100 mm and 200 mm, 12 % had widths between 200 mm and 300 mm, 4 % had widths between 300 mm and 500 mm and 2 % had widths greater than 500 mm. The largest surface deformations comprised a series of parallel cracks resulting in localised slumping. The overall widths of these deformations were between 1 m to 2 m. These impacts represented less than 1 % of the total length of the mapped surface deformations.

Assessed surface deformations for the proposed longwalls

Based on the previous longwall mining experience in the NSW coalfields, the surface cracking in the flatter areas and at higher depths of cover above the proposed longwalls is expected to be typically between 25 mm and 50 mm in approximately 50 % of cases, between 50 mm and 100 mm in approximately 30 % of cases, between 100 mm and 150 mm in approximately 15 % of cases and greater than 150 mm in approximately 5 % of cases. Multiple cracks resulting in deformations over widths of several metres could also occur in some locations (i.e. less than 1 % of cases).

The surface cracking along the steep slopes and at shallower depths of cover above the proposed longwalls is expected to be typically between 50 mm and 100 mm in approximately 60 % of cases, between 100 mm and 200 mm in approximately 25 % of cases, between 200 mm and 300 mm in approximately 10 % of cases and greater than 300 mm in approximately 5 % of cases. Multiple cracks resulting in deformations over several metres can also occur in some locations (i.e. less than 1 % of cases).

Compression heaving and stepping of the surface can also occur above the proposed longwalls. The heights of these deformations are expected to be typically less than 100 mm. However, vertical shear could also occur in some locations with height greater than 300 mm.

The East Graben Fault is located approximately 150 m to the west of WHLW3, at seam level, at its closest point to the proposed longwalls. This normal fault has a dip of 70° (away from the mining area) and a throw of up to 20 m, as shown in Fig. 1.4. The projected surface expression of the East Graben Fault is located approximately 30 m from the corner of the proposed WHLW3. Localised surface deformations could develop at the surface expression of this fault where it is located closest to the proposed longwalls.

The predicted vertical subsidence at the surface expression of the East Graben Fault is less than 20 mm. The ground movements could concentrate at the surface expression of the fault resulting in localised cracking with widths in the order of 20 mm.

As described in Section 1.4, the sill within the Whynot Seam is located above the south-western ends of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams, refer to Fig. 1.5. This sill has a thickness ranging between 1 m and 10 m within the proposed mining area. The Edderton Sill is located across the extents of the proposed mining area. This sill has a thickness of approximately 20 m and it is located approximately 110 m to 130 m above the Woodlands Hill Seam.

It is possible that the sills could partially span across the corners of the proposed longwalls resulting in localised and irregular movements where the depth of cover is shallowest. However, the potential for this spanning is reduced due to the multi-seam mining, with the proposed longwalls staggered so that the longwall corners are not aligned. It is expected that localised cracking and stepping at the surface, due to the presence of these sills, would be typically less than 50 mm where the depth of cover is shallowest.

The land above the proposed mining area is owned by Malabar and it is used for cattle grazing. The surface cracking and deformations could result in safety issues (i.e. trip hazards to people and stock), affect vehicle access (i.e. large deformations in access tracks), or result in increased erosion (especially along the drainage lines and the steeper slopes).

Management strategies and remediation measures can be developed for surface cracking and deformations, which could include the following:

- visual monitoring of the surface in the active subsidence zone, to identify the larger surface cracking and deformations that could affect safety, access, or increase erosion;
- establish methods for surface remediation, which could include 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 vegetation in order to stabilise the steeper slopes in the longer term; and
- develop management plans incorporating the agreed methods to remediate the larger surface cracking, as required.

An example of surface crack remediation in the Newcastle Coalfield is illustrated in Fig. 4.7.

1. Excavator removes soil down to the base of cracking.

2. Trench re-filled and compacted in layers.

3. Surface area re-seeded.

4. Surface rehabilitation completed.

Fig. 4.7 Example of surface crack remediation in the Newcastle Coalfield (Courtesy of Donaldson Coal)

Further discussions are provided in the impact assessments in the following sections of this report.

5.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE NATURAL FEATURES

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

5.1. The Hunter River

5.1.1. Description of the Hunter River

The locations of the Hunter River and the extent of associated alluvial material as mapped by Fluvial Systems (2019) are shown in Drawing No. MSEC986-23.

The Hunter River is located to the south of the proposed mining area. A summary of the minimum distances of the thalweg (i.e. centreline) of the river channel from the proposed panels and longwalls within each seam is provided in Table 5.1. The minimum distances of the river from the 26.5° angle of draw for each seam are also provided in this table.

Table 5.1 Minimum distances of the Hunter River from the proposed panels and longwalls

Seam	Nearest panel or longwall	Minimum distance from the nearest panel or longwall (m)	Minimum distance from the 26.5° angle of draw (m)
Whynot Seam	WNP16	1650	1580
Woodlands Hill Seam	WHLW12	525	375
Arrowfield Seam	AFLW12	550	380
Bowfield Seam	BFLW11	610	410

The thalweg of the channel of the Hunter River is 525 m south of WHLW12, at its closest point to the proposed mining area.

A section through the Hunter River and the proposed longwalls, where the river channel is located closest to the mining area, is shown in Fig. 5.1. The thalweg of the river is located well outside the 26.5° angles of draw from the proposed panels and longwalls in each of the seams. The 50 m buffer to the mapped limit of alluvium is also located outside the angles of draw.

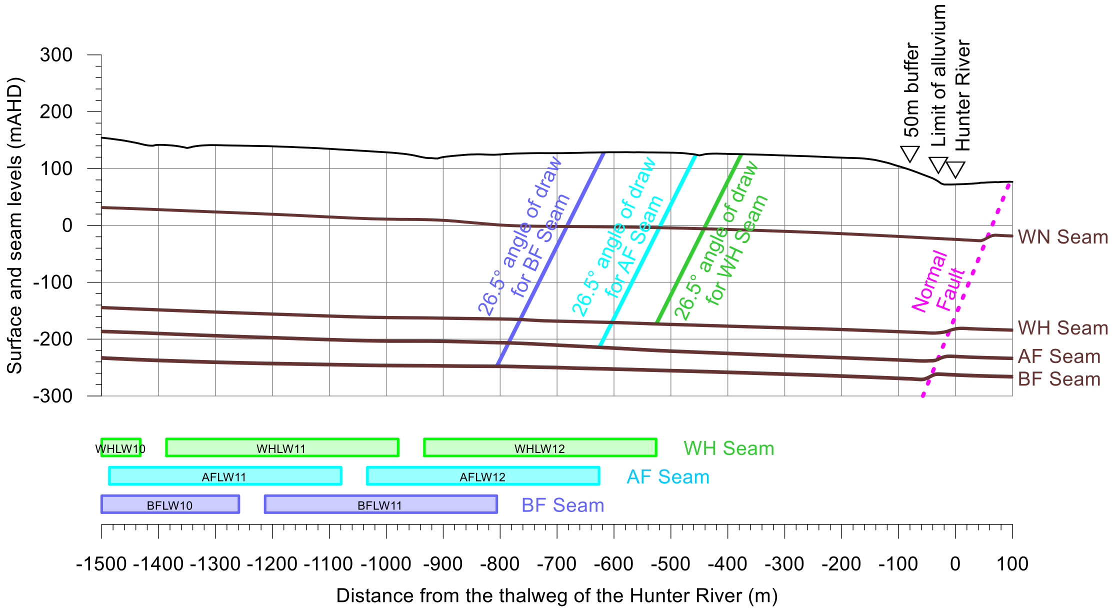


Fig. 5.1 Section through the Hunter River and the proposed longwalls where the river is located closest to the mining area

The river channel is incised into the alluvium. The banks of the river are approximately 5 m to 10 m high. The natural ground rises up towards the proposed mining area, on the northern side of the river channel, with the elevation increasing by 40 m over a distance of approximately 100 m from the river bank. The natural ground is flatter on the southern side of the river, rising by less than 10 m over a distance of approximately 100 m from the river bank.

Photographs of the Hunter River are provided in Fig. 5.2 near the crossing beneath the Golden Highway (left side) and where the river is located closest to the proposed mining area (right side).

Fig. 5.2 Photographs of the Hunter River

Further descriptions of the Hunter River are provided by the specialist surface water and groundwater consultants for the EIS.

5.1.2. Predictions for the Hunter River

The thalweg of the Hunter River is located at a minimum distance of 525 m from the proposed mining area. At this distance, the river channel itself is expected to experience negligible vertical subsidence, i.e. less than 5 mm. The river channel is therefore not expected to experience measurable conventional tilts, curvatures or strains due to the proposed mining.

The equivalent valley height for the Hunter River is equal to the average height of the two valley sides within a distance equal to half the depth of cover from the river thalweg. The depth of cover to the Woodlands Hill Seam above the south-western end of WHLW12 (i.e. closest proposed longwall to the river) is 300 m. The equivalent valley height of the Hunter River is 25 m where it is located closest to the proposed mining area.

The predicted total valley related effects are 20 mm upsidence and 40 mm closure due to the proposed mining in all seams. These predicted values are expected to be conservative since the prediction curves for the 2002 ACARP method (Waddington and Kay, 2002) have been drawn above the empirical data (i.e. upperbound curve) and, therefore, there is an accumulation of survey tolerance when adding the incremental movements from each of the panels and longwalls.

The predicted valley closure and compressive strain have been further refined based on the analysis of ground monitoring lines for valleys with similar heights located at similar distances from previously extracted longwalls in the NSW coalfields, as for the Hunter River from the proposed mining area. The maximum predicted total valley closure derived from this analysis is 20 mm based on the 95 % confidence level. The maximum predicted compressive strain due to valley closure effects is 0.7 mm/m based on the 95 % confidence level. It is noted that the predicted compressive strain comprises a component of survey tolerance in the order of 0.3 mm/m.

5.1.3. Impact assessments for the Hunter River

The thalweg of the Hunter River is located more than 500 m from the proposed mining area. At this distance, the predicted vertical subsidence at the river channel is expected to be negligible. The predicted conventional tilts, curvatures and strains are not expected to be measurable.

The river channel could experience very low-levels of valley related upsidence and closure. The maximum predicted compressive strain is 0.7 mm/m based on the 95 % confidence level. These valley related effects are not expected to be sufficient to result in fracturing of the bedrock beneath the river channel. Fracturing has not been observed at distances of 500 m outside of previous longwall mining in the NSW coalfields. Whilst fracturing has been observed up to 400 m outside of longwall mining in the NSW coalfields, this has occurred in large river valleys in the Southern Coalfield.

The river channel itself is therefore not expected to experience adverse impacts resulting from the conventional or valley related effects due to the proposed mining.

It can be seen from Drawing No. MSEC986-23 and Fig. 5.1, that the mapped limit of alluvium associated with the Hunter River and the 50 m buffer are located outside the 26.5° angle of draw lines from the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. The alluvium is predicted to experience less than 20 mm vertical subsidence due to the proposed mining. Whilst the alluvium could experience very low-levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains.

The potential impacts on the Hunter River, the alluvium and associated aquifer are discussed by the specialist surface water and groundwater consultants in the reports by *WRM Water and Environment* (2019) and *HydroSimulations* (2019), respectively.

5.1.4. Recommendations for the Hunter River

It is recommended that Extraction Plans for the Project include a subsidence effects monitoring program to monitor subsidence movements, including valley closure, and compare measured movements with predictions. Further recommendations for the Hunter River have been provided by the specialist surface water and groundwater consultants for the EIS, including the development and implementation of a monitoring program.

5.2. Saddlers Creek

5.2.1. Description of Saddlers Creek

The locations of Saddlers Creek and the extent of associated alluvial material as mapped by Fluvial Systems (2019) are shown in Drawing No. MSEC986-23.

Saddlers Creek is located to the north of the proposed mining area. A summary of the minimum distances of the thalweg (i.e. centreline) of the creek from the proposed panels and longwalls within each seam is provided in Table 5.2. The minimum distances of the creek from the 26.5° angle of draw for each seam are also provided in this table.

Table 5.2 Minimum distances of Saddlers Creek from the proposed panels and longwalls

Seam	Nearest panel or longwall	Minimum distance from the nearest panel or longwall (m)	Minimum distance from the 26.5° angle of draw (m)
Whynot Seam	WNP5	880	860
Woodlands Hill Seam	WHLW4	240	170
Arrowfield Seam	AFLW1	390	300
Bowfield Seam	BFLW1	370	270

The thalweg of the channel of Saddlers Creek is 240 m north of WHLW4, at its closest point to the proposed mining area. The surveyed position at the top of the high bank of the creek is located 210 m from WHLW4, at its closest point to the mining area.

A section through Saddlers Creek and the proposed longwalls, where the creek channel is located closest to the mining area, is shown in Fig. 5.3. The thalweg of the creek is located outside the 26.5° angles of draw from the proposed panels and longwalls in each of the seams. The mapped limit of alluvium is also located outside the angles of draw.

It is possible Saddlers Creek could be coincident with the surface expression of the fault that is located outside and adjacent to the proposed mining area, as shown in Fig. 5.3. This north-east trending normal fault has a dip of approximately 70° and a throw of up to 5 m.

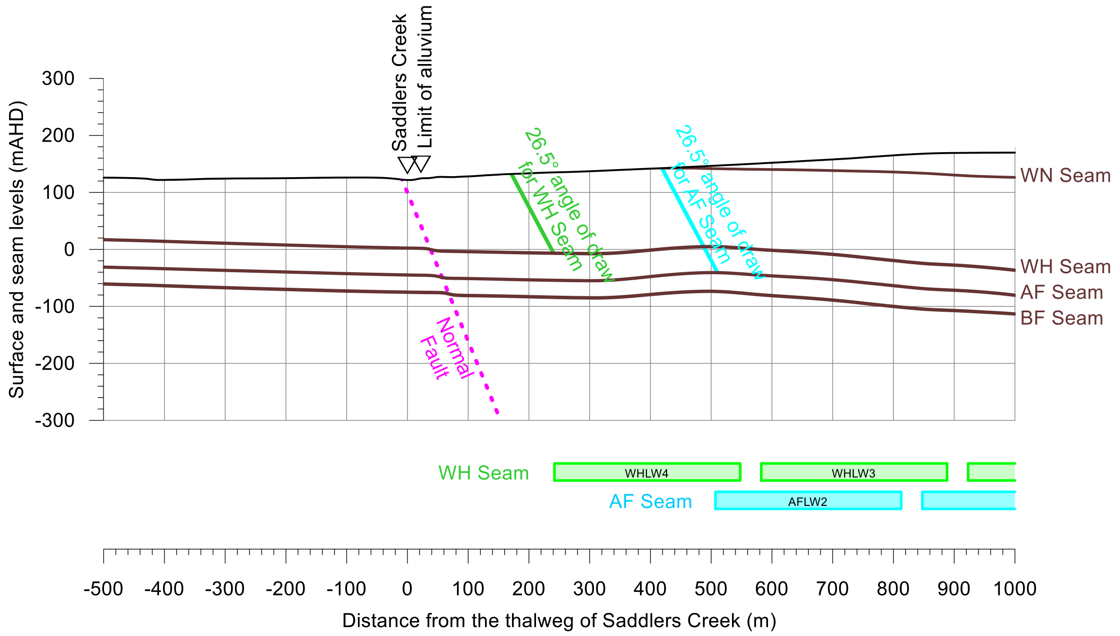


Fig. 5.3 Section through Saddlers Creek and the proposed longwalls where the creek is located closest to the mining area

Saddlers Creek has a shallow incision into the alluvium. The banks of the creek are approximately 3 m to 5 m high. The natural ground rises up towards the proposed mining area, on the southern side of the creek, with the elevation increasing by 10 m over a distance of approximately 100 m from the creek bank. The natural ground is flatter on the northern side of the creek, rising by less than 5 m over a distance of approximately 100 m from the creek bank.

Saddlers Creek flows towards the south-west to where it joints the Hunter River more than 4 km outside of the proposed mining area. Photographs of Saddlers Creek are provided in Fig. 5.4 near the crossing with Edderton Road (left side) and further upstream (right side).

Fig. 5.4 Photographs of Saddlers Creek

Further descriptions of Saddlers Creek are provided by the specialist surface water and groundwater consultants for the EIS.

5.2.2. Predictions for Saddlers Creek

The thalweg of Saddlers Creek is located at a minimum distance of 240 m from the proposed mining area. At this distance, the creek channel itself is expected to experience negligible vertical subsidence, i.e. less than 5 mm. The creek channel is therefore not expected to experience measurable conventional tilts, curvatures or strains due to the proposed mining.

The equivalent valley height for Saddlers Creek is equal to the average height of the two valley sides within a distance equal to half the depth of cover from the creek. The depth of cover to the Woodlands Hill Seam above the north-eastern end of WHLW4 (i.e. closest proposed longwall to the creek) is 140 m. The equivalent valley height of Saddlers Creek is 8 m where it is located closest to the proposed mining area.

The predicted total valley related effects for Saddlers Creek are less than 20 mm upsidence and 20 mm closure due to the proposed mining in all seams. The predicted compressive strain due to the valley related effects is less than 0.5 mm/m.

5.2.3. Impact assessments for Saddlers Creek

The thalweg of Saddlers Creek is located 240 m from the proposed mining area, at its closest point. At this distance, the predicted vertical subsidence at the creek channel is expected to negligible. The predicted conventional tilts, curvatures and strains are not expected to be measurable.

The creek channel could experience very low-levels of upsidence and closure. It is unlikely that the compressive strain due to these valley related effects would be sufficient to result in fracturing in the bedrock beneath the creek. Even if fracturing were to occur in the bedrock beneath Saddlers Creek, it is unlikely that it would be visible at the surface due to the overlying alluvium.

The creek channel itself is therefore not expected to experience adverse impacts resulting from the conventional or valley related effects due to the proposed mining.

It is possible Saddlers Creek could be coincident with the surface expression of the fault that is located outside and adjacent to the proposed mining area, as shown in Fig. 5.3. It is unlikely that localised movements would develop at the surface expression of this fault due to its distance from the proposed mining area and due to its small size. Even if localised movements were to occur at the surface expression of the fault, it is unlikely that these low-level movements would be visible at the surface due to the alluvium.

The potential impacts on Saddlers Creek, the alluvium and associated aquifer are discussed by the specialist surface water and groundwater consultants in the reports by *WRM Water and Environment* (2019) and *HydroSimulations* (2019), respectively.

5.2.4. Recommendations for Saddlers Creek

It is recommended that Extraction Plans for the Project include periodic visual inspections of Saddlers Creek and surrounding areas during the mining period. Further recommendations for Saddlers Creek have been provided by the specialist surface water and groundwater consultants for the EIS.

5.3. Drainage lines

5.3.1. Description of the drainage lines

The locations of the drainage lines within the Study Area are shown in Drawing No. MSEC986-23. It appears from the CMA Map of the area, that there are no “named” drainage lines within the area.

The drainage lines in the southern part of the Study Area are tributaries to the Hunter River and the drainage lines in the northern part of the Study Area are tributaries to Saddlers Creek. The upper reaches are first and second order streams and some parts of the lower reaches are third order streams. The drainage lines are ephemeral, where surface water only flows during and for short periods after rainfall events, although some isolated natural ponding is evident along the flatter lower reaches.

The drainage lines have shallow incisions into the natural surface soils, which are generally derived from the Jerrys Plains Subgroup of the Wittingham Coal Measures, as illustrated in Fig. 1.9. There is rock outcropping along the lower reaches of some of the drainage lines.

The features along the drainage lines have been mapped by *Fluvial Systems* (2019). Rock slabs (i.e. exposed bedrock) have been identified along the drainage lines in four locations directly above the proposed mining area. The locations of the mapped rock slabs are shown in Drawing No. MSEC986-23. There are no standing pools at or upstream of the rock slabs.

Photographs of typical drainage lines within the Study Area are provided in Fig. 5.5 and Fig. 5.6.

Fig. 5.5 Photographs of typical drainage lines within the Study Area

Fig. 5.6 Photographs of typical drainage lines within the Study Area

The natural grades along the drainage lines typically vary between 30 mm/m and 70 mm/m (i.e. 3 % to 7 %, or 1 in 33 to 1 in 14) along the upper reaches and typically between 10 mm/m and 30 mm/m (i.e. 1 % to 3 %, or 1 in 100 to 1 in 33) along the lower reaches.

5.3.2. Predictions for the drainage lines

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

A summary of the maximum predicted vertical subsidence, tilt and curvatures for the drainage lines is provided in Table 5.3. The values are the maxima within the Study Area due to the proposed mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams.

Table 5.3 Maximum predicted conventional subsidence, tilt and curvature for the drainage lines

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Drainage lines	5600	50	2.0	2.0

The maximum predicted total conventional curvatures are 2.0 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 0.5 km. The predicted conventional strains based on applying a factor of 10 to the predicted conventional curvatures are 20 mm/m tensile and compressive.

The distributions of strain above the proposed mining area are provided in Section 4.3. The predicted strains due to the proposed multi-seam mining are 8 mm/m tensile and 9 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.

The predictions for the individual drainage lines vary depending on their locations relative to the proposed panels and longwalls within each seam. To illustrate this variation, the predictions have been provided along four typical drainage lines above the proposed mining area, referred to as Drainage Lines A, B, C and E. It is noted that these four drainage lines are only representative and are no more important than the other drainage lines within the Study Area. The locations of these representative drainage lines are shown in Drawing No. MSEC986-23.

The predicted profiles of vertical subsidence, tilt and curvature along Drainage Lines A, B, C and E are shown in Figs. C.03 to C.06, respectively, in Appendix C. The predicted profiles are shown after the completion of the Whynot Seam (red lines), Woodlands Hill Seam (green lines), Arrowfield Seam (cyan lines) and Bowfield Seam (blue lines). The maximum predicted tilts and curvatures after any panel or longwall in any seam are shown as the grey lines.

The drainage lines could also experience valley related effects due to the proposed mining. The drainage lines have shallow incisions into the natural surface soils and, therefore, the predicted upsidence and closure effects are not expected to be significant when compared with the predicted conventional effects.

5.3.3. Impact assessments for the drainage lines

The impact assessments for the drainage lines are provided in the following sections.

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

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

The maximum predicted tilt for the drainage lines is 50 mm/m (i.e. 5 %, or 1 in 20). The predicted changes in grade are similar to the natural gradients along the upper reaches and are greater than the natural gradients along the lower reaches of the drainage lines.

It is likely, therefore, that there would be areas that would experience increased ponding along the lower reaches of the drainage lines, predominately upstream of the chain pillars in the shallower seams and where the drainage lines exit the proposed mining area. Other areas could also experience increased scouring of the stream beds, predominately downstream of the chain pillars in the shallower seams.

Increased levels of bed scouring could also occur in the locations of the maximum increasing tilts, during times of high surface water flows, where the velocities of the flows exceed 1 metre per second. If significant levels of bed scouring were to occur along the drainage lines, it may be necessary to provide erosion control measures, or to locally regrade the beds of the drainage lines in these locations.

Further discussions on the potential impacts of increased ponding along the drainage lines are provided by the specialist geomorphology and surface water consultants in the reports by *Fluvial Systems* (2019) and *WRM Water and Environment* (2019), respectively.

Potential for cracking in the drainage line beds and fracturing of the bedrock

Fracturing of the uppermost bedrock has been observed in the past, as a result of longwall mining, where the tensile strains have been greater than 0.5 mm/m. Buckling and dilation of the uppermost bedrock have also been observed where the compressive strains have been greater than 2 mm/m. It is likely, therefore, that fracturing, buckling and dilation would occur in the bedrock beneath the soil beds of the drainage lines based on the magnitudes of the predicted strains. Fracturing of the exposed bedrock is also expected.

The assessed surface deformations above the proposed panels and longwalls are provided in Section 4.6. The largest impacts are expected to occur along the steeper sections of the drainage lines, on the sides of the ridgelines in the southern part of the proposed mining area, and where the depths of cover are shallowest, in the northern part of the proposed mining area.

The surface cracking in these areas is expected to be typically between 50 mm and 100 mm in approximately 60 % of cases, between 100 mm and 200 mm in approximately 25 % of cases, between 200 mm and 300 mm in approximately 10 % of cases and greater than 300 mm in approximately 5 % of cases. Multiple cracks resulting in deformations over several metres can also occur in some locations (i.e. less than 1 % of cases).

Rock slabs have been identified along the drainage lines in four locations above the proposed mining area, as shown in Drawing No. MSEC986-23 (after Fluvial Systems, 2019). The rock slab along Drainage Line C is located above the proposed panels in the Whynot Seam, but it is outside the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. The predicted vertical subsidence in this location is less than 100 mm and, therefore, the potential for significant fracturing in this rock slab is considered to be low.

Fracturing could develop in the other three rock slabs that are located directly above the proposed longwalls. The two rock slabs along Drainage Line B are located at its upper reaches where the surface water flows are lower due to the limited tributary area. The exposed bedrock along Drainage Line E is confined to a narrow channel in the base on the stream. There are no standing pools at or upstream of these rock slabs.

The drainage lines 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, however, surface water flows could be diverted into the dilated strata below the beds where the bedrock is shallow or exposed.

It is likely that some remedial measures would be required at the completion of mining. Where necessary, any significant surface cracks in the drainage line beds could be remediated by infilling with the surface soil or other suitable materials, or by locally regrading and recompacting the surface.

The multi-seam mining will result in the development of a network of fractures in the overburden above the extracted panels and longwalls. The changes in permeability and the potential hydrogeological impacts above proposed panels and longwalls are discussed by the specialist groundwater consultant in the report by *HydroSimulations* (2019).

Experience from mining in the Hunter and Newcastle Coalfields indicates that impacts on ephemeral streams are low where the panels are subcritical or where the depths of cover are greater than the order of 200 m. The proposed panels in the Whynot Seam are typically subcritical in width, except in the northern part of the mining area where the depths of cover are shallowest. The proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams are typically at depths of cover greater than 200 m.

For example, ephemeral drainage lines have been directly mined beneath at South Bulga and the Beltana No. 1 Underground Mine by the 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. Similar experience occurred where the North Wambo Underground Mine and United Collieries extracted longwalls in the Whybrow, Wambo and Woodlands Hill Seams (i.e. multi-seam) beneath a number of ephemeral streams, including North Wambo Creek.

Further discussions on the potential impacts on the drainage lines are provided by the specialist geomorphology, surface water and groundwater consultants in the reports by *Fluvial Systems* (2019), *WRM Water and Environment* (2019) and *HydroSimulations* (2019), respectively.

5.3.4. Recommendations for the drainage lines

Management strategies and remediation measures can be developed for the drainage lines, which could include the following:

- visual monitoring of the surface in the active subsidence zone, to identify the larger surface cracking and deformations that could result in increased erosion or the diversion of surface water flows;
- based on the monitoring results, establishing methods for remediation of surface cracking, if required, which could include infilling with soil or other suitable materials, or locally recompacting the surface; and
- based on the monitoring results, implementing erosion protection measures, if required, such as installation of rock control grade structures or use of large wood structures.

Further recommendations for the drainage lines have been provided by the specialist geomorphology and surface water consultants for the EIS.

5.4. Aquifers and groundwater resources

There are groundwater resources associated with the Hunter River alluvial aquifer and other shallow and deeper aquifers within the Study Area. Detailed descriptions of these resources are provided by the specialist groundwater consultant in the report by *HydroSimulations* (2019).

Some groundwater bores within the region are used to extract groundwater for domestic, stock or irrigation use. Other groundwater bores are used for monitoring purposes. The locations of the groundwater bores within the Study Area are shown in Drawing No. MSEC986-24 and their details are provided in Section 6.13.

5.5. Steep slopes

5.5.1. Description of the steep slopes

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

The areas identified as having steep slopes are shown in Drawing No. MSEC986-23.

The steep slopes have been identified along the ridgelines predominately in the south-eastern part of the Study Area. The natural grades of the steep slopes are typically between 1 in 3 (i.e. 33 % or 18.3°) and 1 in 2 (i.e. 50 % or 26.6°), with isolated areas with natural grades up to approximately 1 in 1 (i.e. 100 % or 45°).

Photographs of the steep slopes within the Study Area are provided in Fig. 5.7.

Fig. 5.7 Steep slopes

5.5.2. Predictions for the steep slopes

Although predominantly located in the south-eastern part of the Study Area, the steep slopes are expected to experience the range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4.

A summary of the maximum predicted vertical subsidence, tilt and curvatures for the steep slopes is provided in Table 5.4. The values are the maxima within the Study Area due to the proposed mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams.

Table 5.4 Maximum predicted conventional subsidence, tilt and curvature 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	5600	50	2.0	2.0

The maximum predicted tilt for the steep slopes is 50 mm/m (i.e. 5 % or 1 in 20). The maximum predicted total conventional curvatures are 2.0 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 0.5 km. The predicted conventional strains based on applying a factor of 10 to the predicted conventional curvatures are 20 mm/m tensile and compressive.

The steep slopes in the south-eastern part of the Study Area, in the vicinity of Drainage Line C, are predicted to experience vertical subsidence up to 5400 mm, tilts up to 40 mm/m (i.e. 4 % or 1 in 25) and curvatures up to 1.0 km^{-1} (i.e. minimum radius of curvature of 1 km). The predicted conventional strains based on applying a factor of 10 to the predicted conventional curvatures are 10 mm/m tensile and compressive.

The distributions of strain above the proposed mining area are provided in Section 4.3. The predicted strains due to the proposed multi-seam mining are 8 mm/m tensile and 9 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.

5.5.3. Impact assessments for the steep slopes

The maximum predicted tilt for the steep slopes within the Study Area is 50 mm/m (i.e. 5 %, or 1 in 20). The predicted changes in grade are very small when compared to the natural surface grades, which are greater than 1 in 3. It is unlikely, therefore, that the mining-induced tilts would result in an adverse impact on the stability of the steep slopes. This is consistent with experience from mining in the NSW coalfields, where no instabilities have been observed previously when mining beneath steep slopes.

The steep slopes are more likely to be affected by curvature and strain, rather than tilt. The potential impacts would generally occur from the increased horizontal movements in the downslope direction. This will result 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 assessed surface deformations above the proposed panels and longwalls are provided in Section 4.6. The surface cracking along the steep slopes is expected to be typically between 50 mm and 100 mm in approximately 60 % of cases, between 100 mm and 200 mm in approximately 25 % of cases, between 200 mm and 300 mm in approximately 10 % of cases and greater than 300 mm in approximately 5 % of cases. Multiple cracks resulting in deformations over several metres can also occur in some locations (i.e. less than 1 % of cases).

Compression heaving and stepping of the surface can also occur predominately towards the bases of the steep slopes. The heights of these deformations are expected to be typically less than 100 mm. However, vertical shear could also occur in some locations with height greater than 300 mm.

Photographs showing examples of surface cracking along steep slopes in the NSW coalfields are provided in Section 4.6. An example of surface remediation is also provided in that section.

If large tension cracks were to develop along the steep slopes as a result of mining, it is possible that soil erosion could occur if these cracks were left untreated. It is likely, therefore, that some remediation would 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 on the slopes in the longer term.

The requirement and methodology for any erosion and sediment control and remediation techniques would be determined in consideration of the: potential impacts when unmitigated, including potential risks to safety and the potential for self-healing or long-term degradation; and potential impacts of the control/remediation technique, including site accessibility.

5.5.4. Recommendations for the steep slopes

The Land Management Plan component of the Extraction Plan should include more detailed consideration of slope stability, including input from a specialist geotechnical expert. It is recommended that the steep slopes are visually monitored throughout the mining period and until any necessary mitigation or rehabilitation measures are completed. In addition to this, it is recommended that the larger surface cracking that could result in increased erosion or restrict access to areas be remediated by infilling with soil or other suitable materials, or by locally regrading and compacting the surface.

5.6. Land prone to flooding or inundation

The surface level contours within the proposed mining area are shown in Drawing No. MSEC986-06. The land generally falls towards the Hunter River to the south of the mining area and towards Saddlers Creek to the north of the mining area.

The drainage lines and the natural surface grades are illustrated in Drawing No. MSEC986-23. The natural grades within the Study Area are typically less than 1 in 3 (i.e. 33 % or 18.4°), with areas on the ridgelines in the south-eastern part of the mining area having natural grades typically up to 1 in 2 (i.e. 50 % or 26.6°).

The Probable Maximum Flood (PMF) extent (WRM Water and Environment, 2019) has been reproduced in Fig. 5.8. The PMF extent is located well outside the predicted 20 mm subsidence contour. It is unlikely, therefore, that the PMF extent would be affected due to the proposed mining.

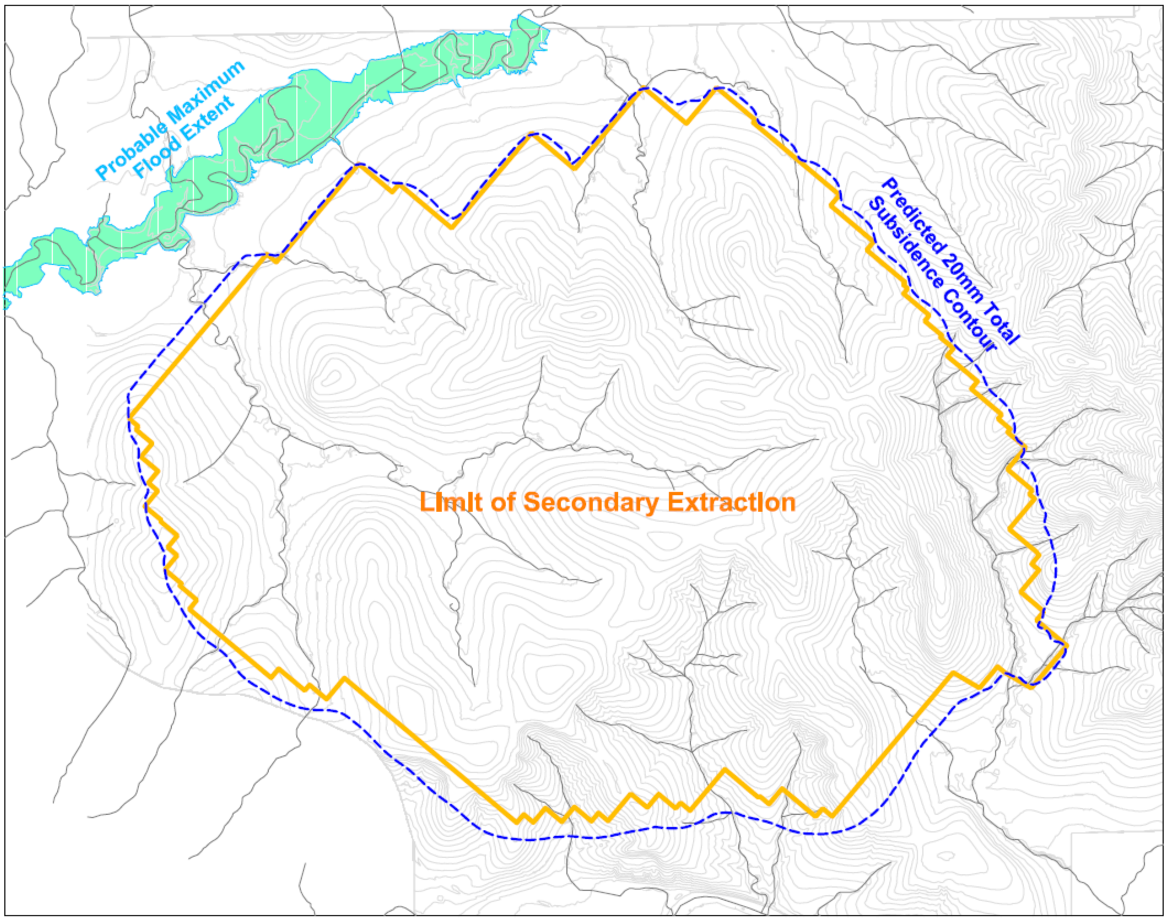


Fig. 5.8 Probable maximum flood event (Source: WRM Water and Environment, 2019)

The natural and predicted post-mining surface levels have been compared to identify areas with the potential for increased ponding as the result of the creation of topographical depressions. Additional topographical depressions (i.e. areas with increased potential for ponding) are expected to develop as a result of the proposed mining, along the alignments of the natural drainage lines or in the vicinity of existing farm dams, away from the steep slopes.

A detailed assessment of the potential for increased ponding has been conducted by the specialist geomorphology and surface water consultants for the EIS in the reports by *Fluvial Systems* (2019) and *WRM Water and Environment* (2019), respectively.

5.7. Swamp, wetlands and water-related ecosystems

There are no swamps or wetlands identified within the Study Area. There are water-related ecosystems within the Study Area, which are described in the report by *Hunter Eco* (2019).

5.8. Threatened, protected species and critical habitats

The descriptions and the discussions on the potential impacts on threatened and protected species within the Study Area are provided by the specialist ecology consultant in the report by *Hunter Eco* (2019).

5.9. Natural vegetation

The land has generally been cleared of overstory vegetation within the Study Area, with natural vegetation remaining on the steeper slopes along the ridgelines. The extent of natural vegetation can be seen from the aerial photograph provided in Fig. 2.3. A survey of the natural vegetation within the Study Area has been undertaken by the specialist ecology consultant and details are provided in the report by *Hunter Eco* (2019).

6.0 DESCRIPTIONS, PREDICTIONS AND IMPACT ASSESSMENTS FOR THE BUILT FEATURES

The Project is not located within a declared Mine Subsidence District (MSD). However, the former Muswellbrook MSD covered the Study Area prior to its revision on 1 July 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 movements or valley related movements and may be sensitive to these movements, have also been included as part of these assessments.

6.1. The Golden Highway

6.1.1. Description of the Golden Highway

The locations of the roads are shown in Drawing No. MSEC986-24.

The Golden Highway (State Route 84) crosses the south-western boundary of the Study Area. The total length of the highway located within the Study Area is approximately 100 m. A summary of the minimum distances of the centreline of the Golden Highway from the proposed panels and longwalls within each seam is provided in Table 6.1. The minimum distances of the highway from the 26.5° angle of draw for each seam are also provided in this table.

Table 6.1 Minimum distances of the Golden Highway from the proposed panels and longwalls

Seam	Nearest panel or longwall	Minimum distance from the nearest panel or longwall (m)	Minimum distance from the 26.5° angle of draw (m)
Whynot Seam	WNP1	1700	1650
Woodlands Hill Seam	WHLW5	210	90
Arrowfield Seam	AFLW6	150	0
Bowfield Seam	BFLW5	160	Partially inside

The section of the Golden Highway near the Study Area comprises a two lane single-carriageway with an asphaltic seal and grass verges with no kerb or guttering. There is a small cutting (less than 3 m in height) located approximately 300 m east of the intersection with Edderton Road and approximately 200 m south of the proposed mining area.

The highway crosses the Hunter River approximately 800 m south of the proposed mining area. The descriptions, predictions and impact assessments for the bridge are provided in Section 6.2.

A photograph of the Golden Highway at the intersection with Edderton Road is provided in Fig. 6.1.

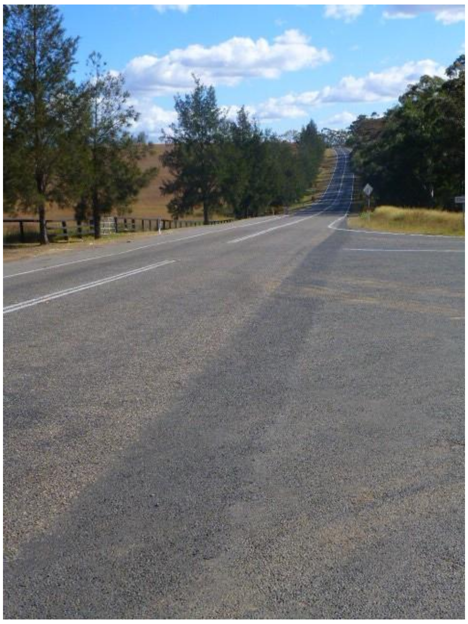


Fig. 6.1 The Golden Highway at the intersection with Edderton Road

The Golden Highway is a NSW State owned road that is maintained by NSW Roads and Maritime Services (RMS).

6.1.2. Predictions for the Golden Highway

The Golden Highway is located outside of the proposed mining area at a minimum distance of 150 m. At this distance, the highway is predicted to experience less than 20 mm vertical subsidence. Whilst the highway could experience very low-levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains.

The highway is located at minimum distances between 150 m and 210 m from the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. The depths of cover at the south-western ends of the nearest proposed longwalls are 245 m above WHLW5, 310 m above AFLW6 and 335 m above BFLW5.

The range of potential strains for the Golden Highway resulting from the extraction of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams, for multi-seam mining conditions, has been based on the observed strains for multi-seam mining in the Hunter and Newcastle Coalfields.

The frequency distribution of the maximum tensile and compressive strains measured in survey bays at distances between 100 m and 200 m from multi-seam longwall mining is provided in Fig. 6.2. The probability distribution functions, based on the fitted GPDs, are also shown in this figure. It is noted that some cases include survey bays above previously extracted goaf and, therefore, provides some conservatism of the Golden Highway which is located completely above solid coal.

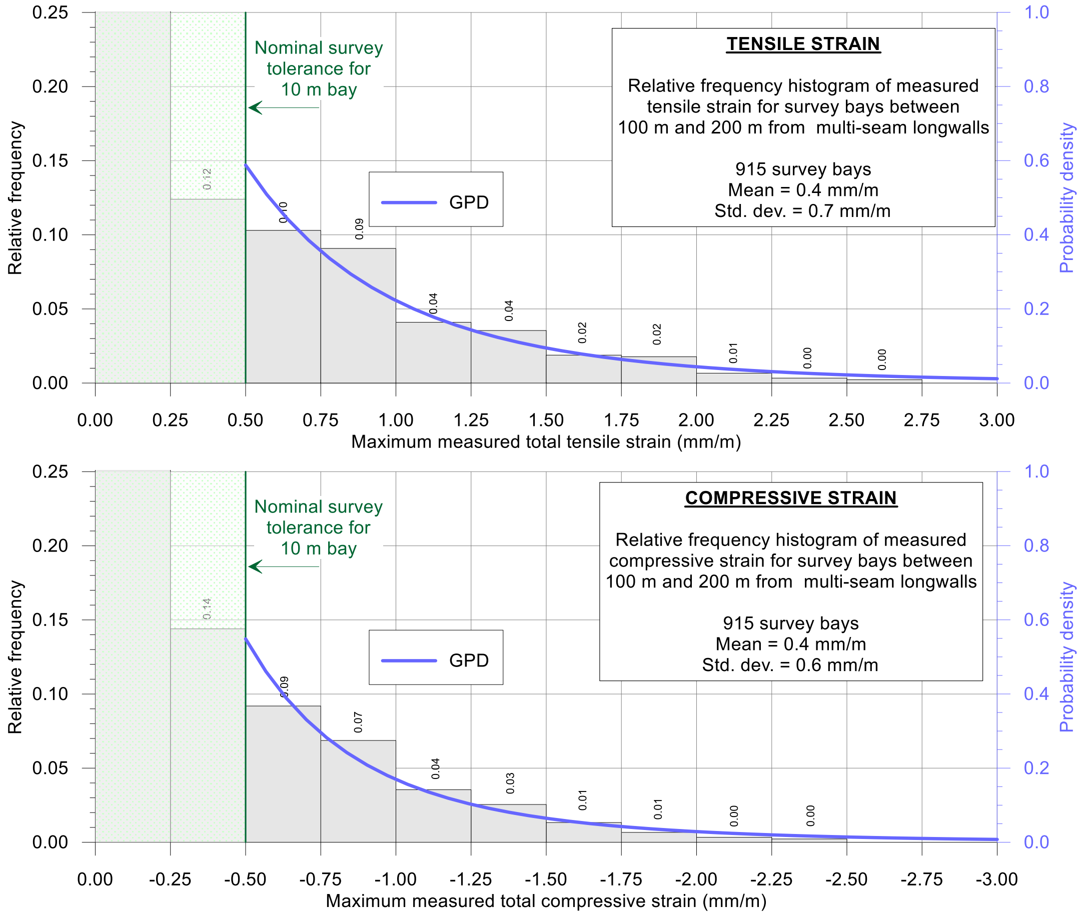


Fig. 6.2 Distributions of the measured tensile and compressive strains for multi-seam longwalls in the Hunter Coalfield

The mean measured strains are less than 0.5 mm/m tensile and compressive. It is expected, therefore, that the strains measured along the Golden Highway will be typically in the order of survey tolerance. The 95 % confidence levels for the maximum strains are 1.7 mm/m tensile and 1.4 mm/m compressive.

6.1.3. Impact assessments for the Golden Highway

The Golden Highway is predicted to experience less than 20 mm vertical subsidence. Whilst the highway could experience very low-levels of vertical subsidence, it is not expected to experience measurable tilts or curvatures. It is unlikely, therefore, that there would be adverse impacts on the profile or the serviceability of the highway due to vertical subsidence.

The strains along the Golden Highway are predicted to be generally in the order of survey tolerance. Low-level strains in the order of 1 mm/m to 2 mm/m could be measured along the section of highway that is located closest to the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. It is unlikely that these low-level strains would result in adverse impacts on the highway.

The Golden Highway crosses the East Graben Fault approximately 1 km west of the intersection with Edderton Road. The surface projection of the fault crosses the highway at a distance of approximately 400 m south-west of the proposed mining area. At this distance, it is unlikely that localised movements would develop at the highway due to the presence of the East Graben Fault.

It is expected that the Golden Highway would remain in safe and serviceable condition during and after the extraction of the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams.

6.1.4. Recommendations for the Golden Highway

It is recommended that a Built Features Management Plan (BFMP) be developed for the Golden Highway in consultation with RMS prior to mining within 500 m of the highway. The management plan could include ground monitoring and periodic visual inspections of the highway during the extraction of the proposed longwalls closest to it. The monitoring and inspections should include the small cutting to the east of Edderton Road and the surface projection of the East Graben Fault.

6.2. Bridge at Bowmans Crossing

6.2.1. Description of the bridge at Bowmans Crossing

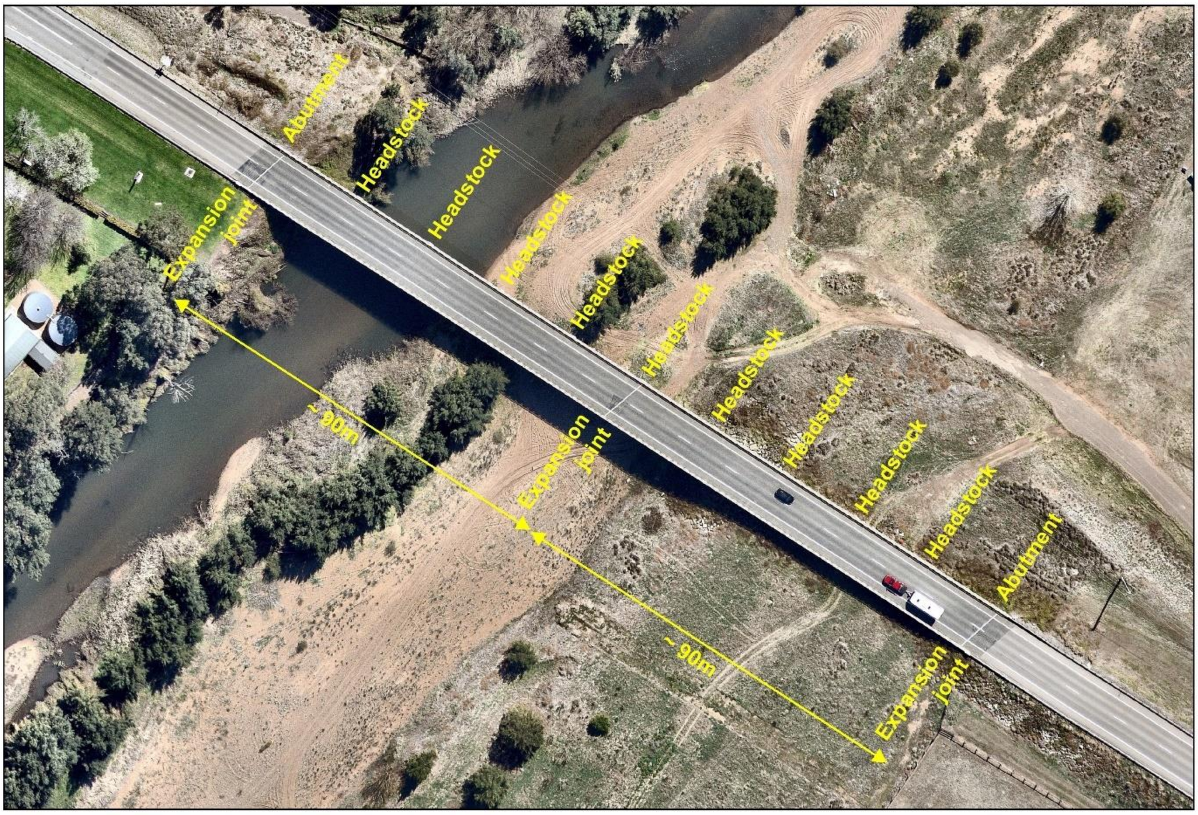
The Golden Highway crosses the Hunter River approximately 800 m south of the proposed mining area. A bridge crosses the river and the adjacent floodplain, referred to as *Bowmans Crossing*. The location of the bridge along the Golden Highway is shown in Drawing No. MSEC986-24.

The bridge comprises a suspended concrete deck supported on concrete abutment wingwalls and nine intermediate concrete headstocks on dual concrete columns. The spans between adjacent headstocks are approximately 18 m. The total length of the bridge between the two abutments is approximately 180 m. Expansion joints in the bridge deck are located at each abutment above the central headstock. The lengths of the two deck segments between the expansion joints are both approximately 90 m.

Photographs of the bridge where the Golden Highway crosses the Hunter River and the adjacent floodplain are provided in Fig. 6.3 and Fig. 6.4. An aerial photograph showing the locations of the abutments, headstocks and expansion joints is provided in Fig. 6.5.

Fig. 6.3 Bridge where the Golden Highway crosses the Hunter River

Fig. 6.4 Bridge across the floodplain adjacent to the Hunter River



Courtesy of Nearmap

Fig. 6.5 Aerial photograph of the bridge

The bridge is maintained by RMS.

6.2.2. Predictions for the bridge at Bowmans Crossing

The bridge where the Golden Highway crosses the Hunter River is located approximately 800 m south of the proposed mining area. At this distance, the bridge is predicted to experience negligible vertical subsidence, tilt, curvature and strain.

The bridge could experience small far-field horizontal movements due to the proposed mining. It can be seen from Fig. 4.4, that incremental far-field horizontal movements in the order of 50 mm to 75 mm have been measured at distances of 800 m from previous longwall mining. However, the potential for adverse impacts on the bridge does not result from absolute far-field horizontal movements, but rather from differential horizontal movements over the length of the structure.

Differential horizontal movements along the alignment of the bridge could potentially affect the widths of the expansion joints or the capacities of the support bearings. Differential horizontal movements across the alignment of the bridge could potentially induce eccentricities into the structure or affect the capacities of the support bearings.

The predicted differential horizontal movements at the bridge have been determined by statistically analysing the available 3D monitoring data from the NSW coalfields. The majority of the far-field horizontal movement data comes from the Southern Coalfield based on single-seam mining at depths of cover between 400 m and 600 m. The proposed multi-seam mining at shallower depths of cover at the Project will result in greater movements above, but lesser movements outside, of the mining area. The far-field horizontal movement data from the Southern Coalfield, therefore, should provide conservative predictions for the far-field horizontal movements at the Project.

The intermediate spans (i.e. distances between the supporting headstocks) for the bridge where the Golden Highway crosses the Hunter River are typically around 20 m. The analyses of differential horizontal movements, therefore, have been based on survey marks spaced at around 20 m.

The measured incremental differential longitudinal movements and horizontal mid-ordinate deviations, for survey marks spaced at 20 m ±10 m relative to the distance from the active longwall, are shown in Fig. 6.6 and Fig. 6.7, respectively. The location of the bridge where the Golden Highway crosses the Hunter River relative to the proposed mining is also shown in these figures.

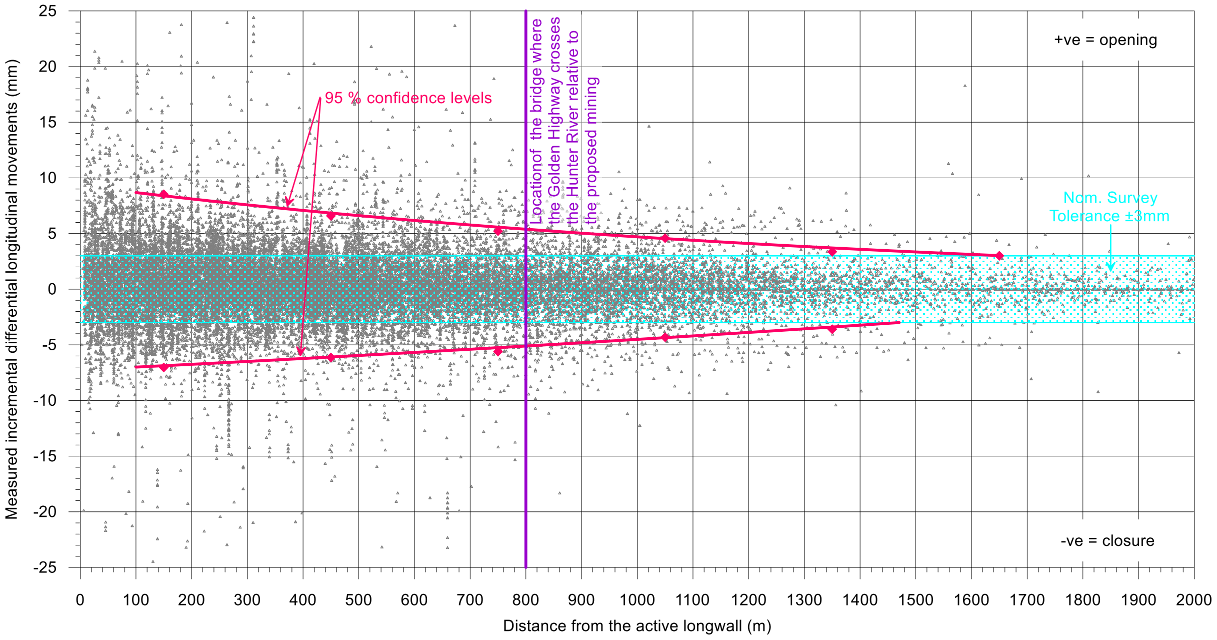


Fig. 6.6 Measured incremental differential horizontal movements versus distance from active longwall for marks spaced at 20 m ±10 m

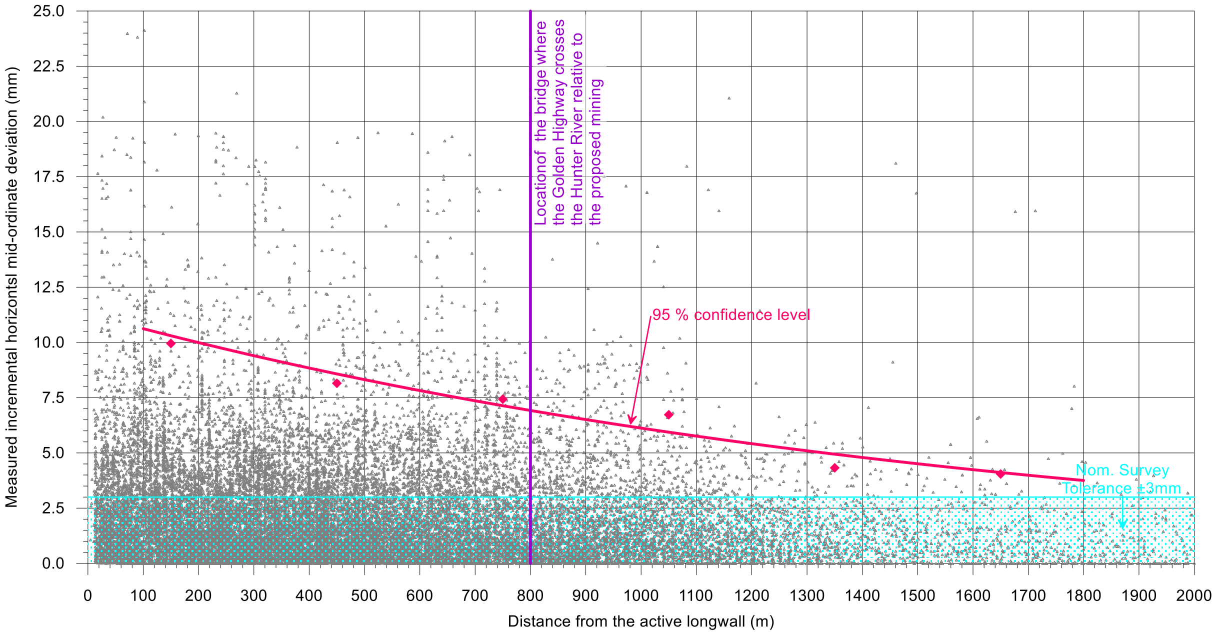


Fig. 6.7 Measured incremental horizontal mid-ordinate deviations versus distance from active longwall for marks spaced at 20 m ±10 m

The 95 % confidence levels have been determined from the empirical data using the fitted GPDs. In the cases where survey bays or marks were measured multiple times during a longwall extraction, the maximum opening, maximum closure and maximum mid-ordinate deviations were used in the analysis (i.e. single opening and single closure measurements per survey bay and single mid-ordinate deviation per survey mark).

The maximum predicted incremental differential longitudinal movements for the survey bays, at a distance of 800 m from active the longwall, are +5 mm opening and -5 mm closure based on the 95 % confidence levels. The maximum predicted incremental horizontal mid-ordinate deviation for the survey marks, at a distance of 800 m from the active longwall, is ±7 mm based on the 95 % confidence level. It is noted that a large proportion of these movements comprise the survey tolerance, which is around ±3 mm.

6.2.3. Impact assessments for the bridge at Bowmans Crossing

The maximum predicted differential incremental horizontal movements between the adjacent headstocks of the bridge are between ±5 mm to ±7 mm based on the 95 % confidence levels. It is again noted that these movements comprise large proportions of survey tolerance, which is around ±3 mm. It is likely, therefore, that the differential horizontal movements due to the proposed mining will be very small and, in some cases, may not be measurable.

Differential horizontal movements between the concrete deck and the supports normally occur due to variations in the temperature of the structure. Typical horizontal movements due to temperature changes, based on a 90 m span (i.e. distance between the expansion joints), a coefficient of thermal expansion of $12x10^{-6}/^{o}C$ and a temperature variation of 20ºC, is around 20 mm.

The predicted mining-induced differential horizontal movements for the bridge, therefore, are less than the movements that normally occur due to the variation in ambient temperature. It is likely, therefore, that the bridge could tolerate the potential movements due to the proposed mining, without adverse impacts, provided that the expansion joints have sufficient redundant capacities. The structural engineers should assess the capacity of the bridge to accommodate the predicted mining-induced movements.

6.2.4. Recommendations for the bridge at Bowmans Crossing

Malabar has commenced consultation with RMS on the bridge at Bowmans Crossing. It is recommended that structural engineers should assess the capacity of the bridge to accommodate the predicted mining-induced movements.

It is also recommended, that a BFMP is developed in consultation with RMS prior to mining within 1200 m of the bridge. The management strategies could include 3D monitoring points on the bridge structure, tell-tales across the expansion joints and periodic visual inspections during the extraction of the proposed longwalls closest to it.

6.3. Edderton Road

6.3.1. Description of Edderton Road

The locations of the roads are shown in Drawing No. MSEC986-24.

Edderton Road crosses the western part of the Study Area and it is located directly above the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. A summary of the longwalls that are proposed to be extracted directly beneath the current alignment of Edderton Road is provided in Table 6.2.

Table 6.2 Longwalls proposed to be extracted directly beneath Edderton Road

Seam	Longwalls proposed to be extracted beneath the road	Length of road above the proposed mining areas (km)
Woodlands Hill Seam	WHLW1 to WHLW6	2.3
Arrowfield Seam	AFLW1 to AFLW6	2.6
Bowfield Seam	BFLW1 to BFLW6	2.2
All seams	As above	2.6

The section of Edderton Road within the Study Area comprises a two lane single-carriageway with a bitumen seal and grass verges with no kerb or guttering. The gross load limit is 14 tonnes.

There are circular concrete drainage culverts (Refs. ER-C1 to ER-C5) where the road crosses the drainage lines. The locations of the drainage culverts are shown in Drawing No. MSEC986-24. The causeway where Edderton Road crosses Saddlers Creek is outside of the Study Area. The causeway is located more than 500 m north-west of the proposed mining area.

Photographs of Edderton Road are provided in Fig. 6.8.

Fig. 6.8 Edderton Road

Edderton Road is owned and maintained by the Muswellbrook Shire Council.

6.3.2. Predictions for the current alignment of Edderton Road

The predicted profiles of vertical subsidence, tilt and curvature along the current alignment of Edderton Road are shown in Fig. C.07, in Appendix C. The predicted profiles are shown after the completion of the Whynot Seam (red lines), Woodlands Hill Seam (green lines), Arrowfield Seam (cyan lines) and Bowfield Seam (blue lines). The maximum predicted tilts and curvatures after any panel or longwall in any seam are shown as the grey lines.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for Edderton Road is provided in Table 6.3. The values are the maxima anywhere along the current alignment of the road within the Study Area.

Table 6.3 Maximum predicted total vertical subsidence, tilt and curvature for the current alignment of Edderton Road

After completion of seam	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})
Whynot Seam	< 20	< 0.5	< 0.01	< 0.01
Woodlands Hill Seam	2300	35	1.4	0.90
Arrowfield Seam	4300	45	1.6	0.90
Bowfield Seam	5100	45	1.6	0.90

The maximum predicted tilt for Edderton Road is 45 mm/m (i.e. 4.5 %, or 1 in 22). The maximum predicted curvatures for the road are 1.6 km^{-1} hogging and 0.90 km^{-1} sagging, which represent minimum radii of curvatures of 0.6 km and 1.1 km, respectively.

The maximum predicted conventional strains for Edderton Road, based on applying a factor of 10 to the maximum predicted conventional curvatures, are 16 mm/m tensile and 9 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.3. The predicted strains directly above the multi-seam longwalls are 8 mm/m tensile and 9 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.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the drainage culverts is provided in Table 6.4. The values are the maxima within 20 m of the mapped locations of each of the culverts due to the proposed mining in all seams.

Table 6.4 Maximum predicted total subsidence, tilt and curvature for the drainage culverts

Reference	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
ER-C1	40	1	0.02	< 0.01
ER-C2	3500	17	0.20	0.15
ER-C3	4250	19	0.12	0.30
ER-C4	4950	20	0.04	0.15
ER-C5	150	5	0.05	< 0.01

The maximum predicted tilt for the drainage culverts is 20 mm/m (i.e. 2.0 %, or 1 in 50). The maximum predicted curvatures for the culverts are 0.20 km^{-1} hogging and 0.30 km^{-1} sagging, which represent minimum radii of curvatures of 5 km and 3.3 km, respectively.

The causeway where Edderton Road crosses Saddlers Creek is predicted to experience less than 20 mm vertical subsidence due to the proposed mining. Whilst the causeway could experience very low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains.

6.3.3. Impact assessments for Edderton Road based on its current alignment

The maximum predicted vertical subsidence along the current alignment of Edderton Road is 5100 mm. The predicted subsidence varies along the length of the road, with greater subsidence developing above the longwall voids (especially where they coincide) and lesser subsidence developing near to the chain pillars.

The maximum predicted change in grade (i.e. tilt) along the alignment of Edderton Road is 45 mm/m (i.e. 4.5 %, or 1 in 22). The greater tilts occur towards the northern part of the proposed mining area, where the depths of cover are shallower.

The existing and predicted post-mining surface levels and grades along the alignment of Edderton Road are illustrated in Fig. 6.9.

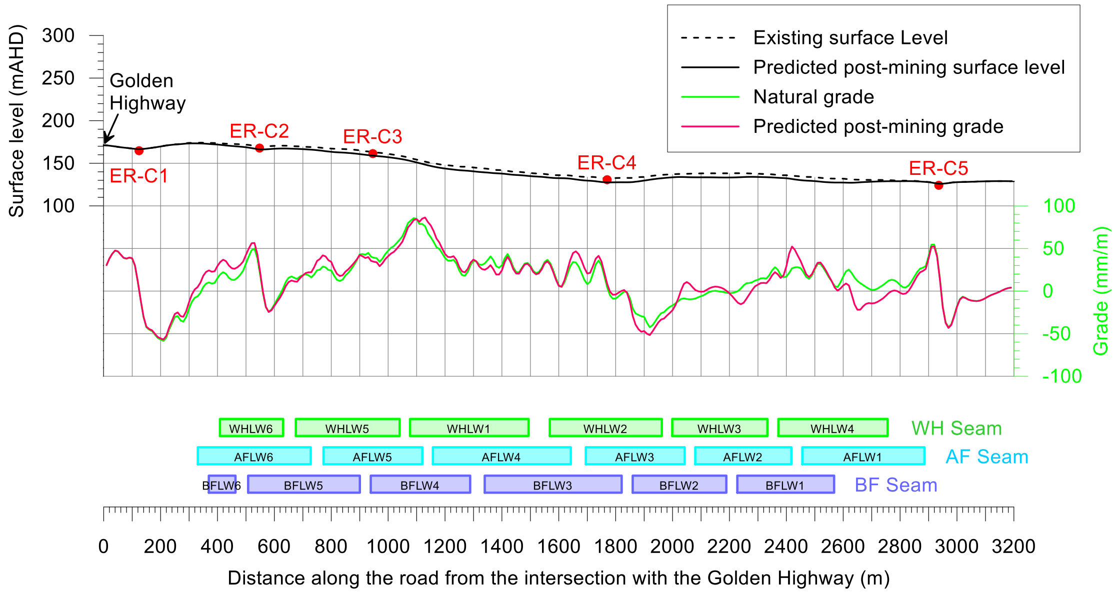


Fig. 6.9 Existing and predicted post-mining surface levels and grades along the current alignment of Edderton Road

The predicted post-mining grades along the current alignment of Edderton Road are reasonably similar to the existing grades. It is unlikely, therefore, that there would be large-scale changes in the surface drainage of the road due to the proposed mining. There is potential for increased ponding near the low-point along the road above the proposed mining area (i.e. near culvert ER-C4) due to the locally increased subsidence in that location.

The maximum predicted curvatures for Edderton Road are 1.6 km^{-1} hogging and 0.90 km^{-1} sagging, which represent minimum radii of curvatures of 0.6 km and 1.1 km, respectively. The road could also experience strains typically between 10 mm/m and 20 mm/m, with some isolated strains greater than 20 mm/m. It is expected that cracking, heaving and possibly stepping of the road pavement would occur based on these levels of predicted curvature and strain.

The maximum predicted curvatures for Edderton Road are of similar orders of magnitude to, but, less than the maxima predicted where Blakefield South Longwalls 2 to 4 were extracted directly beneath Broke Road, which varied between 1.0 km^{-1} and 1.5 km^{-1}. These longwalls were extracted beneath the existing South Bulga longwalls in the Whybrow Seam and, therefore, were also multi-seam mining conditions. The maximum predicted curvatures for Edderton Road are also less than those predicted where Blakefield South Longwalls 1 to 4 were extracted beneath Charlton Road (also multi-seam conditions) and where the Beltana No. 1 Underground Mine Longwalls 1 to 10 were extracted beneath this road (shallow single-seam conditions), which were greater than 3.0 km^{-1}.

The impacts observed along Broke and Charlton Road should, therefore, provide a reasonable guide to the potential impacts that could along Edderton Road, due to the proposed mining, if the road were not to be realigned.

Blakefield South Longwalls 1 to 4 had void widths of 330 m to 400 m and were extracted from the Blakefield Seam at depths of cover ranging between 150 m and 250 m beneath Broke Road and Charlton Roads. The longwalls were extracted beneath the existing South Bulga longwalls in the Whybrow Seam where the interburden thickness typically varied between 70 m and 90 m.

The crack widths observed along Broke and Charlton Roads at the Blakefield South Mine typically varied between 10 mm and 50 mm, with a maximum width of 220 mm. The compression heaving and step heights observed along these roads were typically less than 25 mm, with a maximum height of 50 mm. Examples of the impacts observed at the Blakefield South Mine are provided in Fig. 6.10 for Broke Road and in Fig. 6.11 for Charlton Road.

Fig. 6.10 Impacts observed along Broke Road at the Blakefield South Mine

Fig. 6.11 Impacts observed along Charlton Road at the Blakefield South Mine

Beltana Longwalls 1 to 10 had void widths of 275 m and were extracted from the Whybrow Seam at depths of cover ranging between 80 m and 115 m beneath Charlton Road. The crack widths observed along the road typically varied between 50 mm and 100 mm, with a maximum observed crack width around 380 mm. The heave and step heights observed along the road were typically in the order of 25 mm. Examples of the impacts observed along Charlton Road at the Beltana No. 1 Underground Mine are provided in Fig. 6.12.

Fig. 6.12 Impacts observed along Charlton Road at the Beltana No. 1 Underground Mine

The impacts on Broke and Charlton Roads were managed using visual monitoring and undertaking temporary repairs of the road pavement during active subsidence. The management strategies required some temporary lane closures and speed restrictions whilst repairs were being undertaken. The final remediation of the road pavement was undertaken after the completion of active subsidence.

It is anticipated that the crack widths along the current alignment of Edderton Road would be typically between 25 mm and 50 mm, with isolated cracks greater than 300 mm, due to the proposed mining. Stepping of the road pavement could also occur in the order of 25 mm to 50 mm, with isolated steps with heights greater than 100 mm. The potential impacts on Edderton Road could result in it becoming unsafe or unserviceable if preventive or remediation measures were not to be implemented.

The potential impacts on Edderton Road could be managed using visual monitoring and undertaking remediation of the road pavement during active subsidence. These strategies may require temporary lane closures to undertake the repairs and temporary speed restrictions along the section of the road that is impacted by mining.

Experience of mining beneath roads in the NSW coalfields indicates that the impacts on unbound pavements develop progressively, where the onset of impacts can be identified early by visual monitoring which, in most cases, allows for the remediation measures to be scheduled outside of peak traffic times. It is still possible that more rapidly developing impacts could occur, as a result of compressive buckling of the near surface bedrock, which may require temporary repairs to be undertaken during peak traffic times.

Alternatively, the potential impacts on Edderton Road could be avoided by realigning the road outside of the proposed mining area. Discussions on the potential realignment of the road are provided in the following section.

6.3.4. Predictions and impact assessments for the potential realignment of Edderton Road

An indicative location for the potential realignment of Edderton Road is shown in Fig. 6.13. The section of road located within the Study Area is proposed to be realigned to the west of the proposed mining area.

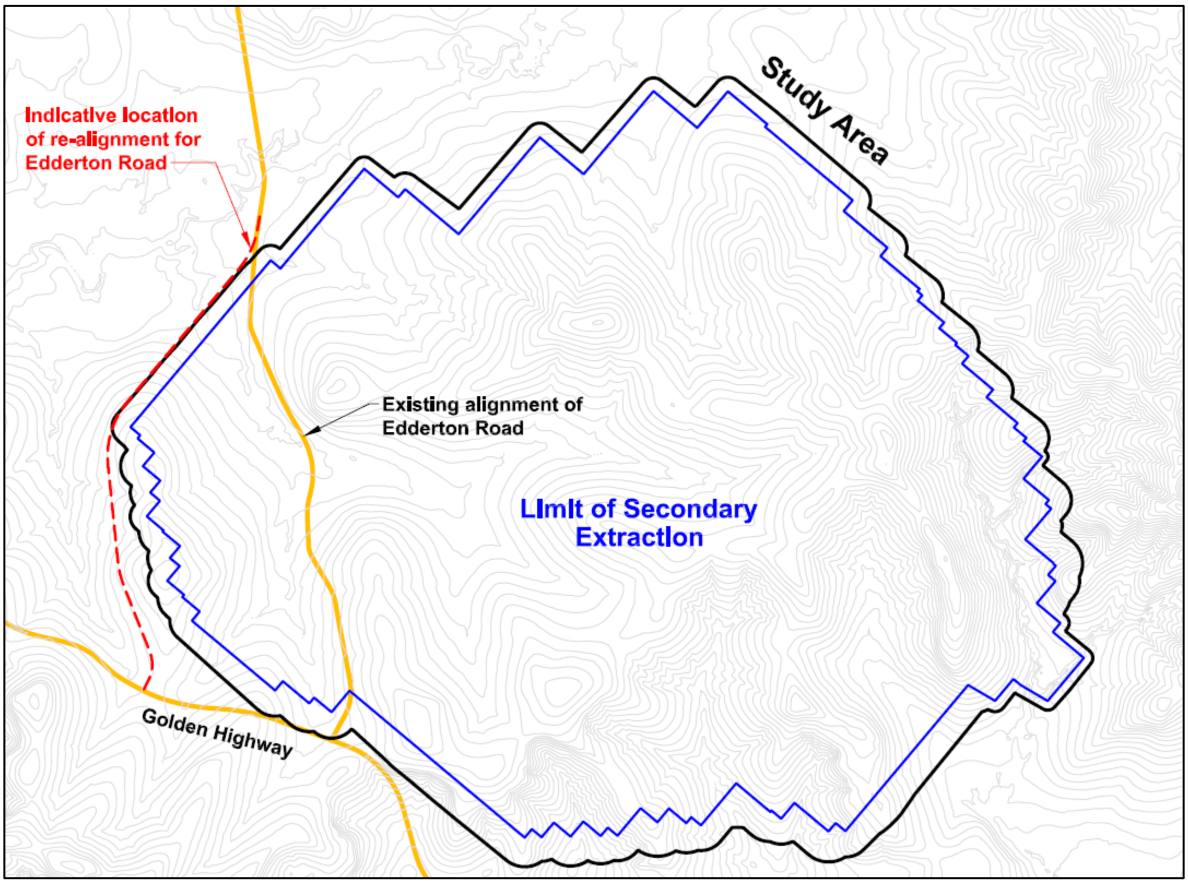


Fig. 6.13 Indicative location for the potential realignment of Edderton Road

The indicative road realignment is predicted to experience less than 20 mm vertical subsidence. Whilst the road realignment could experience very low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains. It is unlikely, therefore, that the indicative realignment of Edderton Road would experience adverse impacts due to the proposed mining.

If the realignment option is not adopted, then the impacts along the existing alignment of the road could be managed during active subsidence, similarly to Broke and Charlton Roads at Blakefield South Mine, as outlined in Section 6.3.3.

6.3.5. Recommendations for Edderton Road

It is recommended that a BFMP be developed for Edderton Road in consultation with the Muswellbrook Shire Council.

In the case that Edderton Road is realigned, ground monitoring and visual inspections of the road realignment should be carried out during the extraction of WHLW4, AFLW1 and BFLW2, to confirm the predicted low levels of vertical subsidence.

Alternatively, if Edderton Road is maintained in its current alignment, the BFMP could include strategies similar to those used to maintain Broke and Charlton Roads in safe and serviceable conditions during active subsidence at the Blakefield South Mine.

6.4. Unsealed tracks

There are unsealed tracks located across the Study Area. Some of these tracks are shown in Drawing No. MSEC986-24. The land above the proposed mining area is owned by Malabar and, therefore, these tracks are not accessible to the public.

The unsealed tracks could experience the range of predicted subsidence movements. A summary of the maximum predicted mine subsidence parameters within the Study Area was provided in Chapter 4. It is expected that cracking, rippling and stepping of the unsealed tracks would occur as each of the proposed panels and longwalls mine beneath them.

The assessed surface deformations above the proposed panels and longwalls are provided in Section 4.6. The largest impacts are expected to occur along the tracks on the sides of the ridgelines, in the southern part of the proposed mining area, and where the depths of cover are shallowest, in the northern part of the proposed mining area.

The unsealed tracks within the Study Area can be maintained in safe and serviceable conditions throughout the mining period using normal road maintenance techniques. It is recommended that management strategies are developed to repair the unsealed tracks. It is also recommended that these tracks are periodically inspected during active subsidence.

6.5. Drainage culverts

Drainage culverts along Edderton Road are located within the Study Area and directly above the proposed mining area. The descriptions, predictions and impact assessments for these culverts are provided in Section 6.3.

6.6. Electrical infrastructure

6.6.1. Description of the powerlines

The locations of the powerlines are shown in Drawing No. MSEC986-24.

An 11 kilovolt (kV) powerline owned by Ausgrid crosses the western part of the Study Area. The powerline follows the alignment of Edderton Road and it is located directly above the proposed longwalls in the Woodlands Hill, Arrowfield and Bowfield Seams. A summary of the longwalls that are proposed to be extracted directly beneath the powerline is provided in Table 6.5.

Table 6.5 Longwalls proposed to be extracted directly beneath the 11 kV powerline

Seam	Longwalls proposed to be extracted beneath the powerline	Length of powerline above the proposed mining areas (km)
Woodlands Hill Seam	WHLW1 to WHLW6	2.3
Arrowfield Seam	AFLW1 to AFLW6	2.6
Bowfield Seam	BFLW1 to BFLW6	2.2
All seams	As above	2.6

The 11 kV powerline comprises aerial copper conductors supported by timber poles. The power pole IDs (as provided by Ausgrid) are shown in Drawing No. MSEC986-24. Photographs of the powerline along Edderton Road are provided in Fig. 6.14.

Fig. 6.14 11 kV voltage powerline along Edderton Road

Another powerline crosses the southern boundary of the Study Area but it is located outside of the proposed mining area. The total length of this powerline within the Study Area is 0.3 km. The powerline services the properties on the northern side of the Hunter River.

6.6.2. Predictions for the powerline

The predicted profiles of vertical subsidence, tilt along and tilt across the alignment of the 11 kV powerline are shown in Fig. C.08, in Appendix C. The predicted profiles are shown after the completion of the Whynot Seam (red lines), Woodlands Hill Seam (green lines), Arrowfield Seam (cyan lines) and Bowfield Seam (blue lines). The maximum predicted tilts after any panel or longwall in any seam are shown as the grey lines.

A summary of the maximum predicted values of total vertical subsidence, tilt along the alignment and tilt across the alignment of the 11 kV powerline is provided in Table 6.6. The values are the maxima anywhere along the powerline (i.e. not necessarily at the pole locations) within the Study Area.

Table 6.6 Maximum predicted total subsidence and tilt for the 11 kV powerline

After completion of seam	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)
Whynot	< 20	< 0.5	< 0.5
Woodlands Hill	2300	40	25
Arrowfield	4300	45	30
Bowfield	5100	45	30

The maximum predicted conventional tilts for the powerline are 45 mm/m (i.e. 4.5 %, or 1 in 22) along the alignment and 30 mm/m (i.e. 3.0 %, or 1 in 33) across the alignment of the powerline. The maximum predicted total tilt in any direction is 50 mm/m (i.e. 5.0 %, or 1 in 20).

The maximum predicted horizontal movement of the ground associated with the maximum predicted tilt is 500 mm. The maximum predicted horizontal movement at the tops of the poles (assuming a height of 15 m) therefore is 1250 mm.

The mining-induced tilts and horizontal movements along the alignment of the powerline will result in net opening and net closure between the tops of the adjacent power poles. A summary of the maximum predicted values of total opening and total closure between the tops of the power poles is provided in Table 6.7. The values are the maxima that occur at the completion of the proposed longwalls in each of the seams. Higher transient movements could occur as the proposed longwalls are extracted directly beneath the powerline.

Table 6.7 Maximum predicted total opening and total closure movements between the tops of the power poles of the 11 kV powerline

Span	Final predicted opening (+ve) or closure (-ve) at the completion of mining within each seam (mm)			Maximum predicted total opening after completion of any proposed longwall (mm)	Maximum predicted total closure after completion of any proposed longwall (mm)
	After WH Seam	After AF Seam	After BF Seam		
AN-10006 to AN-10005	< ±20	+70	+80	+90	< -20
AN-10005 to AN-10004	< ±20	+225	+250	+275	< -20
AN-10004 to AN-10003	< ±20	-275	-100	< +20	-275
AN-10003 to AN-10002	< ±20	-250	-300	+40	-300
AN-10002 to AN-10001	+225	+475	+125	+475	< -20
AN-10001 to AM-70114	+175	+325	+250	+325	< -20
AM-70114 to AM-70113	-625	-600	-325	< +20	-650
AM-70113 to AM-70112	-60	-450	-150	< +20	-475
AM-70112 to AM-70111	+400	+450	+90	+450	< -20
AM-70111 to AM-70110	< ±20	+450	+175	+500	-30
AM-70110 to AM-70109	-250	-350	-50	< +20	-350
AM-70109 to AM-70108	-300	-500	-300	< +20	-500
AM-70108 to AM-70107	+350	+200	+175	+350	< -20
AM-70107 to AM-70106	+100	+175	< ±20	+175	< -20
AM-70106 to AM-70105	+475	+600	+400	+625	< -20
AM-70105 to AM-70104	-550	-300	-250	< +20	-550
AM-70104 to AM-70103	-625	-1000	-575	< +20	-1050
AM-70103 to AM-70102	+800	+675	+350	+850	< -20
AM-70102 to AM-70101	+90	+575	+250	+600	< -20
AM-70101 to AM-70100	-475	-625	-175	< +20	-675
AM-70100 to AM-70099	+200	-225	-90	+225	-250
AM-70099 to AM-70098	+875	+1200	+700	+1200	< -20
AM-70098 to AM-70097	-800	-550	-525	< +20	-800
AM-70097 to AM-70095	-350	-650	-450	< +20	-675
AM-70095 to AM-70094	+275	< ±20	< ±20	+275	< -20
AM-70094 to AM-70093	+90	+275	+275	+275	< -20
AM-70093 to AM-70092	< ±20	+100	+100	+100	< -20

The maximum predicted total differential movements between the tops of the adjacent poles are 1200 mm opening and 1050 mm closure. Higher transient values could occur as the proposed longwalls are mined directly beneath the powerline.

6.6.3. Impact assessments for the powerline

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

The maximum predicted tilt in any direction for the 11 kV powerline along Edderton Road is 50 mm/m (i.e. 5.0 %, or 1 in 20). A rule of thumb used by some electrical engineers is that the tops of the poles may displace up to two pole diameters horizontally before remediation works are considered necessary. Based on pole heights of 15 m and pole diameters of 250 mm, the maximum tolerable tilt at the pole locations is in the order of 20 mm/m.

It is likely, therefore, that the powerline could experience impacts due to the extraction of the proposed longwalls directly beneath it. The impacts could include increased cable tensions and lateral loads on the power poles and/or reduced cable clearances.

The potential for impacts could be managed with the implementation of preventive measures, such as the provision of cable rollers, guy wires or additional poles. Alternatively, the potential impacts could be avoided by realigning the powerline around the area of active subsidence.

Powerlines have been successfully mined beneath in the NSW coalfields where the mine subsidence movements were similar to those predicted for the proposed longwalls. It is expected, therefore, that the powerline along Edderton Road could be maintained in a safe and serviceable condition with the development and implementation of the necessary management and monitoring measures.

The powerline that crosses the southern perimeter of the Study Area is predicted to experience less than 20 mm vertical subsidence due to the proposed mining. Whilst this powerline could experience low-levels of vertical subsidence, it is not expected to experience measurable tilts or differential horizontal movements.

6.6.4. Recommendations for the powerline

It is recommended that a BFMP is developed with Ausgrid prior to longwall extraction within 500 m of the powerline. Preventative measures that could be implemented in advance of mining include the realignment of the powerline around the mining area or the installation of cable rollers, guy wires or additional poles, or the adjustment of cable catenaries. It is recommended that powerlines are visually monitored during active subsidence, to maintain them in safe and serviceable conditions at all times.

6.7. Telecommunications infrastructure

There is no telecommunications infrastructure located within the Study Area. Optical fibre and copper telecommunications cables follow the alignment of the Golden Highway and Edderton Road outside of the Study Area. The locations of these cables are shown in Drawing No. MSEC986-24.

The optical fibre and copper telecommunications cables are located at minimum distances of 800 m and 350 m, respectively, outside of the proposed mining area, at their closest points. At these distances, the cables are predicted to experience negligible vertical subsidence. Whilst the copper cables located closest to the proposed mining area could experience very low-levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

The optical fibre and copper telecommunications cables are supported by the bridge where the Golden Highway crosses the Hunter River approximately 800 m south of the proposed mining area. The predicted far-field horizontal movements at this bridge are discussed in Section 6.2.

It is recommended that the management plan for the bridge includes strategies to maintain the optical fibre and copper telecommunications cables in serviceable conditions.

6.8. Plashett Reservoir

There are no public dams, reservoirs or associated works within the Study Area. Plashett Reservoir is located outside and to the east of the Study Area. The reservoir is shown in Drawing No. MSEC986-24.

Plashett Reservoir serves as an off-river water storage for the Bayswater Power Station, operated by AGL, and also supplies water to Jerrys Plains township. The reservoir is fed by pumps located on the Hunter River and Saltwater Creek and it has a total storage capacity of 67 GL. Plashett Reservoir is a prescribed dam (gazettal date 8 August 1997, gazettal no. 88) that is managed by the DSC. The DSC Notification Area is shown in Drawing No. MSEC986-24. There is no mining proposed within the Notification Area.

Plashett Reservoir is located at a minimum distance of 2 km outside of the proposed mining area. The dam wall is at the south-western corner of the reservoir and it is more than 2 km from the proposed mining area. At these distances, the vertical subsidence at the reservoir and dam wall are expected to be negligible.

The reservoir and dam wall could experience very small far-field horizontal movements due to the proposed mining. It can be seen from Fig. 4.4, that incremental far-field horizontal movements are typically less than 25 mm (i.e. in the order of survey tolerance) at distances of 2000 m from previous longwall mining. The potential for adverse impacts on the dam wall does not result from absolute far-field horizontal movements, but rather from differential horizontal movements over the length of the structure. It is unlikely that the differential horizontal movements (i.e. strains) at the dam wall would be measurable.

Longwall mining has been previously carried out near other prescribed dams in the NSW coalfields, including Lake Liddell and the Avon, Cataract, Cordeaux and Nepean Reservoirs. This previous mining has not resulted in adverse impacts on these structures. For example, the longwalls at Dendrobium Mine have been extracted within 0.9 km of the Upper Cordeaux No. 1 and No. 2 Dam Walls. The detailed ground monitoring indicated that the measured movements were very small and were within the order of survey tolerance (i.e. not measurable).

It is unlikely, therefore, that the Plashett Reservoir and the associated dam wall would experience adverse impacts due to the proposed mining. The panels and longwall series within each seam are progressively mined towards the reservoir and dam wall. This will allow the movements at these features to be measured and reviewed as the mining progresses towards them, if required.

It is recommended that Malabar continue to consult with the DSC and AGL throughout the life of the Project in relation to Plashett Reservoir.

6.9. Agricultural utilisation

All land above the proposed mining area is owned by Malabar and it is primarily used for cattle grazing with small areas of opportunistic fodder cropping (under favourable conditions). The agricultural improvements include fences, farm dams, land contours and cattle yards. The potential impacts on the fences and farm dams are discussed in Sections 6.11 and 6.12, respectively. Photographs of the land contouring and cattle yards are provided in Fig. 6.15 and Fig. 6.16, respectively.

Fig. 6.15 Land contouring within the Study Area

Fig. 6.16 Cattle yard and fences within the Study Area

The main risk to the light cattle grazing within the Study Area is the potential for the mining-induced surface cracking and deformations to injure the cattle or workers. The assessed surface deformations above the proposed panels and longwalls are provided in Section 4.6.

Management strategies can be developed for this agricultural utilisation, which could include:

- visual monitoring of the surface in the active subsidence zone, to identify any surface cracking and deformations that could potentially injure the stock or people;
- consider the installation of temporary fencing and/or the temporary relocation of stock to areas outside the active subsidence zone;
- establish methods of remediation, which could include infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface; and
- develop management plans detailing the appropriate methods to manage surface cracking and deformations within the Study Area.

These management strategies should be developed in consultation with the lessee, as required. The discussions on the potential impacts on the built features and surface improvements associated with the agricultural utilisation are included in the following sections.

6.10. Rural structures and tanks

The locations of the rural structures (i.e. sheds) and tanks within the Study Area are shown in Drawing No. MSEC986-24.

A disused shearers hut, sheep yards and associated structures are located above the proposed mining area. This site is directly above the proposed WHLW6, AFLW6 and BFLW5 and is south-west of the proposed panels in the Whynot Seam. The structures are timber framed with corrugated metal sheeting. The stockyard has a concrete ground slab and a shallow well has a concrete surround. There is a brick fire pit next to the shearers hut. The structures are in varying states of disrepair.

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the disused shearers hut, sheep yards and associated structures is provided in Table 6.8. The values are the maxima within 20 m of the identified location of this site.

Table 6.8 Maximum predicted total vertical subsidence, tilt and curvatures for the disused shearers hut, sheep yards and associated structures

After completion of seam	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})
Whynot	< 20	< 0.5	< 0.01	< 0.01
Woodlands Hill	1250	25	0.35	< 0.01
Arrowfield	3700	25	0.35	0.03
Bowfield	4800	25	0.35	0.03

The disused shearers hut, sheep yards and associated structures are predicted to experience a maximum curvature of 0.35 km^{-1} and strains of 8 mm/m tensile and 9 mm/m compressive based on the 95 % confidence levels. The ground movements are expected to result in considerable deformation of the structures at this site. These structures are of lightweight construction and in varying states of disrepair. The conditions of the timber framing and corrugated sheeting are unlikely to change due to the proposed mining. Cracking could develop in the concrete slab, concrete surround and brickwork.

There are four rural structures (Refs. A01r01 to A01r04) and three tanks (Refs. A01t01 to A01t03) that are located just inside the Study Area. These structures are owned by Malabar. The structures are located at distances between 85 m and 170 m from the proposed mining area, at their closest points.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the rural structures and tanks located outside the proposed mining area is provided in Table 6.9. The values are the maxima within 20 m of the locations of each of the structures.

Table 6.9 Maximum predicted total subsidence, tilt and curvature for the rural structures and tanks located outside the proposed mining area

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})
A01r01	< 20	< 0.5	< 0.01	< 0.01
A01r02	< 20	< 0.5	< 0.01	< 0.01
A01r03	< 20	< 0.5	< 0.01	< 0.01
A01r04	30	0.5	< 0.01	< 0.01
A01t01	< 20	< 0.5	< 0.01	< 0.01
A01t02	< 20	< 0.5	< 0.01	< 0.01
A01t03	< 20	< 0.5	< 0.01	< 0.01

The rural structure that is located closest to the proposed mining area (i.e. Ref. A01r04) is predicted to experience 30 mm vertical subsidence due to the proposed mining. The remaining rural structures and tanks are predicted to experience less than 20 mm vertical subsidence. Whilst the rural structures and tanks located outside the proposed mining area could experience very low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

It is unlikely that the rural structures and tanks located outside the proposed mining area would experience adverse impacts due to the proposed mining. All structures are expected to remain in safe and serviceable conditions throughout the mining period. Similarly, all other structures located outside the Study Area are predicted to experience negligible vertical subsidence and are not expected to experience adverse impacts due to the proposed mining.

6.11. Fences

Fences are located across the Study Area and, therefore, are expected to experience the 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 adverse impacts.

It is expected, at the predicted magnitudes of tilt, curvature and strain, that some sections of the fences within the Study Area would be impacted due to the proposed mining. Impacts on the fences could be remediated by re-tensioning the fencing wire, straightening the fence posts, and if necessary, replacing the affected sections of fencing.

6.12. Farm dams

6.12.1. Description of the farm dams

The locations of the farm dams are shown in Drawing No. MSEC986-24.

There are 18 farm dams within the Study Area. These dams are all located on land owned by Malabar. Part of the land within the Study Area is leased and is used for cattle grazing. The farm dams provide sources of water for this agricultural utilisation.

The dams are of earthen construction and have been established by localised cut and fill operations within the natural drainage lines. The farm dams are shallow, with the dam walls generally being less than 3 m in height.

Photographs of typical farm dams within the Study Area are provided in Fig. 6.17.

Fig. 6.17 Farm dams

The largest farm dam above the proposed mining area has a surface area of 13,000 m^2 and a maximum planar dimension of 140 m. The majority of the remaining dams within the Study Area have surface areas less than 4000 m^2 and maximum planar dimensions of less than 80 m.

6.12.2. Predictions for the farm dams

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

A summary of the maximum predicted vertical subsidence, tilt and curvatures for the farm dams is provided in Table 6.10. The values are the maxima within the Study Area due to the proposed mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams.

Table 6.10 Maximum predicted conventional subsidence, tilt and curvature for the farm dams

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})
Farm dams	5600	50	2.0	2.0

The maximum predicted total conventional curvatures are 2.0 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 0.5 km. The predicted conventional strains based on applying a factor of 10 to the predicted conventional curvatures are 20 mm/m tensile and compressive.

The distributions of strain above the proposed mining area are provided in Section 4.3. The predicted strains due to the proposed multi-seam mining are 8 mm/m tensile and 9 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.

The farm dams are located along the natural drainage lines and, therefore, could also experience valley related effects due to the proposed mining. The drainage lines have shallow incisions into the natural surface soils and, therefore, the predicted upsidence and closure effects are not expected to be significant when compared with the predicted conventional effects.

6.12.3. Impact assessments for the farm dams

The maximum predicted final tilt for the farm dams within the Study Area is 50 mm/m (i.e. 5 %, or 1 in 20). The individual dams will experience varying tilts up to this value, depending on their locations relative to the proposed panels and longwalls in each seam.

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. Tilt can potentially reduce the storage capacity of farm dams, by causing them to overflow, or can affect the stability of the dam walls.

The maximum predicted changes in freeboard occur at the two largest farm dams located adjacent to Edderton Road and above the western part of the proposed mining area. The predicted changes in freeboard for these dams are 1 m. The predicted changes in freeboard for the remaining farm dams located above the proposed mining area vary up to approximately 0.5 m.

It is likely that the storage capacities of the farm dams predicted to experience the greatest changes in freeboard would reduce due to the proposed mining. If the storage capacities of any farm dams were adversely affected, they could be re-established by raising the earthen walls. In some cases, the dam walls may also need to be lengthened on the downslope side. In some cases, the storage capacities of the farm dams could increase due to the proposed mining. It is recommended that, during active mining, Malabar should confirm that any increase in storage capacity remains within harvestable rights and/or water licensing constraints.

The maximum predicted curvatures at the farm dams are 2.0 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 0.5 km. The farm dams will also experience strains typically up to 10 mm/m, with localised and isolated strains up to 20 mm/m.

It is expected, at these magnitudes of predicted curvatures and strains, that many of the farm dams would be affected by cracking, heaving or stepping in the bases of the dam walls. It is also likely that fracturing and buckling of the uppermost bedrock would occur beneath the farm dams. The farm dams which are at higher risk from surface cracking are those located in the final tensile zones, i.e. located at distances around 0.1 times the depth of cover from the longwall edges.

There is also a possibility that high concentrations of strain could occur at faults, fissures and other geological features, or points of weaknesses in the strata, and such occurrences could be coupled with localised stepping in the surface. If this type of phenomenon coincided with a farm dam wall, then, there is a possibility that cracking in the dam wall or base could occur resulting in loss of the stored water.

Surface cracking or leakages in the farm dams could be identified by visual inspections and remediated by re-instating the bases and walls of the dams with cohesive materials. Any loss of stored water from the farm dams would flow into the drainage line in which the dam was formed. Consultation should occur with the lessee during mining to manage any temporary impacts on stock water supply.

6.12.4. Recommendations for the farm dams

Monitoring and management measures for each farm dam should be developed as part of the Extraction Plan process. It is recommended that the stored water levels in the larger farm dams are lowered prior to active subsidence. It is also recommended that farm dams are visually monitored, during active subsidence at the dam, such that any impacts can be identified and remediated accordingly.

6.13. Groundwater bores

The locations of groundwater bores are shown in Drawing No. MSEC986-24.

A summary of groundwater bores located within the Study Area is provided in Table 6.11. These groundwater bores are located on Malabar-owned land. There are also additional groundwater bores that are located outside the Study Area, as shown in Drawing No. MSEC986-24.

Table 6.11 Details of the groundwater bores within the Study Area

Reference	Approximate easting (m)	Approximate northing (m)	Depth (m)
DD1004	299800	6410925	106
DD1005	298800	6410900	139
DD1014	296800	6410875	90
DD1015	298825	6409900	163
DD1016	297800	6410875	126
DD1025	298775	6411900	45
DD1041 - Deep	296200	6409475	387
DD1041 - Shallow	296200	6409475	N/A
DD1043	295200	6409450	203
DD1052	296275	6408525	127
DD1057	295175	6410450	188
RBD1	295175	6409250	111
RD1192	296100	6409050	149
Shearers Well	296900	6410275	N/A
Shearers Well Bore	296925	6410250	N/A
WND16	298125	6408850	126
WND26	299475	6409050	152

It is likely that the groundwater bores will experience impacts as the result of the proposed mining, particularly those located directly above the proposed mining area. Impacts would include 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. Such impacts on the groundwater bores can be managed and, if required, the bores can be reinstated.

The potential impacts on the bores and groundwater resources are provided by the specialist groundwater consultant for the EIS in the report by *HydroSimulations* (2019).

6.14. Business and commercial establishments

There are no business or commercial establishments within the Study Area. There are business and commercial establishments located along the Golden Highway to the south of the Study Area, including horse studs and a vineyard. The establishments near the Study Area are shown in Drawing No. MSEC986-24.

These properties located outside the Study Area will not be affected by mining-induced surface cracking and deformations, nor changes in surface water drainage. The potential impacts on the bores and groundwater resources in the vicinity of the Study Area are provided by the specialist groundwater consultant for the EIS in the report by *HydroSimulations* (2019).

The building structures, surface infrastructure and improvements on the properties located outside the Study Area are predicted to experience negligible vertical subsidence, tilts, curvatures and strains. It is unlikely that these features would experience adverse impacts due to the proposed mining. All structures, infrastructure and improvements on the private properties are expected to remain in safe and serviceable conditions throughout the mining period.

6.15. Aboriginal heritage sites

6.15.1. Descriptions of the Aboriginal heritage sites

The locations of known Aboriginal heritage sites are shown in Drawing No. MSEC986-25. The details of these sites have been provided by *AECOM* (2019).

The Aboriginal heritage sites located within the Study Area and surrounds comprise stone quarries and other open artefact sites, i.e. isolated artefacts, artefact scatters and an artefact scatter with an associated potential archaeological deposit (PAD). The locations of these sites relative to the proposed mining areas are provided in Table D.01, in Appendix D. The locations provided in Table D.01 are based on an amalgamation of the sites and estimated extents due to the proximity of neighbouring sites.

Further details on the Aboriginal heritage sites are provided by *AECOM* (2019).

6.15.2. Predictions for the Aboriginal heritage sites

The maximum predicted total conventional subsidence parameters for each of the Aboriginal heritage sites are provided in Table D.01, in Appendix D. The predictions provided in Table D.01 are based on the maximum values within the amalgamation of the sites and estimated extents.

Summaries of the maximum predicted total vertical subsidence, tilt and curvatures for the stone quarries and the other open artefact sites (i.e. isolated artefacts, isolated artefacts, artefact scatters and artefact scatter with PAD) are provided in Table 6.12 and Table 6.13, respectively.

Table 6.12 Maximum predicted total vertical subsidence, tilt and curvatures for the stone quarries

After completion of seam	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})
Whynot	< 20	< 0.5	< 0.01	< 0.01
Woodlands Hill	< 20	< 0.5	< 0.01	< 0.01
Arrowfield	< 20	< 0.5	< 0.01	< 0.01
Bowfield	< 20	< 0.5	< 0.01	< 0.01

Table 6.13 Maximum predicted total vertical subsidence, tilt and curvatures for the other open artefact sites

After completion of seam	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})
Whynot	325	15	0.5	1.0
Woodlands Hill	3100	45	2.0	1.5
Arrowfield	4800	50	2.0	2.0
Bowfield	5450	50	2.0	2.0

The previously reported stone quarries within the Study Area and surrounds are predicted to experience less than 20 mm vertical subsidence. Whilst the stone quarries located outside the proposed mining area could experience very low-levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

The maximum predicted total conventional curvatures for the other open artefact sites are 2.0 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 0.5 km. The predicted conventional strains based on applying a factor of 10 to the predicted conventional curvatures are 20 mm/m tensile and compressive.

The distributions of strain above the proposed mining area are provided in Section 4.3. The predicted strains due to the proposed multi-seam mining are 8 mm/m tensile and 9 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.

6.15.3. Impact assessments for the Aboriginal heritage sites

The Aboriginal heritage sites are located across the proposed mining area and, therefore, they could experience the range of the predicted mine subsidence movements. These sites can potentially be affected by cracking and heaving of the surface soils due to the proposed mining.

The assessed surface deformations above the proposed panels and longwalls are provided in Section 4.6.

The surface cracking in the flatter areas and at higher depths of cover is expected to be typically between 25 mm and 50 mm in approximately 50 % of cases, between 50 mm and 100 mm in approximately 30 % of cases, between 100 mm and 150 mm in approximately 15 % of cases and greater than 150 mm in approximately 5 % of cases.

The surface cracking in the steeper areas and at shallower depths of cover is expected to be typically between 50 mm and 100 mm in approximately 60 % of cases, between 100 mm and 200 mm in approximately 25 % of cases, between 200 mm and 300 mm in approximately 10 % of cases and greater than 300 mm in approximately 5 % of cases. Multiple cracks resulting in deformations over several metres can also occur in some locations (i.e. less than 1 % of cases).

It is unlikely that the finds, artefacts and deposits themselves would be impacted by surface cracking. It is possible, however, that if remediation of the surface was required after mining, that these works could potentially impact the Aboriginal heritage sites.

It is recommended that Malabar develop appropriate protocols in the event that remediation of the surface is required in the locations of the isolated finds, artefact scatters and deposits. Further assessments of the potential impacts on these sites are provided by *AECOM* (2019).

6.15.4. Recommendations for the Aboriginal heritage sites

Recommendations for Aboriginal heritage sites have been provided by the specialist Aboriginal cultural heritage consultant for the EIS in the report by *AECOM* (2019). It is recommended that the Aboriginal Cultural Heritage Management Plan (ACHMP) include visual inspection of sites prior to mining within 500 m of the site and following the completion of active subsidence at the site. Protocols should be developed to manage sites that may be directly impacted by surface cracking or that may be disturbed during surface remediation activities.

6.16. Historic heritage sites

The locations of the historic heritage sites are shown in Drawing No. MSEC986-25. The details of these sites have been provided by *Extent Heritage* (2019).

Historic heritage sites identified by *Extent Heritage (2019)* are located outside the Study Area. The sites in the region include the Arrowfield Homestead, Bowfield Homestead, Edderton Homestead, Plashett Homestead, Randwick Homestead, Strowan Homestead, Woodlands Homestead and a stockyard.

The historic heritage sites are located at distances between 0.7 km and 5 km outside the proposed mining area. At these distances, these sites are predicted to experience negligible ground movements due to the proposed mining. The potential for mining-induced impacts on these historic heritage sites is considered to be negligible.

Further assessments of the historic heritage sites are provided by *Extent Heritage* (2019).

6.17. Survey control marks

The survey control marks are shown in Drawing No. MSEC986-24. The locations and details of the survey control marks were obtained from *Spatial Services* using the *SCIMS Online* website (SCIMS, 2018).

The survey control marks are located across the Study Area and, therefore, are expected to experience the range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4.

The survey control marks located outside the Study Area are also expected to experience small amounts of subsidence and small far-field horizontal movements. It is possible that the survey control marks could be affected by far-field horizontal movements at distances of 1 km to 2 km outside the proposed mining area. Far-field horizontal movements and the methods used to predict such movements are described further in Sections 3.3 and 4.5.

Malabar should manage the impacts of mine subsidence on survey marks in consultation with NSW Spatial Services, including lodging relevant applications under the NSW *Surveying and Spatial Information Regulation, 2017* as required by the *Surveyor-General's Direction No. 11 Preservation of Survey Infrastructure*.

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	The reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides. It should be noted that the observed closure movement across a valley is the total movement resulting from various mechanisms, including conventional mining-induced movements, valley closure movements, far-field effects, downhill movements and other possible strata mechanisms.
Critical area	The area of extraction at which the maximum possible subsidence of one point on the surface occurs.
Curvature	The change in tilt between two adjacent sections of the tilt profile divided by the average horizontal length of those sections, i.e. curvature is the second derivative of subsidence. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/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.
Subcritical 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.
Subsidence effects	The deformations of the ground mass surrounding a mine, sometimes referred to as ‘components’ or ‘parameters’ of mine subsidence induced ground movements, including vertical and horizontal displacements, tilts, curvatures, strains, upsidence and closure.
Subsidence impacts	The physical changes or damage to the fabric or structure of the ground, its surface and natural features, or built structures that are caused by the subsidence effects. These impacts considerations can include tensile and shear cracking of the rock mass, localised buckling of strata, bed separation, rock falls, collapse of overhangs, failure of pillars, failure of pillar floors, dilation, slumping and also include subsidence depressions or troughs.
Subsidence consequences	The knock-on results of subsidence impacts, i.e. any change in the amenity or function of a natural feature or built structure that arises from subsidence impacts. Consequence considerations include public safety, loss of flows, reduction in water quality, damage to artwork, flooding, draining of aquifers, the environment, community, land use, loss of profits, surface improvements and infrastructure. Consequences related to natural features are referred to as environmental consequences.
Supercritical 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 term uplift is used for the cases where the ground level is raised above the pre-mining level, i.e. when the upsidence is greater than the subsidence. 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

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I:\Projects\Maxwell Project\MSEC986 - EIS Application\Subsdata\Impacts\Prediction Lines\Fig. C.01 - Prediction Line 1.grf

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to the extraction of the WN, WH, AF and BF Seams

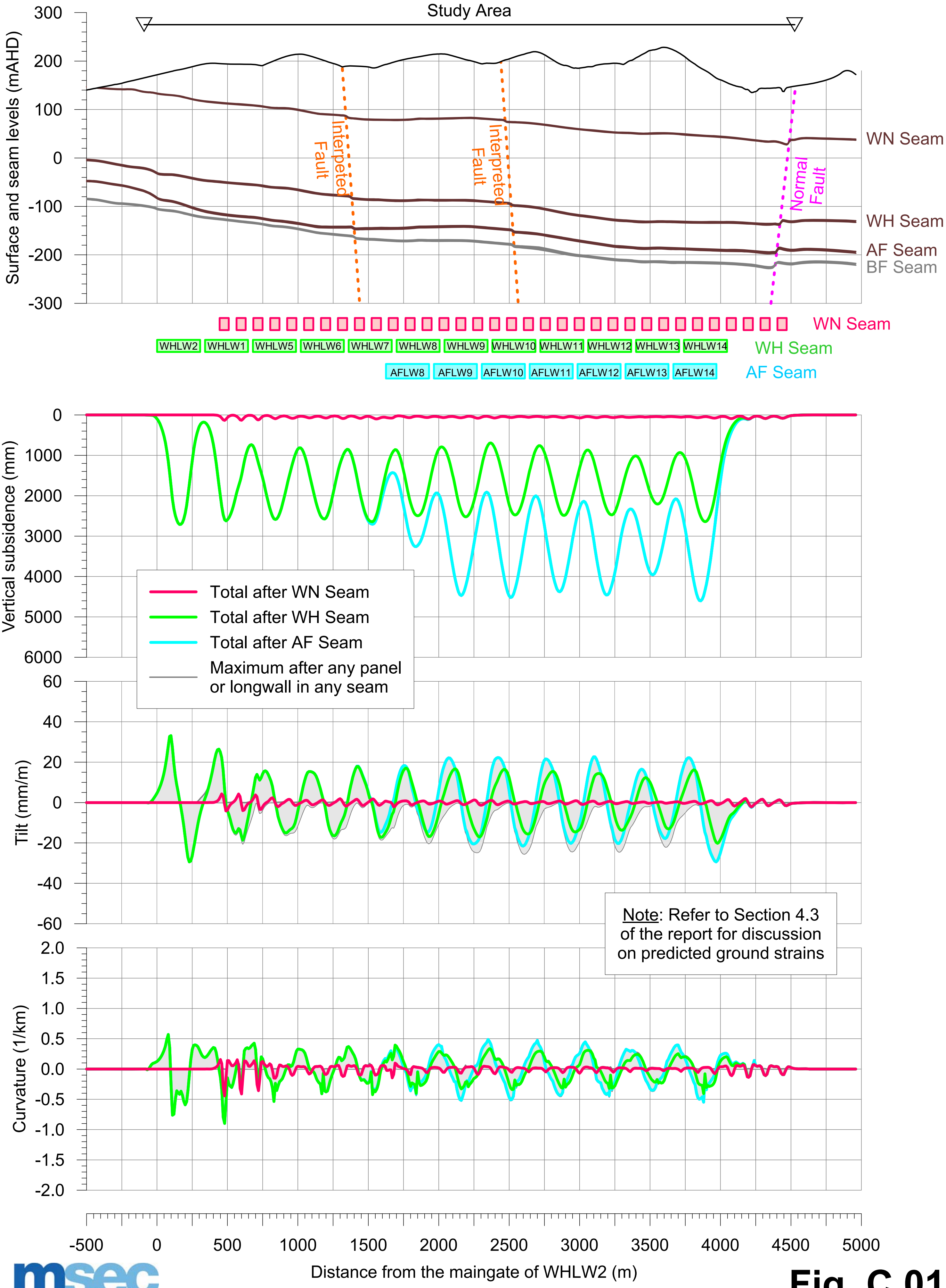

Fig. C.01

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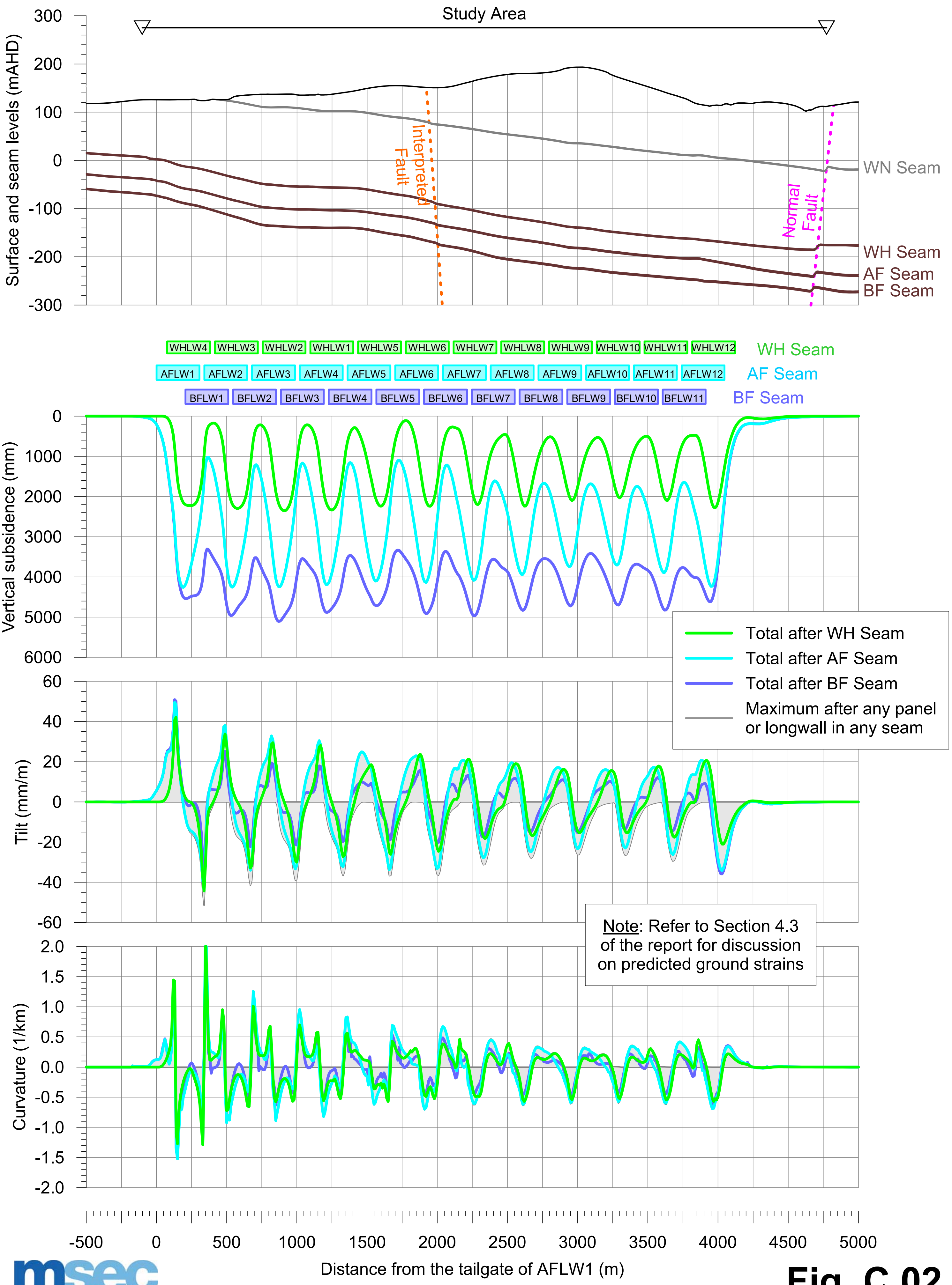
Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to the extraction of the WN, WH, AF and BF Seams



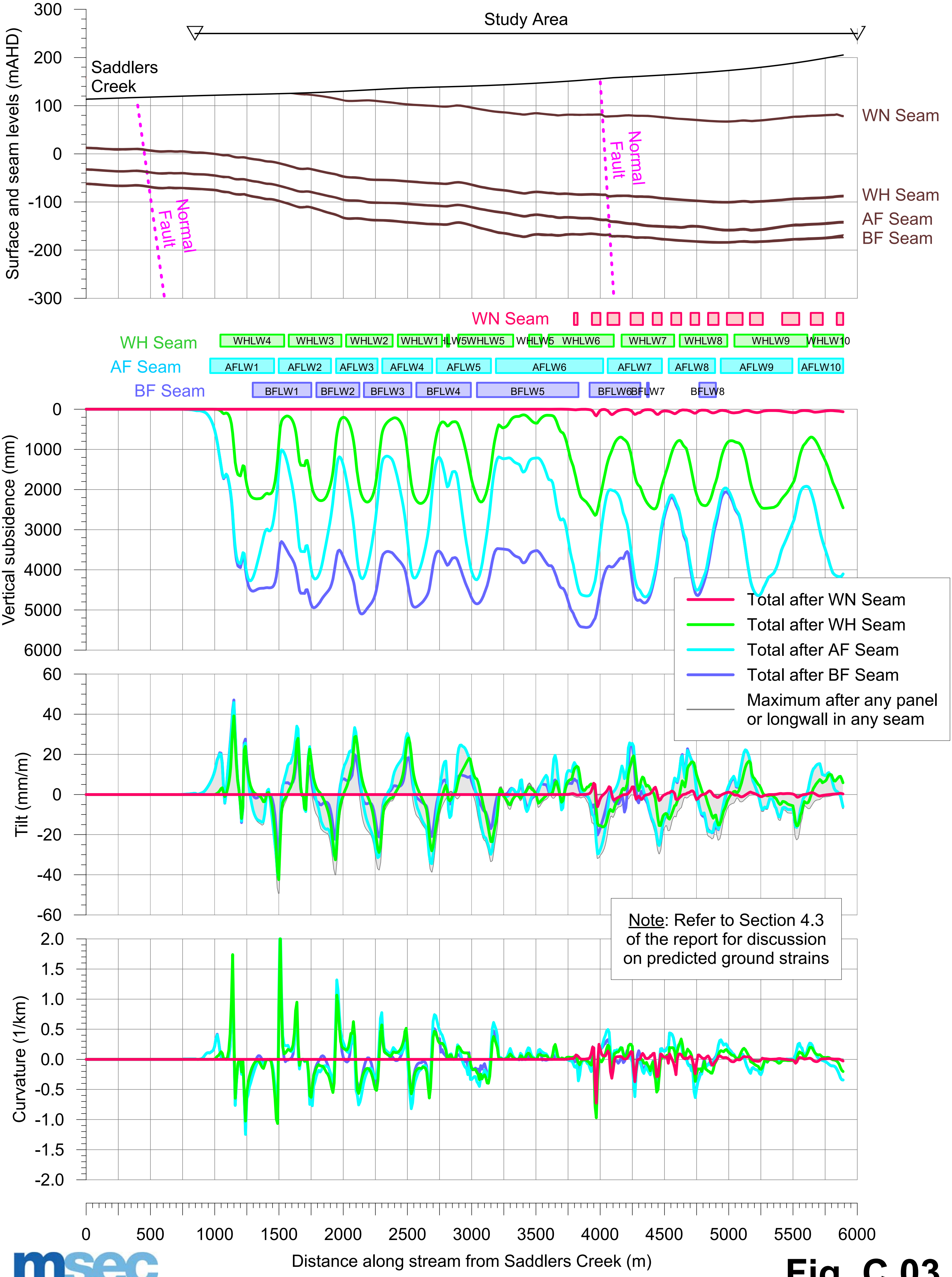
Note: Refer to Section 4.3 of the report for discussion on predicted ground strains

Fig. C.02

TOC

I:\Projects\Maxwell Project\MSEC986 - EIS Application\Subsdata\Impacts\Streams\Fig. C.03 - Drainage Line A.grf

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line A due to the extraction of the WN, WH, AF and BF Seams



Note: Refer to Section 4.3 of the report for discussion on predicted ground strains

Fig. C.03

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I:\Projects\Maxwell Project\MSEC986 - EIS Application\Subsdata\Impacts\Streams\Fig. C.04 - Drainage Line B.grf

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line B due to the extraction of the WN, WH, AF and BF Seams

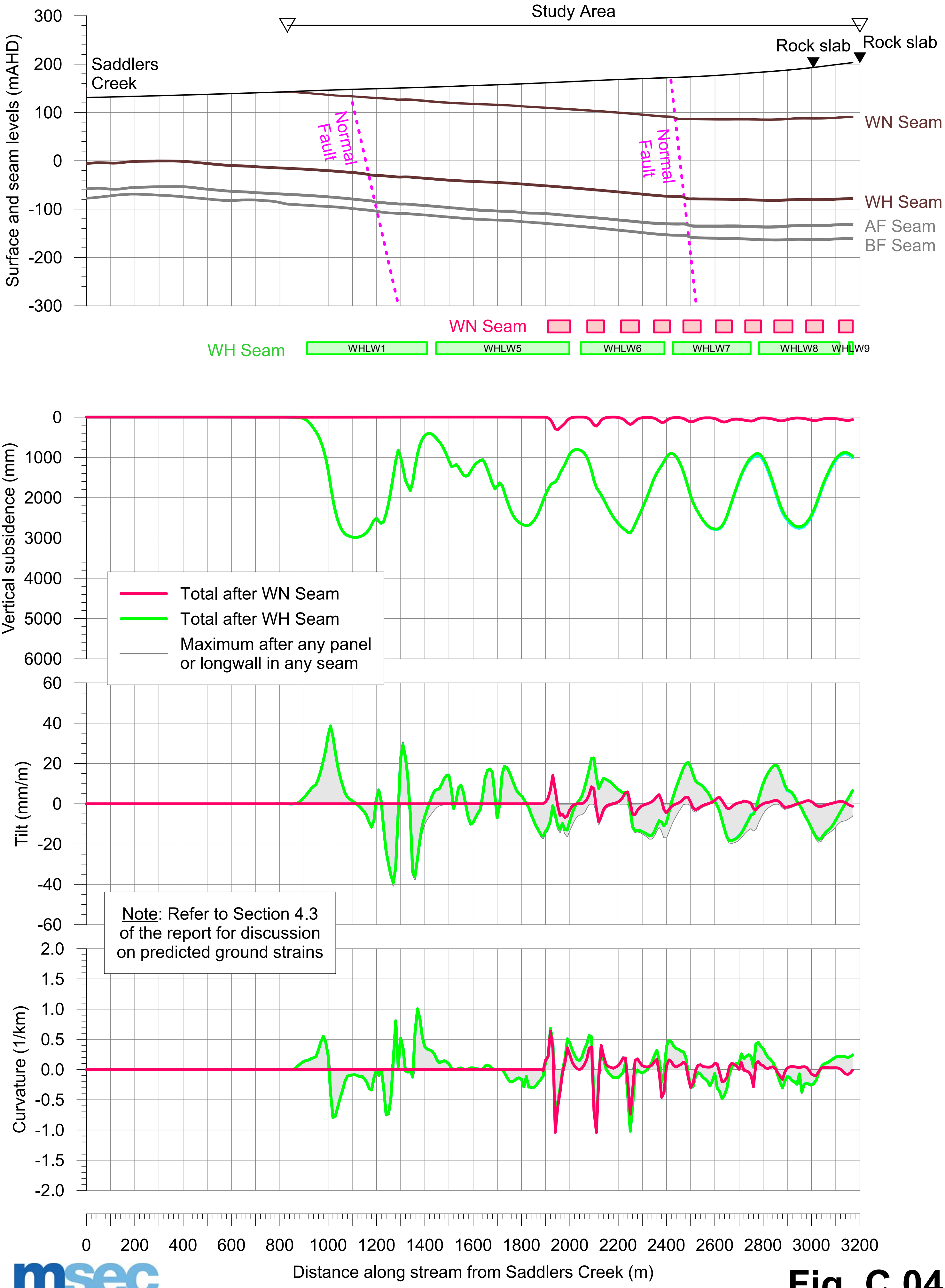

Fig. C.04

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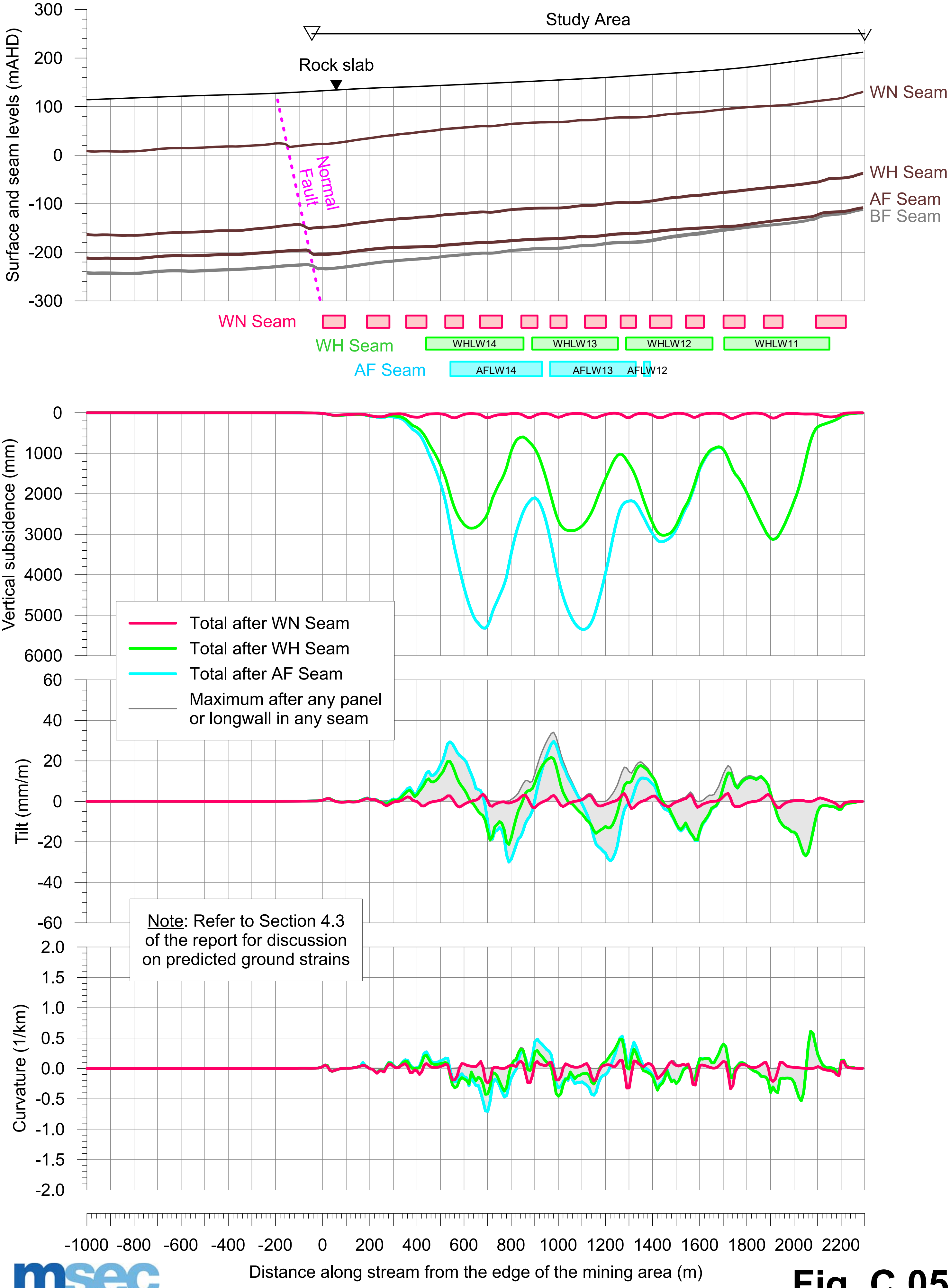
I:\Projects\Maxwell Project\MSEC986 - EIS Application\Subsdata\Impacts\Streams\Fig. C.05 - Drainage Line C.grf

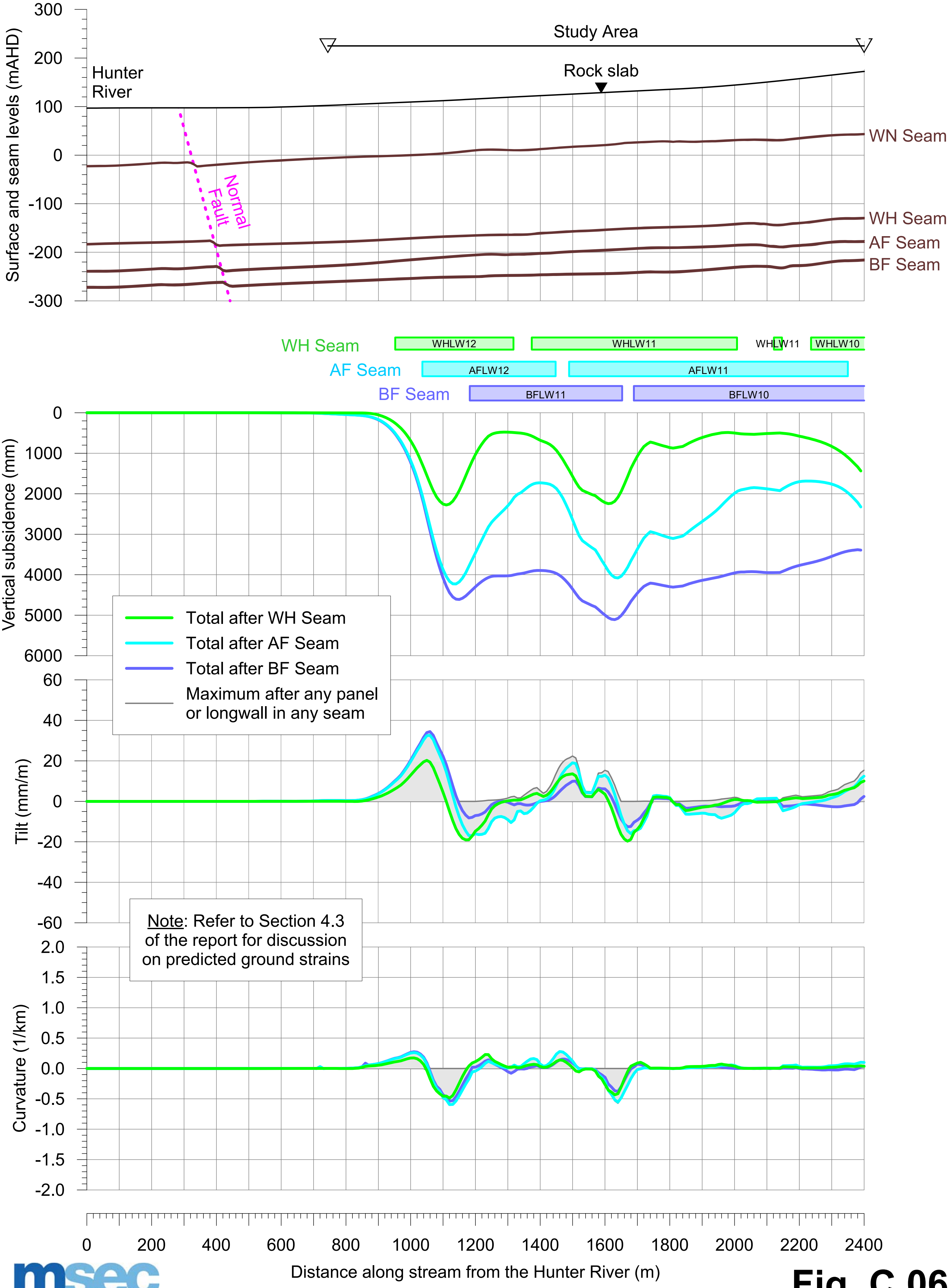
Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line C due to the extraction of the WN, WH, AF and BF Seams



Note: Refer to Section 4.3 of the report for discussion on predicted ground strains

Fig. C.05

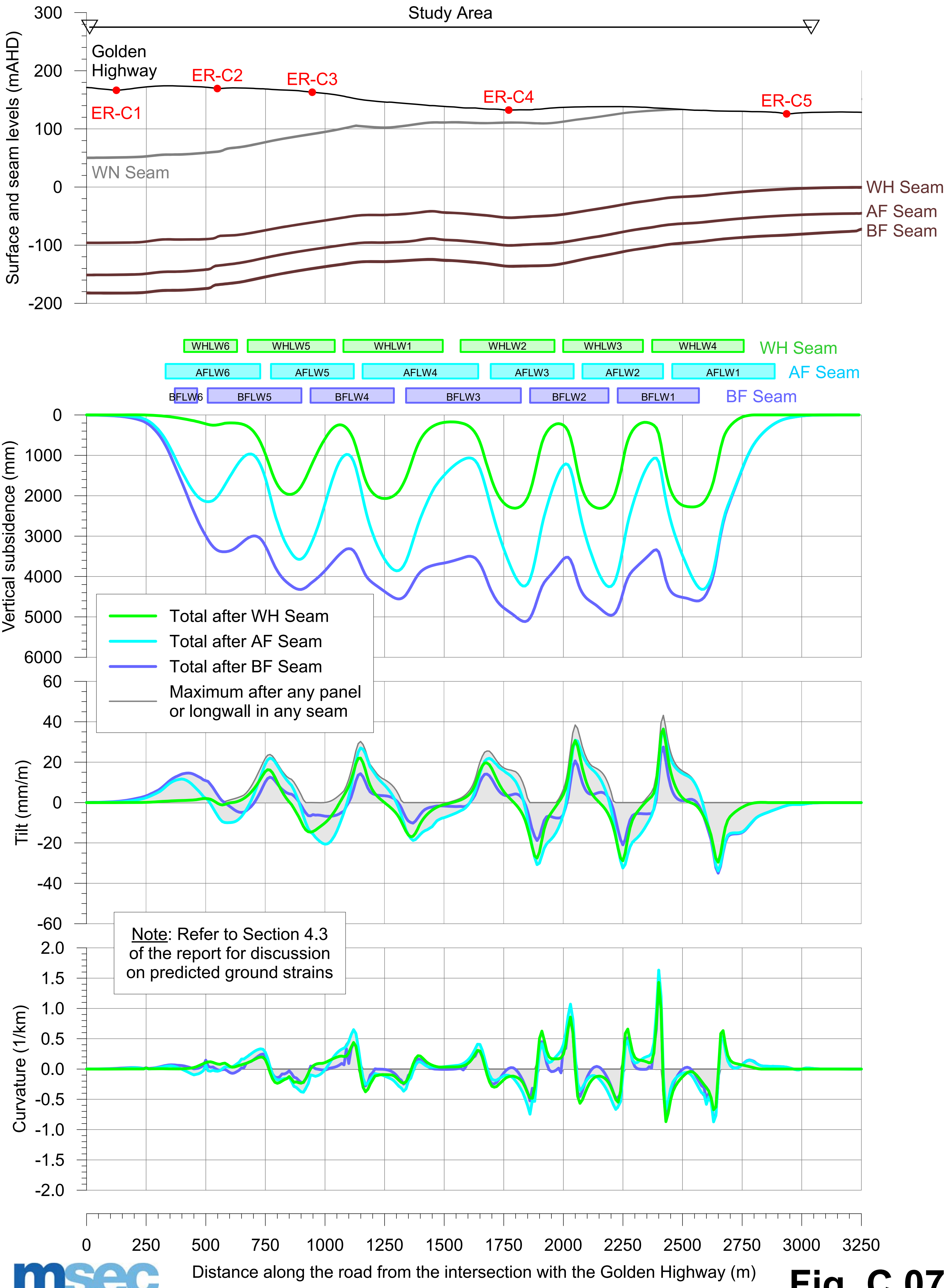
Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line E due to the extraction of the WN, WH, AF and BF Seams



Note: Refer to Section 4.3 of the report for discussion on predicted ground strains

Fig. C.06

Predicted profiles of vertical subsidence, tilt and curvature along Edderton Road due to the extraction of the WN, WH, AF and BF Seams



Note: Refer to Section 4.3 of the report for discussion on predicted ground strains

Fig. C.07

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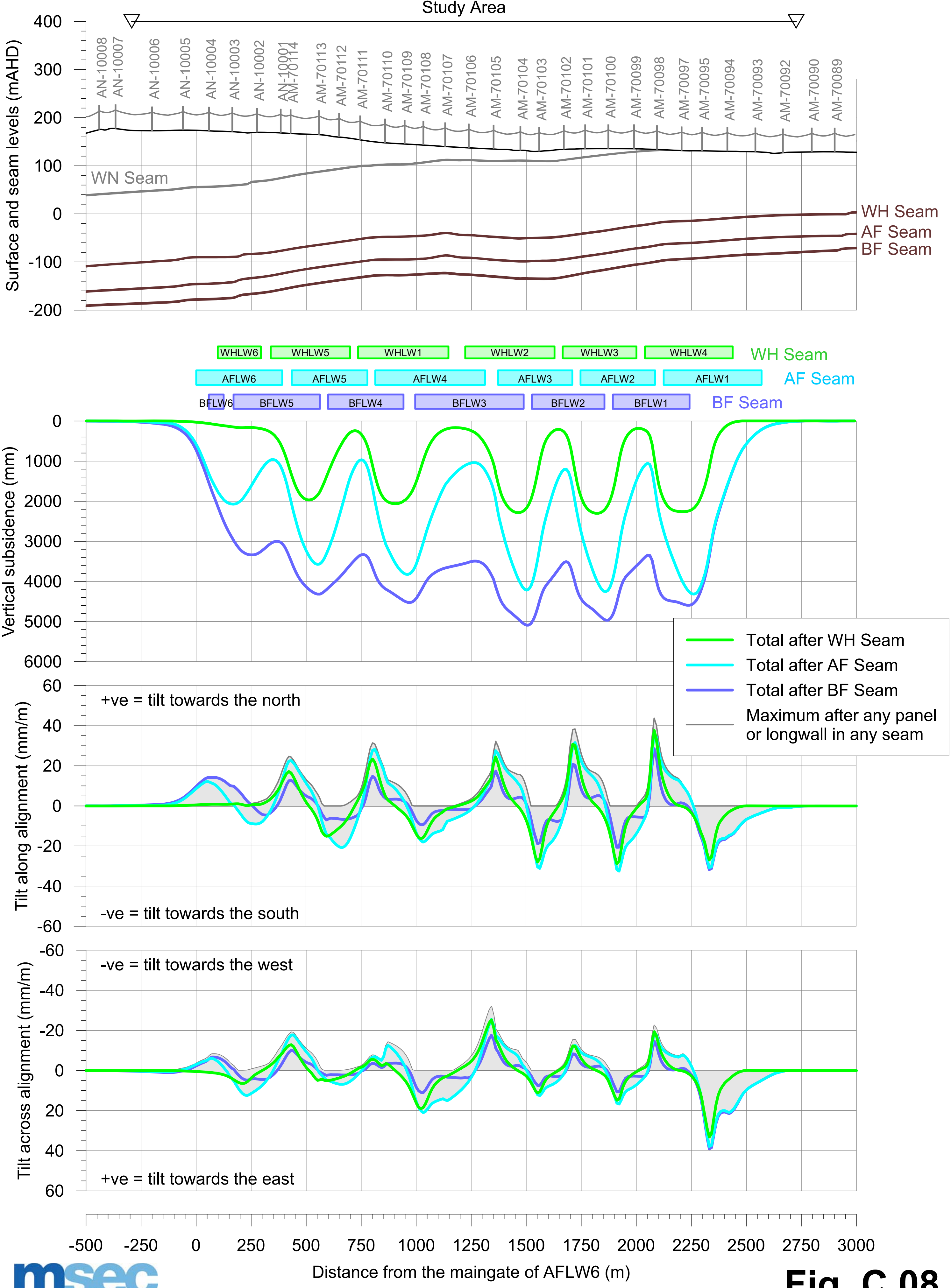
I:\Projects\Maxwell Project\MSEC986 - EIS Application\Subsdata\Impacts\Electrical\Fig. C.08 - 11 kV Powerline.grf

Predicted profiles of vertical subsidence, tilt along and tilt across the 11 kV powerline due to the extraction of the WN, WH, AF and BF Seams



msec

Fig. C.08

APPENDIX D. TABLES

Table D.01 - Details and maximum predicted subsidence effects for the Aboriginal heritage sites within the Study Area

AHIMS	Site type	Located above WN Seam mining area	Located above WH Seam mining area	Located above AF Seam mining area	Located above BF Seam mining area	Located outside of the mining areas	Maximum predicted total vertical subsidence after WN Seam (mm)	Maximum predicted total vertical subsidence after WH Seam (mm)	Maximum predicted total vertical subsidence after AF Seam (mm)	Maximum predicted total vertical subsidence after BF Seam (mm)	Maximum predicted total tilt after BF Seam (mm/m)	Maximum predicted total hogging curvature after BF Seam (1/km)	Maximum predicted total sagging curvature after BF Seam (1/km)
37-2-0004	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0006	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0053	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0069	Artefact Scatter		1	1			< 20	40	525	550	20	0.80	0.40
37-2-0073	Artefact Scatter		1	1	1		< 20	2550	4550	5250	30	1.60	1.30
37-2-0074	Artefact Scatter		1	1	1		< 20	2350	3800	4800	20	0.50	0.35
37-2-0075	Artefact Scatter		1	1	1		< 20	2050	3800	4500	16	0.80	0.60
37-2-0076	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0077	Artefact Scatter		1				< 20	225	225	225	7	0.35	0.03
37-2-0078	Artefact Scatter	1	1				175	2900	2900	2900	20	0.50	1.20
37-2-0080	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-0082	Artefact Scatter	1	1				125	2050	2050	2050	20	0.45	0.20
37-2-0089	Artefact Scatter	1					100	125	125	125	2.5	0.15	0.16
37-2-0090	Artefact Scatter	1					100	125	125	125	2.5	0.15	0.16
37-2-0289	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0362	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0363	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0364	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0365	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0366	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0367	Artefact Scatter		1	1	1		< 20	2300	4250	5100	25	1.10	0.70
37-2-0368	Artefact Scatter		1	1	1		< 20	2300	4250	5100	25	1.10	0.70
37-2-0369	Artefact Scatter		1	1	1		< 20	2050	3800	4500	16	0.80	0.60
37-2-0370	Artefact Scatter		1	1	1		< 20	2050	3800	4500	16	0.80	0.60
37-2-0371	Artefact Scatter		1	1	1		< 20	2050	3700	4400	25	0.45	0.35
37-2-0372	Artefact Scatter		1	1	1		< 20	2050	3700	4400	25	0.45	0.35
37-2-0373	Artefact Scatter		1	1	1		< 20	2050	3700	4400	25	0.45	0.35
37-2-0374	Artefact Scatter			1	1		< 20	70	375	500	13	0.30	< 0.01
37-2-0375	Artefact Scatter		1	1	1		< 20	1950	3600	4200	40	0.30	1.00
37-2-0376	Artefact Scatter		1	1	1		< 20	2050	3800	4500	16	0.80	0.60
37-2-0377	Artefact Scatter		1	1	1		< 20	2050	3650	4500	18	0.20	0.45
37-2-0378	Artefact Scatter		1	1	1		< 20	2050	3800	4500	16	0.80	0.60
37-2-0379	Artefact Scatter		1	1	1		< 20	2050	3800	4500	16	0.80	0.60
37-2-0380	Artefact Scatter		1	1	1		< 20	2300	4250	5100	25	1.10	0.70
37-2-0381	Artefact Scatter		1	1	1		< 20	2300	4250	5100	25	1.10	0.70
37-2-0382	Artefact Scatter		1	1	1		< 20	2300	4250	5100	25	1.10	0.70
37-2-0383	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-0396	Artefact Scatter					1	< 20	40	525	550	20	0.80	0.40
37-2-0397	Artefact Scatter		1	1	1		< 20	2550	4550	5250	30	1.60	1.30
37-2-0398	Artefact Scatter		1	1	1		< 20	2350	4200	4900	9	< 0.01	0.50
37-2-0399	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-0400	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-0401	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90

Table D.01 - Details and maximum predicted subsidence effects for the Aboriginal heritage sites within the Study Area

AHIMS	Site type	Located above WN Seam mining area	Located above WH Seam mining area	Located above AF Seam mining area	Located above BF Seam mining area	Located outside of the mining areas	Maximum predicted total vertical subsidence after WN Seam (mm)	Maximum predicted total vertical subsidence after WH Seam (mm)	Maximum predicted total vertical subsidence after AF Seam (mm)	Maximum predicted total vertical subsidence after BF Seam (mm)	Maximum predicted total tilt after BF Seam (mm/m)	Maximum predicted total hogging curvature after BF Seam (1/km)	Maximum predicted total sagging curvature after BF Seam (1/km)
37-2-0402	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-0403	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-0404	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-0405	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-0406	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-0407	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-0408	Artefact Scatter		1	1	1		< 20	2300	4100	5000	17	0.25	0.45
37-2-0409	Artefact Scatter	1	1				175	2900	2900	2900	20	0.50	1.20
37-2-0410	Artefact Scatter		1				< 20	2750	2750	2750	40	1.10	0.50
37-2-0411	Artefact Scatter		1				< 20	175	175	175	7.5	0.40	0.12
37-2-0412	Artefact Scatter		1				< 20	175	175	175	7.5	0.40	0.12
37-2-0413	Artefact Scatter					1	< 20	1350	1350	1350	50	1.70	0.70
37-2-0414	Artefact Scatter		1				< 20	1350	1350	1350	50	1.70	0.70
37-2-0415	Artefact Scatter		1				< 20	1350	1350	1350	50	1.70	0.70
37-2-0416	Artefact Scatter	1	1				275	3100	3100	3100	30	2.00	1.70
37-2-0417	Artefact Scatter					1	< 20	175	175	175	7.5	0.40	0.12
37-2-0418	Artefact Scatter with PAD	1	1				125	3050	3050	3050	40	0.60	0.80
37-2-0419	Artefact Scatter with PAD	1	1				125	3050	3050	3050	40	0.60	0.80
37-2-0505	Artefact Scatter		1	1	1		< 20	2350	4300	5000	50	2.00	1.70
37-2-1923	Artefact Scatter		1	1	1		< 20	2150	3950	4800	15	0.20	0.45
37-2-1928	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-1929	Artefact Scatter		1	1	1		< 20	1400	2400	3900	13	0.20	< 0.01
37-2-1930	Artefact Scatter		1	1	1		< 20	2250	4200	5150	20	0.40	0.50
37-2-1931	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1932	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1933	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1934	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1935	Artefact Scatter		1				< 20	1350	1350	1350	50	1.70	0.70
37-2-1936	Artefact Scatter		1	1	1		< 20	2550	4550	5250	30	1.60	1.30
37-2-1937	Artefact Scatter		1				< 20	1350	1350	1350	50	1.70	0.70
37-2-1938	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1939	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1940	Artefact Scatter	1	1	1			125	3000	4650	4650	35	0.40	0.70
37-2-1941	Artefact Scatter		1	1	1		< 20	2250	4100	5100	14	0.25	0.45
37-2-1942	Artefact Scatter	1	1	1			80	1950	3400	3400	20	0.45	0.06
37-2-1943	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-1946	Artefact Scatter		1				< 20	1350	1350	1350	50	1.70	0.70
37-2-1947	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1954	Stone Quarry					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1955	Stone Quarry					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1956	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1957	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-1960	Artefact Scatter		1	1	1		< 20	2150	3950	4800	15	0.20	0.45

Table D.01 - Details and maximum predicted subsidence effects for the Aboriginal heritage sites within the Study Area

AHIMS	Site type	Located above WN Seam mining area	Located above WH Seam mining area	Located above AF Seam mining area	Located above BF Seam mining area	Located outside of the mining areas	Maximum predicted total vertical subsidence after WN Seam (mm)	Maximum predicted total vertical subsidence after WH Seam (mm)	Maximum predicted total vertical subsidence after AF Seam (mm)	Maximum predicted total vertical subsidence after BF Seam (mm)	Maximum predicted total tilt after BF Seam (mm/m)	Maximum predicted total hogging curvature after BF Seam (1/km)	Maximum predicted total sagging curvature after BF Seam (1/km)
37-2-1961	Artefact Scatter		1	1	1		< 20	750	2350	3550	4.5	0.15	< 0.01
37-2-1986	Artefact Scatter		1				< 20	2750	2750	2750	40	1.10	0.50
37-2-2035	Artefact Scatter		1	1	1		< 20	750	2350	3550	4.5	0.15	< 0.01
37-2-2329	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-2330	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4226	Artefact Scatter		1	1	1		< 20	175	525	625	19	0.45	0.04
37-2-4227	Artefact Scatter			1	1		< 20	30	300	800	20	0.50	0.02
37-2-4228	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	0.02	< 0.01
37-2-4234	Artefact Scatter		1	1	1		< 20	2150	3900	4500	20	< 0.01	0.60
37-2-4235	Artefact Scatter		1	1	1		< 20	925	2750	4100	25	1.20	0.05
37-2-4236	Artefact Scatter		1	1	1		< 20	2050	3900	4650	18	0.60	0.60
37-2-4237	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4239	Artefact Scatter		1	1	1		< 20	2400	4300	4950	20	0.60	0.35
37-2-4240	Artefact Scatter		1	1	1		< 20	2400	4250	4950	20	0.70	0.45
37-2-4241	Artefact Scatter		1		1		< 20	2500	2550	4100	15	0.12	1.10
37-2-4242	Artefact Scatter		1				< 20	125	125	150	7.5	0.25	< 0.01
37-2-4243	Artefact Scatter		1		1		< 20	2600	2650	3650	45	0.06	1.30
37-2-4245	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4246	Artefact Scatter		1	1	1		< 20	2600	4350	4500	50	1.60	2.00
37-2-4247	Artefact Scatter	1	1	1	1		250	2650	4650	4800	45	0.90	1.10
37-2-4248	Artefact Scatter	1	1	1	1		275	2600	4600	5250	40	0.70	1.10
37-2-4249	Artefact Scatter	1	1	1	1		30	1900	4300	4800	16	0.25	0.30
37-2-4250	Artefact Scatter	1	1	1	1		175	2600	4750	5050	25	0.60	1.50
37-2-4251	Artefact Scatter	1	1	1	1		175	2600	4750	5050	25	0.60	1.50
37-2-4252	Artefact Scatter		1	1	1		< 20	2250	3450	4700	20	0.60	0.60
37-2-4253	Artefact Scatter		1	1	1		< 20	1850	4050	4800	16	0.25	0.40
37-2-4254	Artefact Scatter		1	1	1		< 20	2250	4100	4900	20	0.40	0.45
37-2-4255	Artefact Scatter		1	1	1		< 20	2000	3600	4400	13	0.10	0.40
37-2-4256	Artefact Scatter		1	1	1		< 20	2250	4050	4900	17	0.30	0.50
37-2-4257	Artefact Scatter		1	1	1		< 20	1250	3300	4000	12	0.25	0.08
37-2-4258	Artefact Scatter		1	1	1		< 20	1100	1800	3400	25	0.30	0.15
37-2-4259	Artefact Scatter					1	< 20	< 20	90	90	2	0.09	< 0.01
37-2-4260	Artefact Scatter		1	1	1		< 20	2250	4100	5100	14	0.25	0.45
37-2-4262	Artefact Scatter					1	< 20	40	60	60	1	0.04	< 0.01
37-2-4264	Artefact Scatter	1	1				100	1350	1800	1800	25	0.30	0.13
37-2-4265	Artefact Scatter	1	1	1	1		125	2200	3400	4700	14	0.30	0.09
37-2-4266	Artefact Scatter		1	1	1		< 20	2250	4050	4950	16	0.25	0.45
37-2-4267	Artefact Scatter	1	1	1			70	2550	4500	4500	25	0.45	0.50
37-2-4268	Artefact Scatter	1	1	1			70	2550	4400	4400	25	0.25	0.50
37-2-4269	Artefact Scatter	1	1				90	2550	2650	2650	11	0.13	0.35
37-2-4270	Artefact Scatter	1	1	1			80	1450	3500	3500	25	0.35	0.13
37-2-4271	Artefact Scatter	1	1				90	1750	1750	1750	18	0.45	< 0.01
37-2-4272	Artefact Scatter	1	1				90	1900	1900	1900	20	0.45	< 0.01

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AHIMS	Site type	Located above WN Seam mining area	Located above WH Seam mining area	Located above AF Seam mining area	Located above BF Seam mining area	Located outside of the mining areas	Maximum predicted total vertical subsidence after WN Seam (mm)	Maximum predicted total vertical subsidence after WH Seam (mm)	Maximum predicted total vertical subsidence after AF Seam (mm)	Maximum predicted total vertical subsidence after BF Seam (mm)	Maximum predicted total tilt after BF Seam (mm/m)	Maximum predicted total hogging curvature after BF Seam (1/km)	Maximum predicted total sagging curvature after BF Seam (1/km)
37-2-4274	Artefact Scatter	1	1	1			125	2000	2900	2900	25	0.60	0.20
37-2-4275	Artefact Scatter	1	1	1			125	2500	2750	2750	17	0.35	0.25
37-2-4276	Artefact Scatter	1	1				80	2450	2550	2550	15	0.35	0.40
37-2-4277	Artefact Scatter		1				< 20	650	650	650	16	0.35	< 0.01
37-2-4278	Artefact Scatter	1	1				200	2650	2650	2650	19	0.35	0.90
37-2-4279	Artefact Scatter	1	1				70	2000	2000	2000	15	0.30	0.11
37-2-4280	Artefact Scatter	1	1				250	2400	2400	2400	25	0.70	1.20
37-2-4281	Artefact Scatter		1				< 20	2700	2700	2700	35	0.60	0.70
37-2-4282	Artefact Scatter		1				< 20	2700	2700	2700	35	0.70	0.80
37-2-4283	Artefact Scatter		1				< 20	2750	2750	2750	50	1.40	1.70
37-2-4284	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4285	Artefact Scatter					1	< 20	50	50	50	3.5	0.14	< 0.01
37-2-4286	Artefact Scatter	1	1				< 20	2800	2800	2800	35	0.90	0.70
37-2-4287	Artefact Scatter	1	1				275	2850	2850	2850	30	1.20	1.20
37-2-4288	Artefact Scatter	1	1				325	2800	2800	2800	30	1.30	1.60
37-2-4290	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4291	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4292	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4293	Artefact Scatter		1				< 20	2900	2900	2900	40	0.90	0.80
37-2-4294	Artefact Scatter		1				< 20	3000	3000	3000	40	1.10	0.90
37-2-4296	Artefact Scatter		1				< 20	2900	2900	2900	35	0.60	0.70
37-2-4297	Artefact Scatter	1	1				125	2850	2850	2850	30	2.00	0.60
37-2-4298	Artefact Scatter		1				< 20	2950	2950	2950	40	0.45	1.30
37-2-4299	Artefact Scatter	1	1				175	3050	3050	3050	20	0.25	0.90
37-2-4300	Artefact Scatter		1				< 20	425	425	425	16	0.90	0.04
37-2-4301	Artefact Scatter	1	1				125	2000	2000	2000	20	0.45	0.35
37-2-4302	Artefact Scatter	1	1				200	2800	2800	2800	20	0.20	1.30
37-2-4303	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4307	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4310	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4311	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4312	Artefact Scatter	1	1				175	3100	3100	3100	25	0.12	1.20
37-2-4313	Artefact Scatter					1	< 20	90	90	90	2	0.06	< 0.01
37-2-4317	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4318	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4327	Isolated Find					1	< 20	< 20	60	60	2.5	0.08	0.03
37-2-4328	Isolated Find					1	< 20	< 20	< 20	< 20	0.5	0.03	< 0.01
37-2-4329	Isolated Find		1	1	1		< 20	2200	4250	4550	50	1.50	1.60
37-2-4330	Isolated Find		1	1	1		< 20	750	2400	2650	40	0.80	0.35
37-2-4331	Isolated Find			1			< 20	50	300	375	8.5	0.25	0.02
37-2-4332	Isolated Find					1	< 20	< 20	< 20	30	0.5	0.01	< 0.01
37-2-4333	Isolated Find		1	1	1		< 20	900	2050	4000	17	0.80	0.07
37-2-4334	Isolated Find		1	1	1		< 20	450	1550	1650	30	1.70	0.80

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37-2-4335	Isolated Find	1	1	1	1		150	2450	4600	5150	17	0.30	1.20
37-2-4336	Isolated Find	1	1	1	1		100	2000	4400	5350	17	0.20	0.25
37-2-4337	Isolated Find		1	1	1		< 20	2200	4300	4950	11	0.08	0.35
37-2-4338	Isolated Find		1	1	1		< 20	2100	3500	4500	19	0.35	0.35
37-2-4339	Isolated Find		1	1	1		< 20	1900	3550	4400	15	0.12	0.50
37-2-4340	Isolated Find		1	1	1		< 20	425	2050	2950	25	0.25	0.25
37-2-4341	Isolated Find		1	1	1		< 20	700	2400	3800	4.5	0.25	0.08
37-2-4342	Isolated Find		1	1	1		< 20	1150	2900	3950	9.5	0.25	< 0.01
37-2-4343	Isolated Find					1	< 20	30	80	80	1.5	0.02	< 0.01
37-2-4344	Isolated Find	1	1	1	1		40	1550	3800	4400	20	0.25	0.15
37-2-4345	Isolated Find	1	1	1	1		< 20	2150	3950	4750	14	0.14	0.40
37-2-4346	Isolated Find		1	1	1		< 20	2150	3500	4550	17	0.30	0.17
37-2-4347	Isolated Find	1	1	1			70	2500	4600	4600	20	< 0.01	0.50
37-2-4348	Isolated Find	1	1	1			70	2450	2950	2950	17	0.30	0.25
37-2-4349	Isolated Find	1	1	1			70	2450	4150	4150	25	0.30	0.50
37-2-4350	Isolated Find	1	1				100	2750	2750	2750	16	< 0.01	0.40
37-2-4351	Isolated Find	1	1				175	2900	2900	2900	15	0.45	1.00
37-2-4352	Isolated Find	1	1				125	2550	2550	2550	16	0.35	0.70
37-2-4353	Isolated Find	1	1				150	2100	2100	2100	20	0.35	0.50
37-2-4354	Isolated Find	1	1				125	2400	2400	2400	16	0.30	0.30
37-2-4355	Isolated Find		1				< 20	2750	2750	2750	30	0.40	0.60
37-2-4356	Isolated Find		1				< 20	2850	2850	2850	50	2.00	2.00
37-2-4357	Isolated Find	1	1				200	2350	2350	2350	25	0.60	0.80
37-2-4358	Isolated Find		1				< 20	1050	1050	1050	30	0.90	< 0.01
37-2-4359	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4361	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4362	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4364	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4367	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4370	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4371	Isolated Find	1	1				80	1850	1850	1850	20	0.40	0.08
37-2-4372	Isolated Find	1	1				80	2950	2950	2950	18	< 0.01	0.50
37-2-4373	Isolated Find	1	1	1			125	425	2150	2150	30	0.40	0.45
37-2-4376	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4377	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4378	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4379	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4426	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4427	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-4428	Isolated Find		1		1		< 20	2550	2550	3650	30	0.07	1.00
37-2-4432	Artefact Scatter	1	1	1	1		175	2600	4750	5050	25	0.60	1.50
37-2-4512	Artefact Scatter					1	< 20	20	30	30	1	0.06	< 0.01
37-2-4536	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01

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37-2-4537	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5002	Artefact Scatter		1	1			< 20	1550	2450	2450	35	0.35	< 0.01
37-2-5003	Artefact Scatter		1	1			< 20	2450	4100	4100	35	0.35	0.50
37-2-5004	Artefact Scatter		1	1			< 20	2200	4400	4400	20	0.20	0.40
37-2-5005	Artefact Scatter		1	1	1		< 20	1000	2550	3000	16	0.35	0.03
37-2-5006	Artefact Scatter		1	1	1		< 20	2400	4150	4550	20	0.11	0.60
37-2-5007	Artefact Scatter	1	1	1	1		175	2650	4800	5450	30	0.60	0.90
37-2-5008	Artefact Scatter		1	1	1		< 20	1950	3350	3650	30	0.25	0.45
37-2-5014	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5016	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5022	Isolated Find					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5023	Isolated Find					1	< 20	< 20	30	30	0.5	0.05	< 0.01
37-2-5024	Isolated Find		1	1			< 20	2350	4550	4550	20	0.09	0.70
37-2-5035	Isolated Find		1	1			< 20	1650	4050	4050	20	0.25	0.25
37-2-5036	Isolated Find		1	1			< 20	900	3050	3050	20	0.35	< 0.01
37-2-5043	Artefact Scatter	1	1	1			70	2500	4650	4650	25	0.45	0.70
37-2-5469	Artefact Scatter		1	1	1		< 20	2050	3700	4400	25	0.45	0.35
37-2-5470	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5787	Isolated Artefact					1	< 20	30	125	175	2.5	0.03	< 0.01
37-2-5840	Artefact Scatter					1	< 20	< 20	60	60	1	0.04	< 0.01
37-2-5841	Artefact Scatter					1	< 20	< 20	50	50	1	0.02	< 0.01
37-2-5842	Artefact Scatter					1	< 20	< 20	90	90	2.5	0.10	< 0.01
37-2-5843	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5844	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5845	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5846	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5847	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5848	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5849	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5850	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5851	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5852	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5853	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5854	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5861	Isolated Artefact		1	1	1		< 20	70	1450	1650	25	0.50	0.25
37-2-5862	Artefact Scatter	1	1	1			80	2500	4550	4550	25	0.45	0.45
37-2-5863	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5864	Artefact Scatter	1	1	1			70	2500	4250	4250	20	0.35	0.45
37-2-5865	Artefact Scatter	1	1	1			70	2500	4350	4350	20	0.50	0.60
37-2-5866	Artefact Scatter	1	1	1			60	2300	4000	4000	19	0.45	0.45
37-2-5867	Artefact Scatter	1	1	1			80	2400	3950	3950	20	0.40	0.25
37-2-5868	Isolated Artefact	1	1	1			80	1300	3300	3300	20	0.40	< 0.01
37-2-5869	Artefact Scatter		1	1			< 20	850	3100	3150	20	0.35	< 0.01

Table D.01 - Details and maximum predicted subsidence effects for the Aboriginal heritage sites within the Study Area

AHIMS	Site type	Located above WN Seam mining area	Located above WH Seam mining area	Located above AF Seam mining area	Located above BF Seam mining area	Located outside of the mining areas	Maximum predicted total vertical subsidence after WN Seam (mm)	Maximum predicted total vertical subsidence after WH Seam (mm)	Maximum predicted total vertical subsidence after AF Seam (mm)	Maximum predicted total vertical subsidence after BF Seam (mm)	Maximum predicted total tilt after BF Seam (mm/m)	Maximum predicted total hogging curvature after BF Seam (1/km)	Maximum predicted total sagging curvature after BF Seam (1/km)
37-2-5870	Artefact Scatter	1	1	1			70	2500	4550	4550	20	0.25	0.40
37-2-5871	Artefact Scatter		1	1	1		< 20	2400	4250	5300	25	0.30	0.60
37-2-5872	Artefact Scatter		1	1			< 20	1600	3600	3600	35	0.50	0.50
37-2-5873	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5874	Artefact Scatter		1	1	1		< 20	2300	4250	4600	35	0.30	0.60
37-2-5875	Artefact Scatter		1	1	1		< 20	2350	4200	5300	18	0.25	0.45
37-2-5876	Artefact Scatter		1	1	1		< 20	2100	4000	4950	30	0.20	0.50
37-2-5877	Artefact Scatter		1	1	1		< 20	450	850	2350	18	0.17	0.08
37-2-5878	Artefact Scatter					1	< 20	< 20	30	40	1	0.01	< 0.01
37-2-5879	Artefact Scatter					1	< 20	20	70	125	2.5	0.04	< 0.01
37-2-5880	Artefact Scatter			1			< 20	90	325	425	6.5	0.14	0.01
37-2-5881	Artefact Scatter		1	1	1		< 20	2050	3800	4850	20	0.25	0.45
37-2-5882	Artefact Scatter			1			< 20	< 20	100	150	3	0.08	< 0.01
37-2-5883	Isolated Artefact					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5884	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5885	Artefact Scatter					1	< 20	< 20	< 20	20	1	0.03	< 0.01
37-2-5886	Isolated Artefact	1	1	1			60	1550	2700	2700	19	0.40	0.03
37-2-5887	Isolated Artefact	1	1	1			70	2500	4450	4450	17	< 0.01	0.40
37-2-5888	Isolated Artefact		1	1			< 20	2150	3950	3950	18	< 0.01	0.60
37-2-5889	Isolated Artefact		1	1			< 20	500	1350	1350	25	0.20	0.02
37-2-5890	Isolated Artefact		1	1			< 20	2350	4200	4550	30	0.35	0.60
37-2-5891	Isolated Artefact					1	< 20	< 20	100	100	2	0.03	< 0.01
37-2-5892	Isolated Artefact		1	1			< 20	1050	1800	1800	25	0.35	0.18
37-2-5893	Isolated Artefact		1	1	1		< 20	925	2350	4000	4.5	0.15	0.02
37-2-5894	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
37-2-5895	Isolated Artefact					1	< 20	< 20	40	50	1	0.01	< 0.01
37-2-5896	Isolated Artefact		1	1	1		< 20	1650	3300	3650	30	0.25	0.45
37-2-5897	Isolated Artefact		1	1	1		< 20	100	1150	1550	20	0.30	0.07
37-2-5898	Artefact Scatter					1	< 20	< 20	< 20	< 20	< 0.5	< 0.01	< 0.01
						Maximum	**325**	**3100**	**4800**	**5450**	**50**	**2.00**	**2.00**

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APPENDIX E. DRAWINGS

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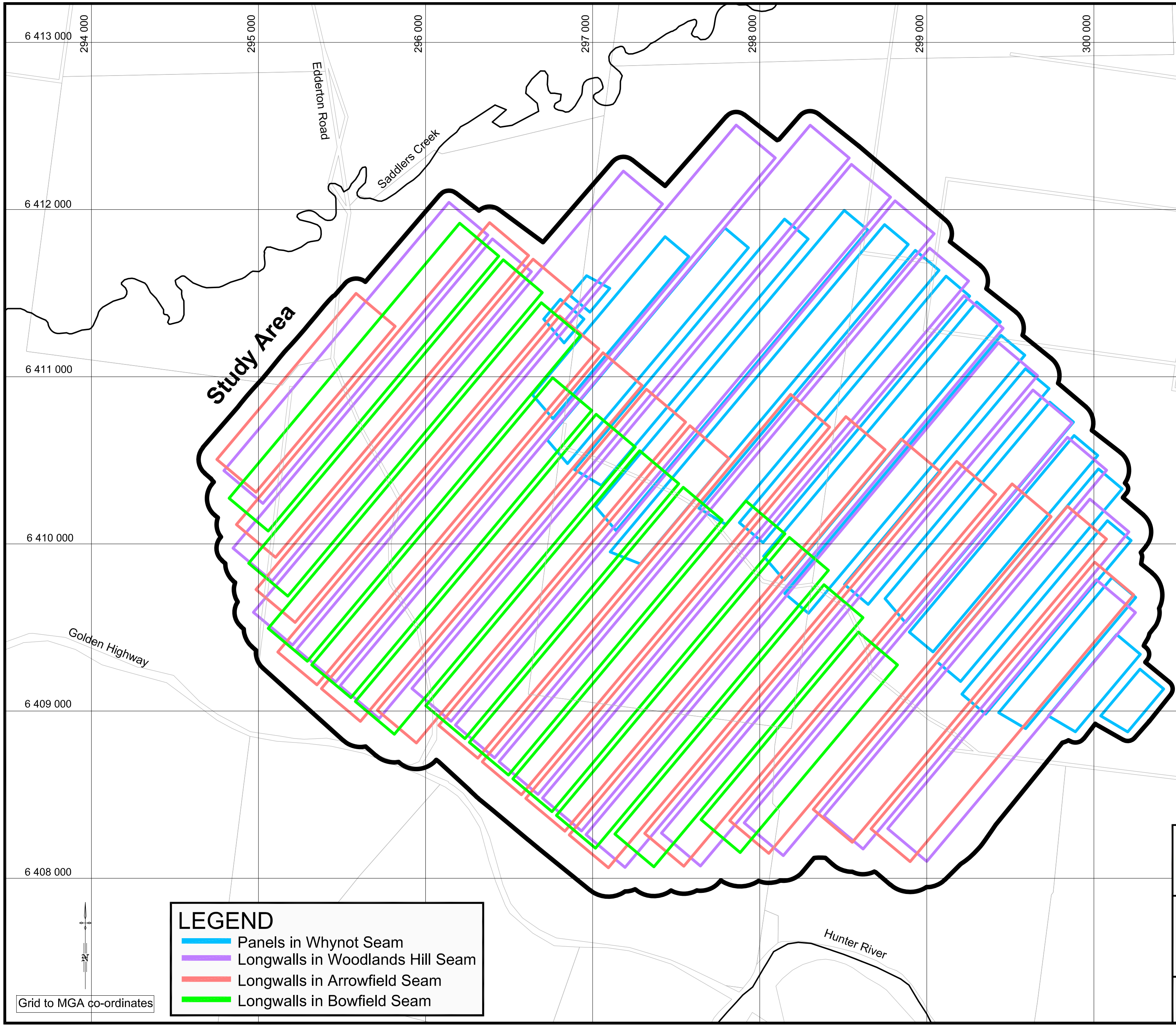

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MAXWELL PROJECT

GENERAL LAYOUT

DATE:	SCALE:	DRAWING No:	Rev No
9 Jul 2019	as shown	MSEC986-01	A

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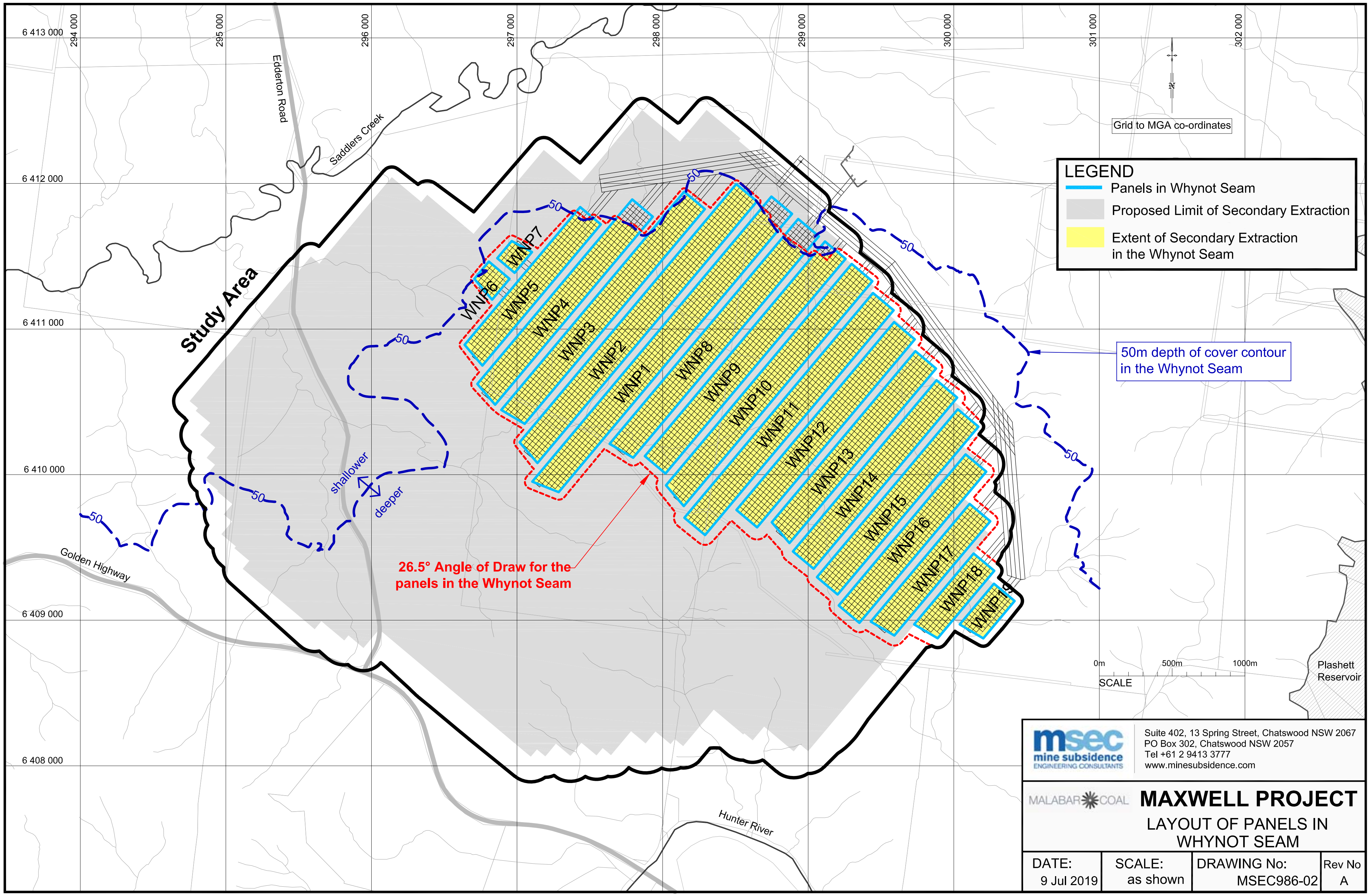

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LAYOUT OF PANELS IN WHYNOT SEAM

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9 Jul 2019	as shown	MSEC986-02	A

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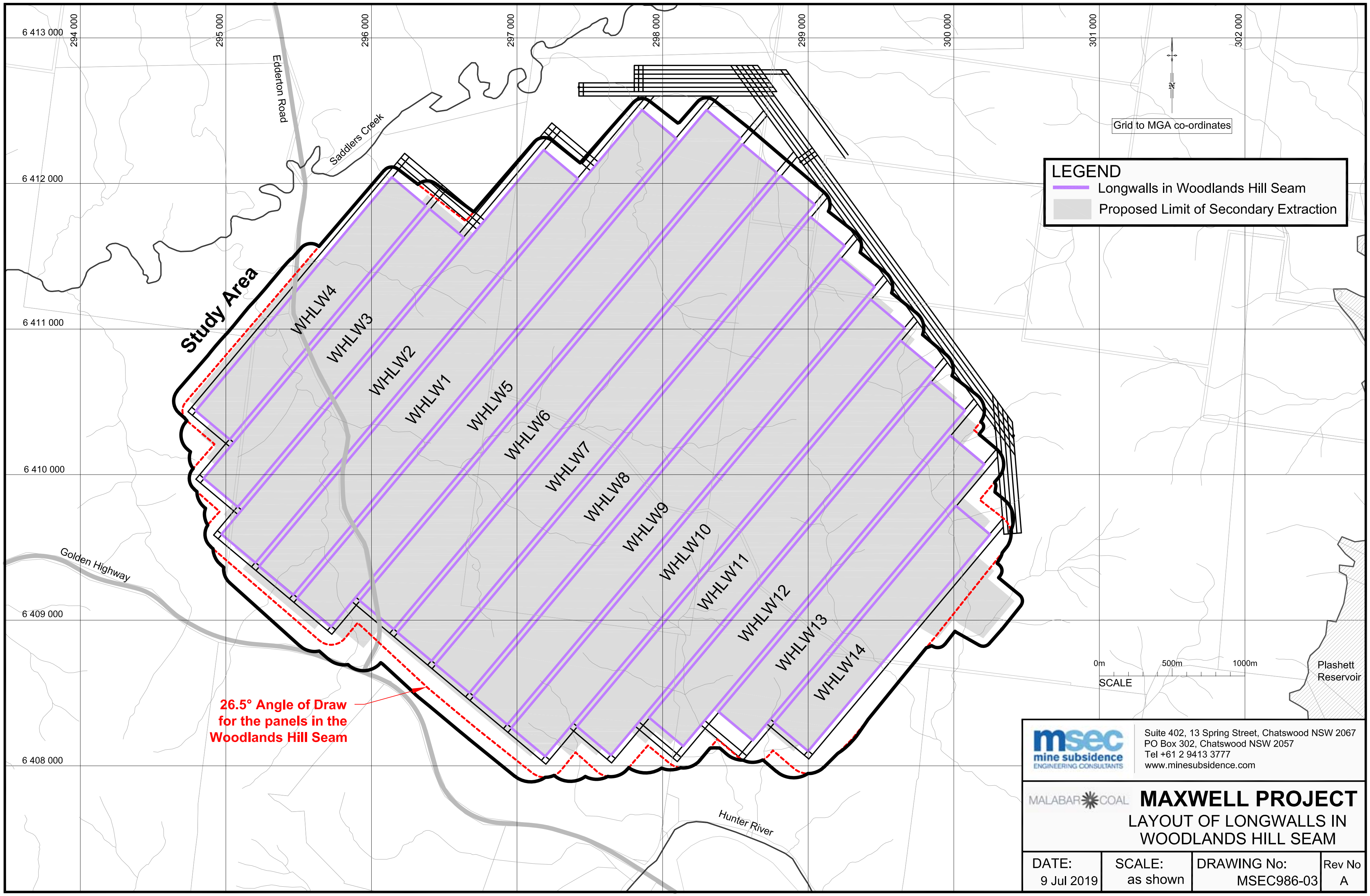

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LAYOUT OF LONGWALLS IN WOODLANDS HILL SEAM

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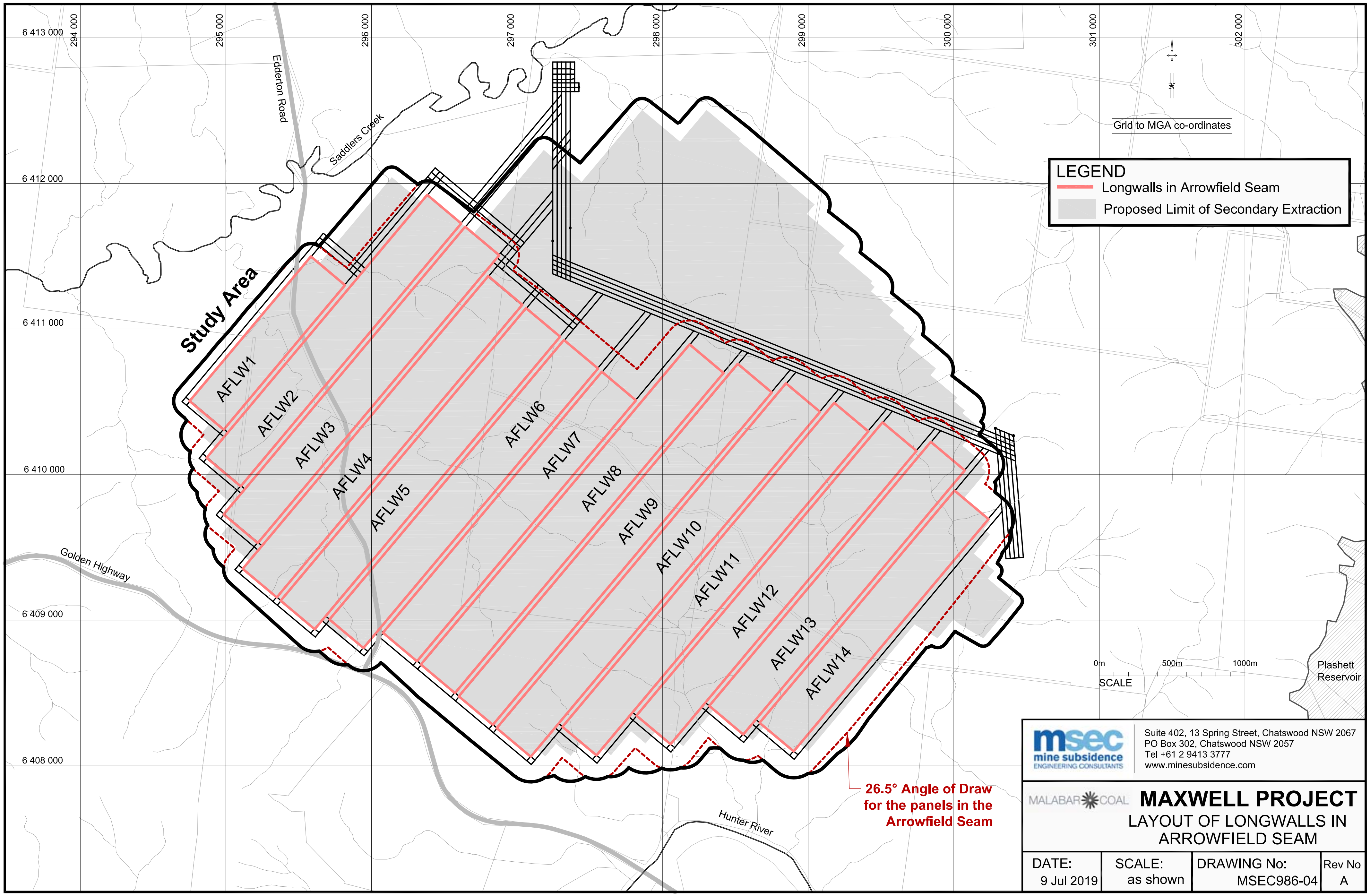

26.5° Angle of Draw for the panels in the Arrowfield Seam

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LAYOUT OF LONGWALLS IN ARROWFIELD SEAM

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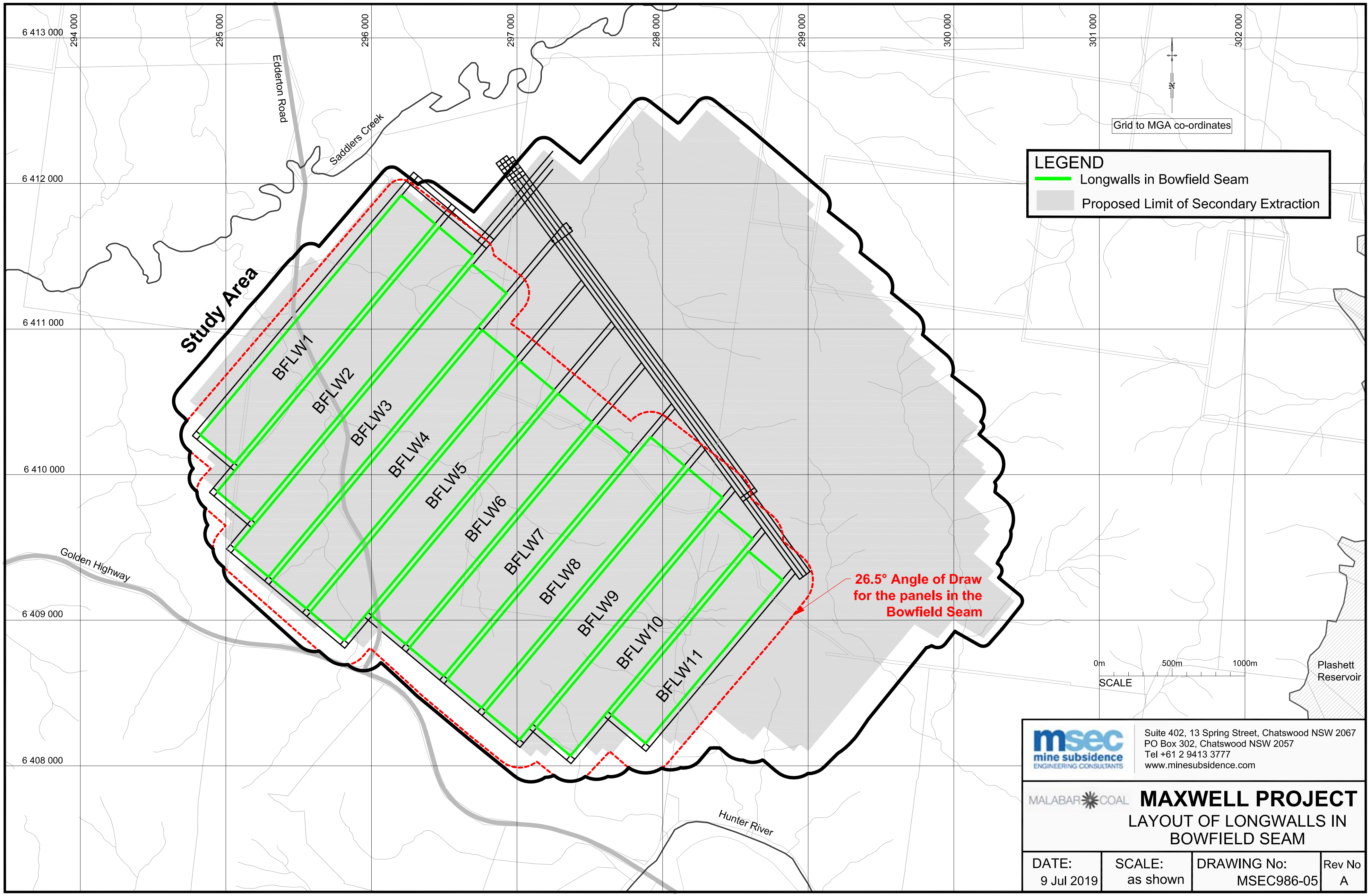

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LAYOUT OF LONGWALLS IN
BOWFIELD SEAM

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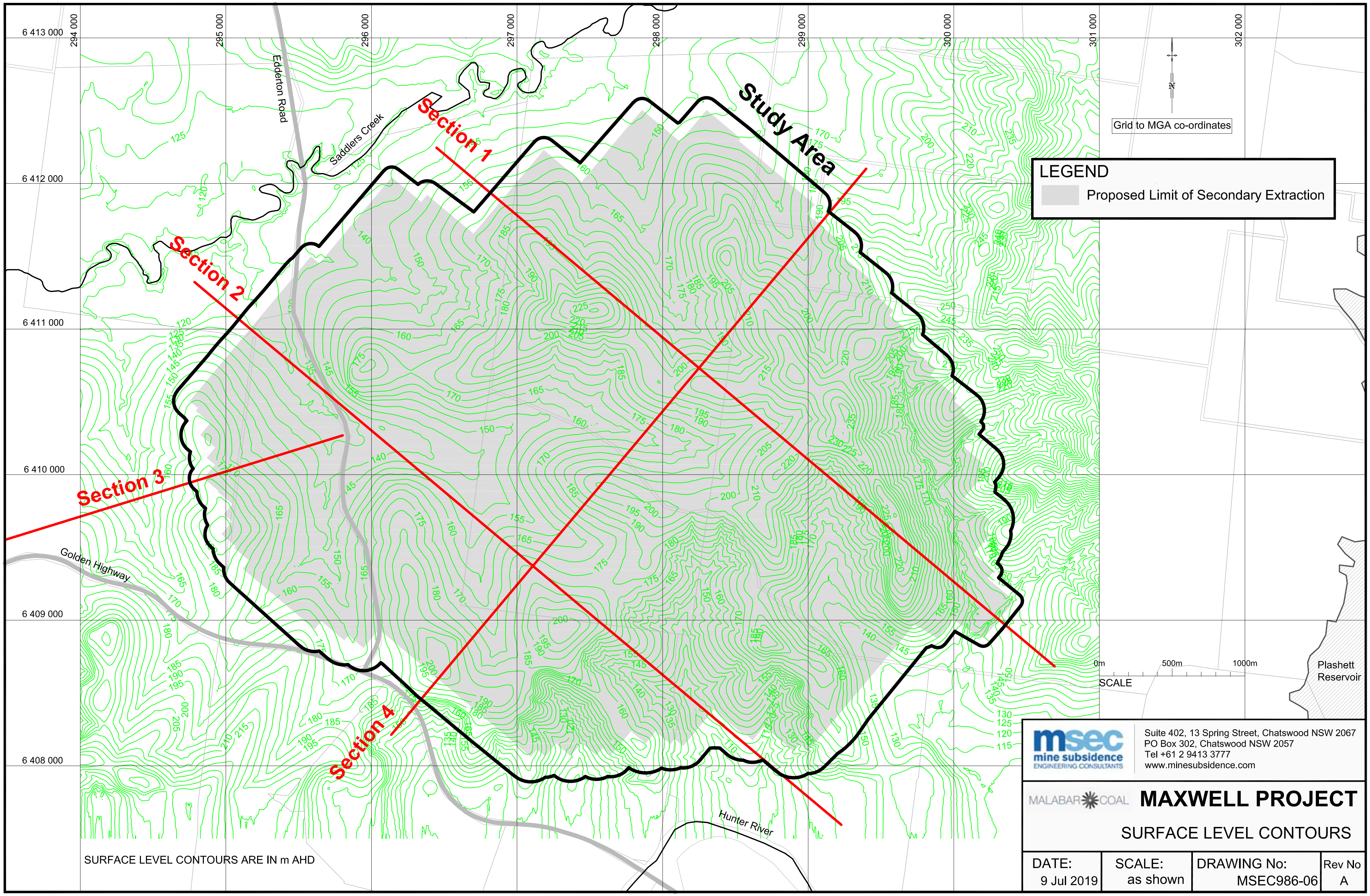

SURFACE LEVEL CONTOURS ARE IN m AHD

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SURFACE LEVEL CONTOURS

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9 Jul 2019	as shown	MSEC986-06	A

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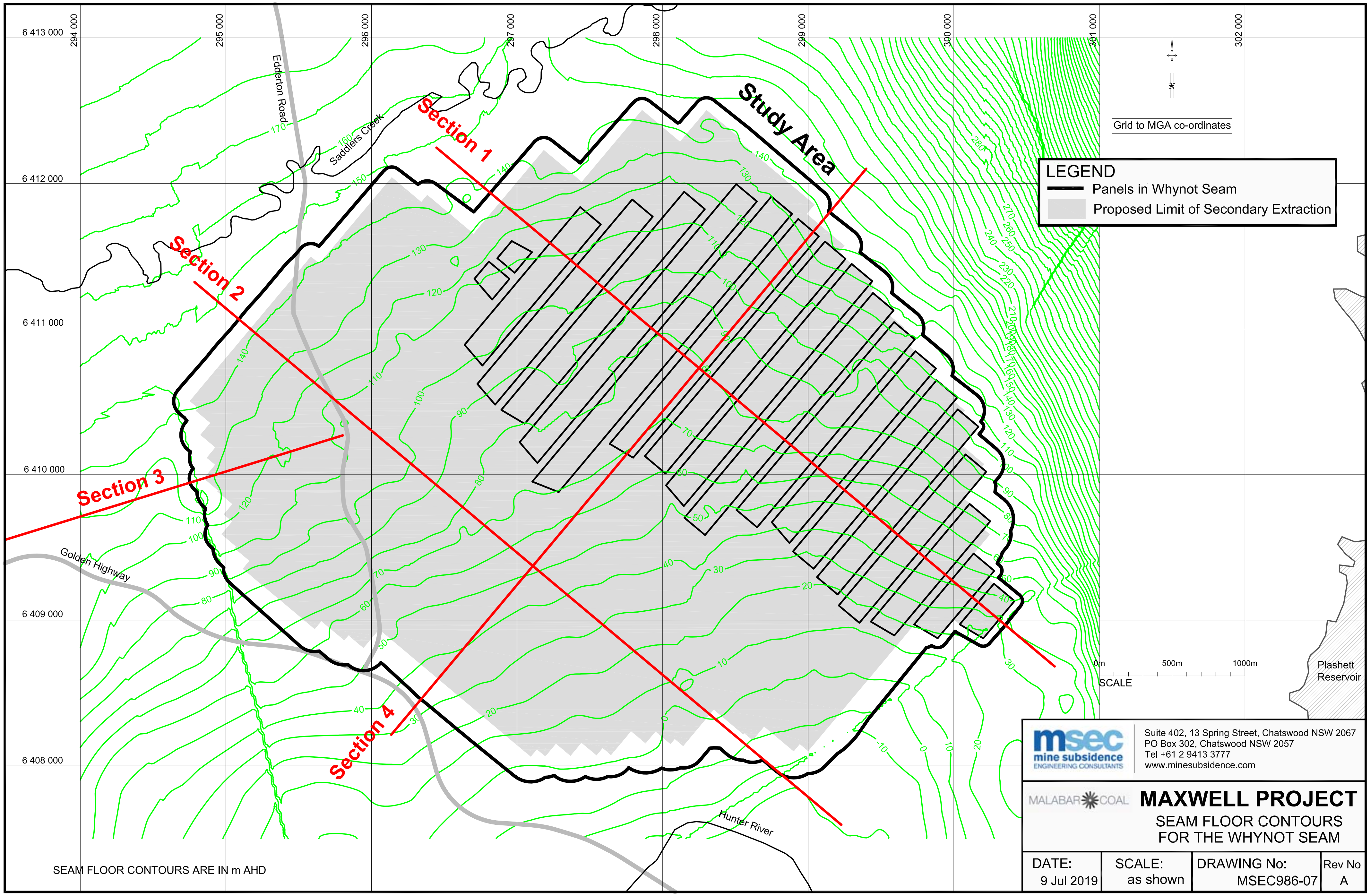

LEGEND

▬	Panels in Whynot Seam
▨	Proposed Limit of Secondary Extraction

SEAM FLOOR CONTOURS ARE IN m AHD

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SEAM FLOOR CONTOURS
FOR THE WHYNOT SEAM

DATE:	SCALE:	DRAWING No:	Rev No
9 Jul 2019	as shown	MSEC986-07	A

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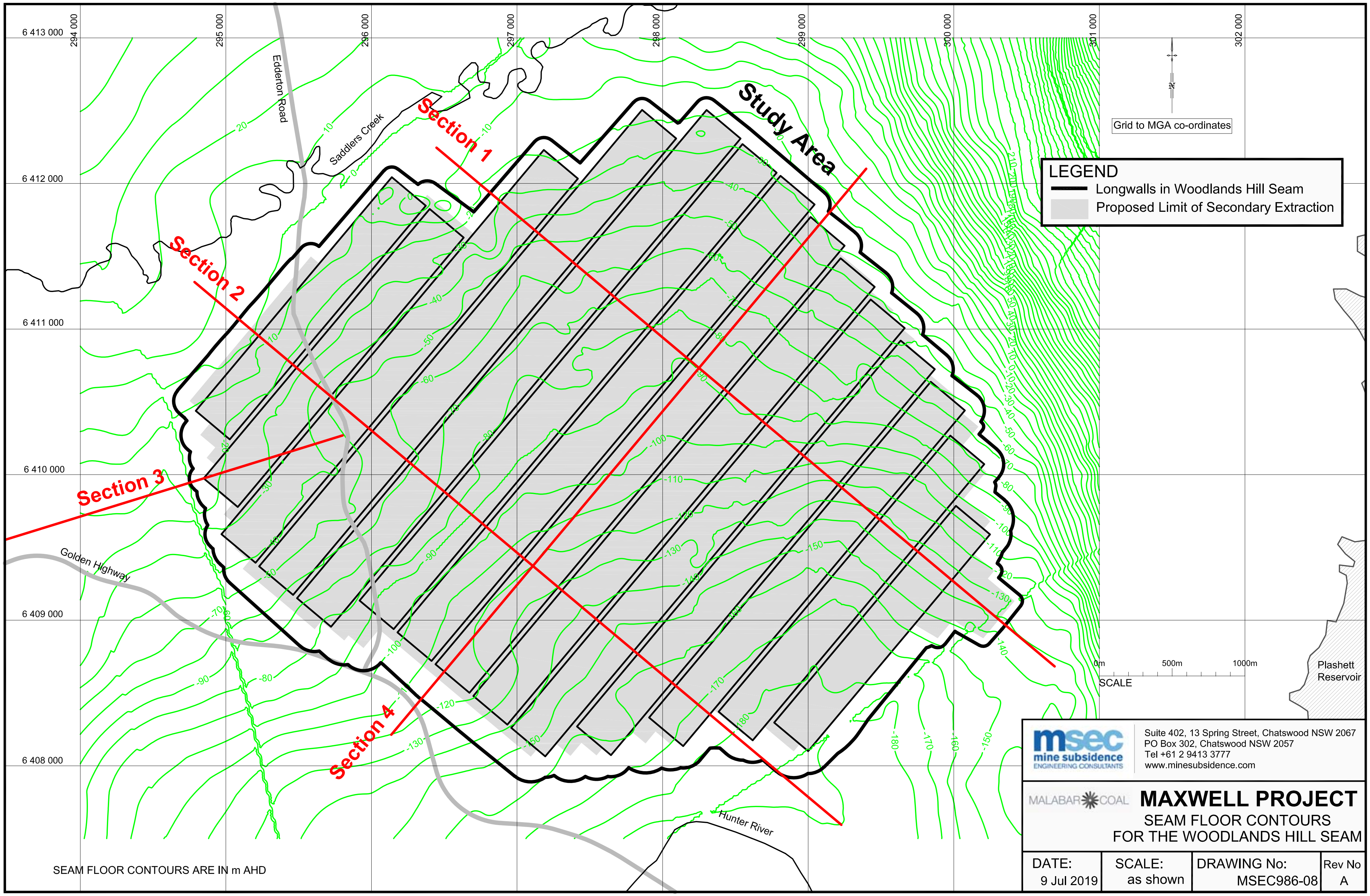

LEGEND

▬	Longwalls in Woodlands Hill Seam
▨	Proposed Limit of Secondary Extraction

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SEAM FLOOR CONTOURS FOR THE WOODLANDS HILL SEAM

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9 Jul 2019	as shown	MSEC986-08	A

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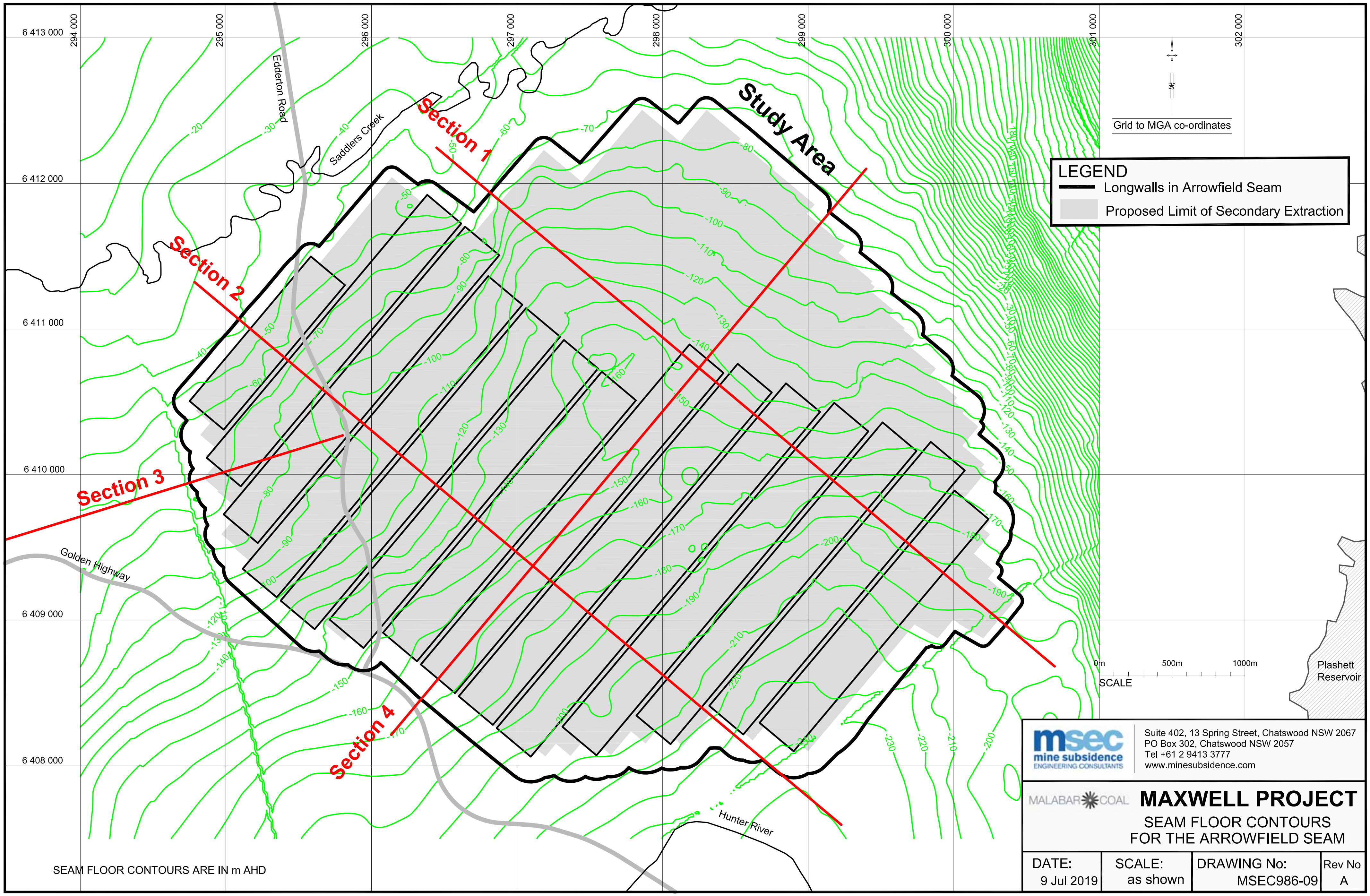

SEAM FLOOR CONTOURS ARE IN m AHD

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SEAM FLOOR CONTOURS FOR THE ARROWFIELD SEAM

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9 Jul 2019	as shown	MSEC986-09	A

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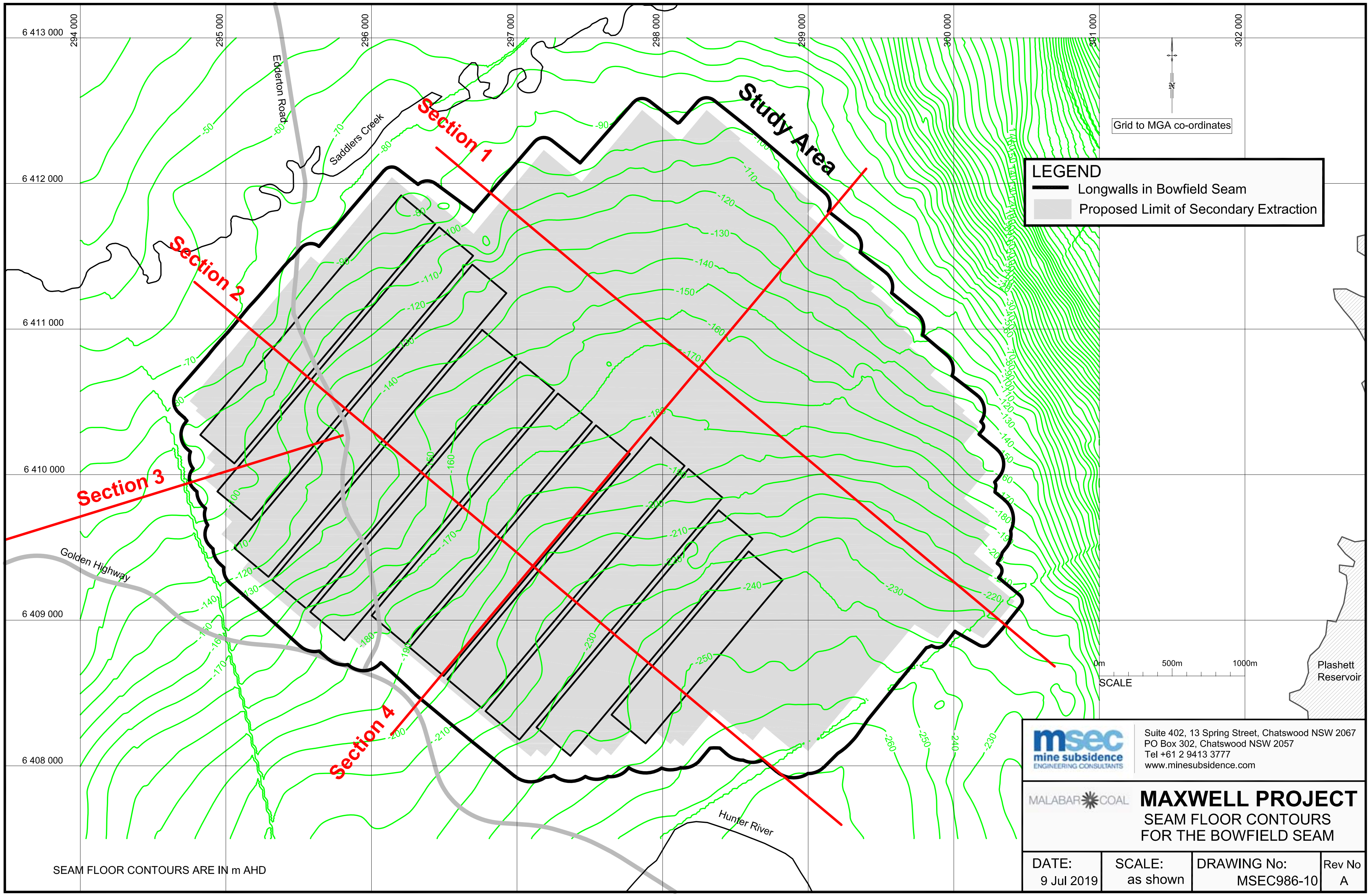

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SEAM FLOOR CONTOURS FOR THE BOWFIELD SEAM

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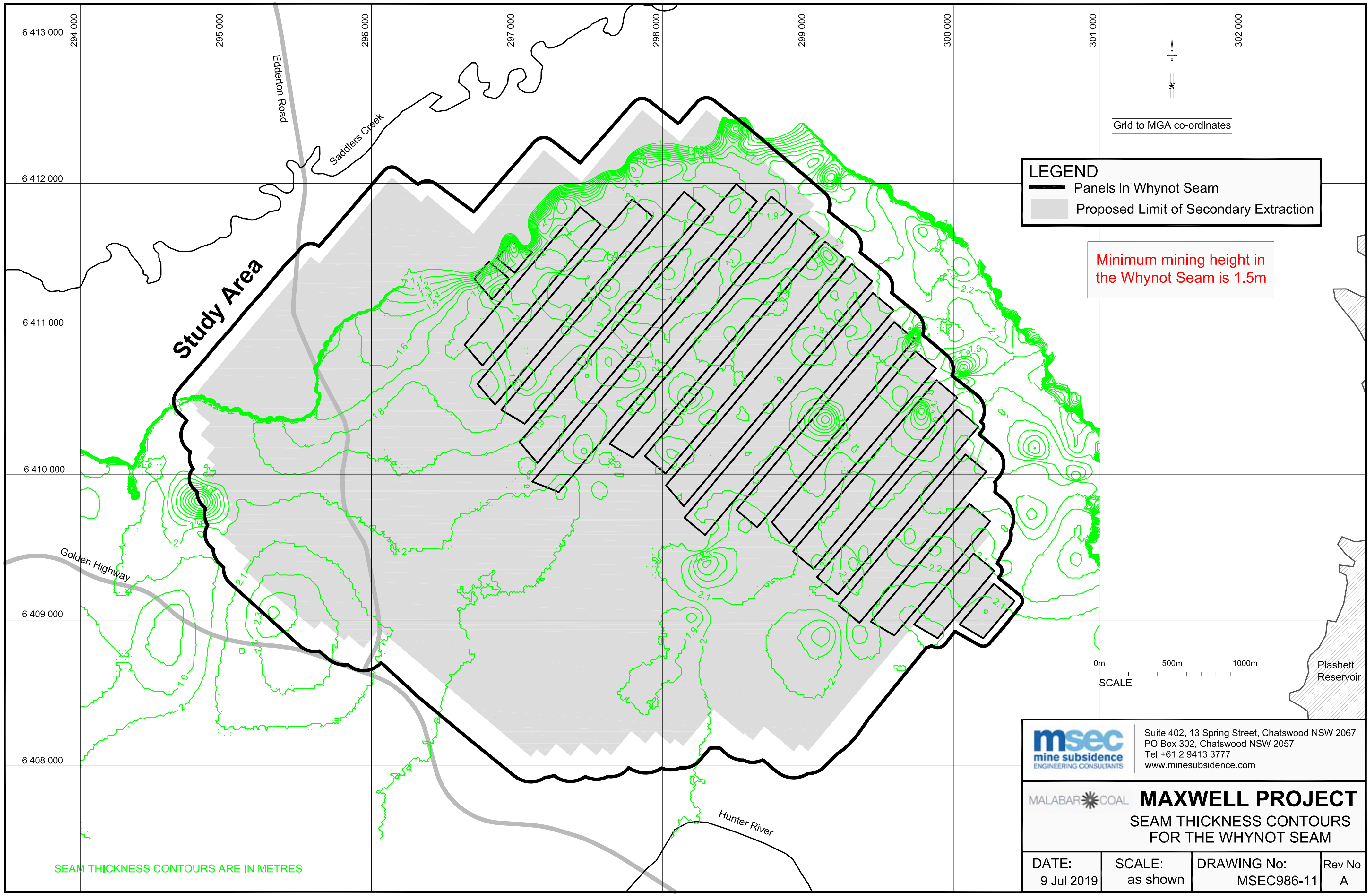

LEGEND

▬	Panels in Whynot Seam
▨	Proposed Limit of Secondary Extraction

Minimum mining height in the Whynot Seam is 1.5m

SEAM THICKNESS CONTOURS ARE IN METRES

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SEAM THICKNESS CONTOURS FOR THE WHYNOT SEAM

DATE:	SCALE:	DRAWING No:	Rev No
9 Jul 2019	as shown	MSEC986-11	A

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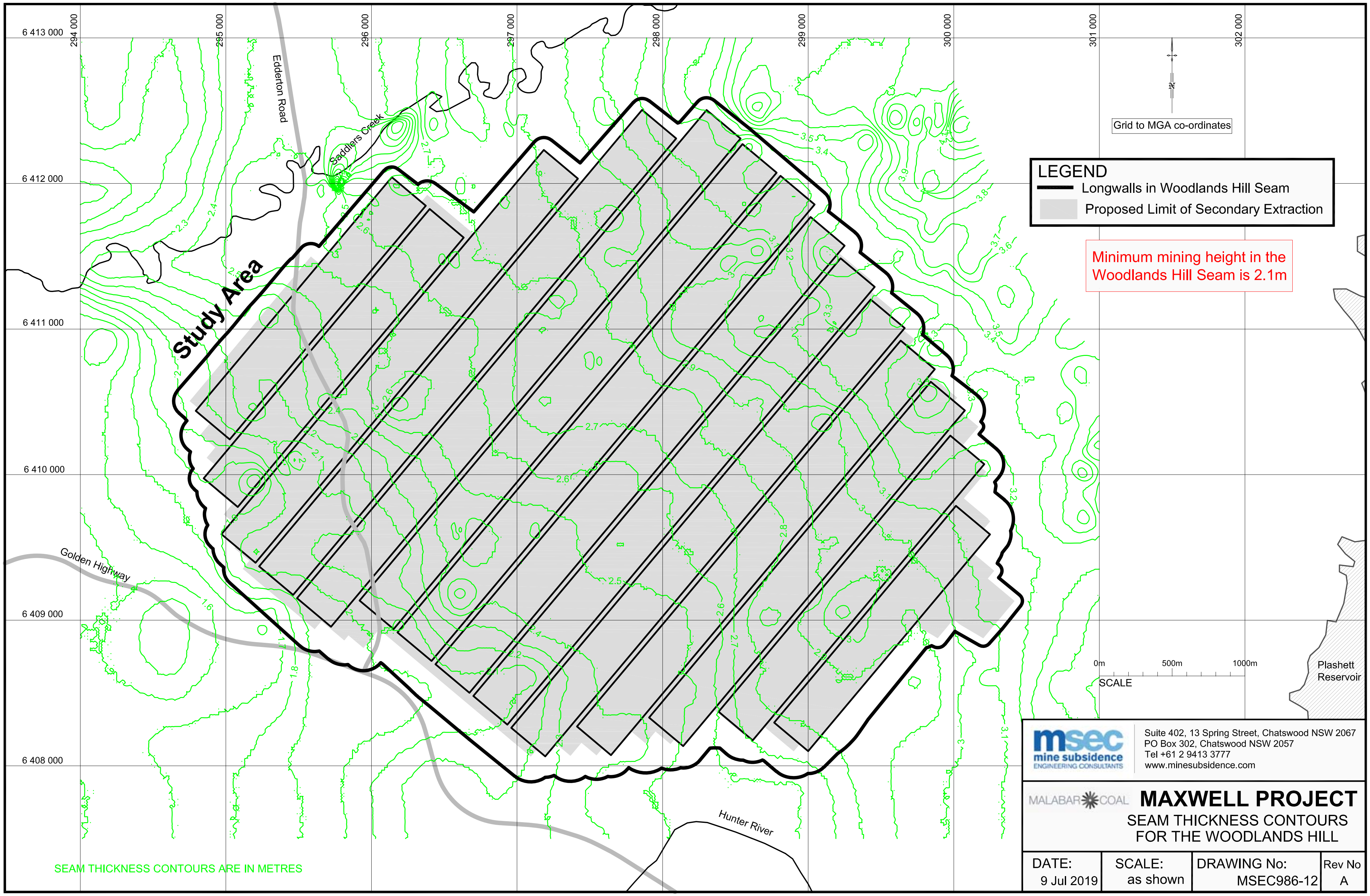
I:\Projects\Maxwell Project\MSEC986 - EIS Application\AcadData\MSEC986-12 Seam Thickness for the Woodlands Hill Seam.dwg



LEGEND

▬ Longwalls in Woodlands Hill Seam

▨ Proposed Limit of Secondary Extraction

Minimum mining height in the Woodlands Hill Seam is 2.1m

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SEAM THICKNESS CONTOURS FOR THE WOODLANDS HILL

DATE:	SCALE:	DRAWING No:	Rev No
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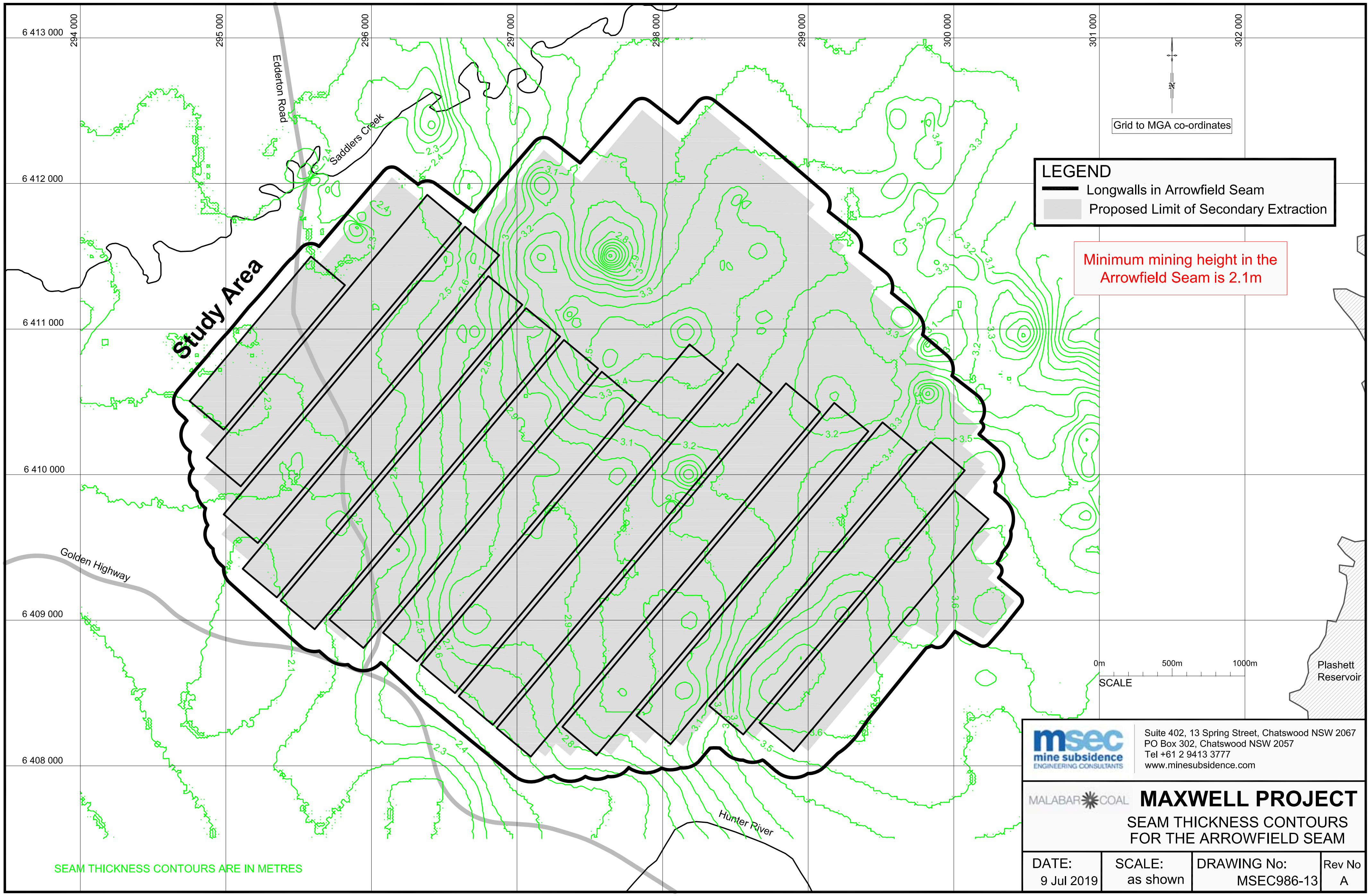

Minimum mining height in the Arrowfield Seam is 2.1m

SEAM THICKNESS CONTOURS ARE IN METRES

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SEAM THICKNESS CONTOURS FOR THE ARROWFIELD SEAM

DATE:	SCALE:	DRAWING No:	Rev No
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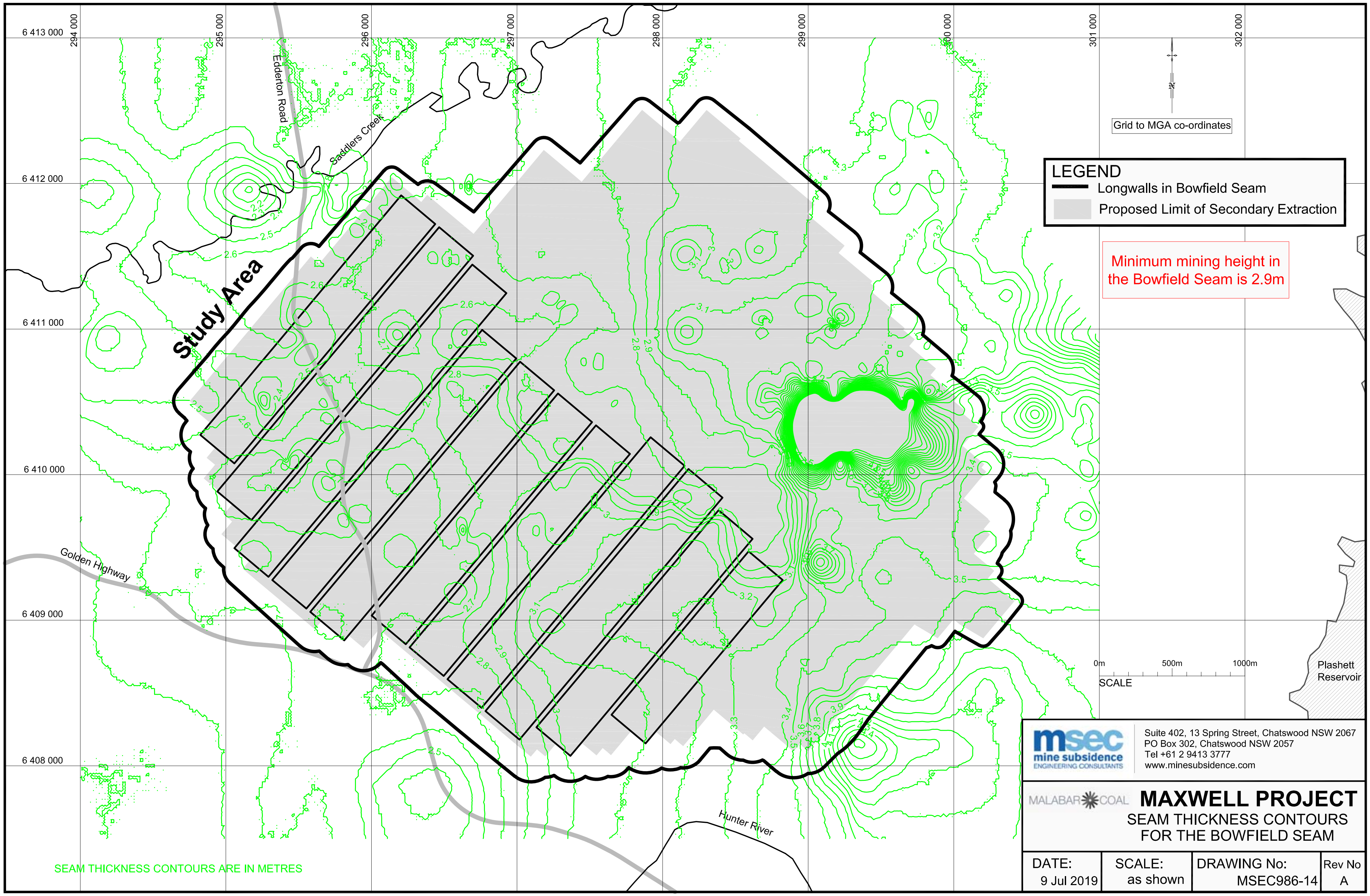

LEGEND

▬	Longwalls in Bowfield Seam
▨	Proposed Limit of Secondary Extraction

Minimum mining height in the Bowfield Seam is 2.9m

SEAM THICKNESS CONTOURS ARE IN METRES

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SEAM THICKNESS CONTOURS FOR THE BOWFIELD SEAM

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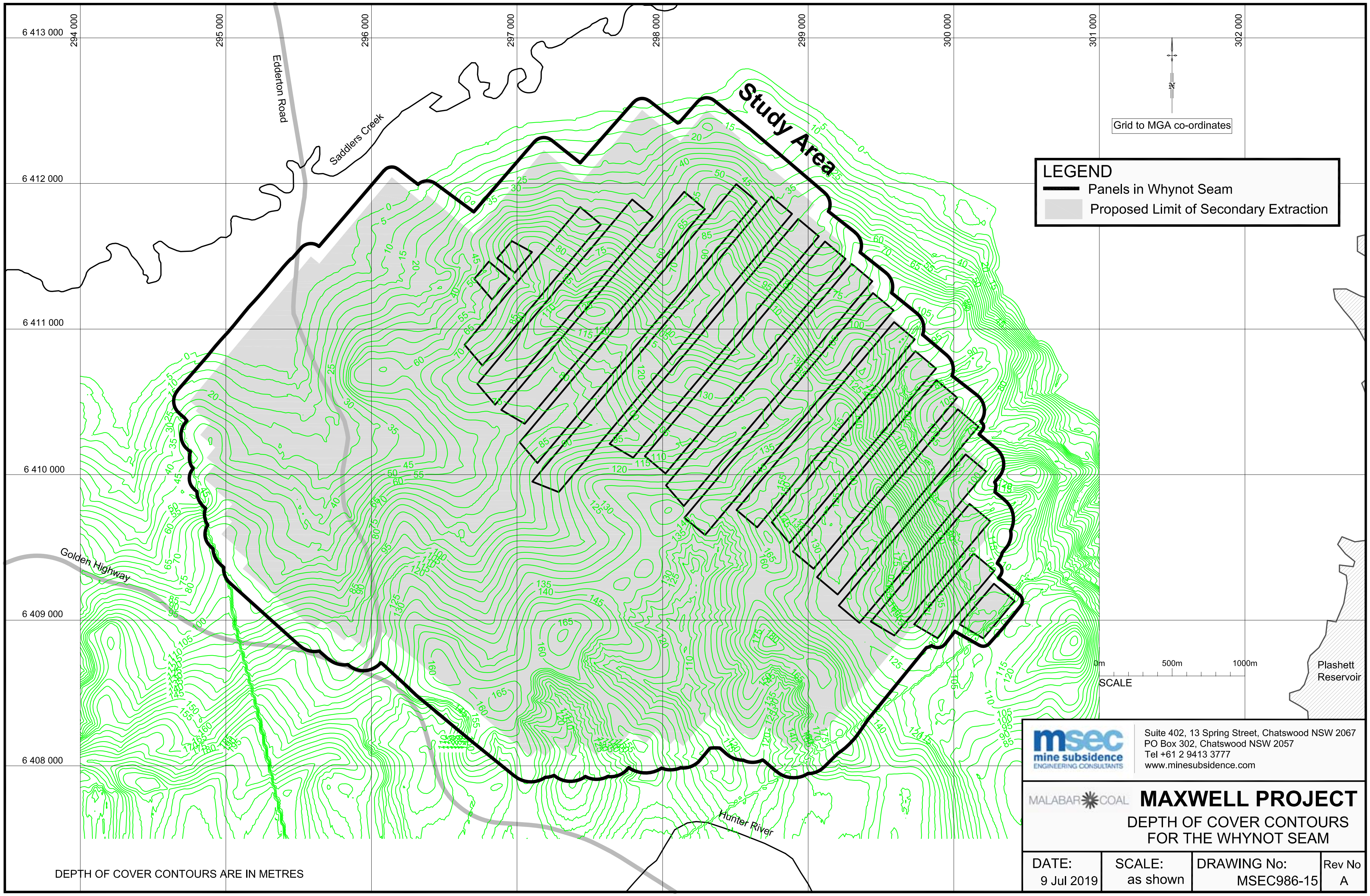

DEPTH OF COVER CONTOURS ARE IN METRES

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DEPTH OF COVER CONTOURS FOR THE WHYNOT SEAM

DATE:	SCALE:	DRAWING No:	Rev No
9 Jul 2019	as shown	MSEC986-15	A

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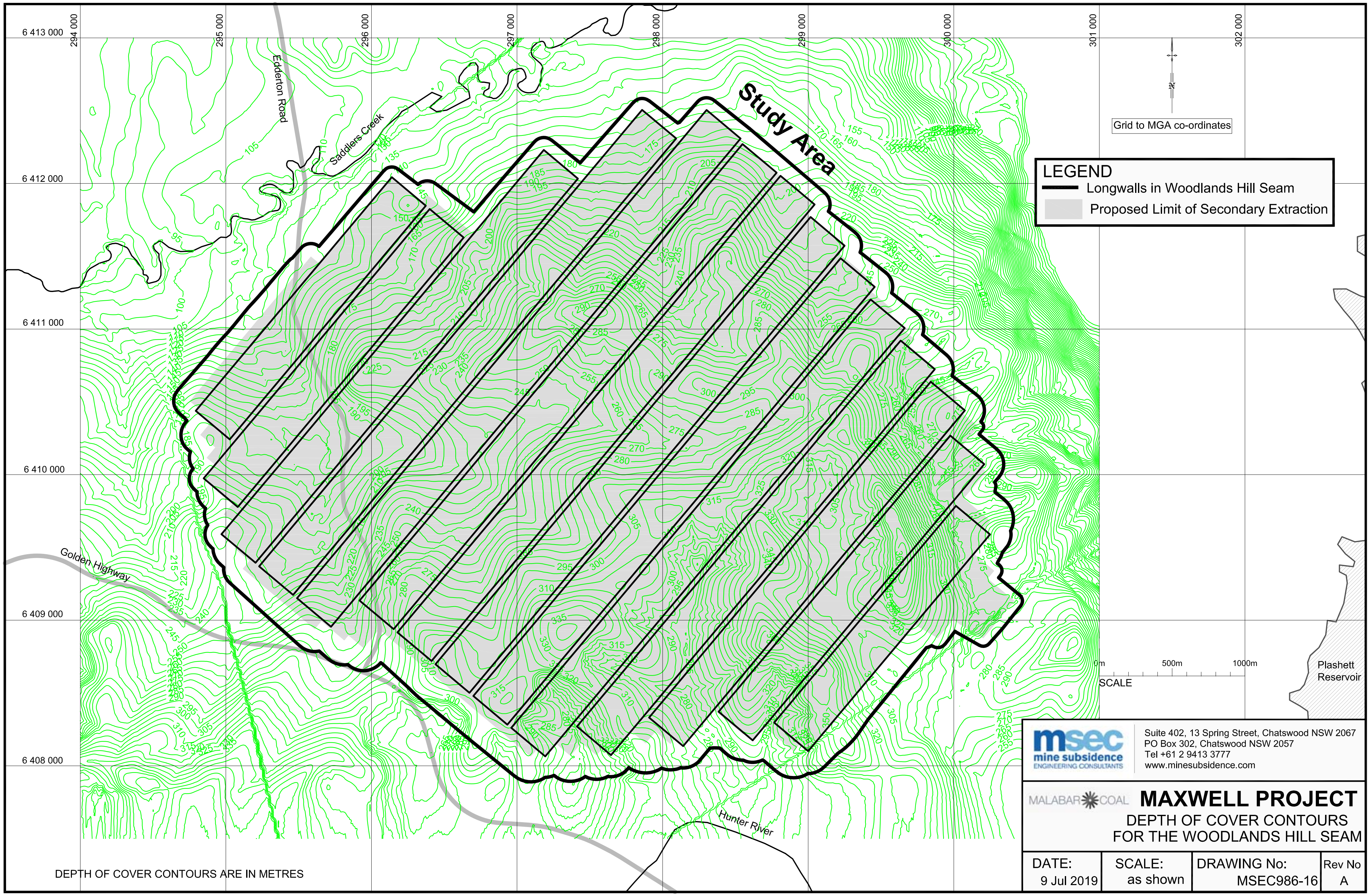
I:\Projects\Maxwell Project\MSEC986 - EIS Application\AcadData\MSEC986-16 DoC for the Woodlands Hill Seam.dwg



LEGEND

▬ Longwalls in Woodlands Hill Seam

▨ Proposed Limit of Secondary Extraction

DEPTH OF COVER CONTOURS ARE IN METRES

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DEPTH OF COVER CONTOURS
FOR THE WOODLANDS HILL SEAM

DATE:	SCALE:	DRAWING No:	Rev No
9 Jul 2019	as shown	MSEC986-16	A

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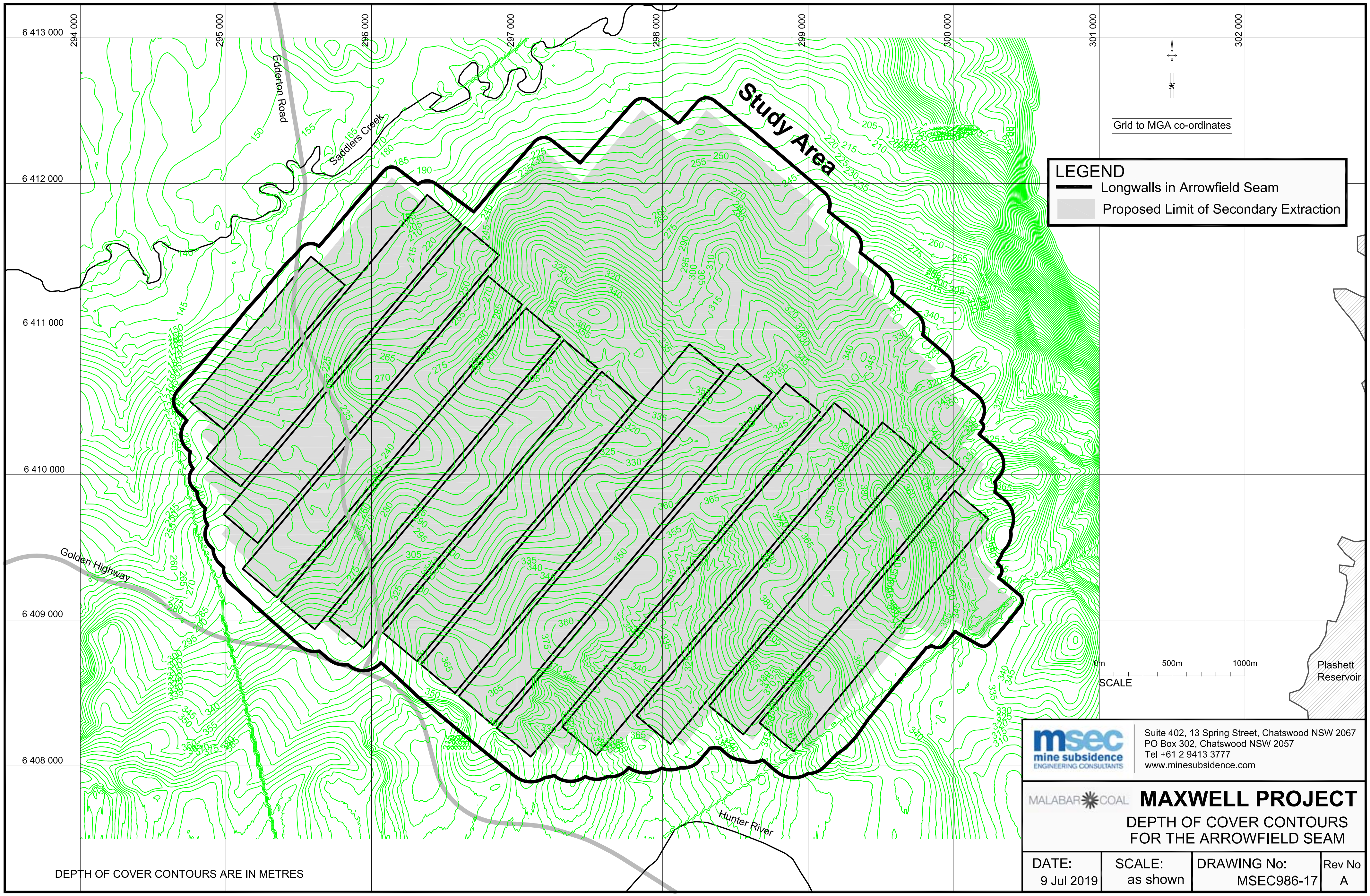

DEPTH OF COVER CONTOURS ARE IN METRES

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DEPTH OF COVER CONTOURS FOR THE ARROWFIELD SEAM

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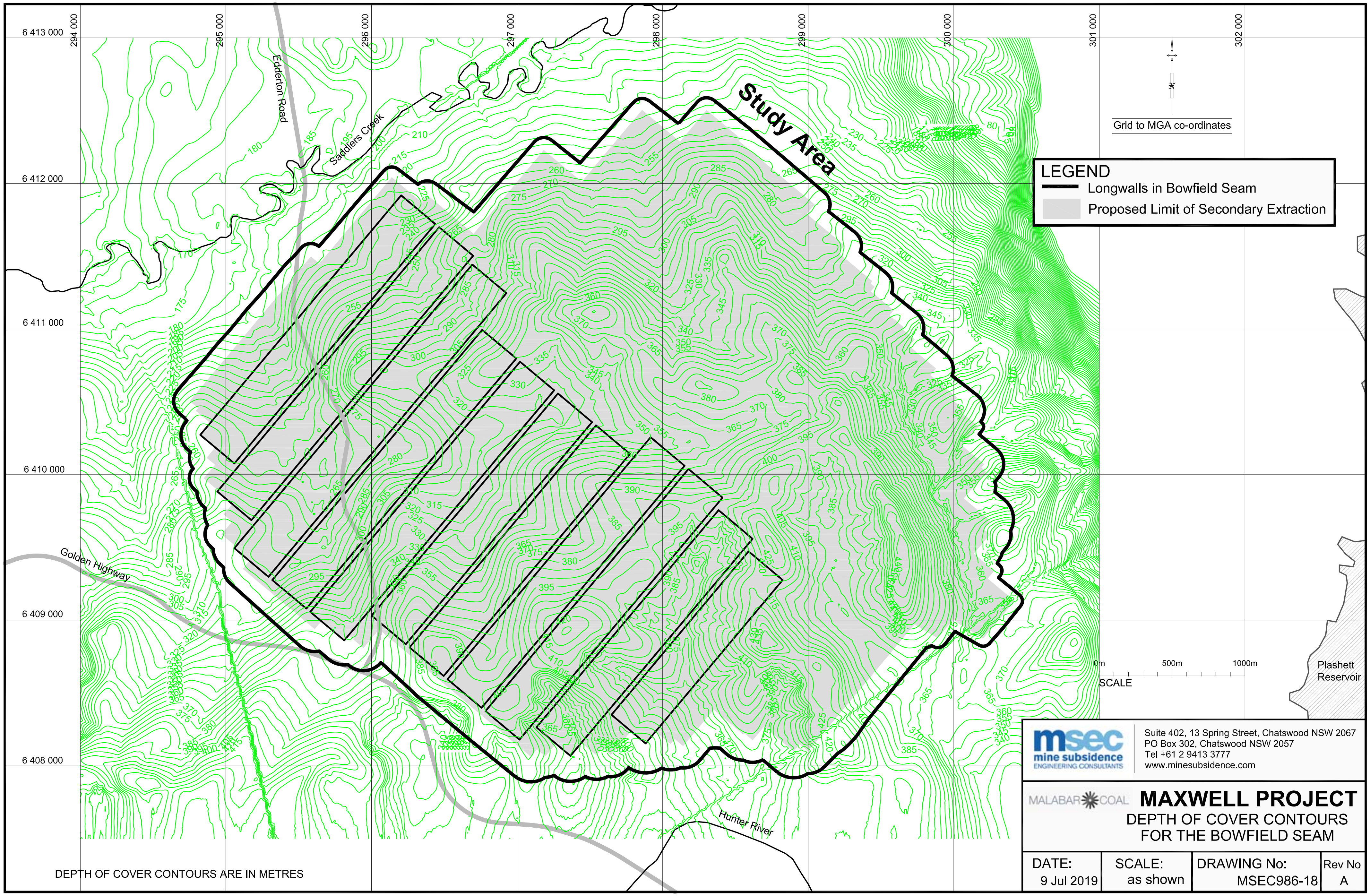

DEPTH OF COVER CONTOURS ARE IN METRES

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DEPTH OF COVER CONTOURS FOR THE BOWFIELD SEAM

DATE:	SCALE:	DRAWING No:	Rev No
9 Jul 2019	as shown	MSEC986-18	A

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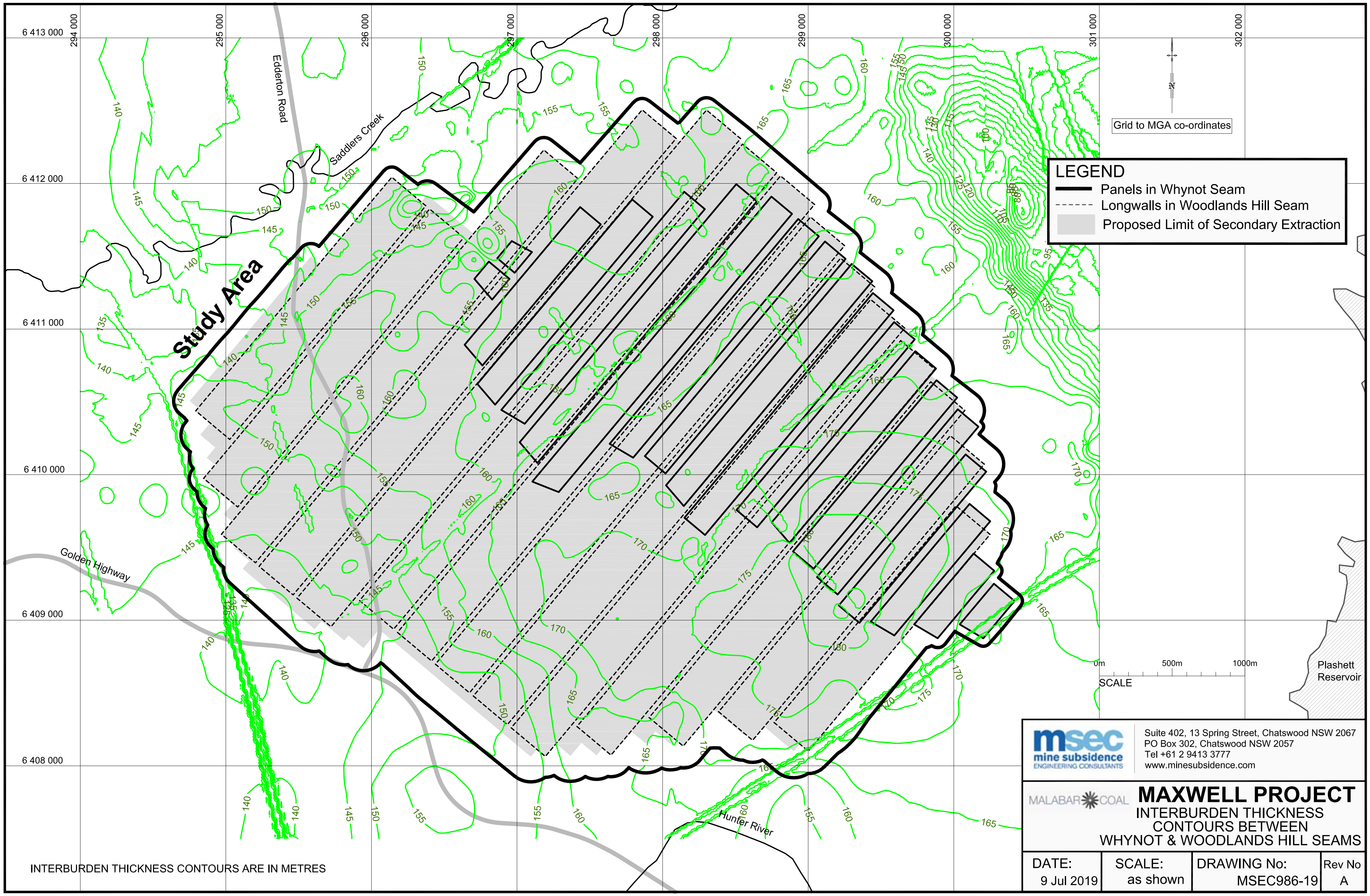

LEGEND
- Panels in Whynot Seam
- Longwalls in Woodlands Hill Seam
- Proposed Limit of Secondary Extraction

INTERBURDEN THICKNESS CONTOURS ARE IN METRES

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MALABAR COAL

MAXWELL PROJECT
INTERBURDEN THICKNESS CONTOURS BETWEEN WHYNOT & WOODLANDS HILL SEAMS

DATE:	SCALE:	DRAWING No:	Rev No
9 Jul 2019	as shown	MSEC986-19	A

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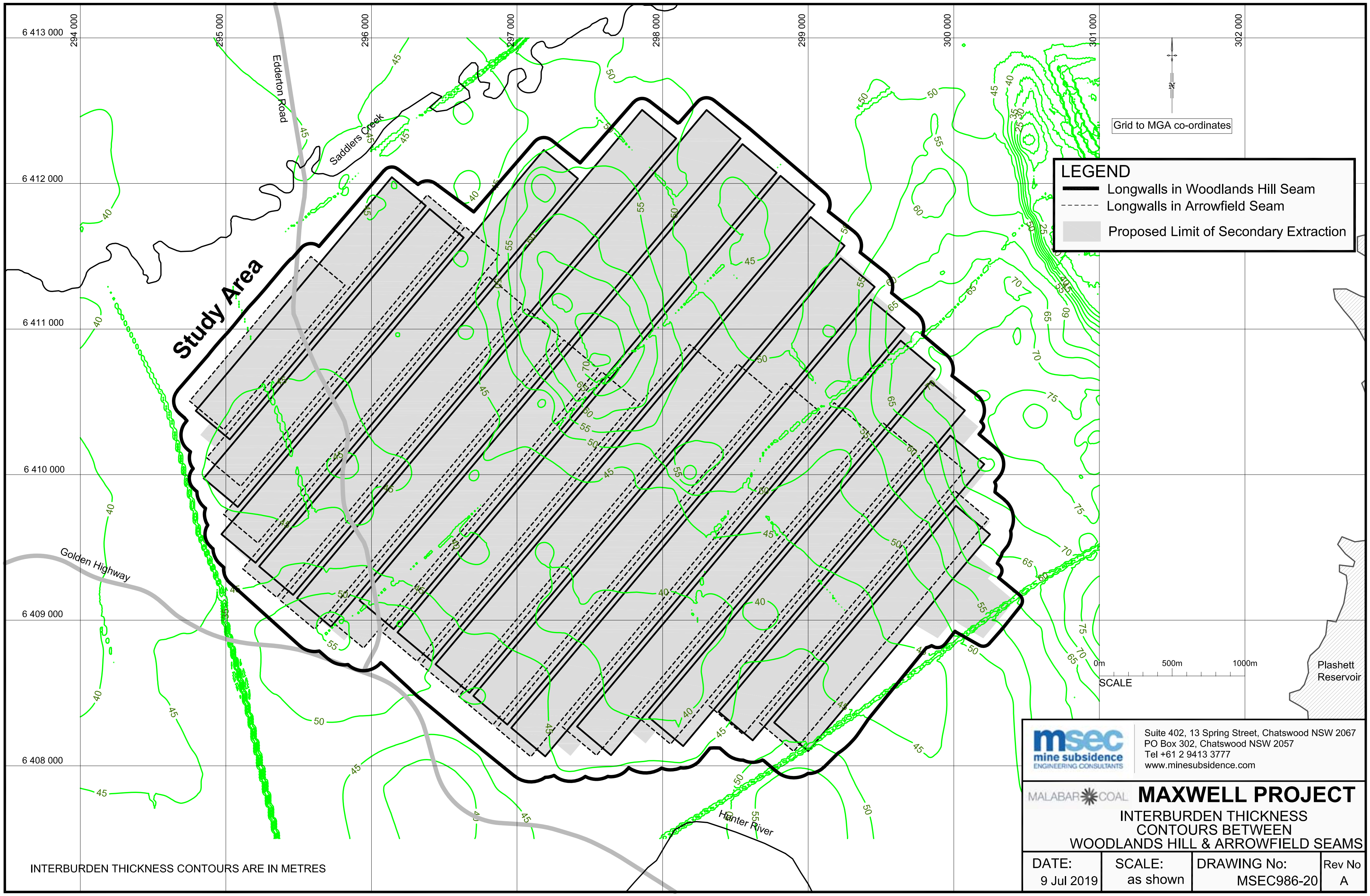

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MAXWELL PROJECT

INTERBURDEN THICKNESS
CONTOURS BETWEEN
WOODLANDS HILL & ARROWFIELD SEAMS

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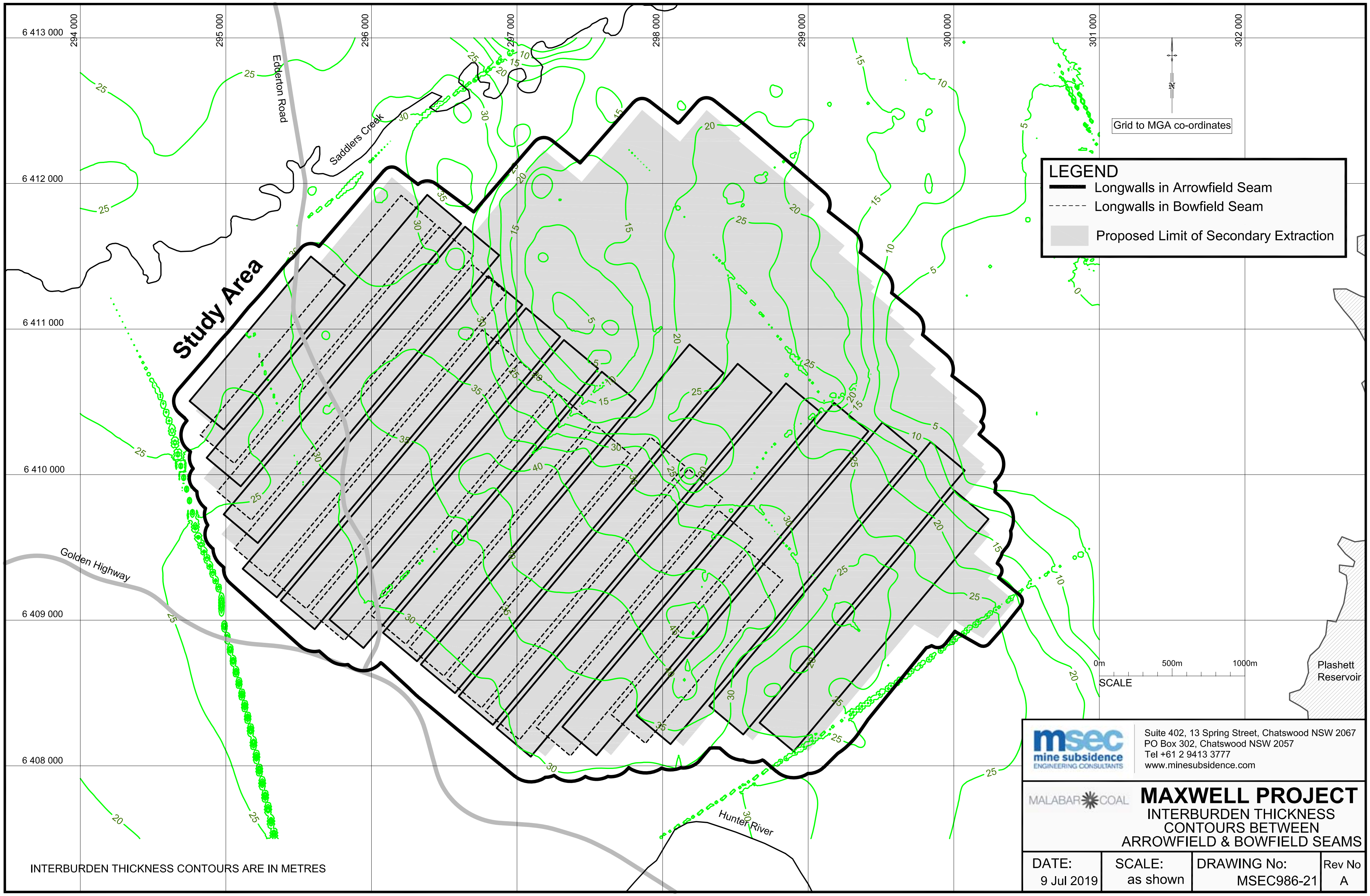

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MAXWELL PROJECT

INTERBURDEN THICKNESS
CONTOURS BETWEEN
ARROWFIELD & BOWFIELD SEAMS

DATE: 9 Jul 2019	SCALE: as shown	DRAWING No: MSEC986-21	Rev No A

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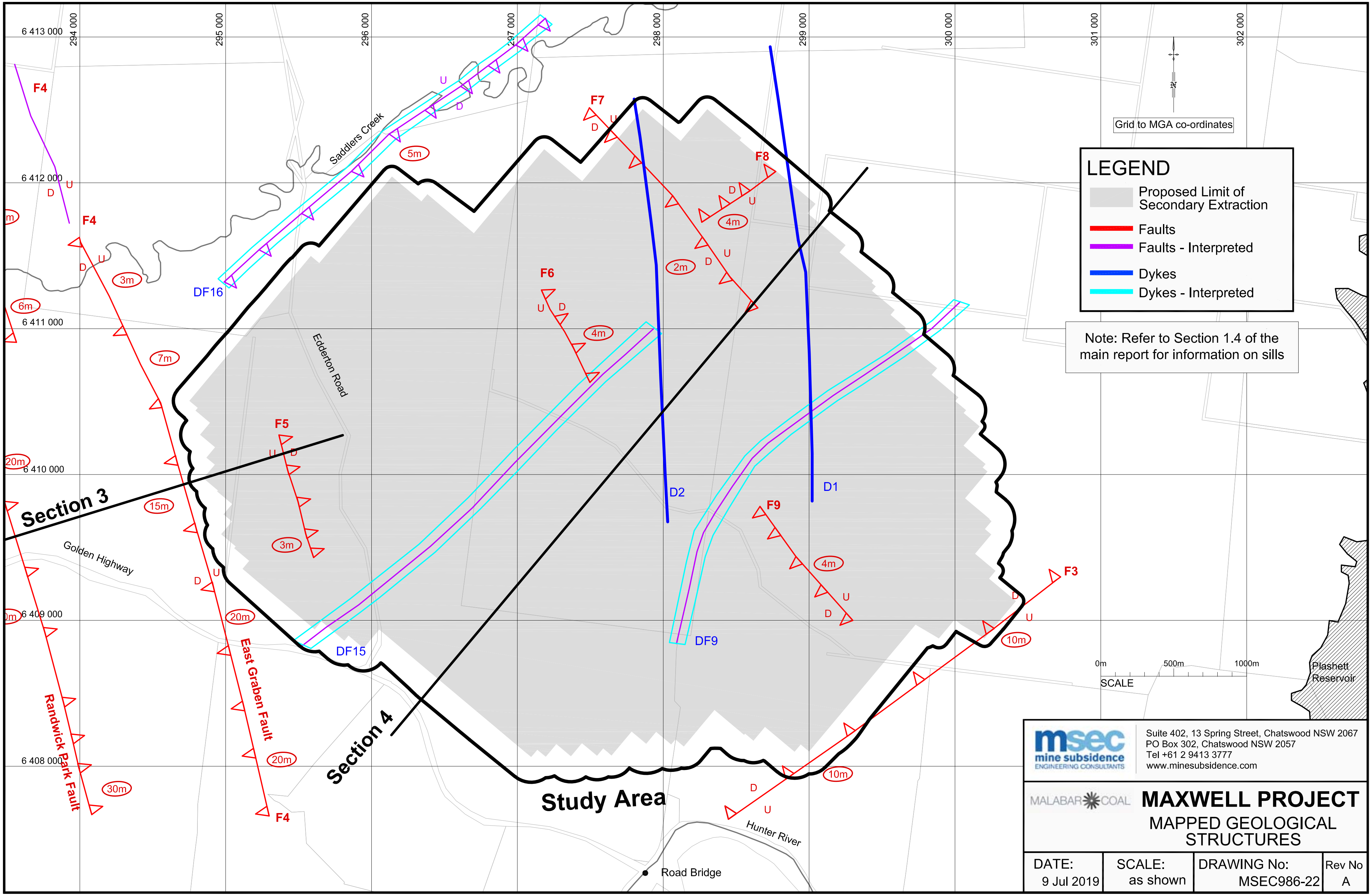

LEGEND

▨	Proposed Limit of Secondary Extraction
🟥	Faults
🟪	Faults - Interpreted
🟦	Dykes
🟦	Dykes - Interpreted

Note: Refer to Section 1.4 of the main report for information on sills

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MAXWELL PROJECT

MAPPED GEOLOGICAL STRUCTURES

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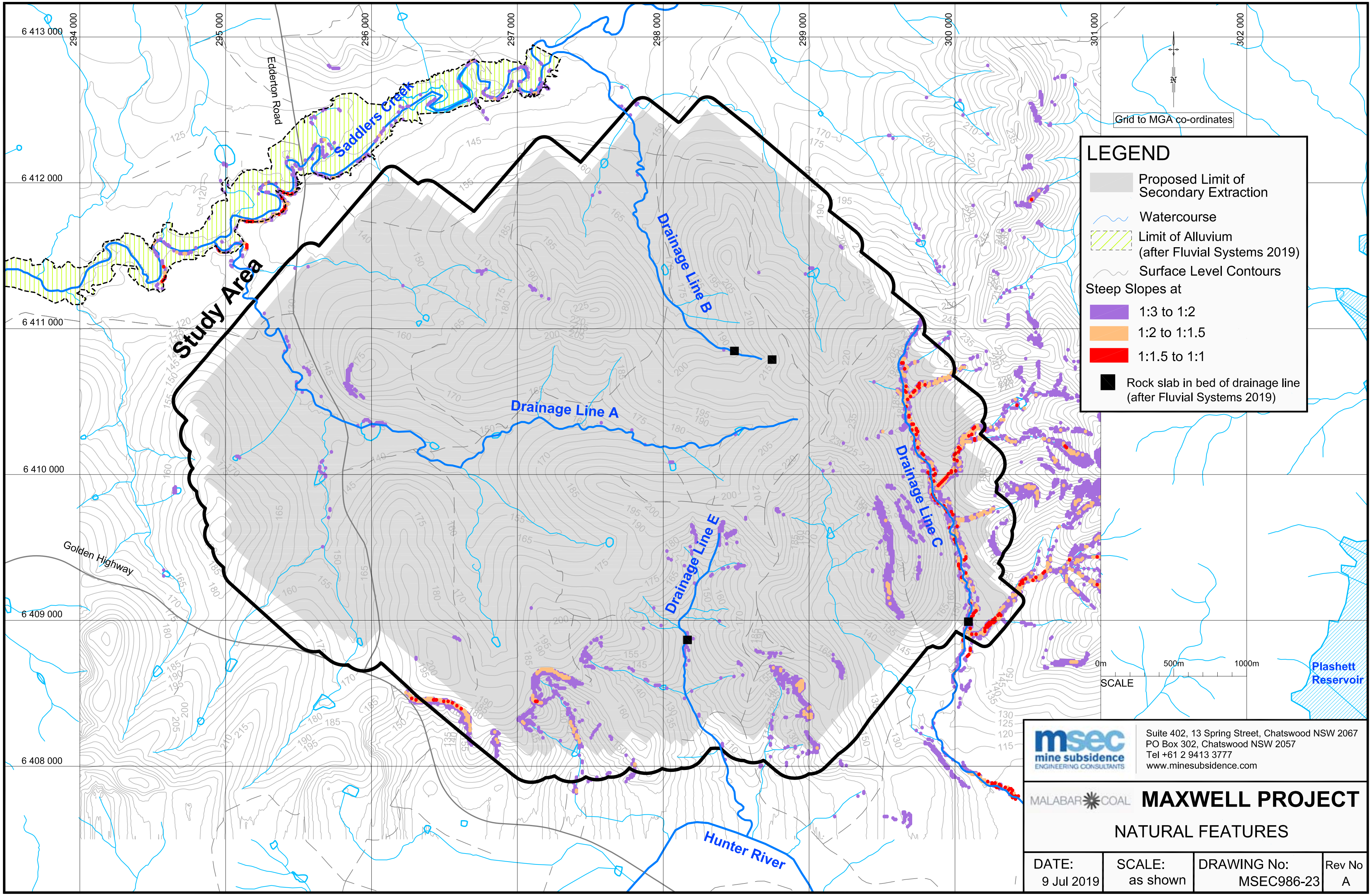

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MAXWELL PROJECT

NATURAL FEATURES

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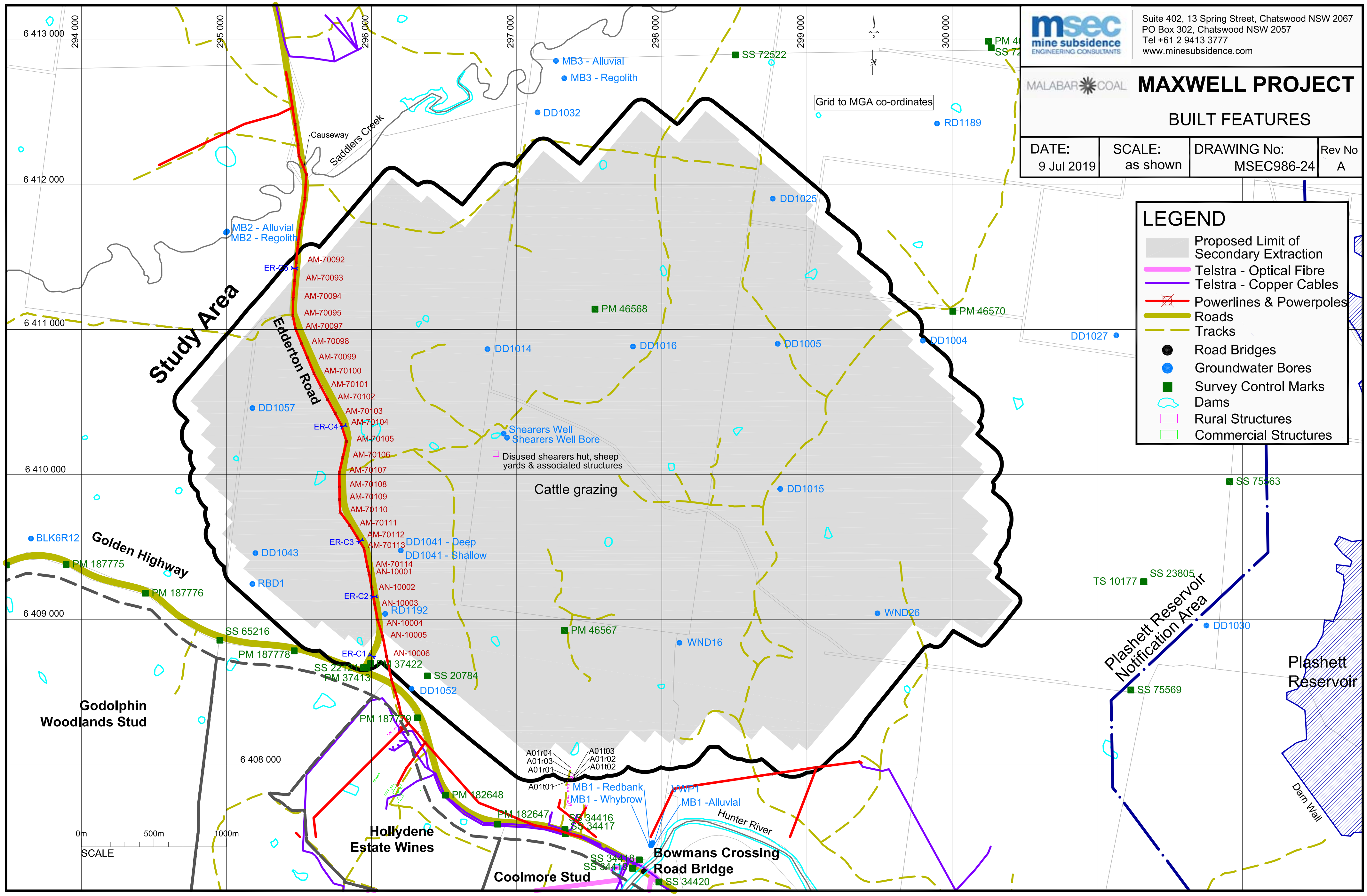

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MAXWELL PROJECT

BUILT FEATURES

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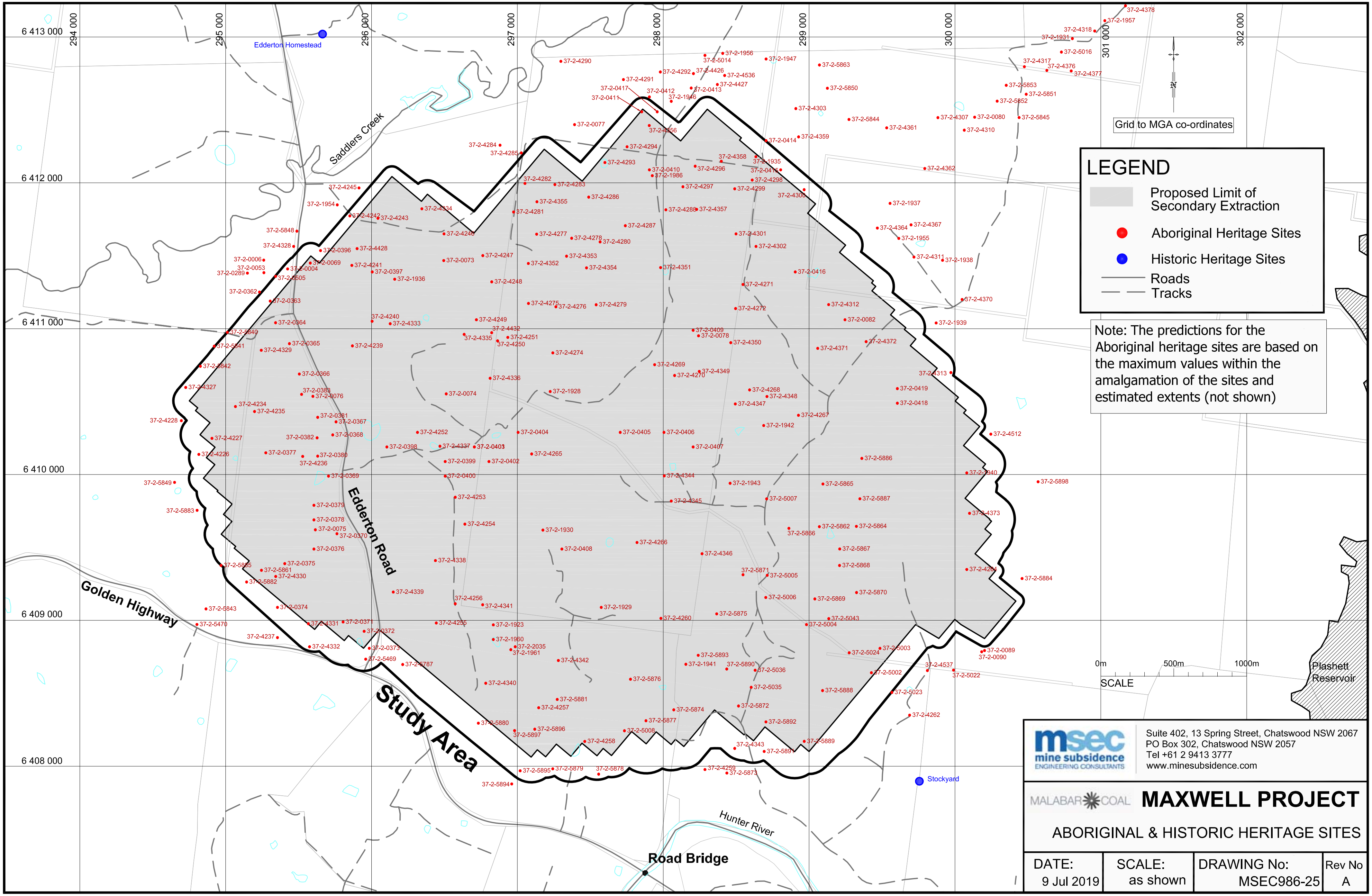
LEGEND

- ▨ Proposed Limit of Secondary Extraction
- Telstra - Optical Fibre
- Telstra - Copper Cables
- Powerlines & Powerpoles
- Roads
- Tracks
- ● Road Bridges
- ● Groundwater Bores
- 🟩 Survey Control Marks
- Dams
- ☐ Rural Structures
- ☐ Commercial Structures

I:\Projects\Maxwell Project\MSEC986 - EIS Application\AcadData\MSEC986-25 Aboriginal Heritage Sites.dwg



LEGEND

- ▨ Proposed Limit of Secondary Extraction
- ● Aboriginal Heritage Sites
- ● Historic Heritage Sites
- Roads
- Tracks

Note: The predictions for the Aboriginal heritage sites are based on the maximum values within the amalgamation of the sites and estimated extents (not shown)

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MAXWELL PROJECT

ABORIGINAL & HISTORIC HERITAGE SITES

DATE:	SCALE:	DRAWING No:	Rev No
9 Jul 2019	as shown	MSEC986-25	A

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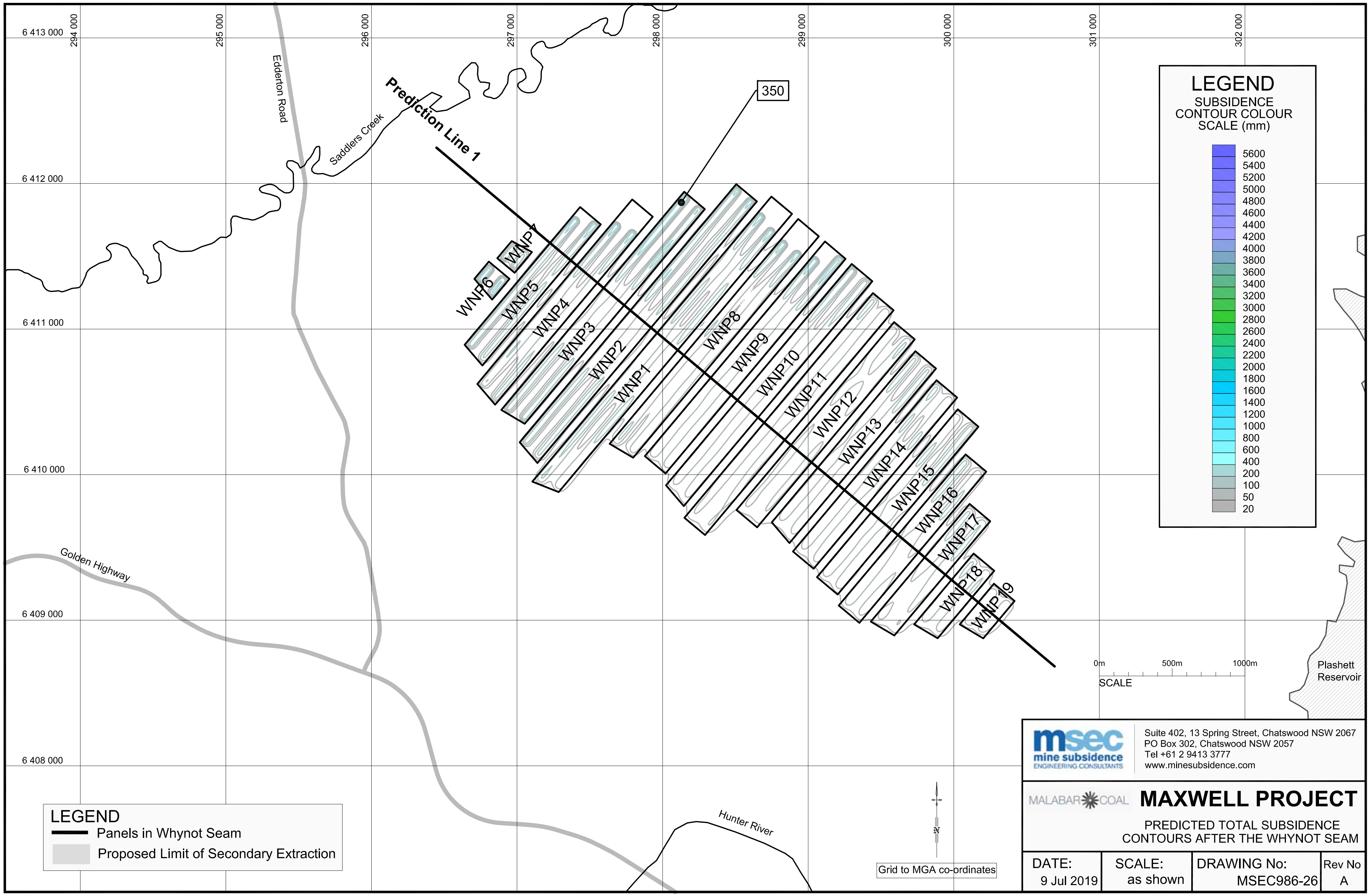

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MAXWELL PROJECT

PREDICTED TOTAL SUBSIDENCE CONTOURS AFTER THE WHYNOT SEAM

DATE:	SCALE:	DRAWING No:	Rev No
9 Jul 2019	as shown	MSEC986-26	A

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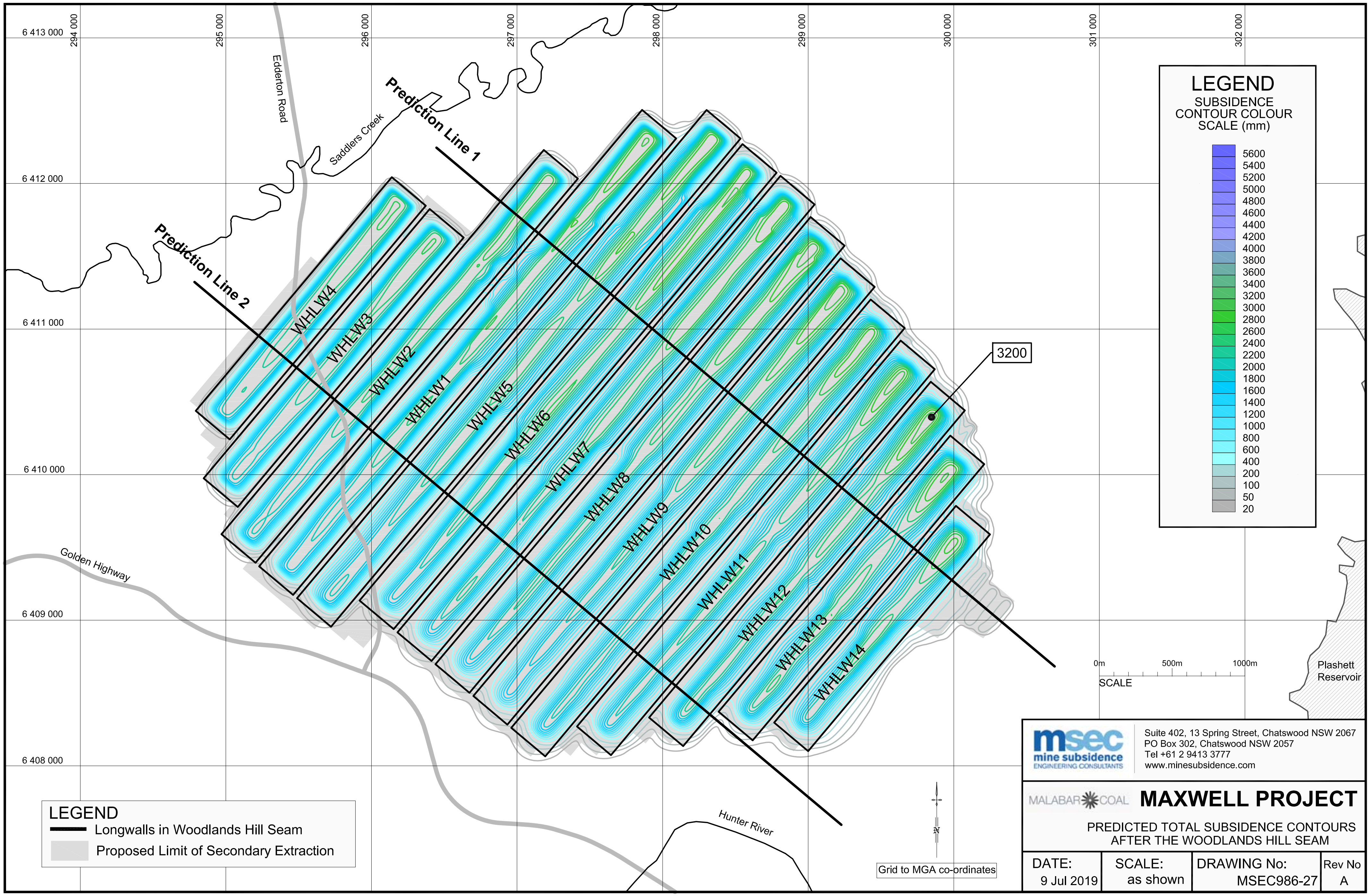

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MAXWELL PROJECT

PREDICTED TOTAL SUBSIDENCE CONTOURS
AFTER THE WOODLANDS HILL SEAM

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PREDICTED TOTAL SUBSIDENCE
CONTOURS AFTER THE ARROWFIELD SEAM

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PREDICTED TOTAL SUBSIDENCE CONTOURS AFTER THE BOWFIELD SEAM

DATE:	SCALE:	DRAWING No:	Rev No
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