APPENDIX G REVISED SUBSIDENCE ASSESSMENT

mine subsidence
ENGINEERING CONSULTANTS

Centennial Coal:

Angus Place Colliery – LW1001 to LW1015

Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Mining of the Proposed LW1001 to LW1015 in Support of the Amended Project Report

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Report produced to: Support the Amended Project Report for submission to the Department of Planning and Environment.

Previous reports: MSEC593 (Rev. C) – Angus Place Mine Extension Project – Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Environmental Impact Statement for the Proposed Longwalls 1001 to 1019 in the Lithgow Seam (April 2014).

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)

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

Angus Place Colliery (Angus Place) is a joint venture operation owned by Centennial and SK Kores. The colliery is located in the Western Coalfield of New South Wales (NSW), within the Newnes State Forest, north-west of the village of Lidsdale.

Centennial previously prepared an Environmental Impact Statement (EIS) for the *Angus Place Mine Extension Project (APMEP)* in 2014 for proposed longwall mining on the eastern side of the Wolgan River and to the north of Springvale Colliery. Mine Subsidence Engineering Consultants previously prepared Report No. MSEC593 (Rev. C) which provided the predicted subsidence effects and assessed impacts in support of the APMEP EIS as submitted.

Angus Place was subsequently placed on care and maintenance in March 2015.

Centennial is now seeking approval to extract the proposed Longwalls 1001 to 1015 (LW1001 to LW1015) in the Lithgow Seam in an Amended Project Report for the APMEP. These currently proposed longwalls are located on the eastern side of the Wolgan River and to the north of Springvale Colliery, as for the previously proposed longwalls adopted for the APMEP EIS. This report provides the subsidence predictions and assessed impacts for the proposed longwalls in support of the Amended Project Report.

The predicted subsidence effects for the existing and proposed longwalls have been obtained using the Incremental Profile Method (IPM). This method has been reviewed and re-calibrated based on the available ground monitoring data from Angus Place and Springvale Collieries. The predicted subsidence effects have been increased by 25 % at the Type 1 and 2 geological structures, as has been observed previously at Angus Place.

The maximum predicted subsidence effects for the proposed longwalls are: 2250 mm vertical subsidence, 25 mm/m tilt (i.e. 2.5 % or 1 in 40), 0.35 km^{-1} hogging (i.e. 2.9 km minimum radius) and 0.40 km^{-1} sagging curvature (i.e. 2.5 km minimum radius). The predicted subsidence is generally greater in the south-western part of the mining area as the depths of cover are shallower and the mining heights are greater. The predicted subsidence is generally lesser in the central and north-eastern part of the mining area; however, locally increased subsidence occurs in the locations of the Types 1 and 2 geological structures.

The predicted strains have been based on a statistical analysis of the ground monitoring data from Angus Place and Springvale Collieries and other relevant collieries elsewhere in the NSW coalfields. The predicted strains in the eastern and northern parts of the mining area are 2.5 mm/m tensile and 4 mm/m compressive based on the 95 % confidence levels. The predicted strains in the south-western part of the mining area are 5 mm/m tensile and 6 mm/m compressive based on the 95 % confidence levels.

The *Study Area* is defined as the surface area that is likely to be affected by the extraction of the proposed LW1001 to LW1015. The extent of the Study Area has been calculated, as a minimum, as the surface area enclosed by the greater of the 26.5° angle of draw from the extents of the proposed longwalls and by the predicted 20 mm subsidence contour due to the extraction of the proposed longwalls. Other 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. In this case, features which could be sensitive to far-field or valley related effects, within but not limited to 600 m from the proposed longwalls, have been assessed.

Natural and built features have been identified within or in the vicinity of the Study Area including the Wolgan River, Carne Creek, drainage lines, cliffs, minor cliffs, pagodas, steep slopes, rock outcrops, swamps, the *Gardens of Stone National Park*, unsealed tracks, Aboriginal heritage sites and survey control marks. There is also mining-related infrastructure that is located within the Study Area.

The impact assessments for the natural and built features include the cumulative effects from the existing longwalls at Angus Place and Springvale Collieries. Longwall 910N at Angus Place has been approved but it has not yet been extracted. The predicted subsidence effects due to this future longwall have also been considered in the assessments provided 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 on the project. The main findings from this report are as follows:

- The *Wolgan River* is located west of the proposed longwalls, at a minimum distance of 180 m from LW1002, at its closest point. Elsewhere, the river is generally located more than 400 m from the proposed longwalls. The upper reaches of the Wolgan River are located above the previously extracted longwalls at Springvale Colliery.

  The Wolgan River is predicted to experience less than 20 mm vertical subsidence, 100 mm upsidence and 160 mm closure due to the extraction of the proposed longwalls. The river has already experienced subsidence effects from the previously extracted longwalls at Angus Place and Springvale Collieries. The predicted total subsidence effects due to the existing and proposed longwalls are less than 20 mm vertical subsidence, 290 mm upsidence and 370 mm closure.

The predicted changes in grade along the river are small when compared to the existing natural grades. It is unlikely, therefore, that there would be adverse changes in the stream alignment due to the extraction of the proposed longwalls.

The predicted total compressive strain along the Wolgan River is 1.5 mm/m based on the 95 % confidence level. Fracturing is generally not observed where the compressive strains are less than 2 mm/m nor at the distances of the Wolgan River from the proposed longwalls.

It is possible that fracturing could occur along the section of the Wolgan River to the south of LW1002, where it is located closest to the proposed mining area. However, the fracturing is expected to be minor and not result in adverse impacts on the surface water flows. Elsewhere, it is considered unlikely that fracturing would occur along the river due to its distance from the proposed mining area.

- *Carne Creek* is located 900 m south-east of the LW1001, at its closest point to the proposed mining area. At this distance, it is unlikely that the creek would experience adverse physical impacts due to the extraction of the proposed longwalls.

- There are unnamed drainage lines located directly above the proposed longwalls. Some sections of the drainage lines located within and downstream of the swamps are third order. The total length of third order streams above the proposed mining area is approximately 2 km. One section of drainage line located outside the proposed mining area but within the Study Area is fourth order.

  The predicted post-mining grades along the drainage lines are similar to the natural grades. It is unlikely, therefore, that there would be adverse changes in ponding or scouring resulting from the mining-related subsidence or tilt. There could be some minor localised areas that could experience small increases in the levels of ponding, where the natural gradients are low immediately upstream of the longwall chain pillars.

  It is expected that fracturing of the bedrock would occur beneath the sections of the drainage lines that are located directly above and adjacent to the proposed longwalls. Where the bedrock is shallow or exposed, then the fracturing will be visible at the surface. Fracturing can also occur outside the extents the proposed longwalls, with fracturing possible at distances up to approximately 400 m outside the mining area.

  Surface water flow diversions could occur along the sections of drainage lines that are located directly above and adjacent to the proposed longwalls. Further discussions on the potential impacts on surface water flows are provided by the specialist surface water consultant on the project.

- The cliffs, minor cliffs and pagoda complexes have been identified within the valleys of the Wolgan River, Carne Creek and the tributaries to the Wolgan River and Carne Creek. The mining layout has been designed such that the majority of the cliffs and pagoda complexes are located outside the 26.5° angle of draw from the extents of the proposed longwalls. However, there are some cliffs located on or inside the angle of draw and minor cliffs and isolated pagodas are located adjacent to and above the proposed mining area.

  Whilst the cliffs and pagodas complexes could experience very low levels of vertical subsidence and horizontal movement, they are not expected to experience measurable tilts, curvatures or strains. These features are located along the valley sides and, therefore, they are not expected to experience the valley related upsidence or compressive strains due to valley closure.

  It is unlikely, therefore, that the cliffs and pagoda complexes would experience adverse impacts due to the proposed longwalls. This is supported by extensive experience from the NSW coalfields, where no large cliff falls have occurred where the cliffs have been located completely outside the angle of draw from previous mining. However, it is still possible, but unlikely, that isolated rock falls could occur due to the proposed mining, due to natural processes, or both.

  There are some minor cliffs, pagodas and other rock formations that are located adjacent to or directly above the proposed longwalls. The proposed mining is likely to result in fracturing of some of these features and, where the rock is marginally stable, this could then result in spalling of the exposed rockfaces. It is expected that the impacts on these minor cliffs, pagodas and rock formations would represent less than 1 % to 3 % of total exposed rockface areas of these features which are located directly above the proposed longwalls.

- The steep slopes and rock outcrops within the Study Area are primarily located along the alignments of the drainage lines. The natural grades of the steep slopes typically range between 1 in 3 (i.e. 33 % or 18º) and 1 in 2 (i.e. 50 % or 27º), with isolated areas having natural grades up to 1 in 1.5 (i.e. 67 % or 34º).

  The potential impacts on these features generally result from increased horizontal movements in the downslope direction, resulting in tension cracks appearing at the tops and on the sides of the steep slopes and rock outcrops, compression ridges forming at the bottoms of the steep slopes, and buckling of the bedrock at the bottoms of the rock outcrops.

If tension cracks were to develop due to the proposed mining, it is possible that soil erosion could occur if these cracks were left untreated. Remediation may be required for the larger surface cracking, including infilling with soil or other suitable materials, or by locally regrading and recompacting the surface. Similarly, where cracking restricts the passage of vehicles along the tracks and fire trails that are required to be open for access, it is recommended that these cracks are treated in the same way.

- The swamps within the Study Area are classified into two fundamental types, being the *Newnes Plateau Shrub Swamps* (shrub swamps) and the *Newnes Plateau Hanging Swamps* (hanging swamps). The shrub swamps are listed as an endangered ecological community (EEC) under the NSW *Biodiversity Conservation Act* 2016. The shrub and hanging swamps have been classified as *Temperate Highland Peat Swamps on Sandstone* (THPSS) under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

  There are two shrub swamps located directly above the proposed mining area. Tri Star Swamp is located above the western ends of the proposed LW1004 and LW1005 and it is also coincident with a Type 1 geological structure. Twin Gully Swamp is located above the western ends of LW1009 and LW1010.

  Fracturing and dilation of the bedrock is expected to develop beneath Tri Star Swamp, Twin Gully Swamp and the hanging swamps within their catchments, and this could result in cracking of the overlying peat layers. Fracturing and dilation of the bedrock can also occur beneath the swamps located adjacent to the mining area, within minor and isolated fracturing occur up to 400 m outside the proposed mining area.

  The impacts to Tri Star Swamp and Twin Gully Swamp could be similar to those previously observed at Junction Swamp, Narrow Swamp North, Narrow Swamp South and East Wolgan Swamp. However, some of these previously observed impacts are partially the result of mine water discharge. The potential impacts on surface water, groundwater and ecology are discussed by the other specialist consultants on the project.

  Japan Swamp and the shrub swamps within the Carne Creek Catchment are located outside the proposed mining area at minimum distances of 85 m and 100 m, respectively. These swamps are not coincident with Type 1 or 2 geological structures; however, the shrub swamps adjacent to the commencing end of LW1007 are located to the south of a Type 2 geological structure.

  It is unlikely therefore that surface cracking or deformation of the overlying soil and peat layers would occur at Japan Swamp and the shrub swamps located within the Carne Creek Catchment due to the proposed mining. The potential impacts on surface water, groundwater and ecology for these swamps are discussed by the other specialist consultants on the project.

  The shrub swamps along the Wolgan River are located at distances of greater than 300 m from the proposed mining area. Whilst these swamps are coincident with the Wolgan lineament zone (Type 1 geological structure), this zone will not be directly mined beneath by the proposed longwalls. Surface cracking or deformations are not expected due to their distances from the proposed mining area.

- The *Gardens of Stone National Park* is located north of the Study Area, at a distance of 1040 m from the proposed LW1011, at its closest point to the proposed mining area. The National Park could experience very small far-field horizontal and valley related effects; however, the associated strains are expected to be negligible.

  Surface cracking and deformation are not expected within the National Park due to its distance from the proposed mining area. This is supported by the observation that the furthest observed fracture outside of longwall mining in the NSW coalfields is 415 m. The potential impacts on surface water, groundwater and ecology are discussed by the other specialist consultants on the project.

  The longwall series is proposed to be extracted towards the National Park which allows for an adaptive management approach. The far-field and valley closure effects can be monitored, as longwalls are progressively mined towards the National Park, allowing an ongoing review of the observed versus predicted movements.

- There are unsealed roads and tracks located directly above the proposed mining area. It is expected that these roads could be maintained in safe and serviceable condition throughout the mining period using normal road maintenance techniques.

- Existing and proposed infrastructure and services will be constructed to support the mining activities. Management plans will be developed by Angus Place for these colliery-owned infrastructure and services, so that they can be maintained in safe and serviceable conditions throughout the mining period.

- There are nine Aboriginal heritage sites identified within the Study Area based on the 600 m boundary. All these sites comprise rock shelters with deposits. Only one site is located directly above the proposed mining area.

Site Ref. 45-1-0084 is located directly above the proposed LW1006. The extraction of this longwall is likely to result in fracturing of the exposed bedrock along the ridgeline and, if the rock is marginally stable, this could then result in rockfalls or instabilities. It has been assessed that the potential for adverse impacts on Site 45-1-0084, including fracturing and movement on existing bedding planes and joints, is approximately 10 %. The fracturing and movement could result in rockfalls where the rock is marginally stable. The potential for rockfalls at this site is considered to be less than 10 %.

The remaining Aboriginal heritage sites are predicted to experience less than 20 mm vertical subsidence. It is unlikely that the sites located outside the proposed mining area would experience adverse impacts due to the proposed longwalls.

- The survey control marks located directly above the proposed longwalls could experience the full range of predicted subsidence effects. Other survey marks located outside the proposed mining area could experience small far-field horizontal movements. It may be necessary on the completion of the proposed longwalls, 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 should be read in conjunction with the assessments provided by the other specialist consultants on the project and the findings in all other relevant reports.

CONTENTS

Tables

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

Figures

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

Drawings

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

1.1. Background

Angus Place Colliery (Angus Place) is a joint venture operation owned by Centennial and SK Kores. The colliery is located in the Western Coalfield of New South Wales (NSW), within the Newnes State Forest, north-west of the village of Lidsdale.

Centennial has completed underground mining at Angus Place on the western side of the Wolgan River. The previous underground mining in the Lithgow Seam includes Longwalls 1 to 10, Longwalls 11 to 13, Longwalls 16 to 24, Longwalls 25 to 26N, Longwall 900W and Longwalls 920 to 980. Springvale Colliery has also completed longwall mining in the Lithgow Seam, to the south of Angus Place, including Longwalls 401 to 421. The locations of some of these existing longwalls are shown in Drawing No. MSEC1046-01, in Appendix D.

Longwall 910N (LW910N) at Angus Place has been approved but it has not yet been extracted. This longwall is located approximately 500 m west of the Wolgan River, as shown in Drawing No. MSEC1046-01. The predicted subsidence effects and assessed impacts for LW910N are provided in the report by Ditton Geotechnical Services (DgS, 2010). The predicted subsidence effects due to this future longwall have been considered in the assessments provided in this report.

Centennial previously prepared an Environmental Impact Statement (EIS) in 2014 for proposed longwall mining on the eastern side of the Wolgan River and to the north of Springvale Colliery, referred to as the *Angus Place Mine Extension Project* (APMEP) for the State Significant Development (SSD) 5602 application. The mine plan in the EIS comprised 19 longwalls in the Lithgow Seam. Mine Subsidence Engineering Consultants previously prepared Report No. MSEC593 (Rev. C) which provided the predicted subsidence effects and assessed impacts in support of the EIS.

Angus Place was subsequently placed on care and maintenance in March 2015.

Centennial is now seeking approval to extract the proposed Longwalls 1001 to 1015 (LW1001 to LW1015) in the Lithgow Seam, over the same mining area previously submitted in the APMEP EIS. These currently proposed longwalls are on the eastern side of the Wolgan River and to the north of Springvale Colliery, as for the previously proposed longwalls adopted for the APMEP.

The comparison between previously proposed longwalls adopted in the APMEP EIS (MSEC593) and the currently proposed longwalls for the Amended Project Report (MSEC1046) is provided in Fig. 1.1. The two longwalls layouts cover similar extents; however, additional longwalls were previously proposed in the EIS to the south and north of the current layout. Whilst the previous layout comprised 19 longwalls, the first six longwalls had void widths of 260 m and 290 m and the following 13 longwalls had void widths of 360 m. The currently proposed layout comprises longwalls each with a void width of 360 m.

Centennial is now preparing an Amended Project Report for the proposed LW1001 to LW1015. MSEC has now been commissioned by Centennial to:

- prepare subsidence predictions for the proposed LW1001 to LW1015;
- identify the natural and built features in the vicinity of the proposed longwalls;
- provide predicted subsidence effects for each of these surface features;
- prepare impact assessments, in conjunction with other specialist consultants, for each of the natural and built features; and
- provide recommend management strategies and monitoring.

This report has been prepared to support the Amended Project Report for SSD 5602 for the proposed LW1001 to LW1015 which will be submitted to the Department of Planning, Industry and Environment (DPIE).

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

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

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

Chapter 4 provides the maximum predicted subsidence effects resulting from the extraction of the proposed longwalls LW1001 to LW1015.

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

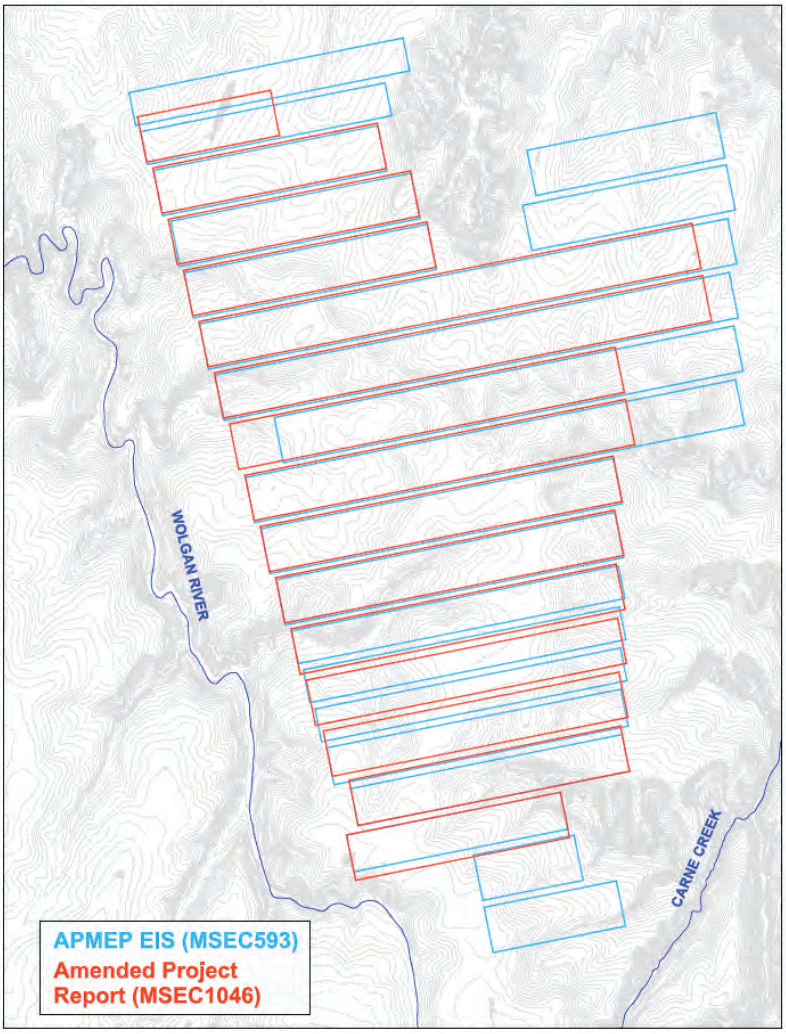

Fig. 1.1 Comparison of the longwalls adopted in the APMEP EIS and Amended Project Report

This report also provides information to satisfy the Director General Requirements for issues relating to subsidence, which has been summarised Table 1.1.

Table 1.1 Director General Requirements (DGRs) relating to subsidence

DGRs for subsidence	Section reference
"The EIS must address the following specific issues:	
• *Subsidence – including a detailed quantitative and qualitative assessment of the potential conventional and non-conventional subsidence impacts of the development that includes:*	
➢ *the identification of the natural and built features (both surface and subsurface) within the area that could be affected by subsidence, and an assessment of the respective values of these features;*	Table 2.1 provides a summary of the natural and build features identified in the area; and Chapters 5 and 6 provide details of these features.
➢ *accurate predictions of the potential subsidence effects and impacts of the development, including a robust sensitivity analysis of these predictions;*	Sections 3.5 and 3.6 describe the subsidence prediction model and the method of calibration; and Sections 3.6 and 3.7 describe the reliability of these prediction methods.
➢ *a detailed assessment of the potential environmental consequences of these effects and impacts on both the natural and built environment, paying particular attention to those features that are considered to have significant economic, social, cultural or environmental values; and*	Chapters 5 and 6 provide the impact assessments for each of the natural and built features.

DGRs for subsidence	Section reference
➢ *a detailed description of the measures that would be implemented to avoid, minimise, remediate and/or offset subsidence impacts and environmental consequences (including adaptive management and proposed performance measures);"*	Chapters 5 and 6 provide discussions and recommendations for the existing and proposed management strategies for the natural and built features.
"In addition, the EIS must include:"	
• *"a detailed assessment of the key issues specified below, and any other significant issues identified in this risk assessment, which includes:"*	
➢ *"an assessment of the potential impacts of all stages of the development, including any cumulative impacts, taking into consideration relevant guidelines, policies, plans and statutes"*	Section 5.1 summarises the natural features which have previously experience mine subsidence movements, with the cumulative impact assessments provided in subsequent sections in Chapter 5.

1.2. Mining geometry

The layout of LW1001 to LW1015 is shown in Drawings Nos. MSEC1046-01 and MSEC1046-02. The proposed longwalls are located east of the previously extracted longwalls at Angus Place and to the north of the completed longwalls at Springvale Colliery.

A summary of the dimensions for the proposed longwalls is provided in Table 1.2.

Table 1.2 Geometry of LW1001 to LW1015

Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
LW1001	2160	360	-
LW1002	1700	360	55
LW1003	2350	360	55
LW1004	2475	360	55
LW1005	2585	360	55
LW1006	2695	360	55
LW1007	2805	360	55
LW1008	3030	360	55
LW1009	3065	360	55
LW1010	3885	360	55
LW1011	3920	360	55
LW1012	1935	360	55
LW1013	1925	360	55
LW1014	1785	360	55
LW1015	1060	360	55

The lengths of longwall extraction excluding the installation headings are approximately 9 m less than the overall void lengths provided in Table 1.2. The longwall face widths excluding the first workings are typically 350 m. The longwalls will be extracted towards the main headings (i.e. from the east to the west).

1.3. Surface and seam levels

The surface level contours are shown in Drawing No. MSEC1046-03.

LW1001 to LW1015 are located on the eastern side of the Wolgan River and on the western side of Carne Creek. A north-south tending ridgeline crosses above LW1001 to LW1009. The natural surface falls towards the Wolgan River in the western part of the mining area and towards Carne Creek in the eastern and northern parts of the mining area.

The surface elevations directly above the proposed longwalls vary between a minimum of 1010 metres above Australian Height Datum (mAHD) above the commencing (i.e. eastern) end of LW1013 and a maximum of 1175 mAHD above the eastern part of LW1008.

LW1001 to LW1015 are proposed to be extracted in the Lithgow Seam. The seam floor contours, seam thickness contours and depth of cover contours are shown in Drawings Nos. MSEC1046-04, MSEC1046-05 and MSEC1046-06, respectively.

The floor of the Lithgow Seam generally dips from the west to the east. The average seam dip across the proposed mining area is approximately 2 % (i.e. 1 in 50). The seam dip is relatively uniform over the lengths of the proposed longwalls.

The thickness of the Lithgow Seam within the proposed mining area varies between 1.8 m and 3.9 m. The seam is thickest in the south-western part of the proposed mining area and thinner in the eastern and northern parts of the mining area.

The existing longwall equipment from Springvale Colliery will be utilised for LW1001 to LW1008 and it has an available mining height ranging between 2.8 m and 3.4 m. New longwall equipment will then be utilised for LW1009 to LW1015 which will have an available mining height ranging between 1.5 m and 2.5 m. A summary of the proposed mining heights, based on the seam thickness and available mining heights, is provided in Table 1.3.

Table 1.3 Seam thicknesses, available mining heights and proposed mining heights

Longwalls	Longwall equipment	Proposed mining height (m)
LW1001 to LW1008	Existing	2.8 to 3.4
LW1009 to LW1015	New	1.9 to 2.5

The depths of cover above the proposed longwalls vary between 270 m and 450 m. The lower depths of cover occur along the drainage lines above the finishing (i.e. western) ends of LW1005, LW1009, LW1010 and LW1012. The higher depths of cover occur along the ridgeline above LW1008. The average depth of cover across the proposed mining area is 370 m.

The natural surface and the Lithgow Seam are illustrated along Sections 1 to 3 in Fig. 1.2 to Fig. 1.4, respectively. Section 1 is north-south cross-section through LW1001 to LW1014. Sections 2 and 3 and long-sections along the centrelines of LW1005 and LW1011, respectively. The locations of these sections are shown in Drawings Nos. MSEC1046-03 to MSEC1046-05. The Type 1 and 2 lineaments indicated in these figures are also shown in Drawing No. MSEC1046-07.

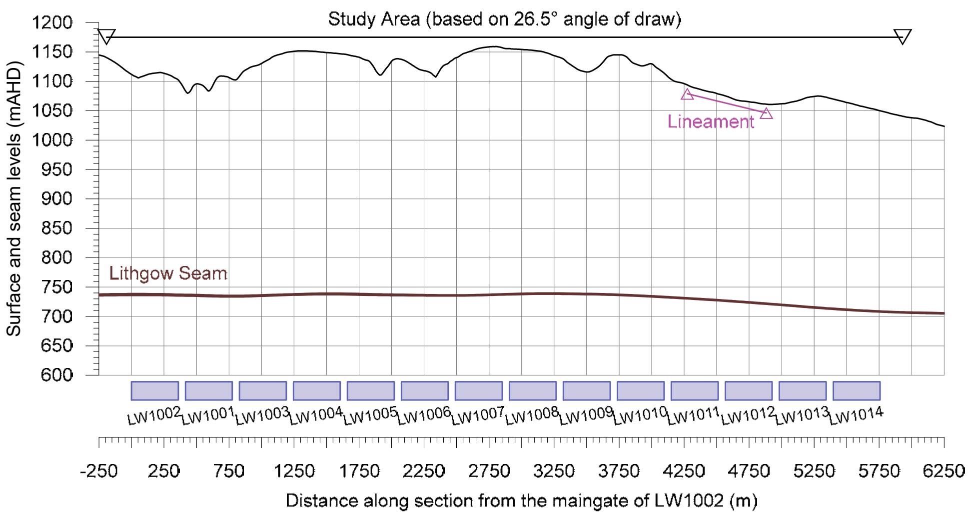

Fig. 1.2 Surface and seam levels along Section 1 (cross-section)

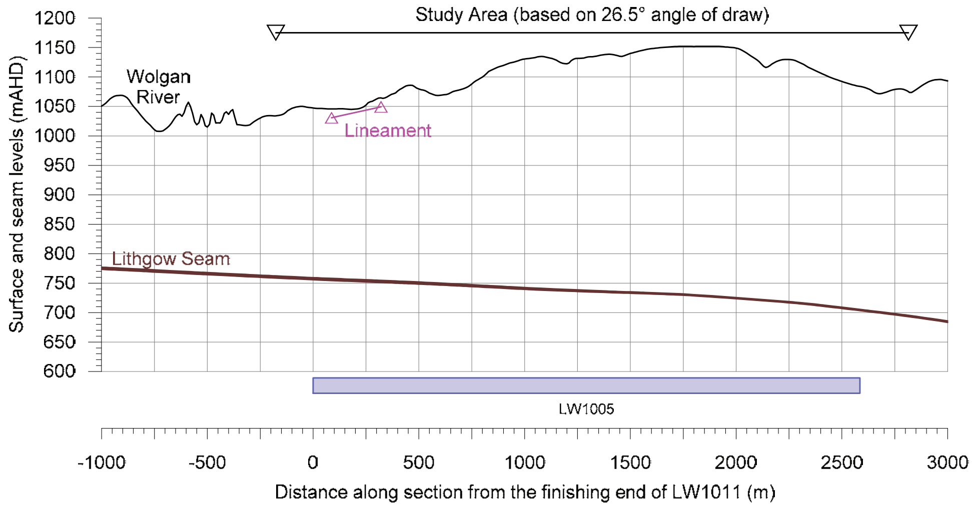

Fig. 1.3 Surface and seam levels along Section 2 (long-section through LW1005)

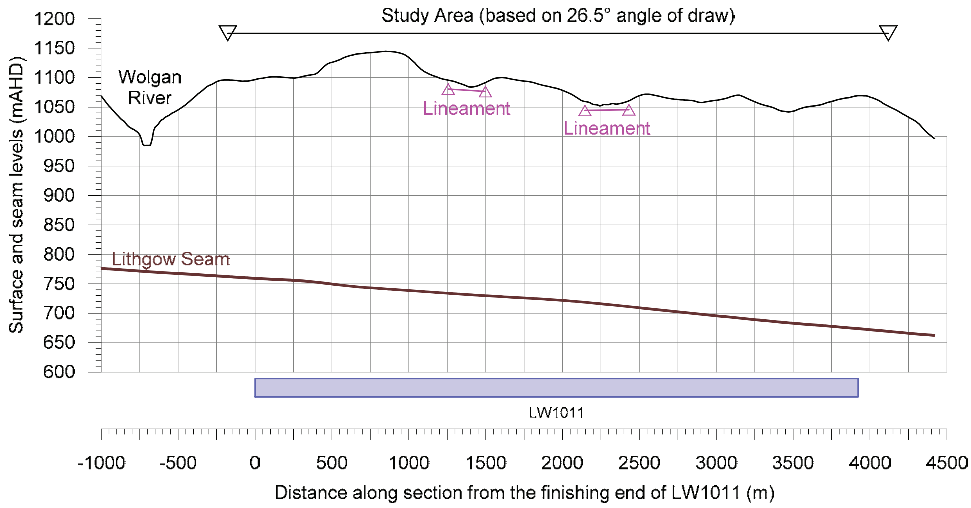

Fig. 1.4 Surface and seam levels along Section 3 (long-section through LW1011)

1.4. Geological details

Angus Place lies in the south-western part of the Western Coalfield of the Sydney Basin. A typical stratigraphic section is provided in Fig. 1.5 (Source: Centennial). The western coalfield mainly consists of relatively flat-lying rocks of Permian and Triassic age. The Upper Permian Illawarra Coal Measures are overlain by the sandstones of the Triassic Narrabeen Group, with interbedded shale and siltstone layers.

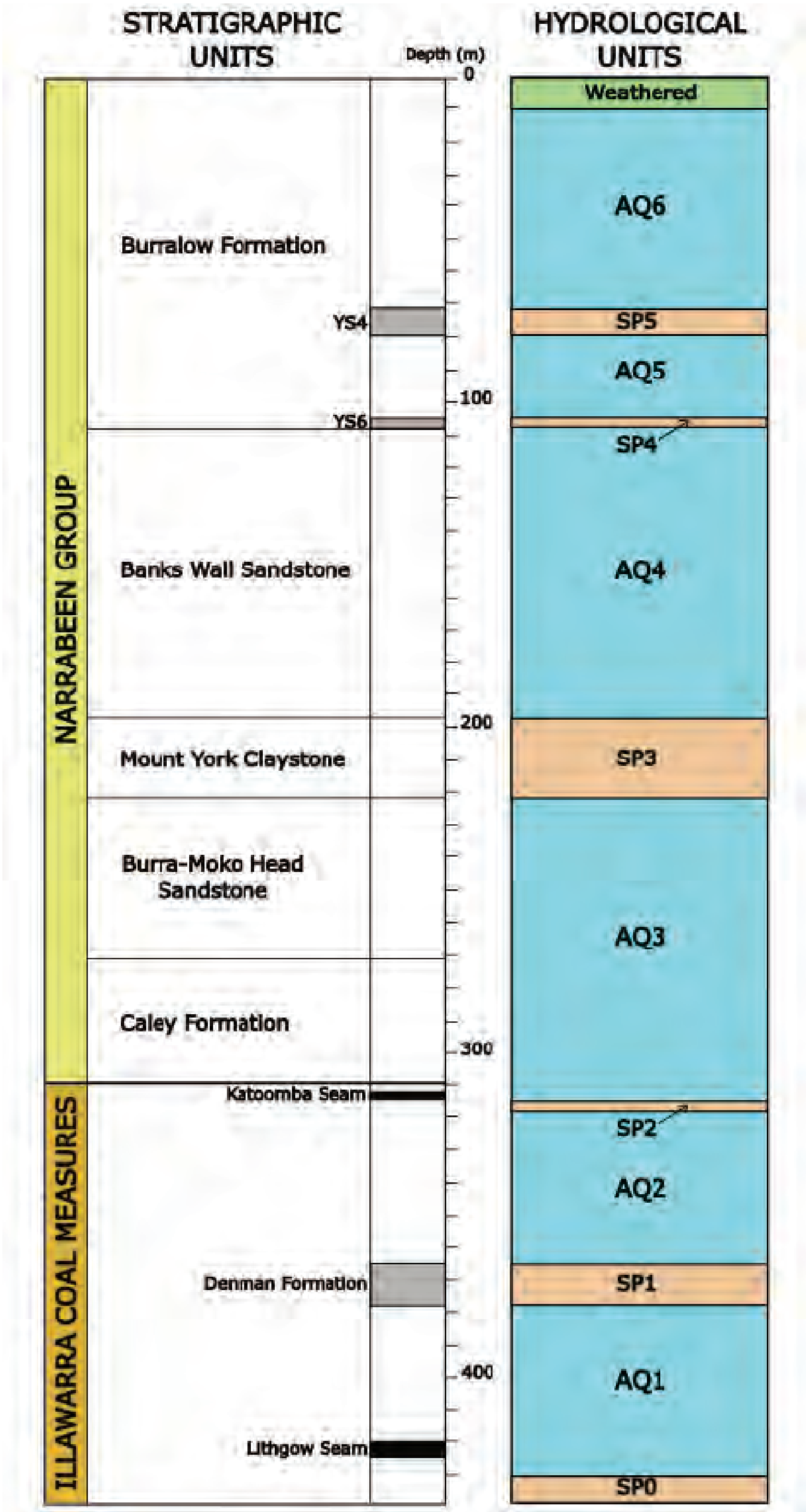

Fig. 1.5 Typical stratigraphic section of the Western Coalfield (Source: Centennial)

The Lithgow/Lidsdale Seam lies within the Cullen Bullen Subgroup of the Illawarra Coal Measures with a combined thickness of about 7 m. It is proposed that only the Lithgow Seam will be extracted having a thickness ranging between 1.9 m and 3.9 m within the proposed mining area. The floor of the Lithgow Seam comprises thinly interbedded sandstone and siltstone layers.

The immediate roof strata layer comprises the Long Swamp Formation that consists of thinly interbedded coal, shale, siltstone, sandstone and mudstone layers. The overlying formations include the Newnes, Glen Davis and Baal Bone Formations, which comprise interbedded siltstone, sandstone and minor coal layers.

Thicker massive conglomerate sandstone units of the Burra-Moko Head Formation and the Banks Wall Sandstone sit about 110 m and 200 m, respectively, above the Lithgow Seam. These higher strength units have been observed to reduce subsidence ground movements above previous extracted longwalls at Angus Place and Springvale Collieries.

The Mount York Claystone separates the Burra-Moko Head Formation and the Banks Wall Sandstone and comprises claystone with interbedded sandstone layers. This unit has a thickness typically varying between 4 m and 35 m, with an average thickness of around 22 m within the proposed mining area. The Mount York Claystone has been found to act as an aquitard.

A composite graphic section for boreholes AP1102SP and AP1204PT is provided in Fig. 1.6 (Palaris, 2013a). The locations of these boreholes are shown in Drawing No. MSEC1046-07.

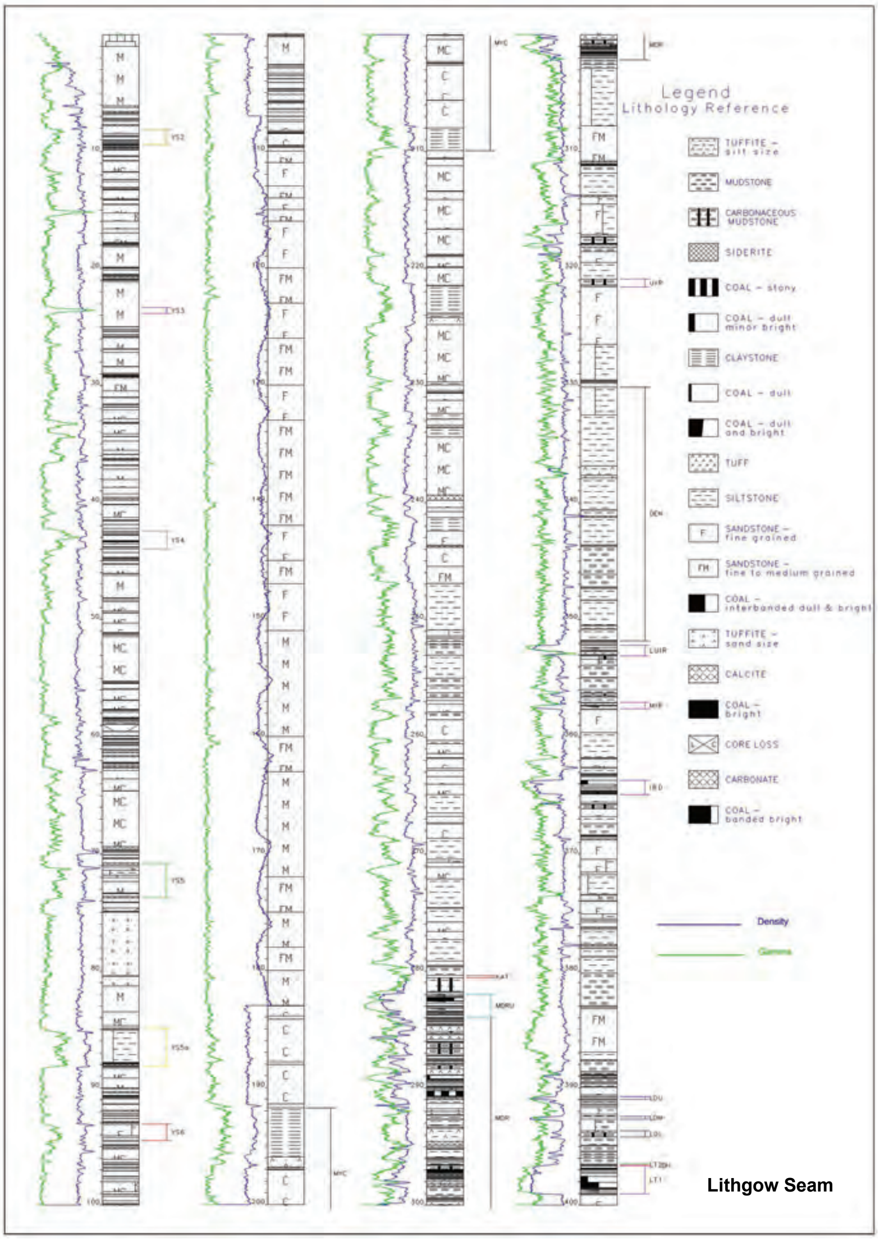

Fig. 1.6 Composite graphic section – Boreholes AP1102SP and AP1204PT (Palaris, 2013a)

The surface lithology in the area is shown in Fig. 1.7, which shows the proposed longwalls overlaid on the *Geological Series Sheets 8930 and 8931*, published by the Department of Mineral Resources (DMR, 1992), now known as the Resources Regulator. The surface lithology above the proposed longwalls comprises the Burralow Formation of the Triassic Narrabeen Group (Tn).

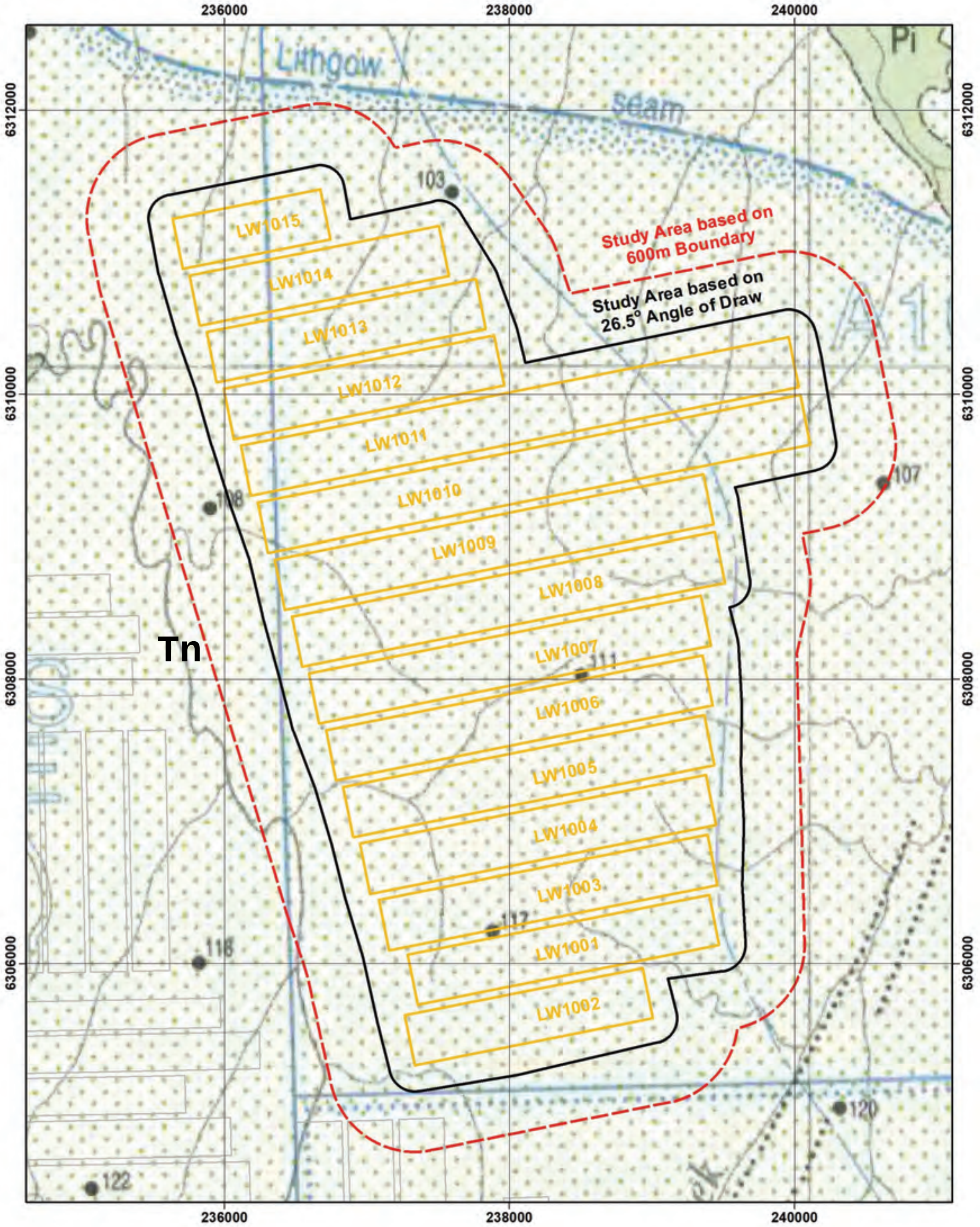

Fig. 1.7 LW1001 to LW1015 overlaid on Geological Map Series 8930 and 8931 (DMR, 1992)

An investigation of the geological structures within the proposed mining area was originally undertaken by Palaris (2013b). The locations of the main geological structures are shown in Drawing No. MSEC1046-07. These structures have been categorised into four types, as described in the report by Palaris (2013b), which have been reproduced below:

- "*Type 1 – are major geological structural zones characterised by their size and length and can be projected for many kilometres. The zones: Have a strong surface expression that includes linear segments of deep valleys/gorges, however, these zones may also extend beneath surface plateaux; Can be mapped from aerial photos (as per the work of Shepherd); Are recognised (in part) as basement features by SRK studies; Have a NNE to NNW trend; Are recognised in underground workings as faulted or highly fractured ground. Typically these occur as fault clusters with variable orientation – occurring within the structure zone but not necessarily related to the orientation of the zone. The density of faulting is noted to increase near the intersection of other basement structure zones.*" ... and that ... "*The Type 1 features are very confidently predicted*".

- *"Type 2 structures have evidence of geological structure in the basement and mine workings except that the structure zone and the overlying topographic relief alignment extend only a limited distance – perhaps one or two kilometres. These segments of linear surface relief are not part of a longer surface lineament. In the immediate workings of Angus Place and Springvale these are uncommon."*
- *"Type 3 – these geological structures are predicted from mapped underground structures (faults, joint zones or stress zones), and basement features. There is no associated surface topographic relief forming part of an alignment."*
- *"Type 4 – identified basement structures"* ... which have ... *"no corresponding structures recognised in mine workings nor is it associated with surface relief. This type of structure prediction is the most common and is regarded as benign with respect to its impact on mining."*

There is one *Type 1* structure that has been identified within the proposed mining area. The NNE trending lineament is coincident with a tributary to Carne Creek above LW1010 to LW1013. There are other Type 1 structures located outside and near to the proposed mining area, along the alignments of the Wolgan River and Carne Creek.

The Wolgan lineament follows the alignment of this river and it is located to the west of the proposed longwalls. The southern extension of the Wolgan lineament trends NNE-SSW and it crosses above the existing longwalls at Angus Place and Springvale Collieries. The Carne Creek lineament follows this creek and it also crosses above the existing longwalls at Springvale Colliery.

There are three short *Type 2* structures which have been identified within the proposed mining area comprising the:

- NW trending lineament which is coincident with a tributary to the Wolgan River and Tri Star Swamp above the western end of LW1005;
- ENE trending lineament which is coincident with a tributary to Carne Creek above the eastern ends of LW1006 and LW1007; and
- NNE trending lineament which is coincident with a tributary to Carne Creek above the mid-lengths of LW1010 and LW1011 and above the eastern ends of LW1012 and LW1013.

As described in the report by Palaris (2013b), these "*Type 1 and Type 2 structure zones are interpreted to be structures that penetrate from the basement strata, through the coal measure strata, to the surface*". It is likely, therefore, that these structures will affect the mine subsidence surface effects due to the extraction of the proposed longwalls. Increased surface subsidence effects have previously been observed at Angus Place and Springvale Collieries. The calibration of the subsidence prediction model for the increased subsidence and strain at the lineaments is discussed in Section 3.6.2.

The *Type 3* and *Type 4* structures have been identified across the extents of the proposed longwalls. As described in the report by Palaris (2013b), the "*Type 3 structure zones are noted to occur only to Lithgow seam level and Type 4 structure zones occur within the basement*". It is unlikely, therefore, that these structures will have a significant influence on the mine subsidence surface effects due to the extraction of the proposed longwalls.

Further details of the geological structures identified within the Study Area are provided in the report by Palaris (2013b).

2.1. Definition of the Study Area

The Study Area is defined as the surface area that could be affected by the extraction of the proposed LW1001 to LW1015. Two areas have been considered in this report, being the *Study Area based on the 26.5° angle of draw* and the *Study Area based on the 600 m boundary*.

The Study Area based on the 26.5° angle of draw represents the minimum extent for the assessments for the conventional ground movements (i.e. vertical subsidence and its associated effects). Low level conventional ground movements can extend beyond the 26.5° angle of draw. The natural and built features located outside the 26.5° angle of draw, which could experience these low level movements and could be sensitive to these movements, have also been included in the assessments provided in this report.

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

The extent of the Study Area based on the 26.5° angle of draw has been calculated by combining the areas bounded by the following limits:

- a 26.5° angle of draw line from the extents of secondary extraction for LW1001 to LW1015; and
- the predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, due to the extraction of the proposed longwalls.

The depth of cover contours for the Lithgow Seam are shown in Drawing No. MSEC1046-06. The depths of cover within the proposed mining area vary between 270 m and 450 m. The 26.5° angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 135 m and 225 m around the limits of the secondary extraction areas.

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, has been determined using the calibrated Incremental Profile Method. The subsidence prediction model and its calibration are described in Chapter 3. The predicted subsidence contours due to the extraction of LW1001 to LW1015, including the 20 mm subsidence contour, are shown in Drawing No. MSEC1046-13.

The predicted total 20 mm subsidence contour is located entirely within the 26.5° angle of draw. A line has therefore been drawn defining the Study Area based upon the 26.5° angle of draw and it is shown in Drawings Nos. MSEC1046-01 and MSEC1046-02.

The Study Area based on a 600 m boundary around the extents of the proposed longwalls is also shown in these drawings. The natural and built features that are located within the 600 m boundary that are predicted to experience valley related effects and could be sensitive to these movements have been included in the assessments provided in this report. These features include the streams and the shrub swamps.

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

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

A number of the major natural and built features within the Study Area can be seen in the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA), Series Sheets 8930 and 8931. The proposed longwalls and the Study Area have been overlaid on an extract of this CMA map in Fig. 2.1.

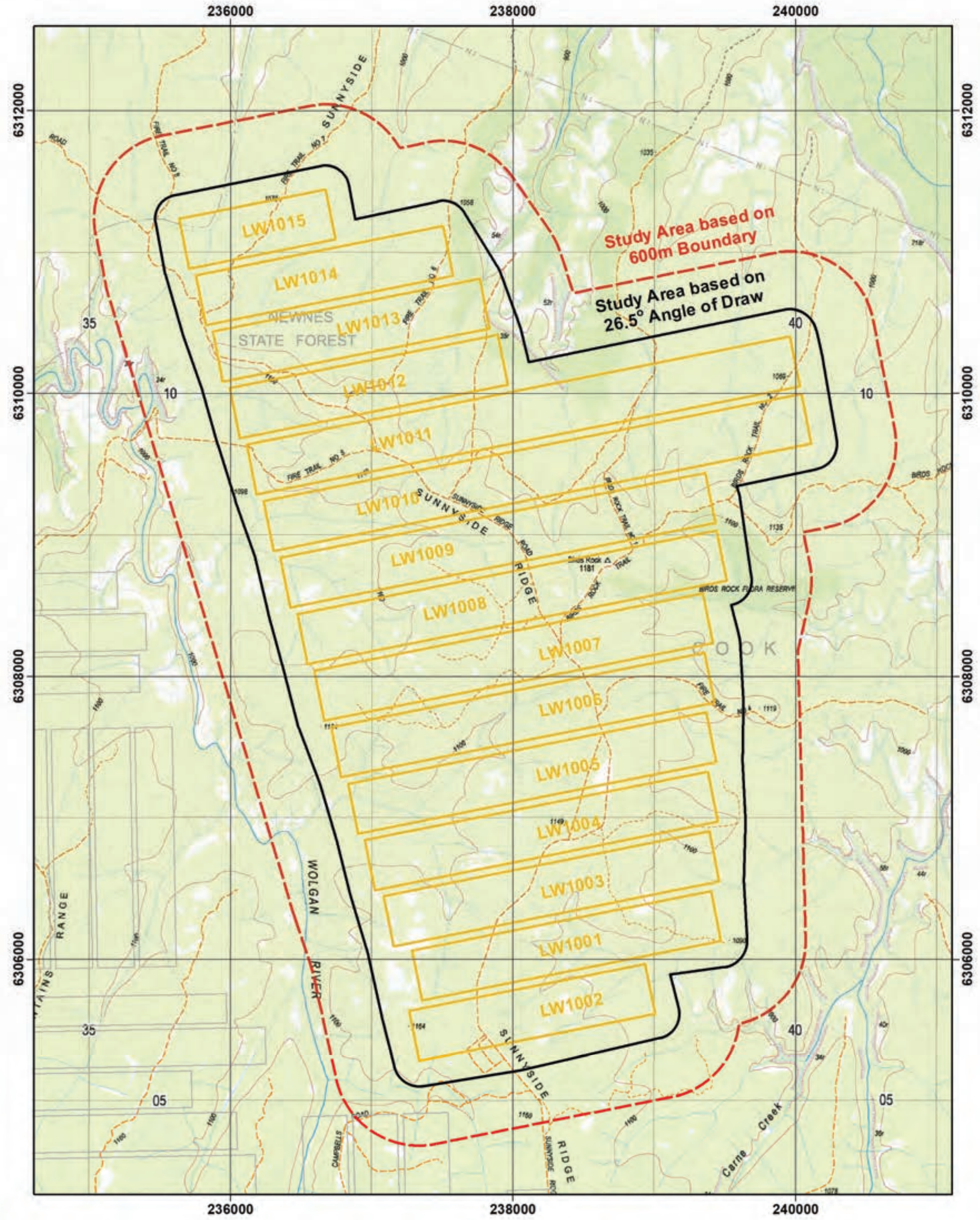

Fig. 2.1 LW1001 to LW1015 overlaid on CMA Map Series Sheets 8930 and 8931

A summary of the natural and built features within the Study Area is provided in Table 2.1. The locations of these features are shown in Drawings Nos. MSEC1046-08 to MSEC1046-12. The descriptions, predictions and impact assessments for each of the natural and built features are provided in Chapters 5 and 6.

Table 2.1 Natural and built features within the Study Area

Item	Within Study Area	Section Number
NATURAL FEATURES		
Drinking Water Catchment Areas or Declared Special Areas	×	
Streams	✓	5.2 to 5.4
Aquifers or Known Groundwater Resources	✓	5.5
Springs or Groundwater Seeps	✓	5.6
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.7
Steep Slopes	✓	5.8
Escarpments	×	
Land Prone to Flooding or Inundation	×	
Swamps or Wetlands	✓	5.11
Water Related Ecosystems	✓	5.12
Threatened or Protected Species	✓	5.13
Lands Defined as Critical Habitat	×	
National Parks	×	5.14
State Forests	✓	5.15
State Recreation or Conservation Areas	×	
Natural Vegetation	✓	5.16
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	✓	5.17
PUBLIC UTILITIES		
Railways	×	
Roads (All Types)	✓	6.2
Bridges	×	
Tunnels	×	
Culverts	✓	6.2
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	×	
Telecommunication Lines or Associated Plants	×	
Water Tanks, Water or Sewage Treatment Works	×	
Dams, Reservoirs or Associated Works	×	
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	×	
Shopping Centres	×	
Community Centres	×	
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

Item	Within Study Area	Section Number
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	×	
Farm Buildings or Sheds	×	
Tanks	×	
Gas or Fuel Storages	×	
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Fences	✓	6.4
Farm Dams	×	
Wells or Bores	✓	6.5
Any Other Farm Features	×	
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Factories	×	
Workshops	×	
Business or Commercial Establishments or Improvements	×	
Gas or Fuel Storages or Associated Plants	×	
Waste Storages or Associated Plants	×	
Buildings, Equipment or Operations that are Sensitive to Surface Movements	×	
Surface Mining (Open Cut) Voids or Rehabilitated Areas	×	
Mine Related Infrastructure Including Exploration Bores and Gas Wells	✓	6.7
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL SIGNIFICANCE	✓	6.8
AREAS OF HISTORICAL SIGNIFICANCE	×	
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.9
RESIDENTIAL ESTABLISHMENTS		
Houses	×	
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

3.1. Introduction

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

3.2. Overview of conventional subsidence effects

The normal ground movements resulting from the extraction of longwalls are referred to as conventional or systematic subsidence effects. These 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 beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.
- **Tilt** is the change in the slope of the ground as a result of differential subsidence and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of curvature** with the units of *1/kilometres (km^{-1})*, but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.
- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile strains** occur where the distances between two points increase and **Compressive strains** occur when the distances between two points decrease. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

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

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

3.3. Far-field movements

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

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

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

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

3.4. Overview of non-conventional subsidence 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 the depth of cover is greater than 300 m, such as the case over a large part of the Study Area, the observed subsidence profiles along monitoring lines are generally smooth. Where the depth of cover is less than 100 m, the observed subsidence profiles along monitoring lines are generally irregular. Very irregular subsidence movements are observed with much higher tilts, curvatures and strains at very shallow depths of cover where the collapsed zone above the extracted longwalls extends up to or near to the surface.

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

- geological structures or changes in surface geology;
- steep topography; and
- valley related mechanisms.

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

3.4.1. Non-conventional subsidence movements due to 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, curvatures and strains.

Even though it may be possible to attribute a reason behind most observed non-conventional ground movements, there remain some observed irregular ground movements that 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 are being included statistically in the predictions and impact assessments, by basing these on the frequency of past occurrence of both the conventional and non-conventional ground movements and impacts. The analysis of strains provided in Section 4.4 includes those resulting from both conventional and non-conventional anomalous movements. The impact assessments for the natural and built features, which are provided in Chapters 5 and 6, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

3.4.2. Non-conventional subsidence movements due to steep topography

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

Further discussions on the potential for downslope movements for the steep slopes within the Study Area are provided in Section 5.8.

3.4.3. Valley related effects

The streams within the Study Area will be affected by valley related movements, which are commonly observed along streams in the NSW coalfields. Valley bulging movements are a natural phenomenon, resulting from the formation and ongoing development of the valley, as illustrated in Fig. 3.1. The potential for these natural movements are influenced by the geomorphology of the valley.

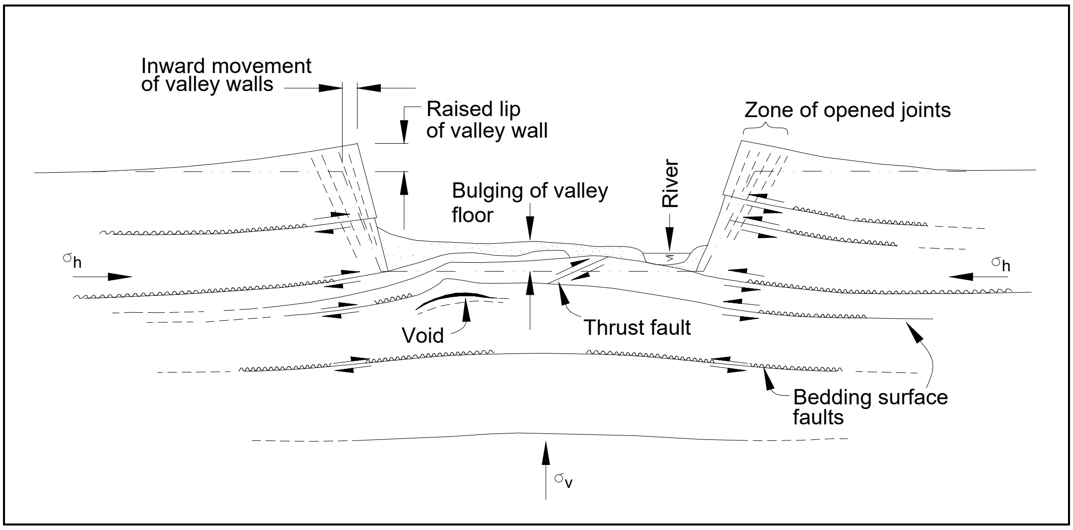

Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

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

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

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

The predicted valley related movements for the streams due to the proposed longwalls have been determined using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002), referred to as the 2002 ACARP method in this report. This method has been used for the previous studies at Angus Place and Springvale Collieries.

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

The predictions based on the 2002 ACARP method can be directly compared with the predictions provided in previous MSEC subsidence reports and with other case studies. This method has also been more widely used and tested than the more recent 2014 ACARP method. The assessments provided in this report, therefore, have been based on the predictions obtained using the 2002 ACARP method.

The reliability of the predicted valley related closure movements is discussed in Section 3.7.

The predicted strains resulting from valley related movements have been determined using the monitoring data for longwalls which have previously mined directly beneath and adjacent to streams at Angus Place and Springvale Collieries. The predicted valley related strains are discussed with the impact assessments for the streams provided in Chapter 5.

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

3.5. The Incremental Profile Method

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

The database consists of detailed subsidence monitoring data 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.

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

Based on the extensive empirical data, MSEC has developed standard subsidence prediction curves for each of the coalfields in NSW and Queensland. The predictions curves can then be further refined, for the local conditions, based on the available ground monitoring and geological data from the area. Discussions on the calibration of the IPM for the proposed longwalls at Angus Place are provided in Section 3.6.

The prediction of subsidence is a three stage process where, firstly, 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 of the longwalls in the series. In this way, subsidence predictions can be made anywhere above or outside the longwalls, based on the local surface and seam information.

For longwalls in the Western Coalfield, the maximum predicted incremental subsidence is initially determined, using the IPM subsidence prediction curves for a single isolated panel, based on the longwall void width (W) and the depth of cover (H). The incremental subsidence is then scaled, using the IPM subsidence prediction curves for multiple panels, based on the longwall series, longwall 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 Western Coalfield, including Angus Place and Springvale Collieries. The profile shapes are derived from the normalised subsidence profiles for monitoring lines where the mining geometry and overburden geology are reasonably similar to those for the proposed longwalls. The profile shapes can be further refined, based on local monitoring data, which is discussed further in Section 3.6.

The comparisons of the predicted total subsidence profiles obtained using the IPM with measured profiles show that this method provides reasonable, if not, slightly conservative predictions where the mining geometry and overburden geology are within the range of the empirical database. The method can also be further tailored to local conditions where ground monitoring data is available close to the mining area.

3.6. Calibration of the Incremental Profile Method

The IPM has been calibrated to local conditions using the ground monitoring data from Angus Place and Springvale Collieries, as well as from other nearby collieries in the Western Coalfield. This has been achieved by comparing the measured profiles along the available monitoring lines with the back-predicted profiles obtained using the standard IPM for the Western Coalfield. The standard model was then refined so that the back-predictions more closely matched those measured.

The initial calibration of the IPM was described in Report No. MSEC593 for the APMEP EIS. The initial review of the ground monitoring data from Angus Place and Springvale Collieries found that the maximum measured values of vertical subsidence were typically less than the maximum predicted values obtained using the standard IPM above each of the longwalls.

The values of vertical subsidence measured above the chain pillars, however, were slightly greater than the predicted values obtained using the standard IPM. This demonstrated that the actual components of pillar compression were greater than the components predicted by the model. The component of pillar compression in the standard model was then increased so that the back-predicted profiles along each monitoring line more closely match those measured.

The monitoring above the previously extracted longwalls at Angus Place and Springvale Collieries also showed that locally increased subsidence occurs in the locations of the Type 1 and Type 2 geological structure zones (i.e. surface lineaments). The following sections, therefore, provide discussions on the review of the IPM outside the locations of the surface lineaments and the calibration of the model in the locations of the surface lineaments.

3.6.1. Reviews of the IPM outside the surface lineaments

Summaries of the ground monitoring lines from Angus Place and Springvale Collieries that were used in the calibration of the IPM are provided in Table 3.1 and Table 3.2, respectively. The locations of these monitoring lines are shown in Drawing No. MSEC1046-01.

Table 3.1 Monitoring lines from Angus Place

Monitoring line	Longwalls	Void widths (m)	Pillar widths (m)	Depths of cover (m)	Width-to-depth ratios (W/H)	Seam thickness (m)
B-Line	LW920 to LW950	260 / 290	35 / 40	360 ~ 380	0.70 ~ 0.80	3.2 ~ 3.3
LW19 to LW24	LW19 to LW24	230 / 260	35	310 ~ 340	0.75 ~ 0.80	3.0 ~ 3.2
LW20, LW25 to LW26N	LW20, LW25 to LW26N	260	35	320	0.80	2.7 ~ 3.0
X-Line	LW11 to LW13	210	35	260 ~ 280	0.75 ~ 0.80	2.6

Table 3.2 Monitoring lines from Springvale Colliery

Monitoring line	Longwalls	Void widths (m)	Pillar widths (m)	Depths of cover (m)	Width-to-depth ratios (W/H)	Seam thickness (m)
B-Line	LW404 to LW409	265	40	300 ~ 380	0.70 ~ 0.85	3.3 (ave.)
	LW410 to LW415	315	40 ~ 45	330 ~ 420	0.75 ~ 1.0	2.6 ~ 3.6
	LW416 to LW421	260	45 / 60	330 ~ 420	0.60 ~ 0.75	2.8 ~ 3.2
M-Line	LW411 to LW413	315	45	380 ~ 400	0.80	2.6 ~ 3.6

The depths of cover above the proposed LW1001 to LW1015 vary between 270 m and 450 m. The lower depths of cover occur on the western side of the proposed mining area and the higher depths of cover occur on the eastern side of the mining area. The width-to-depth ratios for the proposed longwalls, therefore, vary between 0.8 and 1.3.

In the western part of the proposed mining area, the width-to-depth ratios typically vary between 1.0 and 1.3. This range is greater than the previously extracted longwalls at Angus Place and Springvale Collieries. The IPM has therefore been reviewed based on monitoring data from collieries located elsewhere in the Western Coalfield having a similar range of width-to-depth ratios.

The comparison of the measured and predicted profiles of vertical subsidence along a monitoring line from the Western Coalfield is illustrated in Fig. 3.2. The longwall width-to-depth ratios vary between 1.2 and 1.3 and the average mining height was 2.2 m.

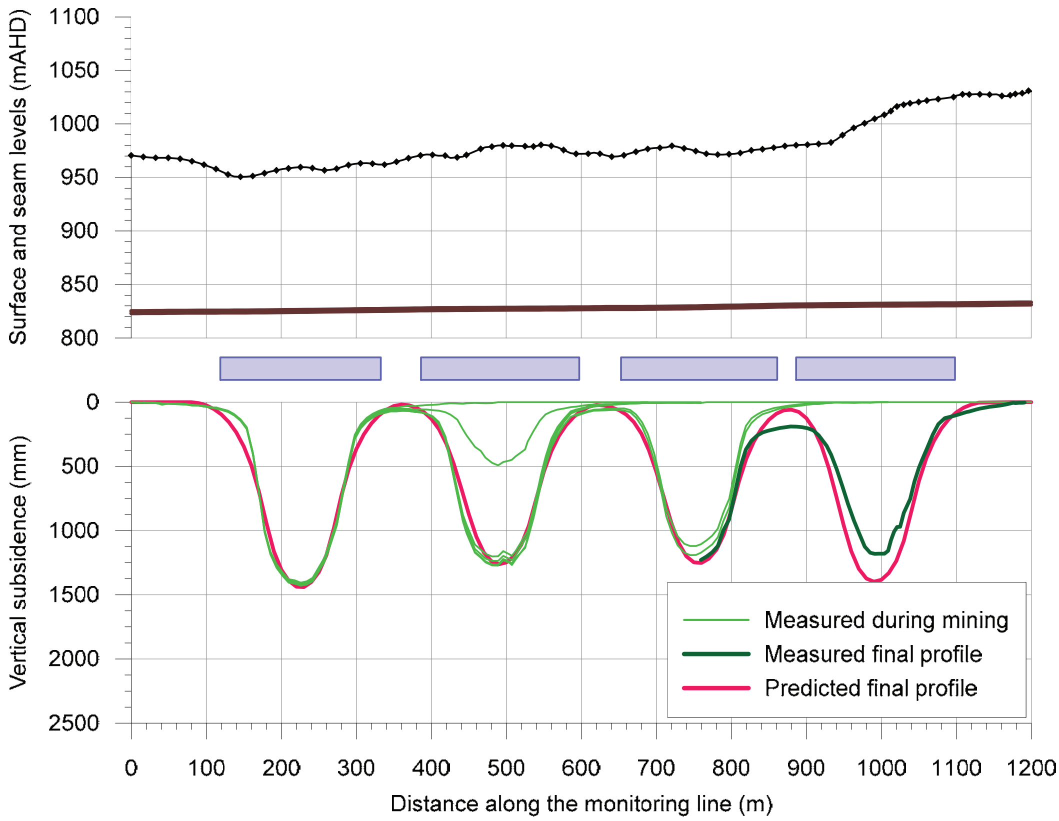

Fig. 3.2 Measured and predicted vertical subsidence along a monitoring line from the Western Coalfield above longwalls with width-to-depth ratios ranging between 1.2 and 1.3

The measured profile of vertical subsidence along this monitoring reasonably matches the predicted profile. The maximum measured values above each of the longwalls are similar to the maximum predicted values. The reason is the longwalls are near supercritical widths and, therefore, the vertical subsidence is close to the maximum achievable for single-seam mining conditions of 60 % to 65 % of the mining height.

Only low levels of vertical subsidence have been measured and predicted above each of the chain pillars. The reason is the longwalls are near supercritical widths and, therefore, the components of pillar compression are very low.

Similar comparisons were observed for other monitoring lines from the Western Coalfield with longwall width-to-depth ratios vary between 1.0 and 1.3.

In the eastern part of the proposed mining area, the width-to-depth ratios typically vary between 0.8 and 1.0. This range is similar to that for the previously extracted longwalls at Angus Place and Springvale Collieries. The IPM has therefore been reviewed based on monitoring data from these collieries.

The comparisons of the measured and predicted profiles of vertical subsidence at Angus Place are provided along the: B-Line in Fig. 3.3; LW19 to LW24 Line in Fig. 3.4; LW20 and LW25 to LW26N Line in Fig. 3.5; and X-Line in Fig. 3.6. The comparison of the profiles at Springvale Colliery are provided along the: B-Line in Fig. 3.7; and the M-Line in Fig. 3.8.

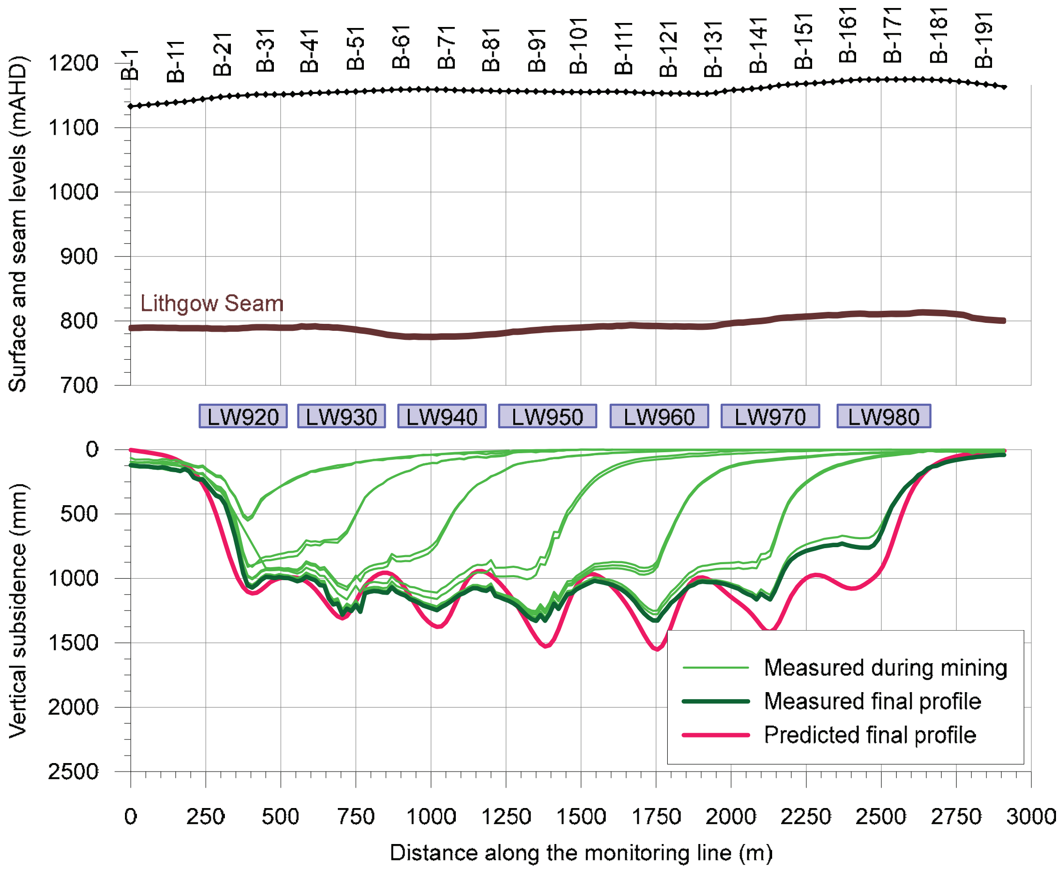

Fig. 3.3 Measured and predicted vertical subsidence along the B-Line above LW920 to LW980 at Angus Place

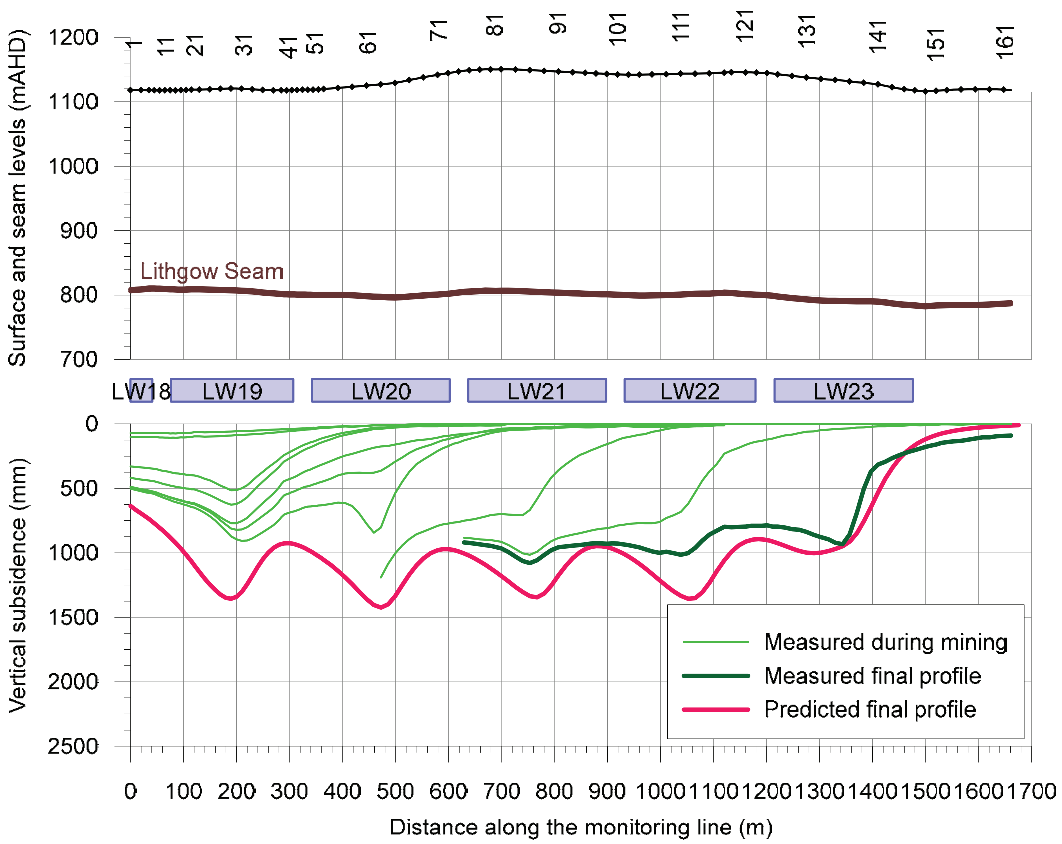

Fig. 3.4 Measured and predicted vertical subsidence along the LW19 to LW24 Line above LW18 to LW23 at Angus Place

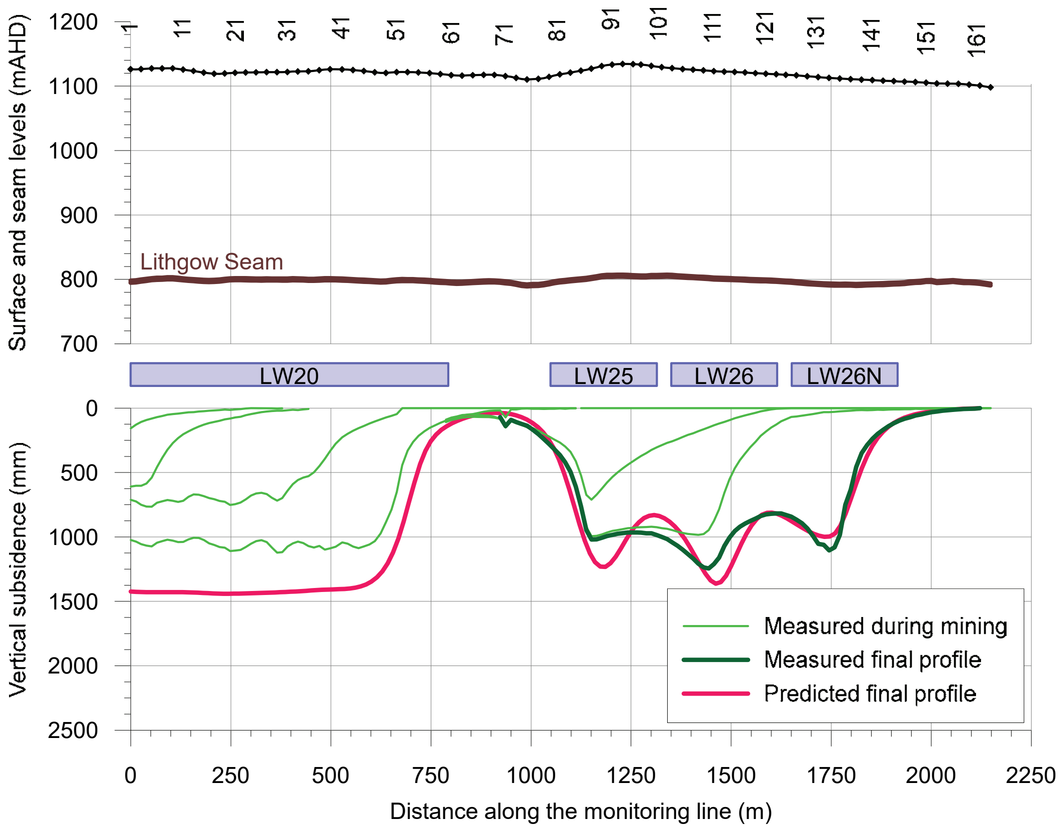

Fig. 3.5 Measured and predicted vertical subsidence along the LW20 and LW25 to LW26N Line above LW20 to LW26N at Angus Place

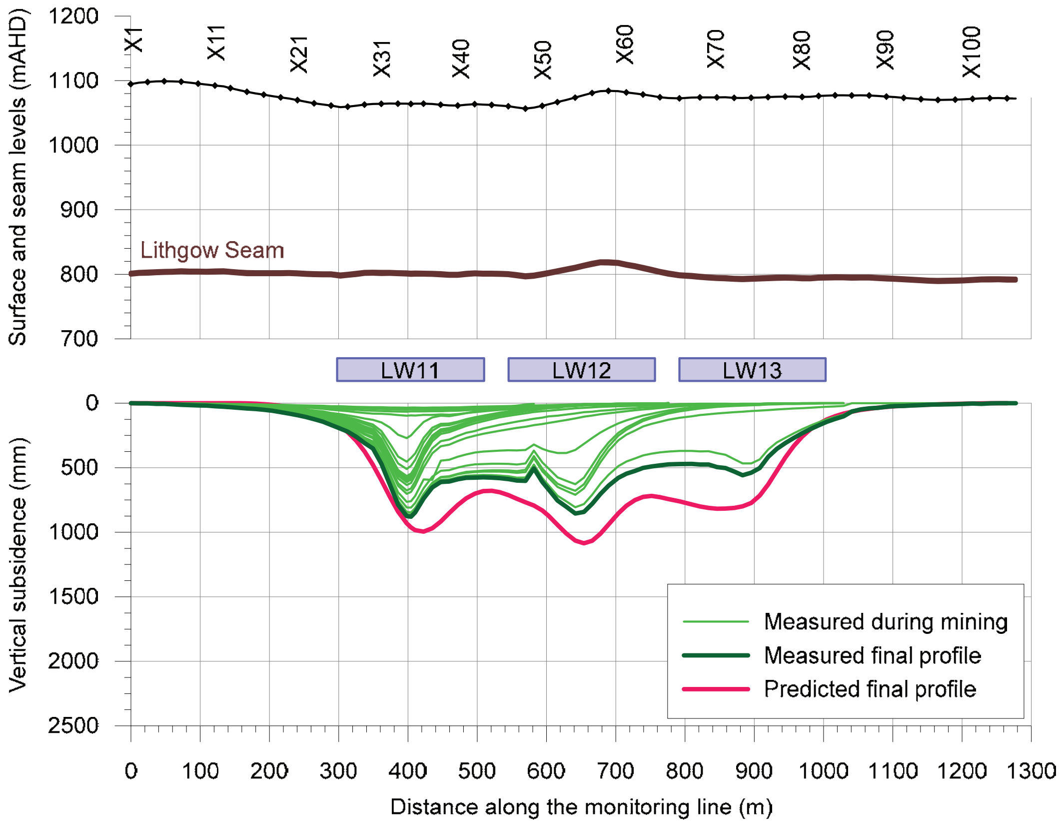

Fig. 3.6 Measured and predicted vertical subsidence along the X-Line above LW11 to LW13 at Angus Place

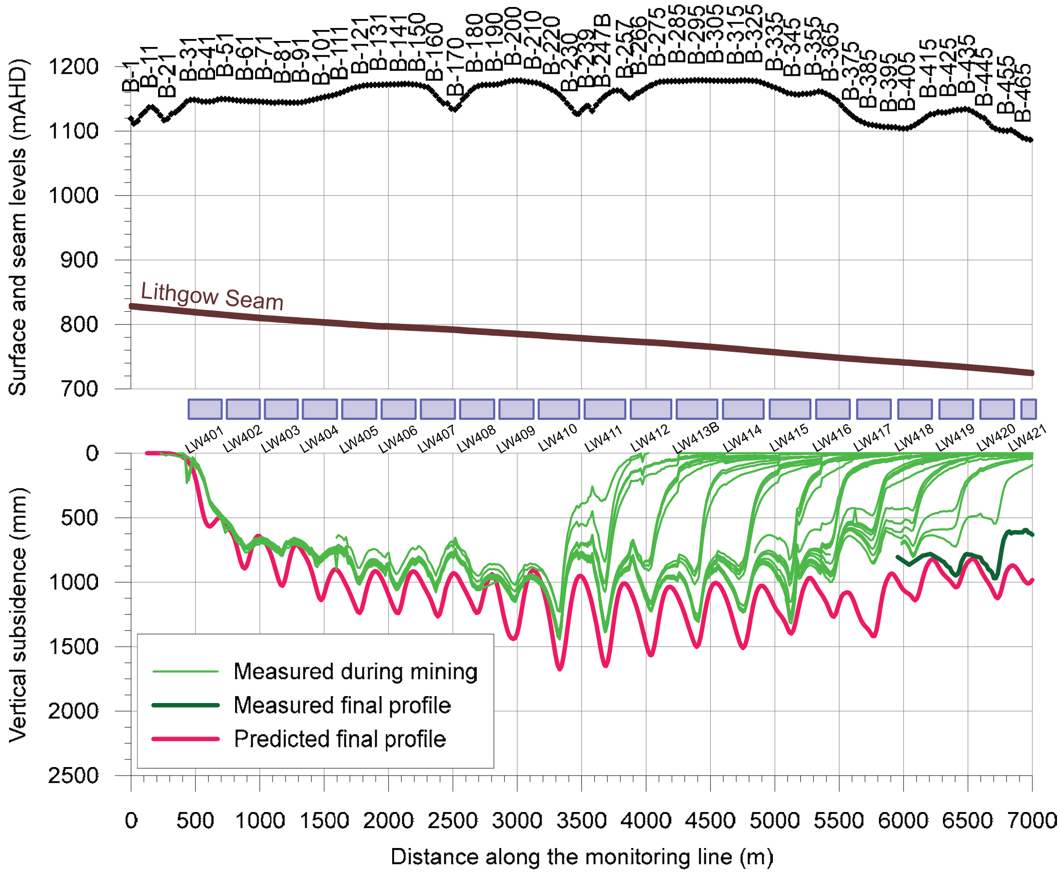

Fig. 3.7 Measured and predicted vertical subsidence along the B-Line aboveLW401 to LW421 at Springvale Colliery

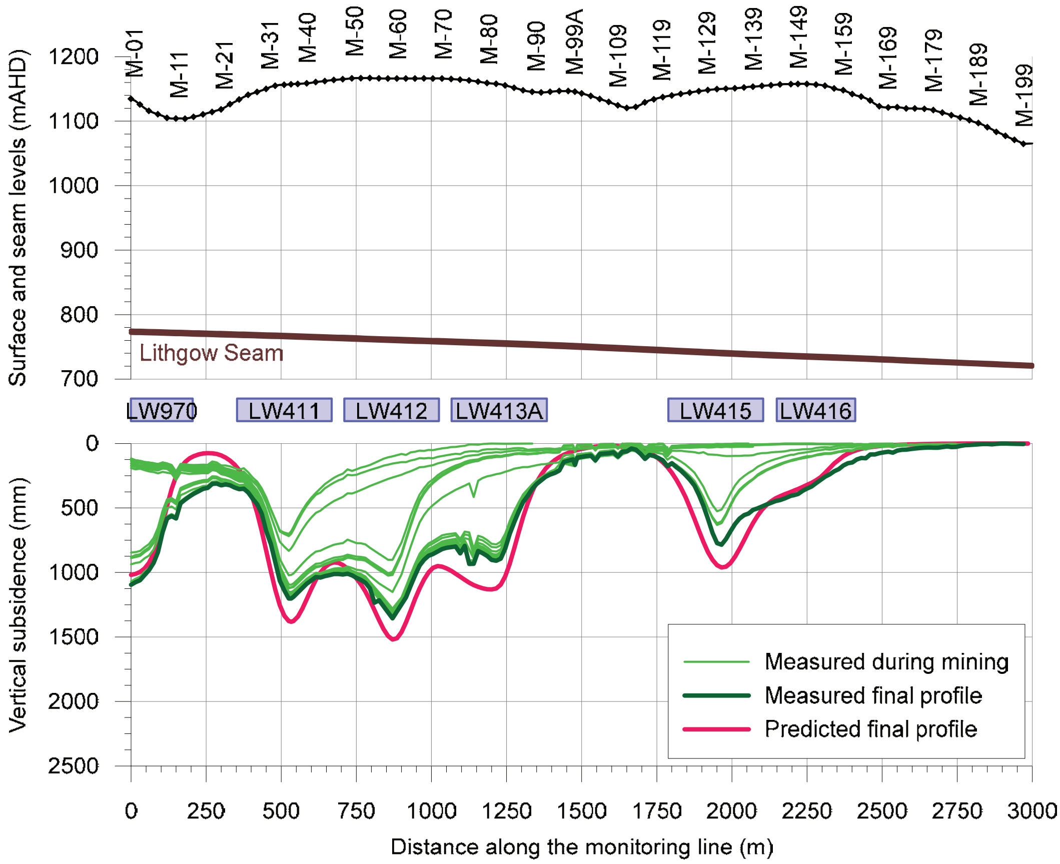

Fig. 3.8 Measured and predicted vertical subsidence along the M-Line above LW411 to LW416 at Springvale Colliery

The maximum measured vertical subsidence directly above each of the extracted longwalls are typically less than the maximum predicted values. The measured vertical subsidence is slightly greater than the predicted value above Angus Place LW26N (refer to Fig. 3.5) and above Angus Place LW970 along the M-Line (refer to Fig. 3.8). These exceedances are between 5 % to 10 % of the predicted values and, therefore, are in the order of accuracy of subsidence prediction methods of ±15 %.

The subsidence measured above some of the chain pillars are slightly greater than the predicted values. These exceedances are typically less than 15 % which is generally accepted for subsidence prediction methods. Also, slightly under-predicting the vertical subsidence above the chain pillars results in slightly increased predicted tilts and this parameter is generally considered more important than the minimum vertical subsidence when assessing the potential for impact.

In some cases, the low level subsidence has been measured outside of the mining area that is slightly greater than the predictions. However, the exceedances are generally less than 50 mm and these are accompanied by only low levels of tilt, curvature and strain. Localised movements have been observed in valleys located outside of the extracted longwalls. These valley related effects have been addressed separately, as described in Section 3.7.

The measured profiles of vertical subsidence reasonably match the predicted profiles, although the magnitudes are smaller. It can be inferred, therefore, that the measured and predicted profiles of tilt and curvature also reasonably match.

A comparison between the maximum measured and maximum predicted total vertical subsidence for the monitoring lines at Angus Place and Springvale Collieries is provided in Fig. 3.9. In all cases, the maximum measured total vertical subsidence were less than the maximum predicted vertical subsidence or were within +15 % or +50 mm of the maximum predicted values.

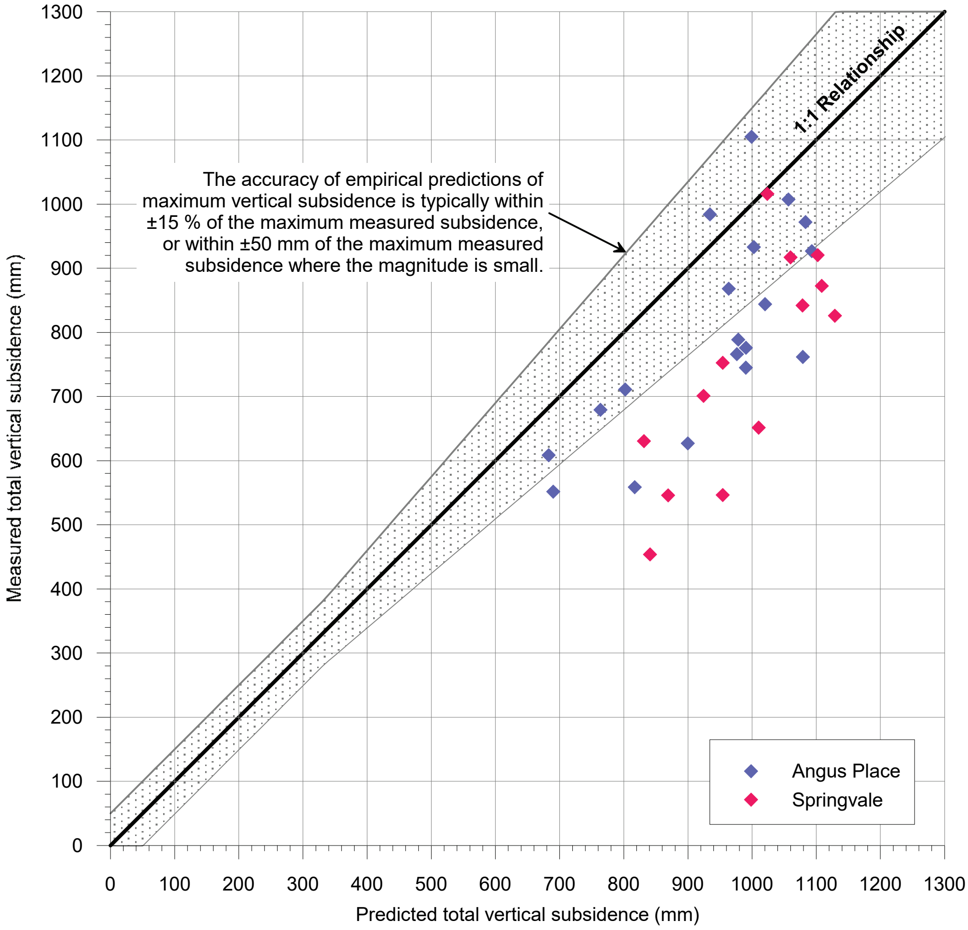

Fig. 3.9 Comparison of maximum measured and maximum predicted total vertical subsidence at Angus Place and Springvale Collieries

The distribution of the ratio of the maximum measured to maximum predicted total vertical subsidence for the monitoring lines is illustrated on the left-side of Fig. 3.10. A gamma distribution has been fitted to the data and this is also shown on the left-side of this figure. The probabilities of exceedance based on the fitted gamma distribution are shown in the right-side of Fig. 3.10.

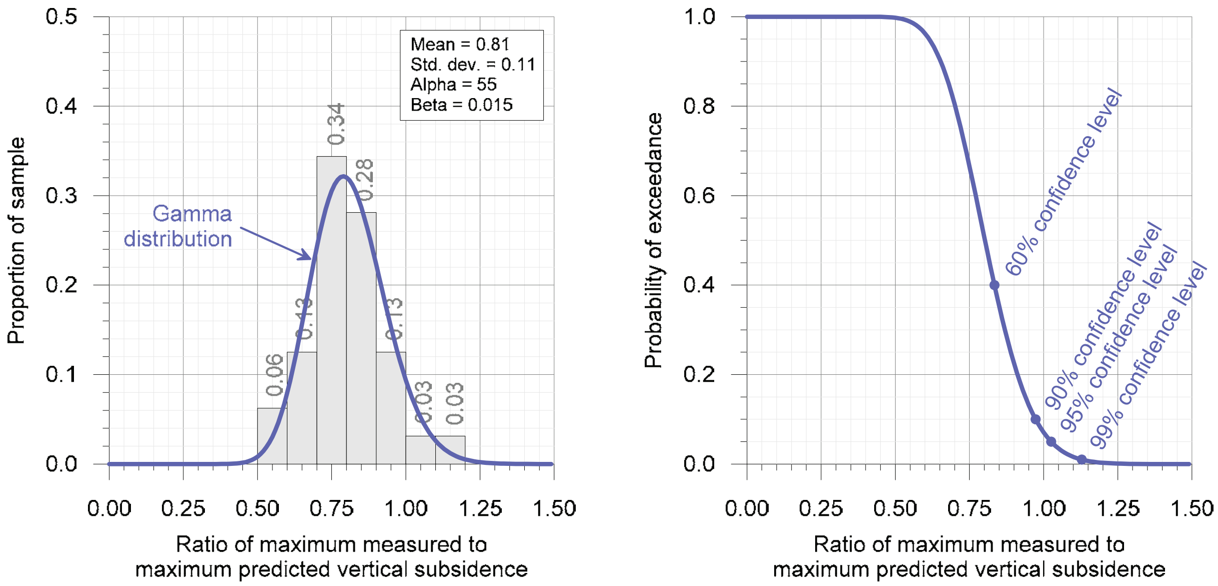

Fig. 3.10 Distribution of the ratio of maximum measured to maximum predicted total vertical subsidence at Angus Place and Springvale Collieries

The mean ratio of the maximum measured to maximum predicted total vertical subsidence for the monitoring lines is 0.81. That is, the maximum measured vertical subsidence were, on average, 81 % of the maximum predicted values. The maximum measured subsidence was, at most, +11 % greater than the maximum predicted value.

The 95 % confidence level approximately represents a ratio of maximum measured to maximum predicted total vertical subsidence of 1.03. That is, there is approximately a 5 % probability that the maximum measured total subsidence exceeds the maximum predicted total value by more than 1.03 times along each of the monitoring lines.

It is considered that the calibrated IPM provides reasonable, if not, slightly conservative predictions of total vertical subsidence at Angus Place and Springvale Collieries and at other collieries elsewhere in the Western Coalfield. It is therefore expected that the calibrated IPM will provide reasonable, if not, slightly conservative predictions of vertical subsidence for the proposed LW1001 to LW1015.

3.6.2. Calibration of the IPM at the surface lineaments

Increased subsidence effects have been observed where previously extracted longwalls at Angus Place and Springvale Collieries have mined beneath Type 1 and Type 2 geological structure zones (i.e. surface lineaments).

These effects were observed where LW920 to LW970 were extracted beneath the southern extension of the Wolgan Lineament Zone. The vertical subsidence was derived from the changes in surface levels measured using the Light Detection and Ranging (LiDAR) surveys.

The initial surface levels were determined from the LiDAR survey was carried out on the 14 December 2005, when Angus Place LW920 was nearing completion and during the extraction of Springvale LW410. The subsided surface levels were determined from the LiDAR survey carried out on the 31 March 2012, when around half of Angus Place LW970 had been extracted and during the extraction of Springvale LW415.

The measured changes in surface level are illustrated in Fig. 3.11, which have been determined by taking the differences between the surface levels measured in 2005 survey from those measured in 2012 survey. Hence, the measured changes in surface level do not include those resulting from the extraction of LW920 and part of LW970.

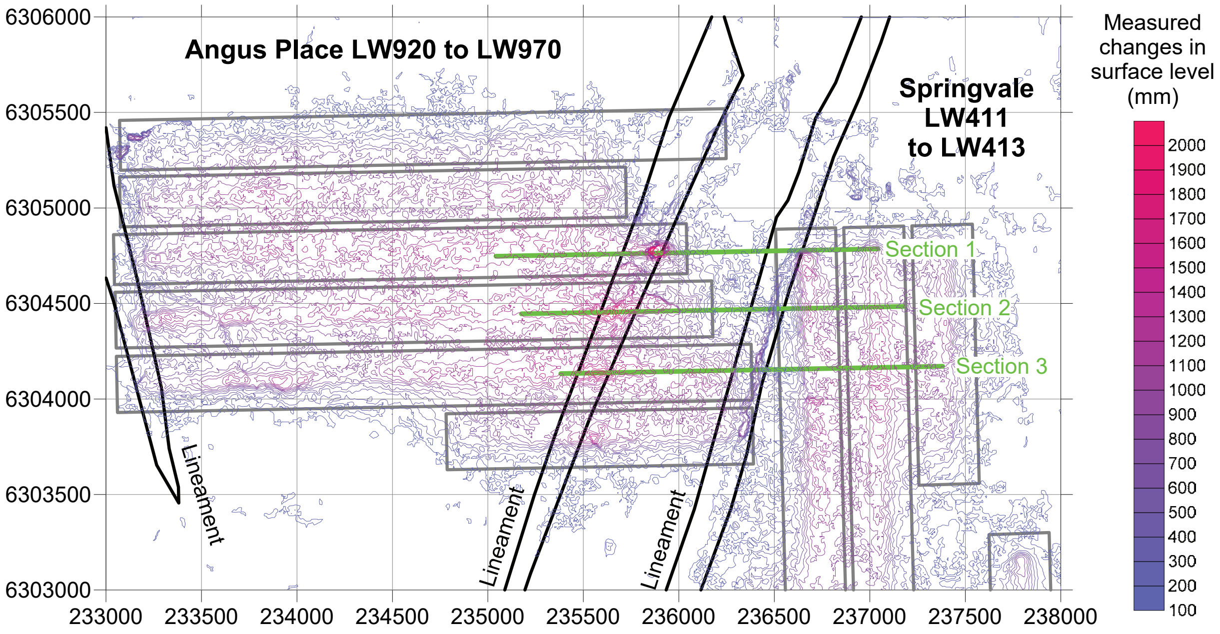

Fig. 3.11 Measured changes in surface level based on LiDAR surveys 2005 and 2012

It is noted that the contours of the measured changes in surface level, developed from the LiDAR surveys, show the changes in the heights of points at fixed eastings and northings. This differs from traditional subsidence contours which include both the vertical and horizontal components of the surface movements of fixed points on the surface. Horizontal movements are usually included in the subsidence profiles, as traditional ground monitoring data is based on the movements of survey marks, which are fixed to the ground.

The contours developed from the LiDAR surveys can be unclear, particularly in the locations of steeply incised terrain, such as at cliffs or steep slopes. The reason is the surface can move horizontally downslope or towards the centre of the goaf, as the ground subsides and, therefore, the level changes at fixed eastings and northings can be large and do not provide a true indication of the actual subsidence at a point. Where the ground is reasonably flat, however, the contours of the measured changes in surface level should provide a good indication of the actual subsidence, except adjacent to the longwall goaf edges where the mining induced horizontal movements are the greatest.

It can be seen from Fig. 3.11 that locally increased vertical movement was observed along the surface lineaments at the eastern ends of the longwalls at Angus Place. Three longitudinal sections have been taken through the longwalls, as indicated in that figure. The profiles of the measured changes in surface level along Sections 1, 2 and 3 are shown in Fig. 3.12, Fig. 3.13 and Fig. 3.14, respectively. The profiles of predicted subsidence obtained from the calibrated IPM are also shown in these figures for comparison.

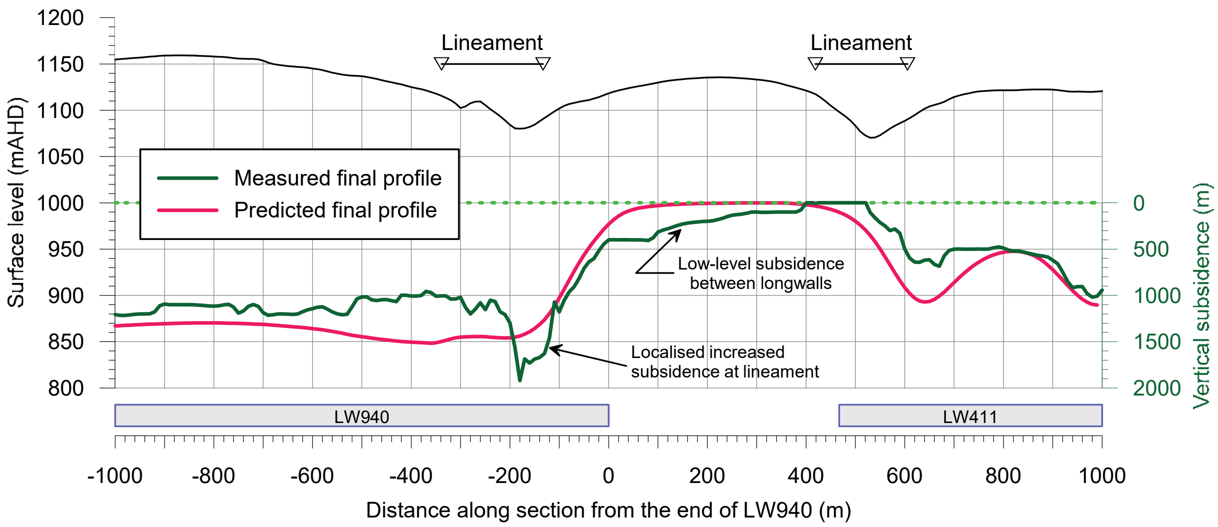

Fig. 3.12 Measured changes in surface level and predicted subsidence along Section 1

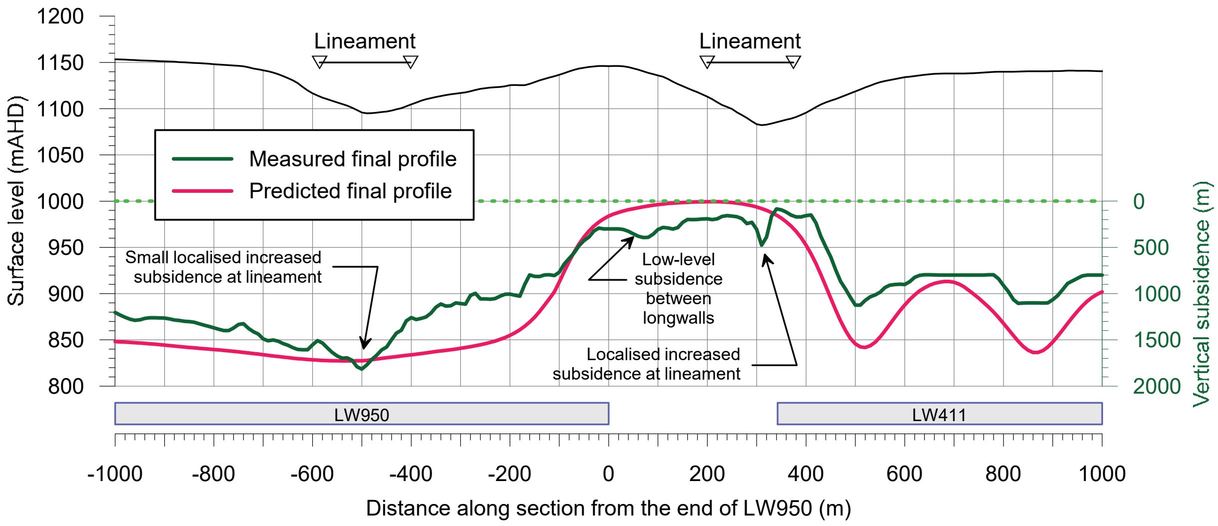

Fig. 3.13 Measured changes in surface level and predicted subsidence along Section 2

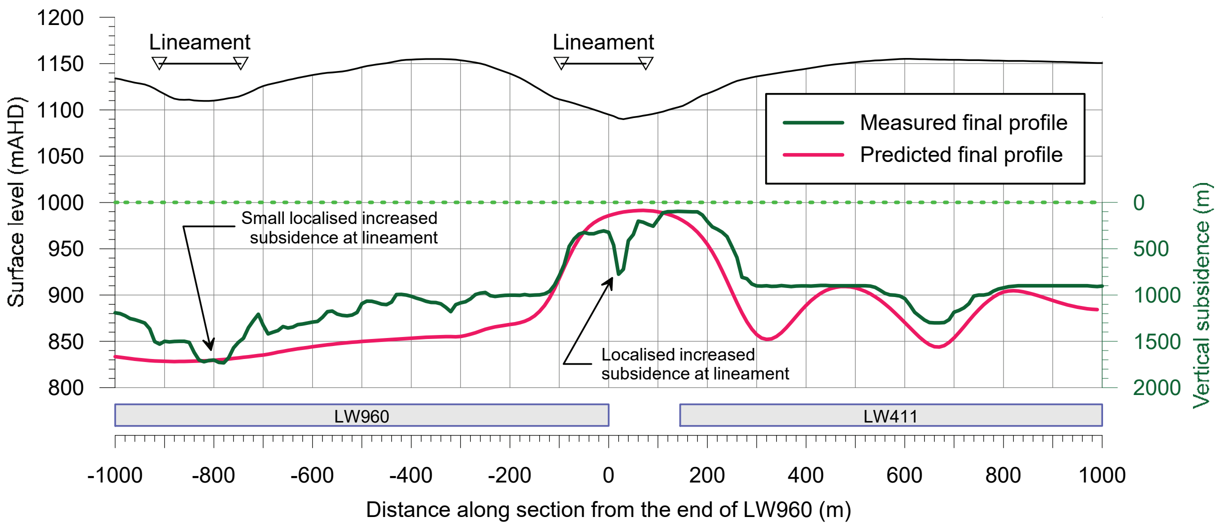

Fig. 3.14 Measured changes in surface level and predicted subsidence along Section 3

Locally increased vertical movements were observed at the lineament above the eastern end of LW940 and, to lesser extents, at the lineaments above the eastern ends of LW950 and LW960. The maximum measured vertical movement above the eastern end of LW940 of 1900 mm exceeded the maximum predicted vertical subsidence obtained using the standard IPM of 1500 mm by around +27 %. The measured maximum vertical movements above the eastern ends of LW950 and LW960 exceeded the predicted maximum vertical subsidence by around 5 % to 10 %.

Locally increased vertical movements were also observed at the lineament between the longwalls at Angus Place and LW411 at Springvale Colliery. The maximum measured vertical movement at the lineament east of LW950 and east of LW960 were 500 mm and 800 mm, respectively, which exceeded the predictions obtained using the standard IPM of less than 100 mm in these locations.

Elevated strains can also occur in the locations of the surface lineaments. The lineaments are generally coincident with the locations of the streams, as the lineaments are zones of weakness that weather more easily to form the valleys. Higher compressive strains can occur within the valleys, therefore, due to both valley related closure movements and the effects of the lineaments.

The overall closure movements were measured across the valleys and the lineaments along the C-Line, E-Line and F-Line at Angus Place, and along the B-Line and EWS-Line at Springvale Colliery, which are illustrated in Fig. 3.20 to Fig. 3.24. As described in Section 3.7, the measured closure movements along these monitoring lines were less than those predicted using the 2002 ACARP method (Waddington and Kay, 2002). That is, the measured closures did not exceed those predicted using the 2002 ACARP method as a result of the presence of the lineaments within these valleys.

Springvale Colliery mined LW405 to LW409 beneath the southern extension of the Wolgan Lineament Zone and mined LW415 to LW419 beneath the Deanes Creek Lineament Zone. The ground movements above these longwalls were measured using the B-Line. The measured and predicted profiles of vertical subsidence along this monitoring line are illustrated in Fig. 3.15.

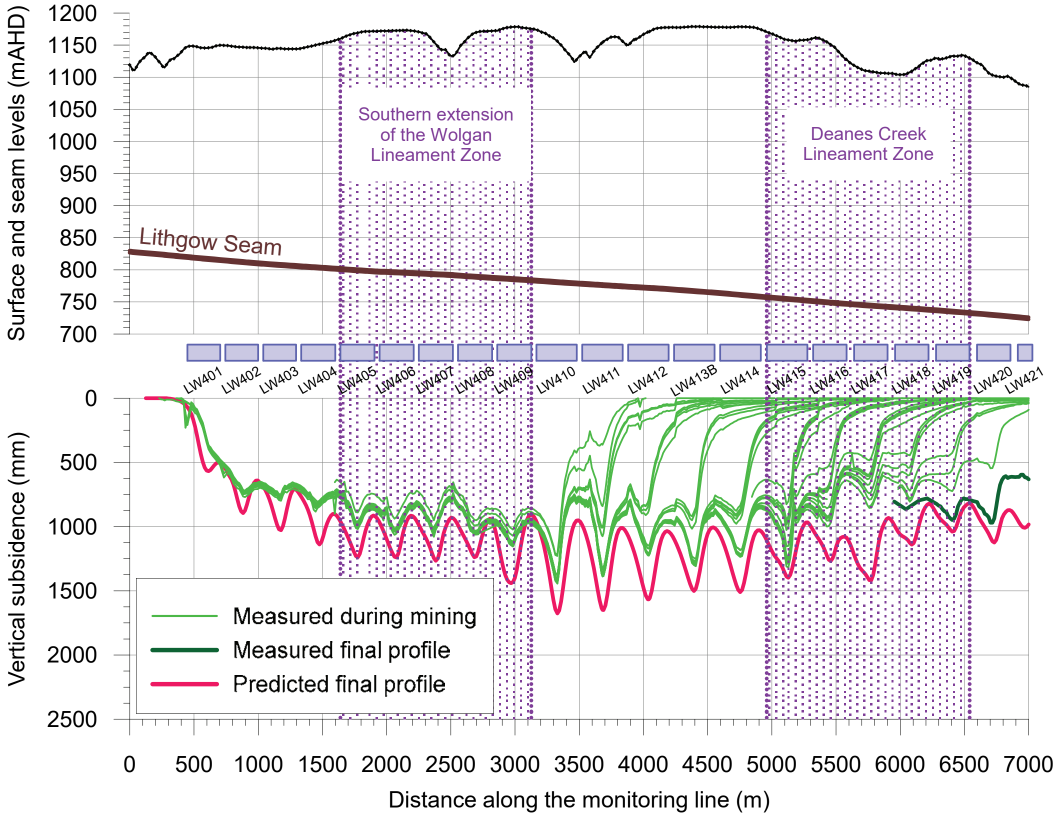

Fig. 3.15 Measured and predicted vertical subsidence along the B-Line at Springvale Colliery

There is no apparent increased vertical subsidence at the southern extension of the Wolgan Lineament Zones or the Deanes Creek Lineament Zone based on the comparison between measured and predicted profiles along the B-Line. Increased subsidence may have developed above LW415 where it mined beneath the western extent of the Deanes Creek Lineament Zone. However, the maximum measured subsidence was still less than the maximum predicted subsidence in that location.

The greater levels of vertical subsidence were measured above LW410 to LW414 (i.e. between the two lineament zones). However, this is due to the increased void widths of these longwalls of 315 m, compared with void widths of 260 m and 265 m elsewhere.

The Deanes Creek Lineament Zone is coincident with Carne Creek and a tributary of this creek above LW416 to LW419. The valley closure effects were measured using the V-Line and W-Line across Carne Creek and the X-Line and Y-Line across the tributary.

The measured and predicted closure movements for the V-Line and W-Line are shown in Fig. 3.16 and Fig. 3.17, respectively. The predicted values shown in these figures are based on the 2002 ACARP method. The distances of the monitoring lines (at the centreline of the creek) from the longwall face are shown at the bottom of the figures. The dates that the longwall face mined directly beneath the lineament zone and directly beneath the monitoring line are also shown.

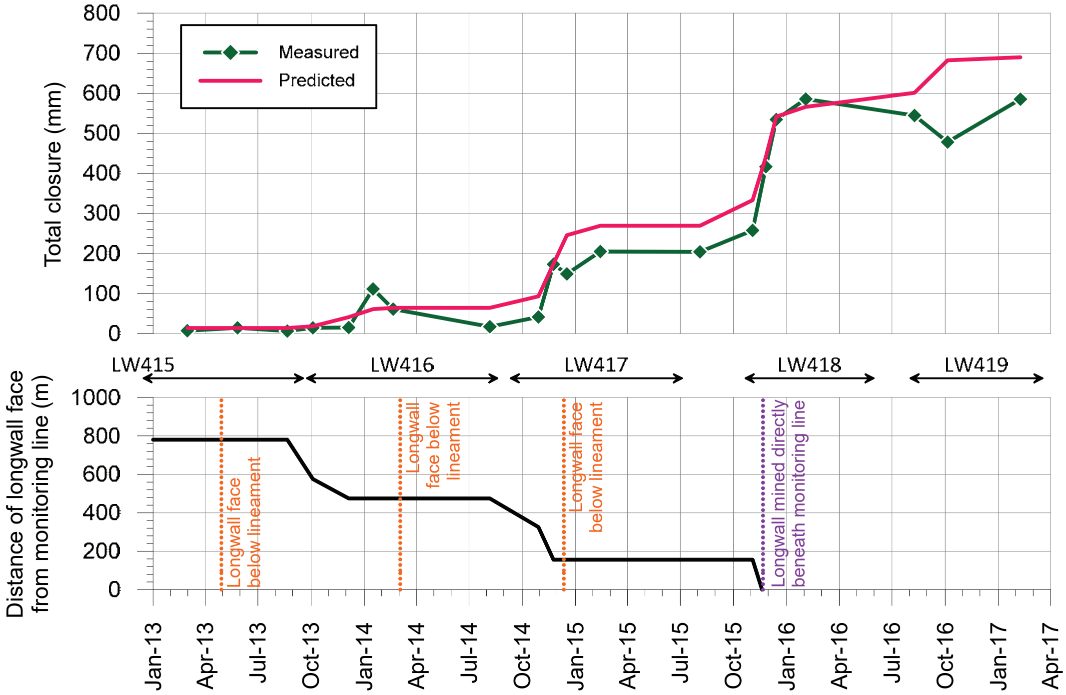

Fig. 3.16 **Measured and predicted total closure for the V-Line across Carne Creek**

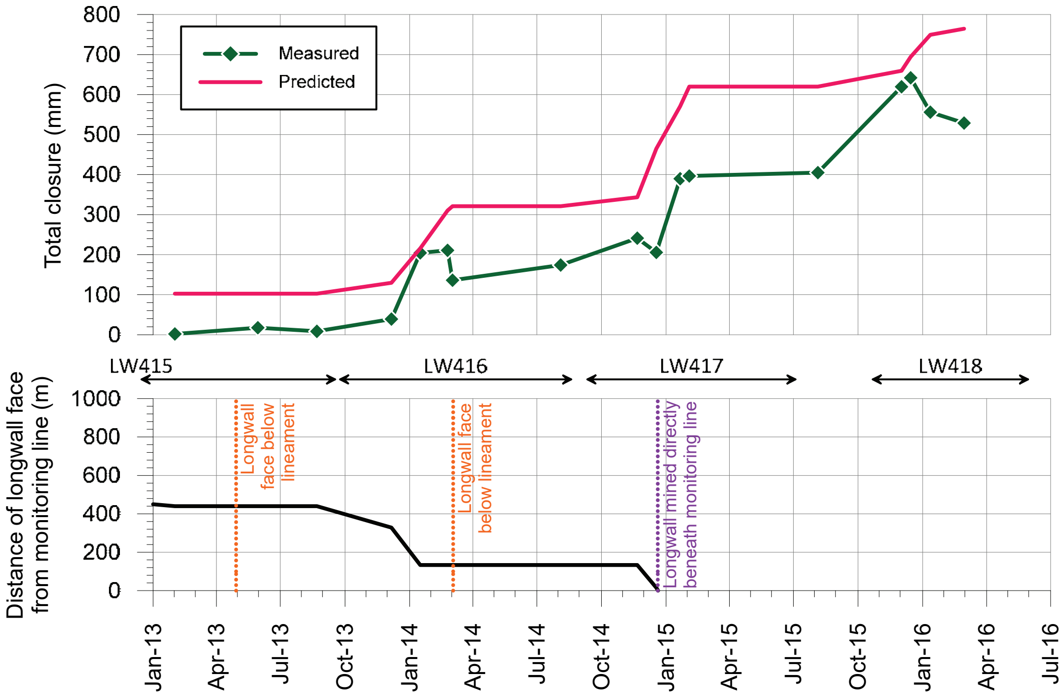

Fig. 3.17 **Measured and predicted total closure for the W-Line across Carne Creek**

The measured closure at the V-Line and W-Line are generally similar to or less than the predicted closure obtained using the 2002 ACARP method. The measured closure is slightly greater than predicted at some intermediate stages of mining for the V-Line; however, these exceedances are similar to the order of survey tolerance and the accuracy of the prediction method.

The measured closure is less than predicted when the earlier longwalls mine directly beneath the lineament zone upstream of the monitoring line. There does not appear to be any localised increased movements when mining beneath the lineament zone when compared with the predicted values. However, there could be small changes that are in the order of the survey tolerance and the accuracy of the prediction method.

Further comparisons of the measured and predicted valley closure movements, in locations both with and without lineaments, are provided in the following Section 3.7.

3.6.3. Adoption of the IPM for the proposed LW1001 to LW1015

The calibrated IPM has been adopted for the proposed LW1001 to LW1015. It is expected that the subsidence model should provide reasonable, if not, slightly conservative predictions outside the locations of the lineament zones.

Type 1 and Type 2 geological structures have been identified within the proposed mining area, as shown in Drawing No. MSEC1046-07. It is expected, that locally increased subsidence and compressive strains will develop in these locations, similar to that previously observed at Angus Place and Springvale Collieries.

The subsidence predictions have therefore been increased by 25 % in the locations of the Type 1 and Type 2 geological structures and directly above the proposed longwalls. As the measured subsidence could exceed the predictions by more than +25 % outside and adjacent to the proposed longwalls, the natural and built features in these locations have been assessed for potential impacts resulting in localised subsidence up to 800 mm.

The potential for impacts generally result from differential movements (i.e. curvature and strain), rather than from vertical subsidence. It is expected that the compressive strains at the lineaments above the proposed LW1001 to LW1015 will be similar to those observed above the previously extracted longwalls at Angus Place and Springvale Collieries. Localised compressive strains between 10 mm/m and 20 mm/m have been measured within the valleys and the lineament zones at these collieries. Further discussions on the predicted strains within the valleys and at the lineament zones are provided in Chapters 5 and 6.

3.6.4. Predicted limit of vertical subsidence

The predicted limit of vertical subsidence has been taken as the predicted total 20 mm subsidence contour due to the mining of LW1001 to LW1015. For simplicity, the predicted limit of vertical subsidence is often taken as the 26.5° angle of draw.

The measured subsidence could exceed that predicted outside the extents of the longwalls. It has been observed that low level subsidence, typically less than 100 mm, develops for some distances outside the extents of extracted longwalls at Angus Place and Springvale Collieries. The distribution of the angles of draw to the measured 20 mm subsidence at Angus Place and Springvale Collieries is provided in Fig. 3.18.

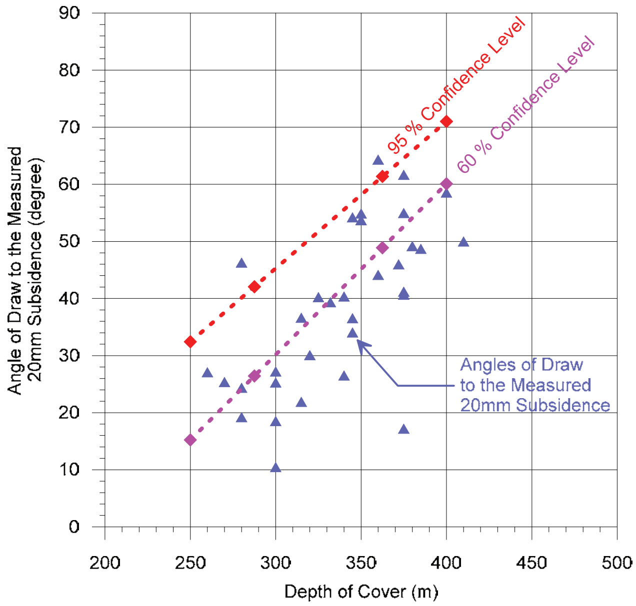

Fig. 3.18 Distribution of the angles of draw to the measured 20 mm subsidence for previously extracted longwalls at Angus Place and Springvale Collieries

The angles of draw to the measured 20 mm subsidence vary between 10° and 64°. The average angles of draw, based on the 60 % confidence level, vary between approximately 30° at 300 m depth of cover and approximately 60° at 400 m depth of cover. The angles of draw, based on the 95 % confidence level, vary between approximately 45° at 300 m depth of cover and approximately 70° at 400 m depth of cover.

Whilst the measured angles of draw are greater than the traditional 26.5° angle of draw, the corresponding tilts, curvatures and strains measured at these distances are generally in the order of survey tolerance. The distribution of strains measured outside the 26.5° angle of draw at Angus Place and Springvale Collieries is discussed further in Section 4.4.3.

3.7. Reliability of the predicted upsidence and closure movements

The predicted valley related effects due to the mining of the existing longwalls at Angus Place and Springvale Collieries and the proposed LW1001 to LW1015 have been made using the empirical method outlined in ACARP Research 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*.

Valley related effects have been observed along the stream alignments at Angus Place and Springvale Collieries. The measured profiles of vertical subsidence and strain within the valleys at Angus Place are provided in: Fig. 3.19 for the A-Line; Fig. 3.20 for the C-Line; Fig. 3.21 for the E-Line; and Fig. 3.22 for the F-Line. The measured profiles with the valleys at Springvale Colliery are provided in: Fig. 3.23 for the B-Line, Fig. 3.24 for the EWS-Line; and Fig. 3.25 for the M-Line.

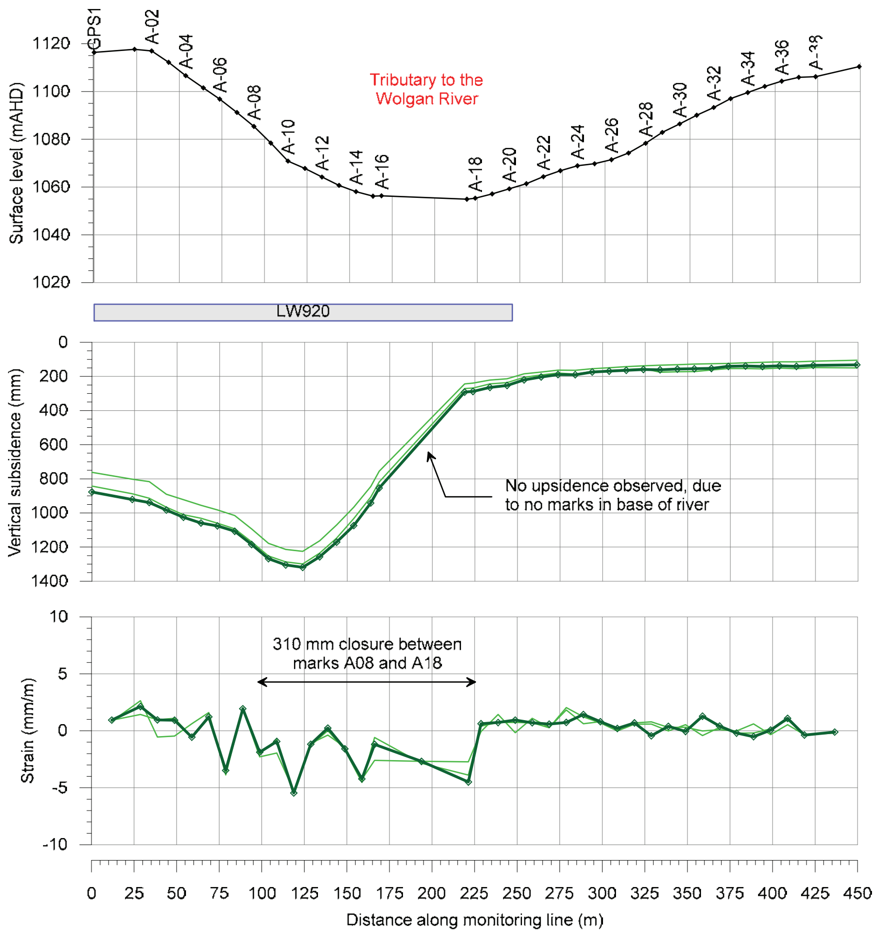

Fig. 3.19 Measured vertical subsidence and strain along the A-Line at Angus Place

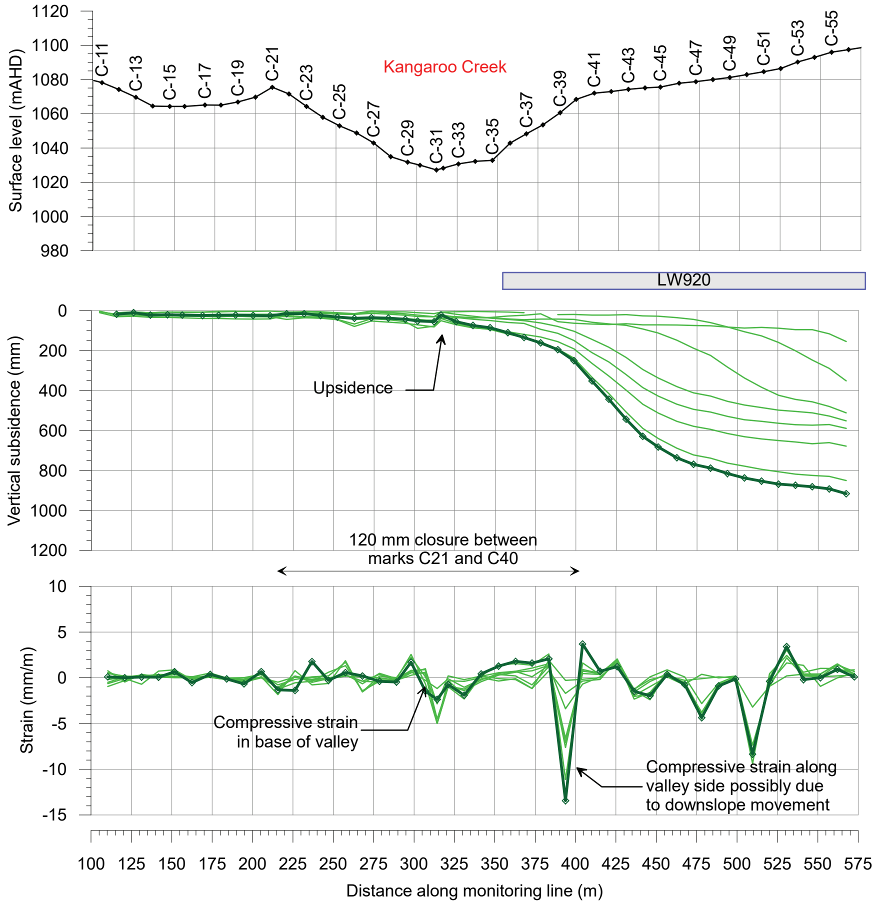

Fig. 3.20 Measured vertical subsidence and strain along the C-Line at Angus Place

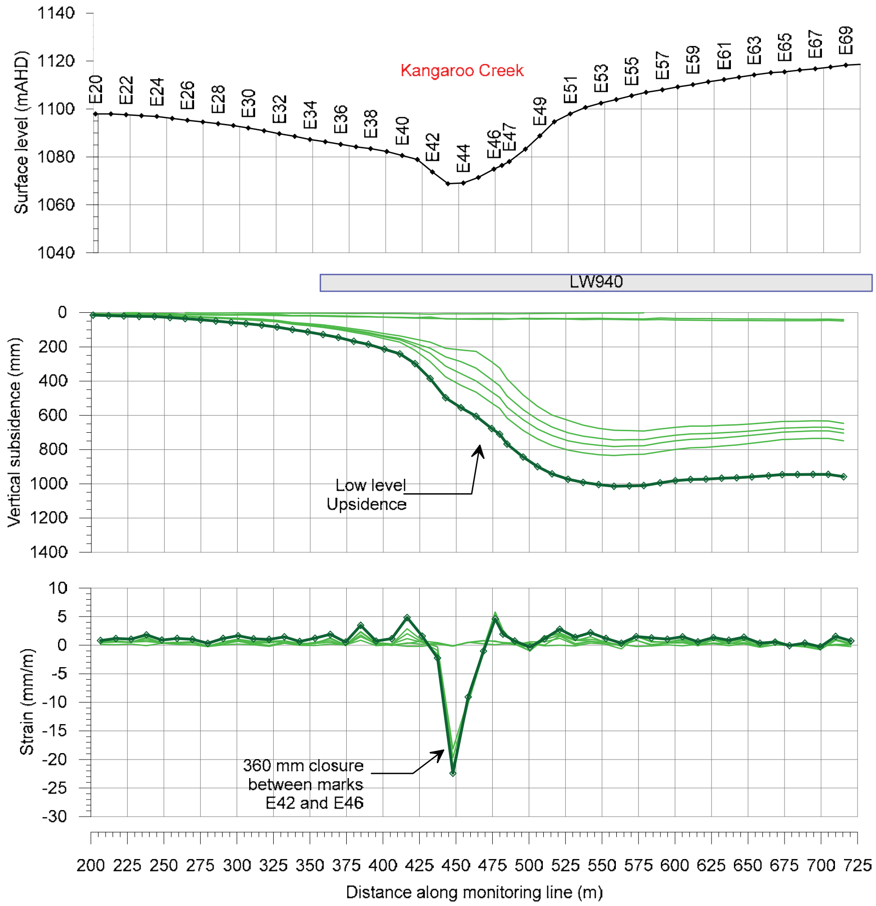

Fig. 3.21 Measured vertical subsidence and strain along the E-Line at Angus Place

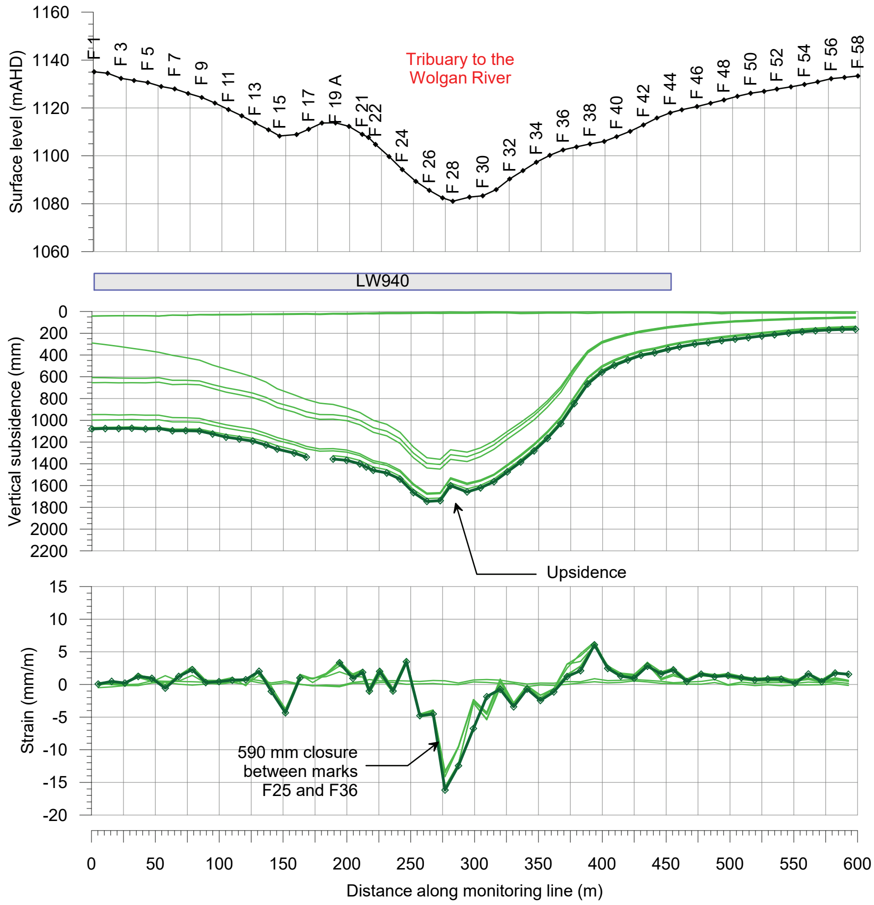

Fig. 3.22 Measured vertical subsidence and strain along the F-Line at Angus Place

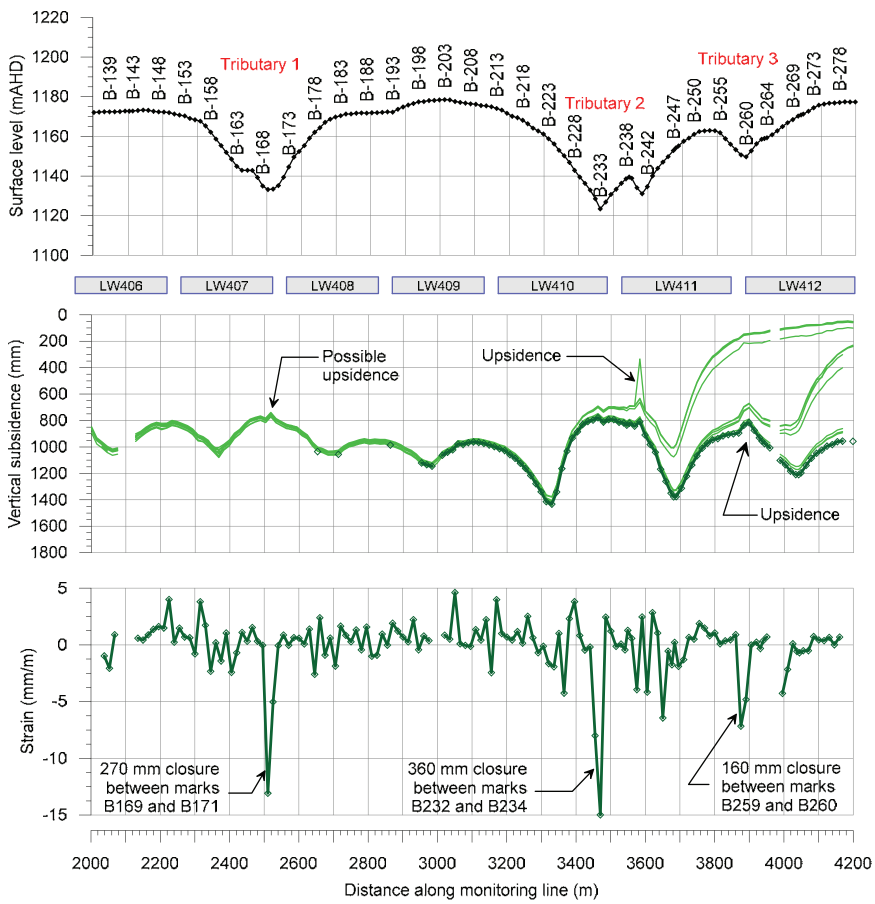

Fig. 3.23 Measured vertical subsidence and strain along the B-Line at Springvale Colliery

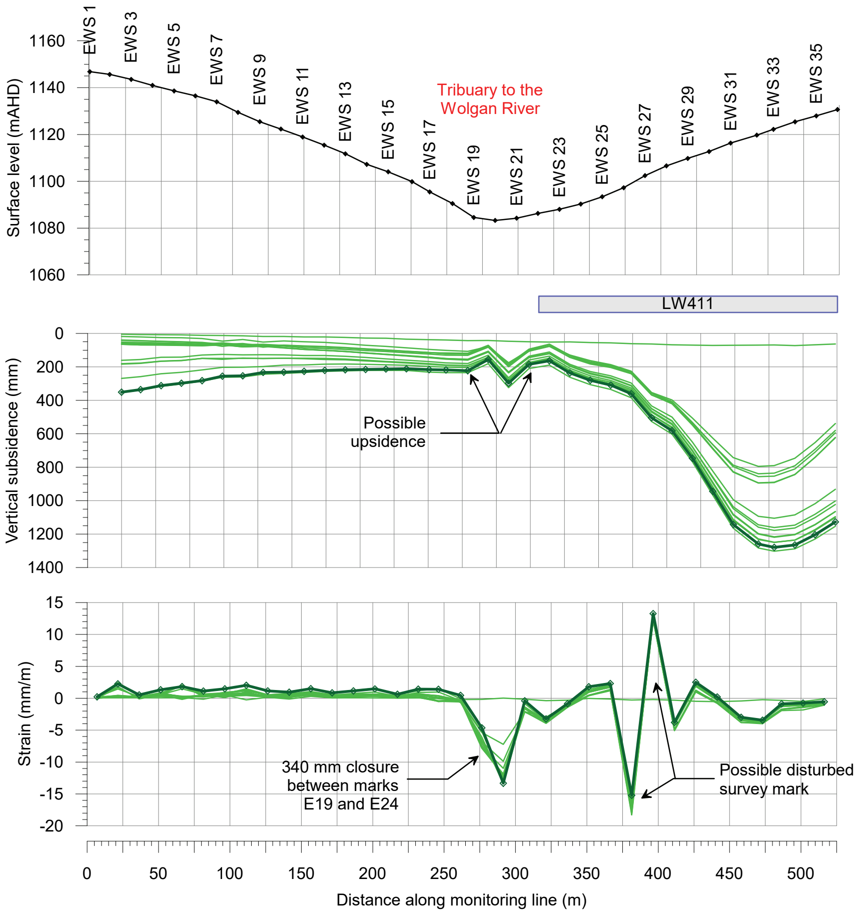

Fig. 3.24 Measured vertical subsidence and strain along the EWS-Line at Springvale Colliery

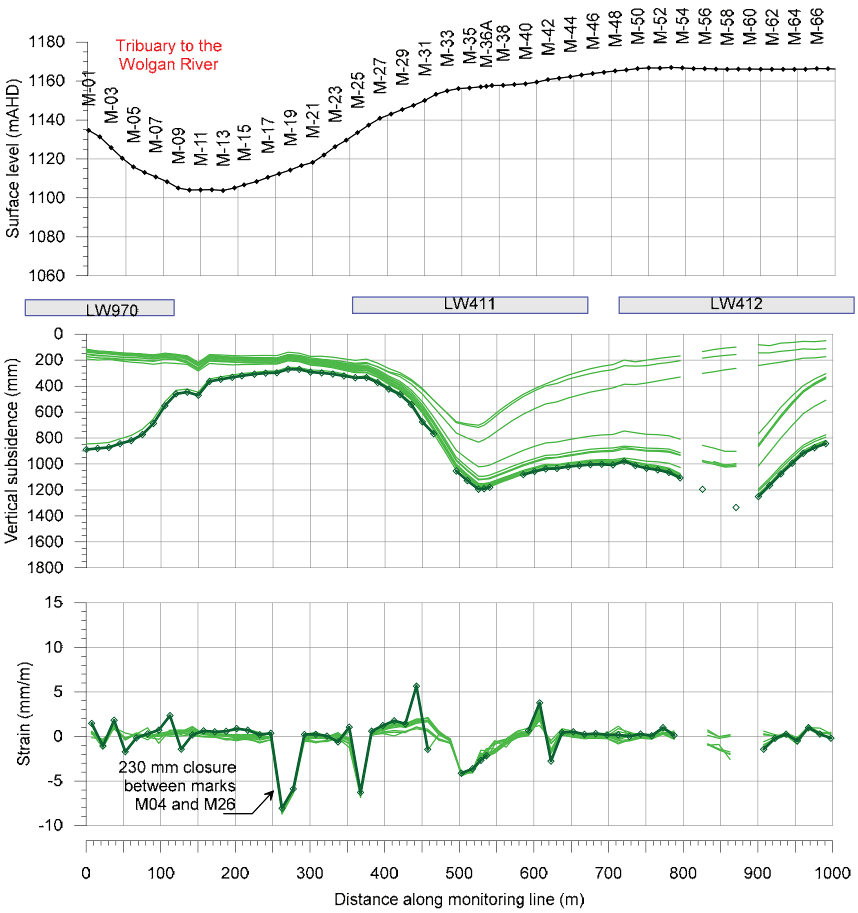

Fig. 3.25 Measured vertical subsidence and strain along the M-Line at Springvale Colliery

The valley closure movements at the stream crossings along each of these monitoring lines have been back-predicted using the 2002 ACARP method. A summary of the measured and predicted closures at the stream crossings is provided in Table 3.3.

Table 3.3 Measured and predicted closures at Angus Place and Springvale Collieries

Colliery	Monitoring line	Stream crossing	Measured closure (mm)	Predicted closure (mm)	Ratio of measured to predicted closure
Angus Place	A-Line	Tributary to the Wolgan River	310	350	0.89
	C-Line	Kangaroo Creek	120	225	0.53
	E-Line	Kangaroo Creek	360	425	0.85
	F-Line	Tributary to the Wolgan River	590	825	0.71
Springvale	B-Line	Tributary 1	270	875	0.31
		Tributary 2	360	950	0.38
		Tributary 3	160	500	0.32
	EWS-Line	Tributary to the Wolgan River	340	525	0.65
	M-Line	Tributary to the Wolgan River	230	325	0.71

In the above cases, the measured closure movements were all less than the predicted closure movements obtained using the 2002 ACARP method. It can be seen from the above table, that there is a large variation between the measured and predicted values at each location, with the ratios varying between 0.31 and 0.89 (i.e. 31 % and 89 %).

The reason for this variation is partly due to the method being based on conservative prediction curves that have been established above the empirical closure data which includes both topographical movements (i.e. valley component) as well as the conventional movements.

In locations directly above the longwalls, such as the streams along the A-Line, E-Line and F-Line at Angus Place, the topographical and conventional components are both compressive and, hence, are additive. Also, outside the extracted longwalls, such as the streams along the EWS-Line and M-Line at Springvale Colliery, the conventional components are small when compared to the topographical components. The measured movements in these locations are expected to be closer to those predicted, typically in the order of 60 % to 90 % of those predicted using the 2002 ACARP method.

In locations directly above the chain pillars, such as the streams along the B-Line at Springvale Colliery, the topographical closure component is reduced by the conventional opening component. The measured movements in these locations are expected to be much less than those predicted, typically in the order of 30 % and 60 % of those obtained using the 2002 ACARP method.

Whilst the 2002 ACARP method of prediction for upsidence and closure is predominately based on monitoring data from the Southern Coalfield, the comparisons between measured and predicted movements at Angus Place and Springvale indicate that the method provides reasonable, if not, conservative predictions at these collieries. The predictions can be further refined, to reduce the conservatism where the streams are located directly above the chain pillars, by adding the conventional opening movements to the predicted topographical closure movement, if required.

3.8. Numerical model

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

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

3.8.1. Calibration of the UDEC model

The UDEC model has been calibrated using the ground monitoring data that was measured above the previously extracted longwalls at Angus Place. The 900-series longwalls have been used in the calibration as they are generally wider than the earlier extracted longwalls at the colliery and, hence, are closer to the void widths of the proposed longwalls.

The widths of the 900-series longwalls are 261 m for LW920, LW930 and LW940 and are 293 m for LW950, LW960 and LW970. The chain pillar widths vary between 35 m and 40 m for LW930 and LW940 and between 40 m and 45 m for LW950 to LW970.

The average depth of cover to the Lithgow Seam above the 900-series longwalls is 360 m. The width-to-depth ratios for these longwalls therefore vary between 0.7 and 0.8. The average mining height for these longwalls is approximately 3.2 m.

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

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

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

The material and joint properties for each of the units were initially taken as those for the equivalent units in the *base model*. These properties have then been calibrated for the local conditions using the available ground monitoring data for the 900-series longwalls. The B-Line (two-dimensional monitoring line) was used to measure the surface subsidence and it was oblique to these longwalls. The other monitoring lines were either longitudinal lines above the longwall ends or only extended partly across the mining area and therefore these could not be used in the calibration.

The initial comparison of the results obtained using the numerical model and the ground monitoring data found that the *base model* (i.e. Material Type M1 and Joint Type J2) under-predicted the vertical subsidence above the longwalls and the chain pillars. This is due to the greater proportion of claystones and siltstones in the lower part of the overburden and above the Lithgow Seam.

The magnitudes and the profiles of vertical subsidence obtained from the numerical model better matched those measured along the B-Line by adopting material bulk and shear moduli that were approximately half those used in the *base model* and adopting joint cohesions and friction angles that were 1.2 times those used in the *base model*. The differences in the appropriate material and joint properties adopted in the model are due to the differences in the overburden lithology between the Southern and Western Coalfields.

The comparison between the modelled and measured vertical subsidence along the B-Line is illustrated in Fig. 3.26. The measured subsidence has been normalised by projecting the profile onto a line transverse to the longwalls so that the modelled and predicted profiles can be directly compared. The normalisation process does not affect the magnitude of the measured vertical subsidence.

The magnitudes of the vertical subsidence obtained from the numerical model reasonably match the measured vertical subsidence above each of the longwalls. The modelled and measured vertical subsidence above the wider longwalls (i.e. LW950 and LW960) are reasonably similar to those above the narrower longwalls (i.e. LW920 to LW940) partly due to their wider pillar widths. The wider longwalls also develop additional subsidence after the mining of subsequence longwalls in the series (i.e. LW970 and LW980) which have not been modelled.

The numerical model slightly underpredicts the vertical subsidence above each of the chain pillars indicating greater pillar compression than that modelled. The vertical subsidence above the chain pillars could be improved by further decreasing the material properties of the coal and the immediate floor and roof units; however, this would then result in the over-prediction of vertical subsidence directly above the longwalls.

The shapes of the vertical subsidence profiles obtained from the numerical model reasonably match the measured profiles. The modelled profiles on the longwall maingate sides are steeper than the measured profiles and, as a result, the model slightly over-predicts the maximum tilts. The model shows low level vertical subsidence slightly greater than that measured outside of the mining area. This model could be slightly improved by decreasing the modelled joint strength properties used; however, this would then result in the over-prediction of vertical subsidence directly above the longwalls.

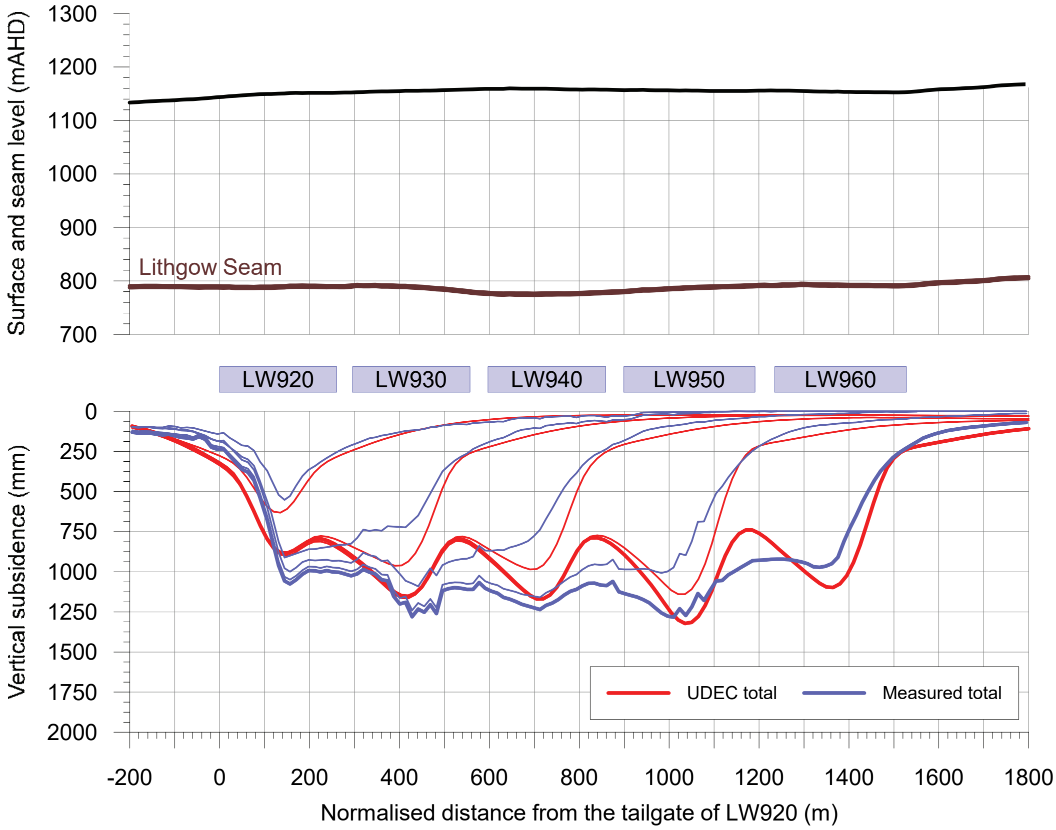

Fig. 3.26 Comparison of modelled and normalised measured subsidence along the B-Line due to the mining of LW920 to LW960

It is considered that the profiles of vertical subsidence obtained from the UDEC model reasonably match those measured using along the B-Line above LW920 to LW960 at Angus Place. Slight improvements could be made to the model to increase the vertical subsidence above the chain pillars or decrease the low level subsidence outside of the mining area. However, this would result in the over-prediction of vertical subsidence directly above the longwalls. It is considered more important to model the vertical subsidence in the locations of maxima (i.e. directly above the longwalls) than elsewhere above or outside the mining area.

A numerical model has therefore been developed for the proposed longwalls based on this calibrated model and it is discussed in the following section.

3.8.2. UDEC model for the proposed longwalls

The widths of the proposed LW1001 to LW1015 are 360 m and the solid chain pillar widths are 55 m. It is recognised that the longwall void widths and chain pillar widths for these proposed longwalls are greater than the void widths and pillar widths for the 900-series longwalls. For this reason, the numerical model has been reviewed further based on the predictions obtained from the empirical IPM.

Only the first five longwalls have been considered in the UDEC model. The edges of the numerical model have been taken as two times the longwall widths (i.e. 720 m) from the nearest longwall edges. The overall width of the model therefore is 3460 m.

The average depth of cover to the Lithgow Seam along Prediction Line 1 and directly above LW1001 to LW1005 is 390 m. The width-to-depth ratio of each of these proposed longwalls therefore is 0.9. These longwalls are proposed to extract an average thickness of 2.8 m from the Lithgow Seam.

A summary of the stratigraphy adopted in the UDEC model, based on the mining geometry for LW1001 to LW1005 along Prediction Line 1, is provided in Table 3.4. The element sizes have been based on Block Type B1 of the *base model*, with minor adjustments to suit the depths of each stratigraphic unit.

Table 3.4 Stratigraphy adopted in the UDEC model for LW1001 to LW1005

Unit	Thickness (m)	Depth to base on unit (m)	Block size (H x V, m x m)
Burralow Formation	70	70	15.0 x 10.0
Banks Wall Sandstone	90	160	15.0 x 10.0
Mt York Claystone	10	170	7.5 x 5.0
Burra Moko Head Sandstone	50	220	15.0 x 10.0
Caley Formation	50	270	15.0 x 10.0
Farmers Creek Formation	10	280	7.5 x 5.0
Newnes Formation	80	360	7.5 x 5.0
Long Swamp Formation	30	390	7.5 x 5.0
Lithgow Seam	3	393	1.5 x 1.0
Sub-Lithgow Seam	100	493	15.0 x 10.0

Summaries of the material and joint properties adopted in the UDEC model are provided in Table 3.5 and Table 3.6, respectively. The joint normal stiffness and shear stiffness have been taken as 30 GPa/m and 3 GPa/m, respectively. The parameter analysis of the joint stiffness properties found that the numerical model is not sensitive to these two parameters (refer to Section 6.9.4 of Barbato, 2017).

Table 3.5 Material properties adopted in the UDEC model for LW1001 to LW1005

Unit	Density (kg/m^3)	Bulk modulus (GPa)	Shear modulus (GPa)	Cohesion (MPa)	Friction angle (deg.)	Tensile strength (MPa)
Burralow Formation	2400	2.00	1.20	7.0	34	0.5
Banks Wall Sandstone	2400	2.00	1.20	7.0	34	0.5
Mt York Claystone	2700	3.00	1.40	6.0	25	0.5
Burra Moko Head Sandstone	2500	3.35	2.50	10	30	0.5
Caley Formation	2500	3.35	2.50	10	30	0.5
Farmers Creek Formation	2700	3.70	2.45	9	30	0.5
Newnes Formation	2700	3.70	2.45	9	30	0.5
Long Swamp Formation	2600	2.75	2.00	10	25	0.5
Lithgow Seam	1500	0.60	0.40	2.0	25	0.5
Sub-Lithgow	2500	3.20	1.90	15	25	0.5

Table 3.6 Joint properties adopted in the UDEC model for LW1001 to LW1005

Unit	Cohesion (MPa)		Friction angle (deg.)	
	Peak	Residual	Peak	Residual
Burralow Formation	3.0	1.8	30	18
Banks Wall Sandstone	3.0	1.8	30	18
Mt York Claystone	3.3	2.0	25	15
Burra Moko Head Sandstone	5.4	3.2	30	17
Caley Formation	5.4	3.2	30	17
Farmers Creek Formation	3.3	2.0	30	17
Newnes Formation	3.3	2.0	30	17
Long Swamp Formation	3.6	2.2	26	16
Sub-Lithgow	5.1	3.1	26	16

The modelled profiles of vertical subsidence obtained from the UDEC model for LW1001 to LW1005 are illustrated as the red lines in Fig. 3.27. The predicted profiles based on the IPM have also been shown as the blue lines in this figure for comparison.

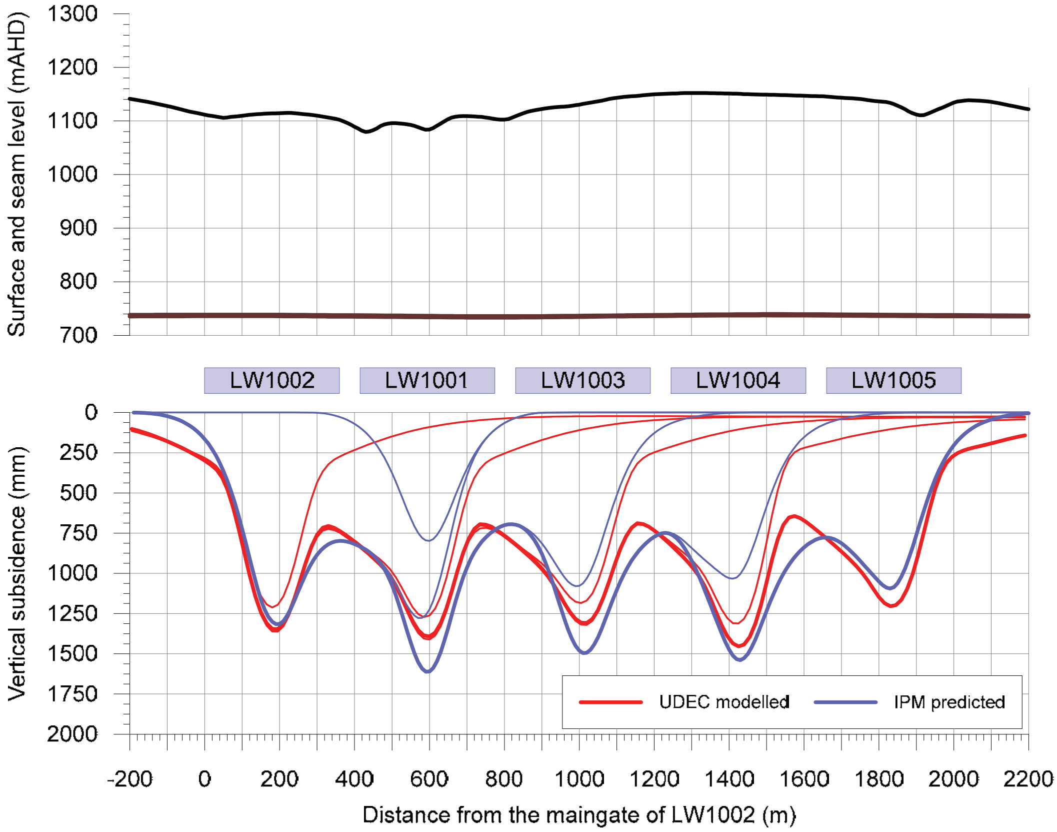

Fig. 3.27 Modelled and predicted profiles of vertical subsidence for proposed LW1001 to LW1005

The profiles of vertical subsidence obtained from the UDEC model reasonably match those predicted using the IPM. The maximum vertical subsidence directly above each of the proposed longwalls are reasonably similar, with the magnitudes being within ±15 %. The differences above LW1001 and, to a lesser extent LW1003, are partly due to the UDEC model being based on mining the panels from left to right, whereas the IPM is based on LW1001 being mined before LW1002.

The numerical model predicts similar but slightly less vertical subsidence above each of the chain pillars compared with that obtained from the IPM. This is not unexpected, as the calibration of the UDEC model also showed that it slightly under-predicted the vertical subsidence above the chain pillars.

The numerical model predicts slightly higher vertical subsidence outside the mining area. Again, this is not unexpected, as the calibration of the model indicated similar behaviour. Whilst the low level subsidence outside the mining area is greater, it is not associated with any significant tilts, curvatures or strains.

The steepness of the vertical subsidence profiles obtained from the UDEC model, on either side of the points of maxima above each of the longwalls, are reasonably similar to those obtained from the IPM. It can therefore be inferred the that maximum tilts derived from the numerical model are reasonably similar to those predicted using the IPM.

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

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence effects resulting from the extraction of the proposed LW1001 to LW1015. The predicted subsidence parameters and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

The predicted vertical subsidence, tilt and curvature have been obtained using the IPM, which has been calibrated for the local conditions, as described in Section 3.6. The predicted strains have been determined by analysing the strains measured at Angus Place and Springvale Collieries and elsewhere in the NSW coalfields where the mining geometries and overburden lithologies are similar.

The maximum predicted subsidence effects and the predicted subsidence contours provided in this report describe and show the conventional movements and these do not include the valley related upsidence and closure effects or anomalous movements. Such effects have been addressed separately in the impact assessments for each feature provided in Chapters 5 and 6.

The IPM has been calibrated in the locations of the Types 1 and 2 geological structures (i.e. major surface lineaments) as discussed in Section 3.6.2. The predicted vertical subsidence has been increased by 25% in these locations. The strains in the locations of the Types 1 and 2 geological structures are discussed in the impact assessments for each feature provided in Chapters 5 and 6.

4.2. Maximum predicted vertical subsidence, tilt and curvature

A summary of the maximum predicted values of incremental conventional vertical subsidence, tilt and curvature due to the extraction of each of LW1001 to LW1015 is provided in Table 4.1. The incremental values are the additional movements due to each proposed longwall.

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

Due to longwall	Maximum predicted incremental subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
LW1001	850	7	0.09	0.15
LW1002	1350	12	0.20	0.18
LW1003	1400	11	0.16	0.20
LW1004	1500	13	0.20	0.25
LW1005	1700	20	0.40	0.35
LW1006	1400	12	0.19	0.20
LW1007	1300	10	0.15	0.19
LW1008	1250	12	0.19	0.19
LW1009	1150	13	0.25	0.25
LW1010	1150	13	0.25	0.25
LW1011	1100	10	0.16	0.17
LW1012	1050	11	0.20	0.19
LW1013	950	10	0.18	0.17
LW1014	875	7	0.11	0.13
LW1015	900	8	0.14	0.14

The predicted total vertical subsidence contours after the extraction of the proposed LW1001 to LW1015 are shown in Drawing No. MSEC1046-13. A summary of the maximum predicted values of total vertical subsidence, tilt and curvature is provided in Table 4.2. The total parameters represent the accumulated movements within the Study Area due to the extraction of the existing and proposed longwalls.

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

After longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
LW1001	850	7	0.09	0.15
LW1002	1450	12	0.20	0.20
LW1003	1950	12	0.20	0.20
LW1004	2000	14	0.20	0.25
LW1005	2150	20	0.40	0.35
LW1006 to LW1015	2250	25	0.35	0.40

The maximum predicted total vertical subsidence of 2250 mm occurs at the western end of LW1005, after the mining of subsequent longwalls in the series, and it represents approximately 66 % of the proposed mining height of 3.4 m in that location. The maximum subsidence occurs at a Type 2 geological structure where the depth of cover of 280 m is near the shallowest within the mining area and where the proposed mining height is the greatest.

The predicted subsidence is generally greater in the south-western part of the mining area as the depths of cover are shallower and the mining heights are greater. The predicted subsidence is generally lesser in the central and north-eastern part of the mining area; however, locally increased subsidence occurs in the locations of the Types 1 and 2 geological structures.

The maximum predicted total tilt is 25 mm/m (i.e. 2.5 %, or 1 in 40). The maximum predicted total conventional curvatures for the proposed longwalls are 0.35 km^{-1} hogging and 0.40 km^{-1} sagging, which represent minimum radii of curvatures of 2.9 km and 2.5 km, respectively.

The predicted conventional subsidence effects vary across the Study Area as the result of, amongst other factors, variations in the longwall geometry, depths of cover, mining heights, overburden geology and the presence of the Types 1 and 2 geological structures. To illustrate this variation, the subsidence effects have been determined along three prediction lines.

The predicted profiles of total vertical subsidence, tilt and curvature along Prediction Lines 1 to 3 are illustrated in Figs. C.01 to C.03, respectively, in Appendix C. The locations of these prediction lines are shown in Drawing No. MSEC1046-13. The prediction lines show that the predicted vertical subsidence is generally between 1500 mm and 2000 mm above the western ends of LW1001 to LW1008 and it is generally between 1000 mm and 1500 mm elsewhere in the mining area.

4.3. Comparison of the predictions

Centennial previously submitted an SSD application for longwall mining in the project area in 2014 for the APMEP EIS. MSEC prepared Report No. MSEC593 (Rev. C) which provided the predicted subsidence effects and assessed impacts in support of that application.

The comparison of the maximum predicted total conventional subsidence effects for the currently proposed longwalls adopted in the Amended Project Report (MSEC1046) with the previous predictions provided for the APMEP EIS (MSEC593) is provided in Table 4.3.

Table 4.3 Comparison of maximum predicted total subsidence effects

Application (Report)	Maximum predicted total conventional subsidence (mm)	Maximum predicted total conventional tilt (mm/m)	Maximum predicted total conventional hogging curvature (km^{-1})	Maximum predicted total conventional sagging curvature (km^{-1})
APMEP EIS (Report No. MSEC593)	1900	20	0.30	0.35
Amended Project Report (Report No. MSEC1042)	2250	25	0.35	0.40

The maximum predicted subsidence effects for the currently proposed longwalls are greater than the maximum predicted values previously provided in Report No. MSEC593 for the APMEP EIS. The reason is the void widths of the first six longwalls in the series have been increased.

The APMEP EIS layout comprised 19 longwalls, where the first six longwalls had void widths of 260 m and 290 m and the following 13 longwalls had void widths of 360 m. The currently proposed layout comprises 15 longwalls each with a void with of 360 m.

The maximum predicted subsidence effects occur in the south-western part of the mining area, where the depths of cover are shallowest and the mining heights are the greatest. The predicted subsidence effects increase in this location due to the change in longwall void width for the first six longwalls.

In the northern part of the mining area, the predicted subsidence effects due to the currently proposed longwalls are similar to the predicted values provided in Report No. MSEC593 for the APMEP EIS. The reason is the void widths in this part of the mining area do not change, being 360 m for both layouts. However, there are differences in some areas due to variations in the proposed mining heights.

The comparison of the predicted profiles of vertical subsidence along Prediction Line 1, based on the APMEP EIS (MSEC593) and the currently proposed layout for the Amended Project Report (MSEC1046) is provided in Fig. 4.1. The predicted vertical subsidence in the APMEP EIS was less than the maximum values provided in Table 4.3 for the Amended Project Report layout, as the prediction line is located near the centrelines of the longwalls, away for the western ends of the longwalls where the depths of cover are shallowest and the predictions are greatest.

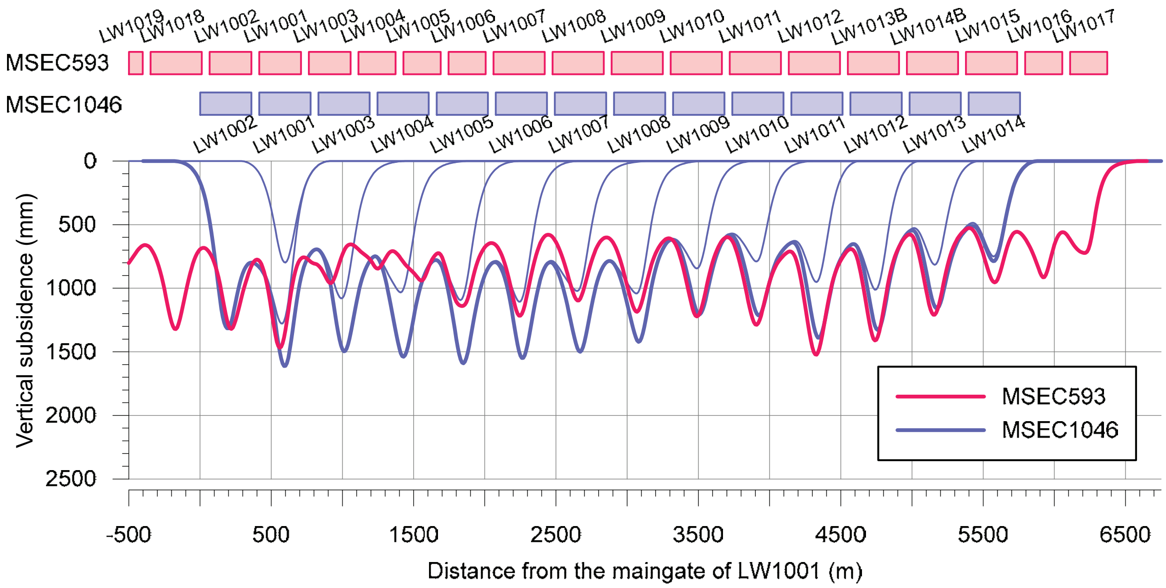

Fig. 4.1 Comparison of the predicted vertical subsidence along Prediction Line 1

The predicted vertical subsidence based on the current longwall layout (MSEC1046) is greater than that predicted above LW1003 to LW1008 in the EIS, due to the changes in longwall void widths and proposed mining heights. However, the predicted profiles of vertical subsidence above LW1009 to LW1014 are similar since both layouts adopt a 360 m void width and due to the similar proposed mining heights.

The extent of vertical subsidence to the north and to the south of the mining area is less for the currently proposed layout. The reason is that the extent of the proposed mining area is reduced along the alignment of the prediction line for the currently proposed layout of LW1001 to LW1015.

4.4. Predicted strains

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

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

Adopting a linear relationship between curvature and strain provides a reasonable prediction for the maximum conventional tensile and compressive strains. However, these conventional (i.e. typical) levels of strain can be exceeded by localised or irregular ground movements. For this reason, the predicted strains have been derived using statistical analyses of ground monitoring data, as described further below. The conventional strains describe the typical ranges of strains so that these effects can be compared from one area to another or with elsewhere in the NSW coalfields.

In the Western 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. 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.

The maximum predicted conventional strains due to the extraction of the proposed LW1001 to LW1015, based on applying a factor of 10 to the maximum predicted curvatures (refer to Table 4.2), are 3.5 mm/m tensile and 4 mm/m compressive. These strains represent typical values when the ground subsides regularly with no localised or elevated strains due to near-surface geological structures or valley closure effects. The maximum strains can be much greater than these typical values, especially in the locations of near-surface geological structures and in the bases of valleys. The predicted strains have been derived using statistical analyses of ground monitoring data, as described further below.

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

The depths of cover and the proposed mining heights vary across the mining area. The predicted strains due to the proposed longwalls therefore also vary across the mining area. Prediction Line 1 is located near the middle of the mining area, as shown in Drawing No. MSEC1046-13. The depths of cover and proposed mining heights along this prediction line therefore represent the typical values for each of the longwalls.

A summary of the mining geometries for each of the proposed longwalls along Prediction Line 1 is provided in Table 4.4. It is noted that LW1015 is not shown in this table as the prediction line does not cross this longwall. The mining geometry for LW1015 is similar to that for the adjacent LW1014.

Table 4.4 Maximum predicted total conventional subsidence, tilt and curvature after the extraction of each of the proposed longwalls

After longwall	Void width (m)	Average depth of cover (m)	Width-to-depth ratio	Proposed mining height (m)
LW1001	360	359	1.00	2.9
LW1002	360	372	0.97	3.1
LW1003	360	396	0.91	2.5
LW1004	360	411	0.88	2.6
LW1005	360	393	0.92	2.7
LW1006	360	386	0.93	2.2
LW1007	360	416	0.87	1.9
LW1008	360	412	0.87	2.2
LW1009	360	387	0.93	2.1
LW1010	360	395	0.91	2.0
LW1011	360	359	1.00	2.0
LW1012	360	341	1.06	1.9
LW1013	360	351	1.02	1.9
LW1014	360	348	1.03	1.9

The void width-to-depth ratios of the proposed longwalls along Prediction Line 1 (i.e. near the middle of the mining area) vary between 0.87 and 1.06. The proposed mining heights along this prediction line vary between 1.9 m and 3.1 m with an average value of 2.3 m.

The depths of cover are shallowest and the proposed mining heights are greatest above the western ends of LW1001 to LW1008. The minimum depth of cover within the mining area is 270 m and the corresponding maximum width-to-depth ratio is 1.33. The maximum proposed mining height is 3.4 m.

The range of potential strains for the proposed longwalls has been determined using monitoring data from the previously extracted longwalls at Angus Place and Springvale Collieries. A summary of the monitoring lines and the longwall void widths, depths of cover, longwall width-to-depth ratios and extraction heights are provided in Table 4.5. The locations of some of these monitoring lines are shown in Drawing No. MSEC1046-01.

Table 4.5 Monitoring lines and mining geometries for the previously extracted longwalls at Angus Place and Springvale Collieries

Colliery	Longwalls	Monitoring lines	Void width (m)	Depth of cover (m)	Width-to-depth ratio	Seam thickness (m)
Angus Place	LW11 to LW13	11-Line, X-Line	210	260 ~ 280	0.75 ~ 0.80	2.6
	LW19 to LW24	LW19 to LW24	230 / 260	310 ~ 340	0.75 ~ 0.80	3.0 ~ 3.2
	LW20, LW25 to LW26N	LW20, LW25 to LW26N	260	320	0.80	2.7 ~ 3.0
	LW920 to LW950	A-Line, B-Line, C-Line, E-Line, F-Line, H-Line, M-Line and WWS-Lines	260 / 290	300 ~ 380	0.70 ~ 0.90	3.2 ~ 3.3
Springvale	LW401 to LW409	B-Line	255 / 265	300 ~ 380	0.70 ~ 0.85	3.3 (ave.)
	LW410 to LW415	B-Line, EWS-Line, M-Line, Q-Line, S-Line, U-Line	315	320 ~ 420	0.75 ~ 1.0	2.6 ~ 3.6
	LW416 to LW421	B-Line, M-Line, V-Line, W-Line, X-Line, Y-Line	260	350 ~ 420	0.60 ~ 0.75	2.8 ~ 3.2

The width-to-depth ratios for the previously extracted LW410 to LW415 at Springvale Colliery typically vary between 0.75 and 1.0. This range is similar to that for the proposed LW1001 to LW1015 along Prediction Line 1 of 0.87 to 1.06. However, the width-to-depth ratios for the other previously extracted longwalls at Angus Place and Springvale Collieries of 0.60 and 0.90 are generally less than the range for the proposed longwalls along the prediction line.

The seam thicknesses for the previously extracted longwalls at Angus Place and Springvale Collieries vary between 2.6 m and 3.6 m, with an average value of approximately 3.2 m. This range is greater than that for the proposed LW1001 to LW1015 which vary between 1.9 m and 3.1 m with an average value of 2.3 m.

The maximum predicted vertical subsidence for the proposed LW1001 to LW1015 along Prediction Line 1 is similar to the range of the maximum predicted values for the previously extracted longwalls at Angus Place and Springvale Collieries. The reason is that the greater width-to-depth ratios of the proposed longwalls are offset by the lesser proposed mining heights.

The strain analysis based on the previously extracted longwalls at Angus Place and Springvale Collieries should therefore provide a reasonable indication of the range of potential strains due to LW1001 to LW1015 in the middle and the north-eastern part of the mining area.

However, the width-to-depth ratios of the proposed longwalls in the south-western part of the mining area are greater than those for the previously extracted longwalls at Angus Place and Springvale Collieries. A separate strain analysis has therefore been carried out using ground monitoring data from previously extracted longwalls elsewhere in the NSW coalfields, where the mining geometries are reasonably similar to the proposed longwalls.

The data used in the analyses of the measured strains included those resulting from both conventional and non-conventional anomalous movements, but did not include those resulting from valley related effects or from damaged or disturbed survey marks. The predictions of strain within the valleys (i.e. at the surface lineaments) have been determined separately using the 2002 ACARP method, as described in Section 3.7.

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. 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).

4.4.1. Distribution of strain above goaf

The survey database has been analysed to extract the maximum tensile and compressive strains that have been measured at any time for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls, which has been referred to as "*above goaf*".

The histograms of the maximum measured tensile and compressive strains measured for the survey bays located directly above goaf at Angus Place and Springvale Collieries is provided in Fig. 4.2. These strain distributions are representative of the predicted range of strains for the proposed LW1001 to LW1015 above the middle and north-eastern parts of the mining area.

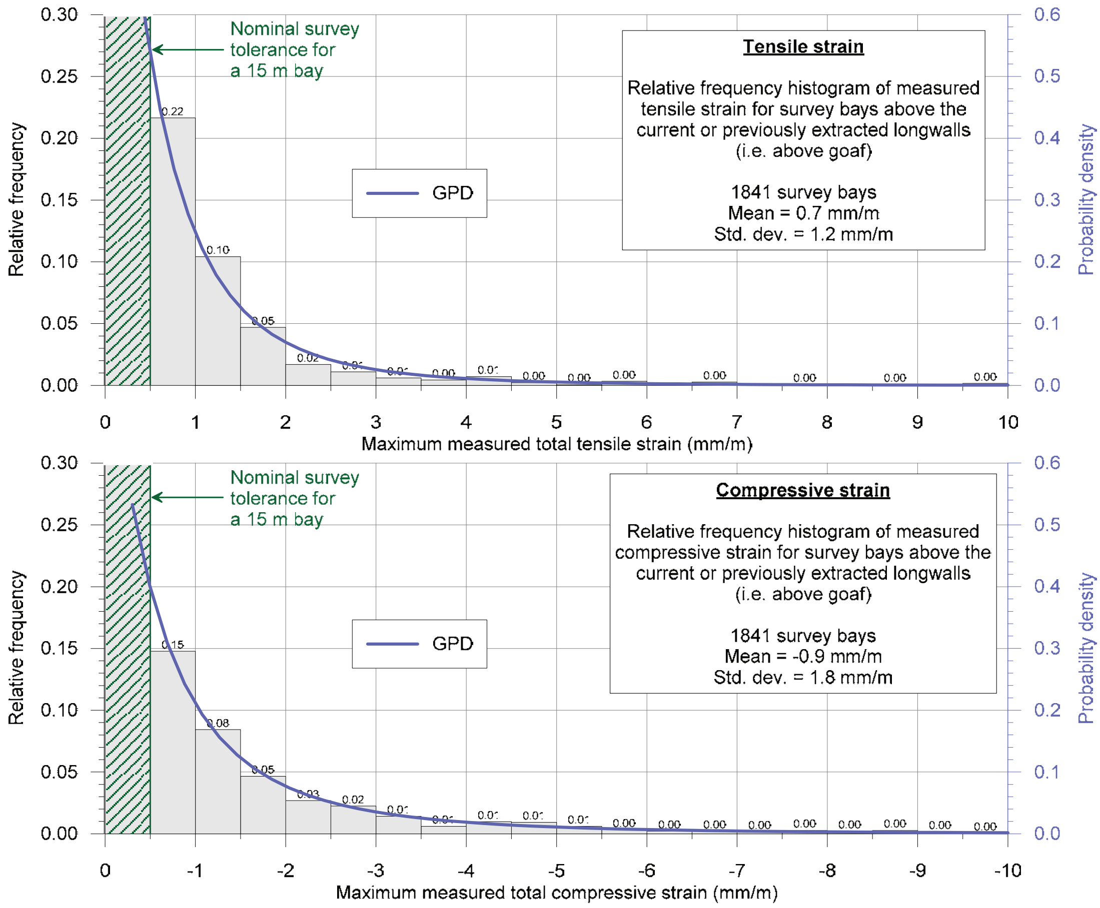

Fig. 4.2 Distributions of the measured maximum tensile and compressive strains for survey bays located directly above goaf at Angus Place and Springvale Collieries

The 95 % confidence levels for the maximum strains that the individual survey bays above goaf experienced at any time during mining were 2.5 mm/m tensile and 4 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays above goaf experienced at any time during mining were 5 mm/m tensile and 9 mm/m compressive.

A separate strain analysis has been carried out using ground monitoring data from previously extracted longwalls elsewhere in the NSW coalfields, where the width-to-depth ratios range between 1.0 and 1.4 and the seam thicknesses range between 3.0 m and 3.5 m. The histograms of the maximum measured tensile and compressive strains measured for the survey bays located directly above goaf is provided in Fig. 4.3. These strain distributions are representative of the predicted range of strains for the proposed LW1001 to LW1008 above the south-western part of the mining area.

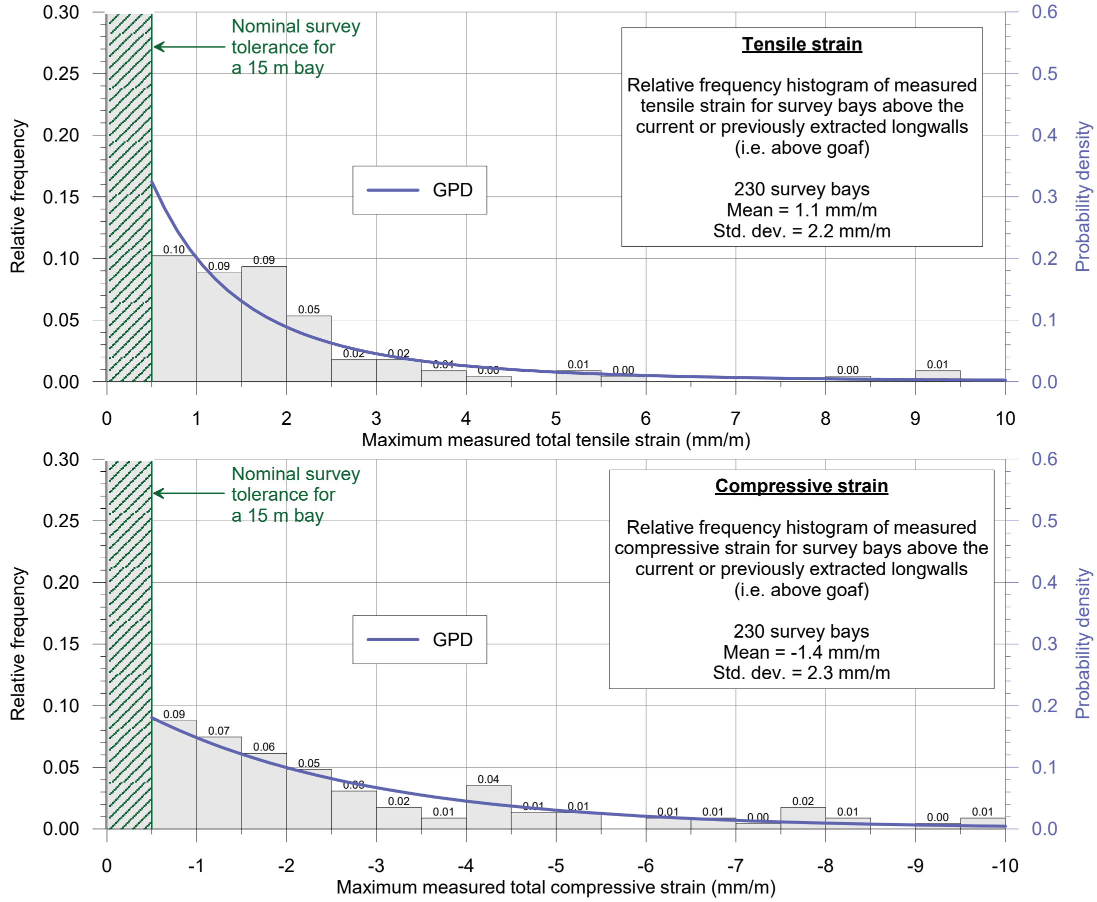

Fig. 4.3 Distributions of the measured maximum tensile and compressive strains for survey bays located directly above goaf in the NSW coalfields

The 95 % confidence levels for the maximum strains that the individual survey bays above goaf experienced at any time during mining were 5 mm/m tensile and 6 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays above goaf experienced at any time during mining were 10 mm/m tensile and 12 mm/m compressive.

4.4.2. Distribution of strain above solid coal

The survey database has also been analysed to extract the maximum tensile and compressive strains that have been measured at any time during the extraction of the previous longwalls at Angus Place and Springvale Collieries, for survey bays that were located outside and within 200 m of the nearest longwall edge, which has been referred to as "*above solid coal*".

The histograms of the maximum measured tensile and compressive strains measured for the survey bays located above solid coal is provided in Fig. 4.4. These strain distributions are representative of the predicted range of strains adjacent to all parts of the mining area.

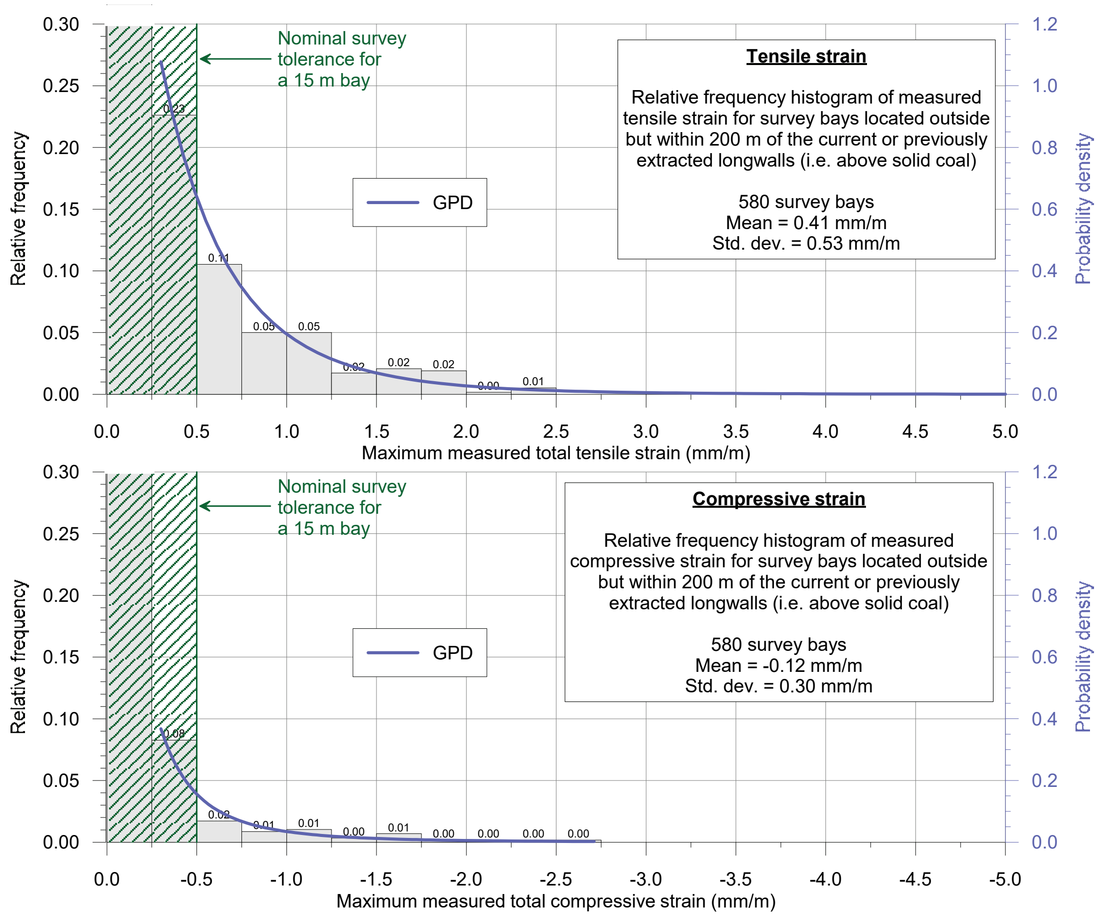

Fig. 4.4 Distributions of the measured maximum tensile and compressive strains for survey bays located above solid coal at Angus Place and Springvale Collieries

The 95 % confidence levels for the maximum strains that the individual survey bays above solid coal experienced at any time during mining were 1.4 mm/m tensile and 0.6 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays above solid coal experienced at any time during mining were 2.4 mm/m tensile and 1.5 mm/m compressive.

4.4.3. Distribution of strain outside the 26.5° angle of draw

The survey database has also been analysed to extract the maximum tensile and compressive strains that have been measured at any time during the extraction of the previous longwalls at Angus Place and Springvale Collieries, for survey bays that were located outside the 26.5° degree angle of draw line and within 600 m of the nearest longwall goaf edge, which has been referred to as "*outside the angle of draw*".

The analysis has been based on the survey bays located outside the larger valleys (i.e. away from the surface lineaments), as the localised strains in these locations are greater than the strains which otherwise occur outside the angle of draw. The strains within the valleys (i.e. at the surface lineaments) have been determined separately using the 2002 ACARP method, as described in Section 3.7. For this reason, the analysis of strains outside the angle of draw has been based on the 11-Line, LW19 to LW24 Line, LW20 and LW25 to LW26N Line and X-Line at Angus Place, and the B-Line at Springvale.

The histograms of the maximum observed tensile and compressive strains measured for the survey bays located outside the angle of draw is provided in Fig. 4.5. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

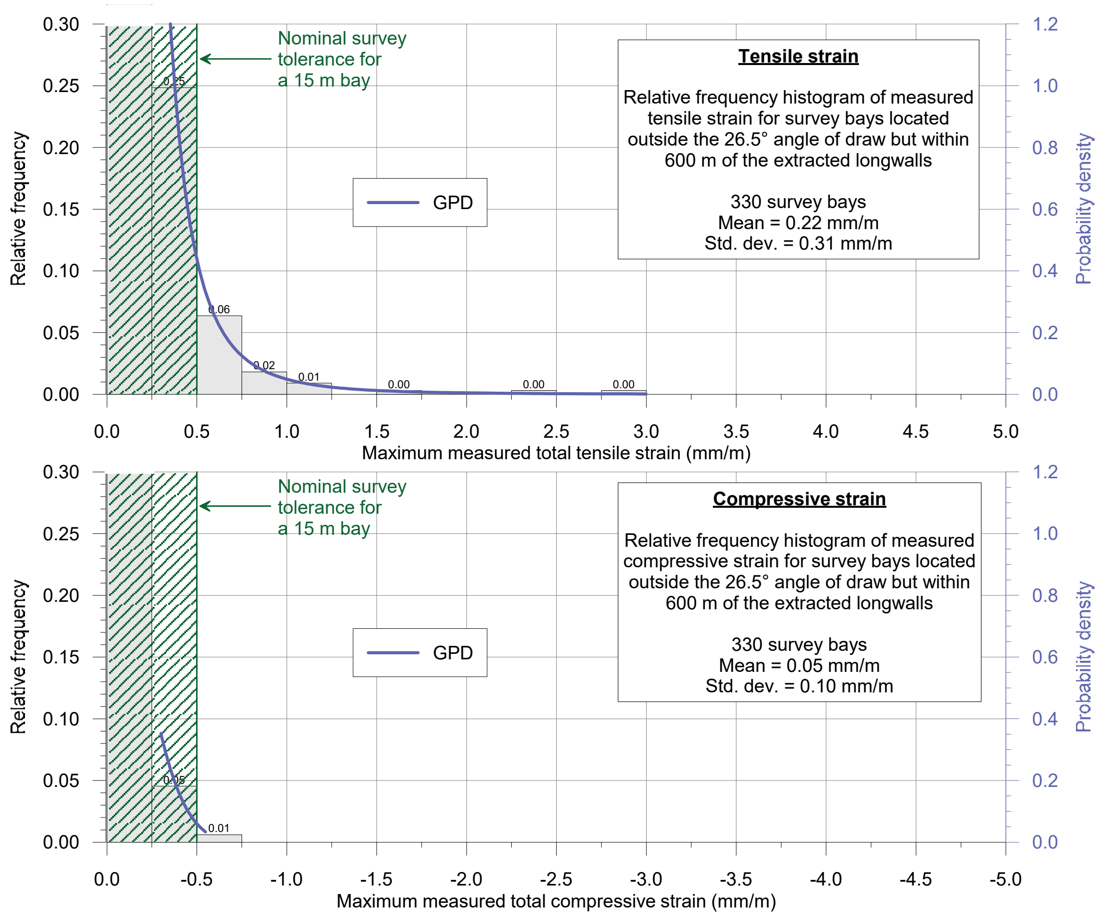

Fig. 4.5 Distributions of the measured maximum tensile and compressive strains for survey bays located outside the angle of draw at Angus Place and Springvale Collieries

The 95 % confidence levels for the maximum strains that the individual survey bays outside the angle of draw experienced at any time during mining were 0.7 mm/m tensile and less than 0.3 mm/m compressive (i.e. in the order of survey tolerance). The 99 % confidence levels for the maximum strains that the individual survey bays outside the angle of draw experienced at any time during mining were 1.3 mm/m tensile and 0.4 mm/m compressive.

4.5. Predicted conventional horizontal movements

The predicted conventional horizontal movements over the proposed longwalls are calculated by applying a factor to the predicted conventional tilt values. In the Western Coalfield a factor of 10 is generally adopted, being the same factor as that used to determine the conventional strains from the conventional curvatures, and this has been found to give a reasonable correlation with measured data. This factor will vary and will be higher at low tilt values and lower at high tilt values. The application of this factor will therefore lead to over-prediction of horizontal movements where the tilts are high and under-prediction of the movements where the tilts are low.

The maximum predicted conventional tilt for the proposed LW1001 to LW1015 is 25 mm/m. The maximum predicted conventional horizontal movement, therefore, is approximately 250 mm, i.e. 25 mm/m multiplied by a factor of 10. Greater movements can develop in incised terrain, due to the increased horizontal movements that develops in the downslope direction.

The distribution of the maximum measured horizontal movements for the 3D survey marks located directly above the longwalls at Angus Place and Springvale Collieries is provided in Fig. 4.6. It can be seen from this figure, that horizontal movements have been measured up to approximately 600 mm. The average measured value is 254 mm and the standard deviation is 117 mm.

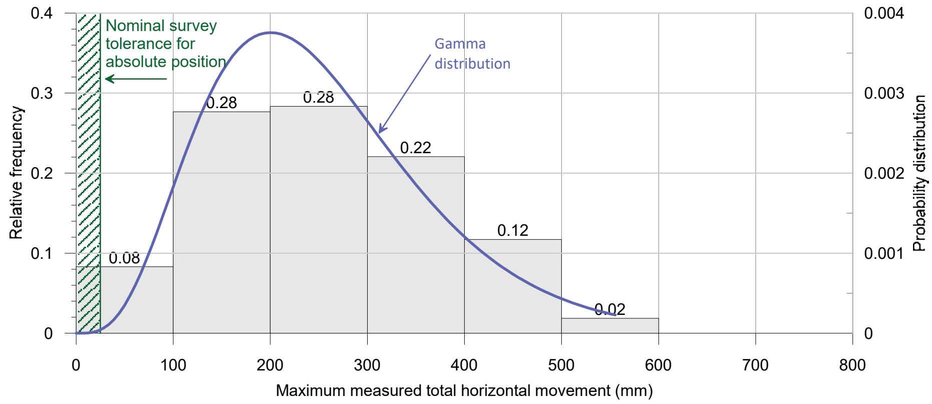

Fig. 4.6 Distribution of the maximum measured horizontal movements for the 3D marks located directly above the longwalls at Angus Place and Springvale Collieries

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

4.6. Predicted far-field horizontal movements

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

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

The measured total far-field horizontal movements due to longwall mining in the Southern and Western Coalfields are shown in Fig. 4.7. The measured values (y-axis) are the accumulated movements due to the mining in each mining domain. The distances (x-axis) are those of the survey marks from the nearest longwall (active or completed) in the mining domain.

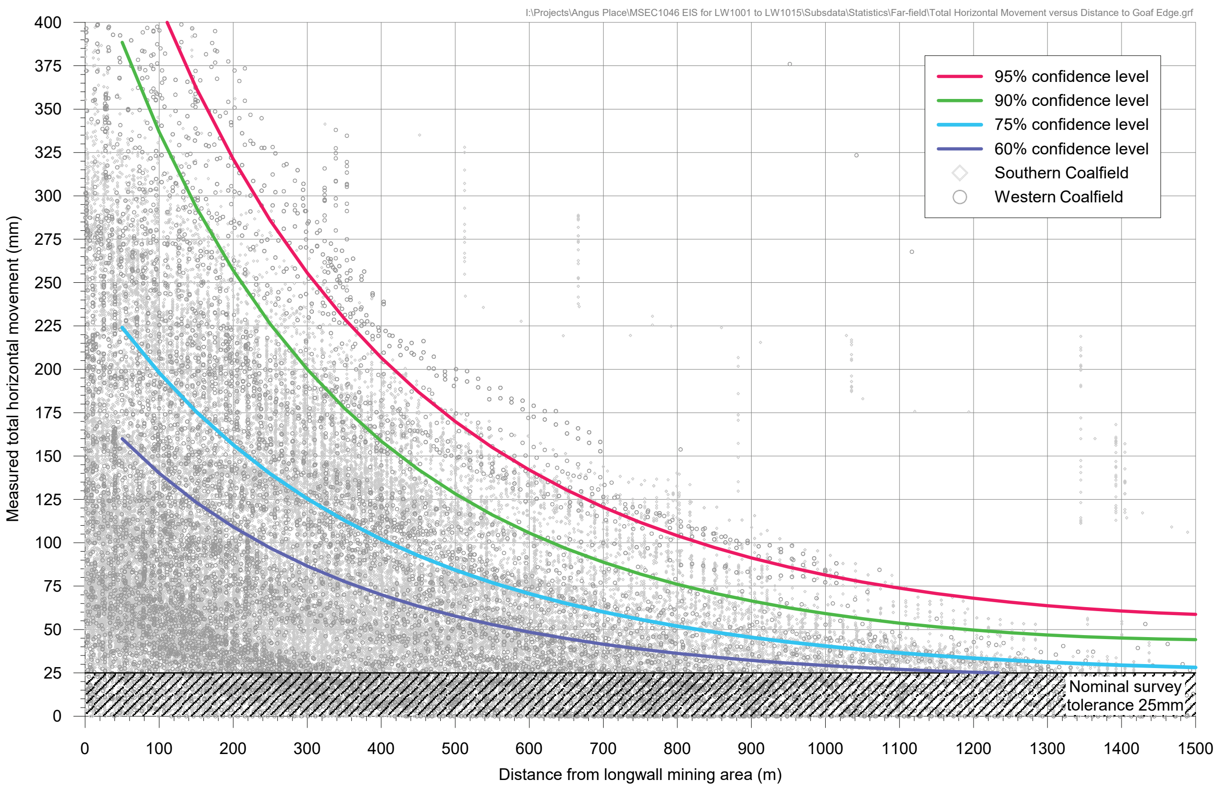

Fig. 4.7 Measured total far-field horizontal movements in the Southern and Western Coalfields

The distribution of far-field horizontal movements in the Western Coalfield is similar to the distribution for the Southern Coalfield. Confidence levels have therefore been fitted to the data from both these coalfields, as illustrated in Fig. 4.7. The predicted far-field horizontal movement at a distance of 1 km outside the mining area is 80 mm based on the 95 % confidence level.

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

4.7. Non-conventional ground movements

It is likely non-conventional ground movements will occur within the Study Area, due to near surface geological conditions, steep topography and valley related effects, which are discussed in Section 3.4. These non-conventional movements are often accompanied by elevated tilts and curvatures that are likely to exceed the conventional predictions.

Specific predictions of upsidence, closure and compressive strain due to the valley related movements are provided for the streams in Sections 5.2 to 5.4. The impact assessments for the streams are based on both the conventional and valley related effects. The potential for non-conventional movements associated with steep topography is discussed in the impact assessments for the steep slopes provided in Section 5.8.

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

4.8. Surface deformations

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

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

Surface deformations can also develop as the result of downslope movements where longwalls are extracted beneath steep slopes. In these cases, the downslope movements can result in the development of tension cracks at the tops and on the sides of the steep slopes and compression ridges at the bottoms of the steep slopes. The impact assessments for downslope movements are provided in Section 5.8.

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

The estimated fracture widths in the topmost bedrock, based on the maximum predicted conventional tensile strain of 3.5 mm/m and based on a typical joint spacing of 10 m, is in the order of 35 mm. In some cases, a series of smaller fractures, rather than one single fracture, would develop in the topmost bedrock. Fracturing would only be visible at the surface where the bedrock is exposed, or where the thickness of the overlying soils is relatively shallow.

Fracturing of bedrock is more likely to occur along the alignments of the streams, due to the compressive strains associated with valley related upsidence and closure effects. The fracture widths in the bedrock are expected to be typically in the order of 25 mm to 50 mm. Where reasonable depths of soils overlie the bedrock, the surface crack widths will be smaller and, in some case, may not visible at the surface.

The cracking in the surface soils are expected to be generally minor in nature due to the reasonable depths of cover above the proposed longwalls, the relatively low magnitudes of predicted strain, and the clayey soils which can more readily absorb ground strains. Surface cracking is expected to be similar to those observed above the previously extracted longwalls at Angus Place and Springvale Collieries.

The surface cracking observed along Kangaroo Creek Road at Angus Place and Sunnyside Ridge Road at Springvale Colliery typically had widths ranging between 10 mm and 50 mm; however, localised cracking also occurred with widths up to approximately 200 mm. Fracturing and buckling of the exposed bedrock occurred along Kangaroo Creek with widths typically ranging between 50 mm and 100 mm. Surface cracking on the valley sides of Kangaroo Creek had widths ranging between 10 mm and 110 mm.

It is possible that larger cracking in the surface soils could occur at the tops and on the sides of the steep slopes as a result of downslope movement. As described in Section 5.8, experience of mining in the NSW coalfields, at similar depths of cover, indicates that surface cracking resulting from downslope movements can be in the order of 100 mm or greater.

Photographs of typical bedrock fracturing and surface cracking above the previously extracted longwalls at Angus Place and Springvale Collieries are provided in Fig. 4.8 and Fig. 4.9.

Fig. 4.8 Fracturing along Kangaroo Creek due to valley closure above Angus Place LW920 (Source: Centennial)

Fig. 4.9 Surface cracking in Kangaroo Creek Road above Angus Place LW950 (left-side) and LW960 (right-side) (Source: Centennial)

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

4.9. Predicted deformations through the overburden

The deformations through the overburden have been determined from the UDEC model, as described in Section 3.8. The modelled profiles of vertical subsidence and horizontal movement through the overburden strata are illustrated in Fig. 4.10. The profiles have been taken through the centreline of LW1005, midway between the centreline and maingate (referred to as the quarter point) and at the maingate of this longwall.

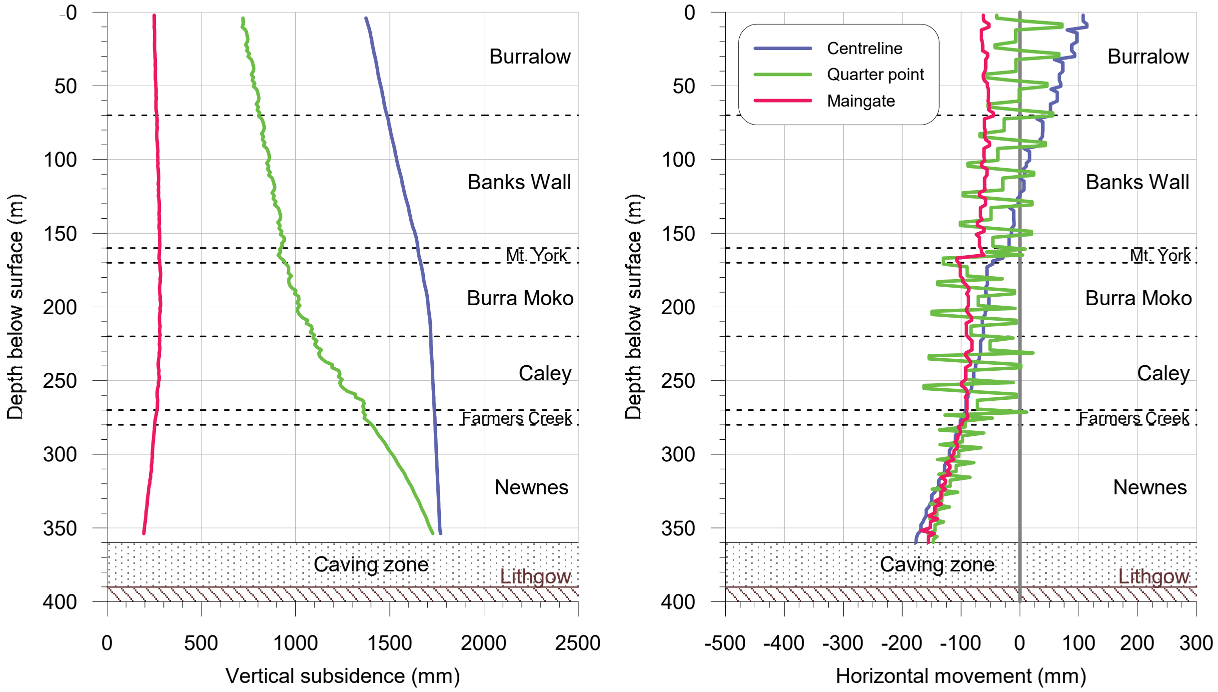

Fig. 4.10 Modelled profiles of vertical subsidence and horizontal movement through the overburden at the centreline, quarter point and maingate of LW1005

The vertical subsidence at the longwall centreline varies between 49 % of the mining height at the surface through to 65 % of the mining heights at the top of the caving zone. The vertical subsidence adjacent to the longwall maingate is 10 % of the mining height through most of the overburden. There is a slight reduction in vertical subsidence in the bottom part of the overburden due to the vertical dilation of the strata resulting from the rotation of the modelled elements.

The vertical strain (over a 20 m height) above the Mt. York Claystone varies between approximately 1 mm/m and 2 mm/m. The maximum vertical strain above the Mt. York Claystone occurs at the longwall centreline with the strains reducing towards the longwall maingate and tailgate.

The vertical strain below the Mt. York Claystone varies between approximately 2 mm/m directly beneath this claystone unit and 7 mm/m within the Caley Formation. The maximum vertical strain below the Mt. York Claystone occurs near the longwall quarter points with the strains reducing towards the longwall centreline, maingate and tailgate.

The horizontal shear on the bedding plane partings varies between approximately 50 mm to 100 mm above the Mt. York Claystone and between approximately 100 mm and 200 mm below this claystone unit. The maximum horizontal shear occurs at the quarter point within the Burra Moko Head Sandstone and the Caley Formation. Horizontal shear along the Mt. York Claystone of 50 mm extends to the longwall maingate and tailgate.

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

5.1. Introduction

The following sections provide the descriptions, predictions and impact assessments for the natural features identified within the Study Area, as summarised in Chapter 2. All significant natural features located outside the Study Area, which may be subjected to valley related or far-field horizontal movements and may be sensitive to these effects, have also been included as part of these assessments.

The natural features within the Study Area which have already experienced mine subsidence movements due to the previously extracted longwalls at Angus Place and Springvale Collieries have been assessed based on the predicted movements due to both the existing and proposed longwalls (i.e. cumulative movements). These features include:

- The Wolgan River,
- Carne Creek,
- Swamps within the Wolgan River valley, and
- Cliffs and pagoda complexes within the Wolgan River valley.

Angus Place also has approval to mine LW910N within the 900 Panel Area on the western side of the Wolgan River. The location of this longwall is shown in Drawing No. MSEC1046-01. LW910N will be mined on retreat following completion of the proposed longwalls in the 1000 Panel Area. The impact assessments for the natural features located between the proposed LW1001 and LW1015 and the LW910N have considered the predicted subsidence effects due to the mining of LW910N.

The following sections provide the descriptions, predictions and impact assessments for all the natural features which have been identified within or in the vicinity of the Study Area.

5.2. Wolgan River

5.2.1. Description of the Wolgan River

The location of the Wolgan River is shown in Drawing No. MSEC1046-08.

The Wolgan River commences above Springvale Colliery and it generally flows in a northerly direction between the existing and proposed longwalls at Angus Place. The river continues to flow in a north to easterly direction to where it drains into the Capertee River, more than 20 km north-east of the proposed longwalls.

The Wolgan River is located to the west of the proposed LW1001 to LW1015. The thalweg (i.e. base or centreline) of the river is generally located outside the 26.5° angle of draw. However, a 100 m section of the river is located just inside the angle of draw to the south of the finishing end of LW1002.

The Wolgan River crosses in and out of the Study Area based on the 600 m boundary on the western side of the proposed longwalls. The total length of the river that is located within the Study Area based on the 600 m boundary is approximately 2.8 km.

A summary of the minimum distances of the proposed longwalls from the thalweg of the Wolgan River is provided in Table 5.1.

Table 5.1 Distances of the proposed longwalls from the thalweg of the Wolgan River

Stream	Longwall	Minimum distance (m)
The Wolgan River	LW1001	750
	LW1002	180
	LW1003	550
	LW1004	470
	LW1005	440
	LW1006	540
	LW1007 to LW1011	> 600
	LW1012	550
	LW1013	500
	LW1014	550
	LW1015	> 600

The Wolgan River is located at a minimum distance of 180 m from the proposed longwalls. The upper reaches of the river are partially located above the completed LW413B and LW414 at Springvale Colliery. They are also located at distances ranging between 100 m and 200 m from the completed LW411 to LW413A and LW415 at Springvale Colliery. Further downstream, the Wolgan River is located at minimum distances of 150 m from LW24, between 200 m and 300 m from LW25 to LW26N and 320 m from LW920 at Angus Place.

Photographs of the Wolgan River and the river valley are provided in Fig. 5.1.

Fig. 5.1 The Wolgan River (left-side) and the river valley (right-side)

The Wolgan River is a perennial stream with small base surface water flows derived from the shrub swamps and perched aquifers. The bed of the river comprises surface soils derived from the Burralow Formation of the Triassic Narrabeen Group, with sandstone bedrock outcropping in some locations.

The natural surface level along the Wolgan River, within the extents of the Study Area based on the 600 m boundary, varies between 1103 mAHD at the upstream end and 976 mAHD at the downstream end. The total length of river between these two points is approximately 7.6 km. The average natural gradient over this section of river therefore is 17 mm/m (1.7 %, or 1 in 59).

Sections through the Wolgan River valley and the proposed longwalls are provided in Fig. 5.2 and Fig. 5.3. The locations of these sections are shown in Drawing No. MSEC1046-08.

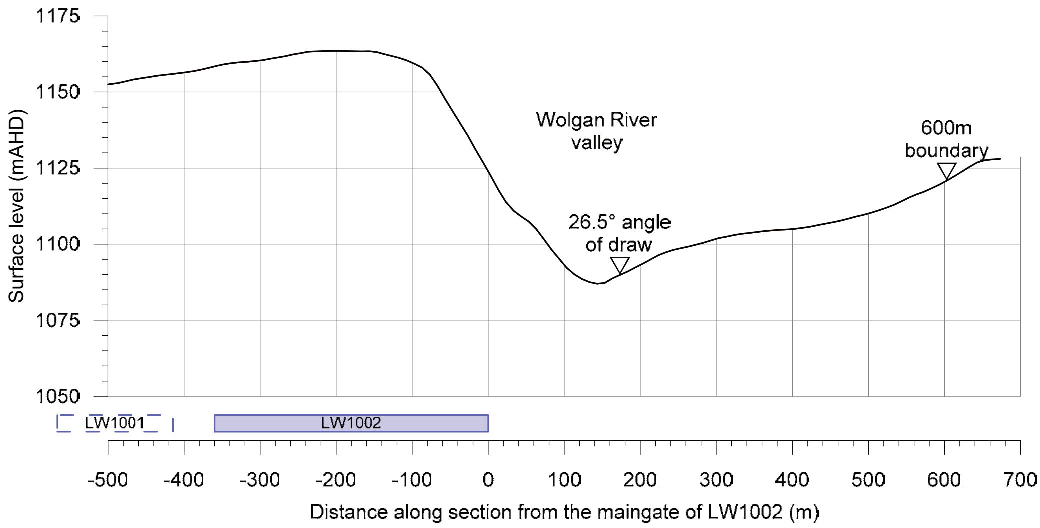

Fig. 5.2 Wolgan River cross-section 1 (looking east)

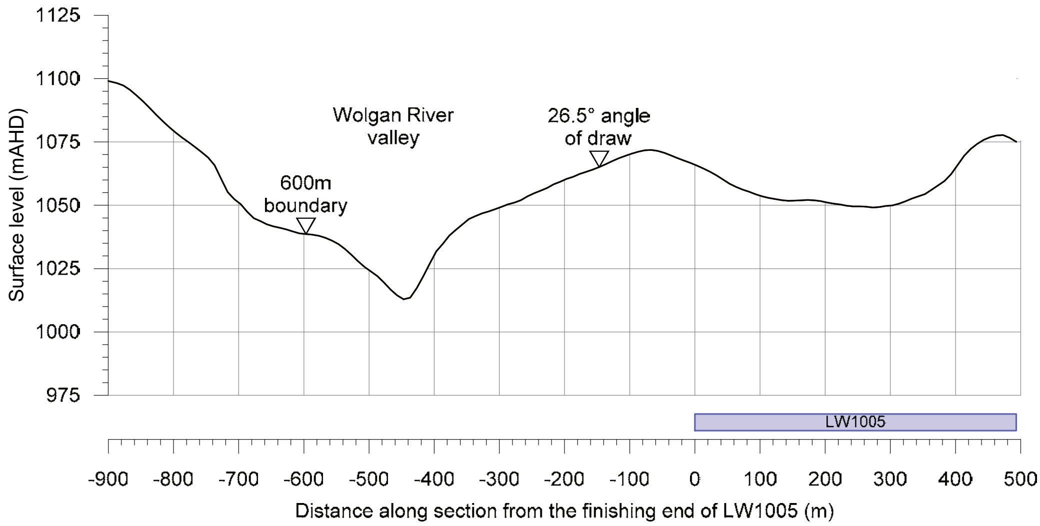

Fig. 5.3 Wolgan River cross-section 2 (looking north)

The height of the Wolgan River valley on the western side of the proposed longwalls varies up to approximately 80 m high. The valley is steeply sided and it contains cliffs, pagodas and talus slopes. The descriptions of the rock features and the steep slopes are provided in Sections 5.7 to 5.8.

Further descriptions of the Wolgan River are provided in the reports by the surface water and ground specialist consultants on the project.

5.2.2. Predictions for the Wolgan River

The predicted profiles of total vertical subsidence, upsidence and closure along the Wolgan River, due to the mining of the existing and proposed longwalls, are shown in Fig. C.04, in Appendix C. The predicted total profiles after the completion of the existing longwalls at Angus Place and Springvale Collieries are shown as cyan lines. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines.

The effective valley height along the alignment of the Wolgan River is shown in Fig. C.04. This height is used to determine the predicted valley related effects for the river based on the ACARP 2002 method. It is equal to the average heights of the two valley sides, within distances equal to half the depth of cover from the thalweg, above the base of the river.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for the Wolgan River is provided in Table 5.2. The values are the maxima anywhere along the section of the river located within the Study Area based on the 600 m boundary, including the predicted movements due to the existing longwalls at Angus Place and Springvale Collieries.

Table 5.2 Maximum predicted total vertical subsidence, upsidence and closure for the Wolgan River within the Study Area based on the 600 m boundary

Case	Maximum predicted vertical subsidence (mm)	Maximum predicted upsidence (mm)	Maximum predicted closure (mm)
Total predicted movements after the extraction of the existing longwalls at Angus Place and Springvale Collieries	< 20	270	310
Total predicted movements after the extraction of the proposed longwalls, including the predicted movements due to the existing longwalls at Angus Place and Springvale Collieries	< 20	290	370
Additional predicted movements due to the extraction of the proposed LW1001 to LW1015 only, excluding the predicted movements due to the existing longwalls at Angus Place and Springvale Collieries	< 20	100	160

The maximum values due to the extraction of the proposed longwalls only are in different locations to the maximum values due to the extraction of the existing longwalls only. The maximum additional movements, therefore, are not equal to the maximum total movements after the proposed longwalls minus the maximum predicted total movements after the completion of the existing longwalls.

The section of the Wolgan River within the Study Area based on the 600 m boundary is predicted to experience less than 20 mm vertical subsidence due to the extraction of both the existing and proposed longwalls. It is unlikely, therefore, that the river would experience measurable conventional strains. However, the Wolgan River is likely to experience compressive strains due to the valley related effects.

The maximum predicted total closure for the section of the Wolgan River within the Study Area based on the 600 m boundary is 370 mm due to the extraction of both the existing and proposed longwalls. However, it can be seen from Fig. C.04, that most of this movement is due to the existing longwalls at Springvale Colliery, as indicated by the cyan line.

The maximum predicted additional closure along the river, due to the extraction of the proposed longwalls only, is illustrated in Fig. 5.4. The maximum predicted additional closure of 160 mm occurs to the south-west of LW1002 and adjacent to the existing LW411 to LW413A at Springvale Colliery. The predicted additional closure adjacent to LW1004 and LW1005 is 130 mm and the predicted additional closure adjacent to LW1012 and LW1013 is 100 mm.

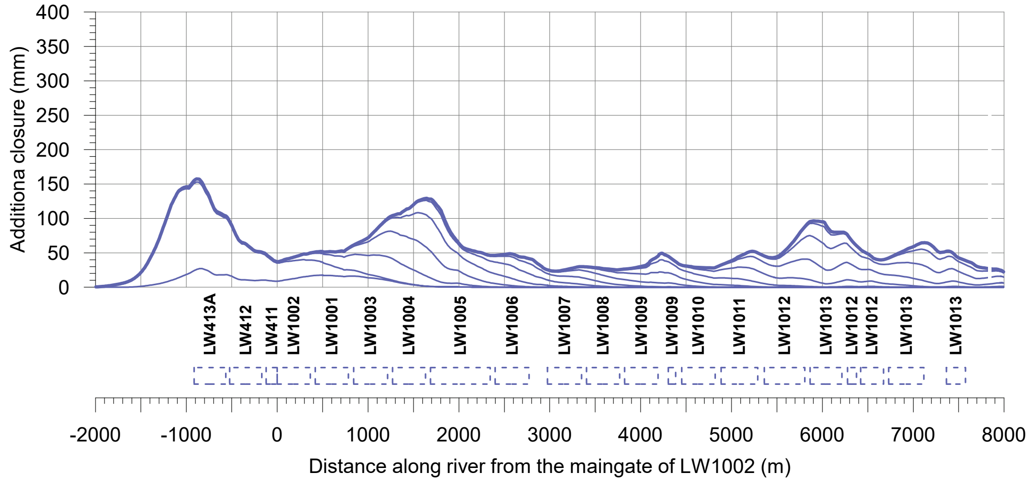

Fig. 5.4 Maximum predicted additional closure along the Wolgan River due to the extraction of the proposed longwalls only

The predicted compressive strains due to valley closure effects for the Wolgan River have been determined by analysing the strains measured in similar sized valleys at similar distances from previously extracted longwalls in the NSW coalfields. The distribution of the total compressive strains measured within valleys, with effective valley heights between 30 m and 60 m and located at distances between 200 m and 400 m from longwall mining, is provided in Fig. 5.5.

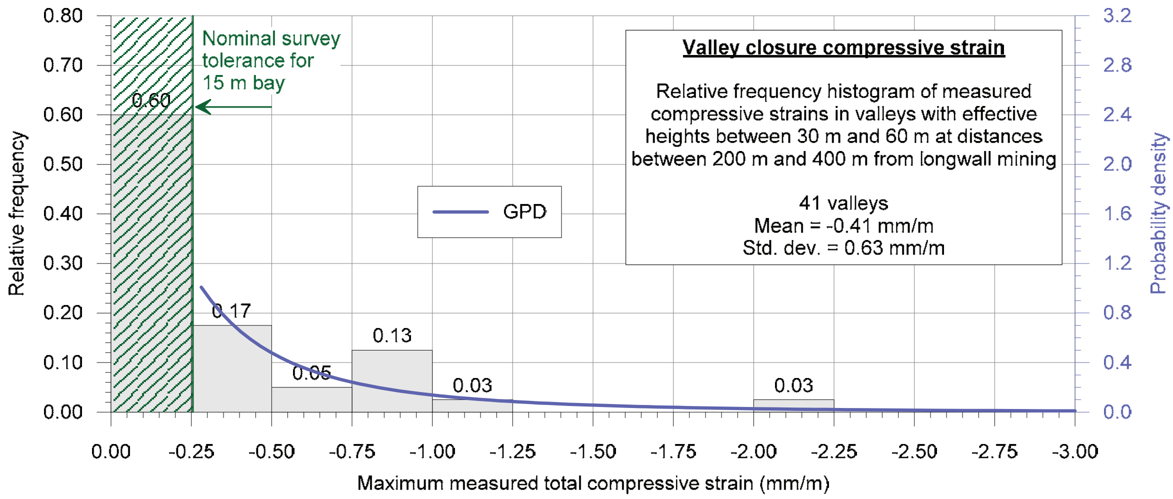

Fig. 5.5 Distribution of measured compressive strains based on effective valley heights between 30 m and 60 m at distances between 200 m and 400 m from longwall mining

It can be seen from the above figure that 77 % of the valleys experienced total compressive strains of less than 0.5 mm/m and that 95 % of the valleys experienced total compressive strains of less than 1 mm/m. A GPD has been fitted to the raw data as shown by the blue line in Fig. 5.5. The predicted total compressive strain derived from the fitted GPD is 1.5 mm/m based on the 95 % confidence level.

5.2.3. Impact assessments for the Wolgan River

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

Potential for increased levels of ponding, flooding and scouring of the river banks

Longwall mining can potentially result in increased levels of flooding or scouring of the stream banks in the locations where the mining-induced tilts considerably increase the natural stream gradients. Longwall mining can also potentially result in increased levels of ponding in the locations where the mining-induced tilts considerably decrease the natural stream gradients. The potential for these impacts are dependent on the magnitudes and locations of the mining-induced tilts, the natural stream bed gradients, as well as the depth, velocity and rate of surface water flows.

The maximum predicted tilt along the alignment of the Wolgan River, due to the extraction of the proposed longwalls, is less than 0.5 mm/m (i.e. less than 0.1 %, or 1 in 2000). The average natural gradient of the section of river within the Study Area is 17 mm/m (i.e. 1.7 %, or 1 in 59).

The predicted mining-induced changes in grade are very small when compared with the natural gradient of the Wolgan River. It is unlikely, therefore, that there would be adverse changes in the levels of ponding, flooding or scouring of the river banks due to the extraction of the proposed longwalls.

Potential for changes in stream alignment

Longwall mining can potentially result in changes in stream alignment due to the mining-induced cross-bed tilts. The potential for mining-induced changes in the stream alignment depends upon the magnitudes and locations of the mining induced cross-bed tilts, the natural stream cross-bed gradients, as well as the depth, velocity and rate of surface water flows. Changes in stream alignment can potentially impact upon riparian vegetation, or result in increased scouring of the stream banks.

The maximum predicted tilt across the alignment of the Wolgan River, due to the extraction of the proposed longwalls, is less than 0.5 mm/m (.e. less than 0.1 %, or 1 in 2000). The Wolgan River valley is steeply incised with the natural cross-bed gradients being orders of magnitude greater than the predicted tilts.

The potential changes in stream alignment are expected to be very minor when compared with the changes in the surface water flow depths and widths that occur during natural flooding events. In the locations where the stream beds comprise sediments and deposited debris, rainfall events can result in changes in the stream alignment. In a large storm event, rocks and vegetation can be carried away downstream. The increased flow velocities in such events are likely to be an order of magnitude greater than those resulting from mining induced changes to bed gradients.

It is unlikely, therefore, that there would be adverse changes in the stream alignment due to the extraction of the proposed longwalls.

Potential for fracturing in the river bed

Fractures and joints in bedrock occur naturally during the formation of the strata and from erosion and weathering processes, which include natural valley bulging movements. When longwall mining occurs in the vicinity of streams, mine subsidence movements can result in additional fracturing or the reactivation of existing joints.

There are various factors that contribute to the potential for mining-induced fracturing and these include:

- mining-related factors that affect the level of mining-induced ground movements in the valley. These include the depth of cover and proximity of the mining to the stream, longwall width and extracted thickness and geology of the overburden;
- topographic factors associated with the stream valley which include valley height, valley width and the shape and steepness of the valley sides;
- local and near-surface geological factors that include bedrock lithology, rock strength, thickness of the strata beds, orientation and dip of strata, degree of cross-bedding and existing jointing;
- horizontal in situ stress in the bedrock; and
- the presence of deep alluvial deposits covering the bedrock.

The compressive strains due to the valley closure effect along the Wolgan River are expected to be typically less than 0.5 mm/m. The maximum predicted compressive strain for the river, based on the analysis of ground monitoring data, is 1.5 mm/m based on the 95 % confidence level. Fracturing of sandstone is rarely observed where the compressive strains are less 2 mm/m.

Monitoring of stream beds affected by longwall mining indicates that mining-induced fractures in bedrock are greatest in size and number directly above the extracted longwalls. Where mining has occurred close to but not directly beneath streams, a smaller number of mining-induced fractures have been observed in the bedrock. These fractures are generally only visible where the bedrock is exposed. The level of pre-existing stress in the valley bedrock varies depending on its position in the natural erosive cycle and the level of regional stress that has been imposed on it. The bedrock strength varies along the streams depending on the type of rock, its layer thickness and extent of natural joints and fractures.

Fracturing has been observed in the NSW coalfields at distances up to approximately 400 m outside of longwall mining. However, at these distances, the fracturing is minor and isolated and it did not result in adverse impacts.

The thalweg of the Wolgan River is located at a minimum distance of 180 m from the proposed LW1002. The total length of river located within 400 m of the mining area is approximately 0.8 km. It is possible that fracturing could occur along the section of the river to the south of LW1002, where it is located closest to the proposed mining area. However, at these distances, the fracturing is expected to be minor and not result in adverse impacts on the surface water flows.

This is supported by the observation that no fracturing or adverse impacts have been observed along the Wolgan River due to the previous longwall mining. This includes LW413B and LW414 at Springvale Colliery mining directly beneath the upper reaches of the Wolgan River and LW411 to LW413A and LW415 at Springvale Colliery mining at minimum distances ranging between 100 m and 200 m from the river.

The section of the Wolgan River to the west of the proposed longwalls is located more than 400 m from the mining area. Based on the historical observations in the NSW coalfields, it is considered unlikely that fracturing or adverse impacts on the surface water flows would occur along the section of the river to the west of the mining area.

Further assessments on the potential impacts on the Wolgan River are provided by the other specialist consultants on the project.

5.2.4. Recommendations for the Wolgan River

It is recommended that a Water Management Plan be developed that includes monitoring and management of the Wolgan River.

5.3. Carne Creek

The location of the Carne Creek is shown in Drawing No. MSEC1046-08.

Carne Creek is situated to the south-east of the proposed longwalls. The creek is located at a minimum distance of 900 m from LW1001 at its closest point to the proposed mining area. At this distance, Carne Creek is predicted to experience negligible conventional and valley related effects.

It is unlikely, therefore, that Carne Creek would experience adverse impacts due to the extraction of the proposed LW1001 to LW1015. Further assessments on the potential impacts on the creek are provided by the other specialist consultants on the project.

5.4. Drainage lines

5.4.1. Description of the drainage lines

The locations of the drainage lines are shown in Drawing No. MSEC1046-08. The drainage lines in the western part of the Study Area drain into the Wolgan River and the drainage lines in the eastern and northern parts of the Study Area drain into Carne Creek.

The drainage lines within the Study Area are unnamed. However, some drainage lines have been labelled to help illustrate the range of predicted subsidence effects and assessed impacts. The labelled drainage lines are shown in Drawing No. MSEC1046-08 and comprise Drainage Lines 1, 2a, 2b, 3a, 3b, 4, 5 and 6.

The upper reaches of the drainage lines are generally first and second order streams. However, sections of Drainage Lines 2a, 2b, 3a and 3b are third order where they are located above the proposed mining area. The lower reaches of Drainage Line 3b are fourth order and the lower reaches of Drainage Lines 5 and 6 are third order where they are located outside of the proposed mining area and inside the Study Area based on the 600 m boundary.

A summary of the third and fourth order sections of the drainage lines that are located within the Study Area based on the 600 m boundary is provided in Table 5.3. The extents of these third and fourth order sections are shown in Drawing No. MSEC1046-08. The third and fourth order sections of the remaining drainage lines are located outside the Study Area based on the 600 m boundary.

Table 5.3 Third and fourth order drainage lines within the Study Area based on the 600 m boundary

Stream	Length of third order section directly above the proposed mining area (km)	Length of third order section within the Study Area based on the 600 m boundary (km)	Length of fourth order section within the Study Area based on the 600 m boundary (km)
Drainage Line 2a	0.7	0.7	-
Drainage Line 2b	0.5	1.1	-
Drainage Line 3a	0.7	1.0	-
Drainage Line 3b	0.1	0.4	0.8
Drainage Line 5	-	0.2	-
Drainage Line 6	-	0.2	-
Totals	2.0	3.6	0.8

The drainage lines have shallow incisions into the natural surface soils which are derived from the Burralow Formation of the Triassic Narrabeen Group. Some sections of the drainage lines have sandstone outcropping, which form a series of steps or drop downs in the steeper sections. There are also debris accumulations which include loose rocks and tree branches.

The sections of the drainage lines downstream of the shrub swamps have small base surface water flows. Elsewhere, the drainage lines are generally ephemeral, although there are some groundwater seeps from the perched aquifers. The natural gradients of the drainage lines typically vary between 25 mm/m (i.e. 2.5 %, or 1 in 40) and 300 mm/m (i.e. 30 %, or 1 in 3) directly above the proposed longwalls.

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

Fig. 5.6 Typical drainage lines within the Study Area

There is a cascade along Drainage Line 3b, downstream of Twin Gully Swamp. This feature is located outside the proposed mining area at a distance of 600 m west of LW1009. The height of the cascade is approximately 5 m. A photograph from the top of the cascade is provided in Fig. 5.7. There is a cliff on the eastern valley side of the cascade, which is also shown in this figure.

Fig. 5.7 Cascade and cliff along Drainage Line 3b outside the proposed mining area

Further descriptions of the drainage lines are provided in the reports by the other specialist consultants on the project.

5.4.2. Predictions for the drainage lines

The drainage lines are located across the Study Area and, therefore, could experience subsidence movements up to the maximum values described in Chapter 4. The site-specific predictions have also been provided below for the drainage lines that include third and fourth order sections.

The predicted profiles of total vertical subsidence, tilt and curvature along Drainage Lines 1, 2a, 2b, 3a, 3b, 4, 5 and 6 are illustrated in Figs. C.05 to C.12, respectively, in Appendix C. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for Drainage Lines 1 to 6 is provided in Table 5.4. The values are the maxima anywhere along the drainage lines located within the Study Area based on the 600 m boundary.

Table 5.4 Maximum predicted total vertical subsidence, tilt and curvature for Drainage Lines 1 to 6

Drainage line	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 Line 1	1950	11	0.12	0.25
Drainage Line 2a	1950	7	0.15	0.25
Drainage Line 2b	2200	20	0.30	0.40
Drainage Line 3a	1500	14	0.20	0.25
Drainage Line 3b	1800	11	0.19	0.25
Drainage Line 4	1200	6	0.09	0.15
Drainage Line 5	1600	8	0.12	0.18
Drainage Line 6	1050	4	0.07	0.05

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the third order sections of the drainage lines is provided in Table 5.5. The third order sections of Drainage Lines 1 and 4 are located outside the Study Area based on the 600 m boundary and, therefore, they have not been included in the table below.

Table 5.5 Maximum predicted total vertical subsidence, tilt and curvature for the third order sections of the drainage lines within the Study Area

Drainage line	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 Line 2a	1950	7	0.15	0.25
Drainage Line 2b	2200	20	0.30	0.40
Drainage Line 3a	1500	14	0.20	0.25
Drainage Line 3b	400	10	0.19	0.02
Drainage Line 5	< 20	< 0.5	< 0.01	< 0.01
Drainage Line 6	< 20	< 0.5	< 0.01	< 0.01

The third order sections along Drainage Lines 2a, 2b and 3a are predicted to experience tilts of up to 20 mm/m (i.e. 0.2 %, or 1 in 50). The maximum predicted total conventional curvatures for the third order sections are 0.30 km^{-1} hogging and 0.40 km^{-1} sagging, which represent minimum radii of curvatures of 3.3 km and 2.5 km, respectively.

The third order sections of Drainage Lines 5 and 6 are located outside of the proposed mining area. These third order sections are predicted to experience less than 20 mm vertical subsidence due to the proposed mining. Whilst the third order sections of Drainage Lines 5 and 6 could experience very low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or conventional strains.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the fourth order section of Drainage Line 3b is provided in Table 5.6. The fourth order section of this drainage line is located outside the proposed mining area.

Table 5.6 Maximum predicted total vertical subsidence, tilt and curvature for the fourth order sections of the drainage lines within the Study Area

Drainage line	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 Line 3b	< 20	< 0.5	< 0.01	< 0.01

The fourth order section of Drainage Line 3b is predicted to experience less than 20 mm vertical subsidence due to the proposed mining. Whilst the fourth order section of this drainage line could experience very low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or conventional strains

The drainage lines could experience valley related upsidence and closure movements. The valley related effects are predicted to be greatest directly above and adjacent to the proposed mining area. The valley related effects are also affected by the effective valley heights, which are the average heights of the two valley sides, within distances equal to half the depth of cover from the thalwegs, above the base of the drainage lines.

The effective valley heights for Drainage Lines 1, 2a, 2b, 3a, 3b, 4, 5 and 6 are shown in Figs. C05 to C.12, respectively, in Appendix C. The effective valley heights of these drainage lines within the Study Area based on the 600 m boundary vary between 10 m and 60 m directly above the proposed mining area and between 40 m and 70 m within the Study Area based on the 600 m boundary.

The compressive strains due to the valley closure effects for the sections of the drainage lines located directly above the proposed longwalls are expected to be similar to those measured at the drainage lines above the previously extracted longwalls at Angus Place and Springvale Collieries. A summary of the maximum measured compressive strains due to valley related effects at the drainage lines located directly above the previously extracted longwalls is provided in Table 5.7.

Table 5.7 **Maximum measured compressive strains at the drainage lines above the previously extracted longwalls at Angus Place and Springvale Collieries**

Colliery	Longwalls	Survey line	Stream	Maximum measured compressive strain (mm/m)
Angus Place	LW11-LW12	X-Line	Lambs Creek tributary 1A	4
	LW920-LW930	A-Line	Wolgan River Tributary 2	5
	LW940-LW950	E-Line	Kangaroo Creek	26
	LW940-LW950	F-Line	Wolgan River Tributary 2	16
	LW940-LW950	LW940 A-Line	Wolgan River Tributary 3	4
Springvale	LW411-LW413A	EWS Line	Wolgan River Tributary 2	18
	LW412-LW414	B-Line	Tributary 1	13
	LW412-LW415	B-Line	Tributary 2	16
	LW412-LW416	B-Line	Tributary 3	9
	LW415-LW419	B-Line	Tributary 4	6
	LW417-LW418	W-Line	Carne Creek	7
	LW418	WC-1 Line	Carne Creek	7
	LW418	YC-2 Line	Tributary to Carne Creek	1
	LW418-LW419	V-Line	Carne Creek	4
	LW418-LW420	B-Line	Tributary 5	5
	LW418-LW420	Y-Line	Tributary to Carne Creek	3
	LW419-LW421	XC-1 Line	Tributary to Carne Creek	1

It can be seen from the above table that 65 % of the valleys experienced total compressive strains of less than 7 mm/m and that 94 % of the valleys experienced total compressive strains of less than 20 mm/m. The maximum measured total compressive strain was 26 mm/m at the E-Line across Kangaroo Creek.

It is expected, therefore, that the sections of the drainage lines that are located directly above and immediately adjacent to the proposed mining area could experience compressive strains due to valley related effects typically between 10 mm/m and 20 mm/m. The greatest compressive strains are expected to occur where the drainage lines are located near the centrelines of the proposed longwalls and lesser values where the drainage lines are located above or near to the chain pillars.

The compressive strains for the sections of the drainage lines that are located outside the extents of the proposed mining area are expected to be less than the values predicted directly above the mining area. The predicted compressive strains due to valley closure effects have been determined by analysing the valley closure effects measured in similar sized valleys located adjacent to previously extracted longwalls in the NSW coalfields.

The effective valley heights for the lower reaches of the drainage lines are similar to that for the Wolgan River. The distribution of the total compressive strains measured within similar valleys located at distances between 200 m and 400 m from longwall mining, is provided in Fig. 5.5.

The total compressive strains measured within valleys in the NSW coalfields versus the distance from longwall mining is illustrated in Fig. 5.8. The data is based on valleys with effective heights ranging between 30 m and 70 m and located at distances between zero and 600 m from previously extracted longwalls.

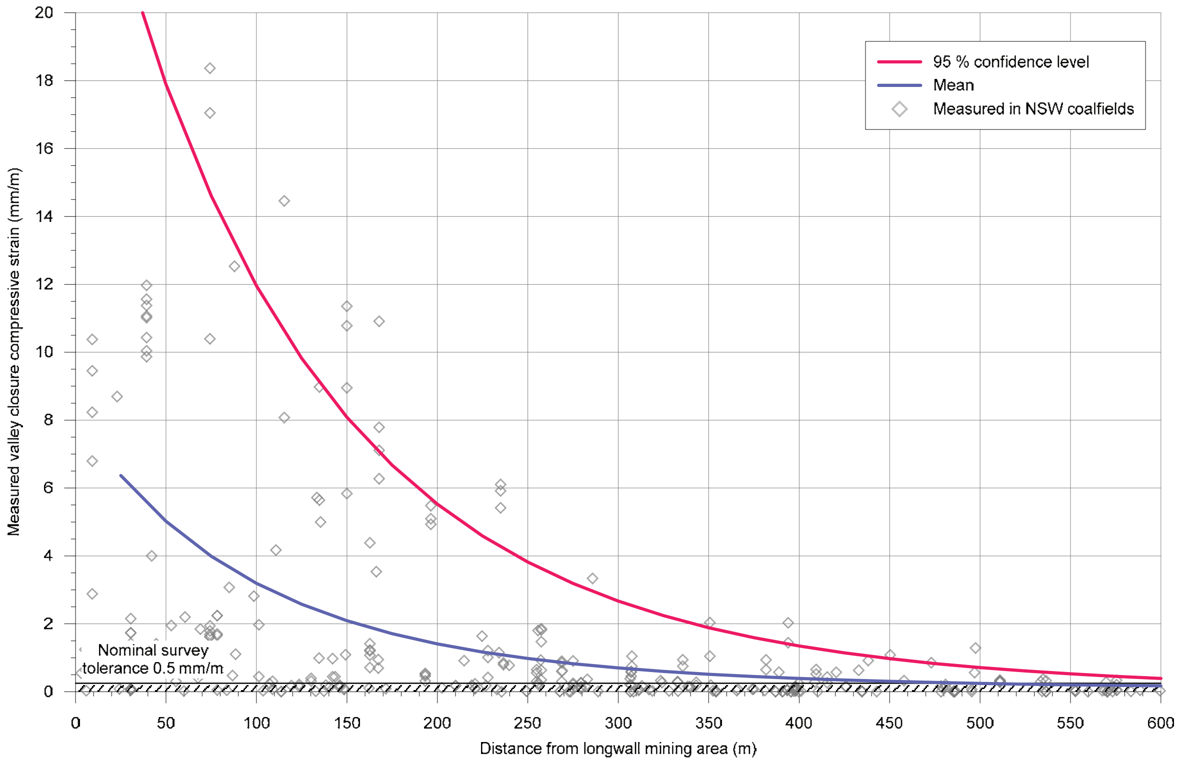

Fig. 5.8 Measured compressive strains based on effective valley heights between 30 m and 70 m at distances between zero and 600 m from longwall mining

The mean and standard deviation of the data are shown as the blue line and red line, respectively, in Fig. 5.8. A summary of the predicted total compressive strains for the sections of the drainage lines located outside the proposed mining area is provided in Table 5.8.

Table 5.8 Predicted total compressive strains for the sections of the drainage lines located outside the proposed longwalls and within the Study Area based on the 600 m boundary

Location	Distance from the proposed longwall mining area (m)	Predicted total valley closure compressive strain (mm/m)	
		Mean	95 % confidence level
Drainage lines	100	3.2	12
	200	1.4	5.5
	300	0.7	2.7
	400	< 0.5	1.3
	500	< 0.5	0.7
	600	< 0.5	< 0.5

The smaller (i.e. unlabelled) tributaries to the drainage lines are located across the Study Area and are expected to experience the full range of predicted subsidence effects, as outlined in Chapter 4. These tributaries have shallow incisions into the sides of the ridgelines and, therefore, the valley related effects are expected to be small when compared with the conventional ground movements above the proposed longwalls.

The cascade along Drainage Line 3b is located 600 m west of the proposed mining area. At this distance, this feature is not predicted to experience measurable conventional subsidence effects. The predicted closure due to the proposed longwalls is 80 mm. The predicted compressive strain due to the valley related effects is 0.5 mm/m based on the 95 % confidence level.

5.4.3. Impact assessments for the drainage lines

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

Potential for increased levels of ponding, flooding and scouring

Mining can potentially result in increased levels of ponding in 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 likelihood of scouring of the stream beds in the locations where the mining-induced tilts considerably increase the natural stream gradients that exist before mining.

The maximum predicted tilt within the Study Area is 25 mm/m (i.e. 2.5 %, or 1 in 40). The average natural gradients of the drainage lines typically vary between 25 mm/m and 300 mm/m (i.e. 30 %, or 1 in 3) directly above the proposed longwalls.

The predicted mining-induced changes in grade are less than the average natural gradients along the drainage lines. It is unlikely, therefore, that the mining-induced tilts would have an adverse impact on the surface water flows. The natural and the predicted post-mining grades along Drainage Lines 1, 2a, 2b, 3a, 3b, 4, 5 and 6 are illustrated in Fig. 5.9 to Fig. 5.16, respectively. The locations of the swamps along each of the drainage lines are also indicated in these figures. It is noted that the hanging swamps are on the valley sides and, therefore, the drainage line do not pass directly through them.

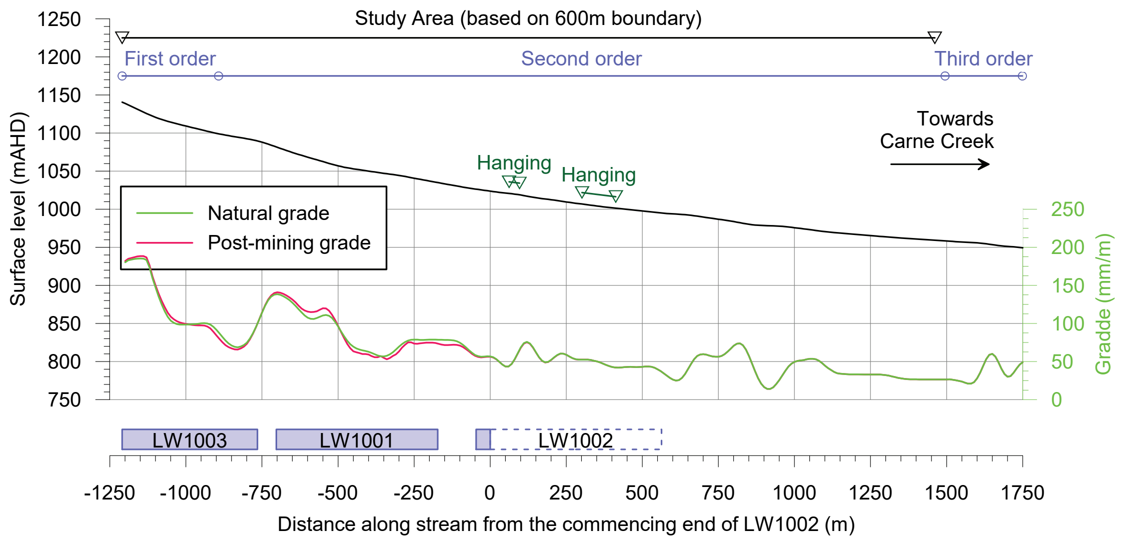

Fig. 5.9 Natural and predicted post-mining surface levels and grade along Drainage Line 1

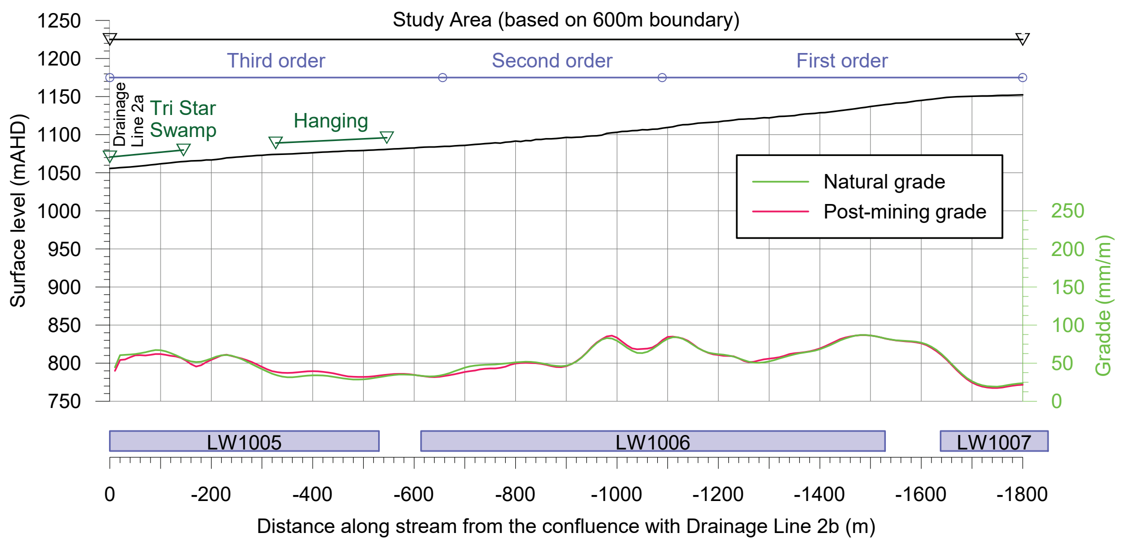

Fig. 5.10 Natural and predicted post-mining surface levels and grade along Drainage Line 2a

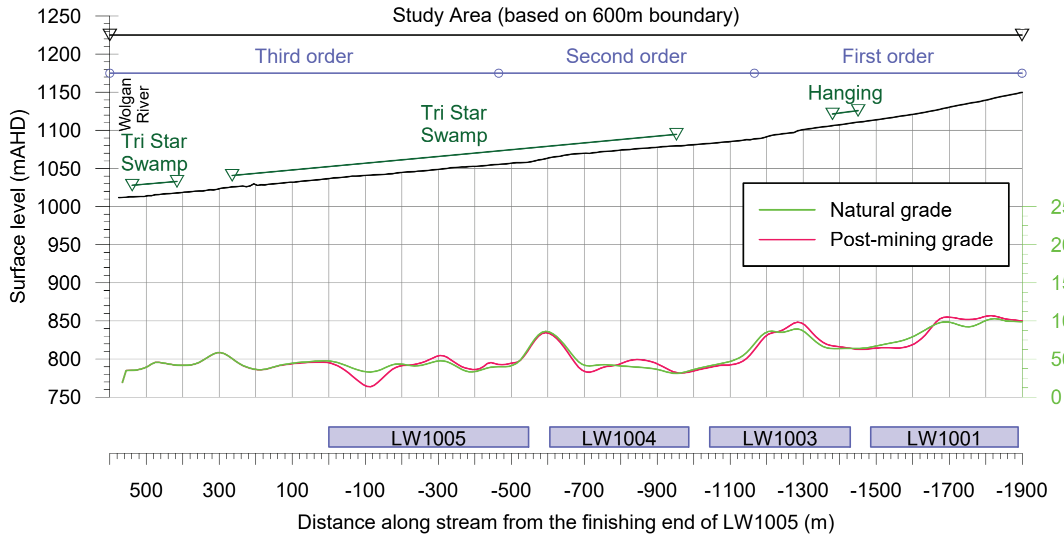

Fig. 5.11 Natural and predicted post-mining surface levels and grade along Drainage Line 2b

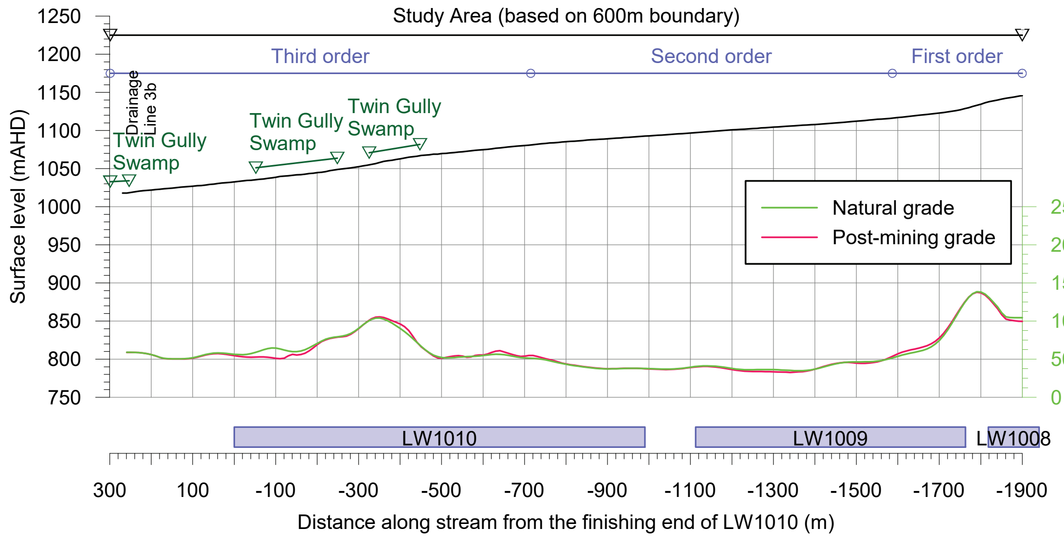

Fig. 5.12 Natural and predicted post-mining surface levels and grade along Drainage Line 3a

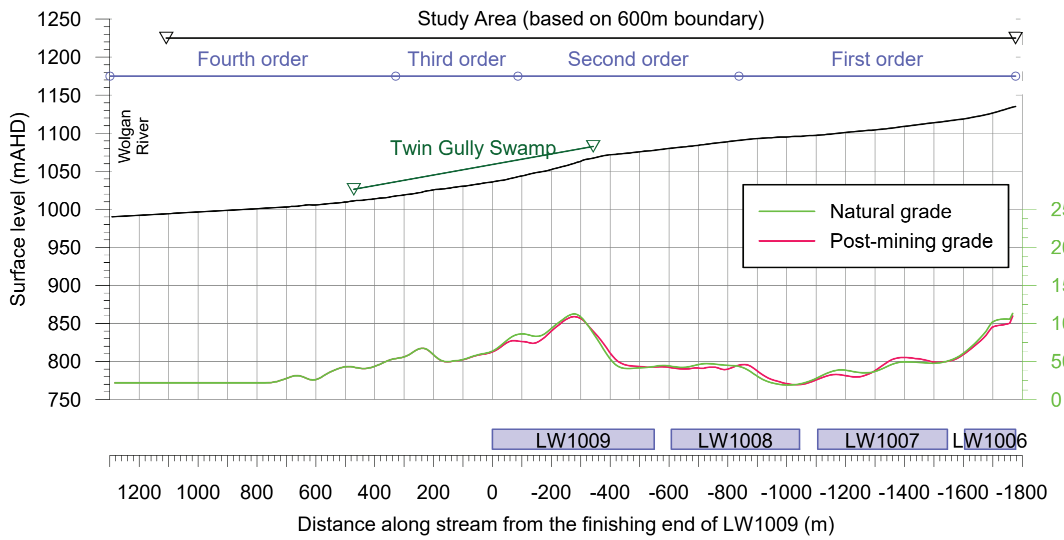

Fig. 5.13 Natural and predicted post-mining surface levels and grade along Drainage Line 3b

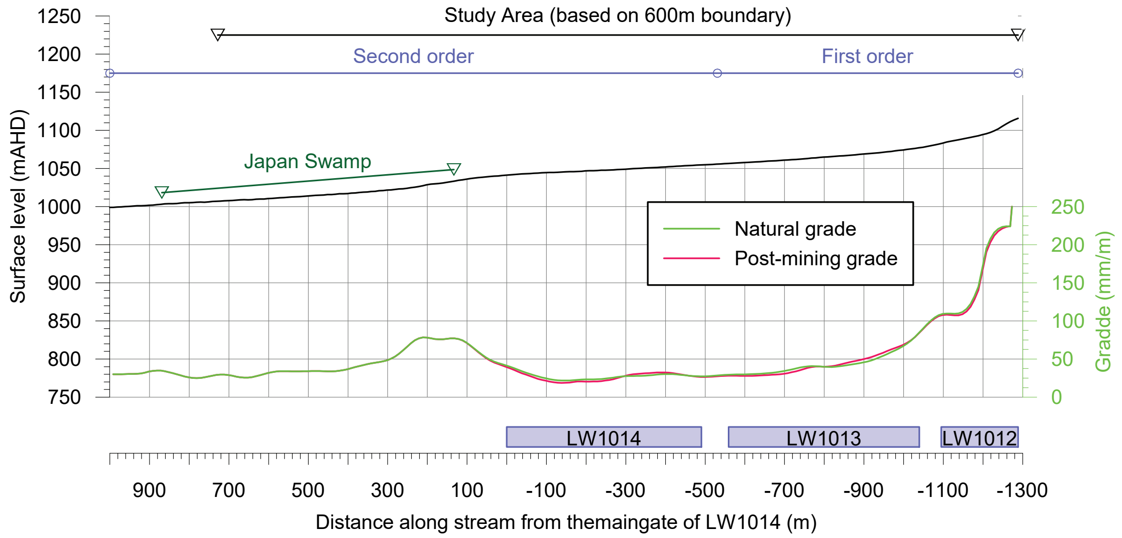

Fig. 5.14 **Natural and predicted post-mining surface levels and grade along Drainage Line 4**

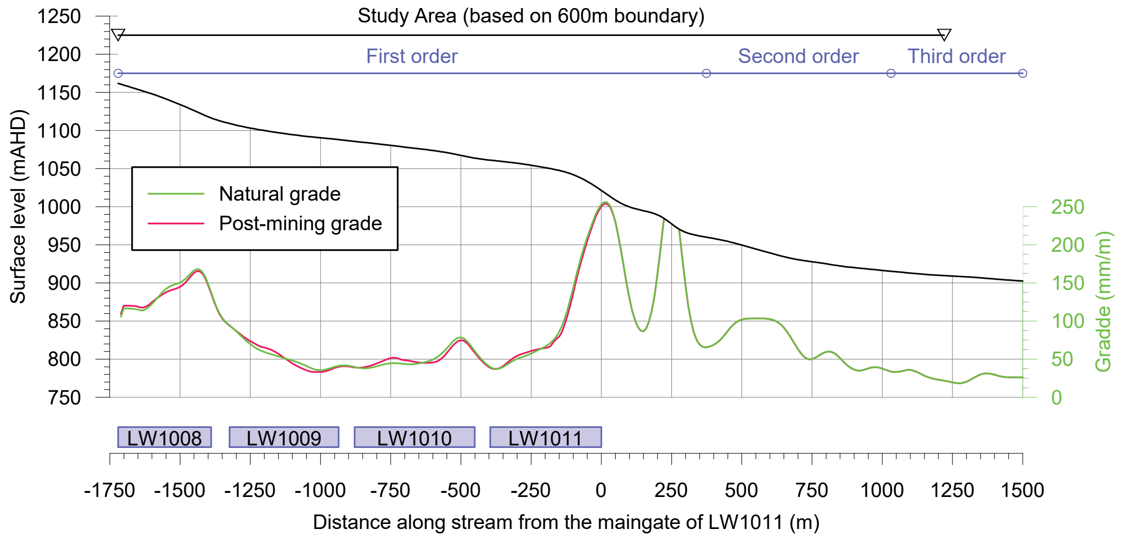

Fig. 5.15 **Natural and predicted post-mining surface levels and grade along Drainage Line 5**

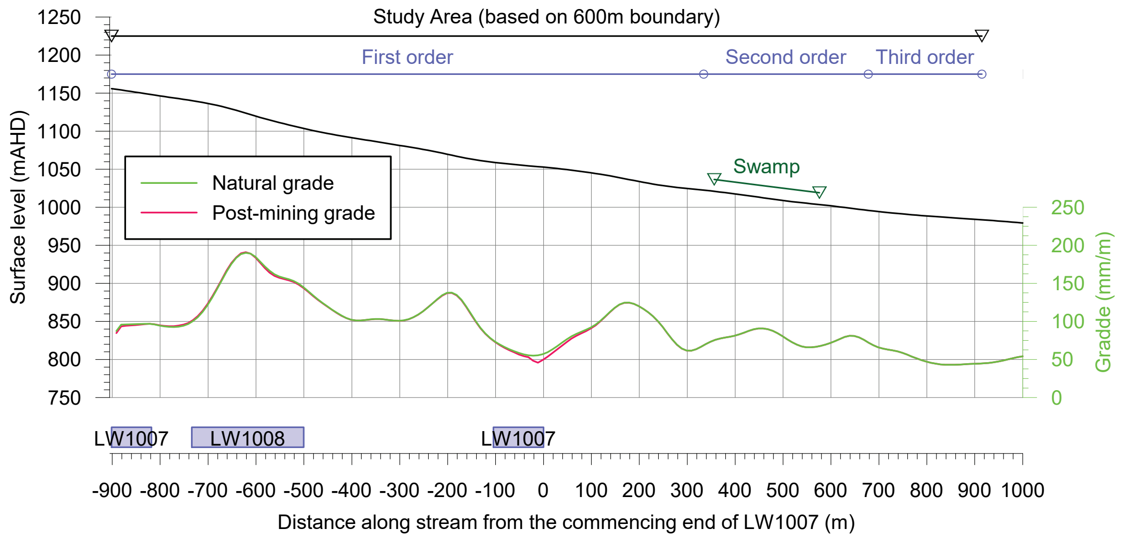

Fig. 5.16 **Natural and predicted post-mining surface levels and grade along Drainage Line 6**

The predicted post-mining grades along Drainage Lines 1, 2a, 2b, 3a, 3b, 4, 5 and 6 are similar to their natural grades. There are no predicted significant reductions or reversals of stream grade. It is not expected, therefore, that there would be adverse changes in ponding or scouring along the drainage lines resulting from the mining-induced tilt.

It is possible that there could be localised areas along the drainage lines that could experience small increases in the levels of ponding, where the natural gradients are low immediately upstream of the longwall chain pillars and around the perimeter of the proposed mining area. As the predicted changes in grade are small, typically less than 10 mm/m to 20 mm/m (i.e. 1 % to 2 %), any localised changes in ponding are expected to be minor and not result in adverse impacts on the drainage lines.

Further discussions on the potential changes in ponding and flooding along the drainage lines are provided by the specialist surface water consultant on the project.

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

Fracturing in bedrock has been observed due to previous longwall mining where the tensile strains have been greater than 0.5 mm/m or where the compressive strains have been greater than 2 mm/m. It is likely, therefore, that fracturing would occur along the drainage lines within the Study Area. Fracturing will predominately occur directly above the proposed mining area. However, fracturing can also occur outside the mining area, with minor and isolated fracturing occurring at distances up to approximately 400 m.

The estimated fracture widths in the topmost bedrock, based on the maximum predicted conventional tensile strain of 3.5 mm/m and based on a typical joint spacing of 10 m, is in the order of 35 mm. In some cases, a series of smaller fractures, rather than one single fracture, would develop in the topmost bedrock.

The drainage lines within the Study Area generally have surface soils overlying the bedrock. Where there are reasonable depths of surface soils, the fracturing in the bedrock may not be visible at the surface. However, where the bedrock is shallow or exposed, then the fracturing will be visible at the surface.

The surface cracking is expected to be similar to that previously observed at Angus Place and Springvale Collieries (refer to Section 4.8). The crack widths are expected to be typically between 10 mm and 50 mm; however, localised cracking with widths greater than 50 mm can also develop. Outside the proposed mining area, the crack widths are expected to be typically less than 10 mm; however, localised cracking with widths greater than 25 mm can also develop.

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

The first and second order sections of the drainage lines are located upstream of the shrub swamps. The upper reaches of the drainage lines are ephemeral and therefore surface water generally flows during and for short periods after rain events. The third order streams are located within and downstream of the shrub swamps. The total length of the third order sections of the drainage lines located directly above the proposed mining area is approximately 2 km.

Surface water flow diversions could occur along the sections of drainage lines that are located directly above and adjacent to the proposed longwalls. In times of heavy rainfall, the majority of the runoff would flow over the fractured bedrock and soil beds and would not be diverted into the dilated strata below. In times of low flow, however, surface water flows can be diverted into the dilated strata below the beds.

Further discussions on the potential impacts on the drainage lines are provided by the other specialist surface water and groundwater consultants on the project.

5.4.4. Recommendations for the drainage lines

It is recommended that a Water Management Plan be developed that includes monitoring and management of the drainage lines.

5.5. Aquifers and known groundwater resources

The descriptions, predictions and the assessment of potential impacts on the aquifers and groundwater resources within the Study Area are provided by the specialist groundwater consultant on the project.

5.6. Springs and groundwater seeps

There are natural springs and groundwater seeps within the Study Area, which are described by the specialist groundwater consultant on the project.

5.7. Cliffs, minor cliffs and pagodas

5.7.1. Descriptions of the cliffs, minor cliffs and pagodas

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

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

The locations of the cliffs, minor cliffs and pagodas have been determined using the 1 m surface level contours that were generated from the Light Detection and Ranging (LiDAR) survey, the aerial photograph and site investigations. The locations of these features are shown in Drawing No. MSEC1046-10.

The cliffs, minor cliffs and pagoda complexes have been identified within the valleys of the Wolgan River, Carne Creek and the tributaries to the Wolgan River and Carne Creek. These features have formed from sandstone of the Triassic Narrabeen Group. The pagodas within the Study Area are "*platy pagodas*" which are formed from the combination of sandstone and ironstone.

The mining layout has been designed such that the majority of the cliffs and pagoda complexes are located outside the 26.5° angle of draw from the extents of the proposed longwalls. The commencing (i.e. western) ends of LW1012 to LW1014 have been set back from the cliffs and pagoda complexes along the lower reaches of Drainage Line 5. Similarly, the finishing ends of the proposed longwalls have been set back from the cliffs and pagoda complexes along the tributaries to the Wolgan River.

There are three cliffs (Refs. AP-C1, AP-C2 and AP-C3) that are located within the Study Area based on the 26.5° angle of draw. The locations of these cliffs are shown in Drawing No. MSEC1046-10. A summary of the three cliffs identified within the Study Area is provided in Table 5.9. There are also other nearby cliffs that are located on the Study Area boundary as shown in the drawing.

Table 5.9 Cliffs identified within the Study Area

Reference	Total length within the Study Area	Maximum height (m)	Location
AP-CL1	50	20	Along Drainage Line 1, approximately 120 m south of LW1001 maingate and 150 m east of LW1002 commencing end
AP-CL2	75	25	Along Drainage Line 2b, approximately 150 m west of the finishing end of LW1005
AP-CL3	150	25	Along a tributary to Drainage Line 5, approximately 180 m east of the commencing end of LW1014.

Sections through Cliffs AP-C1, AP-C2 and AP-C3 and are provided in Fig. 5.17, Fig. 5.18 and Fig. 5.19, respectively. These sections have been taken through the cliffs and the nearest proposed longwall.

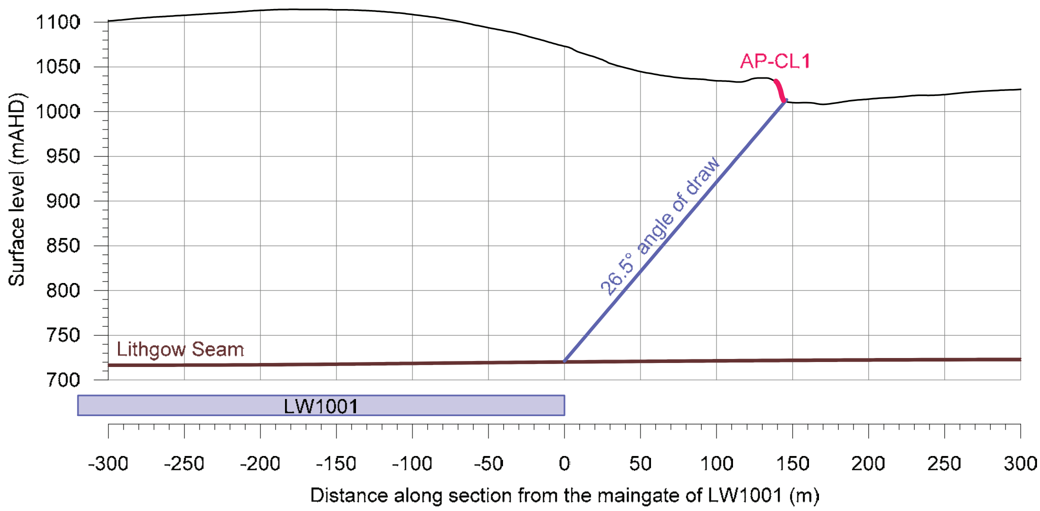

Fig. 5.17 Section through Cliff AP-CL1

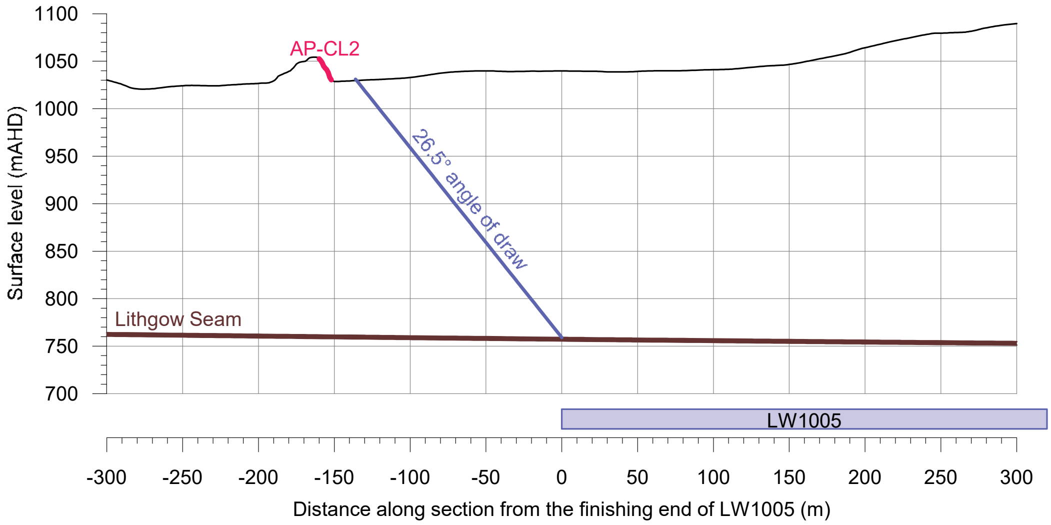

Fig. 5.18 Section through Cliff AP-CL2

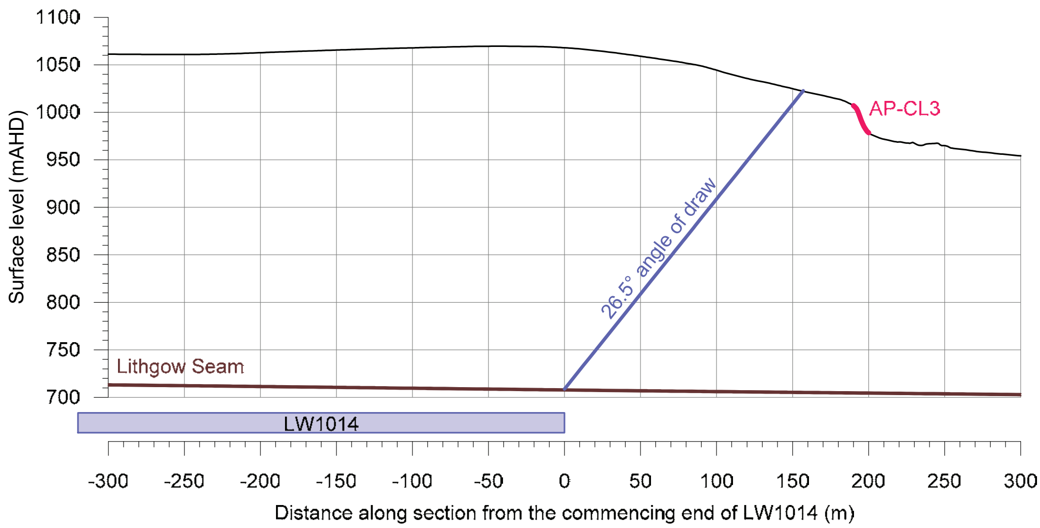

Fig. 5.19 Section through Cliff AP-CL3

The toe of Cliff AP-C1 is located just inside the 26.5° angle of draw. However, Cliffs AP-C2 and AP-C3 are located outside the 26.5° angle of draw. The reason is the Study Area differs from the 26.5° angle of draw line, as the Study Area is based on the depth of cover at the perimeter of the mining area and, therefore, it does not take into account the decreasing surface elevation outside of the mining area.

Hence, there is only one cliff (AP-C1) that has been identified within the 26.5° angle of draw. The remaining cliffs (including AP-C2 and AP-C3) are located outside the 26.5° angle of draw. The cliffs along the upper reaches of the drainage lines are located within the Study Area based on the 600 m boundary.

There is one minor cliff (Ref. AP-MC1) that is located within the Study Area, adjacent to the commencing (i.e. eastern) ends of LW1012 and LW1013. The minor cliff has an overall length of 350 m and an average height of 5 m. The northern end of the minor cliff is located above the commencing end of LW1013.

The pagoda complexes are located outside the proposed mining area. The pagodas along the upper reaches of Drainage Lines 1 and 5 and the tributaries to the Wolgan River are located adjacent to the mining area. Further downstream, the main pagoda complexes are located on or outside the 26.5° angle of draw. There are isolated pagodas that are located directly above the proposed mining area.

Photographs of the cliffs and pagoda complexes along the Wolgan River valley, located west of the proposed mining area, are provided in Fig. 5.20 and Fig. 5.21. Photographs of the pagoda complexes along Drainage Line 5, located north-east of the proposed mining area, are provided in Fig. 5.22.

Fig. 5.20 Cliffs along the Wolgan River

Fig. 5.21 Cliff AP-CL2 and nearby pagoda complex

Fig. 5.22 Pagoda complexes located along Drainage Line 5

5.7.2. Predictions for the cliffs, minor cliffs and pagoda complexes

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the cliffs identified within the Study Area is provided in Table 5.10. This table provides the maximum predicted values within 20 m of the mapped extents of each of the cliffs.

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

Reference	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
AP-CL1	< 20	< 0.5	< 0.01	< 0.01
AP-CL2	< 20	< 0.5	< 0.01	< 0.01
AP-CL3	< 20	< 0.5	< 0.01	< 0.01
Other cliffs located on or outside the Study Area	< 20	< 0.5	< 0.01	< 0.01

The cliffs within the Study Area are predicted to experience less than 20 mm vertical subsidence due to the extraction of the proposed longwalls. Whilst the cliffs located closest to the mining area could experience very low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the minor cliff identified within the Study Area is provided in Table 5.11. This table provides the maximum predicted values within 20 m of the mapped extent of the minor cliff.

Table 5.11 Maximum predicted total vertical subsidence, tilt and curvature for the minor cliff

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})
AP-MC1	60	1.0	0.02	< 0.01
Other minor cliffs located outside the mining area	< 20	< 0.5	< 0.01	< 0.01

The Minor Cliff AP-MC1 is predicted to experience a tilt of 1.0 mm/m (i.e. 0.1 %, or 1 in 1000). The maximum predicted curvatures are 0.02 km^{-1} hogging and less than 0.01 km^{-1} sagging, which represent minimum radii of curvatures of 50 km and greater than 100 km, respectively.

The Minor Cliff AP-MC1 is located outside and adjacent to the commencing ends of LW1012 and LW1013. The distribution of the predicted strains above solid coal is described in Section 4.4.2. The predicted strains for the minor cliff are 1.4 mm/m tensile and 0.6 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 pagoda complexes identified within the Study Area is provided in Table 5.12. This table provides the maximum predicted values within 20 m of the mapped extents of these features.

Table 5.12 Maximum predicted total vertical subsidence, tilt and curvature for the pagoda complexes

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})
Pagodas along the upper reaches of Drainage Lines 1 and 5 and the tributaries to the Wolgan River	150	3.0	0.04	< 0.01
Pagoda complexes along Drainage Lines 1 and 5 and the Wolgan River	< 20	< 0.5	< 0.01	< 0.01

The pagodas located along the upper reaches of Drainage Lines 1 and 5 and the tributaries to the Wolgan River are predicted to experience up to 150 mm vertical subsidence and 3.0 mm/m tilt (i.e. 0.3 %, or 1 in 330). The maximum predicted curvatures are 0.04 km^{-1} hogging and less than 0.01 km^{-1} sagging, which represent minimum radii of curvatures of 25 km and greater than 100 km, respectively.

The pagodas along the upper reaches of the streams are located outside and adjacent to the proposed mining area. The distribution of the predicted strains above solid coal is described in Section 4.4.2. The predicted strains for the pagodas are 1.4 mm/m tensile and 0.6 mm/m compressive based on the 95 % confidence levels.

The main pagoda complexes located further downstream are predicted to experience less than 20 mm vertical subsidence. Whilst the main pagoda complexes could experience very low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

The isolated pagodas located directly above the proposed longwalls could experience subsidence effects up to the maximum values described in Chapter 4. The maximum predicted subsidence effects are 2250 mm vertical subsidence, 25 mm/m tilt, 0.35 km^{-1} hogging curvature and 0.40 km^{-1} sagging curvature.

The distribution of the predicted strains above goaf is described in Section 4.4.1. The predicted strains in the eastern and northern parts of the mining area are 2.5 mm/m tensile and 4 mm/m compressive based on the 95 % confidence levels. The predicted strains in the south-western part of the mining area are 5 mm/m tensile and 6 mm/m compressive based on the 95 % confidence levels.

The cliffs, minor cliffs and pagodas located outside the proposed mining area could also experience far-field horizontal movements. The measured total far-field horizontal movements due to longwall mining in the Southern and Western Coalfields are shown in Fig. 4.7. The predicted absolute horizontal movements, based on the 95 % confidence level, are 250 mm at a distance of 300 m, 140 mm at a distance of 600 m and 80 mm at a distance of 1 km.

The cliffs, minor cliffs and pagodas are located on the sides of the valleys. These features are therefore not expected to experience the valley related upsidence or compressive strains due to valley closure, as these occur near the valley base, rather than along the valley sides.

5.7.3. Impact assessments for the cliffs, minor cliffs and pagodas

The impact assessments for the cliffs, minor cliffs and pagodas are provided in the following sections. The assessments provided in this report should be read in conjunction with the assessments provided by the other specialist consultants on the project.

Cliffs

The cliffs identified within the Study Area are located at a minimum distance of 150 m outside the proposed mining area. At these distances, the cliffs are predicted to experience less than 20 mm vertical subsidence. Whilst the cliffs located closest to the proposed mining area could experience low levels of vertical subsidence, they are not predicted to experience measurable tilts, curvatures or strains.

The cliffs will also experience far-field horizontal movements towards the proposed mining area. However, these effects tend to be bodily movements towards the mining area that are accompanied by very low levels of strain. The cliffs are not predicted to experience the valley related upsidence or compressive strains due to the valley closure effects as they are located along the valley sides.

It is unlikely that the cliffs would experience adverse impacts due to their distances outside of the proposed mining area and the low levels of predicted movement. This is based on the extensive experience of mining near to but not directly beneath cliffs in the NSW coalfields, where no large cliff falls have occurred where the cliffs have been located completely outside the angle of draw from previous mining. However, it is still possible, but unlikely, that isolated rock falls could occur due to the proposed mining, due to natural processes, or both.

Cliff AP-CL1 is located just inside the 26.5° angle of draw and Cliffs AP-CL2, AP-CL3 and other nearby cliffs are located on or just outside the 26.5° angle of draw. Rock falls could occur at some of these cliffs due to the proposed mining; however, these impacts are expected to represent less than 1 % of the face areas of the cliffs.

Minor cliffs

The northern end of the Minor Cliff AP-MC1 is located above the commencing end of LW1013. This minor cliff could experience fracturing and, where the rock is marginally stable, this could then result in localised spalling of the exposed rockface. Previous experience of mining beneath and immediately adjacent to minor cliffs in the NSW coalfields, at similar depths of cover, indicates that adverse impacts represent less than 3 % of face area of the minor cliff.

The other minor cliffs are located outside the proposed mining area and typically outside the 26.5° angle of draw. At these distances, it is unlikely that adverse impacts would occur at these minor cliffs. Rock falls could occur at some of the minor cliffs located closest to the proposed mining; however, these impacts are expected to represent less than 1 % of the face areas of the minor cliffs.

Pagodas

The pagodas along the upper reaches of Drainage Lines 1 and 5 and the upper reaches of the tributaries to the Wolgan River are predicted to experience up to 150 mm vertical subsidence. The predicted strains for these pagodas are 1.4 mm/m tensile and 0.6 mm/m compressive based on the 95 % confidence levels.

Fracturing of bedrock has been observed in the NSW coalfields where the tensile strains have been greater than 0.5 mm/m or where the compressive strains have been greater than 2 mm/m. It is possible, therefore, that fracturing could develop in the pagodas that are located closest to the proposed longwalls.

Greater impacts tend to occur due to the compressive strains that can result in failure and spalling of the free rockface. In this case, the predicted compressive strains are less than 2 mm/m based on the 95 % confidence level. However, the tensile strains could be sufficient to result in fracturing and, where the exposed face is marginally stable, this could then result in rockfalls. These impacts are expected to represent less than 1 % of the face areas of the pagodas that are located within the 26.5° angle of draw.

The main pagoda complexes are located on or outside the 26.5° angle of draw. At these distances, the complexes are predicted to experience less than 20 mm vertical subsidence. The complexes will experience far-field horizontal movements towards the proposed mining area. However, these effects tend to be bodily movements towards the mining area that are accompanied by very low levels of strain. The pagoda complexes are not predicted to experience the valley related upsidence or compressive strains due to the valley closure effects as they are located along the valley sides.

It is possible, but unlikely, that minor fracturing could occur at main pagoda complexes located on or near to the 26.5° angle of draw. Whilst fracturing has been observed up to approximately 400 m outside of longwall mining in the NSW coalfields, this has occurred in the bases of streams. Pagodas are freestanding rock features that are less likely to experience the localised compressive strains that occur in the bases of streams.

It is therefore considered unlikely that fracturing would occur at the main pagoda complexes that are located on or outside the 26.5° angle of draw.

Isolated pagodas are located directly above the proposed mining area. These features are likely to experience fracturing and, where the rock is marginally stable, this could then result in spalling of the exposed rockfaces. The isolated pagodas are discontinuous and, therefore, are less susceptible to impacts when compared to cliffs and minor cliffs. It is expected that the impacts resulting from the proposed mining would represent less than 1 % of total surface area of the isolated pagodas which are located directly above the proposed longwalls.

5.7.4. Recommendations for the cliffs, minor cliffs and pagodas

It is recommended that a Landscape Management Plan be developed for cliffs, minor cliffs and pagoda complexes as part of the Extraction Plans for the mine. Periodic visual inspection should be carried out when mining adjacent to these features and for a period after the completion of mining.

5.8. Steep slopes and rock outcrops

5.8.1. Descriptions of the steep slopes and rock outcrops

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

The areas identified as having steep slopes are shown in Drawing No. MSEC1046-11. The steep slopes within the Study Area are primarily located along the alignments of the drainage lines. The natural grades of the steep slopes typically range between 1 in 3 (i.e. 33 % or 18º) and 1 in 2 (i.e. 50 % or 27º), with isolated areas having natural grades up to 1 in 1.5 (i.e. 67 % or 34º).

The surface soils along the steep slopes are derived from weathered sandstone from the Triassic Narrabeen Group (Tn), as can be inferred from Fig. 1.7. The majority of the slopes are stabilised by the natural vegetation, which can be seen in Fig. 5.32.

Rock outcrops are defined as exposed rockfaces with heights of less than 10 m, lengths of less than 20 m or slopes of less than 2 in 1. There are rock outcrops located across the Study Area, primarily within the valleys of the streams and along the steep slopes. The rock outcrops have not been shown in the drawings, as their specific locations could not be derived from the aerial laser scan or the orthophotograph.

Photographs of typical rock outcropping within the Study Area are provided in Fig. 5.23.

Fig. 5.23 Rock outcropping within the Study Area

The discussions for the cliffs, minor cliffs and pagodas within the Study Area are provided in Section 5.7.

5.8.2. Predictions for the steep slopes and rock outcrops

The steep slopes and rock outcrops are located across the Study Area and are expected to experience the full range of predicted subsidence effects, as outlined in Chapter 4. A summary of the maximum predicted values of total vertical subsidence, tilt and curvatures for the steep slopes and rock outcrops is provided in Table 5.13.

Table 5.13 Maximum predicted total vertical subsidence, tilt and curvatures for the steep slopes and rock outcrops

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 and rock outcrops	2250	25	0.35	0.40

The maximum predicted tilt for the steep slopes and rock outcrops is 25 mm/m (i.e. 2.5 %, or 1 in 40). The maximum predicted curvatures for these features are 0.35 km^{-1} hogging and 0.40 km^{-1} sagging, which represent minimum radii of curvature of 2.9 km and 2.5 km, respectively.

The predicted strains in the eastern and northern parts of the mining area are 2.5 mm/m tensile and 4 mm/m compressive based on the 95 % confidence levels. The predicted strains in the south-western part of the mining area are 5 mm/m tensile and 6 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.

5.8.3. Impact assessments for the steep slopes and rock outcrops

The maximum predicted tilt for the steep slopes and rock outcrops within the Study Area is 25 mm/m (i.e. 2.5 %, or 1 in 40). 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 adverse impacts on the stabilities of the steep slopes and rock outcrops.

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

Surface cracking previously observed at Angus Place and Springvale Collieries was typically within the range of less than 5 mm to 25 mm, but with isolated surface cracking in some locations greater than 50 mm. Soil slumping has occurred once at these collieries, where tension cracks developed on the western valley side of Narrow Swamp, having widths greater than 50 mm and lengths around 10 m. Experience elsewhere in the NSW coalfields, at similar depths of cover, indicates that surface cracking resulting from downslope movements could potentially be in the order of 100 mm or greater.

Photographs showing some examples of tension cracks which have developed along steep slopes as a result of longwall mining in the NSW coalfields are provided in Fig. 5.24.

Fig. 5.24 Surface cracking on steep slopes due to longwall mining in the NSW coalfields

If tension cracks were to develop due to the proposed mining, it is possible that soil erosion could occur if these cracks were left untreated. Remediation may be required for the larger surface cracking, including infilling with soil or other suitable materials, or by locally regrading and recompacting the surface. Similarly, where cracking restricts the passage of vehicles along the tracks and fire trails that are required to be open for access, it is recommended that these cracks are treated in the same way.

The proposed longwalls are likely to result in fracturing of the rock outcrops and, where the rock is marginally stable, this could then result in spalling of the exposed rockfaces. The rock outcrops are small and discontinuous and, therefore, are less susceptible to impacts when compared with cliffs.

Previous experience of mining beneath rock outcrops in the NSW coalfields, at similar depths of cover, indicates that the percentage of rock outcrops that are likely to be impacted by mining is very small. It is expected that the impacts resulting from the proposed mining would represent less than 1 % of total exposed rockface areas of the rock outcrops that are located directly above the proposed mining area.

5.8.4. Recommendations for the steep slopes and rock outcrops

It is recommended that a Landscape Management Plan be developed for steep slopes and rock outcrops as part of the Extraction Plans for the mine. Periodic visual inspection should be carried out when mining directly beneath these features.

Remediation should be carried out on the larger surface cracking which could result in increased erosion or restrict access. This could be achieved by infilling with soil or other suitable materials, or by locally regrading and compacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the slopes in the longer term.

It is also recommended that management strategies be developed to ensure that these measures are implemented and that these measures themselves (i.e. use of plant or other equipment) do not adversely impact on the environment. With appropriate management strategies in place, it is unlikely that there would be long term impacts on the steep slopes and rock outcrops resulting from the proposed mining.

5.9. Escarpments

There are no escarpments located within the Study Area. There are cliffs located in the vicinity of the proposed longwalls, which are discussed in Section 5.7.

5.10. Land Prone to Flooding or Inundation

The land naturally drains towards the Wolgan River in the western part of the Study Area, and towards Carne Creek in the eastern and northern parts of the Study Area. Discussions on the potential for increased ponding along the drainage lines are provided in Section 5.4. Further discussions on the potential for increased flooding and inundation are provided by the specialist surface water consultant on the project.

5.11. Swamps

5.11.1. Descriptions of the swamps

The locations of the swamps within the Study Area are shown in Drawing No. MSEC1046-09. The swamps in the region have been classified into two fundamental types, being the *Newnes Plateau Shrub Swamps* (shrub swamps) and the *Newnes Plateau Hanging Swamps* (hanging swamps), which are described below.

The *shrub swamps* develop in the bases of natural valleys and are formed from the accumulation of sediments along relatively flat sections of the drainage lines. These swamps have dense peat layers which overlie the shallow surface soils derived from the Triassic Narrabeen Sandstone group. Some swamps have bedrock outcropping at the downstream end which helps retain the soil and peat. The vegetation types within the swamp include grasses, ferns and shrubs, with trees rarely growing within the swamps.

The peat layers in the shrub swamps retain water derived from the shallow groundwater aquifers, surface runoff and rainfall. The water retention is high due to the relatively flat grades and, hence, the substrate is generally permanently waterlogged. In some locations the swamps have been observed to grow and extend over highly cracked and porous rock platforms where the moisture within the swamp appeared to be maintained by the dense and tightly packed matted root structure of the swamp plants.

There are two shrub swamps above the proposed mining area. Tri Star Swamp is located above the western ends of LW1004 and LW1005 and Twin Gully Swamp is located above the western ends of LW1009 and LW1010. Photographs of Tri Star Swamp and Twin Gully Swamp are provided in Fig. 5.25 and Fig. 5.26, respectively.

Fig. 5.25 Tri Star Swamp (shrub swamp)

Fig. 5.26 Twin Gully Swamp (shrub swamp)

Japan Swamp (formally Trial 6 Swamp) is outside of the proposed mining area but partially within the Study Area based on the 26.5° angle of draw. This swamp is located 85 m north of the maingate of LW1014 and 190 m east of the commencing end of LW1015. Other shrub swamps are located within the Study Area based on the 600 m boundary, along the Wolgan River to the west of the proposed mining area, and along the tributaries to Carne Creek to the east of the mining area.

The *hanging swamps* develop on the sides of valleys where groundwater seepage occurs from perched aquifers, downslope of sandstone layers which overlie less permeable claystone or shale layers. These swamps have shallow peat substrates which tend to be waterlogged, due to water from the perched aquifers, surface runoff and rainfall. The hanging swamps develop in areas with higher natural gradients and, hence, are less able to retain water when compared with the shrub swamps.

Photographs of typical hanging swamps within the Study Area are provided in Fig. 5.27.

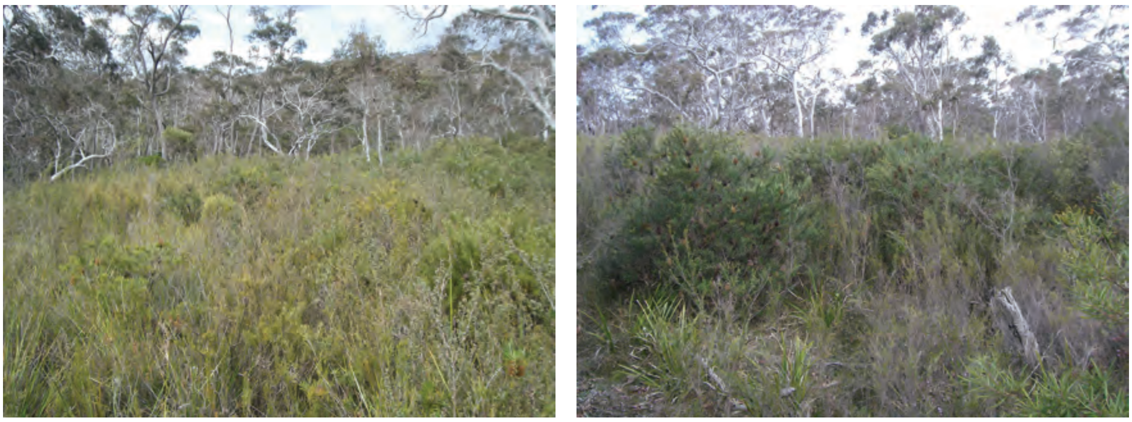

Fig. 5.27 Typical hanging swamps

Investigations have also shown that some swamps display the characteristics of both shrub and hanging type swamps. These hybrid swamps generally develop near the bases of valleys, but are more dependent on rainfall and surface runoff, rather than shallow groundwater aquifers.

The shrub swamps are listed as an endangered ecological community (EEC) under the NSW *Biodiversity Conservation Act* 2016 and provide important habitat for a range of plants and animals. The shrub and hanging swamps have been classified as *Temperate Highland Peat Swamps on Sandstone* (THPSS) under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The THPSS, the shrub and hanging swamps are considered to be commensurate with the Plant Community Type (PCT) 657 *Baeckea linifolia - Grevillea acanthifolia subsp. acanthifolia* shrub/sedge swamp on sandstone, Sydney Basin Bioregion.

Further descriptions of the swamps within the Study Area are provided by the specialist ecology, surface water and groundwater consultants on the project.

5.11.2. Predictions for the swamps

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the shrub swamps within the Study Area based on the 600 m boundary is provided in Table 5.14. This table provides the maximum predicted values within 20 m of the mapped extents of each of the swamps.

Table 5.14 Maximum predicted total vertical subsidence, tilt and curvatures for the shrub swamps within the Study Area based on the 600 m boundary

Shrub swamp	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})
Tri Star Swamp	2250	25	0.35	0.40
Twin Gully Swamp	1600	16	0.25	0.30
Japan Swamp	20	0.5	0.01	< 0.01
Wolgan River Swamps	< 20	< 0.5	< 0.01	< 0.01
Carne Creek Tributary Swamps	60	1	0.02	< 0.01

The greatest predicted subsidence effects occur at Tri Star and Twin Gully Swamps, as they are located directly above the proposed mining area. The maximum predicted curvatures are 0.35 km^{-1} hogging and 0.40 km^{-1} sagging, which represent minimum radii of curvatures of 2.9 km and 2.5 km, respectively. The predicted subsidence effects at Tri Star Swamp have been increased by 25 % as it is coincident with a Type 2 geological structure.

The shrub swamps are located along the alignments of the drainage lines and, therefore, they are likely to experience valley related effects. A summary of the maximum predicted total upsidence and closure for the shrub swamps is provided in Table 5.15.

Table 5.15 Maximum predicted total upsidence and closure for the shrub swamps

Shrub swamp	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Tri Star Swamp	750	1000
Twin Gully Swamp	750	1000
Japan Swamp	90	120
Wolgan River Swamps*	100 (proposed longwalls only) 290 (existing and proposed longwalls)	160 (proposed longwalls only) 370 (existing and proposed longwalls)
Carne Creek Tributary Swamps	260	350

Note: * denotes that the Wolgan River Swamps are predicted to have experienced valley closure effects due to the previous extraction of longwalls at Angus Place and Springvale Collieries. The predicted accumulated valley related effects along the Wolgan River, after the completion of the existing longwalls and after the completion of the proposed longwalls, are illustrated in Fig. C.04, in Appendix C.

The greatest predicted valley closure effects occur at Tri Star Swamp and Twin Gully Swamps, as they are located directly above the proposed mining area. The predicted upsidence and closure are greater for the sections of swamps located near the centrelines of the longwalls and lesser for the sections of swamps located near the chain pillars or outside the proposed mining area. As described in Section 3.7, the actual valley related effects are expected to be around 60 % to 90 % of the maximum predicted values near the centrelines of the longwalls and around 30 % and 60 % of the maximum predicted values near the chain pillars and near the perimeter of the proposed mining area.

The predicted compressive strains due to the valley related effects are the same as the drainage lines, which is described in Section 5.4.2. Tri Star and Twin Gully Swamps are predicted to experience compressive strains between 10 mm/m and 20 mm/m. Tri Star Swamp is coincident with a Type 2 geological structure and therefore the compressive strains are likely to be at the upper end of this predicted range. The review of valley closure in the locations of the surface lineaments found that these can be derived from the 2002 ACARP method, as described in Section 3.6.2.

The predicted compressive strains are less for the other swamps located outside the proposed mining area, as illustrated in Fig. 5.8. The predicted compressive strain for Japan Swamp, based on the 95 % confidence level, varies between 10 mm/m at the southern extent (i.e. closest to the proposed mining area) and 0.5 mm/m at the northern extent (i.e. further from the proposed mining area).

The predicted compressive strains due to the valley related effects for the swamps along the Wolgan River are the same as this river, which are discussed in Section 5.2.2. The swamps along the Wolgan River are predicted to experience compressive strains of up to 1.5 mm/m based on the 95 % confidence level.

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the hanging swamps within the Study Area based on the 600 m boundary is provided in Table 5.16. This table provides the maximum predicted values within 20 m of the mapped extents of each of the swamps.

Table 5.16 Maximum predicted total vertical subsidence, tilt and curvatures for the hanging swamps within the Study Area based on the 600 m boundary

Hanging swamp	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})
Tri Star Catchment	2000	13	0.16	0.20
Twin Gully Catchment	1500	8	0.12	0.20
Japan Catchment	50	1	0.02	< 0.01
Wolgan River Catchment	< 20	< 0.5	< 0.01	< 0.01
Carne Creek Catchment	170	3.5	0.12	0.01

The greatest predicted subsidence effects occur at the hanging swamps in the Tri Star and Twin Gully Catchments, as they are located directly above the proposed mining area. The maximum predicted tilt for the hanging swamps is 13 mm/m (i.e. 1.3 %, or 1 in 77). The maximum predicted curvatures for these swamps are 0.16 km^{-1} hogging and 0.20 km^{-1} sagging, which represent minimum radii of curvature of 6 km and 5 km, respectively.

The distribution of the predicted strains above goaf is described in Section 4.4.1. The predicted strains in the eastern and northern parts of the mining area are 2.5 mm/m tensile and 4 mm/m compressive based on the 95 % confidence levels. The predicted strains in the south-western part of the mining area are 5 mm/m tensile and 6 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 hanging swamps are located on the sides of the valleys. These swamps are therefore not expected to experience the valley related upsidence or compressive strains due to valley closure, as these occur near the valley base, rather than along the valley sides.

5.11.3. Previous longwall mining beneath swamps at Angus Place and Springvale Collieries

A summary of the shrub swamps that have been directly mined beneath by previous longwall mining at Angus Place and Springvale Collieries is provided in Table 5.17. Further discussions on the environmental consequences and the changes in groundwater levels are provided by the other specialist consultants on the project.

Table 5.17 Shrub swamps above previous longwall mining at Angus Place and Springvale Collieries

Name	Longwalls	Type 1 or Type 2 structures	Measured subsidence effects (near swamp)	Observed changes to piezometer levels	Observed physical impacts and environmental consequences
Junction Swamp	Above Springvale LW408 and LW409	Wolgan lineament zone (Type 1)	1058 mm subsidence 4.1mm/m tensile strain 13.1 mm/m comp. strain	Correlation between aquifer standing water levels adjacent to the swamp and the cumulative rainfall deviation over 15 years of monitoring. Baseline monitoring commenced in May 2002. The Wolgan Lineament (west) was mined beneath, to the south-west of the swamp, by LW405 in December 2000, by LW406 in October 2001 and by LW407 in August 2002.	Vegetation dieback, major incision and erosion (in some instances down to bedrock), associated with loss of peat layer, significant loss of ecosystem function and ecological resilience, and ecological and geomorphic threshold exceedance.
Kangaroo Creek Swamp	Above Angus Place LW940 and LW950	Kangaroo Creek lineament (Type 1)	1012 mm subsidence 5.8 mm/m tensile strain 26.3 mm/m comp. strain	Reduction in swamp piezometer levels when LW940 mined directly beneath the swamp and lineament. Following declines, all water levels remain predominantly below base of piezometer.	Change in species assemblage (diversity of native species), change in condition of key species, increase in non-live vegetation.
West Wolgan Swamp	Above Angus Place LW930 to LW950	J Lineament (identified by J. Shepherd)	1071 mm subsidence 4.0 mm/m tensile strain 6.2 mm/m comp. strain	Correlation between swamp standing water levels and the cumulative rainfall deviation over 14 years of monitoring. Baseline monitoring commenced in May 2005. The J Lineament was mined beneath, to the north of the swamp, by LW920 in October 2004 and by LW24 in the first quarter of 2000. Piezometer data reflects periodic waterlogging in response to rainfall.	Vegetation monitoring undertaken but sufficient baseline data not available to assess impact of mining.
Narrow Swamp North	Above Angus Place LW920 and LW940	Wolgan lineament zone (Type 1)	1739 mm subsidence 6.2 mm/m tensile strain 15.4 mm/m comp. strain	Narrow Swamp North piezometers (NS3 and NS4) were installed in February 2008, after mining directly beneath the swamp was completed in May 2007. All water levels remain predominantly below base of piezometer.	Water ripping, waterlogging and changes to water quality. Observed impacts likely due to mine water discharge from Springvale Colliery, any impacts due to longwall mining likely to be completely masked.
Narrow Swamp South	Above Angus Place LW950 and LW960	Wolgan lineament zone (Type 1)	Not measured, expected to be similar to Narrow Swamp North	Reduction in swamp piezometer levels when LW940 mined directly beneath the lineament approximately 0.2 km north of the swamp. Some changes may be due to the cessation of mine water discharge along the drainage line. Following declines, all water levels remain predominantly below base of piezometer.	Incision, a massive active head cut, and with significant impairment of resilience and ecosystem processes. Observed impacts likely due to mine water discharge from Springvale Colliery, any impacts due to longwall mining likely to be completely masked.
East Wolgan Swamp	Above Angus Place LW960 to LW980 and Springvale LW411 and LW412	Wolgan lineament zone (Type 1)	365 mm subsidence 13.3 mm/m ten. strain 17.6 mm/m comp. strain	Reduction in swamp piezometer levels (bottom of bores) when LW411 mined directly beneath the swamp and lineament. Some changes may be due to the cessation of mine water discharge along the drainage line. Following declines, all water levels remain predominantly below base of piezometer.	Vegetation dieback, major incision and erosion (in some instances down to bedrock), associated with loss of the peat layer, significant loss of ecosystem function and ecological resilience, and with ecological and geomorphic threshold exceedance. Some impacts likely to be associated with mine water discharge from Springvale Colliery.
Sunnyside Swamp	Between Springvale LW413A/B, LW414 and LW415	-	100 mm subsidence 1 mm/m tensile strain 3 mm/m comp. strain	No detected mining-related changes in swamp piezometers levels.	No surface cracking or deformations identified.

Name	Longwalls	Type 1 or Type 2 structures	Measured subsidence effects (near swamp)	Observed changes to piezometer levels	Observed physical impacts and environmental consequences
Sunnyside East Swamp	Above Springvale LW416 to LW419	Deanes Creek lineament (Type 1)	607 mm subsidence 5.8 mm/m tensile strain 6.5 mm/m comp. strain	Temporary changes in swamp piezometer levels when LW414 mined beneath the Deanes Creek lineament at a distance of 2.25 km. Reduction in swamp piezometer levels when LW415 mined beneath the Deanes Creek lineament at a distance of 1.5 km. Following declines, all water levels remain predominantly below base of piezometer.	No surface cracking identified. Change in species assemblage (diversity of native species), change in condition of key species, increase in non-live vegetation.
Carne West Swamp	Above Springvale LW418 and LW419	Deanes Creek lineament (Type 1)	750 mm subsidence 1.0 mm/m tensile strain 3.1 mm/m comp. strain	Temporary changes in swamp piezometer levels when LW415 mined beneath the Deanes Creek lineament at a distance of 1.8 km. Reduction in swamp piezometer levels when LW416 mined beneath the Deanes Creek lineament at a distance of 1.6 km. Following declines, all water levels remain predominantly below base of piezometer.	No surface cracking identified. Change in species assemblage (diversity of native species), change in condition of key species, increase in non-live vegetation cover.
Gang Gang Swamp South West	Above Springvale LW420 and LW421	Type 2	969 mm subsidence 3.4 mm/m tensile strain 9.6 mm/m comp. strain	Reduction in swamp water levels at GW1 and GW2 prior to being directly mined beneath. Possibly related to LW417 and LW418 intersection of structures. Decline at GW3 following undermining of swamp and intersection of lineament at GW1. Following declines, all water levels remain predominantly below base of piezometer.	No surface cracking identified. Change in species assemblage (diversity of native species), change in condition of key species, increase in non-live vegetation.
Gang Gang Swamp East	Above Springvale LW420 and LW421	Type 2	652 mm subsidence 3.3 mm/m tensile strain 3.3 mm/m comp. strain	Slow decline at GG1 from August 2016 consistent with CRD. Decline accelerates in August 2017 as LW420 intersects underlying lineament. GG2 decline in October 2016, no apparent correlation to longwall activity (but noting limited baseline data). Abrupt decline at GG3 from March 2018 as LW421 approached lineament beneath GG1. Following declines, all water levels remain predominantly below base of piezometer.	No surface cracking identified. Change in species assemblage (diversity of native species), change in condition of key species, increase in non-live vegetation.
Pine Swamp Upper Swamp	Outside and adjacent to Springvale LW425	-	253 mm subsidence 12.0 mm/m ten. strain 7.7 mm/m comp. strain	Declines in water levels at BS1 and BS2 from October 2017 that are consistent with CRD. Further strong declines from January 2019 that coincide with intersection of LW425 with underlying lineament. Following declines, all water levels remain predominantly below base of piezometer.	No surface cracking identified.
Paddy's Creek Swamp	150 m south-west of Springvale LW425	-	< 20 mm subsidence	Several water level declines and recoveries following commencement of LW425 in August 2018. Temporary changes in swamp piezometer levels which may be related to the extraction of LW425.	No surface cracking or deformations identified.

Impacts on swamp piezometer levels have been observed at Junction Swamp, Kangaroo Creek Swamp, Narrow Swamp South and East Wolgan Swamp. These impacts occurred when the longwalls mined directly beneath each of these swamps. Kangaroo Creek Swamp and East Wolgan Swamp are both coincident with Type 2 geological structures that are parallel to the coal barriers between extracted longwall series.

Temporary or minor changes in swamp piezometer levels were also observed at Sunnyside East Swamp and Carne West Swamp. Both these swamps are coincident with the Deanes Creek lineament zone (Type 1 geological structure). The impacts occurred when the longwalls were mined beneath the Deanes Creek lineament zone at distances between 1.5 km and 2.25 km from these swamps.

Further discussions on the effects of longwall mining on groundwater dependent ecosystems, including the shrub swamps, are provided in the reports by the specialist surface water, groundwater and ecology consultants on the project.

Surface deformations and impacts to vegetation were observed at Junction Swamp, Narrow Swamp North, Narrow Swamp South and East Wolgan Swamp. The impacts at Narrow Swamp North, Narrow Swamp South and East Wolgan Swamp are likely to be partly due to mine water discharge from Springvale Colliery along the associated drainage lines.

Further discussions on the effects of longwall mining on the vegetation are provided in the report by the specialist ecology consultant on the project.

5.11.4. Impact assessments for the swamps

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

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

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

The maximum predicted tilt for the shrub swamps is 25 mm/m (i.e. 2.5 %, or 1 in 40) and for the hanging swamps is 13 mm/m (i.e. 1.3 %, or 1 in 77). The mining-induced tilts are small when compared with the natural gradients within the swamps. This is illustrated in Fig. 5.9 to Fig. 5.16 which show the natural and predicted post-mining grades along the drainage lines and, hence, for the shrub swamps. These figures show that the predicted post-mining grades are similar to the natural grades and that there are no predicted reversals in grade. The hanging swamps are located on the sides of the valleys and, therefore, natural gradients are greater than those along the drainage lines.

The natural (green lines) and predicted post-mining (red lines) surface level contours are shown in Fig. 5.28 for Tri Star Swamp and are shown in Fig. 5.29 for Twin Gully Swamp. The natural surface level contours have been derived from the LiDAR survey. The predicted post-mining contours are after the completion of LW1001 to LW1015.

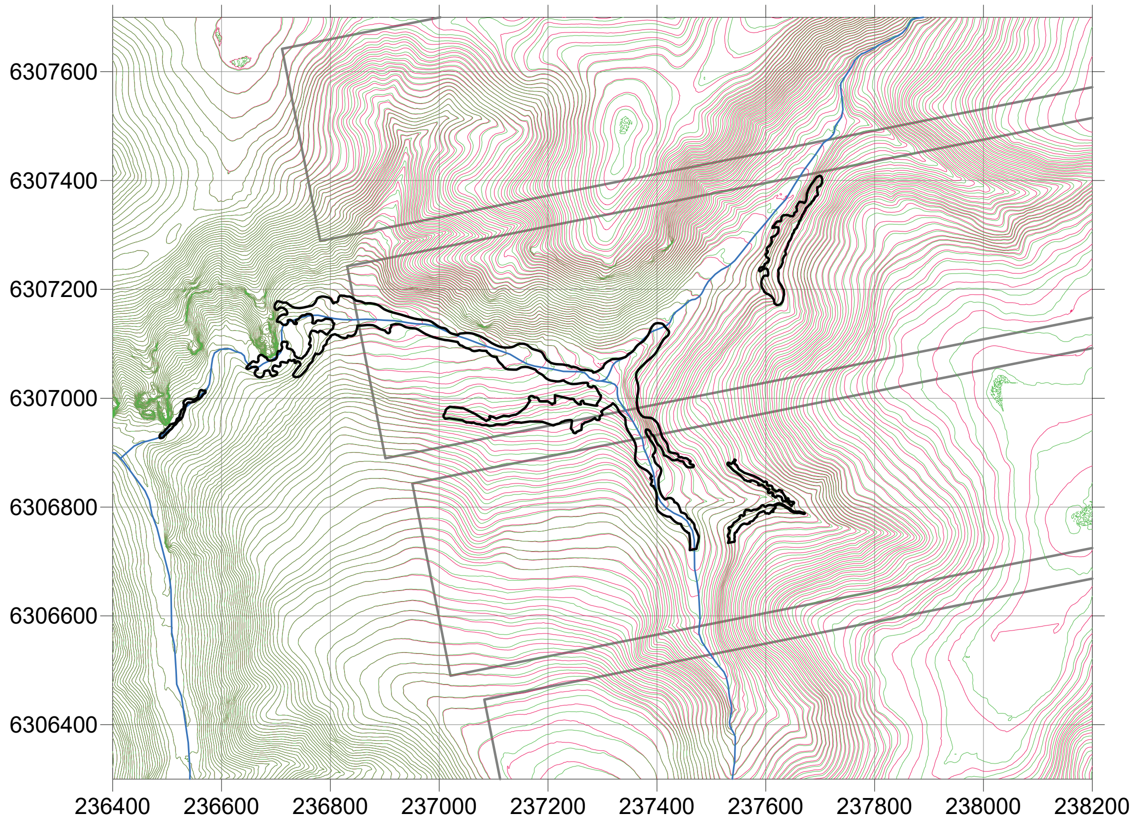

Fig. 5.28 Natural and predicted post-mining surface level contours for Tri Star Swamp

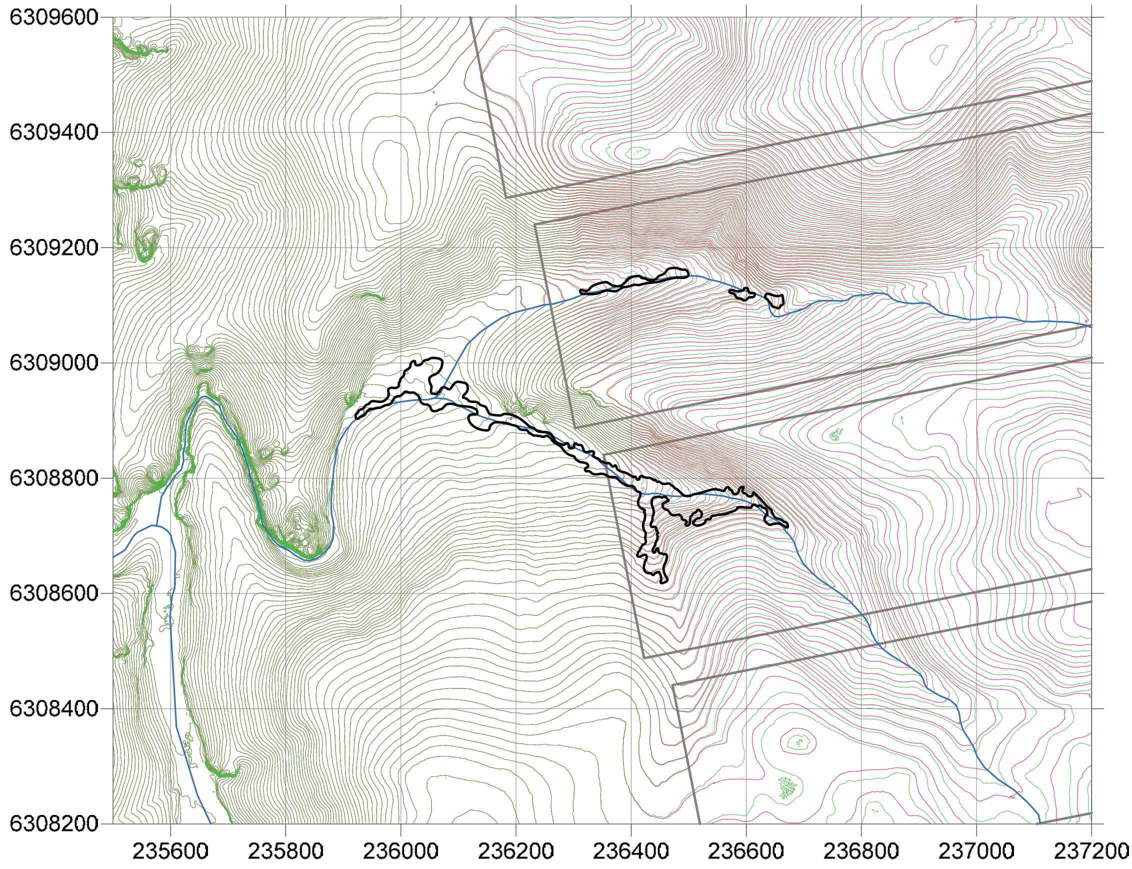

Fig. 5.29 Natural and predicted post-mining surface level contours for Twin Gully Swamp

There are no apparent changes in the alignments of the drainage lines through Tri Star Swamp and Twin Gully Swamp due to the proposed mining. There are also no topographical depressions predicted to develop within the extents of these swamps. It is considered unlikely, therefore, that there would be adverse changes in the levels of ponding or scouring in these swamps based on the predicted mining-induced vertical subsidence and tilt.

Further discussions on the potential impacts due to changes in surface water flows and storage are provided in the report by the specialist surface water consultant on the project.

Potential for cracking in the swamps and fracturing of bedrock

Fracturing in bedrock has been observed due to previous longwall mining where the tensile strains have been greater than 0.5 mm/m or where the compressive strains have been greater than 2 mm/m. It is likely, therefore, that fracturing would occur beneath the swamps that are located directly above the proposed mining area. Fracturing can also occur outside the mining area, with minor and isolated fracturing occurring at distances up to approximately 400 m.

The estimated fracture widths in the topmost bedrock, based on the maximum predicted conventional tensile strain of 3.5 mm/m and based on a typical joint spacing of 10 m, is in the order of 35 mm. In some cases, a series of smaller fractures, rather than one single fracture, would develop in the topmost bedrock. The fracture widths outside the proposed mining area are expected to be typically less than 10 mm.

The shrub swamps have peat layers that overlie the shallow natural surface soils and underlying bedrock along the alignments of the drainage lines. In most cases, cracking would generally not be visible at the surface within these swamps, except where the depths of bedrock are shallow or exposed. The hanging swamps have soft soil or peat layers which overly the bedrock on the valley sides. It is expected that the potential for fracturing in these locations would be less when compared to the bases of the valleys, where higher compressive strains occur due to the valley related effects, and due to the higher depths of cover along the valley sides.

The crack widths are expected to be typically less than 25 mm; however, localised cracking with widths greater than 50 mm can also develop. Larger surface deformations could also occur if increased scouring were to develop due to changes in the swamp vegetation. Further discussions on the potential impacts on the swamp vegetation is provided by the specialist ecology consultant on the project.

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

Tri Star Swamp is coincident with a Type 2 geological structure, as shown in Drawing No. MSEC1046-09. This swamp is also predicted to experience the maximum predicted subsidence effects above the proposed mining area, as it is located where the depth of cover is shallowest and the mining height is greatest. It is likely, therefore, that this swamp would experience adverse impacts due to the proposed mining. Twin Gully Swamp is also likely to experience adverse impacts, to a lesser extent, as it is not coincident with a Type 1 or 2 geological structure and due to the lower predicted subsidence effects.

The impacts to Tri Star Swamp and Twin Gully Swamp could be similar to those previously observed at Junction Swamp, Narrow Swamp North, Narrow Swamp South and East Wolgan Swamp. However, some of these previously observed impacts are partially the result of mine water discharge. The potential impacts on surface water, groundwater and ecology are discussed by the other specialist consultants on the project.

Japan Swamp and the shrub swamps within the Carne Creek Catchment are located outside the proposed mining area at minimum distances of 85 m and 100 m, respectively. These swamps are also not coincident with Type 1 or 2 geological structures. However, the shrub swamps adjacent to the commencing end of LW1007 are located to the south of a Type 2 geological structure.

It is unlikely therefore that surface cracking or deformation of the overlying soil and peat layers would occur at Japan Swamp and the shrub swamps located within the Carne Creek Catchment due to the proposed mining. The potential impacts on surface water, groundwater and ecology for these swamps are discussed by the other specialist consultants on the project.

The shrub swamps along the Wolgan River are located at distances of greater than 300 m from the proposed mining area. Whilst these swamps are coincident with the Wolgan lineament zone (Type 1 geological structure), this zone will not be directly mined beneath by the proposed longwalls. No surface cracking or deformations were observed at these swamps due to the previous longwall mining at Angus Place on the western side of the Wolgan River.

The shrub swamps along the Wolgan River are predicted to experience tensile strains less than 0.5 mm/m and compressive strains less than 2 mm/m due to the proposed mining. It is unlikely therefore that surface cracking or deformations would occur at these swamps due to the proposed mining. The potential impacts on surface water, groundwater and ecology for the shrub swamps along the Wolgan River are discussed by the other specialist consultants on the project.

5.11.5. Recommendations for the swamps

MSEC provides the following recommendations for the swamps, which should be read in conjunction with the recommendations from the other specialist consultants on the project:

- install ground monitoring lines in the vicinity of the shrub swamps to measure the subsidence effects during the proposed mining. The locations of the ground monitoring lines should be determined at the Extraction Plan stage of the project, based on accessibility (i.e. vegetation, line of site and location of access tracks) and the proximity to the swamps;
- compare the measured ground movements with those predicted during active subsidence and at the completion of each longwall. The impact assessments for the swamps should be reviewed if the observed ground movements exceed those predicted;
- establish appropriate surface water and groundwater monitoring programs for the swamps, based on the recommendations from the specialist surface and ground water consultants on the project;
- develop a Trigger Action Response Plan (TARP), based on the ground, visual, surface water and groundwater monitoring programs. Similar TARPs have been established for swamps which have been previously mined beneath at Angus Place and Springvale Collieries.

Management plans have been developed for the swamps which have been previously mined beneath at Angus Place and Springvale Collieries. These included methods of remediation where adverse impacts have been observed as a result of subsidence, which included:

- soft engineering solutions – such as coir logs, jute matting, geotextile, rock armouring and timber log water dissipaters; and
- hard engineering solutions – such as the use of concrete and various grouting techniques.

It is recommended, that the existing management strategies and methods of remediation are reviewed, based on the assessments provided in this report and the reports by other specialist consultants on the project.

5.12. Water related ecosystems

There are water related ecosystems within the Study Area. The descriptions and assessed impacts for these ecosystems, including the groundwater dependent ecosystems, are provided by the specialist surface water, groundwater, terrestrial ecology and aquatic ecology consultants on the project.

5.13. Threatened or protected species

An investigation of the biodiversity values within the Study Area has been undertaken by the specialist ecology consultant on the project.

5.14. National Parks or Wilderness Areas

There are no National Parks or Wilderness Areas located within the Study Area. The *Gardens of Stone National Park* (the National Park) is situated to the north of the Study Area, as shown in Drawings Nos. MSEC1046-01 and MSEC1046-02.

A summary of the minimum distances of the proposed longwalls from the Gardens of Stone National Park is provided in Table 5.18. The National Park is located 1040 m north of the proposed LW1011, at its closest point to the proposed mining area.

Table 5.18 Distances of the proposed longwalls from the National Park

Location	Longwall	Minimum distance (m)
Gardens of Stone National Park	LW1001 to LW1009	> 2000
	LW1010	1390
	LW1011	1040
	LW1012	1790
	LW1013	1460
	LW1014	1210
	LW1015	1280

A section through the Gardens of Stone National Park and LW1011 is provided in Fig. 5.30. This section has been taken where the National Park is located closest to the proposed mining area.

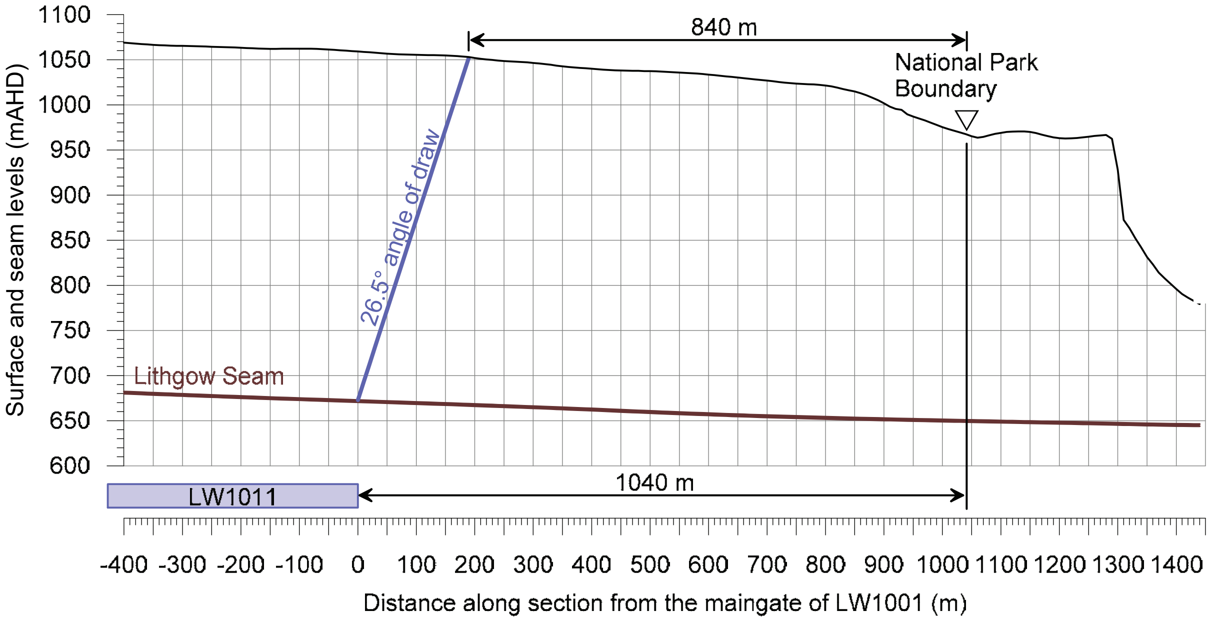

Fig. 5.30 Section through the National Park and LW1011

The Gardens of Stone National Park is located at a minimum distance of 840 m outside the 26.5° angle of draw from the proposed mining area. At this distance, the vertical subsidence and its related effects (i.e. conventional tilt, curvature and strain) are not expected to be measurable. Surface impacts (i.e. soil cracking or rock fracturing) are not expected to occur due to the predicted conventional ground movements.

The National Park will experience far-field horizontal movements towards the proposed mining area. The measured total far-field horizontal movements due to longwall mining in the Southern and Western Coalfields are shown in Fig. 4.7. The predicted far-field horizontal movements at the National Park boundary (i.e. at a distance of 1000 m from the proposed longwall mining) is 80 mm based on the 95 % confidence level.

The furthest far-field horizontal movement that has been measured in the NSW coalfields, above the survey tolerance of 25 mm for traditional surveying techniques, was at a distance of 3 km north of Appin Colliery Longwall 703. The depth of cover in this location was around 575 m and, therefore, this represents an equivalent distance of 5.1 times the depth of cover.

Far-field horizontal effects tend to be bodily movements towards the mining area that are accompanied by very low levels of strain. The absolute horizontal movements do not result in adverse impacts, except where they are experienced by large built structures which are sensitive to differential horizontal movements, such as freeway bridges or large industrial buildings.

The strains associated with these low level absolute horizontal movements are predicted to be negligible. Surface impacts (i.e. soil cracking or rock fracturing) are not expected to occur due to the predicted far-field horizontal movements.

The streams located near the National Park could experience very small valley related effects. The measured total valley closure movements due to longwall mining in the Southern and Western Coalfields are shown in Fig. 5.31. The data has been based on valley heights ranging between 30 m and 70 m, which is similar to the valley heights for the drainage lines located near to the Study Area.

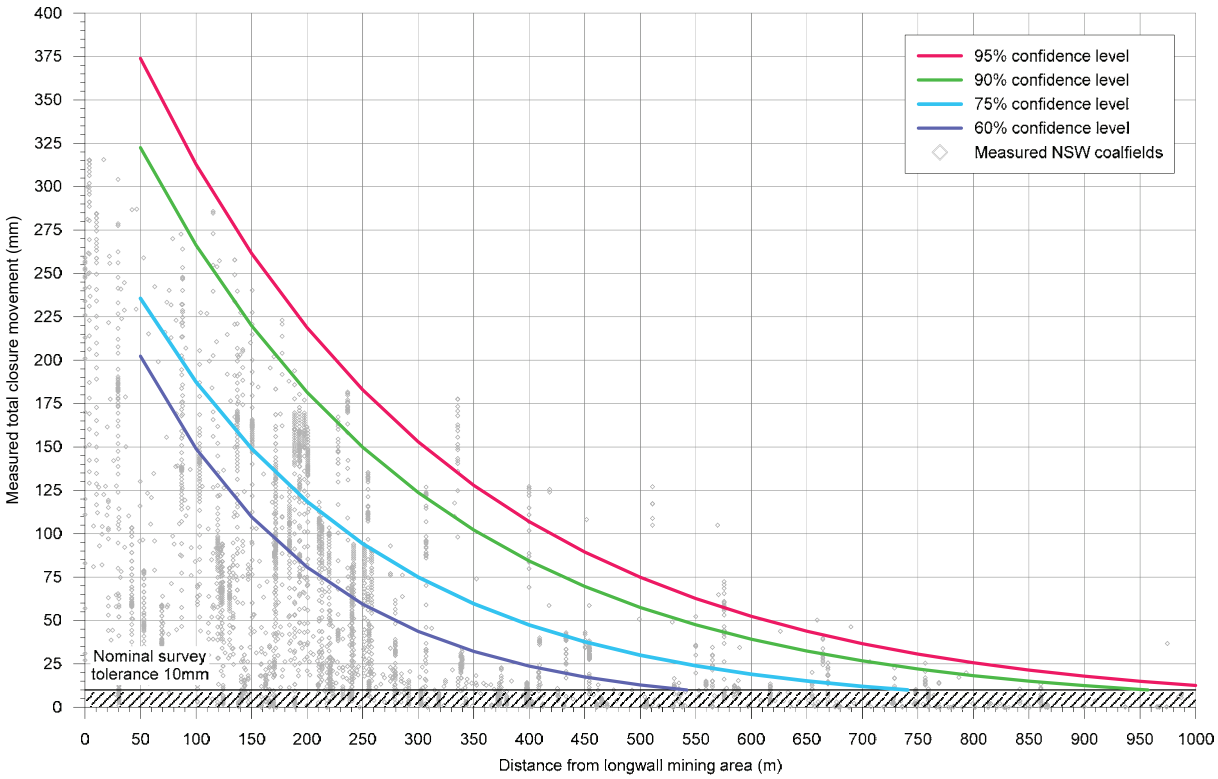

Fig. 5.31 Measured total valley closure movements in the Southern and Western Coalfields

Confidence levels have been fitted to the data, as illustrated in Fig. 5.31. The predicted valley closure movement at a distance of 1 km outside the mining area is 13 mm based on the 95 % confidence level. The measured movements at this distance outside the mining area are likely to largely comprise the survey tolerance.

Valley closure effects have been measured up to approximately 1 km outside of longwall mining in the NSW coalfields. The furthest measurement above the nominal survey tolerance of 10 mm, for traditional surveying techniques, was along Wongawilli Creek at a distance of 975 m from the longwalls in Area 3B at Dendrobium Mine.

The total compressive strains measured within valleys in the NSW coalfields versus the distance from longwall mining is illustrated in Fig. 5.8 and is summarised in Table 5.8. The measured compressive strain at a distance of 600 m outside the mining area is less than 0.5 mm/m (i.e. in the order of survey tolerance). There are limited valley closure strain measurements at distances greater than 600 m.

It is expected, therefore, that the strains due to valley closure effects at the National Park (i.e. at a minimum distance of 1000 m) will not be measurable. Surface impacts (i.e. soil cracking or rock fracturing) are not expected to occur due to the predicted valley closure effects.

Fracturing of bedrock is generally not observed where the tensile strains are less than 0.5 mm/m and compressive strains are less than 2 mm/m. The predicted strains due to the conventional and valley related effects are less than 0.5 mm/m tensile and compressive.

The furthest distance that a fracture has been observed outside of longwall mining was at the base of Broughtons Pass Weir, which was located approximately 415 m from Appin Colliery Longwall 401. Another minor fracture was also recorded in the upper Cataract River, approximately 375 m from Appin Colliery Longwall 301. This fracture occurred in a large rockbar, which was formed in thinly bedded sandstone, which had experienced movements from nearby previously extracted longwalls. These are the furthest most recorded fractures from longwall mining in the NSW coalfields.

It is unlikely that fracturing or adverse surface impacts would occur in the Garden of Stones National Park would due to the proposed LW1001 to LW1015. Whilst low level far-field horizontal movements and very low level valley closure effects could occur in the National Park, these are not expected to result in measurable strains.

The longwall series is proposed to be extracted towards the National Park which allows for an adaptive management approach. The far-field and valley closure effects can be monitored, as longwalls are progressively mined towards the National Park, allowing an ongoing review of the observed versus predicted movements. The potential for adverse impacts in the National Park could then be avoided with the implementation of suitable strategies, which could include the following:

- the establishment of survey control marks in the vicinity of the National Park to measure the far-field horizontal movements during mining. The observed movements can be compared with those predicted, after the completion of each of the longwalls, allowing the impact assessments to be continually reviewed based on the available monitoring data;
- visually monitor the drainage lines on the northern side of the Study Area, after the completion of each of the longwalls, to identify any fracturing or other adverse impacts in the exposed bedrock. The results could be used to better establish the extent of minor and isolated fracturing in the tributaries outside the active subsidence zone, based on the earlier longwalls, prior to mining closer to the National Park;
- develop a Trigger Action Response Plan (TARP), in consultation with the relevant authorities, defining the appropriate ground and visual monitoring in the vicinity of the National Park and the trigger levels for this monitoring;
- develop appropriate actions for each of the triggers, which could include refinement of the longwalls that are located closest to the National Park. These actions should be progressively reviewed based on the outcomes of the ground and visual monitoring from the earlier longwalls; and
- form a Technical Committee, including representatives from the Angus Place, the relevant authorities and specialist consultants, to review the monitoring data and to act on the recommendations outlined in the TARP during mining.

There will be ground and visual monitoring from nine longwalls prior to mining within 2 km of the National Park boundary. By that stage there will be extensive data to develop, review and refine the management strategies to ensure that no adverse surface impacts would occur within the National Park.

Further discussions on the potential impacts are provided by the specialist surface water, groundwater and ecology consultant on the project.

5.15. State Forests

The Study Area is located within the *Newnes State Forest* which is managed by the *Forestry Corporation of NSW*. The potential impacts include changes in surface water, changes to ground water and surface cracking, which are discussed in the impact assessments provided in Chapters 5 and 6.

Further discussions on the potential impacts are provided by the specialist surface water, ground water and ecology consultants on the project.

5.16. Natural Vegetation

The vegetation within the Study Area generally comprises undisturbed natural bush, which can be seen from the aerial photograph in Fig. 5.32. A detailed survey of the natural vegetation has been undertaken by the specialist ecology consultant on the project.

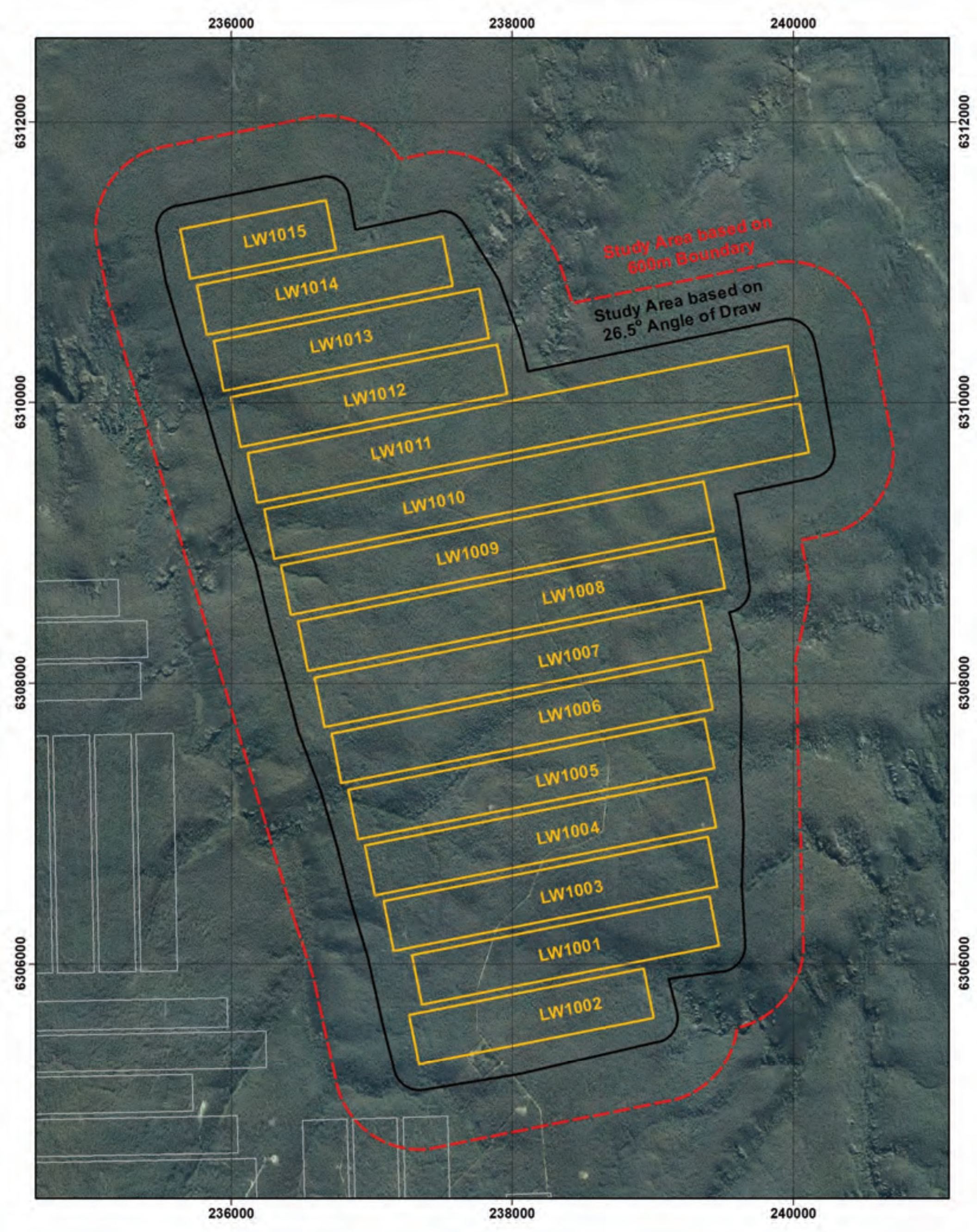

Fig. 5.32 Aerial photograph showing locations of the proposed LW1001 to LW1015

5.17. Other natural features considered significant

The *Birds Rock Flora Reserve* is partially located within the Study Area, as shown in Drawings Nos. MSEC1046-01 and MSEC1046-02. The reserve is located above the eastern ends of the proposed LW1006 to LW1009.

The potential impacts on this site include changes in surface water drainage (refer to Section 5.4), surface cracking (refer to Sections 4.7 and 5.8), and fracturing and spalling of the exposed rock formations (refer to Section 5.8). Further impact assessments are provided by the other specialist consultants on the project.

The following sections provide the descriptions, predictions and impact assessments for the built features identified within the Study Area, as summarised in Chapter 2. All significant built features located outside the Study Area, which may be subjected to valley related or far-field horizontal movements and may be sensitive to these effects, have also been included as part of these assessments.

The built features within the Study Area which have already experienced mine subsidence movements due to the previously extracted longwalls at Angus Place and Springvale Collieries have been assessed based on the predicted movements due to both the existing and proposed longwalls (i.e. cumulative movements).

Angus Place also has approval to mine LW910N within the 900 Panel Area on the western side of the Wolgan River. The location of this longwall is shown in Drawing No. MSEC1046-01. LW910N will be mined on retreat following completion of the proposed longwalls in the 1000 Panel Area. The impact assessments for the built features located between the proposed LW1001 and LW1015 and the LW910N have considered the predicted subsidence effects due to the mining of LW910N.

6.1. Public utilities

As listed in Table 2.1, there are no public utilities that have been identified within the Study Area, apart from the unsealed roads and associated drainage culverts. The descriptions, predictions and impact assessments for these built features are provided in the following sections.

6.2. Unsealed roads and tracks

6.2.1. Descriptions of the unsealed roads and tracks

There are unsealed roads and tracks located across the Study Area, as shown in Drawing No. MSEC1046-12. The roads provide access to the area, including for fire-fighting and recreational activities. Photographs of typical unsealed roads and tracks within the Study Area are provided in Fig. 6.1.

Fig. 6.1 Unsealed roads and tracks within the Study Area

There are small drainage culverts located within the Study Area that are associated with the unsealed roads and tracks. These culverts comprise small concrete pipes which are located at the drainage line crossings.

The *Spanish Steps* is a four-wheel drive access track (No. 5 fire trail) leading down to the Wolgan River, as shown in Drawing No. MSEC1046-12. This feature is located approximately 500 m west of the finishing (i.e. western) end of LW1012. A photograph of the Spanish Steps is provided in Fig. 6.2.

Fig. 6.2 Spanish Steps along the No. 5 Fire Trail

6.2.2. Predictions for the unsealed roads and tracks

The unsealed roads and tracks are located across the Study Area and are expected to experience the full range of predicted subsidence effects, as outlined in Chapter 4. A summary of the maximum predicted values of total vertical subsidence, tilt and curvatures for these features is provided in Table 6.1.

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

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})
Unsealed roads and tracks	2250	25	0.35	0.40

The maximum predicted tilt for the unsealed roads and tracks is 25 mm/m (i.e. 2.5 %, or 1 in 40). The maximum predicted curvatures for these features are 0.35 km^{-1} hogging and 0.40 km^{-1} sagging, which represent minimum radii of curvature of 2.9 km and 2.5 km, respectively.

The distribution of the predicted strains above goaf is described in Section 4.4.1. The predicted strains in the eastern and northern parts of the mining area are 2.5 mm/m tensile and 4 mm/m compressive based on the 95 % confidence levels. The predicted strains in the south-western part of the mining area are 5 mm/m tensile and 6 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 Spanish Steps is predicted to experience less than 20 mm vertical subsidence due to the mining of LW1001 to LW1015. Whilst this feature could experience very low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains.

6.2.3. Impact assessments for the unsealed roads and tracks

Surface cracking and heaving of the unsealed road and track surfaces are expected to occur where they are directly mined beneath. The surface deformations are expected to be similar to those observed during previous longwall mining at Angus Place and Springvale Collieries (refer to Section 4.8).

In the flatter sections of the unsealed roads and tracks (i.e. along the ridgelines), the crack widths are expected to be typically less than 25 mm; however, localised cracking with widths greater than 50 mm can also develop. Larger surface cracking could develop along the steeper sections of the unsealed roads and tracks and at the drainage line crossings. The crack widths in these areas are expected to be typically between 25 mm and 50 mm; however, localised impacts widths greater than 100 mm can also develop.

It is expected that the unsealed roads and tracks can be maintained in safe and serviceable conditions throughout the mining period using normal road maintenance techniques.

The drainage culverts could experience the full range of predicted subsidence effects, as outlined in Chapter 4. The mining-induced tilts could result in a reduction or, in some cases, a reversal of grade of the drainage culverts. In these cases, the culverts would need to be re-established to provide the minimum required grades. The predicted curvatures and ground strains could result in cracking of the concrete culverts. It may be necessary to repair, or in some cases, replace the affected culverts.

The Spanish Steps is located approximately 500 m west of the proposed mining area and it is predicted to experience less than 20 mm vertical subsidence. At this distance, it is unlikely that fracturing or adverse surface impacts would occur at this feature due to the proposed mining.

6.2.4. Recommendations for the unsealed roads and tracks

The unsealed roads and tracks within the Study Area can be maintained in safe and serviceable conditions throughout the mining period using normal road maintenance techniques. There are existing management strategies for the unsealed roads and tracks located above the previously extracted longwalls at the Mine. It is recommended that these same strategies are used to maintain the unsealed roads and tracks located within the Study Area. It is also recommended that these roads and tracks are periodically inspected during active subsidence.

6.3. Public amenities

As listed in Table 2.1, there are no public amenities that have been identified within the Study Area.

6.4. Fences

There are fences located across the Study Area and, therefore, these could experience the full range of predicted subsidence effects, as outlined in Chapter 4. The maximum predicted subsidence effects are 2250 mm vertical subsidence, 25 mm/m tilt (i.e. 2.5 %, or 1 in 40), 0.35 km^{-1} hogging curvature (i.e. 2.9 km minimum radius) and 0.40 km^{-1} sagging curvature (i.e. 2.5 km minimum radius).

The 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 directly beneath them. These types of fences are generally flexible in construction and can usually tolerate tilts of up to 10 mm/m and strains of up to 5 mm/m without significant impacts.

It is possible, therefore, that some of the wire fences within the Study Area could 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 some sections of fencing.

It is expected that the potential impacts on the fences could be managed with the establishment of the appropriate management strategies.

6.5. Registered ground water bores

The registered groundwater bores within the Study Area are shown in Drawing No. MSEC1046-12. The locations and details of these bores were obtained from the Australian Groundwater Explorer, which is publicly available online (BOM, 2019).

There are seven registered groundwater bores located within the Study Area based on the 600 m boundary. A summary of these bores is provided in Table 6.2. There are other groundwater bores that are located outside and in the vicinity of the Study Area, as shown in Drawing No. MSEC1046-12.

Table 6.2 Registered groundwater bores located within the Study Area based on the 600 m boundary

Reference	Location	Depth (m)	Authorised / intended use
GW112413	380 m north-west of LW1015	343	Monitoring bore
GW112419	390 m east of LW1008	445	Monitoring bore
GW112427	Above the maingate of LW1011	360	Monitoring bore
GE112429	Above the maingate of LW1001	380	Monitoring bore
GW112432	Directly above LW1014	342	Monitoring bore
GW112563	160 m south of LW1002	472	Dewatering
GW112565	160 m south of LW1002	466	Dewatering

The registered groundwater bores located within the Study Area are owned and maintained by Angus Place.

The groundwater bores could experience adverse impacts due to LW1001 to LW1015, particularly where the bores are located directly above the proposed mining area. Impacts could 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.

Further discussions on the potential impacts on the groundwater resources are provided by the specialist groundwater consultant on the project.

6.6. Industrial, commercial or business establishments

As listed in Table 2.1, there are no industrial, commercial or business establishments that have been identified within the Study Area.

6.7. Mining infrastructure

An airshaft compound and substation are located above the western ends of the proposed LW1001 and LW1002. Other infrastructure and services will be constructed to support the mining activities, including drillholes, powerlines, water pipelines and groundwater bore compounds. Management plans will be developed by Angus Place for these colliery-owned infrastructure and services, so that they can be maintained in safe and serviceable conditions throughout the mining period.

6.8. Aboriginal heritage sites

6.8.1. Descriptions of the Aboriginal heritage sites

The locations of the Aboriginal heritage sites within the Study Area are shown in Drawing No. MSEC1046-12. The locations and details of these sites have been provided by the specialist heritage consultant on the project.

There are two Aboriginal heritage sites (Refs. 45-1-0084 and 45-1-0137) that have been identified within the Study Area based on the 26.5° angle of draw. There are an additional seven sites that have been identified within the Study Area based on the 600 m boundary. Only one site (Ref. 45-1-0084) is located directly above the proposed mining area.

A summary of the Aboriginal heritage sites located within the Study Area based on the 600 m boundary is provided in Table 6.3.

Table 6.3 Aboriginal heritage sites within the Study Area based on the 600 m boundary

Reference	Location	Description
45-1-0084	Directly above the proposed LW1006	Rock shelter with deposit
45-1-0137	150 m west of the proposed LW1005	Rock shelter with deposit
45-1-0144	420 m west of the proposed LW1005	Rock shelter with deposit
45-1-0145	380 m west of the proposed LW1005	Rock shelter with deposit
45-1-0146	570 m west of the proposed LW1006	Rock shelter with deposit
45-1-0149	460 m west of the proposed LW1005	Rock shelter with deposit
45-1-0150	560 m west of the proposed LW1005	Rock shelter with deposit
45-1-0153	570 m north and east of the proposed LW1011 and LW1012, respectively	Rock shelter with deposit
45-1-0156	340 m east of the proposed LW1015	Rock shelter with deposit

Detailed descriptions of the Aboriginal heritage sites located within the Study Area are provided by the specialist heritage consultant on the project.

6.8.2. Predictions for the Aboriginal heritage sites

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the Aboriginal heritage sites identified within the Study Area is provided in Table 6.4. This table provides the maximum predicted values within 20 m of the mapped extents of each of the sites.

Table 6.4 Maximum predicted total vertical subsidence, tilt and curvature for the Aboriginal heritage sites

Reference	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
45-1-0084	1900	9.5	0.13	0.20
Remaining sites	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted tilt for Site Ref. 45-1-0084 is 9.5 mm/m (i.e. 0.95 %, or 1 in 105). The maximum predicted curvatures are 0.13 km^{-1} hogging and 0.20 km^{-1} sagging, which represent minimum radii of curvature of 8 km and 5 km, respectively.

Site Ref. 45-1-0084 is located in the south-western part of the proposed mining area. The distribution of the predicted strains above goaf is described in Section 4.4.1. The predicted strains in the south-western part of the mining area are 5 mm/m tensile and 6 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 remaining sites are predicted to experience less than 20 mm vertical subsidence due to the mining of LW1001 to LW1015. Whilst these sites could experience very low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

The Aboriginal heritage sites located outside the proposed mining area could experience far-field horizontal movements. The measured total far-field horizontal movements due to longwall mining in the Southern and Western Coalfields are shown in Fig. 4.7. The predicted absolute horizontal movements, based on the 95 % confidence level, are 350 mm at a distance of 150 m, 250 mm at a distance of 300 m and 140 mm at a distance of 600 m. However, these effects tend to be bodily movements towards the mining area that are accompanied by very low levels of strain.

The Aboriginal heritage sites within the Study area are all rock shelters with deposits. The shelters are located on the sides of the valleys. These sites are therefore not expected to experience the valley related upsidence or compressive strains due to valley closure, as these occur near the valley base, rather than along the valley sides.

6.8.3. Impact assessments for the Aboriginal heritage sites

Site Ref. 45-1-0084 is located directly above the proposed LW1006. The extraction of this longwall is likely to result in fracturing of the exposed bedrock along the ridgeline and, if the rock is marginally stable, this could then result in rockfalls or instabilities. The fracturing and rock falls could adversely impact the rock shelter if it were to occur coincident with this site.

It is extremely difficult to assess the likelihood of impacts on the rock shelters based upon predicted ground movements. The likelihood of a rock fall or instability is dependent on many factors that are difficult to fully quantify. Some of these factors include jointing, inclusions, weaknesses within the rockmass, groundwater pressure and seepage flow behind the rockface. Even if these factors could be determined, it would still be difficult to quantify the extent to which these factors may influence the stability of the rock shelter naturally or when it is exposed to mine subsidence movements.

The predicted curvatures and conventional strains for Site Ref. 45-1-0084 are similar to the movements that are typically observed in the Southern Coalfield, where these is extensive experience of mining beneath rock shelters. It has been reported that, where longwall mining has previously been carried out in the Southern Coalfield, beneath 52 shelters, that approximately 10 % of the shelters have been affected by fracturing of the strata or shear movements along bedding planes and that none of the shelters have collapsed (Sefton, 2000).

It has therefore been assessed that the potential for adverse impacts on Site 45-1-0084, including fracturing and movement on existing bedding planes and joints, is approximately 10 %. The fracturing and movement could result in rockfalls where the rock is marginally stable. The potential for rockfalls at this site is considered to be less than 10 %.

The remaining Aboriginal heritage sites are located at distances between 150 m and 570 m outside the proposed mining area. These sites are predicted to experience less than 20 mm vertical subsidence. Whilst these sites could experience very low levels of vertical subsidence and far-field horizontal movements, they are not expected to experience measurable tilts, curvatures or strains. Adverse physical impacts are not expected for the sites that are located outside the proposed mining area.

Further assessments of the potential impacts on the Aboriginal heritage sites are provided by the specialist heritage consultant on the project.

6.8.4. Recommendations for the Aboriginal heritage sites

The recommendations for the Aboriginal heritage sites are provided by the specialist heritage consultant.

6.9. State survey control marks

The survey control marks are shown in Drawing No. MSEC1046-12. The locations and details of the survey control marks were obtained from *Spatial Services* using the *SCIMS Online* website (SCIMS, 2019).

There are five survey control marks identified within the Study Area based on the 600 m boundary. A summary of the survey control marks identified within the Study Area is provided in Table 6.5.

Table 6.5 Survey control marks located within the Study Area based on the 600 m boundary

Survey mark	Location	Status	Horizontal class / order (GDA94)	Vertical class / order (AHD71)
SS 21307	Directly above LW1002	Not Found in database	U / U	LC / L3
SS 21308	Directly above LW1004	Not found in database	U / U	LC / L3
SS 21309	Directly above LW1008	Found intact	E / 5	LC / L3
SS 21310	Directly above LW1011	Found intact	E / 5	LC / L3
TS 6278	Directly above LW1008	Found intact - Birds Rock (P)	2A / 0	LC / L3

There are additional survey control marks located outside and in close proximity to the Study Area based on the 600 m boundary, as shown in MSEC1046-12.

The survey control marks located directly above the proposed mining area could experience the full range of predicted subsidence effects, as outlined in Chapter 4. The survey control marks located outside the proposed mining area could also experience vertical and horizontal effects. The marks located up to approximately 3 km outside the proposed mining area could experience small far-field horizontal movements.

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

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

Glossary of Terms and Definitions

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

Angle of draw	The angle of inclination from the vertical of the line connecting the goaf edge of the workings and the limit of subsidence (which is usually taken as 20 mm of subsidence).
Chain pillar	A block of coal left unmined between the longwall extraction panels.
Cover depth (H)	The depth from the surface to the top of the seam. Cover depth is normally provided as an average over the area of the panel.
Cliffs	Continuous rockfaces having minimum heights of 10 metres, minimum lengths of 20 metres and minimum slopes of 2 to 1, i.e. having minimum angles to the horizontal of 63°
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.
Minor Cliffs	Continuous rockfaces having heights between 5 metres and 10 metres, minimum lengths of 20 metres and a minimum slope of 2 to 1.
Panel	The plan area of coal extraction.
Panel length (L)	The longitudinal distance along a panel measured in the direction of (mining from the commencing rib to the finishing rib.
Panel width (Wv)	The transverse distance across a panel, usually equal to the face length plus the widths of the roadways on each side.

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

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APPENDIX C. FIGURES

I:\Projects\Angus Place\MSEC1046 EIS for LW1001 to LW1015\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 LW1001 to LW1015

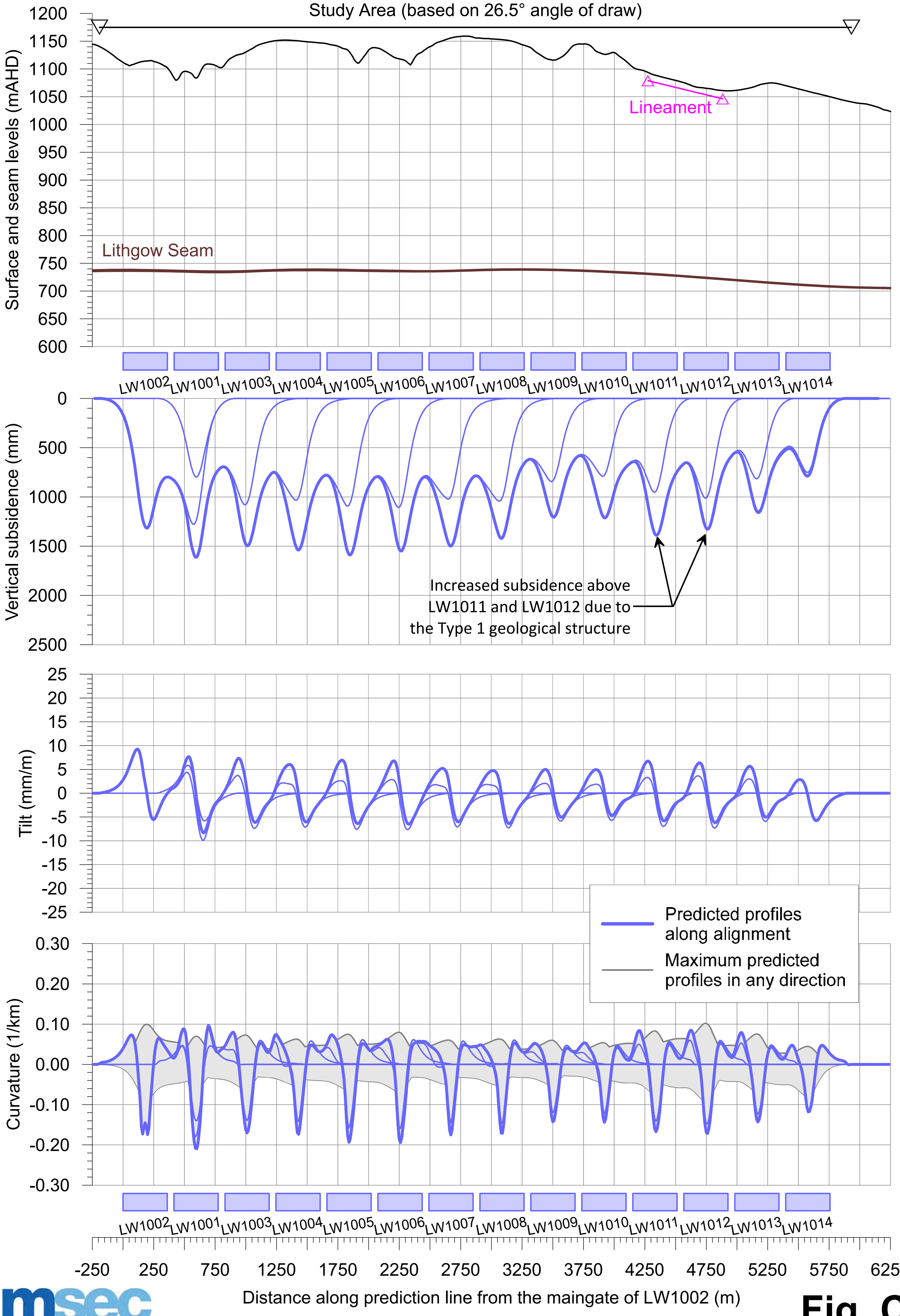

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Fig. C.01

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to LW1001 to LW1015

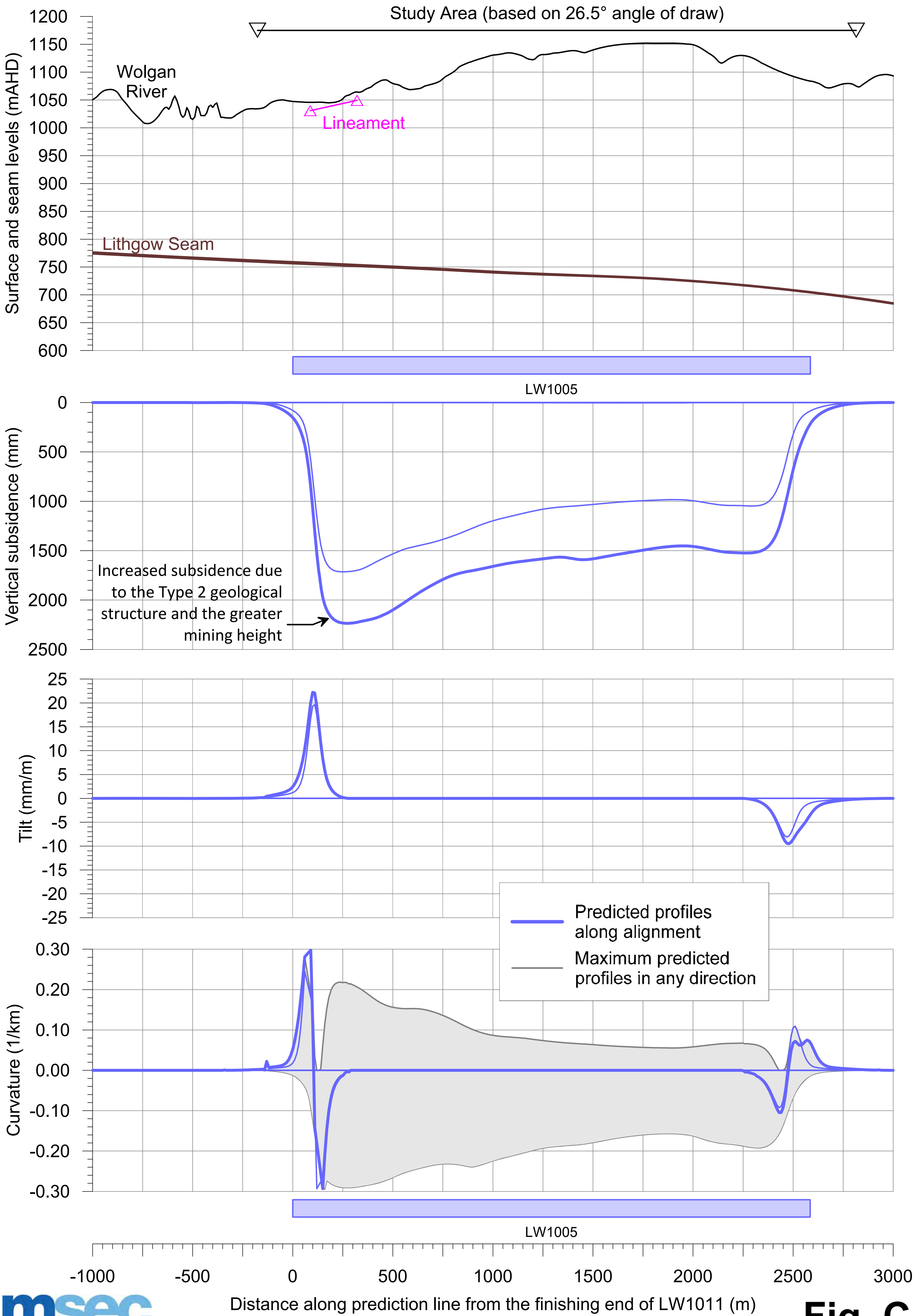

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Fig. C.02

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 3 due to LW1001 to LW1015

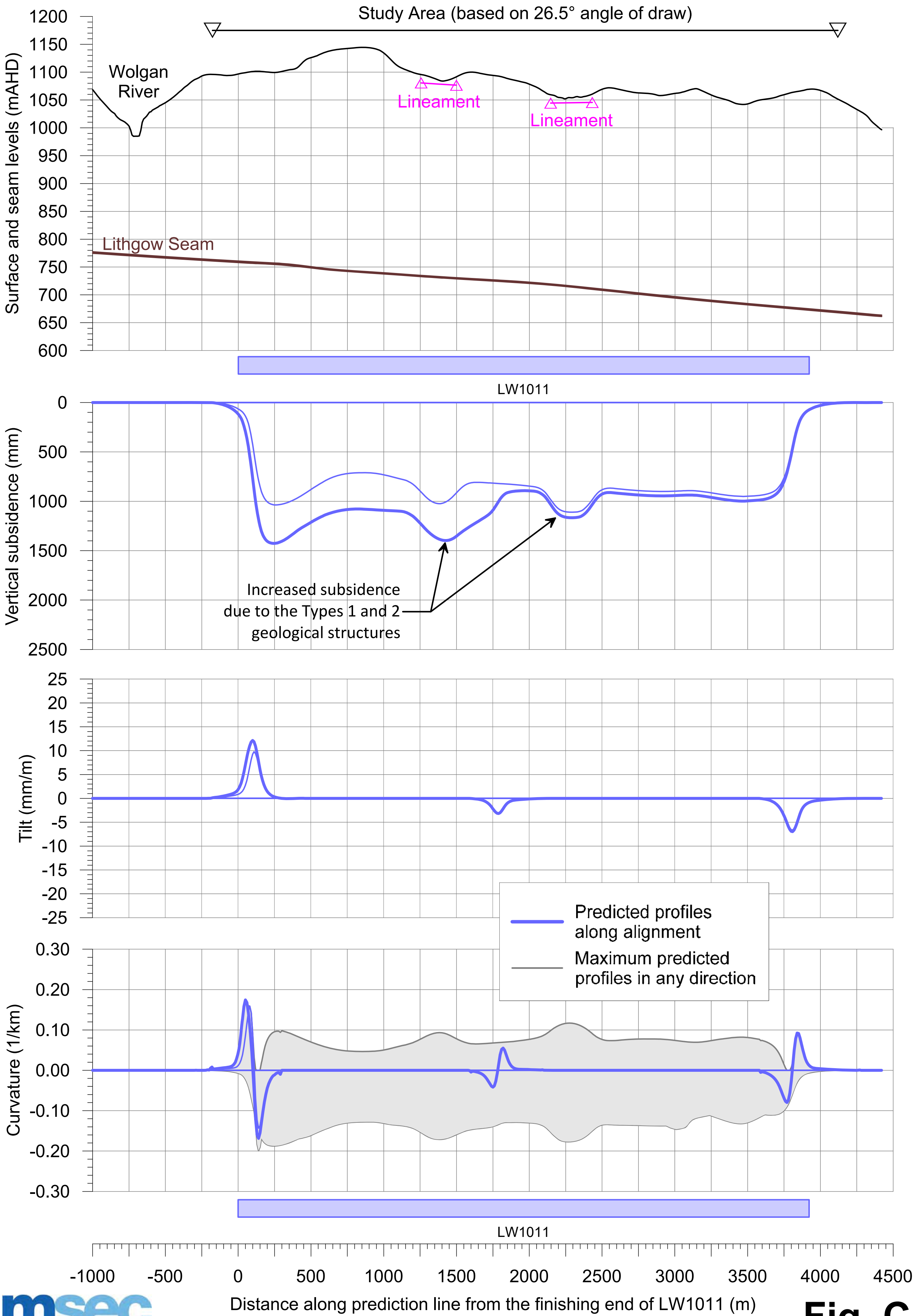

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Fig. C.03

Predicted profiles of vertical subsidence, upsidence and closure along the Wolgan River due to the extraction of LW1001 to LW1015

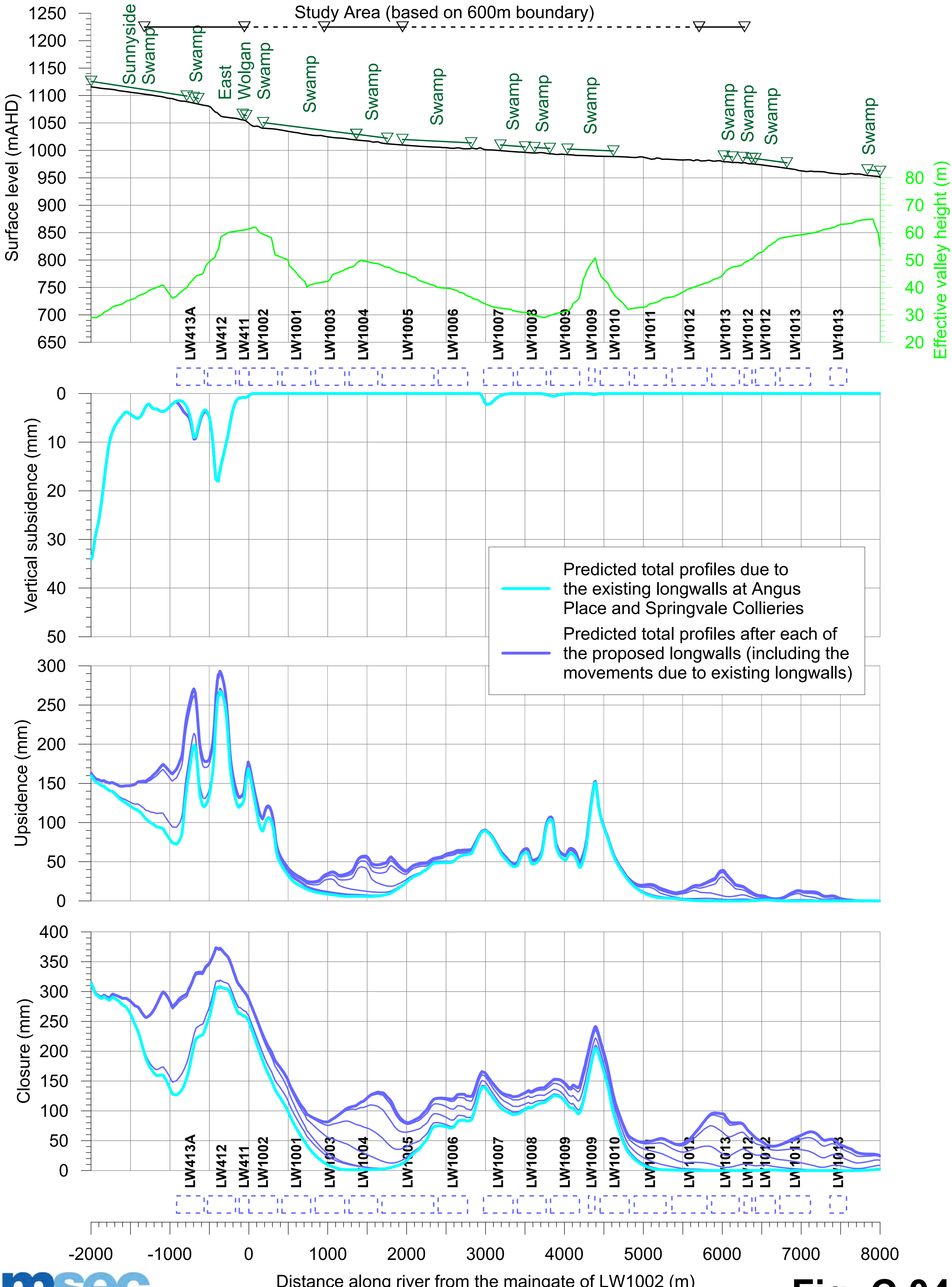

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Fig. C.04

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 1 due to the extraction of LW1001 to LW1015

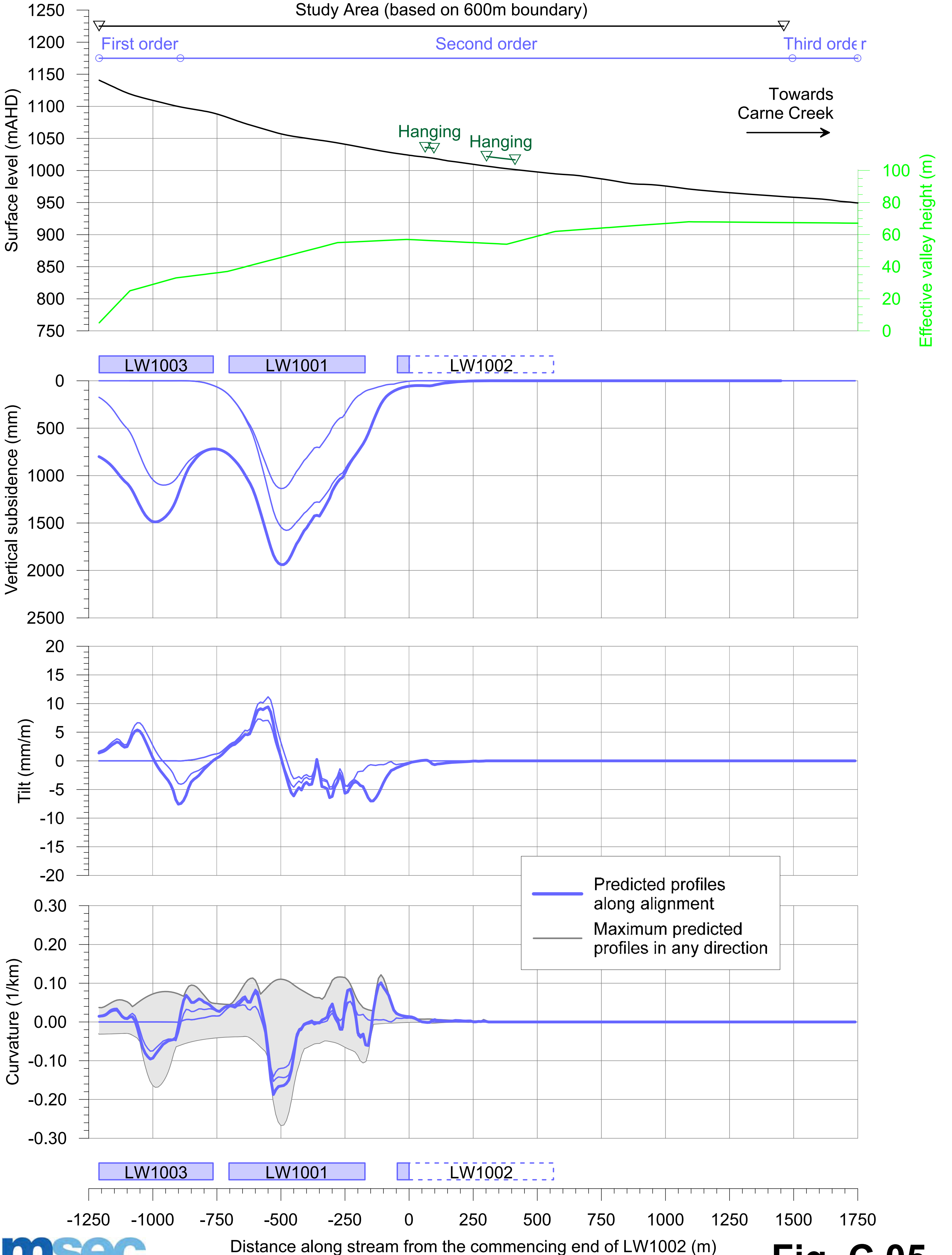

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Fig. C.05

I:\Projects\Angus Place\MSEC1046 EIS for LW1001 to LW1015\Subsdata\Impacts\Streams\Fig. C.06 - Drainage Line 2a.grf

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 2a due to the extraction of LW1001 to LW1015

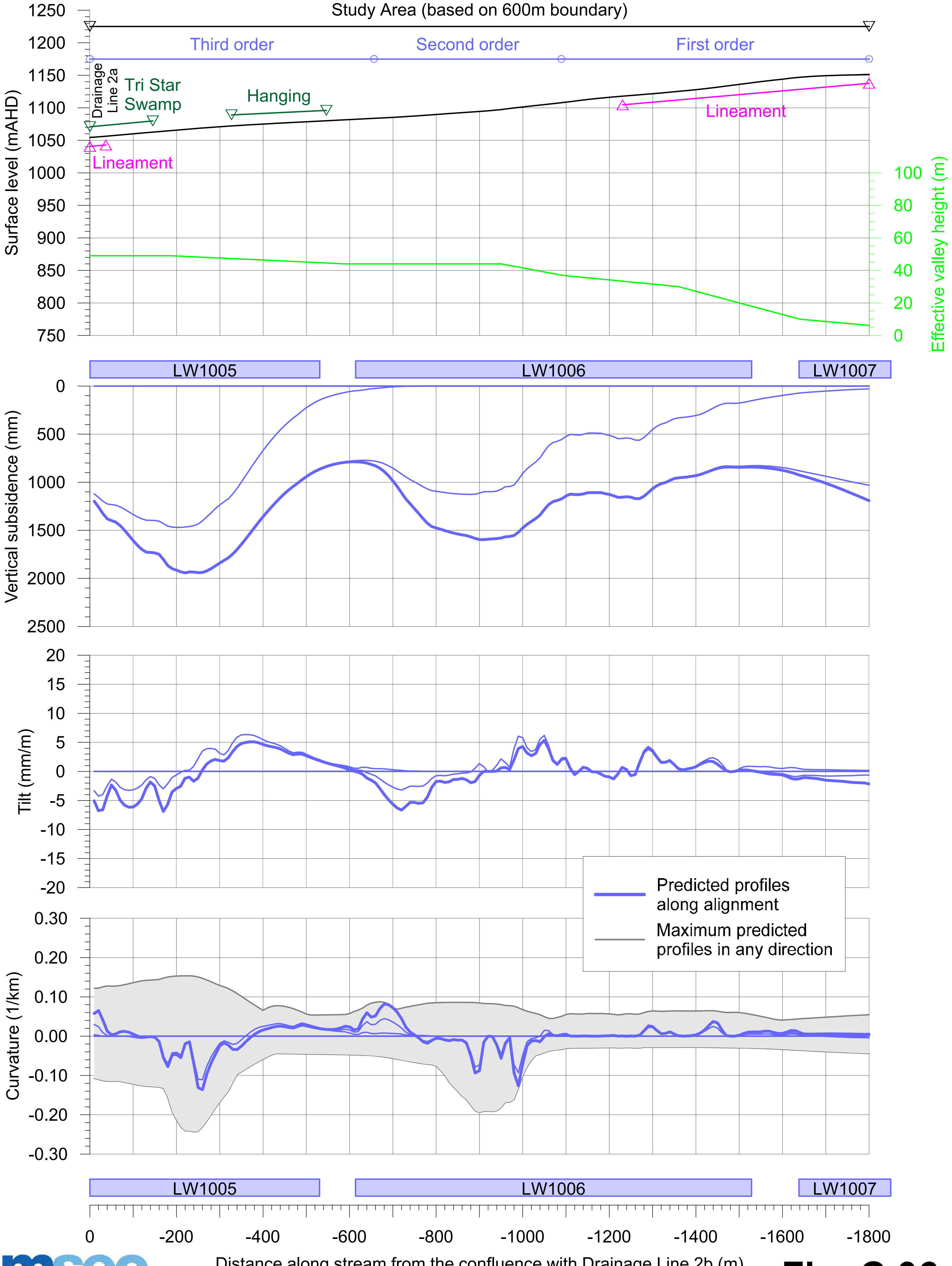

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Fig. C.06

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 2b due to the extraction of LW1001 to LW1015

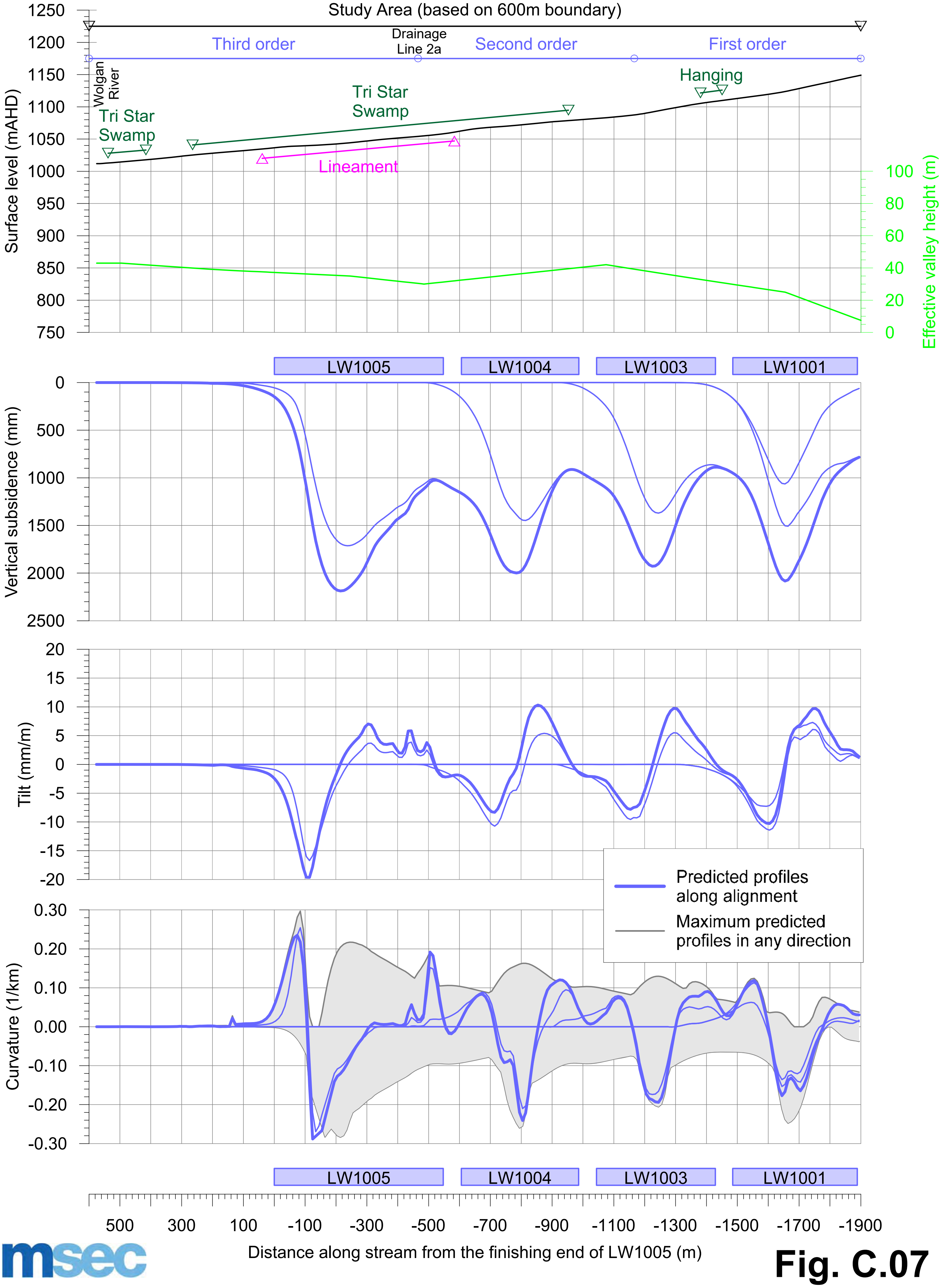

Fig. C.07

I:\Projects\Angus Place\MSEC1046 EIS for LW1001 to LW1015\Subsdata\Impacts\Streams\Fig. C.08 - Drainage Line 3a.grf

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 3a due to the extraction of LW1001 to LW1015

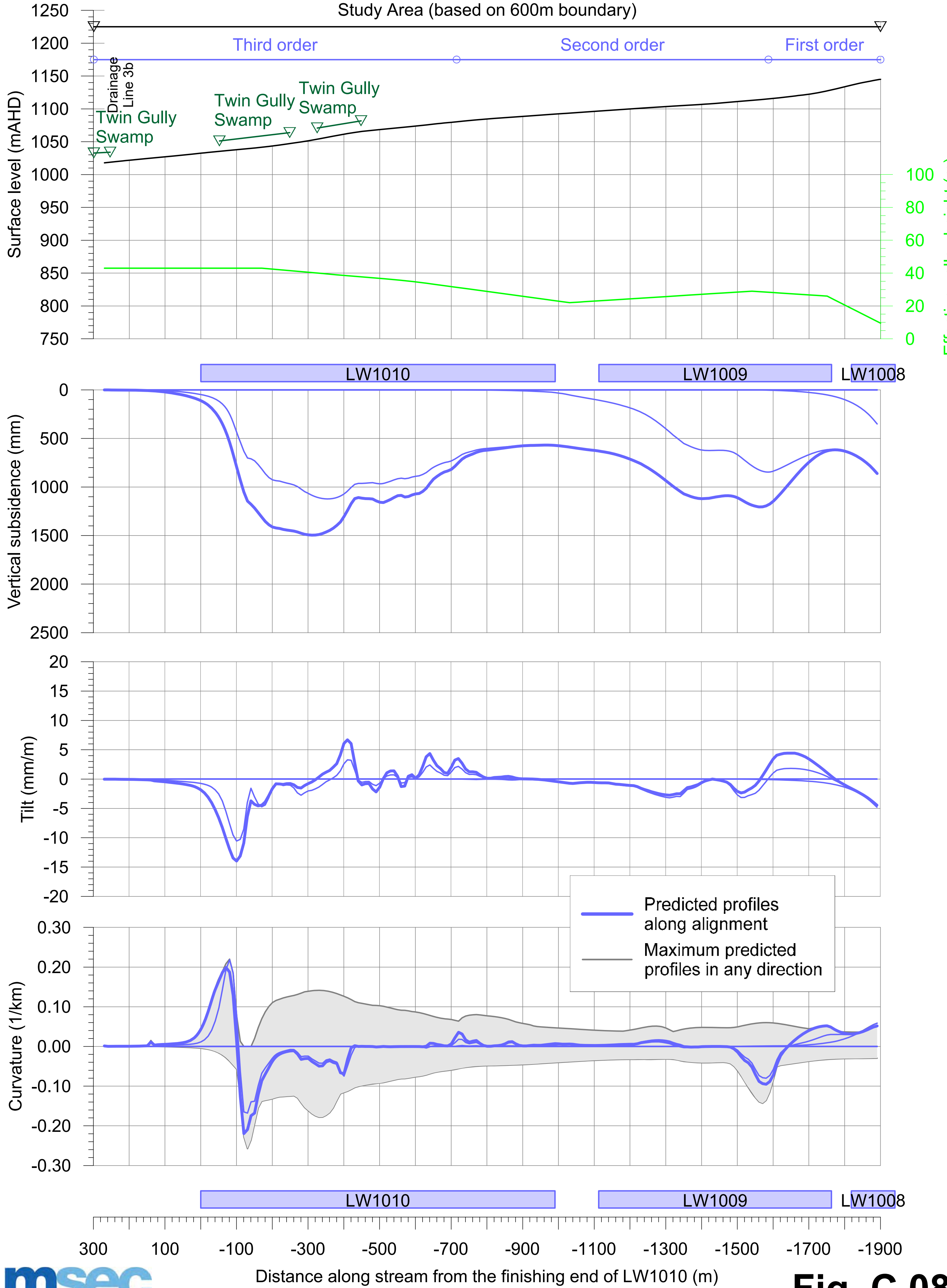

Fig. C.08

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 3b due to the extraction of LW1001 to LW1015

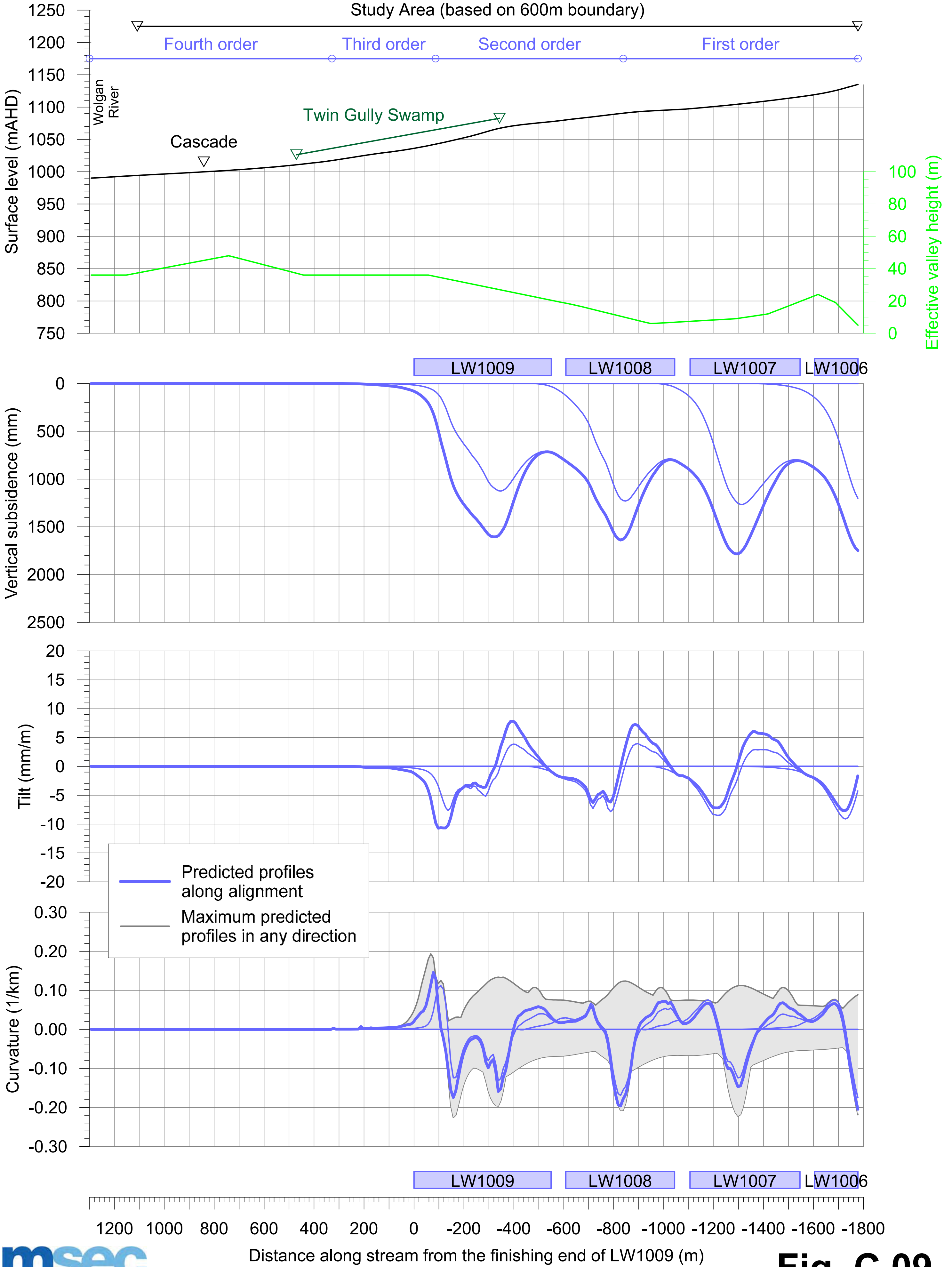

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Fig. C.09

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 4 due to the extraction of LW1001 to LW1015

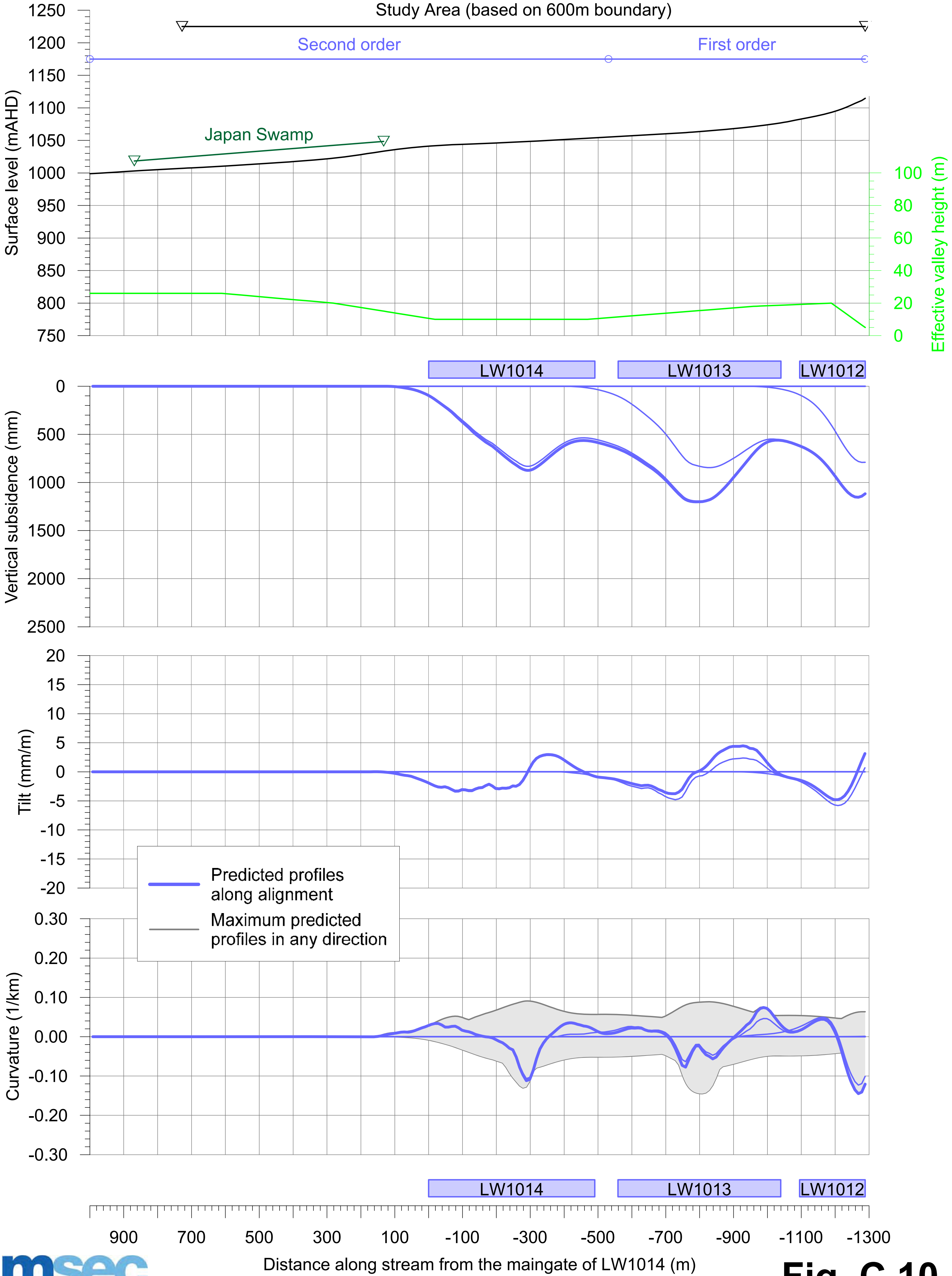

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Fig. C.10

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 5 due to the extraction of LW1001 to LW1015

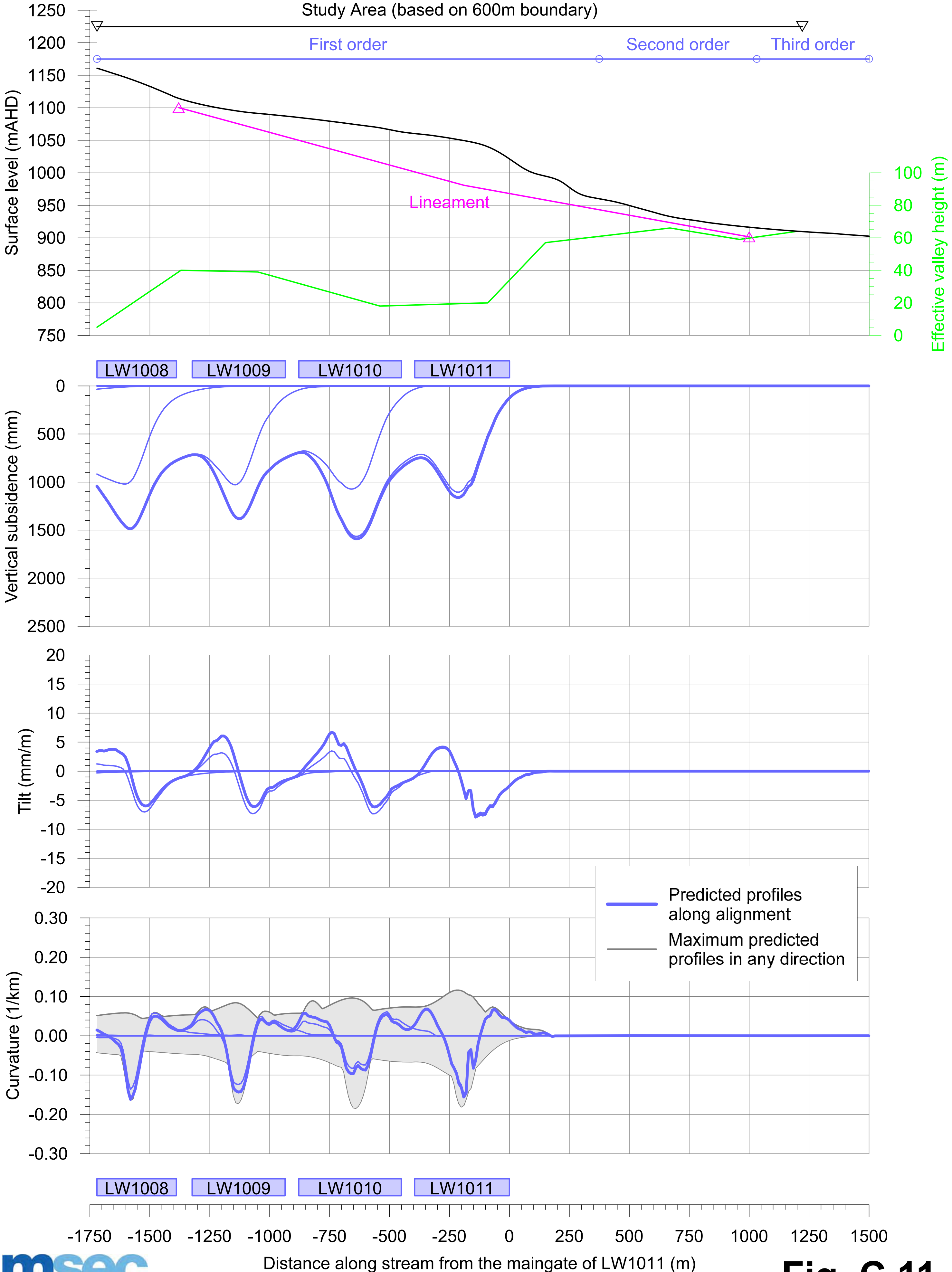

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Fig. C.11

Predicted profiles of vertical subsidence, tilt and curvature along Drainage Line 6 due to the extraction of LW1001 to LW1015

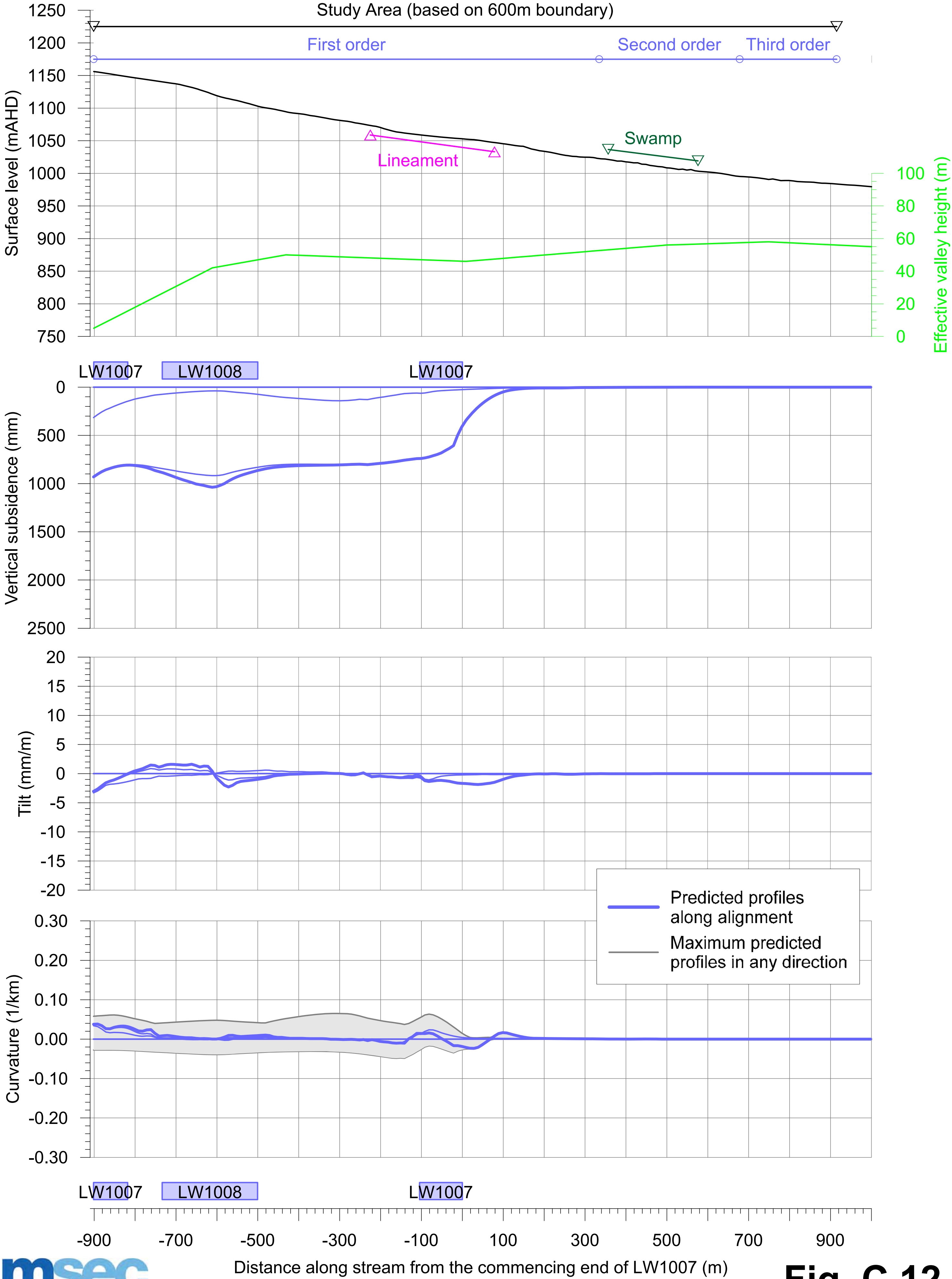

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Fig. C.12

APPENDIX D. DRAWINGS

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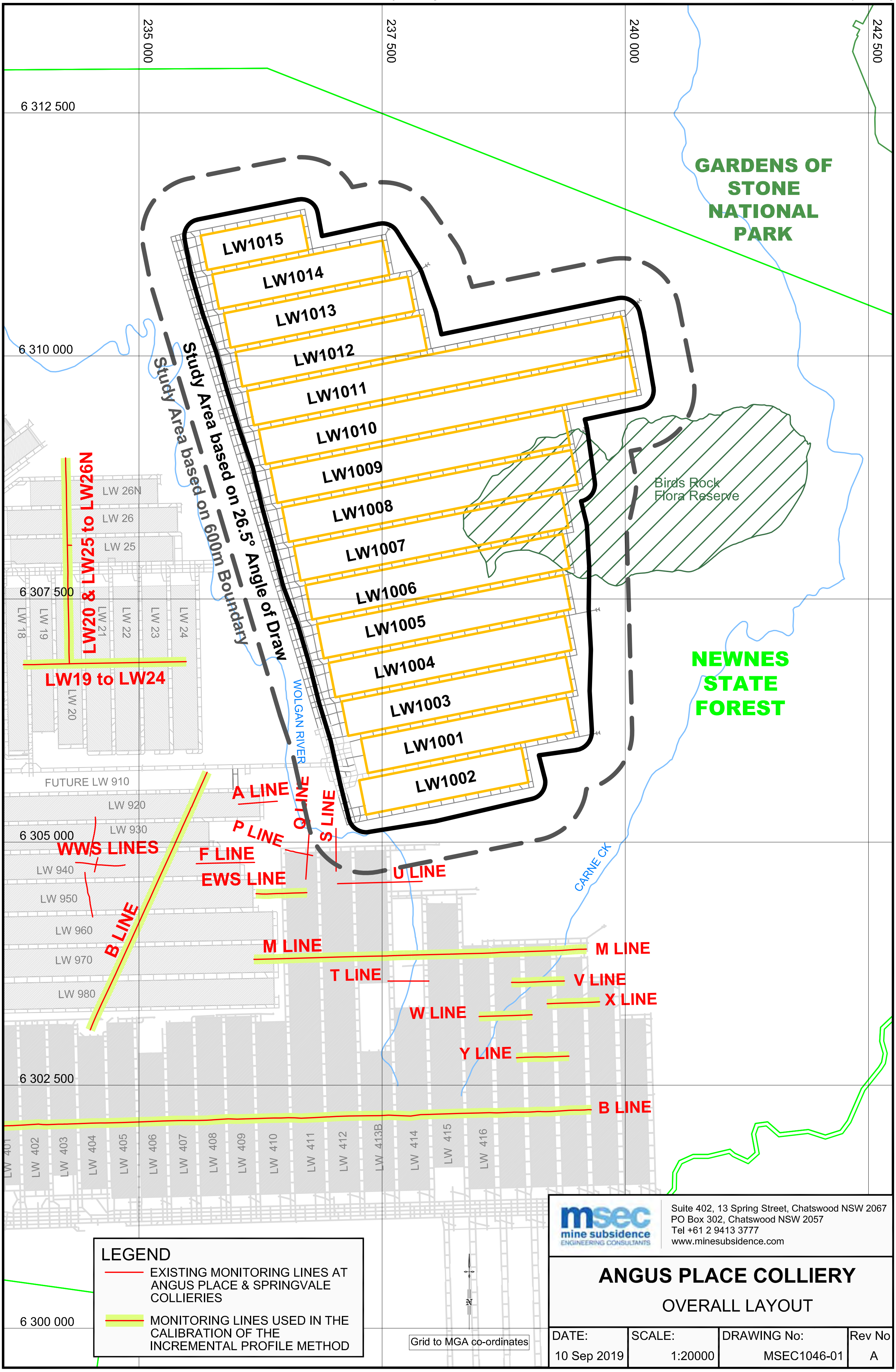

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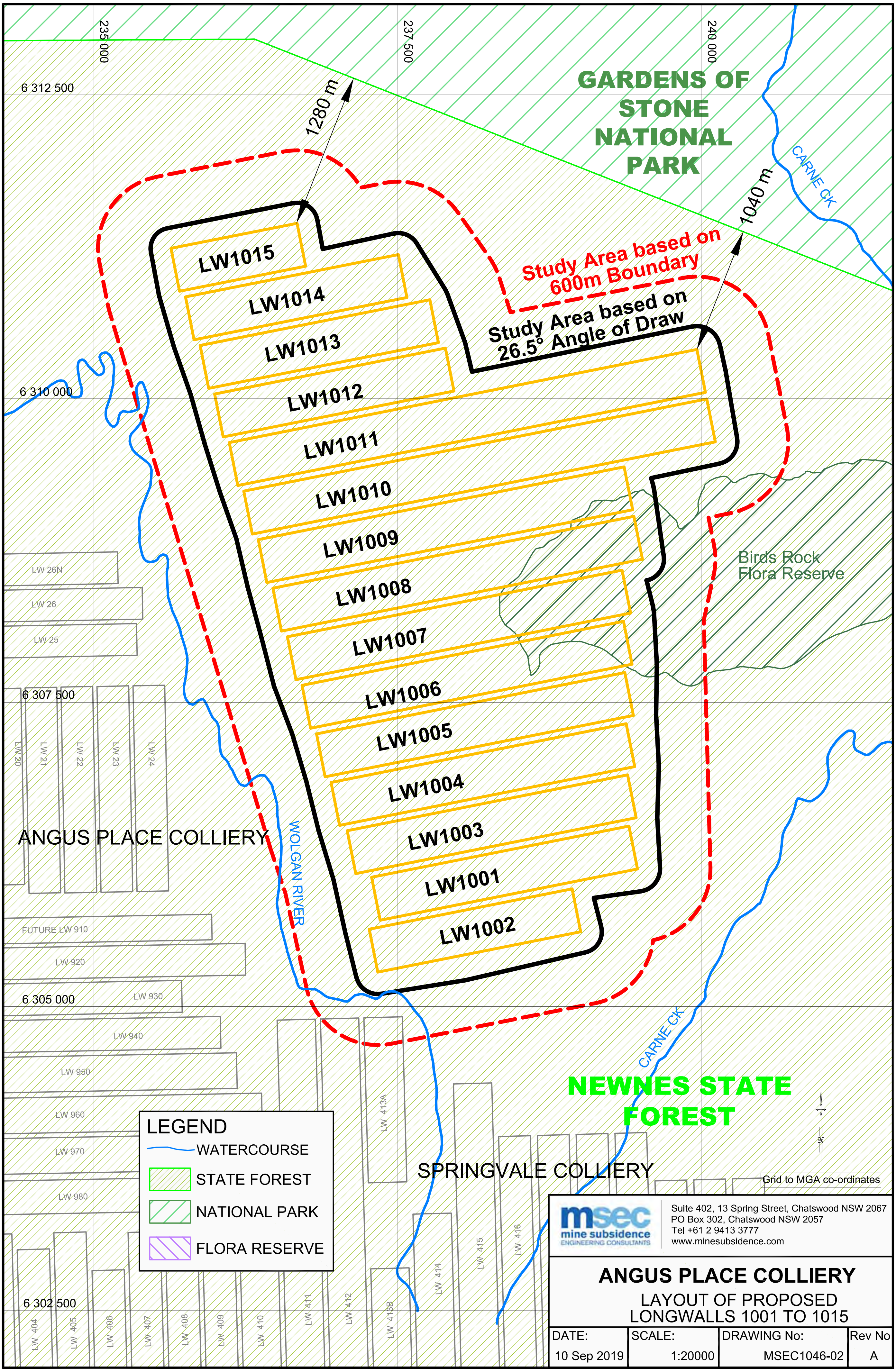

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ANGUS PLACE COLLIERY

LAYOUT OF PROPOSED LONGWALLS 1001 TO 1015

DATE:	SCALE:	DRAWING No:	Rev No
10 Sep 2019	1:20000	MSEC1046-02	A

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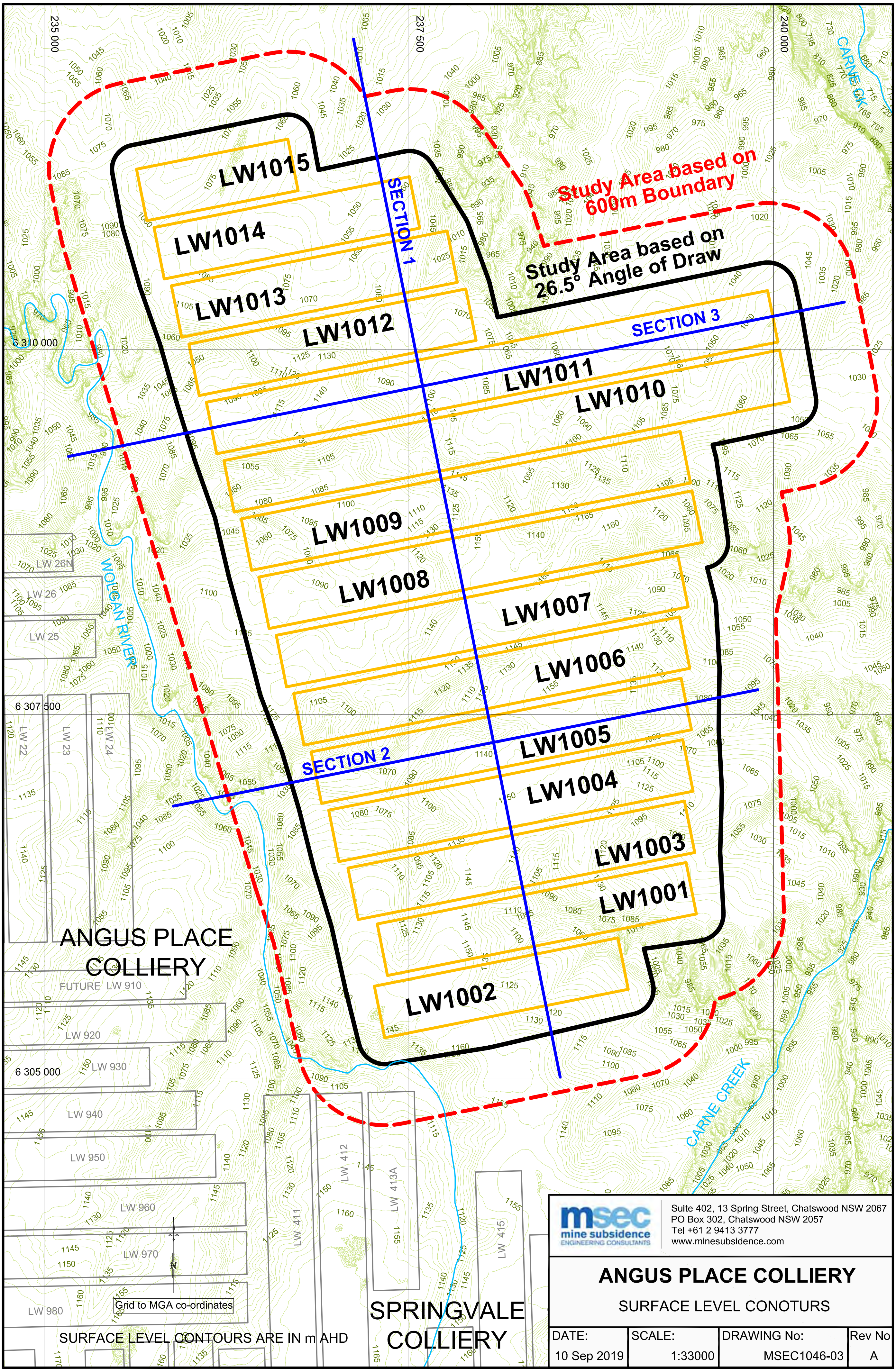

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SURFACE LEVEL CONOTURS

DATE:	SCALE:	DRAWING No:	Rev No
10 Sep 2019	1:33000	MSEC1046-03	A

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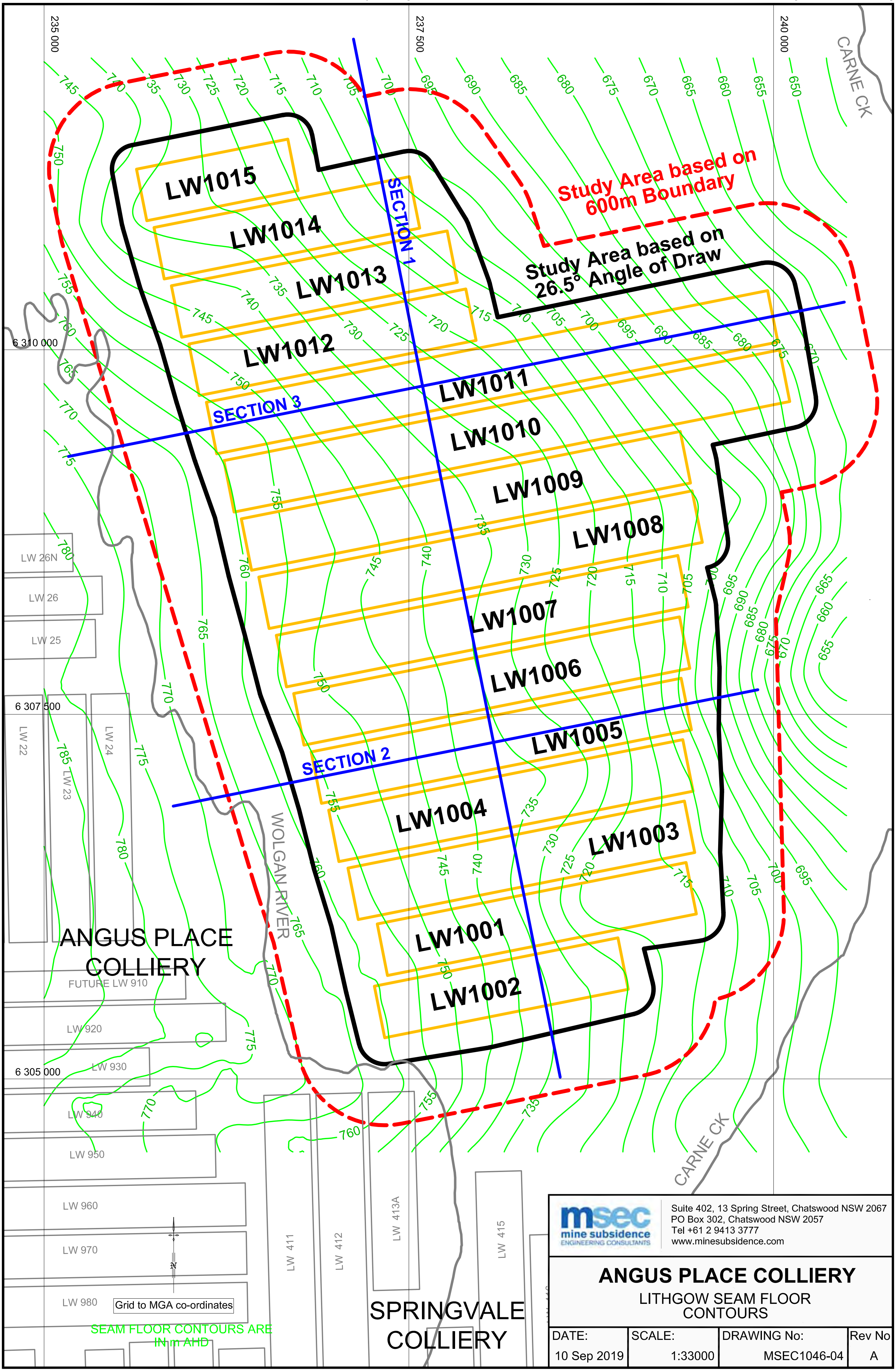

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LITHGOW SEAM FLOOR CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
10 Sep 2019	1:33000	MSEC1046-04	A

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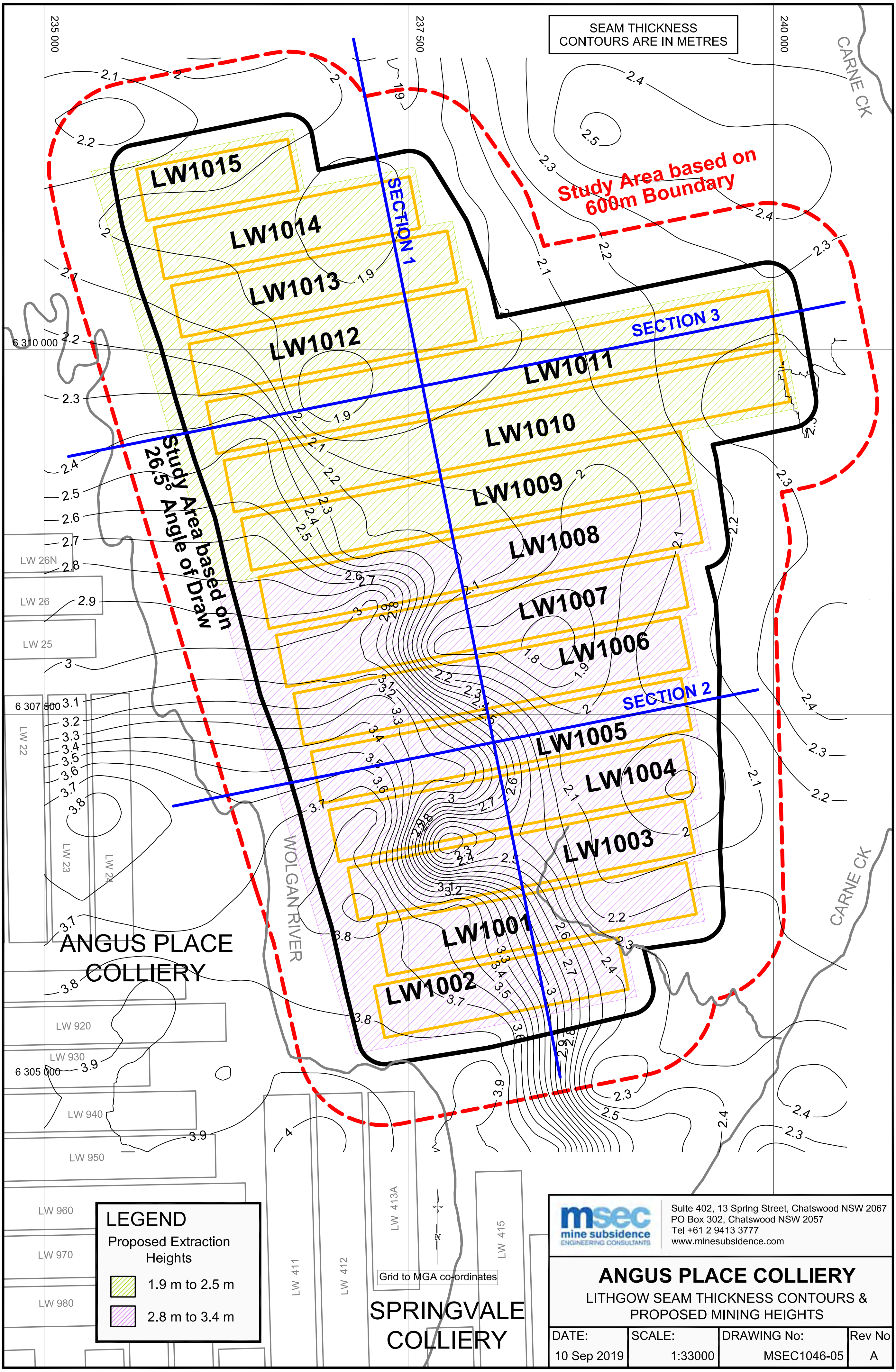

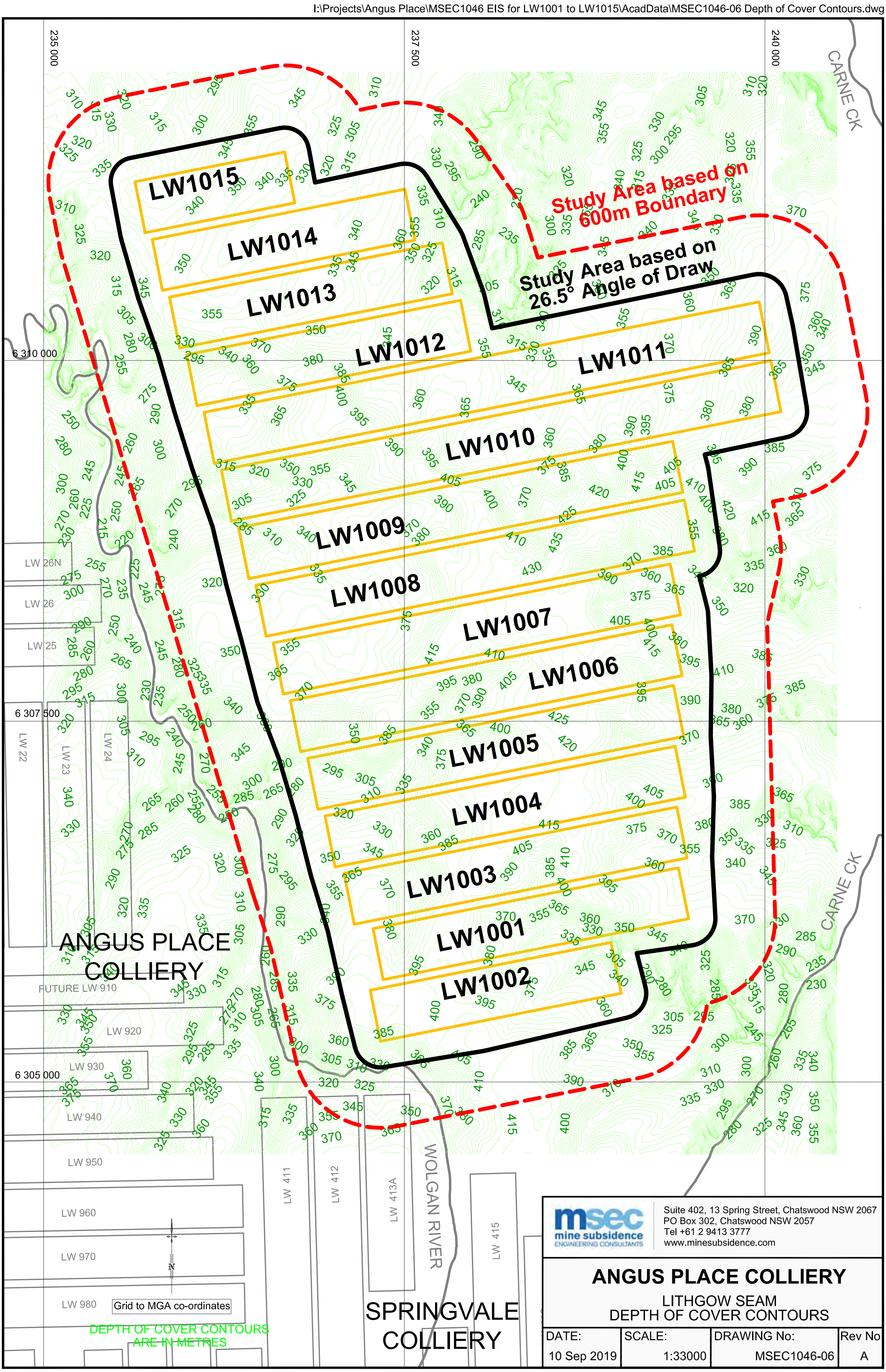
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235 000
237 500
240 000
6 310 000
6 307 500
6 305 000
CARNE CK
Study Area based on 600m Boundary
Study Area based on 26.5° Angle of Draw
LW1015
LW1014
LW1013
LW1012
LW1011
LW1010
LW1009
LW1008
LW1007
LW1006
LW1005
LW1004
LW1003
LW1001
LW1002
LW 26N
LW 26
LW 25
LW 22
LW 23
LW 24
ANGUS PLACE COLLIERY
FUTURE LW 910
LW 920
LW 930
LW 940
LW 950
LW 960
LW 970
LW 980
LW 411
LW 412
LW 413A
LW 415
WOLGAN RIVER
SPRINGVALE COLLIERY
Grid to MGA co-ordinates
DEPTH OF COVER CONTOURS ARE IN METRES
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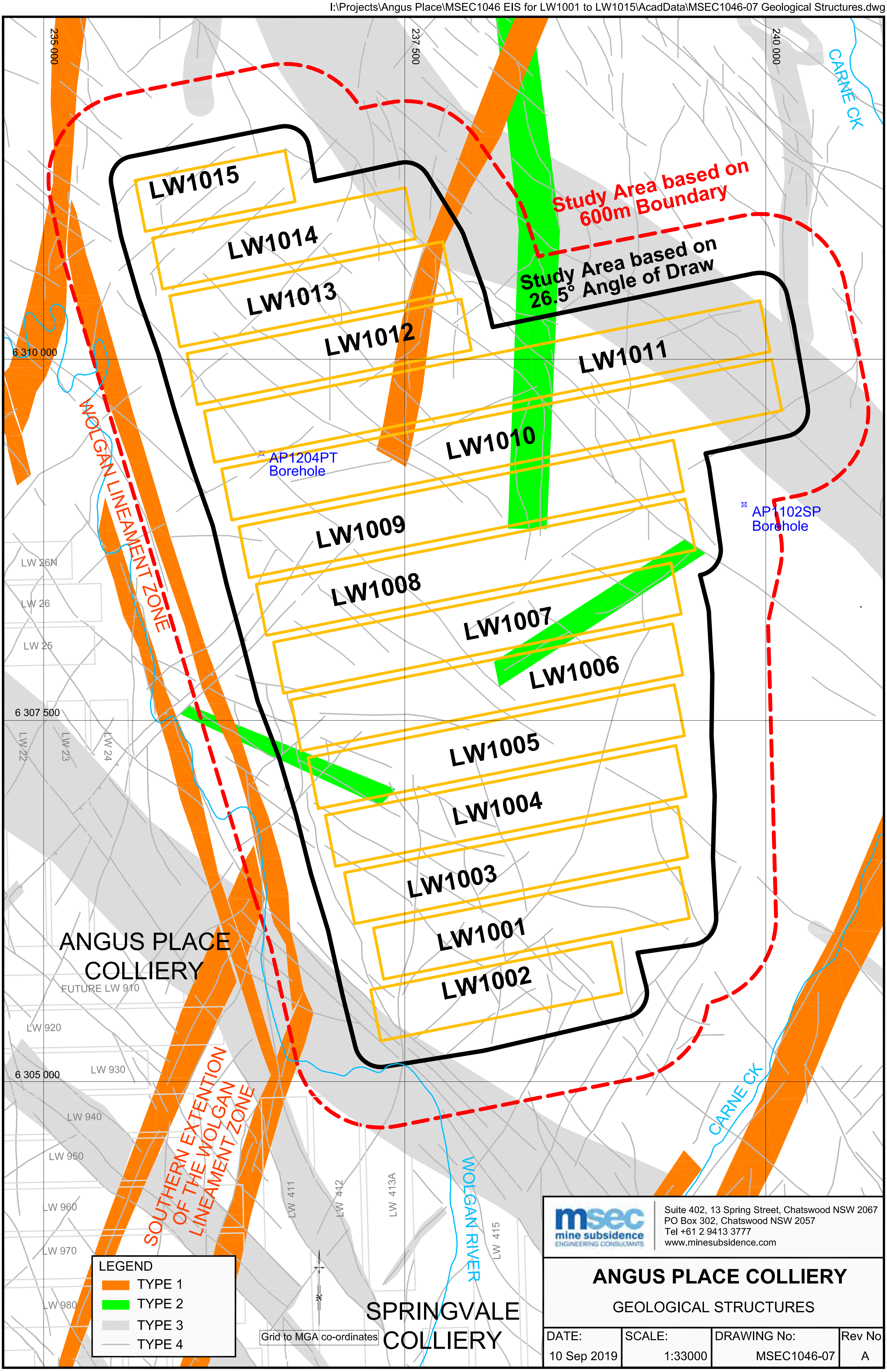
ANGUS PLACE COLLIERY
LITHGOW SEAM
DEPTH OF COVER CONTOURS
DATE: 10 Sep 2019
SCALE: 1:33000
DRAWING No: MSEC1046-06
Rev No A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235 000
237 500
240 000
6 310 000
6 307 500
6 305 000
CARNE CK
Study Area based on 600m Boundary
Study Area based on 26.5° Angle of Draw
LW1015
LW1014
LW1013
LW1012
LW1011
LW1010
LW1009
LW1008
LW1007
LW1006
LW1005
LW1004
LW1003
LW1001
LW1002
AP1204PT Borehole
AP1102SP Borehole
WOLGAN LINEAMENT ZONE
LW 26N
LW 26
LW 25
LW 22
LW 23
LW 24
ANGUS PLACE COLLIERY
FUTURE LW 910
LW 920
LW 930
LW 940
LW 950
LW 960
LW 970
LW 980
SOUTHERN EXTENTION OF THE WOLGAN LINEAMENT ZONE
LW 411
LW 412
LW 413A
LW 415
WOLGAN RIVER
CARNE CK
SPRINGVALE COLLIERY
Grid to MGA co-ordinates
LEGEND
TYPE 1
TYPE 2
TYPE 3
TYPE 4
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GEOLOGICAL STRUCTURES
DATE: 10 Sep 2019
SCALE: 1:33000
DRAWING No: MSEC1046-07
Rev No A

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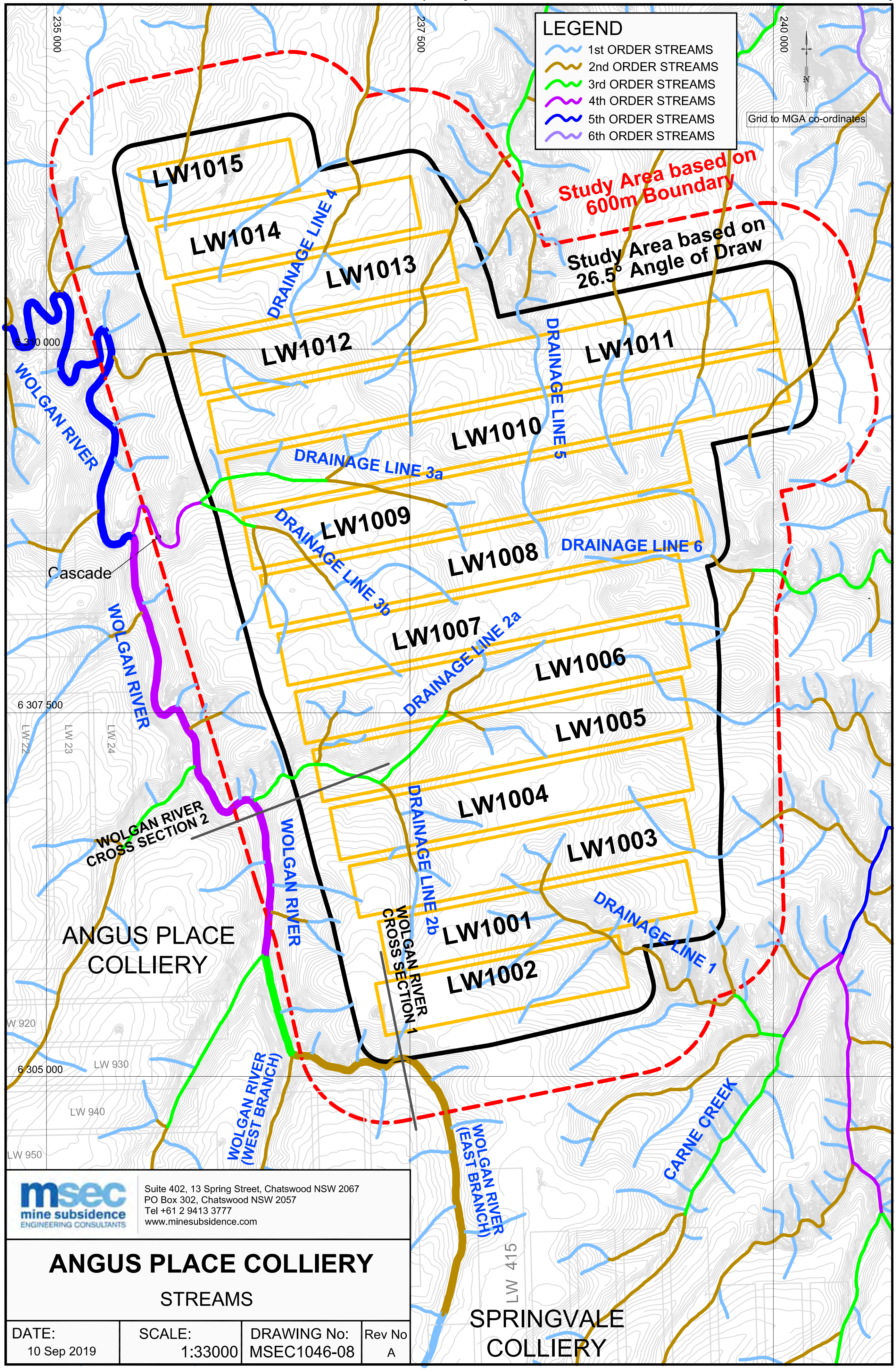

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STREAMS

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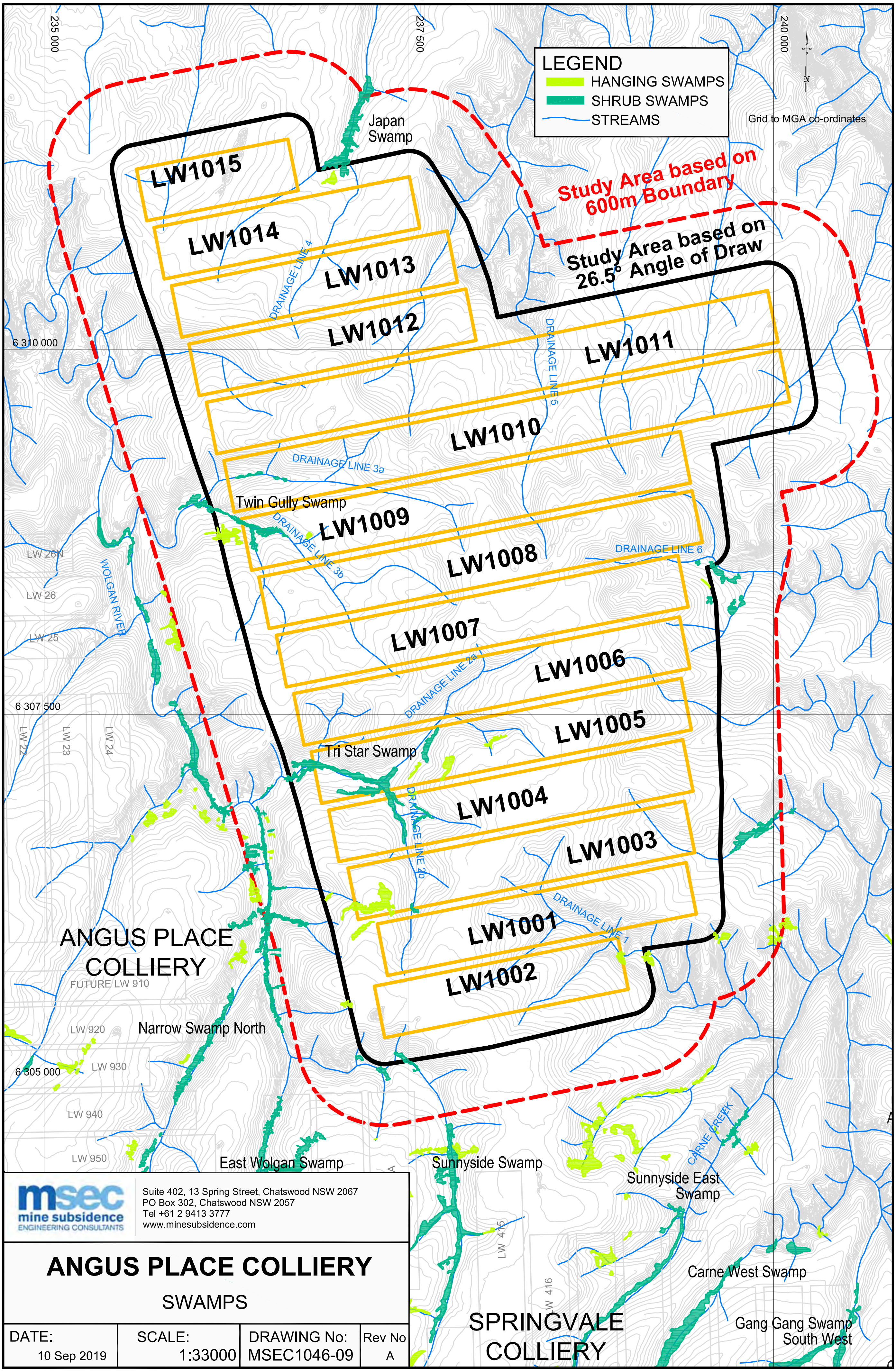

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SWAMPS

DATE:	SCALE:	DRAWING No:	Rev No
10 Sep 2019	1:33000	MSEC1046-09	A

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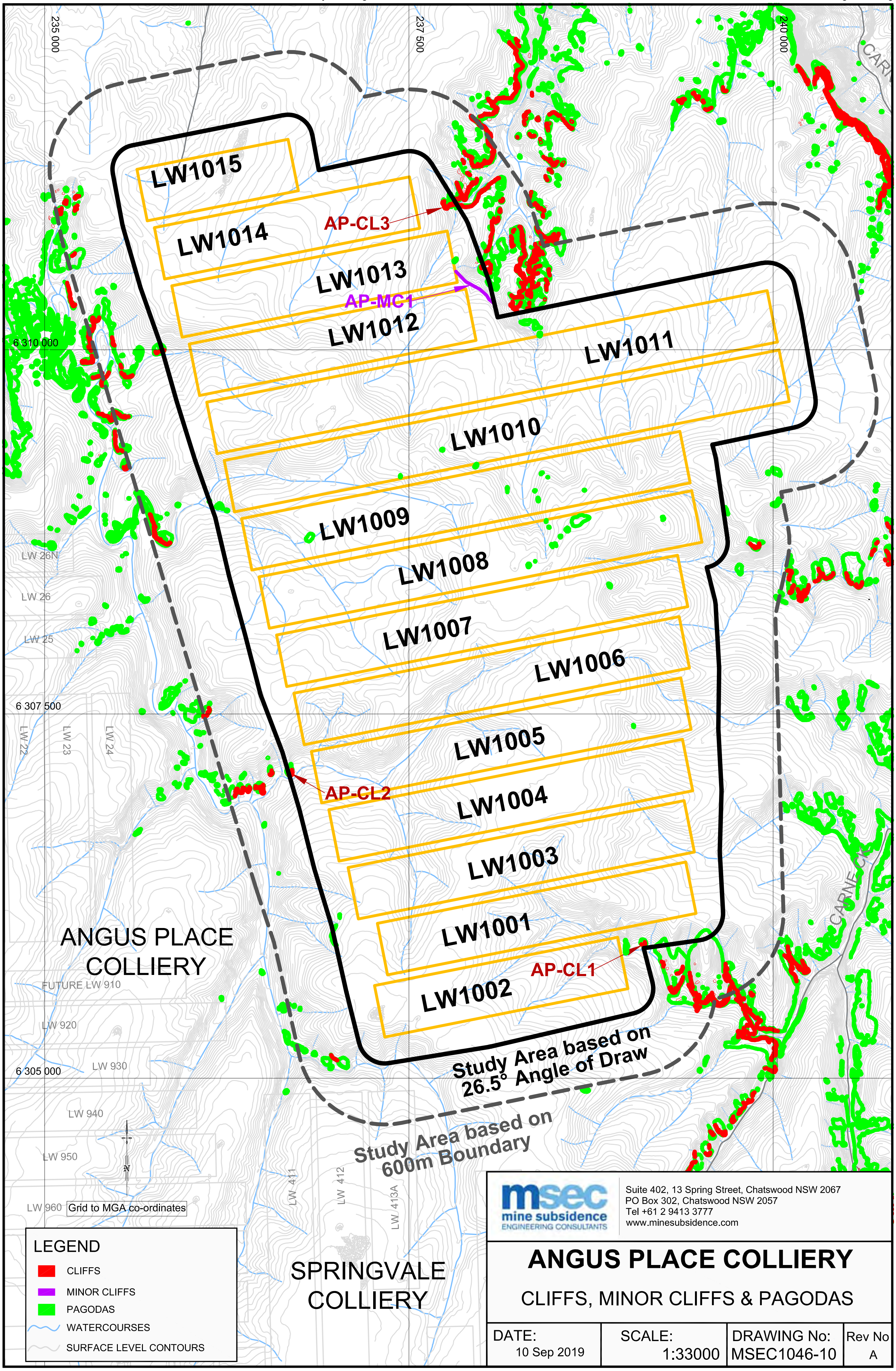

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CLIFFS, MINOR CLIFFS & PAGODAS

DATE:	SCALE:	DRAWING No:	Rev No
10 Sep 2019	1:33000	MSEC1046-10	A

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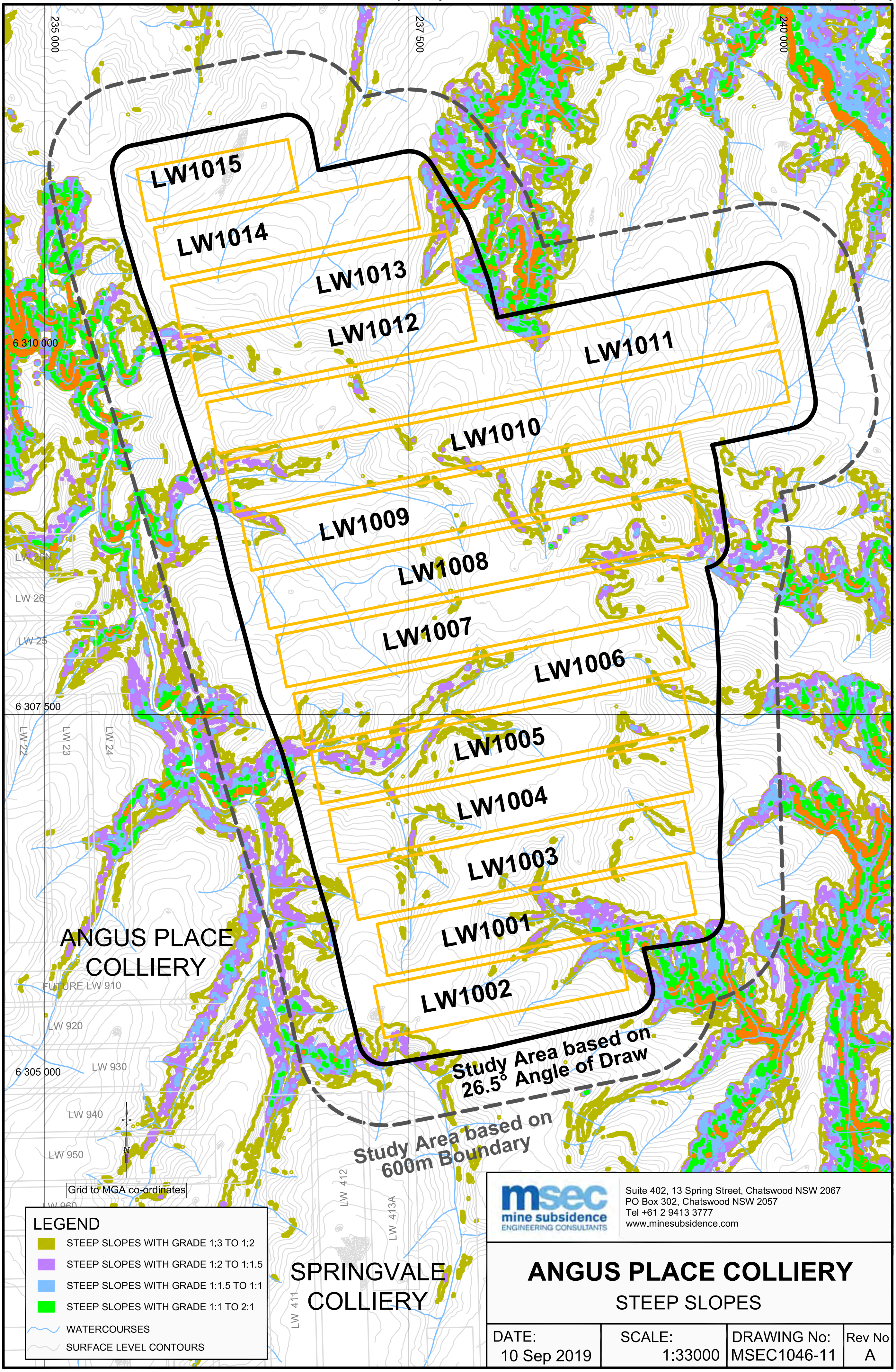

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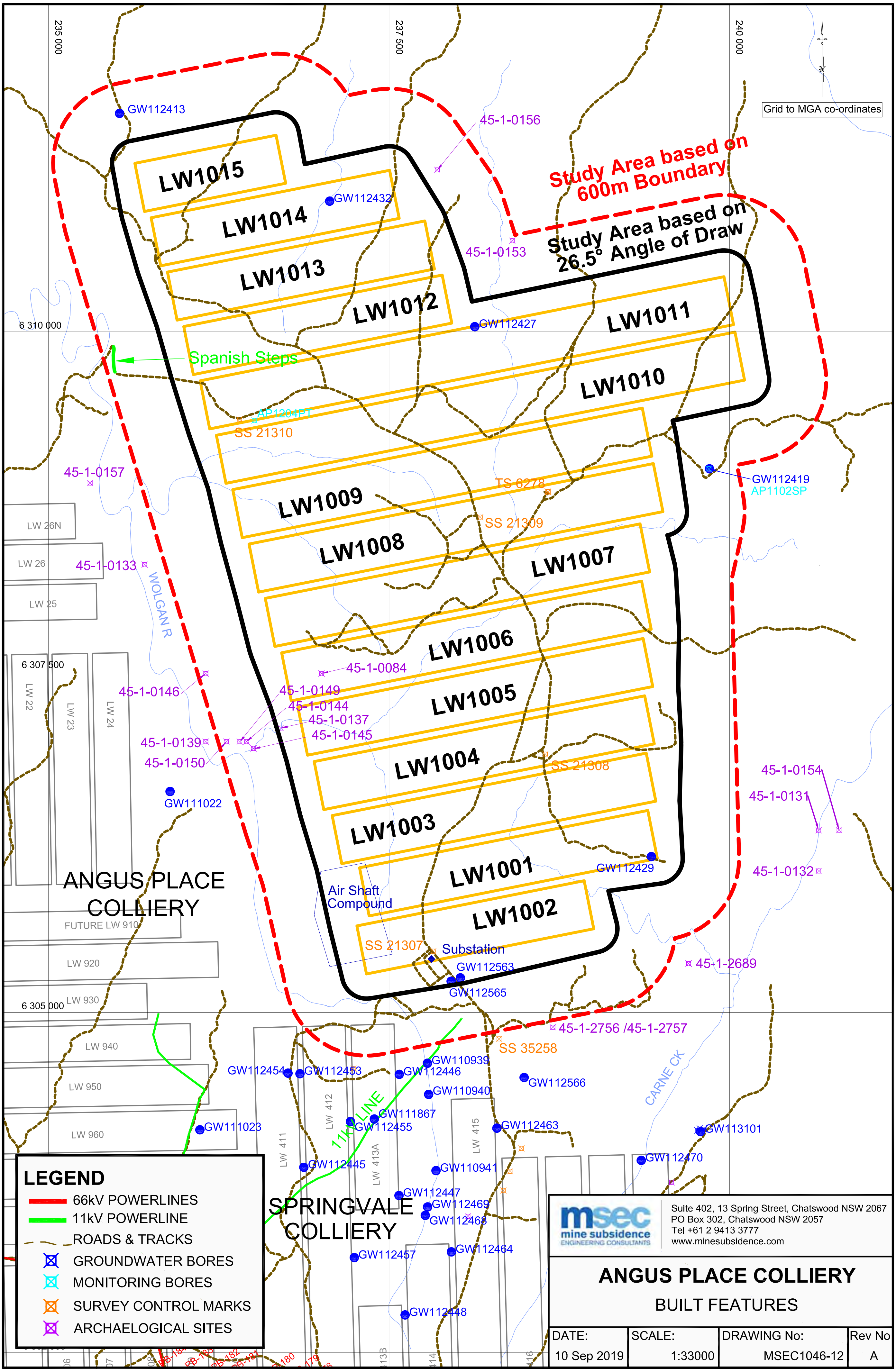

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BUILT FEATURES

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