CENTENNIAL COAL:

Angus Place Colliery 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

DOCUMENT REGISTER

Revision	Description	Author	Checker	Date
01	Draft Issue	JB	-	21st Dec 12
02	Draft Issue	JB	-	23rd Jan 13
03	Draft Issue	JB	PA	11th Mar 13
04	Draft Issue	JB	PA	28th May 13
A	Final Issue	JB	PA	24th Oct 13
B	Minor Updates	JB	PA	29th Jan 14
C	Minor Updates	JB	PA	2nd Apr 14

Report produced to:- Support the Environmental Impact Statement for submission to the Department of Planning and Infrastructure.

Background reports available at *www.minesubsidence.com:-*

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

Centennial Coal Pty Limited (Centennial) operates the Angus Place Colliery (Angus Place), which is located in the western coalfield of New South Wales. Centennial is seeking approval to extract the proposed Longwalls 1001 to 1019 in the Lithgow Seam, which is referred to as the *Angus Place Colliery Mine Extension Project*. The layout of the proposed longwalls is shown in Drawing Nos. MSEC593-01 and MSEC593-02, in Appendix E.

The project briefing paper provided by Centennial (2012) outlines the objectives of the project which have been reproduced below:-

> "*The overall objective of this Project is to obtain approval for the continuation of mining at the Angus Place Colliery. The objectives of the Project are as follows.*
>
> - *Design of the extension project in accordance with ecological sustainable principles;*
> - *Coal production of a total of up to 4 million tonnes per annum (Mtpa) of coal from the Lithgow coal seam;*
> - *Extraction of coal using longwall mining techniques from an area identified as Angus Place East within the Project Application Area (refer Figure 2);*
> - *Construction and operation of the following facilities to support the extension Project:*
>   - ➢ *A ventilation facility (APC-VS3) consisting of a single downcast (intake) shaft;*
>   - ➢ *Dewatering borehole sites to deliver water into the existing Springvale-Delta Water Transfer Scheme;*
>   - ➢ *Water management structures;*
>   - ➢ *Shaft spoil emplacement area;*
> - *Upgrade of access track from Sunnyside Ridge Road to the proposed ventilation facility (APC-VS3) and dewatering borehole sites; and*
> - *Continue to provide employment of a full time workforce of 225 persons and up to 75 contractors.*"

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

- provide subsidence predictions for the proposed Longwalls 1001 to 1019,
- review the natural and built features located in the vicinity of the proposed longwalls,
- provide subsidence predictions for each of these natural and built features, and
- undertake impact assessments, in conjunction with other specialist consultants, for each of these natural and built features.

This report provides information that will support the Environmental Impact Statement which will be issued to the Department of Planning and Infrastructure (DP&I). In some cases, this report will refer to other sources of information on specific natural and built features, and these reports should be read in conjunction with this report.

The *Extension Area* is defined as the surface area that is likely to be affected by the extraction of the proposed LW1001 to LW1019 in the Lithgow Seam. The extent of the Extension Area has been calculated, as a minimum, the surface area enclosed by the greater of the 26.5 degree angle of draw line from the extents of the proposed longwalls and by the predicted 20 mm subsidence contour resulting from the extraction of the proposed longwalls. Other features which could be subjected to far-field or valley related movements and could be sensitive to such movements have also been assessed in this report. In this case, features which could be sensitive to far-field or valley related movements, within but not limited to 600 metres from the proposed longwalls, have been assessed.

A number of natural and built features have been identified within or in the vicinity of the Extension Area, including the Wolgan River, Carne Creek, drainage lines, cliffs, minor cliffs, pagodas, steep slopes, swamps, the *Gardens of Stone National Park*, unsealed tracks, archaeological sites and survey control marks.

The mining layout has been designed such that the majority of the cliffs and pagoda complexes are located outside the 26.5 degree angle of draw line from the proposed longwalls. The proposed LW1010 has also been setback such that Twin Gully Swamp will not be directly mined beneath. The widths of the proposed longwalls have also been narrowed beneath Tri Star and Trail 6 Swamps, so as to reduce the potential impacts on these swamps.

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 distance of around 240 metres from Longwall 1002, at its closest point. The 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 river is predicted to experience less than 20 mm subsidence, 80 mm upsidence and 140 mm closure due to the extraction of the proposed longwalls. The compressive strains due to the valley closure movements are expected to be less than 1 mm/m.

  The predicted changes in grade along the river are small when compared to the existing natural grades and, therefore, it is unlikely that there would be any significant changes in the levels of ponding, flooding or scouring of the river banks, or any significant changes in the stream alignment.

  It is possible that some minor and isolated fracturing could occur in the bed of the Wolgan River resulting from the extraction of the proposed longwalls. The fractures are expected to be shallow and discontinuous and, therefore, are not expected to result in any diversion of surface water flows into subterranean flows.

- *Carne Creek* is located around 400 metres south-east of the Longwall 1019, at its closest point to the proposed longwalls. The remaining proposed longwalls are located more than 600 metres from the creek.

  The creek is predicted to experience less than 20 mm subsidence, 25 mm upsidence and 50 mm closure due to the extraction of the proposed longwalls. The compressive strains due to the valley closure movements are expected to be less than 0.5 mm/m.

  The predicted movements at the Carne Creek are small and, therefore, it is unlikely that it would experience any adverse impacts resulting from the extraction of the proposed longwalls.

- There are unnamed drainage lines which are located across the proposed mining area. These 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 includes loose rocks and tree branches.

  The sections of these 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 predicted post mining grades along the drainage lines are similar to the natural grades and, therefore, it is not expected that there would be any significant adverse changes in ponding or scouring resulting from the proposed mining. There could be some very minor localised areas which 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 some sections of the drainage lines which are located directly above the proposed longwalls. Where the beds of the drainage lines have exposed bedrock, there may be some diversion of surface water flows into the dilated strata beneath them. It is unlikely that there would be any net loss of water from the catchment, however, as any diverted surface water is likely to re-emerge into the catchment further downstream.

  The surface cracking would tend to be naturally filled with soil during subsequent flow events, especially during times of heavy rainfall. If any surface cracks were found not to fill naturally, some remedial measures may be required at the completion of mining. Where necessary, any significant surface cracks in the drainage line beds could be remediated by infilling with soil or other suitable materials, or by locally regrading and recompacting the surface.

- For the purposes of discussion in this report, a *cliff* has been defined as a continuous rockface having a minimum height of 10 metres, a minimum length of 20 metres and a minimum slope of 2 to 1, i.e. having a minimum angle to the horizontal of 63°. *Minor cliffs* have been defined as continuous rockfaces having heights between 5 metres and 10 metres, minimum lengths of 20 metres and a minimum slope of 2 to 1. Pagodas have been defined as isolated freestanding rock formations with heights greater than 5 metres. The cliffs, minor cliffs and pagoda complexes have been identified within the valleys of the Wolgan River, Carne Creek and the tributaries to Carne Creek.

The mining layout has been designed such that the majority of the cliffs and pagoda complexes are located outside the 26.5 degree angle of draw line from the extents of the proposed longwalls. There are two cliffs and some pagoda complexes which have been identified within the 26.5 degree angle of draw line, however, they are all located outside the extents of the proposed longwalls. There is one minor cliff which has been identified immediately adjacent to the eastern end of the proposed LW1014B and some isolated pagodas identified elsewhere above the proposed longwalls.

Whilst the cliffs and pagodas complexes could experience low levels of subsidence, they are not expected to experience any significant conventional tilts, curvatures or strains. These features are located along the valley sides and, therefore, 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 any adverse impacts resulting from the extraction of the proposed longwalls. This is supported by extensive experience from the NSW Coalfields, at depths of cover greater than 200 metres, where no cliff instabilities have been observed where cliffs have been located wholly outside the extents of extracted longwalls. It is noted, however, that there has been some minor and isolated rock falls observed outside the extents of extracted longwalls.

There are some minor cliffs, pagodas and other rock formations which are located immediately adjacent to or directly above the proposed longwalls. The proposed mining is likely to result in some fracturing in these features and, where the rock is marginally stable, 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.

- For the purposes of discussion in this report, a *steep slope* has been defined as an area of land having a natural gradient greater than 1 in 3 (i.e. a grade of 33 %, or an angle to the horizontal of 18°), but less than 2 in 1 which is the limit used to define cliffs. The steep slopes are primarily located along the alignments of the drainage lines, having natural grades typically 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 would generally result from the downslope movement of the soil, resulting in tension cracks appearing at the tops and along the sides of the steep slopes and compression ridges forming at the bottoms of the steep slopes.

  Soil slumping has occurred once at Angus Place and Springvale Collieries, where tension cracks developed on the western valley side of Narrow Swamp, having widths greater than 50 mm and lengths around 10 metres. These cracks were naturally infilled with the surface soils over a period of months after the completion of mining. 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.

  It is possible that some remediation might be required, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the slopes in the longer term.

- The swamps within the Extension Area are classified into two fundamental types, being the *Newnes Plateau Shrub Swamps* (shrub swamps) and the *Newnes Plateau Hanging Swamps* (hanging swamps). The swamps in the Sydney Basin Bioregion have been listed as an Endangered Ecological Community under the NSW Threatened Species Conservation Act 1995. The shrub and hanging swamps have been classified as *Temperate Highland Peat Swamps on Sandstone* under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999.

  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. *Tri Star Swamp* and *Trail 6 Swamp* are located directly above the proposed longwalls and *Twin Gully Swamp* is located immediately adjacent to the proposed longwalls. There are also shrub swamps along the Wolgan River and a tributary to Carne Creek which are located within 600 metres of the proposed longwalls.

  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. There are around ten hanging swamps located directly above the proposed longwalls and around a further 14 hanging swamps which are located outside the proposed longwalls but are within the Extension Area.

  The shrub swamps are predicted to experience subsidence up to 1900 mm, tilts up to 20 mm/m, and curvatures up to 0.30 km^{-1} hogging and 0.35 km^{-1} sagging. These swamps are located near the bases of valleys and, therefore, are also predicted to experience upsidence up to 750 mm and closure up to 1000 mm. The hanging swamps are predicted to experience subsidence up to 1450 mm, tilts up to 11 mm/m, and curvatures up to 0.20 km^{-1} hogging and sagging.

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

Fracturing of the bedrock is expected beneath the swamps which are located directly above the proposed longwalls. The swamps have peat layers and, in most cases, cracking would not be visible at the surface within these swamps, except where the depths of bedrock are shallow or exposed. Whilst some cracking could occur in the swamps resulting from the extraction of the proposed longwalls, the previous experience of mining beneath swamps at Angus Place, Springvale and in the Southern Coalfield indicate that the likelihoods and extents of these impacts are small.

The valley related upsidence movements could result in the dilation of the strata beneath the drainage lines, which could result in the diversion of some surface water flows beneath parts of the shrub swamps. It is noted, however, that the drainage lines upstream of the swamps are generally ephemeral and, therefore, surface water flows occur during and shortly after rainfall events. The experience of mining directly beneath swamps at Angus Place and Springvale Collieries, as well as on the Woronora Plateau in the Southern Coalfield, indicates that the likelihood and extents of these impacts are low.

The previous longwalls at Angus Place and Springvale Collieries have been extracted directly beneath or partially beneath 13 shrub swamps and 26 hanging swamps. Surface impacts have been observed at four swamps which were directly mined beneath, being Narrow Swamp North, Narrow Swamp South, East Wolgan Swamp and Junction Swamp. Investigations into these impacts were undertaken by Goldney et al (2010), who were engaged by the Federal Department of the Environment, Water, Heritage and the Arts (now referred to as SEWPaC).

The report by Goldney et al (2010) indicates that the impacts observed at Narrow Swamp North and Narrow Swamp South were primarily the result of mine water discharge, but it is possible that some lesser impacts have also occurred as a result of mine subsidence ground movements, but these could not be quantified. The impacts observed at East Wolgan Swamp and Junction Swamp appear to be the result of a combination of mine subsidence ground movements, mine water discharge and erosion from nearby roads, however, the proportion of each of these mechanisms could not be quantified.

Also, over 500 swamps have been directly mined beneath in the Southern Coalfield. Impacts have been reported in only a few swamps on the Woronora Plateau, most notably being Drill Hole Swamp, Flat Rock Swamp, Swamp 18 and Swamp 19. Investigations into these impacts indicate that they appear to have been initiated by other influences, such as bush fires, heavy rainfall, vehicular access and the installation of monitoring and other site investigations. Whilst mine subsidence ground movements may have accelerated these impacts, its influence is still unclear. The experience shows that the impact of mine subsidence ground movements on swamps on the Woronora Plateau is relatively low.

- The *Gardens of Stone National Park* is located immediately north of the Extension Area, at a distance of 170 metres from Longwall 1014A, at its closest point to the proposed longwalls. The National Park could experience very small vertical and horizontal movements, but it is not expected to experience any measurable conventional tilts, curvatures or strains.

  The tributaries within the National Park, closest to the proposed longwalls, could experience very small valley related movements. Whilst very minor and isolated fracturing has been observed up to around 400 metres from previously extracted longwalls in the NSW Coalfields, these have occurred within large river valleys within the Southern Coalfield. It is not expected that any significant fracturing would occur within the small tributaries within the National Park.

  The longwalls are proposed to be extracted towards the National Park which allows for an adaptive management approach. The ground movements in the vicinity of the National Park can be monitored, as longwalls in the series are progressively mined towards it, allowing the 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 a Trigger Action Response Plan (TARP).

- There are unsealed roads located across the Extension Area. It is expected that these roads could be maintained in safe and serviceable condition throughout the mining period using normal road maintenance techniques.

- There are a number of services which are proposed to be constructed to support the mining activities, including an air shaft compound, powerlines, switch yards, water pipelines and ground water bore compounds. Management plans will be developed by the colliery for these proposed services so that they can be maintained in safe and serviceable conditions throughout the mining period.

- The archaeological sites within the Extension Area comprise two rock shelters with deposits and one rock shelter with art and grinding groove. There are also seven additional rock shelters and one stone arrangement which are located outside the Extension Area but are within 600 metres of the proposed longwalls.

  One rock shelter is located directly above the proposed Longwall 1007 and another rock shelter is located directly above the proposed Longwall 1019. The predicted curvatures and conventional strains at these sites are similar to the movements typically observed in the Southern Coalfield, where these is extensive experience of mining beneath rock shelters. Experience from the Southern Coalfield indicates that around 10 % of rock shelters located directly above mining have been adversely impacted.

  The remaining archaeological sites are predicted to experience vertical subsidence of 20 mm or less. It is unlikely, that these sites would be adversely impacted by the proposed mining.

- The survey control marks in the vicinity of the proposed longwalls could experience small far-field horizontal movements. It will be necessary on the completion of the 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 indicate that the levels of impact on the natural and built features can be managed by the preparation and implementation of the appropriate management strategies. It should be noted, however, that more detailed assessments of some natural and built features have been undertaken by other specialist consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

CONTENTS

Tables

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

Figures

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

Drawings

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

1.1. Background

Centennial Coal Pty Limited (Centennial) operates Angus Place Colliery (Angus Place), which is located in the western coalfield of New South Wales. Centennial is seeking approval to extract the proposed Longwalls 1001 to 1019 (LW1001 to LW1019) in the Lithgow Seam, which is referred to as the Angus Place Colliery Mine Extension Project. The layout of the proposed longwalls is shown in Drawing Nos. MSEC593-01 and MSEC593-02, in Appendix E.

The location of the project application area is shown in Fig. 1.1 (after Centennial). The proposed longwalls have also been overlaid on an orthophoto of the area, which is shown in Fig. 1.2.

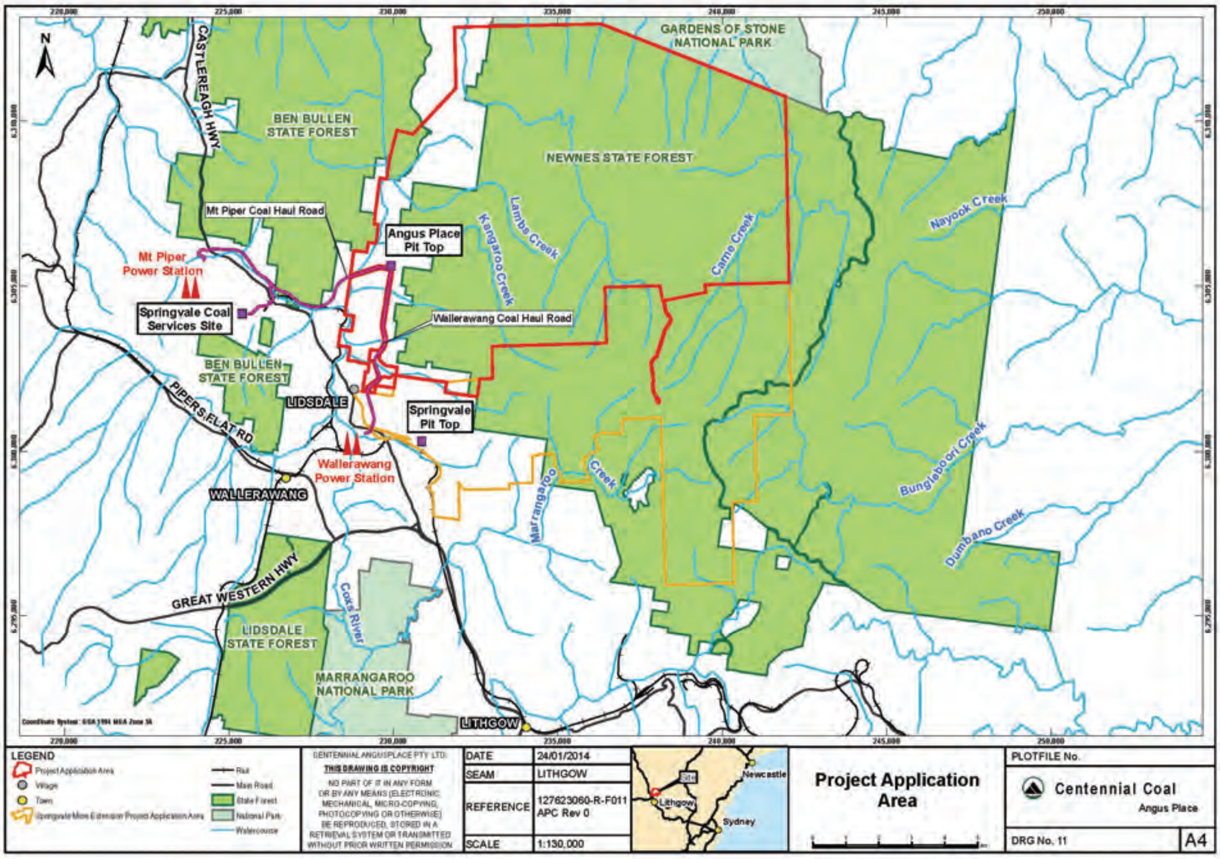


Fig. 1.1 Location Plan (after Centennial)

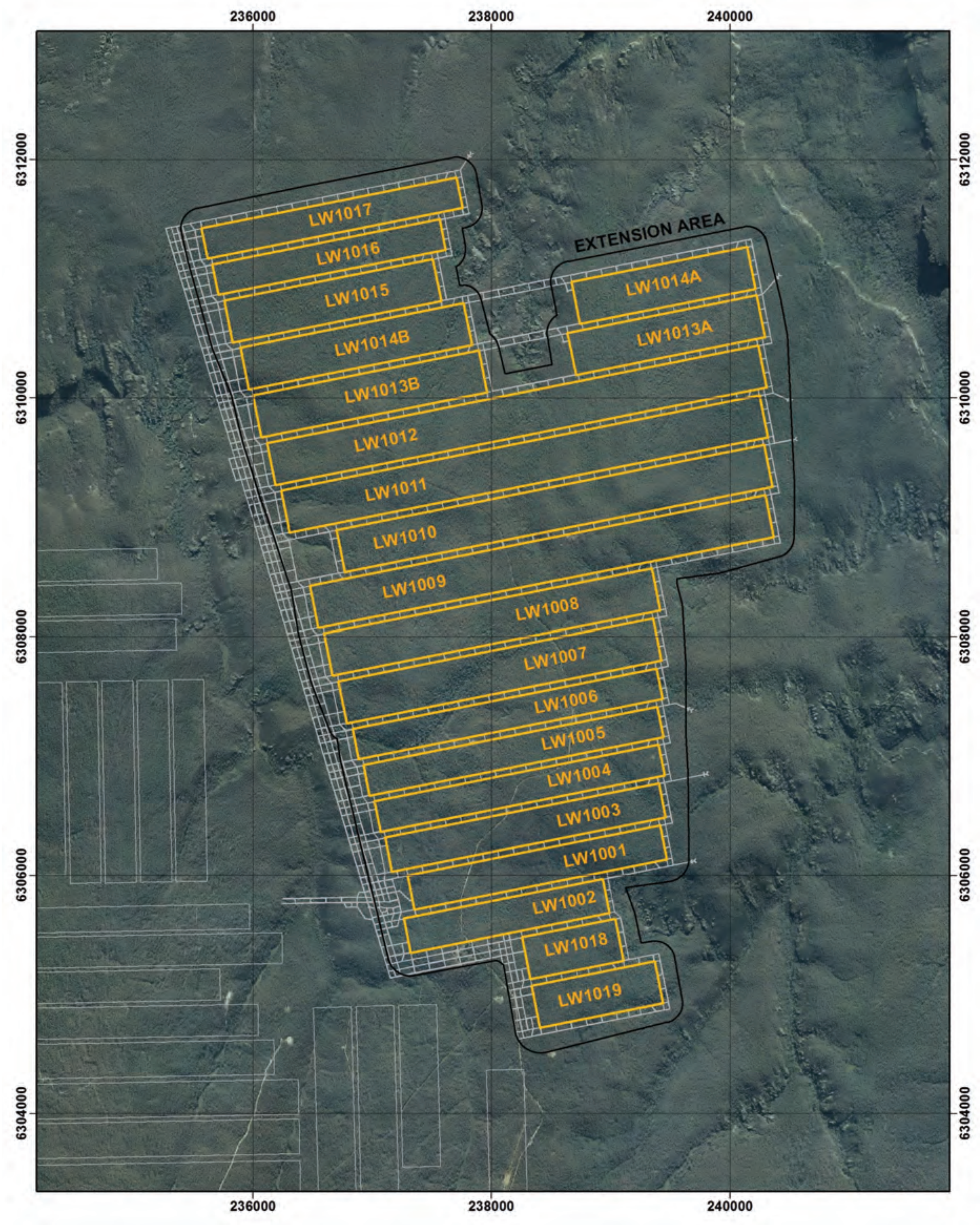


Fig. 1.2 Aerial Photograph Showing Locations of the Proposed LW1001 to LW1019

The project briefing paper provided by Centennial (2012) outlines the objectives of the project which have been reproduced below:-

> "*The overall objective of this Project is to obtain approval for the continuation of mining at the Angus Place Colliery. The objectives of the Project are as follows.*
>
> - *Design of the extension project in accordance with ecological sustainable principles;*
> - *Coal production of a total of up to 4 million tonnes per annum (Mtpa) of coal from the Lithgow coal seam;*
> - *Extraction of coal using longwall mining techniques from an area identified as Angus Place East within the Project Application Area (refer Figure 2);*

- *Construction and operation of the following facilities to support the extension Project:*
    - *A ventilation facility (APC-VS3) consisting of a single downcast (intake) shaft;*
    - *Dewatering borehole sites to deliver water into the existing Springvale-Delta Water Transfer Scheme;*
    - *Water management structures;*
    - *Shaft spoil emplacement area;*
- *Upgrade of access track from Sunnyside Ridge Road to the proposed ventilation facility (APC-VS3) and dewatering borehole sites; and*
- *Continue to provide employment of a full time workforce of 225 persons and up to 75 contractors.*"

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

- provide subsidence predictions for the proposed LW1001 to LW1019,
- review the natural and built features located in the vicinity of the proposed longwalls,
- provide subsidence predictions for each of these natural and built features, and
- undertake impact assessments, in conjunction with other specialist consultants, for each of these natural and built features.

This report provides information that will support the Environmental Impact Statement which will be issued to the Department of Planning and Infrastructure (DP&I). In some cases, this report will refer to other sources of information on specific natural and built features, and these reports should be read in conjunction with this report.

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

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

Chapter 3 includes overviews of mine subsidence parameters and the methods that have been used to predict the mine subsidence movements for the proposed longwalls.

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

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

This report also provides information to satisfy the 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 3.7 and 3.8 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 LW1001 to LW1019 are proposed to be extracted in the Lithgow Seam. A summary of the dimensions for the proposed longwalls is provided in Table 1.2.

Table 1.2 Geometry of the Proposed Longwalls

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
LW1001	2160	295	-
LW1002	1700	295	55
LW1003	2340	295	55
LW1004	2430	260	55
LW1005	2515	260	55
LW1006	2600	260	55
LW1007	2690	360	55
LW1008	2800	360	55
LW1009	3895	360	55
LW1010	3655	360	55
LW1011	4090	360	55
LW1012	4200	360	55
LW1013A	1620	360	55
LW1013B	1935	360	55
LW1014A	1500	360	55
LW1014B	1910	360	55
LW1015	1785	360	55
LW1016	1945	260	55
LW1017	2180	260	55
LW1018	800	360	55
LW1019	1050	360	55

It should be noted that the overall void widths provided in the above table include the headings (i.e. first workings). The actual widths extracted by longwall mining (i.e. second workings) are 10 metres narrower than those provided in the above table.

1.3. Surface and Seam Levels

The surface levels and the Lithgow Seam levels are illustrated along Cross-sections A1 and A2 in Fig. 1.3 and Fig. 1.4, respectively. The locations of these cross-sections are shown in Drawing Nos. MSEC593-03 to MSEC593-05.

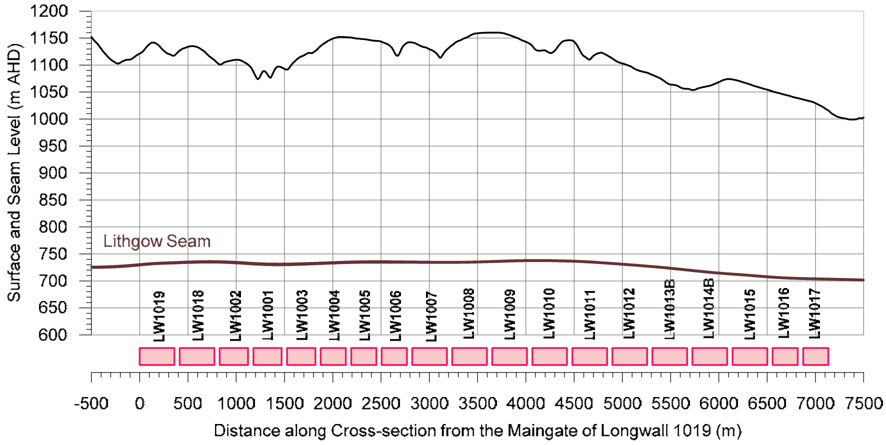


Fig. 1.3 Surface and Seam Levels along Cross-section A1

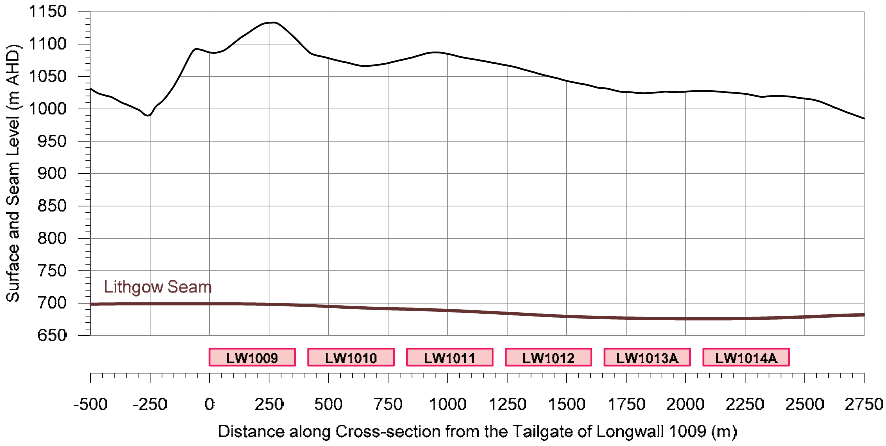


Fig. 1.4 Surface and Seam Levels along Cross-section A2

The surface level contours in the vicinity of the proposed longwalls are shown in Drawing No. MSEC593-03. The land above the western part of the mining area naturally drains towards the Wolgan River, and the land above the eastern part of the mining area naturally drains towards Carne Creek. The natural surface gradients typically vary up to 1 in 3 (i.e. 33 %, or 18 degrees), with isolated areas having gradients up to around 1 in 1.5 (i.e. 67 %, or 34 degrees).

The surface levels directly above the proposed longwalls vary from a low point of approximately 980 mAHD above the maingate of the proposed LW1014A, to a high point of approximately 1170 mAHD above the maingate of the proposed LW1009.

The seam floor contours, seam thickness contours and depth of cover contours for the Lithgow Seam are shown in Drawing Nos. MSEC593-04, MSEC593-05, and MSEC593-06, respectively. The contours are based on the latest seam information provided by Centennial.

The depth of cover to the Lithgow Seam, directly above the proposed longwalls, varies between a minimum of 270 metres above the finishing (western) end of the proposed LW1011, and a maximum of 450 metres above the middle of the proposed LW1009.

The seam floor within the mining area generally dips from the west towards the east, having an average dip around 2 %, or 1 in 50. The seam dip is relatively uniform over the lengths of the proposed longwalls. The thickness of the Lithgow Seam, within the extents of the proposed longwalls, varies between 1.8 metres and 3.2 metres. The proposed extraction heights are shown in Drawing No. MSEC593-05.

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 (Palaris, 2013a). 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.

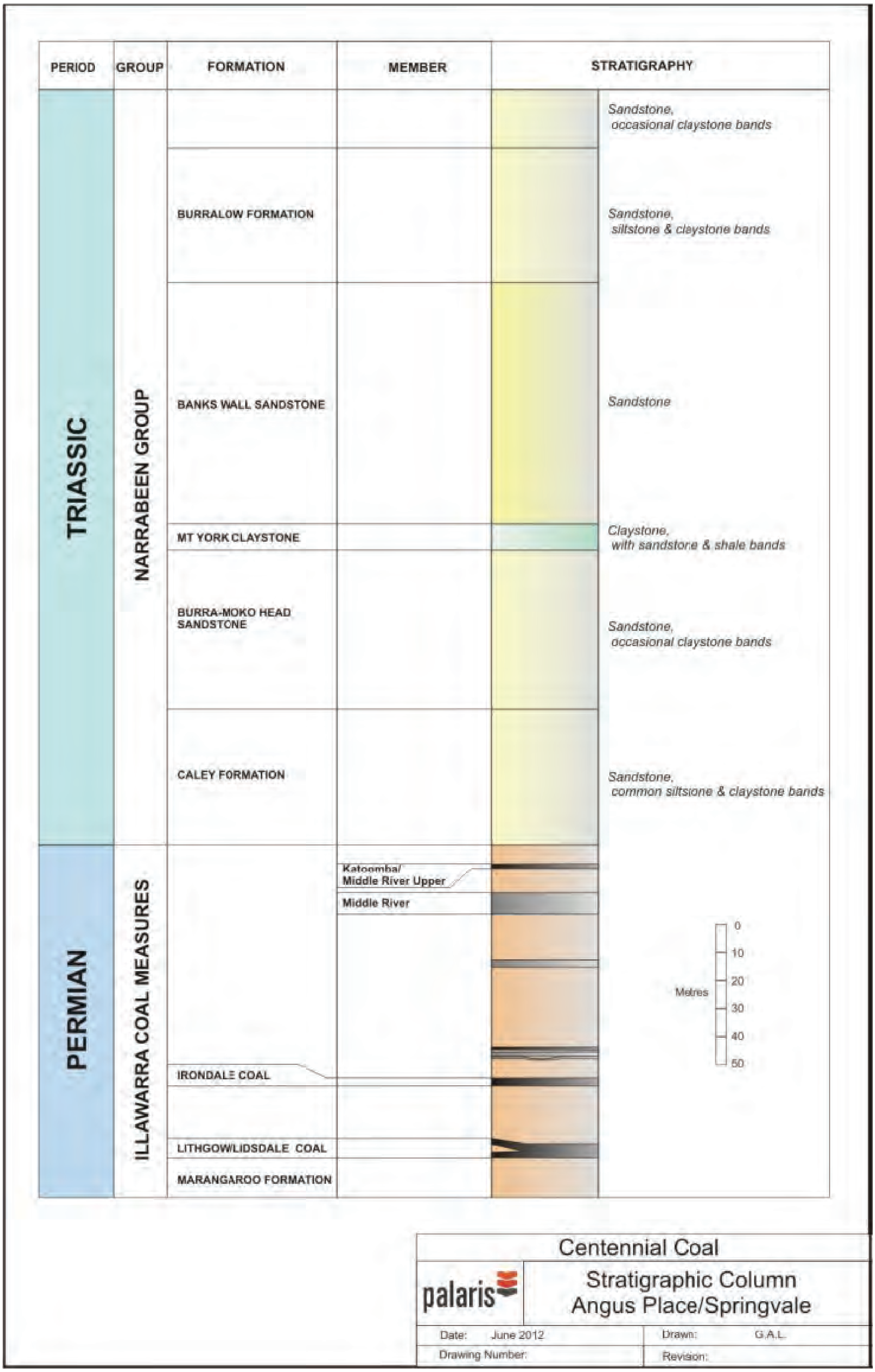


Fig. 1.5 Typical Stratigraphic Section (Palaris, 2013a)

The Lithgow/Lidsdale Seam lies within the Cullen Bullen Subgroup of the Illawarra Coal Measures, which has a combined thickness of about 7 metres. It is proposed that only the Lithgow Seam will be extracted, which has a thickness between 1.8 metres and 3.2 metres within the 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, which 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 metres and 200 metres, respectively, above the target seam. These higher strength units have been observed to reduce subsidence ground movements above previous longwall mining 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 metres and 35 metres, with an average thickness of around 22 metres within the Extension 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 indicated in Drawing No. MSEC593-07.

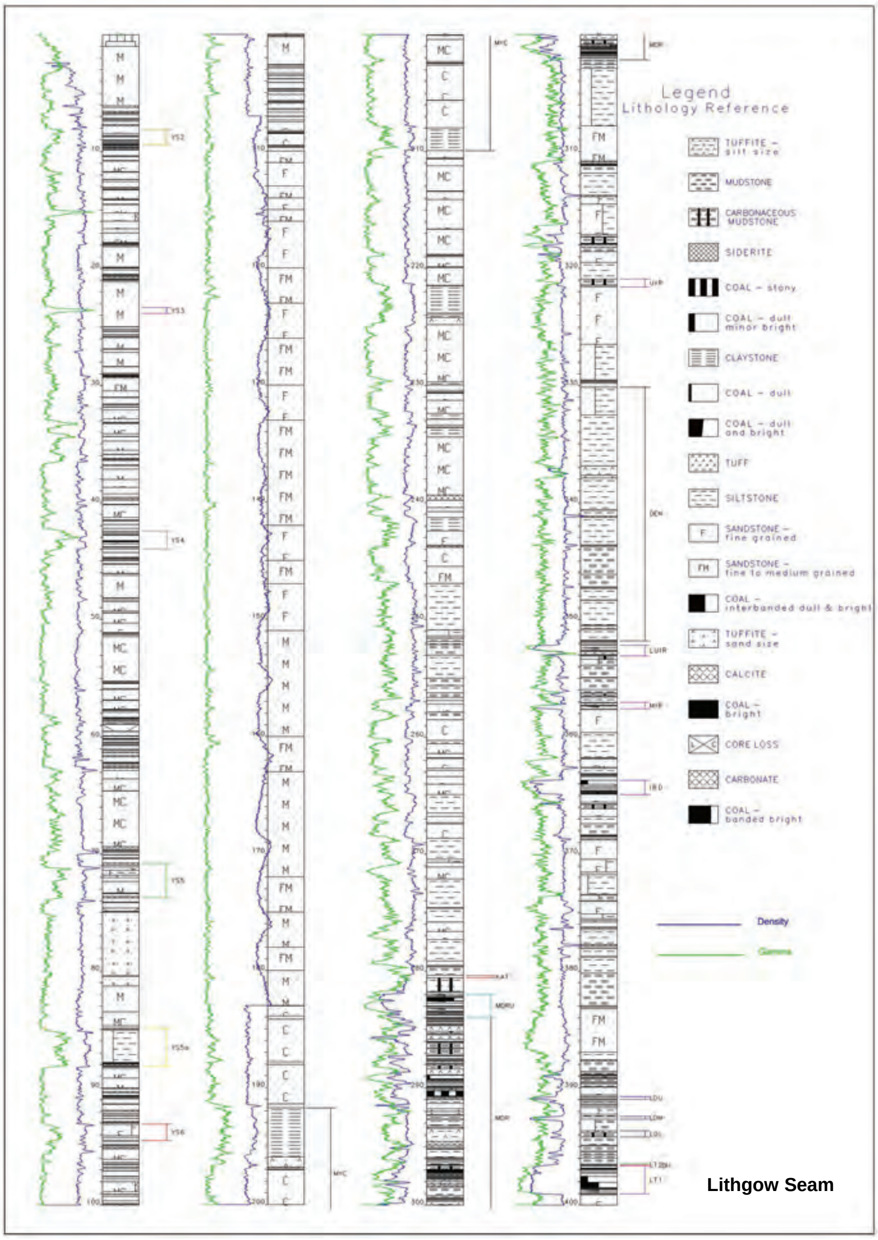


Fig. 1.6 Composite Graphic Section – Boreholes AP1102SP and AP1204PT (Palaris, 2013a)

Further details of the stratigraphy within the Extension Area are provided in the report by Palaris (2013a).

The surface lithology in the area can be seen in Fig. 1.7, which shows the proposed longwalls overlaid on the *Geological Series Sheets 8930 and 8931*, which was published by the Department of Mineral Resources (DMR, 1992), now known as DTIRIS. It can be seen from this figure, that the surface lithology above the proposed longwalls comprises the Burralow Formation of the Triassic Narrabeen Group (Tn).

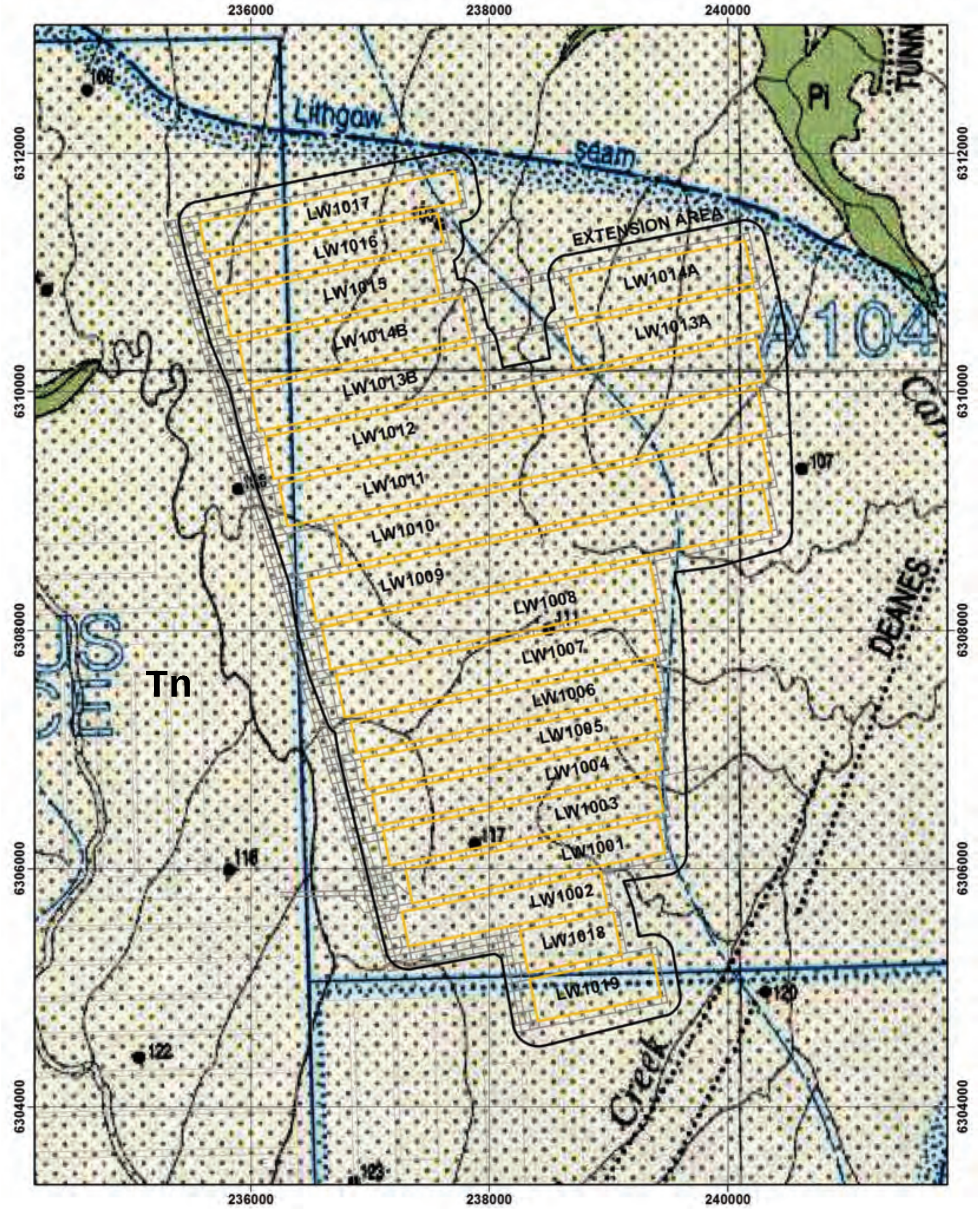


Fig. 1.7 Proposed Longwalls Overlaid on Geological Map Series Sheets 8930 and 8931

An investigation of the geological structures within the Extension Area was undertaken by Palaris (2013b) and the locations of these structures have been shown in Drawing No. MSEC593-07. The geological 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 which has been identified within the extents of the proposed longwalls. The NNE trending lineament is coincident with a tributary to Carne Creek above the proposed LW1011 to LW1014B. The *Wolgan Lineament* is also located to the west of the proposed longwalls which is coincident with the Wolgan River. As described in the report by Palaris (2013b) that "*The basement has a dominant north-west structure direction and few features aligned with an extension of the NNE trending Wolgan lineaments*".

There are three short *Type 2* structures which have been identified within the extents of the proposed longwalls, which are:-

- NW trending lineament which is coincident with a tributary to the Wolgan River and Tri Star Swamp above the western end of the proposed LW1006,
- NE trending lineament which is coincident with a tributary to Carne Creek above the eastern end of the proposed LW1008, and
- NNE trending lineament which is coincident with a tributary to Carne Creek, referred to as Drainage Line 3 in this report, above the middle of the proposed LW1010 to LW1012.

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 movements resulting from the extraction of the proposed longwalls, as has been observed above the previously extracted longwalls 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 any significant affect on the mine subsidence surface movements resulting from the extraction of the proposed longwalls.

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

2.1. Definition of the Extension Area

The Extension Area is defined as the surface area that is likely to be affected by the extraction of the proposed LW1001 to LW1019 in the Lithgow Seam. The extent of the Extension Area has been calculated by combining the areas bounded by the following limits:-

- The 26.5 degree angle of draw line from the extents of the proposed LW1001 to LW1019, and
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour resulting from the extraction of the proposed longwalls.

The depth of cover contours are shown in Drawing No. MSEC593-06. It can be seen from this drawing that the depth of cover to the Lithgow Seam, directly above the proposed longwalls, varies between a minimum of 270 metres above the finishing (western) end of LW1011, and a maximum of 450 metres above the middle of LW1009. The 26.5 degree angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 135 metres and 225 metres around the limits of the proposed extraction areas.

The predicted limit of vertical subsidence, taken as the predicted 20 mm subsidence contour due to the extraction of LW1001 to LW1009, has been determined using the calibrated Incremental Profile Method, which is described in Chapter 3. The predicted total subsidence contours due to the extraction of the proposed longwalls are shown in Drawing No. MSEC593-11, which includes the predicted 20 mm subsidence contour.

A line has therefore been drawn defining the Extension Area, based upon the 26.5 degree angle of draw line and the predicted 20 mm subsidence contour, whichever is furthest from the proposed longwalls, and is shown in Drawing Nos. MSEC593-01 and MSEC593-02.

There are areas that lie outside the Extension Area that may experience either far-field movements, or valley related movements. The surface features which could be sensitive to such movements have been identified and have been included in the assessments provided in this report. In this case, features which could be sensitive to far-field or valley related movements, within but not limited to 600 metres from the proposed mining, have been assessed.

2.2. Overview of the Natural and Built Features within the Extension Area

A number of the major natural and built features within the Extension 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 Extension Area have been overlaid on an extract of this CMA map in Fig. 2.1.

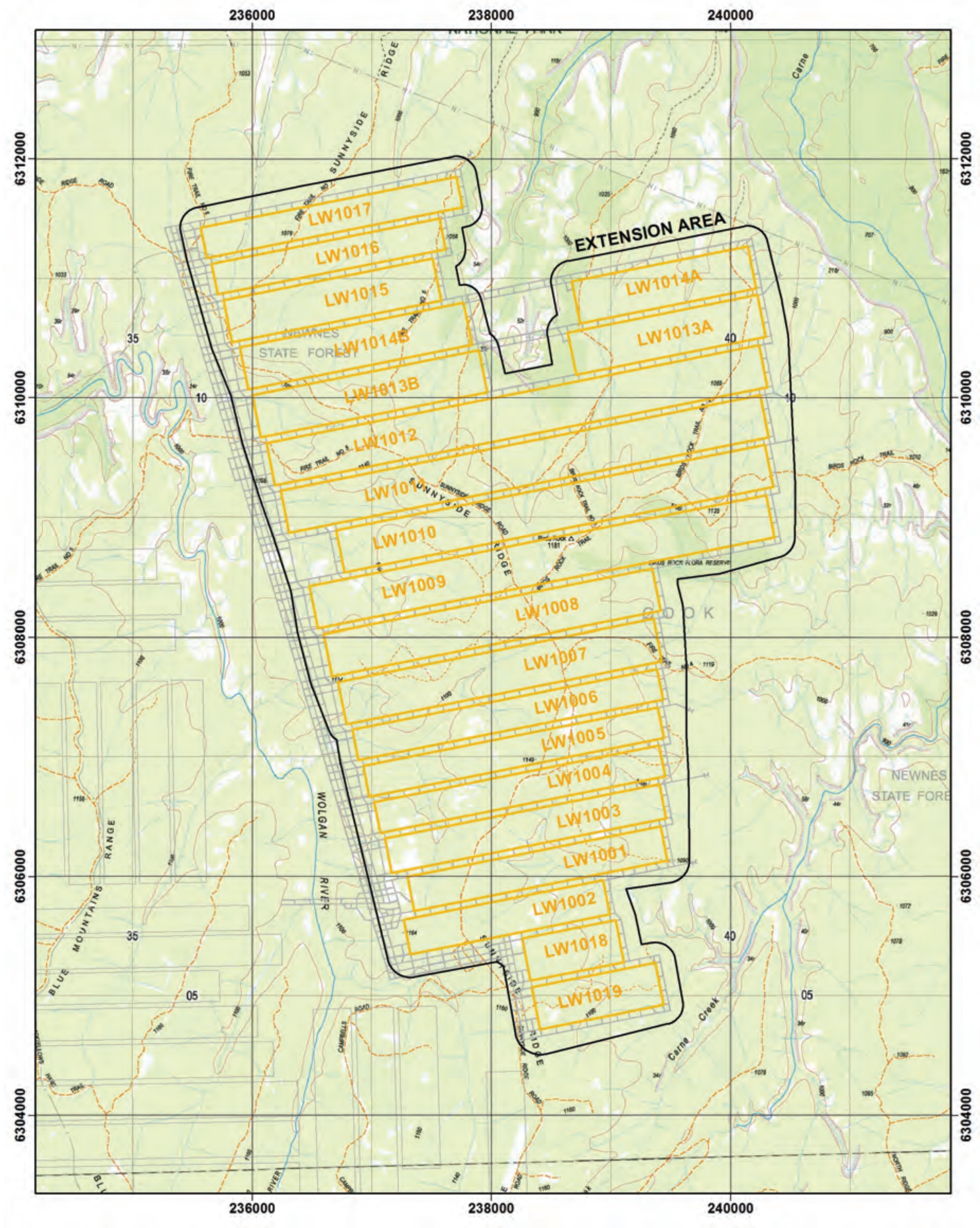


Fig. 2.1 Proposed LW1001 to LW1019 Overlaid on CMA Map Series Sheets 8930 and 8931

A summary of the natural and built features within the Extension Area is provided in Table 2.1. The locations of these features are shown in Drawing Nos. MSEC593-08 to MSEC593-10. 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 Extension Area

Item	Within Extension 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	✓	5.9
Escarpments	×	
Land Prone to Flooding or Inundation	×	5.11
Swamps or Wetlands	✓	5.12
Water Related Ecosystems	✓	5.13
Threatened or Protected Species	✓	5.14
Lands Defined as Critical Habitat	×	
National Parks	×	5.15
State Forests	✓	5.16
State Recreation or Conservation Areas	×	
Natural Vegetation	✓	5.17
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	✓	5.18
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 Extension 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

This chapter provides a brief overview of conventional and non-conventional mine subsidence movements and the methods that have been used to predict these movements resulting from the extraction of the proposed longwalls.

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

3.2. Overview of Conventional Subsidence Parameters

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

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small, such as beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.
- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres* (km^{-1}), but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.
- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile Strains** occur where the 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 **total** subsidence, tilts, curvatures and strains are the accumulated parameters after the completion of each longwall. 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 or built features, except where they are experienced by large structures which are very sensitive to differential horizontal movements.

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

3.4. Overview of Non-Conventional Subsidence Movements

Conventional subsidence profiles are typically smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata spanning the extracted void and the compression of the pillars and the strata above the pillars. 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. Irregular subsidence movements are generally associated with:-

- shallow depths of cover,
- sudden or abrupt changes in geological conditions,
- steep topography, and
- valley related mechanisms.

Non-conventional movements due to abovementioned conditions are discussed in the following sections.

3.4.1. Non-Conventional Subsidence Movements due to Shallow Depth of Cover

Irregular ground movements are commonly observed in shallow mining situations, where the collapsed zone, which develops above the extracted longwalls, extends near to the surface. This type of irregularity is generally only seen where panel widths are supercritical and where the depths of cover are less than 100 metres.

The depths of cover directly above LW1001 to LW1019 varies between 270 metres and 450 metres and the proposed longwalls are not supercritical in width. It is not expected, therefore, that irregular movements due to shallow depths of cover would occur in this case.

3.4.2. Non-conventional Subsidence Movements due to Changes in Geological Conditions

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

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

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

In this report, non-conventional ground movements 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 4.3 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.

3.4.3. Non-conventional Subsidence Movements due to Steep Topography

Non-conventional movements can also result from downslope movements where longwalls are extracted beneath steep slopes. In these cases, elevated tensile strains develop near the tops of the steep slopes and elevated compressive strains develop near the bases of the steep slopes. The potential impacts resulting from downslope 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 Extension Area are provided in Section 5.9.

3.4.4. Valley Related Movements

The watercourses within the Extension Area may be subjected to valley related movements, which are commonly observed along stream alignments 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.

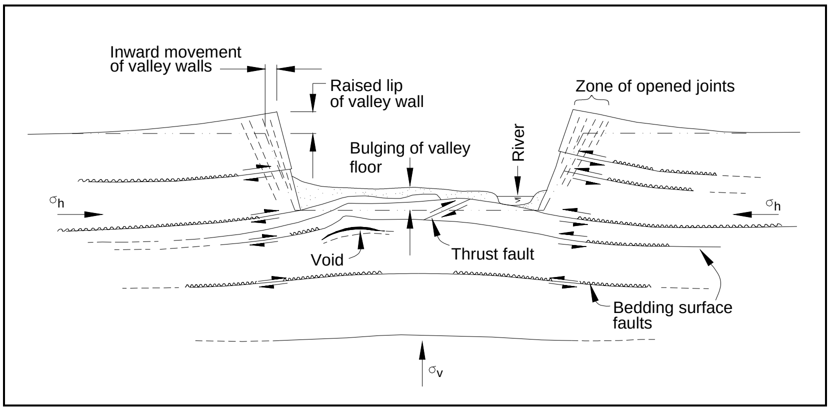


Fig. 3.1 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

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 down slope 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 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 resulting from the extraction of the proposed longwalls were made using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002). Discussions on the reliability of the 2002 ACARP method of prediction for valley related movements in the Western Coalfield are provided in Section 3.8.

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

3.5. The Incremental Profile Method

The predicted conventional subsidence parameters for the longwalls were determined using the Incremental Profile Method, which was developed by MSEC, formally known as Waddington Kay and Associates. The method is an empirical model based on a large database of observed monitoring data from previous mining within the Southern, Newcastle, Hunter and Western Coalfields of New South Wales.

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

Based on the extensive empirical data, MSEC has developed standard subsidence prediction curves for each of the Coalfields in New South Wales and Queensland. The predictions curves can then be further refined, for the local geology and local conditions, based on the available monitoring data from the area. Discussions on the calibration of the Incremental Profile Method (IPM) for the proposed longwalls associated with the Angus Place Colliery Mine Extension Project are provided in Section 3.6.

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

For longwalls in the 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 increased, using the IPM subsidence prediction curves for multiple panels, based on the longwall series, panel width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H). In this way, the influence of the panel width (W), depth of cover (H), as well as panel width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H) are each taken into account.

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

Finally, the total subsidence profiles resulting from the series of longwalls are derived by adding the predicted incremental profiles from each of the longwalls. Comparisons of the predicted total subsidence profiles, obtained using the Incremental Profile Method, with observed profiles indicates that the method provides reasonable, if slightly conservative, predictions where the mining geometry and overburden geology are within the range of the empirical database. The method can also be further tailored to local conditions where observed monitoring data is available close to the mining area.

3.6. Calibration of the Incremental Profile Method

The Incremental Profile Method has been calibrated to local conditions using ground monitoring data from Angus Place and Springvale, as well as from other nearby collieries in the Western Coalfield. This has been achieved by comparing the observed mine subsidence movements along monitoring lines with those back-predicted using the standard Incremental Profile Method for the Western Coalfield. The standard model was then calibrated (i.e. refined), so that the back-predictions more closely match those previously observed.

The monitoring above the previously extracted longwalls at Angus Place and Springvale Collieries indicates 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 general calibration of the Incremental Profile Method (i.e. outside the locations of the surface lineaments) and specific calibration in the locations of the surface lineaments.

3.6.1. Calibration of the Incremental Profile Method outside the Surface Lineaments

Summaries of the available monitoring lines from Angus Place and Springvale which were used in the calibration of the subsidence model are provided in Table 3.1 and Table 3.2, respectively.

Table 3.1 Monitoring Lines from Angus Place 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	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)	Panel Width-to-Depth Ratios (W/H)	Seam Thickness (m)
B-Line	LW404 to LW414	265 / 315	40 / 45	330 ~ 420	0.70 ~ 0.85	3.2 ~ 3.4
M-Line	LW411 to LW413	315	45	380 ~ 400	0.80	2.6 ~ 3.6
EWS-Line	LW411	315	45	320 ~ 360	0.90	3.2 ~ 3.3

It can be seen from the above tables, that the previously extracted longwalls at Angus Place and Springvale had overall void widths between 210 and 315 metres, chain pillar widths between 35 metres and 45 metres, depths of cover between 260 metres and 420 metres and seam thicknesses between 2.6 metres and 3.6 metres. The longwall void width-to-depth ratios varied between 0.70 and 0.90, but were typically within the range of 0.75 to 0.85.

The proposed LW1001 to LW1006 have overall void widths of 260 metres or 295 metres and have chain pillar widths of 55 metres. The depths of cover directly above these proposed longwalls varies between a minimum of 280 metres and a maximum of 430 metres, but are typically within the range of 330 metres and 420 metres. The width-to-depth ratios for these proposed longwalls are typically within the range of 0.60 to 0.85 and, therefore, are slightly less than those for the previously extracted longwalls at Angus Place and Springvale Collieries.

The proposed LW1007 to LW1019 have void widths of 360 metres and chain pillar widths of 55 metres. The depths of cover above these proposed longwalls varies between a minimum of 380 metres and a maximum of 450 metres, but are typically in the range of 360 metres to 420 metres. The width-to-depth ratio for these proposed longwalls are typically within the range of 0.85 to 1.0 and, therefore, are similar to or slightly greater than those for the previously extracted longwalls at the collieries.

It has been considered, therefore, that the monitoring data over the previously extracted longwalls at Angus Place and Springvale Collieries are appropriate for the calibration of the subsidence prediction model for the proposed LW1001 to LW1019.

Initially, the magnitudes and shapes of the observed incremental subsidence profiles along each monitoring line were compared with the back-predicted subsidence profiles obtained using the standard Incremental Profile Method, which is based on the typical Western Coalfield subsidence profiles.

The back-predictions, made using the standard Incremental Profile Method, used the longwall void widths and solid chain pillar widths, and used the local depths of cover and extracted seam thicknesses at the locations of the monitoring lines. The standard Incremental Profile Method was not modified for the presence of any thick massive strata units, which can reduce the sag subsidence directly above the extracted longwalls.

It was found from these initial comparisons, that the values of maximum observed incremental subsidence for the previously extracted longwalls along each monitoring line were similar to the values of maximum back-predicted incremental subsidence obtained using the standard Incremental Profile Method.

The magnitudes of subsidence observed above the chain pillars, however, were slightly greater than those predicted using the standard model, indicating that the actual pillar compression was greater than predicted. The standard model was then calibrated, using the available monitoring data, so that the shapes of the back-predicted incremental subsidence profiles along each monitoring line more closely match those observed.

The comparisons of the observed subsidence, tilt and curvature for monitoring lines at Angus Place and Springvale with those back-predicted using the calibrated Incremental Profile Method illustrated in Figs. C.01 to C.08 in Appendix C. Following provides discussions on these comparisons.

In all cases, the maximum observed subsidence directly above the extracted longwalls were less than the maximum predicted. The observed subsidence above the chain pillars, however, slightly exceeded those predicted in some cases. The exceedances were typically less than 15 %, which is generally accepted for subsidence prediction methods.

The observed subsidence also slightly exceeded those predicted in some locations outside the extents of the extracted longwalls (i.e. above solid coal), however, these were generally not accompanied by any significant tilts, curvatures or strains. Localised movements were observed in valleys outside the extracted longwalls, and these valley related movements have been addressed separately, as described in Section 3.8.

The maximum observed tilts were similar to the maximum predicted tilts. In some locations, the observed tilts exceeded those predicted, including in the bases of valleys due the localised upsidence movements and, in some cases, in the locations of near surface geological features.

The profiles of observed subsidence and tilt reasonably matched the profiles predicted. In some locations, there are small lateral shifts between the observed and predicted profiles, which could be the result of surface dip, seam dip, or variations in the overburden geology.

The observed curvatures were very irregular, which can be partly due to survey tolerance and, in some cases, due to disturbed survey marks. It is then noted, that the observed curvatures represent the localised differential subsidence between adjacent survey marks, whereas the predicted curvatures represent the more global curvature of the ground. The observed zones of net hogging curvature and net sagging curvature reasonably match those predicted.

Based on these comparisons, it would appear that the calibrated Incremental Profile Method provides adequate predictions of subsidence, tilt and curvature for the monitoring lines above the previously extracted longwalls at Angus Place and Springvale Collieries. It is expected, therefore, that the calibrated Incremental Profile Method should also provide reasonable predictions for the proposed longwalls.

3.6.2. Calibration of the Incremental Profile Method at the Surface Lineaments

The observations above the previously extracted longwalls at Angus Place and Springvale Collieries indicate that locally increased subsidence can occur in the locations of the Type 1 and Type 2 geological structure zones (i.e. surface lineaments). This is demonstrated by 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 14th 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 31st 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. 3.2, which were 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 did not include those resulting from the extraction of LW920 and part of LW970.

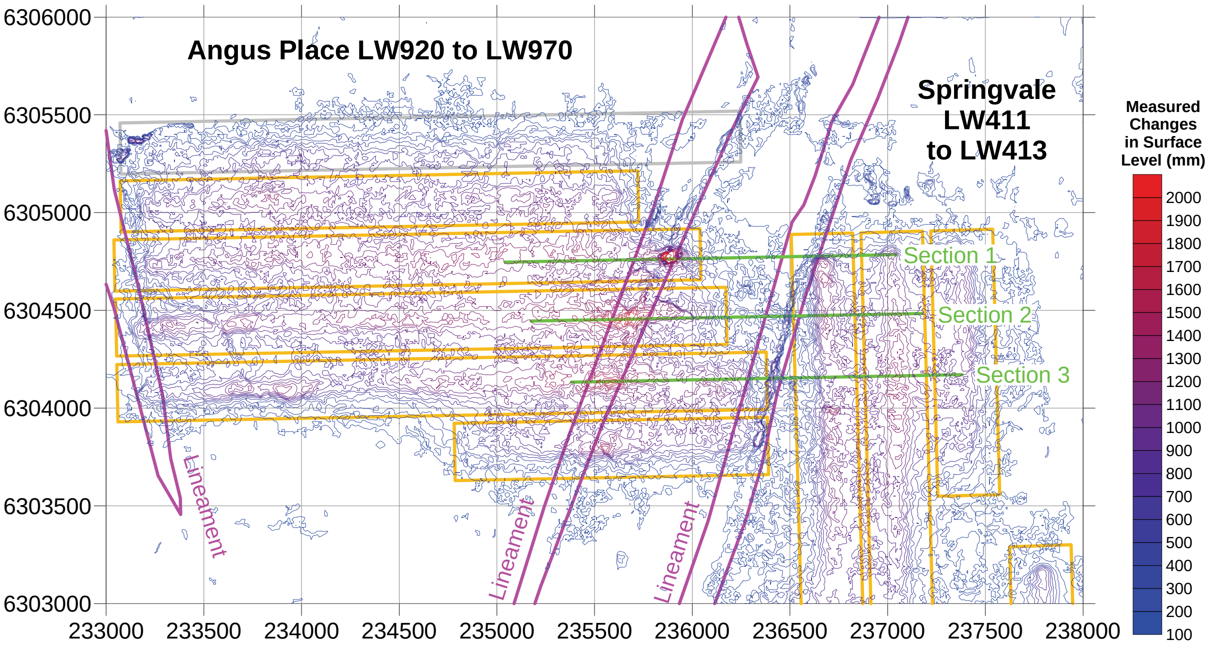


Fig. 3.2 Observed Changes in Surface Level based on LiDAR Surveys 2005 and 2012

It should be noted that the contours of the observed 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 for this is that the surface can move horizontally downslope, or towards the centre of the goaf, as the ground subsides and, therefore, the level changes at 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 observed 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. 3.2, that locally increased vertical movement was observed along the surface lineaments at the eastern ends of the longwalls at Angus Place Colliery. Three longitudinal sections have been taken through the longwalls, as indicated in this figure. The profiles of the measured changes in surface level along Sections 1, 2 and 3 are shown in Fig. 3.3, Fig. 3.4 and Fig. 3.5, respectively. The profiles of predicted subsidence obtained from the calibrated Incremental Profile Method are also shown in these figures for comparison.

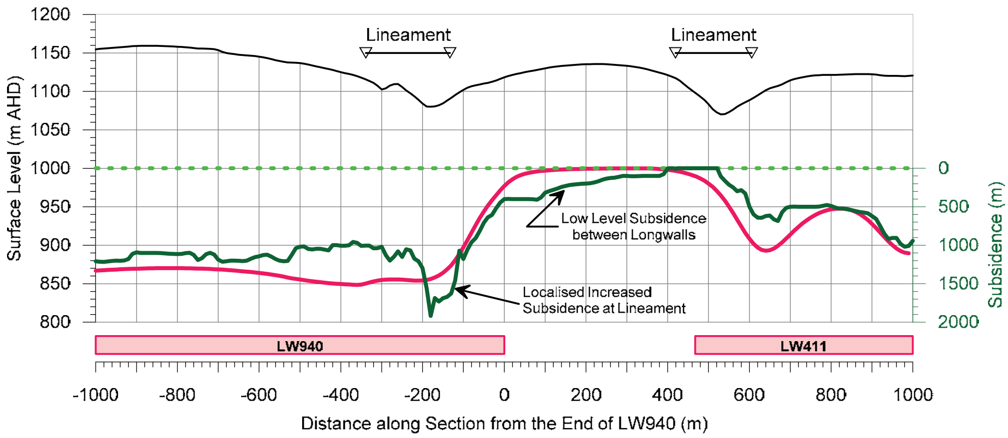


Fig. 3.3 Observed Changes in Surface Level and Predicted Subsidence along Section 1

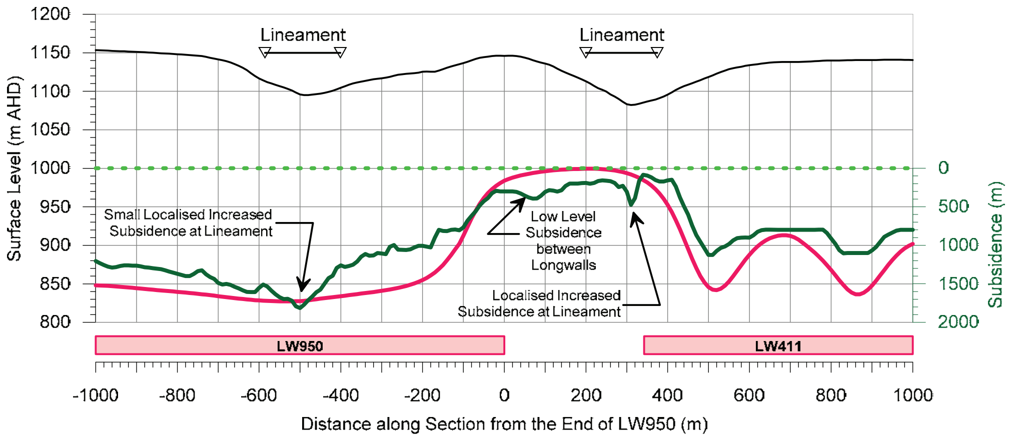


Fig. 3.4 Observed Changes in Surface Level and Predicted Subsidence along Section 2

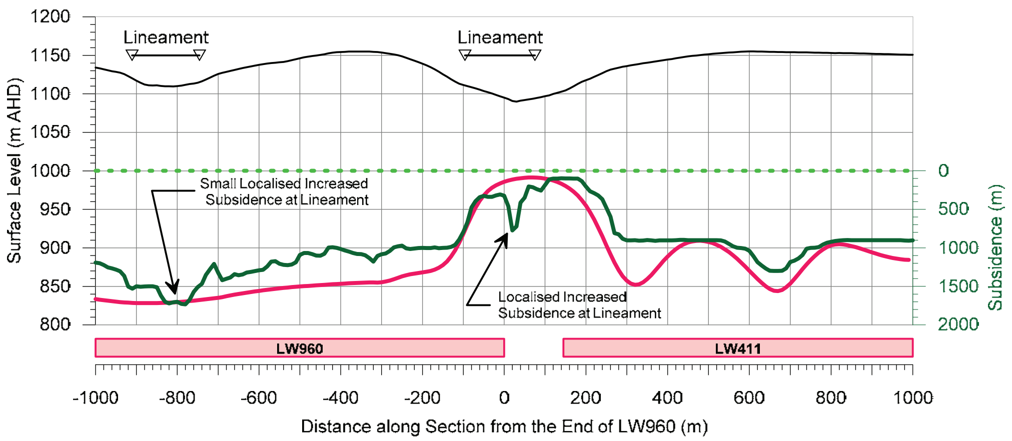


Fig. 3.5 Observed Changes in Surface Level and Predicted Subsidence along Section 3

It can be seen from the above figures, that locally increased vertical movement was 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 observed vertical movement above the eastern end of LW940 of 1900 mm exceeded the maximum predicted subsidence of 1500 mm by around +27 %. The observed maximum vertical movements above the eastern ends of LW950 and LW960 exceeded the predicted maximum subsidence obtained using the standard prediction model by around 5 % to 10 %.

Locally increased vertical movement was also observed at the lineament between the longwalls at Angus Place Colliery and LW411 at Springvale Colliery. The maximum observed vertical movement at the lineament east of LW950 and east of LW960 were 500 mm and 800 mm, respectively, which exceeded the predictions 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 which 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 Colliery, and along the B-Line and EWS-Line at Springvale Colliery, which are illustrated in Fig. 3.12 to Fig. 3.16. As described in Section 3.8, the observed closures movements along these monitoring lines were less than those predicted using the 2002 ACARP method (Waddington and Kay, 2002). That is, the observed closures did not exceed those predicted using the 2002 ACARP method as a result of the presence of the lineaments within these valleys.

Type 1 and Type 2 geological structure zones have been identified within the Extension Area, which are shown in Drawing No. MSEC593-07. It is expected, that locally increased subsidence and compressive strains will be observed in these locations. For this reason, the subsidence predictions have been increased by 25 % in the locations of these surface lineaments directly above the proposed longwalls. As the observed 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 LW1019 will be similar to those observed above the previously extracted longwalls at Angus Place and Springvale Collieries, which were typically between 5 mm/m and 15 mm/m.

3.7. Reliability of the Predicted Conventional Subsidence Parameters

The Incremental Profile Method is based upon a large database of observed subsidence movements in the NSW Coalfields and has been found, in most cases, to give reasonable, if slightly conservative, predictions of maximum subsidence, tilt and curvature. In this case, the Incremental Profile Method was calibrated using local monitoring data from the previously extracted longwalls at Angus Place and Springvale Collieries.

Regular reviews of the subsidence predictions would also be undertaken at the appropriate stages of the project, such as End of Panel reports and at the Extraction Plan stages. The subsidence model can then be further refined, if required, based on the latest available ground monitoring data.

The predicted profiles obtained using the Incremental Profile Method also reflect the way in which each parameter varies over the mined area and indicate the movements that are likely to occur at any point on the surface. It is expected, that this method should provide reasonable predictions for the maximum subsidence, tilt and the overall curvature above the proposed longwalls.

The reliability of the predictions obtained using the Incremental Profile Method is illustrated by comparing the magnitudes of the observed movements with those predicted for the ground monitoring lines above the previously extracted longwalls at Angus Place and Springvale Collieries. The comparison between the maximum observed and maximum predicted total subsidence directly above the extracted longwalls is illustrated in Fig. 3.6.

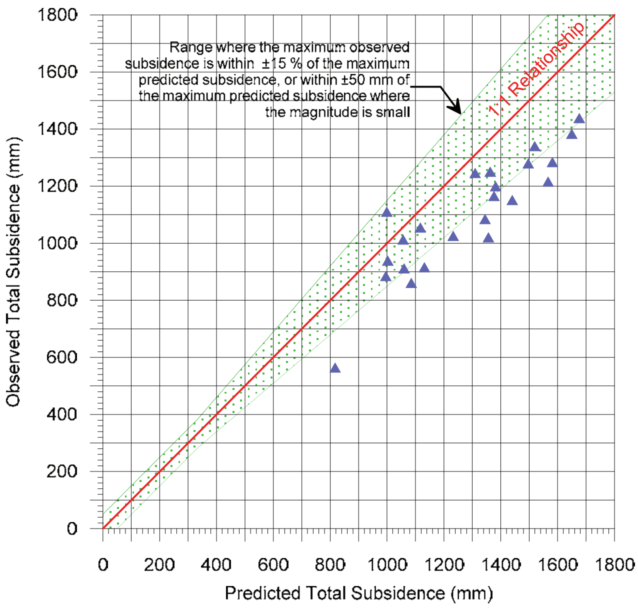


Fig. 3.6 Comparisons between Maximum Observed and Maximum Predicted Total Subsidence Directly Above the Previously Extracted Longwalls at Angus Place and Springvale Collieries

It can be seen from the above figure, that the maximum observed total subsidence were less than the maximum predicted total subsidence in all but one case, being LW20 and LW25 to LW26N Line, above LW26N. The maximum observed total subsidence in this location was within +15 % of the maximum predicted total subsidence, which is generally considered acceptable in the industry for predictions of total subsidence.

The distribution of the ratio of the maximum observed to maximum predicted total subsidence directly above the extracted longwalls is illustrated in Fig. 3.7 (LHS). A gamma distribution function has been fitted to the data which is also shown in this figure.

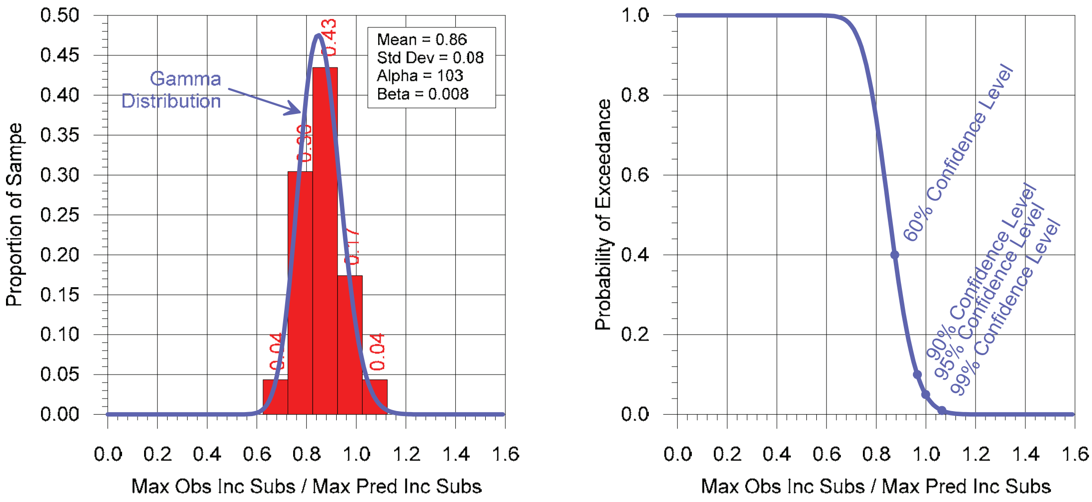


Fig. 3.7 Distribution of the Ratio of the Maximum Observed to Maximum Predicted Total Subsidence for Previously Extracted Longwalls at Angus Place and Springvale Collieries

The probabilities of exceedance have been determined, based on the gamma distribution function, which is shown in Fig. 3.7 (RHS). It can be seen from this figure that, based on the monitoring data, there is an approximate 95 % confidence level that the maximum observed total subsidence will be less than the maximum predicted total subsidence. The maximum observed total subsidence is, on average, around 86 % of the maximum predicted total subsidence.

Away from the points of maxima, there will be a higher variation between the observed and predicted subsidence. For example, the comparison between the observed and predicted total subsidence directly above the chain pillars is illustrated in Fig. 3.8.

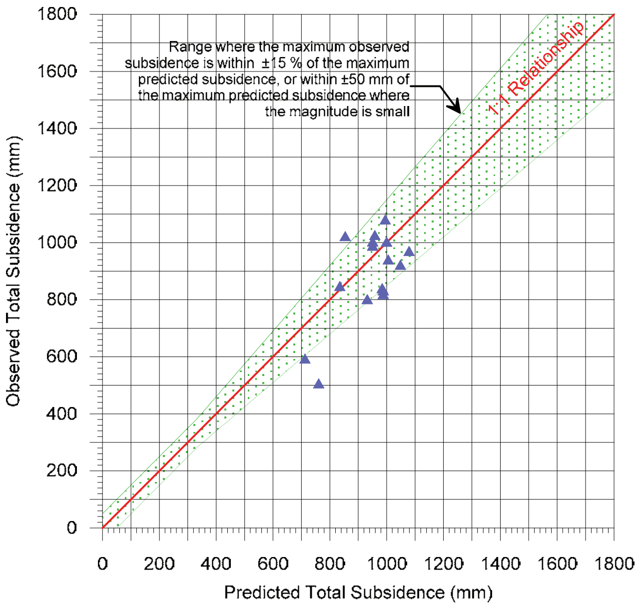


Fig. 3.8 Comparisons between Observed and Predicted Total Subsidence Directly Above the Chain Pillars for the Previously Extracted Longwalls at Angus Place and Springvale Collieries

It can be seen from the above figure, that the observed total subsidence were typically within ±15 % of the predicted total subsidence directly above the chain pillars, which is generally considered acceptable for predictions of total subsidence. The distribution of the ratio of the observed to predicted total subsidence directly above the chain pillars is illustrated in Fig. 3.9 (LHS).

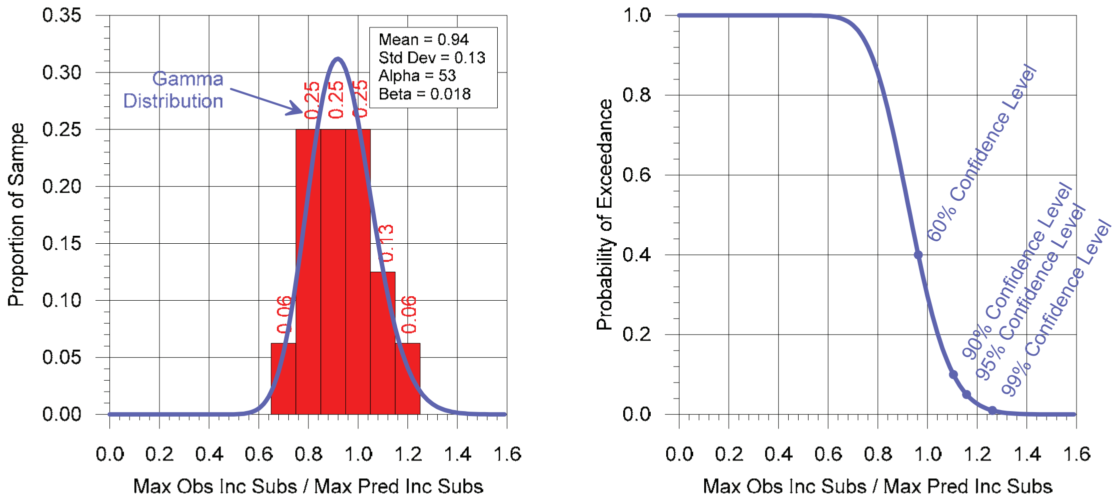


Fig. 3.9 Distribution of the Ratio of the Observed to Predicted Total Subsidence Above the Chain Pillars for Previously Extracted Longwalls at Angus Place and Springvale Collieries

The probabilities of exceedance have been determined, based on the gamma distribution function, which is shown in Fig. 3.9 (RHS). It can be seen from this figure that, based on the monitoring data, there is an approximate 95 % confidence level that the observed total subsidence will be less than +15 % of the predicted total subsidence directly above the chain pillars. The observed total subsidence is, on average, around 94 % of the predicted total subsidence above the chain pillars.

The observed 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. 3.10.

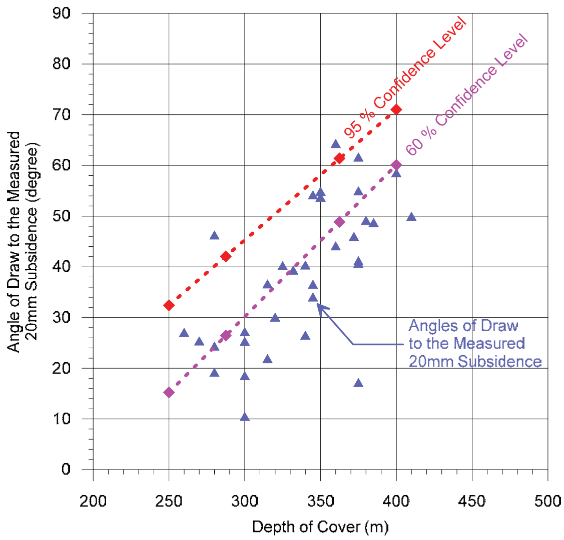


Fig. 3.10 Distribution of the Angles of Draw to the Measured 20 mm Subsidence for Previously Extracted Longwalls at Angus Place and Springvale Collieries

It can be seen from the above figure, that the angles of draw to the measured 20 mm subsidence vary between 10 degrees and 64 degrees. The average angles of draw, based on the 60 % confidence level, vary between approximately 30 degrees at 300 metres depth of cover, and approximately 60 degrees at 400 metres depth of cover. The angles of draw, based on the 95 % confidence level, vary between approximately 45 degrees at 300 metres depth of cover, and approximately 70 degrees at 400 metres depth of cover.

Whilst the angles of draw are greater than 26.5 degrees, which is the typical angle adopted for the limit of vertical subsidence, the tilts, curvatures and strains measured outside the 26.5 degree angle of draw at Angus Place and Springvale are very small, generally in the order of survey tolerance. The distribution of strains measured outside the 26.5 degree angle of draw at Angus Place and Springvale is discussed in Section 4.3.3.

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

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

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

The tilts, curvatures and strains observed at the streams are likely to be greater than the predicted conventional movements, as a result of valley related movements, which is discussed in Section 3.4.4. Specific predictions of upsidence, closure and compressive strain due to the valley related movements are provided for the streams in Sections 5.2 to 5.4. The impact assessments for the streams are based on both the conventional and valley related movements. The reliability of the predicted valley related movements for the proposed longwalls is discussed in the following section.

3.8. Reliability of the Predicted Upsidence and Closure Movements

The predicted valley related movements resulting from the proposed mining were 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*.

The development of the predictive methods for upsidence and closure are the result of recent and ongoing research and the methods do not, at this stage, have the same confidence level as conventional subsidence prediction techniques. As further case histories are studied, the method will be improved, but it can be used in the meantime, so long as suitable factors of safety are applied. This is particularly important where the predicted levels of movement are small, and the potential errors, expressed as percentages, can be higher.

Whilst the major factors that determine the levels of movement have been identified, there are some factors that are difficult to isolate. One factor that is thought to influence the upsidence and closure movements is the level of in situ horizontal stress that exists within the strata. In situ stresses are difficult to obtain and not regularly measured and the limited availability of data makes it impossible to be definitive about the influence of the in situ stress on the upsidence and closure values. The methods are, however, based predominantly upon the measured data from Tower Colliery in the Southern Coalfield, where the in situ stresses are high. The methods should, therefore, tend to over-predict the movements in areas of lower stress.

Valley related movements have been observed along the stream alignments at Angus Place and Springvale Collieries. These are illustrated in Fig. 3.11, Fig. 3.12, Fig. 3.13 and Fig. 3.14, which show the observed closure movements along the A-Line, C-Line, E-Line and F-Line, respectively, at Angus Place Colliery, and Fig. 3.15, Fig. 3.16 and Fig. 3.17 which shows the observed closure movements along the B-Line, EWS-Line and M-Line, respectively, at Springvale Colliery.

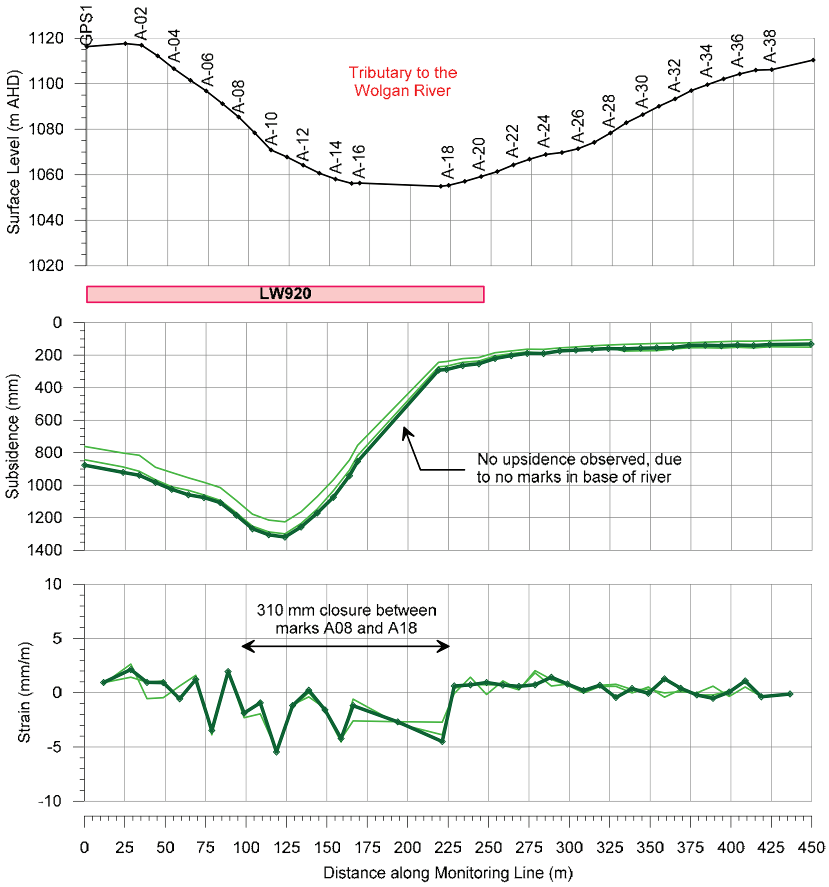


Fig. 3.11 Observed Closure along the A-Line at Angus Place Colliery

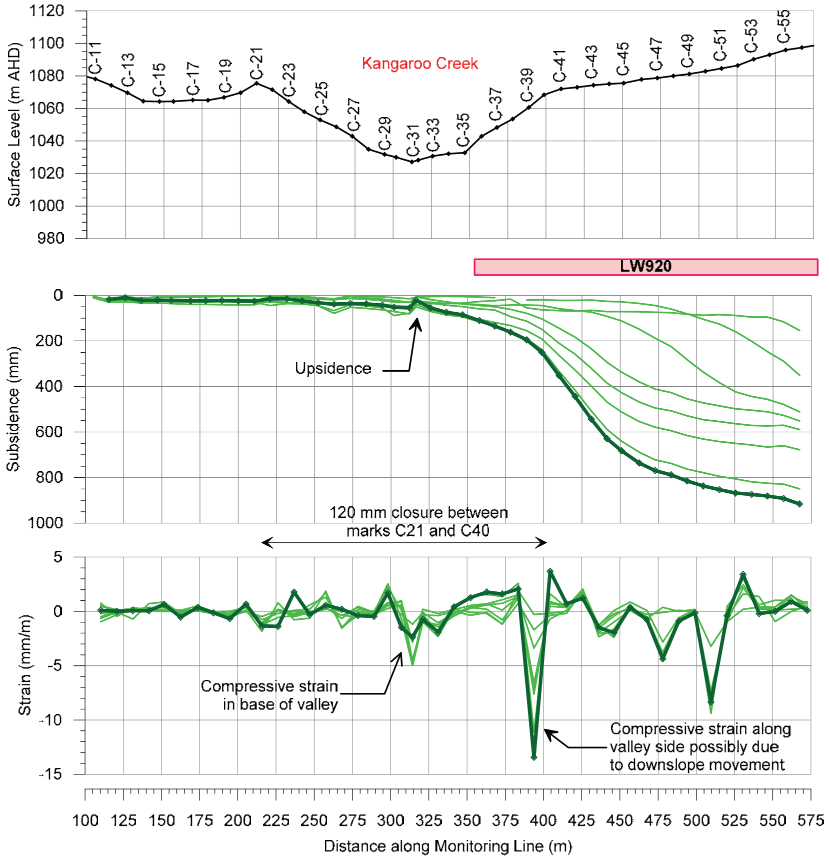


Fig. 3.12 Observed Closure along the C-Line at Angus Place Colliery

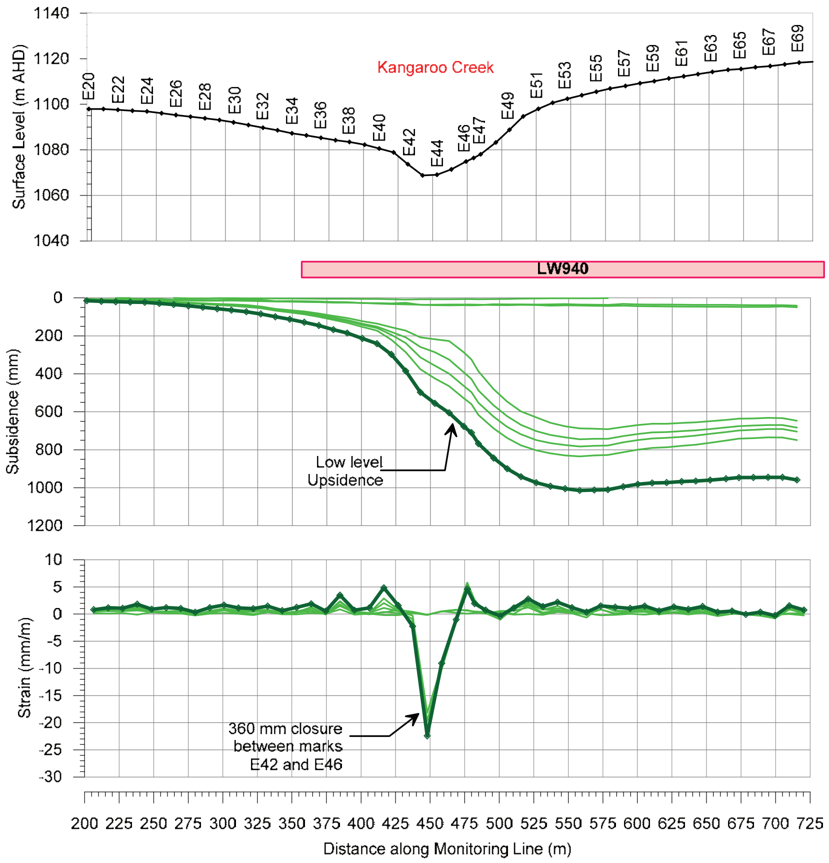


Fig. 3.13 Observed Closure along the E-Line at Angus Place Colliery

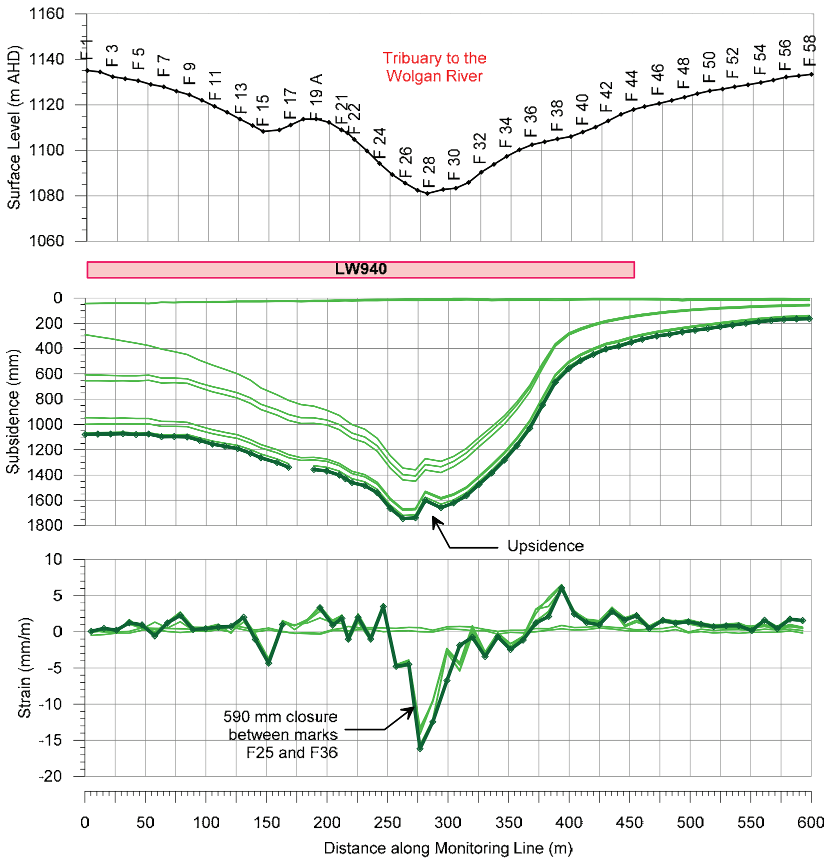


Fig. 3.14 Observed Closure along the F-Line at Angus Place Colliery

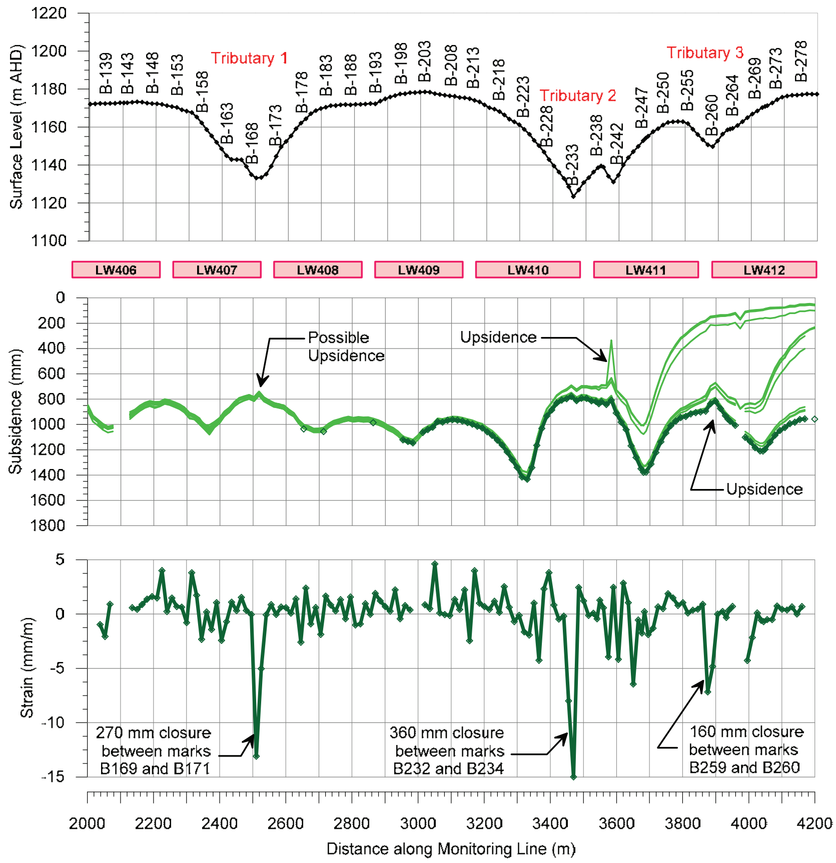


Fig. 3.15 Observed Closure along the B-Line at Springvale Colliery

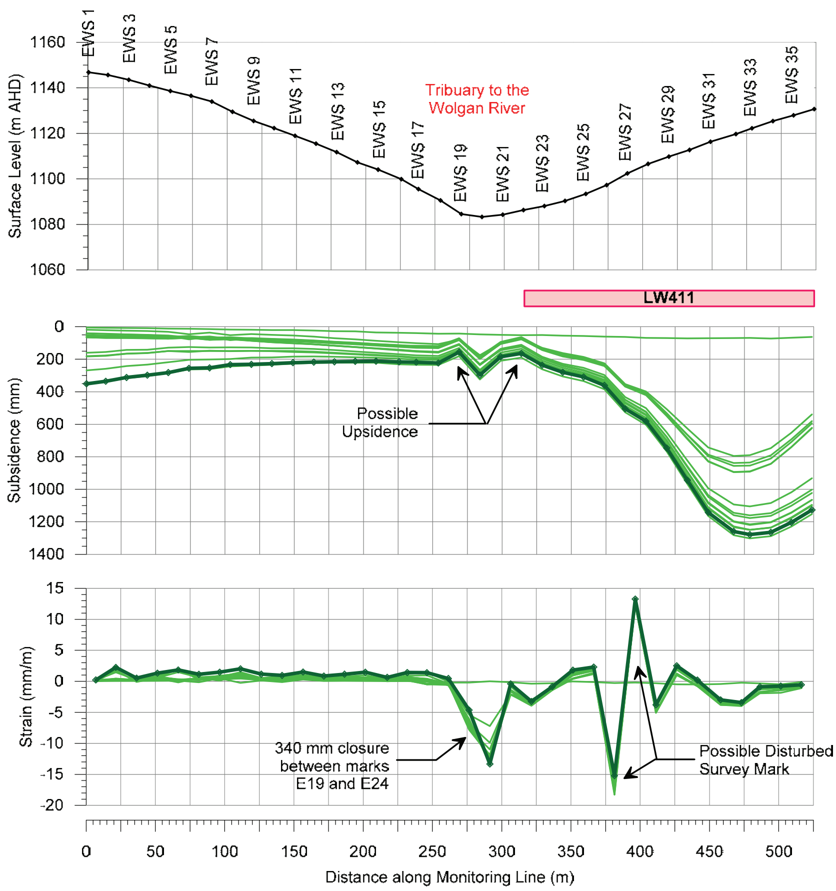


Fig. 3.16 Observed Closure along the EWS-Line at Springvale Colliery

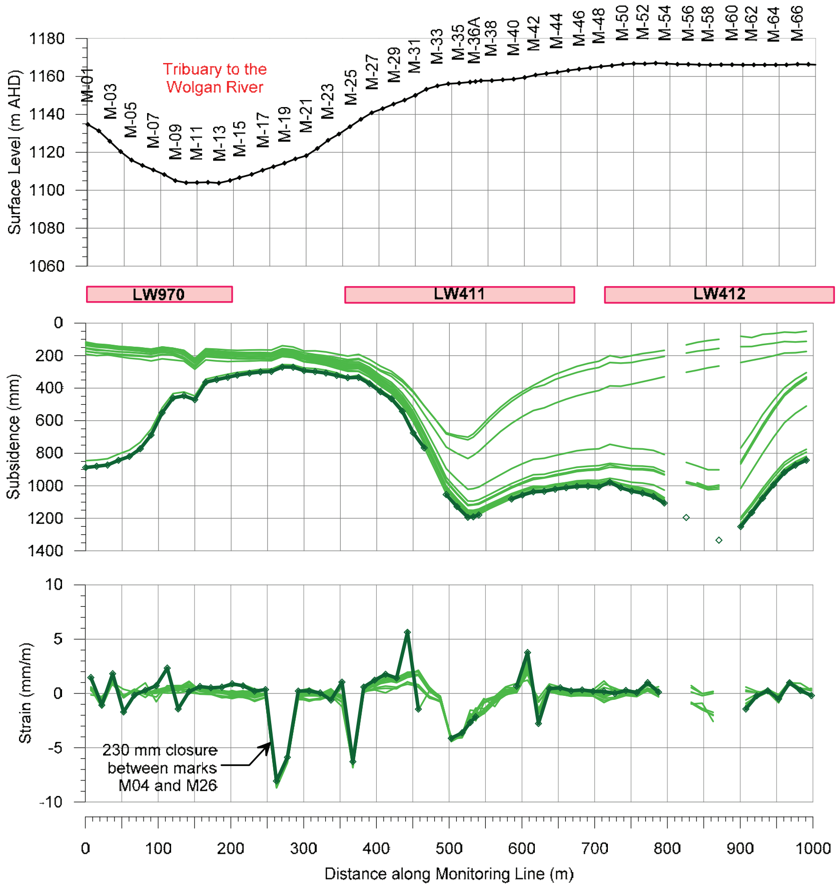


Fig. 3.17 Observed Closure along the M-Line at Springvale Colliery

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

Table 3.3 Observed and Predicted Closures at Angus Place and Springvale Collieries

Colliery	Monitoring Line	Stream Crossing	Observed Closure (mm)	Predicted Closure (mm)	Ratio of Observed 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

It can be seen from the above table that, in all cases, the observed closures were less than those predicted using the 2002 ACARP method. It can also be seen, that there is a large variation between the observed and predicted closures 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 which 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 Colliery, 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 observed movements in these locations are expected to be closer to those predicted, typically in the order of 60 % to 90 % of that 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 observed movements in these locations are expected to be much less than those predicted, typically in the order of 30 % and 60 % of that predicted 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 observed and predicted movements at Angus Place and Springvale indicate that the method provides reasonable, if 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.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed LW1001 to LW1019 in the Lithgow Seam at Angus Place Colliery. The predicted subsidence parameters and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

The predicted subsidence, tilt and curvature have been obtained using the Incremental Profile Method, which has been calibrated for 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.

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

The calibration and the reliability of the predictions of subsidence, tilt and curvature, obtained using the Incremental Profile Method, are discussed in Sections 3.6 and 3.7. The reliability of the predictions of upsidence and closure, obtained using the 2002 ACARP method, is discussed in Section 3.8.

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

The maximum predicted conventional subsidence parameters resulting from the extraction of the proposed longwalls were determined using the Incremental Profile Method, which was described in Chapter 3. A summary of the maximum predicted values of incremental conventional subsidence, tilt and curvature, due to the extraction of each of the proposed longwalls, is provided in Table 4.1.

Table 4.1 Maximum Predicted Incremental Conventional Subsidence, Tilt and Curvature Resulting from the Extraction of Each of the Proposed Longwalls

Due to Longwall	Maximum Predicted Incremental Conventional Subsidence (mm)	Maximum Predicted Incremental Conventional Tilt (mm/m)	Maximum Predicted Incremental Conventional Hogging Curvature (km^{-1})	Maximum Predicted Incremental Conventional Sagging Curvature (km^{-1})
LW1001	1000	7	0.10	0.20
LW1002	900	8	0.10	0.15
LW1003	1050	8	0.10	0.20
LW1004	850	7	0.10	0.15
LW1005	1050	10	0.15	0.25
LW1006	1050 *(1300)*	14	0.25	0.30
LW1007	1300	11	0.20	0.20
LW1008	1250 *(1250)*	10	0.15	0.20
LW1009	1250	11	0.20	0.20
LW1010	1000 *(1100)*	10	0.20	0.15
LW1011	1150 *(1150)*	13	0.25	0.25
LW1012	1050 *(1150)*	10	0.15	0.20
LW1013A	1050	8	0.10	0.15
LW1013B	1000 *(1100)*	11	0.20	0.20
LW1014A	1200	9	0.15	0.20
LW1014B	900 *(1050)*	11	0.20	0.20
LW1015	950	8	0.10	0.15
LW1016	650	6	0.10	0.15
LW1017	700	7	0.15	0.15
LW1018	1050	9	0.15	0.15
LW1019	1000	9	0.15	0.15

It is noted, that the values provided in the above table are the maximum predicted conventional parameters outside the extents of the Type 1 and 2 geological structure zones (i.e. surface lineaments). The predicted localised increased subsidence at the surface lineaments are shown in the brackets, and the non-conventional tilts and curvatures are addressed separately in this report.

The predicted total conventional subsidence contours, resulting from the extraction of the proposed LW1001 to LW1019 are shown in Drawing No. MSEC593-11. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature, after the extraction of each of the proposed longwalls, is provided in Table 4.2. The predicted tilts provided in this table are the maxima after the completion of each of the proposed longwalls. The predicted curvatures are the maxima at any time during or after the extraction of each of the proposed longwalls.

Table 4.2 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature after the Extraction of Each of the Proposed Longwalls

After Longwall	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})
LW1001	1000	7	0.10	0.20
LW1002	1300	10	0.10	0.20
LW1003	1550	10	0.15	0.25
LW1004	1600	10	0.15	0.25
LW1005	1600	10	0.15	0.25
LW1006	1600 *(1600)*	15	0.25	0.30
LW1007	1650 *(1900)*	20	0.30	0.35
LW1019	1700 *(1900)*	20	0.30	0.35

It is noted, that the values provided in the above table are the maximum predicted conventional parameters outside the extents of the Type 1 and 2 geological structure zones (i.e. surface lineaments). The predicted localised increased subsidence at the surface lineaments are shown in the brackets, and the associated non-conventional tilts and curvatures are addressed separately in this report.

The maximum predicted total conventional subsidence, after the completion of all the proposed longwalls, is 1700 mm which represents around 53 % of the extraction height of 3.2 metres. The maximum predicted localised subsidence at the surface lineaments is 1900 mm, which represents around 62 % of the extraction height of 3.05 metres in this location.

The maximum predicted total conventional tilt is 20 mm/m (i.e. 2.0 %), which represents a change in grade of 1 in 50. The maximum predicted total conventional curvatures are 0.30 km^{-1} hogging and 0.35 km^{-1} sagging, which represent minimum radii of curvature of 3.3 kilometres and 3 kilometres, respectively.

The predicted conventional subsidence parameters vary across the Extension Area as the result of, amongst other factors, variations in the longwall geometry, depths of cover and extraction heights. To illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along Prediction Lines A1 and A2, the locations of which are shown in Drawing No. MSEC593-11.

The predicted profiles of conventional subsidence, tilt and curvature along Prediction Lines A1 and A2, resulting from the extraction of the proposed longwalls, are shown in Figs. D.01 and D.02, respectively, in Appendix D. The predicted incremental profiles along the prediction lines, due to the extraction of each of the proposed longwalls, are shown as dashed black lines. The predicted total profiles along the prediction lines, after the extraction of each of the proposed longwalls, are shown as solid blue lines. The range of predicted curvatures in any direction to the prediction lines, at any time during or after the extraction of the proposed longwalls, is shown by the grey shading.

4.3. Predicted Strains

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

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

Adopting a linear relationship between curvature and strain provides a reasonable prediction for the conventional tensile and compressive strains. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and the locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones. 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 maximum predicted conventional strains resulting from the extraction of the proposed LW1001 to LW1019, based on applying a factor of 10 to the maximum predicted conventional curvatures, are 3 mm/m tensile and 3.5 mm/m compressive.

At a point, however, there can be considerable variation from the linear relationship, resulting from non-conventional movements or from the normal scatters which are observed in strain profiles. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strain for low magnitudes of curvature. 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 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 (W/H) ratios and extraction heights are provided in Table 4.3.

Table 4.3 Monitoring Lines and Mine Geometry for the Previously Extracted Longwalls at Angus Place and Springvale Collieries

Colliery	Longwalls	Monitoring Lines	Void Widths (m)	Depths of Cover (m)	Width-to-Depth Ratios (W/H)	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	360 ~ 380	0.70 ~ 0.80	3.2 ~ 3.3
Springvale	LW401 to LW409	B-Line	255 / 265	300 ~ 380	0.70 ~ 0.85	3.3 (average)
	LW410 to LW414	B-Line, EWS-Line, M-Line, P-Line, Q-Line, S-Line, T-Line and U-Line	315	320 ~ 420	0.75 ~ 1.0	2.6 ~ 3.6

It can be seen from the above table, that the width-to-depth ratios for the previously extracted longwalls at Angus Place Colliery and LW401 to LW409 at Springvale Colliery typically varied between 0.70 and 0.85. The width-to-depth ratios for the previously extracted LW410 to LW414 at Springvale Colliery typically varied between 0.75 and 1.0.

The width-to-depth ratios for the proposed LW1001 to LW1006 are typically between 0.60 and 0.85, which are similar to or less than those for the previously extracted longwalls at Angus Place and Springvale Collieries. The width-to-depth ratios for the proposed LW1007 to LW1019 are typically between 0.85 and 1.0, which are similar to those for the previously extracted LW410 to LW414 at Springvale Colliery.

The strain analysis based on the previously extracted longwalls at Angus Place and Springvale Collieries, therefore, should provide a reasonable indication of the range of potential strains resulting from the extraction of the proposed LW1001 to LW1019. The observed strains will vary across the extents of the proposed longwalls, with greater strains occurring in the bases of the streams, due to the shallower depths of cover and valley related movements, and smaller strains occurring along the plateaus, due to the higher depths of cover. The strain analysis, therefore, provides an indication of the range of strains across the mining area.

The data used in the analysis of observed strains included those resulting from both conventional and non-conventional anomalous movements, but did not include those resulting from valley related movements 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 3.8.

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).

4.3.1. 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 during the extraction of the previous longwalls at Angus Place and Springvale Collieries, 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 observed tensile and compressive strains measured for the survey bays located directly above goaf is provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

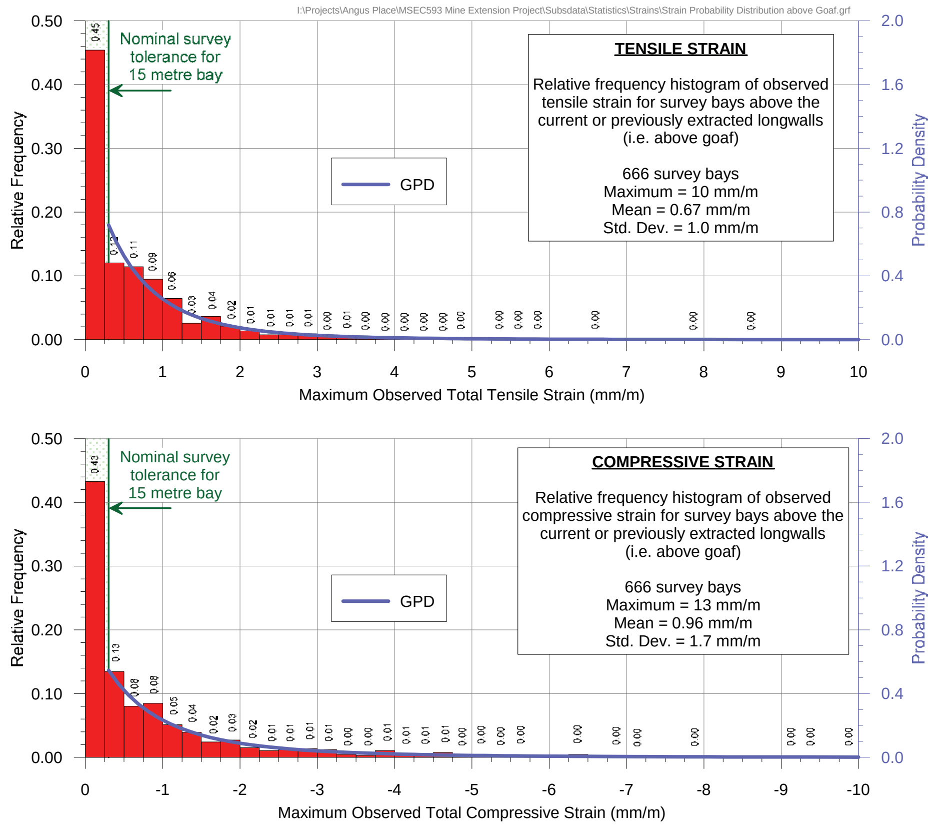


Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located Directly Above Goaf at Angus Place and Springvale Collieries

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 8 mm/m compressive.

4.3.2. 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 metres of the nearest longwall goaf edge, which has been referred to as "*above solid coal*".

The histograms of the maximum observed tensile and compressive strains measured for the survey bays located directly above solid coal is provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

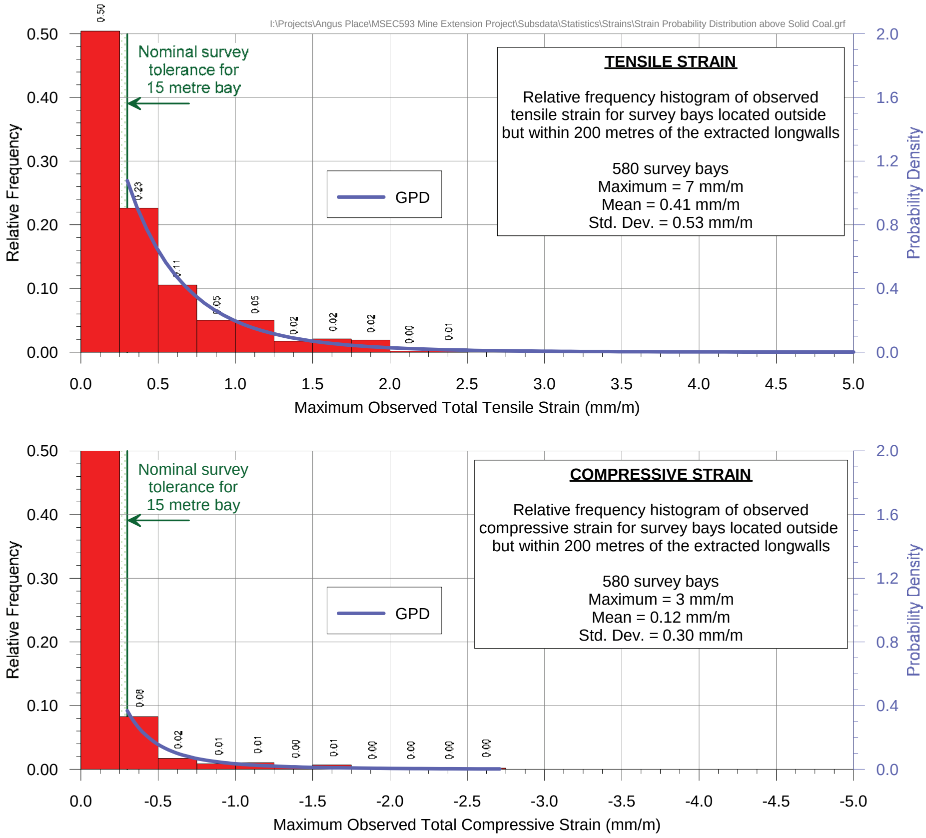


Fig. 4.2 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located Above Solid Coal at Angus Place and Springvale Collieries

The 95 % confidence levels for the maximum strains that the individual survey bays above solid coal experienced at any time during mining were 1.5 mm/m tensile and 0.5 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 2.5 mm/m tensile and 1.5 mm/m compressive.

4.3.3. Distribution of Strain outside the 26.5 Degree 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 metres 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 3.8. 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. 4.3. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

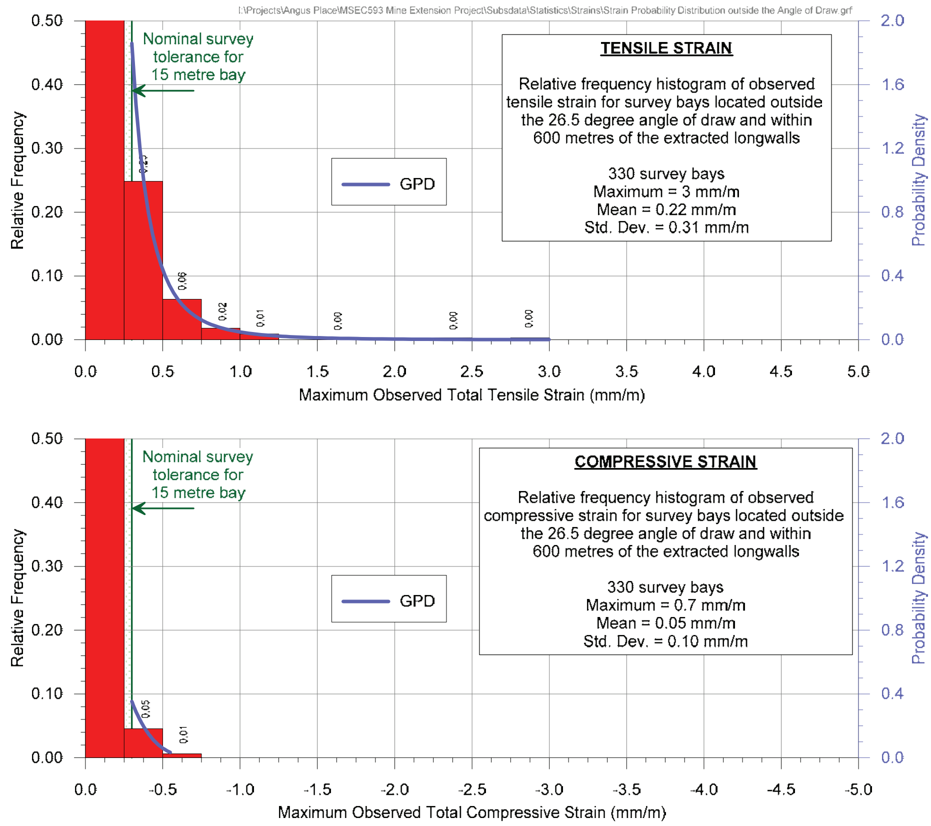


Fig. 4.3 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located Outside the Angle of Draw at Angus Place and Springvale Collieries

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 0.5 mm/m compressive.

4.4. Predicted Far-field Horizontal Movements

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

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

The observed incremental far-field horizontal movements resulting from the extraction of a single longwall, in any location above goaf or solid coal, are provided in Fig. 4.4. The observed incremental far-field horizontal movements above solid coal only (i.e. outside the extents of extracted longwalls) are provided Fig. 4.5. The confidence levels, based on fitted *Generalised Pareto Distributions* (GPDs), have also been shown in these figures to illustrate the spread of the data.

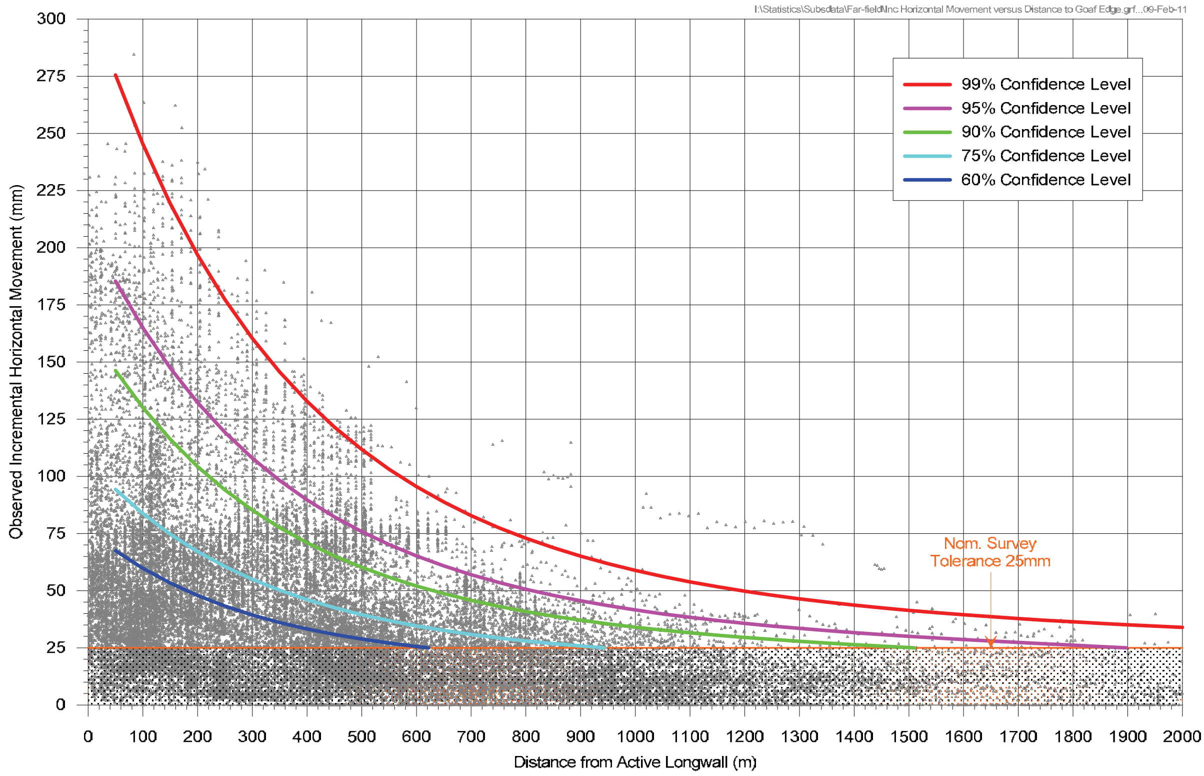


Fig. 4.4 Observed Incremental Far-Field Horizontal Movements above Goaf or Solid Coal

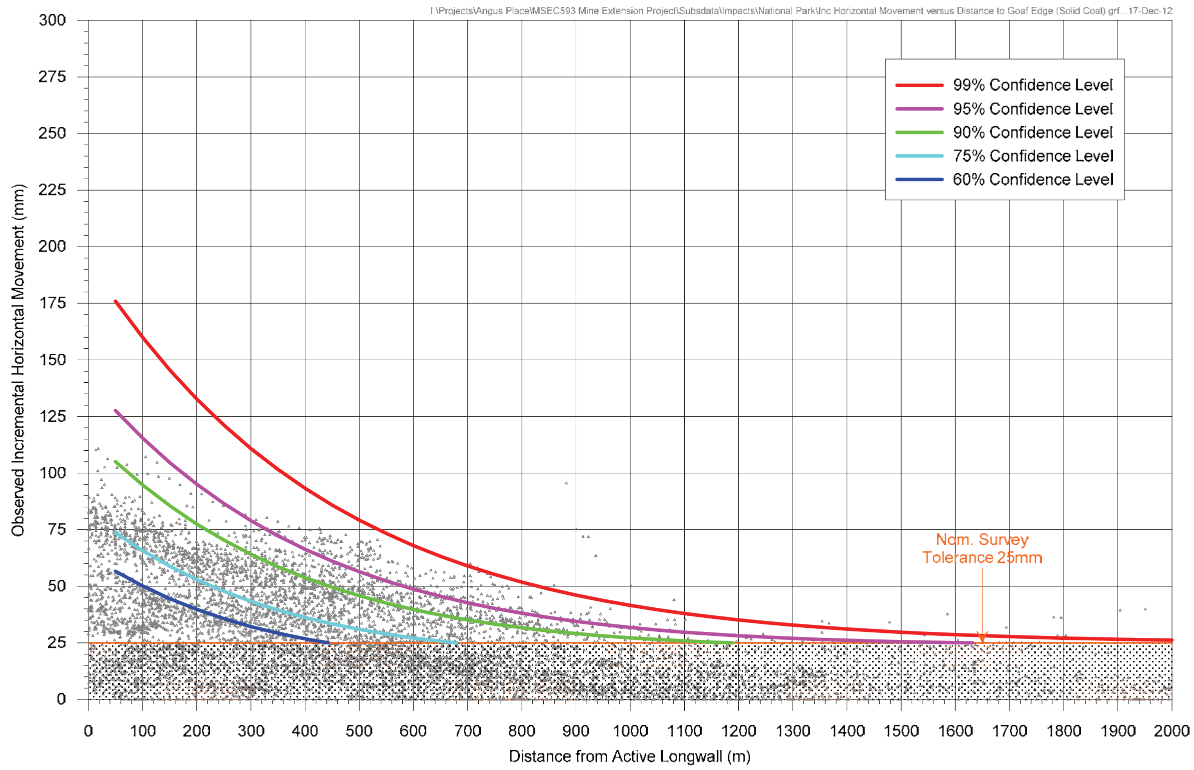


Fig. 4.5 Observed Incremental Far-Field Horizontal Movements above Solid Coal Only

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

The predicted far-field horizontal movements resulting from the extraction of the proposed longwalls are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than 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.

4.5. General Discussion on Mining Induced Ground Deformations

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

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

As subsidence occurs, surface cracks will generally appear in the tensile zone, i.e. within 0.1 to 0.4 times the depth of cover from the longwall perimeters. Most of the cracks will occur within a radius of approximately 0.1 times the depth of cover from the longwall perimeters. The cracks will generally be parallel to the longitudinal edges or the ends of the longwalls.

At shallower depths of cover, it is also likely that transient surface cracks will occur above and parallel to the moving extraction face, i.e. at right angles to the longitudinal edges of the longwall, as the subsidence trough develops. This cracking, however, tends to be transient, since the tensile phase of the travelling wave, which causes the cracks to open up, is generally followed by a compressive phase, which partially recloses them. It has been observed in the past, however, that surface cracks which occur during the tensile phase of the travelling wave do not fully close during the compressive phase, and tend to form compressive heaving at the surface.

The incidence of surface cracking is dependent on the location relative to the extracted longwall goaf edges, the depth of cover, the extracted seam thickness and the thickness and inherent plasticity of the soils that overlie the bedrock. The widths and frequencies of the cracks are also dependent upon the pre-existing jointing patterns in the bedrock. Large joint spacing can lead to concentrations of strain and possibly the development of fissures at rockhead, which are not necessarily coincident with the joints.

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 movements. 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 isolated and 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, which were typically within the range of less than 5 mm to 25 mm, but with isolated surface cracking in some locations greater than 50 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 5.9, 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. 4.6.

Fig. 4.6 Photographs of Fracturing along Kangaroo Creek due to Valley Closure above Angus Place LW920 (after Centennial)

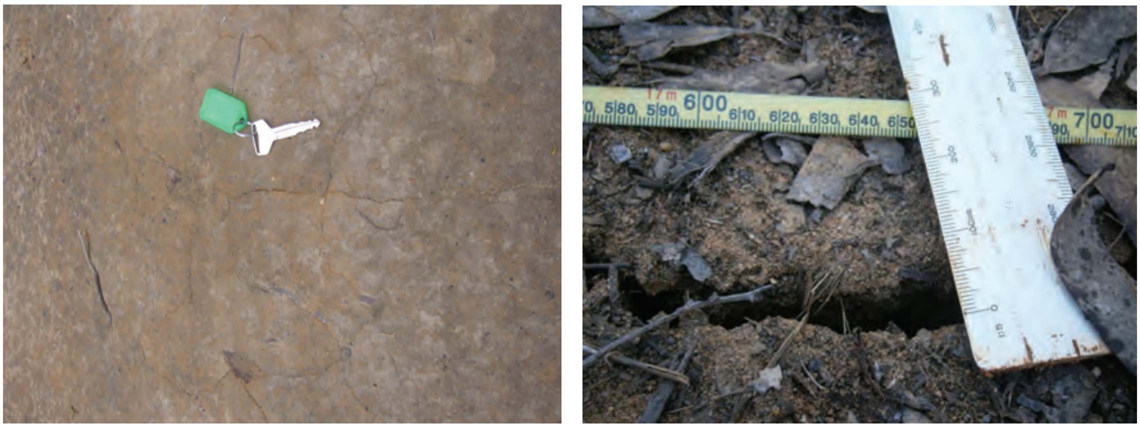


Fig. 4.7 Photographs of Typical Surface Cracking in Kangaroo Creek Road above Angus Place LW950 (LHS) and LW960 (RHS) (after Centennial)

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*.

4.6. Estimated Height of the Fractured Zone

The extraction of longwalls results in deformation throughout the overburden strata. The terminology used by different authors to describe the strata deformation zones above extracted longwalls varies considerably and caution should be taken when comparing the recommendations from differing authors. Forster (1995) noted that most studies have recognised four separate zones, as shown in Fig. 4.8, with some variations in the definitions of each zone.

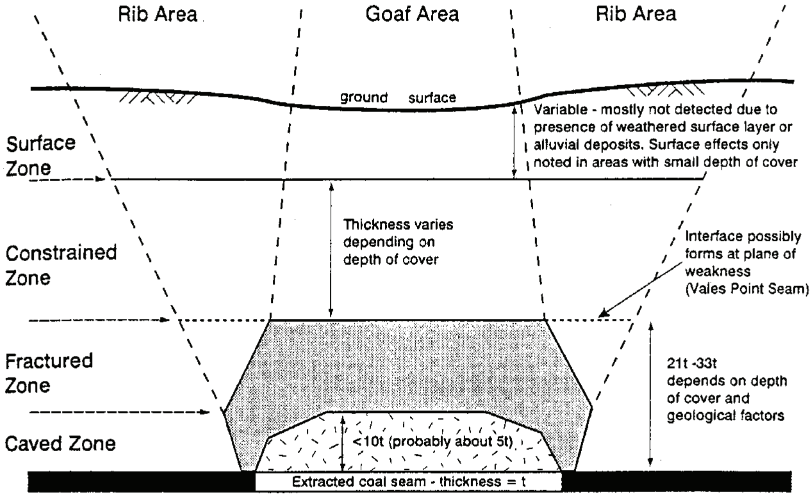


Fig. 4.8 Zones in the Overburden according to Forster (1995)

Peng and Chiang (1984) recognised only three zones as reproduced in Fig. 4.9.

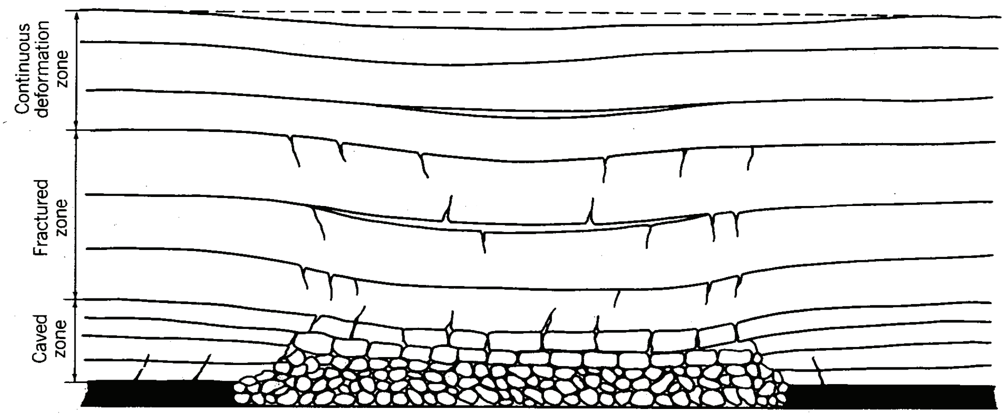


Fig. 4.9 Zones in the Overburden According to Peng and Chiang (1984)

McNally et al (1996) also recognised three zones, which they referred to as the caved zone, the fractured zone and the elastic zone. Kratzsch (1983) identified four zones, but he named them the immediate roof, the main roof, the intermediate zone and the surface zone.

For the purpose of these discussions, the following zones, as described by Singh and Kendorski (1981) and proposed by Forster (1995), as shown in Fig. 4.8, have been adopted:-

- *Caved* or *Collapsed Zone* comprises loose blocks of rock detached from the roof and occupying the cavity formed by mining. This zone can contain large voids. It should be noted, that some authors note primary and secondary caving zones.
- *Disturbed* or *Fractured Zone* comprises in situ material lying immediately above the caved zone which have sagged downwards and consequently suffered significant bending, fracturing, joint opening and bed separation. It should be noted, that some authors include the secondary caving zone in this zone.
- *Constrained* or *Aquiclude Zone* comprises confined rock strata above the disturbed zone which have sagged slightly but, because they are constrained, have absorbed most of the strain energy without suffering significant fracturing or alteration to the original physical properties. Some bed separation or slippage can be present as well as some discontinuous vertical cracks, usually on the underside of thick strong beds, but not of a degree or nature which would result in connective cracking or significant increases in vertical permeability. Some increases in horizontal permeability can be found. Weak or soft beds in this zone may suffer plastic deformation.
- *Surface Zone* comprises unconfined strata at the ground surface in which mining induced tensile and compressive strains may result in the formation of surface cracking or ground heaving.

Just as the terminology differs between authors, the means of determining the extents of each of these zones also varies. Some of the difficulties in establishing the heights of the various zones of disturbance above extracted longwalls stem from the imprecise definitions of the fractured and constrained zones, the differing zone names, the use of different testing methods and differing interpretations of monitoring data, such as extensometer readings.

Some authors interpret the collapsed and fractured zones to be the zone from which groundwater or water in boreholes would flow freely into the mine and, hence, look for the existence of aquiclude or aquitard layers above this height to confirm whether surface water would or would not be lost into the mine.

The heights of the collapsed and fractured zones above extracted longwalls are affected by a number of factors, which include the:-

- widths of extraction,
- heights of extraction,
- depths of cover,
- types of previous workings, if any, above the current extractions,
- interburden thicknesses to previous workings,
- presence of pre-existing natural joints within each strata layer,
- thickness, geology, geomechanical properties and permeability of each strata layer,
- angle of break of each strata layer,
- spanning capacity of each strata layer, particularly those layers immediately above the collapsed and fractured zones,
- bulking ratios of each strata layer within the collapsed zone, and the
- presence of aquiclude or aquitard zones.

Some authors have suggested simple equations to estimate the heights of the collapsed and fractured zones based solely on the extracted seam height, others have suggested equations based solely on the widths of extraction, whilst others have suggested equations based on the width-to-depth ratios of the extractions. As this is a complex issue, MSEC understand that no simple geometrical equation can properly estimate the heights of the collapsed and fractured zones and a more thorough analysis is required, which should include other properties, such as geology and permeability, of the overburden strata. The following discussions provide background information and an estimation of the height of fracturing based on mining geometry only.

While there are many factors that may influence the height of fracturing and dilation, it is generally considered by various authors, e.g. Gale (ACARP C13013, 2008) and Guo et al (ACARP C14033, 2007), that an increase in panel width will generally result in an increase in the height of fracturing and dilation.

The theoretical height of the fractured zone can be estimated from the mining geometry, as being equal to the panel width (W) minus the span (w) divided by twice the tangent of the angle of break. These are illustrated in Fig. 4.10.

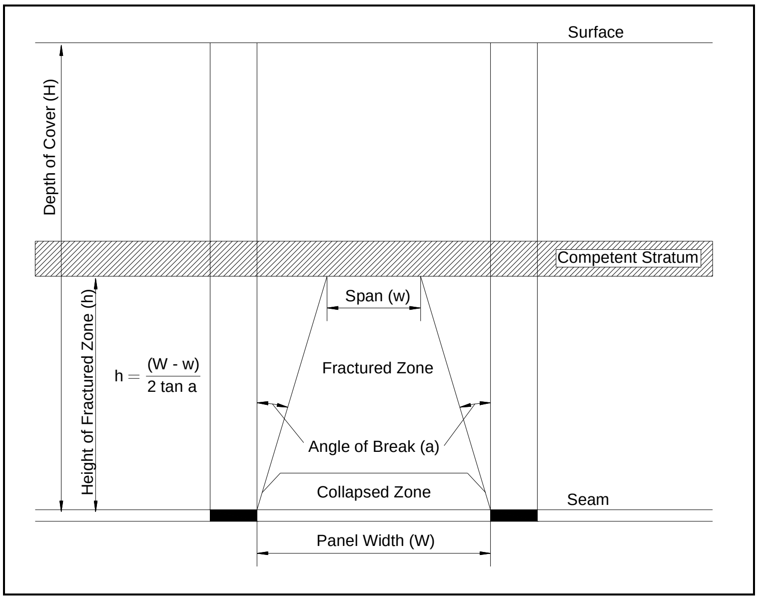


Fig. 4.10 Theoretical Model Illustrating the Development and Limit of the Fractured Zone

MSEC has gathered observed data sourced from a number of literature studies. The data points collected to date are shown in Fig. 4.11. The data points are compared with the results of the theoretical model developed by MSEC, using an angle of break of 20 degrees and spanning width of 30 metres. The results are also compared with lines representing factors of 1.0 times and 1.5 times the panel width, which was suggested by Gale (2008).

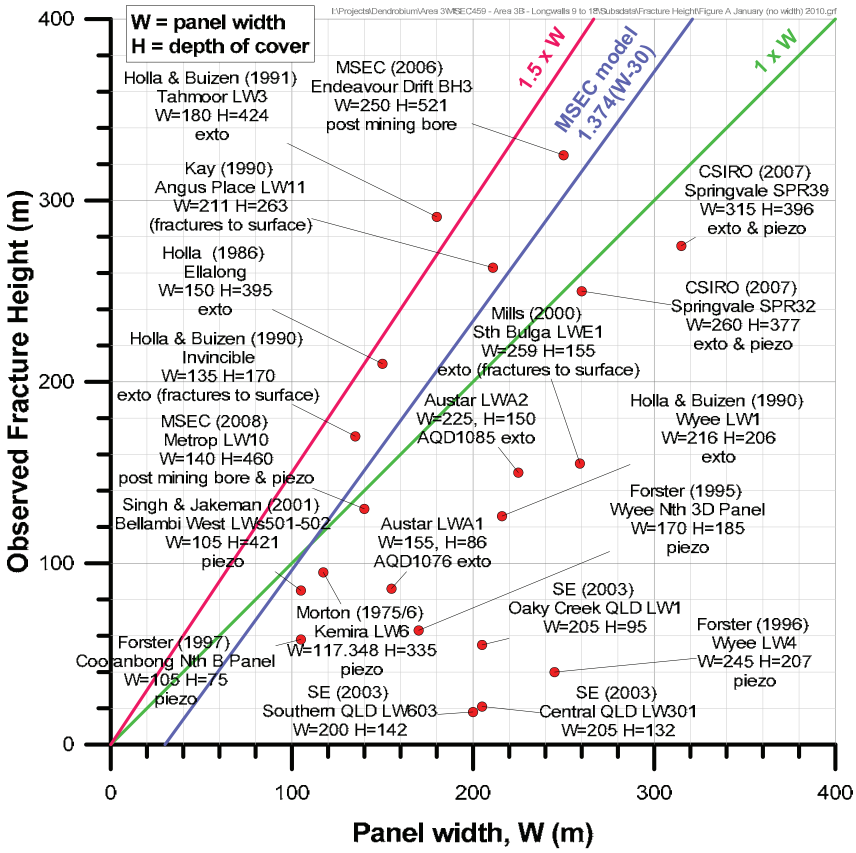


Fig. 4.11 Observed Fracture Heights versus Panel Width

It can be seen from Fig. 4.11, that the MSEC theoretical model and Gale's suggested factors of 1.0 and 1.5 provide similar estimates for the height of fracturing based on panel width. As described previously, however, it is necessary to undertake a more detailed review of the site specific geology and permeability before determining whether these heights are reasonable for this site.

Fracturing from the seam to the surface does not necessarily imply that there will be hydraulic connectivity, as the vertical fractures can be discontinuous near to the surface and at the horizons of less permeable strata layers. The Mount York Claystone separates the Burra-Moko Head Formation and the Banks Wall Sandstone, which has a thickness typically varying between 4 metres and 35 metres, with an average thickness of around 22 metres within the mining area. This unit has been found to act as an aquitard.

There are also several smaller claystone layers above the Mount York Claystone, which have been named YS1 to YS6, and are indicated in Fig. 4.12 (Palaris, 2013a). This section has been taken at Springvale Colliery, to the south of the Extension Area. These fine-grained plies generally consist of interbedded claystone, shale, siltstone and fine-grained sandstone, and have also been found to act as aquitards.

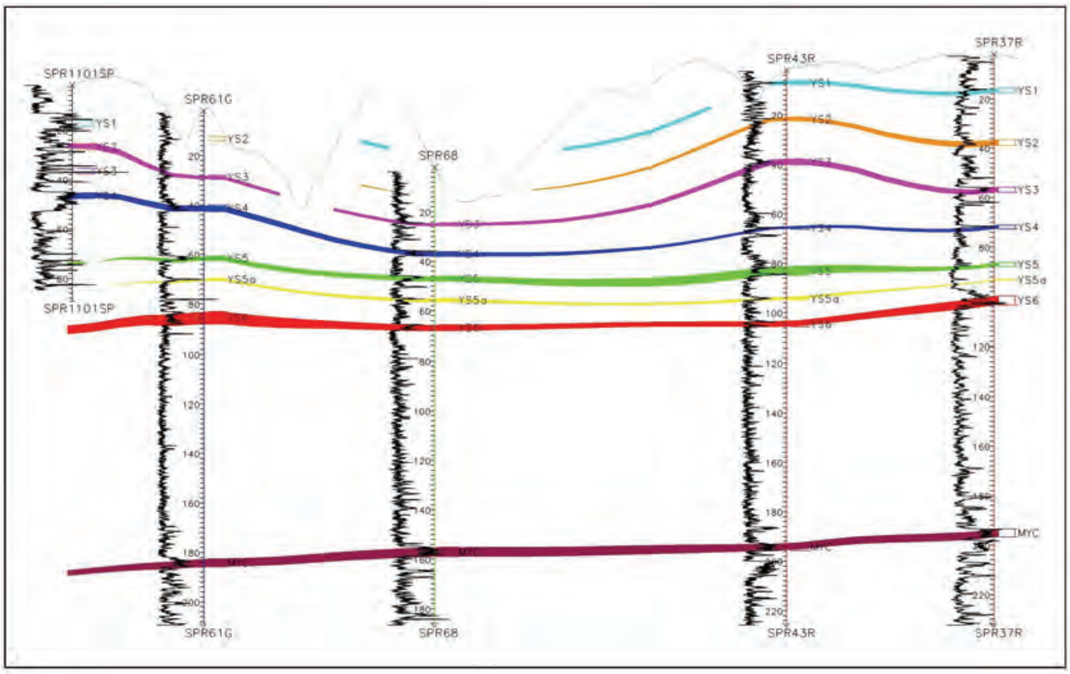


Fig. 4.12 Claystone Units in the Narrabeen Group (Palaris, 2013a)

A Fast Lagrangian Analysis of Continua (FLAC) caving model has been developed by *CSIRO* (2013) which assesses the height of fracturing for the proposed longwalls based on the site specific geology and permeability of the overburden. Further details on sub-surface strata movements are provided in the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

5.1. Introduction

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

The natural features within the Extension Area which have already experienced mine subsidence movements due to the previously extracted of 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,
- Shrub swamps within the Wolgan River valley, and
- Cliffs and pagoda complexes within the Wolgan River valley.

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 Extension Area.

5.2. Wolgan River

5.2.1. Description of the Wolgan River

The location of the Wolgan River is shown in Drawing No. MSEC593-08. It can be seen from this drawing, that the river is located to the west of the proposed longwalls, outside the Extension Area. The river has been included in the assessments provided in this report, as it is likely to experience valley related movements and could be sensitive to these movements.

The Wolgan River commences above Springvale Colliery and generally flows in a northerly direction between the existing and proposed longwalls at Angus Place Colliery. The river continues to flow in a north to easterly direction to where it drains into the Capertee River, more than 20 kilometres north-east of the proposed longwalls. Photographs of the Wolgan River and river valley are provided in Fig. 5.1.

Fig. 5.1 Photographs of the Wolgan River (LHS) and River Valley (RHS)

The total length of the Wolgan River located within a distance of 600 metres from the extents of the proposed longwalls is approximately 3 kilometres. A summary of the minimum distances of the proposed longwalls from the centreline of the river is provided in Table 5.1.

Table 5.1 Minimum Distances of the Proposed Longwalls from the Wolgan River

Longwall	Minimum Distance from the Centreline of River (m)
LW1001	590
LW1002	240
LW1003	560
LW1004	510
LW1005	460
LW1006	450
LW1007	530
LW1008 ~ LW1013A	> 600
LW1013B	550
LW1014A	> 600
LW1014B	520
LW1015	540
LW1016 ~ LW1019	> 600

It can be seen from the above table, that the river is located at a minimum distance of 240 metres from LW1002, at its closest point from the proposed longwalls. The previously extracted longwalls at Angus Place Colliery have been extracted up to 150 metres from the centreline of the Wolgan River. The previously extracted longwalls at Springvale Colliery have been partially extracted beneath the upper reaches of the river.

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 gradient of the river typically varies between 25 mm/m (i.e. 2.5 %, or 1 in 40) and 200 mm/m (i.e. 20 %, or 1 in 5), with an average natural gradient of approximately 75 mm/m (i.e. 7.5 %, or 1 in 13) within the Extension Area.

The valley of the Wolgan River west of the proposed longwalls is up to around 80 metres high and is steeply sided, comprising cliffs, pagodas and talus slopes in a number of locations. The descriptions of the cliffs, minor cliffs, pagodas and steep slopes are included in Sections 5.7 to 5.9. Cross-sections through the valley are provided in Fig. 5.2 and Fig. 5.3, the locations of which are indicated in Drawing No. MSEC593-08.

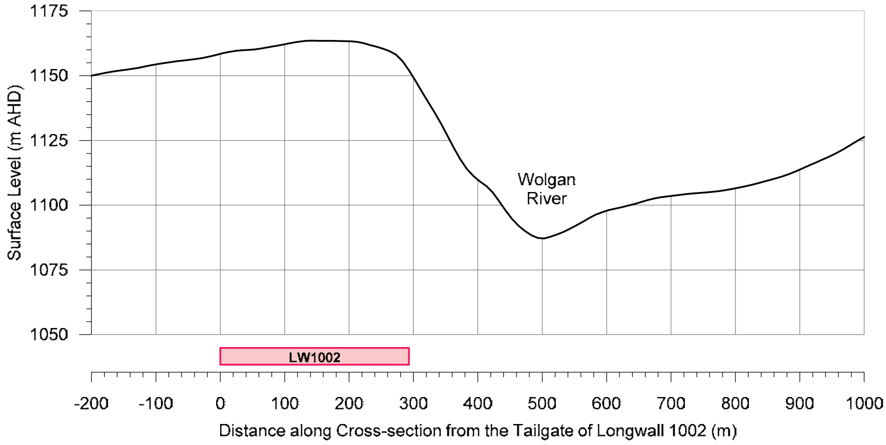


Fig. 5.2 Wolgan River Cross-section 1 (Looking East)

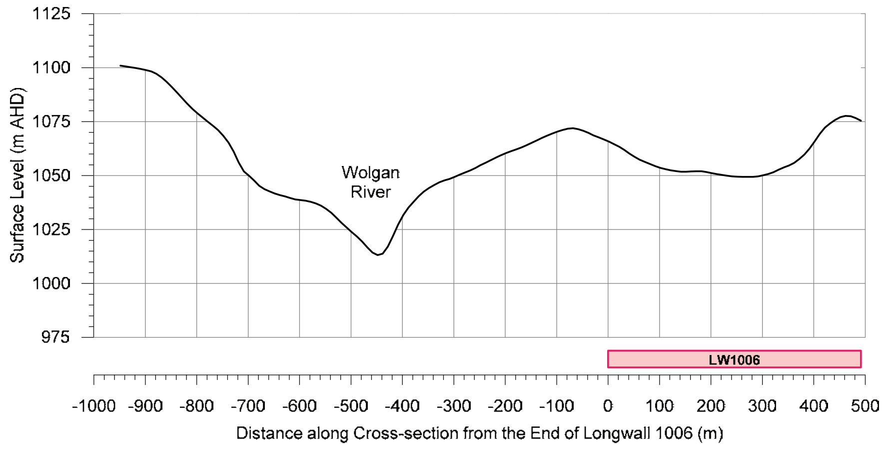


Fig. 5.3 Wolgan River Cross-section 2 (Looking North)

Further descriptions of the Wolgan River are provided by the specialist surface water consultant in the report by *RPS* (2014a).

5.2.2. Predictions for the Wolgan River

The predicted profiles of subsidence, upsidence and closure along the Wolgan River, resulting from the extraction of the existing and proposed longwalls, are shown in Fig. D.03, in Appendix D. 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 the proposed longwalls, including the movements resulting from the extraction of the existing longwalls are shown as blue lines.

The profile of the effective valley height used to determine the predicted valley related upsidence and closure movements along the Wolgan River is shown in Fig. D.03, which is the height of the valley within a half depth of cover of the valley base. No solid coal or valley shape factors have been applied to the effective valley heights.

A summary of the maximum predicted values of total subsidence, upsidence and closure along the river, after the extraction of the existing and proposed longwalls, is provided in Table 5.2. The values provided in the table are the maxima within the Extension Area, based on the section of stream within a distance of 600 metres from the proposed longwalls.

Table 5.2 Maximum Predicted Total Subsidence, Upsidence and Closure for the Wolgan River Resulting from the Extraction of the Existing and Proposed Longwalls

Case	Maximum Predicted Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Total Movements after the Extraction of the Existing Longwalls at Angus Place and Springvale Collieries	< 20	270	310
Total Movements after the Extraction of the Proposed Longwalls (Including the Movements due to the Existing Longwalls at Angus Place and Springvale Collieries)	< 20	290	360
Additional Movements due to the Extraction of the Proposed LW1001 to LW1019 Only (Excluding the Movements due to the Existing Longwalls)	< 20	80	140

It is noted, that the maxima due to the extraction of the proposed longwalls only are in different locations to the maxima 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 Wolgan River is predicted to experience less than 20 mm subsidence and, therefore, the river is not predicted to experience any measurable conventional strains. The river, however, is likely to experience compressive strains due to valley related movements. The predicted compressive strains due to valley closure 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 compressive strains measured within valleys, having effective valley heights between 30 metres and 60 metres and at distanced between 200 metres and 400 metres from edges of longwalls, is provided in Fig. 5.4.

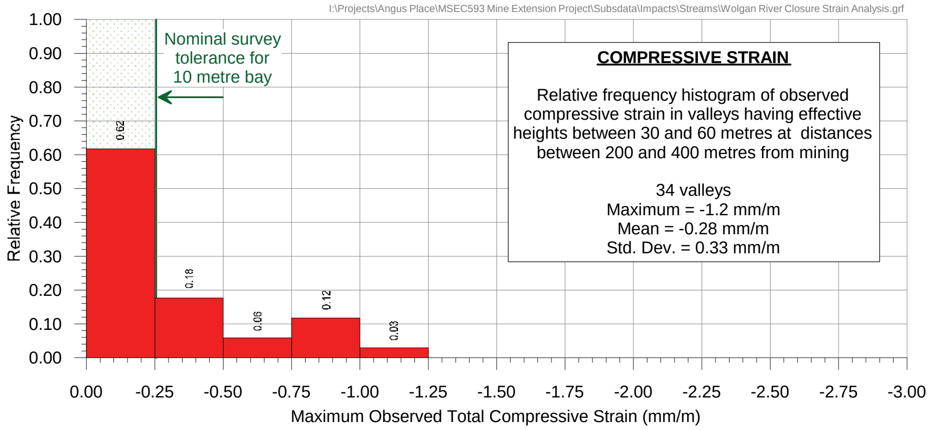


Fig. 5.4 Distribution of Observed Compressive Strains in Valleys having Effective Valley Heights between 30 metres and 60 metres at Distances between 200 metres and 400 metres from Longwall Mining in the NSW Coalfields

It can be seen from the above figure, that 80 % of the valleys experienced compressive strains less than 0.5 mm/m and that 98 % of the valleys experienced compressive strains less than 1 mm/m. The maximum observed compressive strain was 1.2 mm/m.

The predictions for the shrub swamps located along the alignment of the Wolgan River are provided in Section 5.12.2.

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 specialist surface water consultant in the report by *RPS* (2014a).

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, resulting from the extraction of the proposed longwalls, is less than 0.2 mm/m (i.e. < 0.1 %), which represents a change in grade of less than 1 in 5,000. The average natural gradients along the river typically vary between 25 mm/m and 200 mm/m, with an average natural gradient of around 75 mm/m within the Extension Area.

The predicted changes in grade are small when compared to the existing natural grades along the alignment of the Wolgan River. It is unlikely, therefore, that there would be any significant changes in the levels of ponding, flooding or scouring of the river banks resulting from the extraction of the proposed longwalls.

Potential for Changes in Stream Alignment

Longwall mining can potentially result in changes in stream alignment as the result of 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 conventional tilt across the alignment of the Wolgan River, resulting from the extraction of the proposed longwalls, is less than 0.2 mm/m (i.e. < 0.1 %), which represents a change in cross-grade of less than 1 in 5,000. The predicted maximum change in cross-gradient for the river is very small and is unlikely, therefore, to result in any significant changes in stream alignment.

The predicted changes in the cross-bed gradients are small and are expected to be an order of magnitude less than the natural stream cross-bed gradients. The potential impacts associated with changes in the stream alignment, resulting from the extraction of the proposed longwalls are, therefore, not expected to be significant.

The potential impacts of the changes in stream alignment are expected to be minor when compared to 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.

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 reactivation of existing joints. A number of factors are thought to contribute to the likelihood of mining-induced fracturing and these are listed below:-

- Mining-related factors, which affect the level of mining-induced ground movements in the valley. These include, amongst other factors, the depth of cover and proximity of the mining to the stream, panel width and extracted thickness and geology of the overburden,
- Topographic factors associated with the stream valley, which include valley depth, valley width and the shape and steepness of the valley sides,
- Local, near-surface geological factors, which include bedrock lithology such as rock strength, thickness of beds within the strata, orientation and dip of strata, degree of cross-bedding and existing jointing,
- In situ horizontal stresses in the bedrock, and
- Presence of deep alluvial deposits covering the bedrock.

The compressive strains due to the valley closure movements along the Wolgan River are expected to be typically less than 0.5 mm/m, with strains in the order of 1 mm/m where the river is located closest to the proposed longwalls. Fracturing of sandstone is rarely observed where 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 were observed in the bedrock. These fractures would generally only be visible when 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.

In this case, LW1001 to LW1019 are not proposed to be extracted directly beneath the Wolgan River. The proposed longwalls are located at a distance of 240 metres from the centreline of the river, at their closest point. Away from this location, the river is located at distances more than 400 metres from the proposed longwalls. Historical observations indicate that, at these distances, only isolated and minor fracturing is expected to occur in the bed of the river.

The furthest distance of an observed fracture from longwall mining in the NSW Coalfields was at the base of Broughtons Pass Weir, which was located approximately 415 metres from Appin Colliery Longwall 401. Another minor fracture was also recorded in the upper Cataract River, approximately 375 metres 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.

It is expected, that any fracturing that occurs in the bed of the Wolgan River, resulting from the extraction of the proposed longwalls, will be isolated and minor in nature. Fractures would only be visible within the base of the river valley in exposed areas of bedrock. The fractures are expected to be shallow and discontinuous and, therefore, are not expected to result in any diversion of surface water flows into subterranean flows.

The maximum predicted additional valley related movements, due to the extraction of the proposed longwalls only, are 80 mm upsidence and 140 mm closure. It has also been predicted that the river has already experienced valley related movements up to 270 mm upsidence and 310 mm closure due to the extraction of the existing longwalls at Angus Place and Springvale Collieries. No significant fracturing or surface water flow diversions have been observed along the river due to the existing mining. It is unlikely, therefore, that the extraction of the proposed longwalls would result in any significant fracturing or surface water flow diversions.

5.2.4. Impact Assessments for the Wolgan River Based on Increased Predictions

If the actual conventional subsidence movements exceeded those predicted by a factor of 2 times, the tilts along and across the alignment of the Wolgan River would still be less than 0.5 mm/m (i.e. < 0.1 %), which represents a change in grade of less than 1 in 2,000. The increased levels of ponding, flooding and scouring of the river banks would still be small in comparison with those which occur during natural flooding conditions.

If the actual valley related upsidence and closure movements exceeded those predicted by a factor of 2 times, the likelihood and extent of fracturing in the bedrock would increase in the section of river closest to the proposed longwalls. The Wolgan River is located at a minimum distance of 240 metres from the proposed longwalls, with the majority of the river located more than 400 metres from the proposed longwalls. It is unlikely, therefore, that the fracturing would result in the diversion of surface water flows into subterranean flows, as this has not been observed in streams within the NSW Coalfields as similar distances.

While the predicted ground movements are important parameters when assessing the potential impacts on the Wolgan River, the previous mining at Angus Place and Springvale Collieries has not resulted in any adverse impacts on the river. It is unlikely, therefore, that the proposed longwalls would result in adverse impacts on the river, as they are located at greater distances than the existing longwalls.

5.2.5. Recommendations for the Wolgan River

It is recommended that management strategies are developed for the Wolgan River, in conjunction with the relevant authorities, which could include ground monitoring, surface water flow and quality monitoring, and visual monitoring.

5.3. Carne Creek

The location of the Carne Creek is shown in Drawing No. MSEC593-08. It can be seen from this drawing, that the creek is located to the east of the proposed longwalls, outside the Extension Area. The river has been included in the assessments provided in this report, as it could experience valley related movements and could be sensitive to these movements.

Carne Creek is located 400 metres south-east of LW1019, at its closest point to the proposed longwalls. The remaining proposed longwalls are located more than 600 metres from the creek. The total length of Carne Creek located within a distance of 600 metres from the extents of the proposed longwalls is approximately 0.9 kilometres.

The maximum predicted subsidence at Carne Creek, due to the extraction of the proposed longwalls, is less than 20 mm. Whilst the creek could experience some very low level vertical subsidence, it is not expected to experience any measurable conventional tilts or curvatures, even if the predictions were exceeded by a factor of 2 times.

The maximum predicted valley related movements at Carne Creek, due to the extraction of the proposed longwalls, are 25 mm upsidence and 50 mm closure. The compressive strains due to valley closure are expected to be less than 0.5 mm/m, which is in the order of survey tolerance.

The section of Carne Creek located within 600 metres of the proposed longwalls could also experience some low level movements resulting from the extraction of the future longwalls at Springvale Colliery. The predicted conventional and valley related strains along this section of creek, due to mining at Springvale Colliery, are also expected to be less than 0.5 mm/m, which is in the order of survey tolerance.

It is unlikely, therefore, that Carne Creek would be adversely impacted as a result of the extraction of the proposed LW1001 to LW1019. Further impact assessments of the creek are provided by the specialist surface water consultant in the report by *RPS* (2014a).

5.4. Drainage Lines

5.4.1. Description of the Drainage Lines

The locations of the unnamed drainage lines are shown in Drawing No. MSEC593-08. The drainage lines in the western part of the Extension Area drain into the Wolgan River, and the drainage lines in the eastern part of the Extension Area drain into Carne Creek.

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 includes 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 Extension Area are provided in Fig. 5.5.

Fig. 5.5 Photographs of Typical Drainage Lines

5.4.2. Predictions for the Drainage Lines

The drainage lines are located across the Extension Area and, therefore, could experience subsidence movements up to the maxima described in Chapter 4.

The analysis of strains measured during the previous longwall mining at Angus Place and Springvale Collieries is provided in Section 4.3. Non-conventional movements can also occur as a result of, amongst other things, anomalous movements and valley related movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The drainage lines could experience valley related upsidence and closure movements. The compressive strains resulting from the valley closure movements are expected to be similar to those measured at the drainage lines located above the previously extracted longwalls at Angus Place and Springvale Collieries. A summary of the maximum observed compressive strains due to valley related movements at the drainage lines located directly above the previously extracted longwalls is provided in Table 5.3.

Table 5.3 Maximum Observed Compressive Strains at the Drainage Lines above the Previously Extracted Longwalls at Angus Place and Springvale Collieries

Colliery	Monitoring Line	Stream Crossing	Maximum Observed Compressive Strain (mm/m)
Angus Place	A-Line	Tributary to the Wolgan River	5
	F-Line	Tributary to the Wolgan River	16
Springvale	B-Line	Tributary 1	13
		Tributary 2	15
		Tributary 3	7
	EWS-Line	Tributary to the Wolgan River	13
	M-Line	Tributary to the Wolgan River	8

It is expected, therefore, that the drainage lines located directly above the proposed longwalls will experience compressive strains due to valley related movements between 5 mm/m and 16 mm/m. The greatest compressive strains are expected to occur where the drainage lines are located near the centrelines of the proposed longwalls, and less where the drainage lines are located near the chain pillars.

The compressive strains for the drainage lines located outside the extents of the proposed longwalls are expected to be less again. The distribution of measured compressive strains for drainage lines which were located outside the extents of previously extracted longwalls in the NSW Coalfields is provided in Fig. 5.6. The results are based on valleys which have an effective heights less than 30 metres and were located more than 100 metres from the nearest extracted longwall.

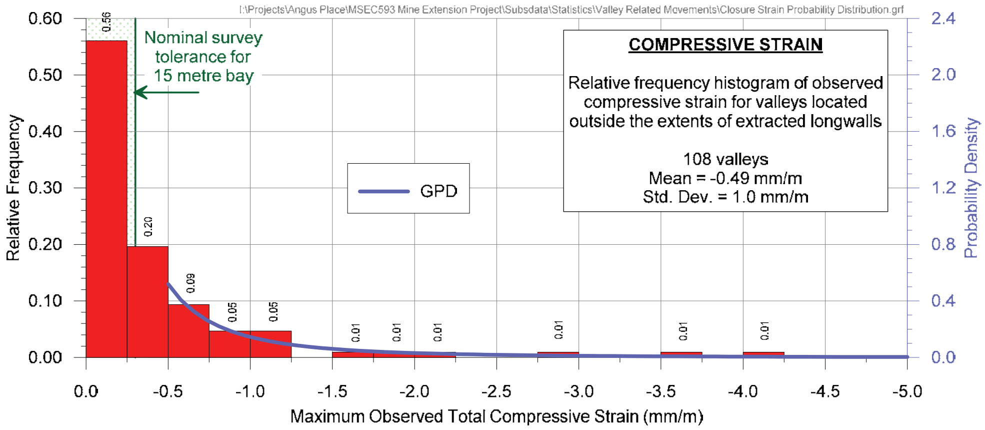


Fig. 5.6 Distribution of Measured Closure Strains for Drainage Lines Located Outside the Extents of Previously Extracted Longwalls in the NSW Coalfields

It can be seen from the above figure, that the drainage lines located outside the extents of the previously extracted longwalls generally experience less than 1 mm/m compressive strain. The compressive strain for these drainage lines based on the 95 % confidence level is 1.8 mm/m. It is expected, therefore, that the drainage lines located outside the extents of the proposed longwalls will generally experience compressive strains due to valley related movements less than 1 mm/m to 2 mm/m.

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 specialist surface water consultant in the report by *RPS* (2014a).

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 Extension Area is 20 mm/m (i.e. 2.0 %), which represents a change in grade of 1 in 50. The predicted changes in grade are less than the natural gradients along the drainage lines, which typically vary between 25 mm/m and 300 mm/m and, therefore, are unlikely to have an adverse impact on the surface water flows.

This is illustrated in Fig. 5.7 to Fig. 5.9 which show the natural grades and the predicted post mining grades along three typical drainage lines within the Extension Area. The locations of these drainage lines are indicated in Drawing No. MSEC593-08.

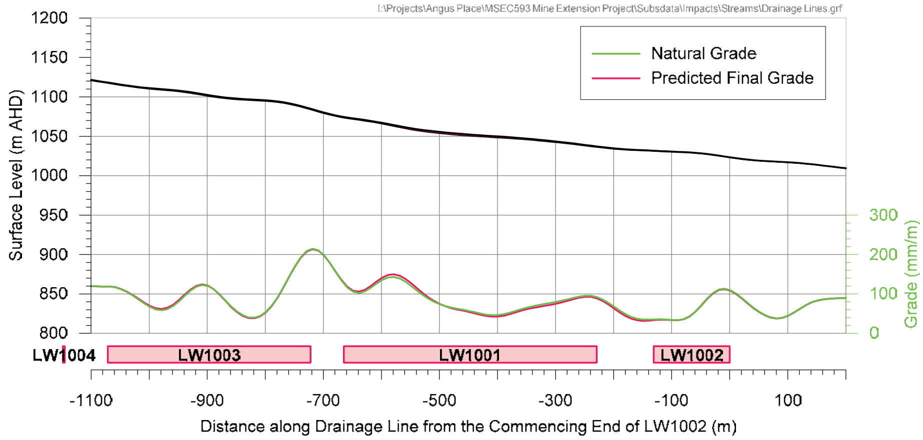


Fig. 5.7 Natural and Predicted Post Mining Surface Levels along Drainage Line 1

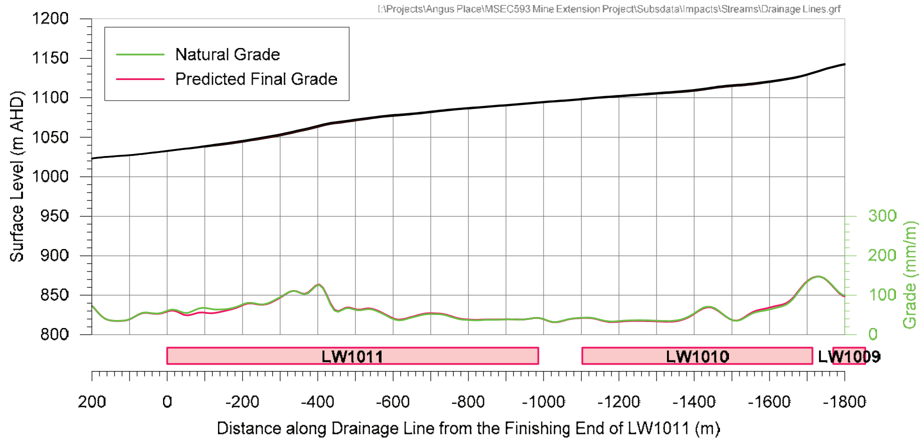


Fig. 5.8 Natural and Predicted Post Mining Surface Levels along Drainage Line 2

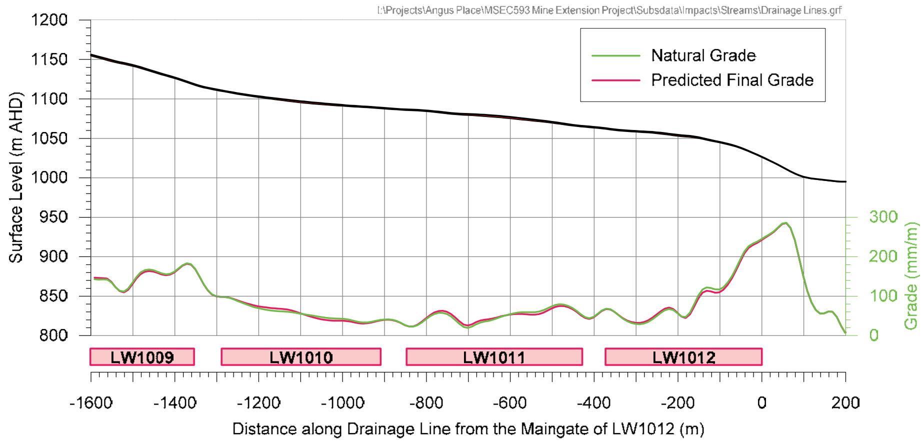


Fig. 5.9 Natural and Predicted Post Mining Surface Levels along Drainage Line 3

It can be seen from the above figures, that the predicted post mining grades are similar to the natural grades along these typical drainage lines. There are no predicted significant reductions or reversals of stream grade. It is not expected, therefore, that there would be any adverse changes in ponding or scouring along the drainage lines resulting from the proposed mining.

It is possible that there could be very localised areas along the drainage lines which could experience small increases in the levels of ponding, where the natural gradients are low immediately upstream of the longwall chain pillars. As the predicted changes in grade are small, less than 10 mm/m to 20 mm/m (i.e. 1 % to 2 %), however, 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 specialised surface water consultant in the report by *RPS* (2014a).

Potential for Cracking in the Drainage Line Beds and Fracturing of Bedrock

Fracturing of the uppermost bedrock has been observed in the past, as a result of longwall mining, where the tensile strains have been greater than 0.5 mm/m or where the compressive strains have been greater than 2 mm/m. It is likely, therefore, that fracturing would occur in the uppermost bedrock based on the predicted maximum strains. It has been observed in the past, that the depth of fracturing and dilation of the uppermost bedrock, resulting from longwall mining, is generally less than 10 metres to 15 metres (Mills 2003, Mills 2007, and Mills and Huuskes 2004).

Where the beds of the drainage lines comprise natural surface soils, it is possible that fracturing in the bedrock would not be seen at the surface. In the event that fracturing of the bedrock occurs in these locations within the alignments of the drainage lines, the fractures are likely to be filled with soil during subsequent flow events.

Where the beds of the drainage lines have exposed bedrock, there may be some diversion of surface water flows into the dilated strata beneath them and the draining of pooled water within the alignments. It is unlikely that there would be any net loss of water from the catchment, however, as the depth of dilation and fracturing is expected to be less than 10 metres to 15 metres and, therefore, any diverted surface water is likely to re-emerge into the catchment further downstream.

The drainage lines downstream of the swamps have small base surface water flows. Elsewhere, the drainage lines are ephemeral and so water typically flows during and for a period of time after each rain event. In times of heavy rainfall, the majority of the runoff would flow over the beds and would not be diverted into the dilated strata below. In times of low flow, however, some of the water could be diverted into the dilated strata below the beds and this could affect the quality and quantity of the water flowing in the drainage lines. It is unlikely, however, that this would result in adverse impacts on the overall quantity and quality of water flowing from the catchment.

Any surface cracking would tend to be naturally filled with soil during subsequent flow events, especially during times of heavy rainfall. If any surface cracks were found not to fill naturally, some remedial measures may be required at the completion of mining. Where necessary, any significant surface cracks in the drainage line beds could be remediated by infilling with soil or other suitable materials, or by locally regrading and recompacting the surface.

Centennial has previously extracted longwalls beneath more than 40 kilometres of creeks and drainages lines at Angus Place and Springvale Collieries. Changes in surface water flows and a decline in the piezometric surface at an adjacent monitoring bore were observed along Kangaroo Creek after the extraction of Angus Place LW940. A letter by Centennial (2008) to the then Department of Primary Industries stated that "*Following rainfall during the last week, surface flow has resumed over the Longwall 940 surface area of Kangaroo Creek and water level in the bore has returned to within 50mm of the previous level*", which indicates that these impacts appear to be transient. Elsewhere, there has been no reported loss of surface water flows or adverse impacts on the drainage lines for the previous mining at these collieries.

Further discussions on the potential impacts on the drainage lines are provided by the specialist surface water and groundwater consultants in the reports by *RPS* (2014a), *RPS* (2014b) and *CSIRO* (2013).

5.4.4. Impact Assessments for the Drainage Lines Based on Increased Predictions

If the actual conventional subsidence movements exceeded those predicted by a factor of 2 times, the maximum tilt within the Extension Area would be 40 mm/m (i.e. 4.0 %), which represents a change in grade of 1 in 25. In this case, the predicted changes in grade would be similar to the natural gradients along the drainage lines, which typically vary between 25 mm/m and 300 mm/m. This is illustrated in Fig. 5.10, Fig. 5.11 and Fig. 5.12, which show the natural and predicted final surface levels and grade along Drainage Lines 1, 2 and 3, respectively, based on the subsidence exceeding the predictions by a factor of 2 times.

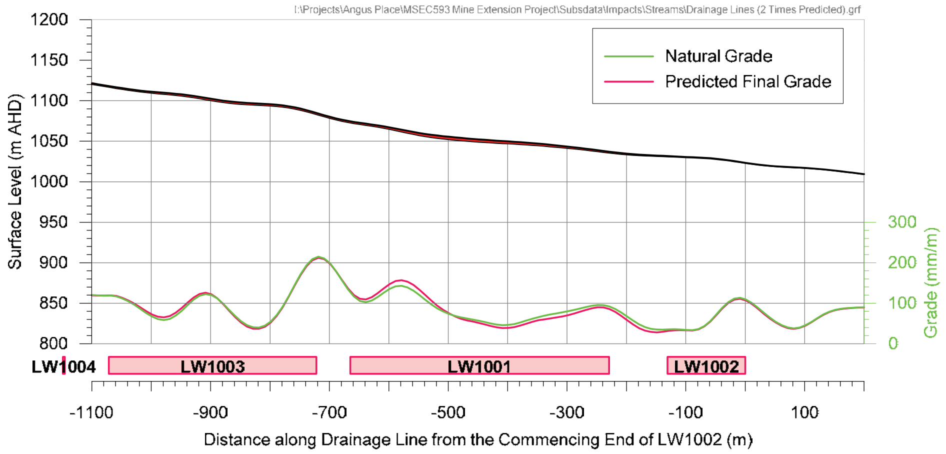


Fig. 5.10 Natural and Predicted Post Mining Surface Levels along Drainage Line 1 Based on Subsidence Exceeding Predictions by a Factor of 2 Times

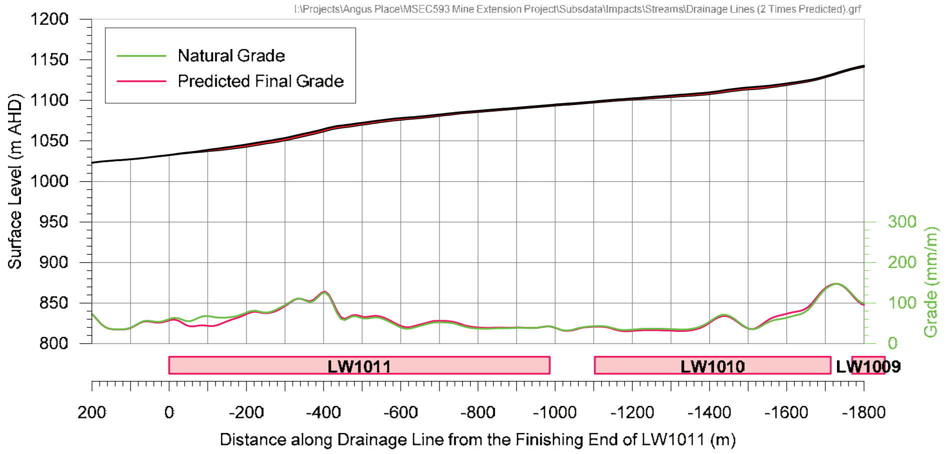


Fig. 5.11 Natural and Predicted Post Mining Surface Levels along Drainage Line 2 Based on Subsidence Exceeding Predictions by a Factor of 2 Times

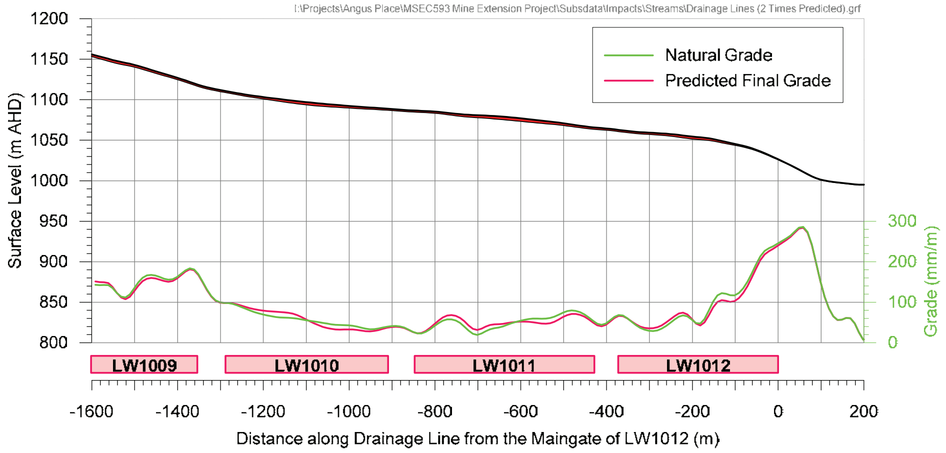


Fig. 5.12 Natural and Predicted Post Mining Surface Levels along Drainage Line 3 Based on Subsidence Exceeding Predictions by a Factor of 2 Times

It can be seen from the above figures, that the predicted post mining grades are similar to the natural grades along these typical drainage lines, even if the predictions were exceeded by a factor of 2 times. There are no predicted significant reductions or reversals of stream grade.

If the actual curvatures, strains or valley related movements exceeded those predicted by a factor of 2 times, it would be expected that the extent of fracturing in the uppermost bedrock would increase along the drainage lines which are located directly above the proposed longwalls. The depth of fracturing and dilation would still be expected to extend no greater than 10 metres to 15 metres and, therefore, no loss of surface water from the catchment would be anticipated.

While the predicted ground movements are important parameters when assessing the potential impacts on the drainage lines, it is noted that the previous experience at Angus Place and Springvale Collieries indicates that the potential impacts on the drainage lines are low.

5.4.5. Recommendations for the Drainage Lines

It is recommended that the drainage lines are periodically visually monitored during the extraction of the proposed longwalls. The assessed impacts on the drainage lines can be managed by the implementation of suitable management strategies. With these strategies in place, it is unlikely that there would be any significant long term impacts on the drainage lines resulting from the extraction of the proposed longwalls.

5.5. Aquifers and Known Ground Water Resources

The descriptions, predictions and the assessment of potential impacts on the aquifers and groundwater resources within the Extension Area are provided by the specialist groundwater consultants in the reports prepared by *CSIRO* (2013) and *RPS* (2014b).

5.6. Springs and Groundwater Seeps

There are natural springs and groundwater seeps within the Extension Area, which are described by the specialist groundwater consultants in the reports prepared by *CSIRO* (2013) and *RPS* (2014b).

5.7. Cliffs, Minor Cliffs and Pagodas

5.7.1. Descriptions of the Cliffs, Minor Cliffs and Pagodas

For the purposes of discussion in this report, *cliffs* have been defined as 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°. *Minor cliffs* have been defined as continuous rockfaces having heights between 5 metres and 10 metres, minimum lengths of 20 metres and a minimum slope of 2 to 1. *Pagodas* have been defined as isolated freestanding rock formations with heights greater than 5 metres.

The locations of the cliffs, minor cliffs and pagodas were determined using the 1 metre surface level contours which 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. MSEC593-09.

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 Extension 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 degree angle of draw line from the extents of the proposed longwalls. There are two cliffs and some pagoda complexes which have been identified within the 26.5 degree angle of draw line, however, all these features are located outside the extents of the proposed longwalls. There is one minor cliff which has been identified immediately adjacent to the eastern end of the proposed LW1014B and some isolated pagodas identified elsewhere above the proposed longwalls.

A summary of the details of the two cliffs which have been identified within the 26.5 degree angle of draw line from the proposed longwalls is provided in Table 5.4. The locations of these cliffs are shown in Drawing No. MSEC593-09.

Table 5.4 Cliffs within the 26.5 degree Angle of Draw Line from the Proposed Longwalls

Cliff ID	Total Length within the 26.5 deg Angle of Draw Line (m)	Maximum Height (m)	Location
AP-CL1	50	20	Northern side of tributary, approx. 125 metres south of the eastern end of LW1001 and 150 metres east of LW1002
AP-CL2	100	25	Southern side of spur, approx. 50 metres south of the eastern end of LW1009

Photographs of Cliff AP-CL2 and typical cliffs along the Wolgan River valley are provided in Fig. 5.13 and Fig. 5.14, respectively. Photographs of the pagoda complexes located east of the proposed LW1014B are provided in Fig. 5.15.

Fig. 5.13 Photographs of Cliff AP-CL2

Fig. 5.14 Photographs of Typical Cliffs along the Wolgan River

Fig. 5.15 Photographs of Pagoda Complexes Located East of the Proposed LW1014B

5.7.2. Predictions for the Cliffs, Minor Cliffs and Pagodas

A summary of the maximum predicted total conventional subsidence parameters for the cliffs which are located within the Extension Area is provided in Table 5.5. The values provided in this table are the maxima within 20 metres from the mapped extents of these cliffs.

Table 5.5 Maximum Predicted Total Conventional Subsidence Parameters for the Cliffs

Cliff ID	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})
AP-CL1	50	0.5	0.01	< 0.01
AP-CL2	75	1.0	0.02	< 0.01
Remaining Cliffs	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted conventional curvatures for the cliffs are 0.02 km^{-1} hogging and less than 0.01 km^{-1} sagging, which represent minimum radii of curvature of 50 kilometres and greater than 100 kilometres, respectively.

The pagoda complexes are located outside the extents of the proposed longwalls. These features could experience low levels of vertical subsidence generally less than 100 mm. The pagoda complexes are also predicted to experience tilts less than 0.5 mm/m, hogging curvatures of 0.02 km^{-1}, or less, and sagging curvatures less than 0.01 km^{-1}.

The minor cliff which is located immediately adjacent to the eastern end of the proposed LW1014B is predicted to experience 75 mm subsidence, 1 mm/m tilt, 0.02 km^{-1} hogging curvature and less than 0.01 km^{-1} sagging curvature. The analysis of strains measured above solid coal for the previously extracted longwalls at Angus Place and Springvale Collieries is discussed in Section 4.3.2.

The isolated pagodas located directly above the proposed longwalls could experience subsidence movements up to the maxima described in Chapter 4.

The cliffs, minor cliffs and pagodas are located on the sides of the valleys and, therefore, are not expected to experience significant valley related upsidence movements or compressive strains due to closure movements, which occur near the bases of the valleys.

5.7.3. Impact Assessments for the Cliffs, Minor Cliffs and Pagodas

The two cliffs and the pagoda complexes located within the 26.5 degree angle of draw line, but outside the extents of the proposed longwalls, could experience low levels of subsidence, generally less than 100 mm. The analysis of strains measured outside but within 200 metres of the previously extracted longwalls at Angus Place and Springvale Collieries is discussed in Section 4.3.2.

The maximum predicted strains for the cliffs and pagoda complexes, based on the 95 % confidence level for the strains measured above solid coal, are 1.5 mm/m tensile and 0.5 mm/m compressive. Adverse impacts on these features are generally the result of compressive strains, which result in spalling of the free rock surfaces. In this case, compressive strains of 0.5 mm/m, or less, are unlikely to have any adverse impacts on the cliffs or pagoda complexes.

The cliffs and pagoda complexes are also likely to experience small far-field horizontal movements, which are described in Sections 3.3 and 4.4. It can be seen from Fig. 4.5, that incremental horizontal movements less than 100 mm have generally been measured outside previously extracted longwalls in the NSW Coalfields. These movements, however, tend to be bodily movements which are not associated with any measurable conventional tilts, curvatures or strains.

It is unlikely, therefore, that the cliffs and pagoda complexes would experience any adverse impacts resulting from the extraction of the proposed longwalls. This is supported by extensive experience from the NSW Coalfields, at depths of cover greater than 200 metres, where no cliff instabilities have been observed where cliffs have been located wholly outside the extents of extracted longwalls. It is noted, however, that some minor rock falls have been observed outside the extents of extracted longwalls.

The minor cliff located immediately adjacent to the eastern end of the proposed LW1014B could experience some fracturing and, where the rock is marginally stable, could then result in some localised spalling of the exposed rockface. Previous experience of mining immediately adjacent to minor cliffs in the NSW Coalfields, at similar depths of cover, indicates that the potential impacts resulting from the proposed mining would represent less than 1 % of total exposed rockface area of the minor cliff.

The isolated pagodas which are located directly above the proposed longwalls are also likely to experience some fracturing and, where the rock is marginally stable, could then result in spalling of the exposed rockfaces. The isolated pagodas are discontinuous and, therefore, are less susceptible to impacts when compared with 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. Impact Assessments for the Cliffs, Minor Cliffs and Pagodas Based on Increased Predictions

If the actual subsidence movements exceeded those predicted by a factor of 2 times, the likelihood of impacts on the cliffs and pagoda complexes would still be extremely low, as they are located outside the extents of the proposed longwalls. This is based on the extensive experience from the NSW Coalfields, at depths of cover greater than 200 metres, where no cliff instabilities have been observed where cliffs have been located wholly outside the extents of extracted longwalls.

If the actual subsidence movements exceeded those predicted by a factor of 2 times, the likelihood of impacts on the minor cliff located immediately adjacent to the eastern end of the proposed LW1014B and on the isolated pagodas would increase. In this case, it would be expected that the impacts would represent less than 3 % of the exposed rockface area of the minor cliff and less than 3 % of the total exposed rockface areas of the isolated pagodas which are located directly above the proposed longwalls.

5.7.5. Recommendations for the Cliffs, Minor Cliffs and Pagodas

It is recommended that the cliffs, minor cliffs and pagodas are periodically visually monitored throughout the mining period and for a period after the completion of mining.

5.8. Rock Outcrops

5.8.1. Descriptions of the Rock Outcrops

For the purposes of this report, a rock outcrop has been defined as an isolated rockface having a height of less than 5 metres, or having a slope less than 2 in 1, i.e. having an angle to the horizontal of less than 63°. There are rock outcrops located across the Extension Area. The locations of the rock outcrops have not been shown in the drawings, as their specific locations of all these features could not be derived from the aerial laser scan or topographic photograph.

Photograph of typical rock outcropping within the Extension Area are provided in Fig. 5.16.

Fig. 5.16 Photograph of Typical Rock Outcropping

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

5.8.2. Predictions for the Rock Outcrops

The rock outcrops are located across the Extension Area and, therefore, could experience subsidence movements up to the maxima described in Chapter 4.

The analysis of strains measured during the previous longwall mining at Angus Place and Springvale Collieries is provided in Section 4.3. Non-conventional movements can also occur 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 Rock Outcrops

The extraction of the proposed longwalls are likely to result in some fracturing of the rock outcrops and, where the rock is marginally stable, 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 longwalls.

5.8.4. Impact Assessments for the Rock Outcrops Based on Increased Predictions

If the actual subsidence movements exceeded those predicted by a factor of 2 times, the extent of fracturing and, hence, the incidence of impacts would increase for the rock outcrops located directly above the proposed longwalls. Based on previous experience of mining beneath rock outcrops in the NSW Coalfields, it would still be expected that the incidence of impacts on the rock outcrops would represent less than 3 % of total exposed rockface areas of these features which are located directly above the proposed longwalls.

5.8.5. Recommendations for the Rock Outcrops

It is recommended that the rock outcrops are periodically visually monitored throughout the mining period and for a period after the completion of mining.

5.9. Steep Slopes

5.9.1. Descriptions of the Steep Slopes

For the purposes of discussion in this report, a steep slope has been defined as an area of land having a natural gradient greater than 1 in 3 (i.e. a grade of 33 %, or an angle to the horizontal of 18°), but less than 2 in 1 which is the limit used to define cliffs. The locations of the steep slopes were identified from the 1 metre surface level contours which were generated from the Light Detection and Ranging (LiDAR) survey of the area. The locations of the steeps slopes within the Extension Area are shown in Drawing No. MSEC593-09.

The steep slopes 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. 1.2.

5.9.2. Predictions for the Steep Slopes

The steep slopes are located across the Extension Area and, therefore, could experience subsidence movements up to the maxima described in Chapter 4.

The analysis of strains measured during the previous longwall mining at Angus Place and Springvale Collieries is provided in Section 4.3. Non-conventional movements can also occur as a result of, amongst other things, anomalous movements and downslope movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.9.3. Impact Assessments for the Steep Slopes

The maximum predicted tilt for the steep slopes of 20 mm/m (i.e. 2.0 %, or 1 in 50) is small when compared to the natural grades of the steep slopes, which are greater than 1 in 3. It is unlikely, therefore, that the mining induced tilts themselves would result in any adverse impact on the stability of the steep slopes.

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

Soil slumping has occurred once at Angus Place and Springvale Collieries, where tension cracks developed on the western valley side of Narrow Swamp, having widths greater than 50 mm and lengths around 10 metres. These cracks were naturally infilled with the surface soils over a period of months after the completion of mining. 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. 5.17.


Fig. 5.17 Photographs of Typical Tension Cracks on Steep Slopes from the NSW Coalfields

If tension cracks were to develop, as a result of the extraction of the proposed longwalls, it is possible that soil erosion could occur if these cracks were left untreated. It is possible, therefore, that 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.

5.9.4. Impact Assessments for the Steep Slopes Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum tilt at the steep slopes would be 40 mm/m (i.e. 4.0 %), which represents a change in grade of 1 in 25. The tilts at the steep slopes would still be small in comparison with the existing natural grades, which exceed 1 in 3.

If the actual curvatures or strains exceeded those predicted by a factor of 2 times, more extensive surface cracking would be anticipated, in the order of 150 mm or greater. Any significant surface cracking could be remediated by infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface.

5.9.5. Recommendations for the Steep Slopes

It is recommended that the steep slopes are visually monitored throughout the mining period and until any necessary rehabilitation measures are complete. In addition to this, it is recommended that any significant surface cracking which could result in increased erosion or restrict access to areas be remediated by infilling with soil or other suitable materials, or by locally regrading and compacting the surface. 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 significant long term impacts on the steep slopes resulting from the proposed mining.

5.10. Escarpments

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

5.11. Land Prone to Flooding or Inundation

The land naturally drains towards the Wolgan River in the western part of the Extension Area, and towards Carne Creek in the eastern part of the Extension Area. Discussions on the potential for increased ponding along the drainage lines were provided in Section 5.4. Further discussions on the potential for increased flooding and inundation are provided by the specialist surface water consultant in the report by *RPS* (2014a).

5.12. Swamps

5.12.1. Descriptions of the Swamps

The locations of the swamps within the Extension Area are shown in Drawing No. MSEC593-08. 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.

Photographs of typical shrub swamps within the Extension Area are provided in Fig. 5.18 and Fig. 5.19.

Fig. 5.18 Photographs of Tri Star Swamp (Shrub Swamp)

Fig. 5.19 Photographs of Sunnyside Swamp (Shrub Swamp)

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 Extension Area are provided in Fig. 5.20.

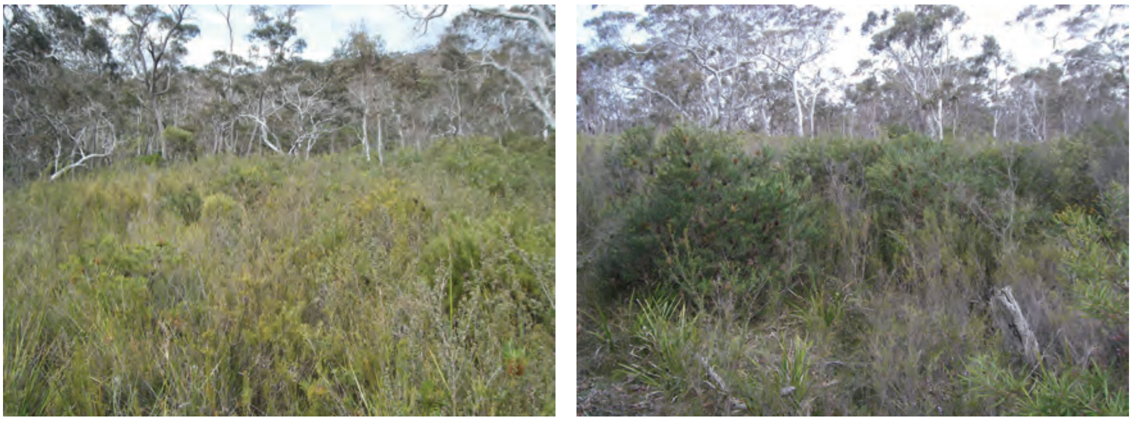


Fig. 5.20 Photographs of Typical Hanging Swamps

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 swamps in the Sydney Basin Bioregion have been listed as an Endangered Ecological Community under the NSW Threatened Species Conservation Act 1995. The shrub and hanging swamps have been classified as *Temperate Highland Peat Swamps on Sandstone* under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999.

Further descriptions of the swamps within the Extension Area are provided by the specialist ecology consultant in the report by *RPS* (2014c).

5.12.2. Predictions for the Swamps

Summaries of the maximum predicted subsidence, tilts and curvatures for the shrub swamps and the hanging swamps within the Extension Area are provided in Table 5.6 and Table 5.7, respectively. The predictions are the maxima within the extents of the swamps, at any time during or after the extraction of the proposed longwalls.

Table 5.6 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Shrub Swamps within the Extension Area

Swamp	Ref.	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})
Tri Star Swamp	(a)	1500	8	0.08	0.20
	(b)	1200	8	0.09	0.15
	(c)	1400	10	0.15	0.30
	(d)	1900	20	0.30	0.35
	(e)	25	1	< 0.01	< 0.01
Twin Gully Swamp	-	250	2	0.03	0.02
Trail 6 Swamp	-	950	7	0.08	0.20
Wolgan River Swamps	-	< 20	< 0.5	< 0.01	< 0.01
Carne Creek Tributary Swamp	-	< 20	< 0.5	< 0.01	< 0.01

Table 5.7 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Hanging Swamps within the Extension Area

Location	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})
Tri Star Swamp Catchment	1450	10	0.15	0.20
Twin Gully Swamp Catchment	75	1	0.01	< 0.01
Trail 6 Swamp Catchment	900	4	0.06	0.06
Carne Creek Tributaries Catchment	1050	11	0.20	0.15
Remaining Swamps outside the Extents of the Proposed Longwalls	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted conventional curvatures for the shrub swamps are 0.30 km^{-1} hogging and 0.35 km^{-1} sagging, which represent minimum radii of curvature of 3.3 kilometres and 3 kilometres, respectively. The maximum predicted conventional curvatures for the hanging swamps are 0.20 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 5 kilometres.

The maximum predicted conventional strains for the swamps, based on applying a factor of 10 to the maximum predicted conventional curvatures, are 3.0 mm/m tensile and 3.5 mm/m compressive for the shrub swamps, and 2 mm/m tensile and compressive for the hanging swamps.

Non-conventional movements can also occur as a result of, amongst other things, anomalous movements. The analysis of strains measured during the previous longwall mining at Angus Place and Springvale Collieries is provided in Section 4.3, which includes the strains resulting from both conventional and non-conventional anomalous movements.

The shrub swamps are located along the alignments of drainage lines and, therefore, are likely to experience valley related movements. A summary of the maximum predicted total upsidence and closure for the shrub swamps is provided in Table 5.8. Discussions on the method and the reliability of the prediction method for valley related movements are provided in Section 3.8.

Table 5.8 Maximum Predicted Total Upsidence and Closure for the Shrub Swamps

Swamp	Ref.	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
Tri Star Swamp	(a)	750	1000
	(b)	750	1000
	(c)	350	450
	(d)	600	800
	(e)	250	350
Twin Gully Swamp	-	200	300
Trail 6 Swamp	-	300	400
Wolgan River Swamps	-	< 20 ~ 75	25 ~ 150
Carne Creek Tributary Swamp	-	50	100

The predicted upsidence and closure are greatest for the parts of swamps located near the centrelines of the longwalls and less for the parts of swamps located near the chain pillars. As described in Section 3.8, the actual valley related movements are expected to be around 60 % to 90 % of the maxima predicted near the centrelines of the longwalls, and around 30 % and 60 % of the maxima predicted near the chain pillars.

The compressive strains due to valley closure for the shrub swamps which are located directly above the proposed longwalls are expected to be similar to those for the drainage lines, which are between 5 mm/m and 16 mm/m, as described in Section 5.4.2. The compressive strains due to valley closure movements for Twin Gully Swamp are predicted to be less than 2 mm/m. The compressive strains for the shrub swamps located along the Wolgan River and elsewhere outside the extents of the proposed longwalls are predicted to be less than 1 mm/m.

The hanging swamps are located on the sides of the valleys and, therefore, are not expected to experience significant valley related upsidence movements or compressive strains due to closure movements, which occur near the bases of the valleys.

5.12.3. History of Mining beneath Swamps

Swamps have been directly mined beneath on the Newnes Plateau and elsewhere in the NSW Coalfields, most notably on the Woronora Plateau in the Southern Coalfield. The following provides an overview of the history of mining beneath swamps at Angus Place and Springvale Collieries and on the Woronora Plateau in the Southern Coalfield.

Angus Place and Springvale Collieries on the Newnes Plateau

The previous longwalls at Angus Place and Springvale Collieries have been extracted directly beneath or partially beneath 13 shrub swamps and 26 hanging swamps. A summary of the mining geometries for the longwalls which have been extracted beneath these swamps is provided in Table 5.9.

Table 5.9 Mining Geometries for Previously Extracted Longwalls at Angus Place and Springvale Collieries

Colliery (LWs)	Overall Void Widths (m)	Depths of Cover (m)	Width-to Depth Ratios	Extracted Seam Thickness (m)	Maximum Observed Subsidence (m)	Observed Strains (mm/m)	Number of Swamps Fully or Partially Directly Mined Beneath
Angus Place (LW16 to LW24)	210, 230 and 260	220 ~ 360	0.70 ~ 0.95	2.8 ~ 3.2	1.0 ~ 1.2	Typically between 3 tensile and 5 comp.	1 shrub swamp, and 1 partial hanging swamp
Angus Place (LW920 to LW970)	260 and 290	220 ~ 380	0.75 ~ 1.0	3.1 ~ 3.4	1.0 ~ 1.2	Typically between 3 tensile and 5 comp.	7 fully and 2 partial shrub swamps, and 9 fully and 2 partial hanging swamps
Springvale (LW1 and LW401 to LW414)	255, 265 and 315	220 ~ 420	0.75 ~ 1.0	2.8 ~ 3.4	1.0 ~ 1.4	Typically between 1 tensile and 5 comp.	1 fully and 2 partial shrub swamps, and 11 fully and 3 partial hanging swamps

Surface impacts have been observed at four swamps which were directly mined beneath by the previously extracted longwalls at Angus Place and Springvale Collieries, being Narrow Swamp North, Narrow Swamp South, East Wolgan Swamp and Junction Swamp. Investigations into these impacts were undertaken by Goldney et al (2010), who were engaged by the Federal Department of the Environment, Water, Heritage and the Arts (now referred to as SEWPaC), which stated that:-

- Narrow Swamp North – The impacts comprised "*water ripping, waterlogging and changed water quality. A variable depth of sand has been deposited over the swamp. Ecosystem cycles and resilience have been adversely impacted and ecological and geomorphic thresholds exceeded. The observed impacts are very likely due to flow releases from Springvale mine. Any adverse impacts due to LWM* [Longwall Mining] *and mine subsidence per se, if present, are likely to be completely masked by the major impacts described.*" (Goldney et al, 2010).
- Narrow Swamp South – The impacts comprised an "*incision, a massive active head cut, and with significant impairment of resilience and ecosystem processes*" and that the "*potential impacts from mine water discharge are a very likely explanation along with possible direct impacts from LWM. Any impacts from LWM are likely masked by the possible significant impacts of mine water discharge.*" (Goldney et al, 2010).
- East Wolgan Swamp – The impacts comprised "*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 exceedence.*" and that these impacts "*are likely due to synergisms between subsidence induced impacts and mine water discharge.*" (Goldney et al, 2010).
- Junction Swamp – The impacts comprised "*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 exceedence*" and that "*Very likely significant adverse impacts due to LWM complicated by erosion from nearby roads.*" (Goldney et al, 2010). In one location, however, "*The incision was assessed as predating LWM due to mature vegetation being present within a deep, stable incision.*" (Goldney et al, 2010).

It is also noted, that there were three control sites (i.e. swamps) "*that were impacted, but not undermined by LWM.*" (Goldney et al, 2010). The impacts included burning "*apparently as a result of a NSW Forests fuel reduction burn*", deposition of a sand layer "*likely due to valley slope erosion associated with pine plantation management*", and "*sheet erosion deposited from the surrounding valley sides due to indeterminate causes, but possibly fire or management related. The impacts on these three sites are independent of LWM.*" (Goldney et al, 2010).

The report by Goldney et al (2010) indicates that the impacts observed at Narrow Swamp North and Narrow Swamp South were primarily the result of mine water discharge, but it is possible that some lesser impacts have also occurred as a result of mine subsidence ground movements, but these could not be quantified. The impacts observed at East Wolgan Swamp and Junction Swamp appear to be the result of a combination of mine subsidence ground movements, mine water discharge and erosion from nearby roads, however, the proportion of each of these mechanisms could not be quantified.

Centennial has recognised that past mining related surface activities, i.e. the discharge of high quantities of mine water and construction of various roads and access paths, have resulted in surface impacts to some swamps. Centennial has developed management plans to minimise the potential for future impacts resulting from these mining related surface activities.

The mining layout has also been designed so as to reduce the potential impacts on the shrub swamps resulting from mine subsidence movements. The proposed LW1010 has also been setback such that Twin Gully Swamp will not be directly mined beneath. The widths of the proposed longwalls have also been narrowed beneath Tri Star and Trail 6 Swamps, which is discussed further in Section 5.12.4.

Mining on the Woronora Plateau

The Woronora Plateau is located in the Southern Coalfield of New South Wales. The upland swamps are generally categorised into two fundamental types, which are referred to as *Valley Infill* and *Headwater* type swamps in the Southern Coalfield. The *valley infill swamps* develop along drainage lines near the bases of valleys, similar to the *shrub swamps* of the Newnes Plateau. The *headwater swamps* develop within relatively low sloped areas of the sides of valleys on weathered sandstone where perched aquifers exist, similar to the *hanging swamps* of the Newnes Plateau.

Whilst the soil and vegetation types for the swamps on the Woronora Plateau differ from those for the swamps on the Newnes Plateau, these swamps share many similarities including the mechanisms of development, nature of the substrate and underlying bedrock and, hence, their susceptibility to mine subsidence. The extensive experience of mining beneath the swamps on the Woronora Plateau, therefore, provides supporting information for assessing the potential impacts for swamps on the Newnes Plateau.

Over 500 swamps have been directly mined beneath in the Southern Coalfield. A summary of the mining geometries for the more recent longwall and total extraction mining beneath swamps on the Woronora Plateau is provided in Table 5.10 below.

Table 5.10 Mining Geometries for More Recent Longwall and Total Extraction Mining beneath Swamps on the Woronora Plateau

Colliery	Type of Extraction	Overall Void Widths (m)	Depths of Cover (m)	Width-to Depth Ratios	Extracted Seam Thickness (m)	Maximum Observed Subsidence (m)	Maximum Observed Conventional Strains (mm/m)	Number of Swamps Directly Mined Beneath
Appin	LW20 to LW29	205	400 ~ 480	0.4 ~ 0.5	2.2 ~ 2.7	1.2	1 tension 2 compression	2 fully and 2 partially
Bellambi	LW301 to LW310 and LW501 to LW509	110 ~ 190	330 ~ 460	0.3 ~ 0.5	2.5	1.0	1 tension 1 compression	4 partially
Coal Cliff	Total Extraction	> 1000	350 - 400	> 2.5	2.8	1.7	1.5 tension 3 compression	1 fully 2 partially
Cordeaux	LW17 to LW20	140 ~ 150	440	0.35	2.65	0.9	1 tension 2 compression	1 partially
Darkes Forest	Total Extraction	> 800	400	> 2.0	3	1.5	*Not surveyed*	> 20
Delta	LW11B, LW14 and LW17	130 ~ 150	320 ~ 360	0.4 ~ 0.5	3.5 ~ 3.8	0.3	*Not surveyed*	4 partially
Dendrobium	LW3 to LW8	250	200 ~ 400	0.6 ~ 1.3	3.6 ~ 3.9	1.4 ~ 2.2	2 tension 8 compression	3
Elouera	LW1 to LW11	150 ~ 185	320 ~ 370	0.4 ~ 0.6	3.0 ~ 3.6	0.7 ~ 1.4	2 tension 3 compression	8 fully and 3 partially
Excelsior	Total Extraction	> 600	300	> 2.0	3	1.5	*Not surveyed*	Swamps across half of the mining area
Metropolitan	LW1 to LW21	125 to 160	420 ~ 520	0.2 ~ 0.4	2.5 ~ 3.5	1.1 ~ 1.45	3 tension 3 compression	7 fully 6 partially
North Bulli	Total Extraction	> 400	300	> 2.0	3	1.2	*Not surveyed*	Swamps across the majority of mining area
South Bulli	LW1 to LW11	120 ~ 150	320 ~ 340	0.4 ~ 0.5	2.7	0.9	1 tension 2 compression	2 fully 1 partially
South Bulli	LW202 to LW212 and LWK to LWO	140 ~ 190	400 ~ 500	0.4	2.1 ~ 2.5	1.2	1 tension 2 compression	2 fully 3 partially
South Clifton	Total Extraction	> 1000	360	> 2.0	3	1.6	*Not surveyed*	Swamps across the majority of mining area
West Cliff	Total Extraction	370	430 ~ 460	0.8 ~ 0.9	2.2	1.2	*Not surveyed*	1
West Cliff	LW8 and LW16 to LW24	160 ~ 210	450 ~ 470	0.3 ~ 0.5	2.2 ~ 2.8	1.0	1 tension 2 compression	5
Wongawilli	Total Extraction (Multi-seam)	100 ~ 450	260 ~ 310	0.4 ~ 1.7	1.5 ~ 4.5	2.4	2 tension 3 compression	8

Impacts above previous longwall mining have been reported in only a few swamps on the Woronora Plateau, most notably being Drill Hole Swamp at Wongawilli Colliery, Flat Rock Swamp at Darks Forest and Metropolitan Collieries, and Swamps 18 and 19 at Elouera Colliery, which are all Valley Infill swamps. A summary of these swamps with reported impacts is provided in Table 5.11 below.

Table 5.11 Impacted Swamps on the Woronora Plateau

Type	Drill Hole Swamp	Flat Rock Swamp	Swamp 18	Swamp 19
Colliery	Wongawilli	Darks Forest and Metropolitan	Elouera	Elouera
Longwalls	4NA-4NB and 3NB1-3NB4	LW9 and LW10	LW1 to LW4, LW9 and LW10	LW3 to LW5
Seam	Bulli and Wongawilli	Bulli	Wongawilli	Wongawilli
Year Mined Beneath	1966 to 1975	2001 to 2002	1994 to 2005	1997 to 2000
Depth of Cover (m)	300 (Wongawilli) 270 (Bulli)	400	320	320
Seam Thickness (m)	3 (Wongawilli) 1.7 (Bulli)	3.4	3.6	3.6
Overall Void Widths (m)	450	140	160	185
Pillar Widths (m)	-	35	40	40
Width-to-Depth Ratios	1.5	0.35	0.5	0.6
Monitoring Line	Kapp	-	Maldon-Dombarton	Maldon-Dombarton

Type	Drill Hole Swamp	Flat Rock Swamp	Swamp 18	Swamp 19
Monitoring Date	1973	1970's & 2003	2005	2005
Maximum Observed Subsidence (m)	2.4	1.2	1.2	1.4
Maximum Observed Strain (mm/m)	8	-	-	-
Maximum Observed Valley Closure (mm)	100	700	-	-

The NSW Government established an independent Inquiry into underground coal mining in the Southern Coalfield in December 2006 and appointed an Independent Expert Panel to conduct the Inquiry. The Inquiry was established by the Minister for Planning and the final report of the Inquiry (DP&I, 2008) stated that:-

> "*The swamps of the Woronora Plateau have been studied in some detail. Pioneering work was done in the 1980s by Dr Ann Young (Young 1982, 1986a, 1986b). Other work has been undertaken by DECC, Illawarra Coal (through its consultants Biosis and Ecoengineers) and by Macquarie University as part of a collaborative research effort with SCA. Localised studies have also been conducted by the SCA as part of impact assessments in respect of development of the Kangaloon aquifer, and by other mining companies, including Helensburgh Coal*."

> "*Some research has been undertaken in an endeavour to determine whether mining subsidence has contributed to the impacts which have occurred at a number of valley infill swamps in the Southern Coalfield. Probably the most detailed work was undertaken in 2005 by Macquarie University in conjunction with the SCA (Tomkins and Humphreys 2006)*."

Tomkins and Humphreys (2006) were engaged by the Sydney Catchment Authority to undertake an assessment of erosion in swamps on the Woronora Plateau. Their investigation included Swamp 18, Flat Rock Swamp and Drill Hole Swamp. The conclusions from the report were that:-

> *"Human disturbance in the catchment, particularly direct physical disturbance such as at Drillhole Swamp has been found to be an important trigger of erosion of swamps. The impact of mine subsidence, however is less clear. Both Swamp 18 and Flat Rock Swamp featured scour pools and gully erosion well before any direct effects of mining were observed. It may be likely that dewatering of swamps due to mining increases the sensitivity of swamps to other influences such as wildfires."*

The report also stated that:-

> *"The impacts of mining on erosion of Swamp 18 and Flat Rock Swamp is less clear as both swamps were already in the process of erosion prior to the commencement of known mining and ground subsidence. It is possible that subsidence accelerated dewatering of Swamp 18 during the late 1990's which enhanced burning during the 2001-02 wildfires. Alternatively, the gully erosion through the lower part of the swamp prior to 1990 could have drained the swamp sufficiently to cause a similar effect."*

The Southern Coalfields Inquiry (DP&I, 2008) stated that:-

> *"The Panel was not made aware of any significant impacts on headwater swamps caused by mining subsidence. Although it is likely that subsidence impacts observed elsewhere in the landscape are likely to take place beneath such swamps, the Panel is not in a position to draw firm conclusions regarding the potential for subsidence to have adverse consequences on these swamps.*
>
> *Most impacted swamps that the Panel was made aware of were valley infill swamps (e.g. Flatrock Swamp and Swamps 18 and 19). However, at all sites inspected by the Panel, there had been a range of other environmental factors in play, including evidence of pre-existing scour pools, previous initiation of erosion, concurrent drought, and subsequent heavy rainfall and/or severe bushfires. The sequence of events was not clear in relation to the swamp impacts (drying, erosion and scouring, water table drop, burning, vegetation succession, etc).*
>
> *Whilst the Panel cannot be certain that subsidence either initiated or contributed to the overall damage at these swamps, the available evidence suggests a significant possibility that undermining of valley infill swamps could cause drainage, water table drop and consequent degradation to swamp water quality and associated vegetation. Further research is required before a definitive conclusion can be reached."*

The inquiry also found in relation to Drill Hole Swamp that:-

> *"...gully erosion was not directly caused by mining subsidence, per se. Significant site disturbance took place as a result of site clearing, soil disturbance and erosion associated with the drilling of a stratigraphic drillhole in 1976 for the Reynolds Inquiry. Tomkins and Humphreys conclude that the cause of the gully erosion was this site disturbance, coupled with an extreme rainfall event."*

Studies undertaken by Illawarra Coal on the affects of longwall mining on the swamps at Elouera Colliery and Dendrobium Mine have found that the overall soil moisture conditions in the swamps, which have experience mine subsidence movements, were not significantly different to swamps which have not experienced mine subsidence movements (IC, 2011).

Richardson and Ryan (2007) presented a paper at the 7th Triennial Mine Subsidence Technological Society Conference which outlined the findings of vegetation monitoring of Swamp 18A which was directly mined beneath at Elouera Colliery. The paper states that:-

> *"Our study reports that since the commencement of the monitoring program in 2003 there has been no detectible alteration of vegetation structure or composition within the Upland Swamp that has been mined beneath when compared with the Upland Swamps that have not. Our study supports the idea that Upland Swamps are not likely to be characteristically altered by mine subsidence in the short to medium term. It also supports the need for long-term monitoring of ecological values in relation to subsidence and the value of an interdisciplinary approach to ecological monitoring projects."*

It appears from these studies, that whilst over 500 swamps have been directly mined beneath on the Woronora Plateau, impacts have been observed in only a few swamps. In each of these cases, however, it appears that impacts have been initiated by other influences, such as bush fires, heavy rainfall, vehicular access and the installation of monitoring and other site investigations. Whilst mine subsidence ground movements may have accelerated these impacts, the influence of mine subsidence ground movements is still unclear. The experience shows that the impact of mine subsidence ground movements on swamps on the Woronora Plateau is relatively low.

5.12.4. Mine Design Considerations for the Swamps

Tri Star Swamp and Trail 6 Swamp are the only two shrub swamps which are located directly above the proposed longwalls. The proposed LW1004 to LW1006 and the proposed LW1016 and LW1017, which mine beneath these swamps, have been narrowed to overall void widths of 261 metres. Elsewhere, the proposed longwalls have overall void widths of 360 metres.

Adopting overall longwall void widths of 261 metre beneath the shrub swamps has resulted in the predicted subsidence parameters reducing by around 20 % to 30 % when compared to equivalent longwalls having overall void widths of 360 metres.

The depth of cover beneath the shrub swamps, directly above the proposed longwalls, varies between around 280 metres and 330 metres for Tri Star Swamp, and around 300 metres and 330 metres for Trail 6 Swamp. The longwall width-to-depth ratio beneath these swamp, therefore, are within the range of 0.80 to 0.90 (i.e. critical in width).

The longwall width-to-depth ratios where the longwalls have been previously mined beneath shrub swamps were in the ranges of 0.70 to 0.95 for Angus Place LW16 to LW25, 0.75 to 1.0 for Angus Place LW920 to LW970, 0.70 to 0.85 for Springvale LW404 to LW409, and 0.75 to 1.0 to Springvale LW410 to LW414.

The width-to-depth ratios for the proposed longwalls, beneath Tri Star and Trail 6 Swamps, therefore, are similar to those where the previously extracted at Angus Place and Springvale Collieries have mined directly beneath shrub swamps.

5.12.5. Impact Assessments for the Swamps

The impact assessments for the swamps based on the predicted mine subsidence movements are provided in the following sections. These assessments do not consider the potential impacts due to other mining related activities, such as mine water discharge, installation of monitoring, or vehicular access, which are covered by the relevant management plans.

The assessments provided in this report should be read in conjunction with the assessments provided by the specialist surface water consultant in the report by *RPS* (2014a), the specialist ground water consultants in the reports by *RPS* (2014b) and *CSIRO* (2013), and the specialist ecology consultant in the report by *RPS* (2014c).

Potential for Changes in Surface Water Flows

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 captured water within swamps.

The maximum predicted tilts are 20 mm/m (i.e. 2.0 %, or 1 in 50) for the shrub swamps and 11 mm/m (i.e. 1.1 %, or 1 in 90) for the hanging swamps within the Extension Area. The mining induced tilts are small when compared with the natural gradients within the swamps. This is illustrated in Fig. 5.21 to Fig. 5.24, which show the natural grades and the predicted post mining grades along the alignments of the drainage lines through the shrub swamps.

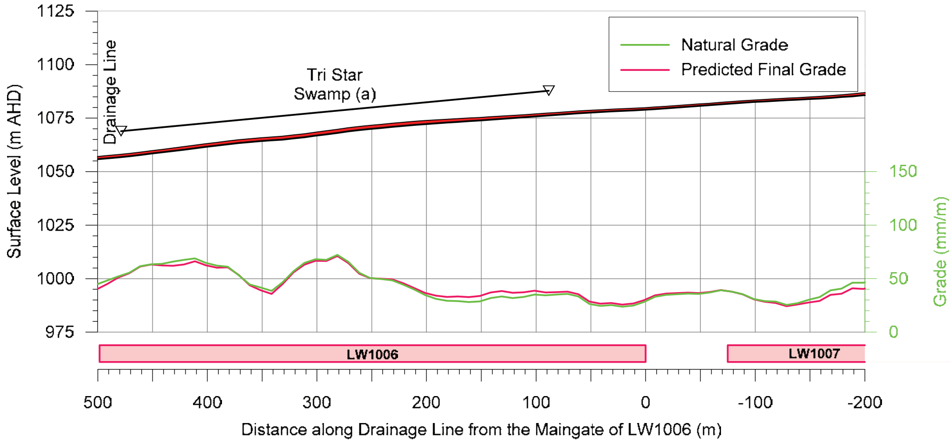


Fig. 5.21 Natural and Predicted Post Mining Levels and Grades for Tri Star Swamp (a)

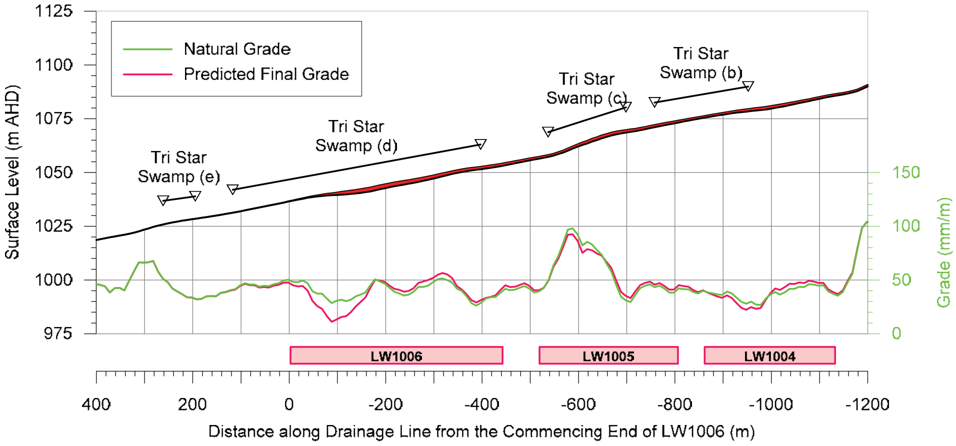


Fig. 5.22 Natural and Predicted Post Mining Levels and Grades for Tri Star Swamp (b) ~ (e)

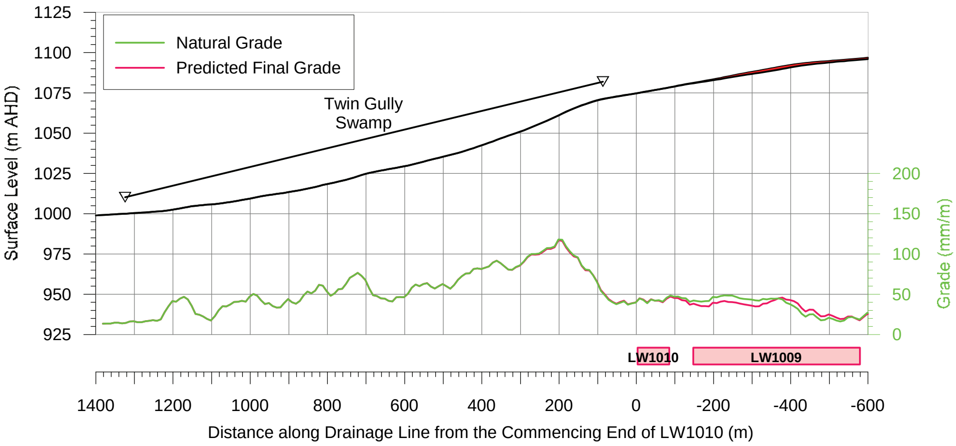


Fig. 5.23 Natural and Predicted Post Mining Levels and Grades for Twin Gully Swamp

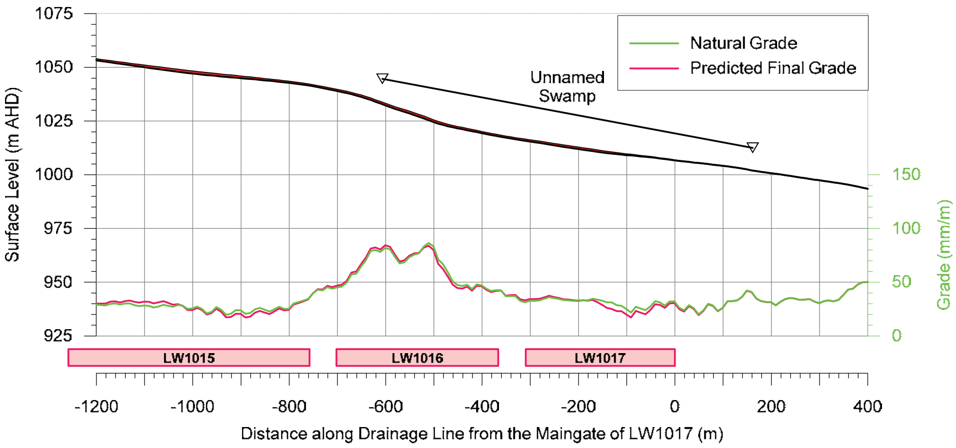


Fig. 5.24 Natural and Predicted Post Mining Levels and Grades for Trail 6 Swamp

It can be seen from the above figures, that the predicted post mining grades are similar to the natural grades within the shrub swamps. There are no predicted significant reductions or reversals of grade. The hanging swamps are located on the sides of the valleys and, therefore, that natural gradients are greater than those shown for the shrub swamps and, in addition to this, the predicted mining induced tilts are less.

It is not expected, therefore, that there would be any adverse changes in ponding or scouring within the swamps resulting from the predicted mine subsidence movements. It is also not anticipated that there would be any significant changes in the distribution of the stored surface waters within the swamps as a result of the mining induced tilt or vertical subsidence.

Whilst scouring was observed in a number of swamps located above the previously extracted longwalls at Angus Place and Springvale Collieries, investigations have shown that these were generally the result of other activities such as mine water discharge, rather than mine subsidence itself, as described in Section 5.12.3.

Further discussions on the potential impacts due to changes in surface water flows and storage are provided by the specialised surface water consultant in the report by *RPS* (2014a) and the specialist ecology consultant in the report by *RPS* (2014c).

Potential for Cracking in the Swamps and Fracturing of Bedrock

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

The swamps which are located outside the extents of the proposed longwalls, including Twin Gully Swamp and 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 the bedrock beneath these swamps would experience any significant fracturing.

Fracturing has been observed in streams located outside the extents of previously extracted longwalls in the NSW Coalfields. Minor and isolated fracturing has been observed up to 400 metres from longwalls, however, these have occurred within large river valleys in the Southern Coalfield and have not resulted in any adverse impacts. Hence, it is possible that some minor and isolated fracturing could occur in the bedrock beneath the swamps located outside the extents of the proposed longwalls, however, it is unlikely to result in any adverse impacts on these swamps.

The swamps which are located directly above the proposed longwalls are predicted to experience tensile strains greater than 0.5 mm/m and compressive strains greater than 2 mm/m. It is expected, therefore, that fracturing would occur in the top most bedrock beneath these swamps.

The surface cracking across the mining area is expected to be generally isolated and minor in nature, due to the reasonable depths of cover which typically vary between 270 metres and 450 metres, and due to the plasticity of the surface soils which allows them to more readily absorb the ground strains. Surface crack widths are expected to be similar to those observed above the previously extracted longwalls at Angus Place and Springvale Collieries, which were typically between 5 mm and 25 mm, but with isolated surface cracking in some locations greater than 50 mm.

The shrub swamps have peat layers which overlie the shallow natural surface soils and underlying bedrock along the alignments of the drainage lines. In most cases, cracking would not be visible at the surface within these swamps, except where the depths of bedrock are shallow or exposed. The shrub swamps comprise significant quantities of sediment and, therefore, fracturing of shallow bedrock beneath these swamps are likely to be filled with soil during subsequent flow events along the drainage lines.

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 movements, and due to the higher depths of cover along the valley sides.

Whilst some minor surface cracking could occur in the swamps resulting from the extraction of the proposed longwalls, the previous experience of mining beneath swamps at Angus Place, Springvale and in the Southern Coalfield indicate that the likelihoods and extents of these impacts are very small.

The valley related upsidence movements could result in the dilation of the strata beneath the shrub swamps. It has been observed in the past, that the depth of fracturing and dilation of the uppermost bedrock, resulting from valley related movements, is generally less than 10 metres to 15 metres (Mills 2003, Mills 2007, and Mills and Huuskes 2004).

The dilated strata beneath the drainage lines, upstream of the swamps, could result in the diversion of some surface water flows beneath parts of the shrub swamps. It is noted, however, that the drainage lines upstream of the swamps are generally ephemeral and, therefore, surface water flows occur during and shortly after rainfall events. Any diverted surface water flows are expected to remerge short distances downstream, due to the limited depth of fracturing and dilation and due to the high natural stream gradients.

An environmental monitoring program was established to assess the effects of longwall mining on the groundwater systems associated with the swamps at Angus Place and Springvale Collieries. The monitoring comprised swamp piezometers, shallow aquifer piezometers and multi-level vibrating wire piezometers at Junction, Sunnyside, Sunnyside West and West Wolgan Swamps. The monitoring results were reviewed by RPS (2012) which found that:

> "*In general, swamp water level fluctuations show a strong relationship to the CRD* [cumulative rainfall distribution] *for both A and C type swamps rather than a relationship due to longwall mining*".

That is, the monitoring results provided no evidence that longwall mining had affected the groundwater systems for these swamps. Further discussions on the potential impacts on the shallow groundwater system are provided by the specialist groundwater consultants in the reports by RPS (2014b) and CSIRO (2013).

The width-to-depth ratios for the proposed beneath the shrub swamps are typically between 0.80 and 0.90, which are similar to those where the previously extracted at Angus Place and Springvale Collieries have mined directly beneath shrub swamps. Also, the predicted conventional and valley related movements for the swamps located above the proposed longwalls are similar to the ranges predicted for the swamps previously mined beneath on the Woronora Plateau. The potential impacts for the swamps within the Extension Area, therefore, are expected to be similar to those which have occurred where longwalls have been previously extracted beneath swamps.

As described in Section 5.12.3, 13 shrub swamps and 26 hanging swamps have been directly or partially mined beneath at Angus Place and Springvale Collieries, and over 500 swamps have been directly mined beneath on the Woronora Plateau in the Southern Coalfield. The studies undertaken indicate that the incidence of impacts on swamps due to mine subsidence ground movements is very low and, in some of these cases, the impacts that were observed were associated with natural events or mining related surface activities, as described in Section 5.12.3. It is expected, therefore, that the incidence of impacts on the swamps within the Extension Area resulting from mining induced ground movements will also be low.

Further discussions on the potential impacts due to changes in surface water flows and storage are provided by the specialised surface water consultant in the report by *RPS* (2014a) and the specialist ecology consultant in the report by *RPS* (2014c).

5.12.6. Impact Assessments for the Swamps Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum tilts would be 40 mm/m (i.e. 4.0 %, or 1 in 25) for the shrub swamps, and 22 mm/m (i.e. 2.2 %, or 1 in 45) for the hanging swamps. In this case, the mining induced tilts would still be similar to or less than the natural gradients within the swamps, which typically vary between 25 mm/m and 300 mm/m. It would still be unlikely that there would be any adverse impacts on the surface water flows and storage within the swamps.

If the actual curvatures, strains or valley related movements exceeded those predicted by a factor of 2 times, the likelihood and extent of fracturing, buckling and dilation in the topmost bedrock would increase for the swamps which are located directly above the proposed longwalls. As discussed previously, significant quantities of sediment are found above the bedrock at the swamps which is highly fractured and weathered naturally.

While the predicted ground movements are important parameters when assessing the potential impacts on the swamps, experience from mining beneath swamps at Angus Place, Springvale and in the Southern Coalfield indicate that the potential for impacts is low.

Further discussions on the potential impacts on the swamps are provided by the specialist surface water consultant in the report by *RPS* (2014a), the specialist ground water consultants in the reports by *RPS* (2014b) and *CSIRO* (2013), and the specialist ecology consultant in the report by *RPS* (2014c).

5.12.7. 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 movements during 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 observed 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 ground water 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 ground water 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.

5.13. Water Related Ecosystems

There are water related ecosystems within the Extension Area, which are described and assessed in the report prepared by *RPS* (2014c).

5.14. Threatened or Protected Species

An investigation of the flora and fauna within the Extension Area has been undertaken, which is described and assessed in the reports prepared by *RPS* (2014c).

5.15. National Parks or Wilderness Areas

There are no National Parks or Wilderness Areas located within the Extension Area. The *Gardens of Stone National Park* (the National Park) is located immediately to the north of the Extension Area, at a distance of 170 metres from LW1014A, at its closest point to the proposed longwalls.

The National Park is located outside the 26.5 degree angle of draw line from the limit of extraction for the proposed longwalls. Whilst the area closest to the proposed longwalls could experience very low levels of vertical subsidence (i.e. less than 20 mm), it is not predicted to experience any measureable conventional tilts, curvatures or strains. The analysis of strains measured outside the 26.5 degree angle of draw line, for previously extracted longwalls at Angus Place and Springvale Collieries, is discussed in Section 4.3.3.

The National Park is also likely to experience small far-field horizontal movements, which are described in Sections 3.3 and 4.4. These movements themselves do not result in impacts on natural or built features, except where they are experienced by large structures which are sensitive to differential horizontal movements, such as freeway bridges, or large industrial buildings.

The available far-field horizontal movements measured outside the extents of mining (i.e. above solid coal) in the NSW Coalfields are illustrated in Fig. 4.5. The magnitudes of far-field horizontal movements are dependent on a number of factors, including the panel widths, depths of cover, extraction heights, surface topography, seam dip, horizontal in situ stress, the presence of geological structures and the distance from the active longwall.

The majority of the empirical data comes from the Southern Coalfield where the depths of cover are typically between 400 metre and 500 metres and, hence, are higher than those at Angus Place Colliery. This far-field horizontal movement data has been reproduced in Fig. 5.25, below, with the distance from the active longwall normalised based on depth of cover.

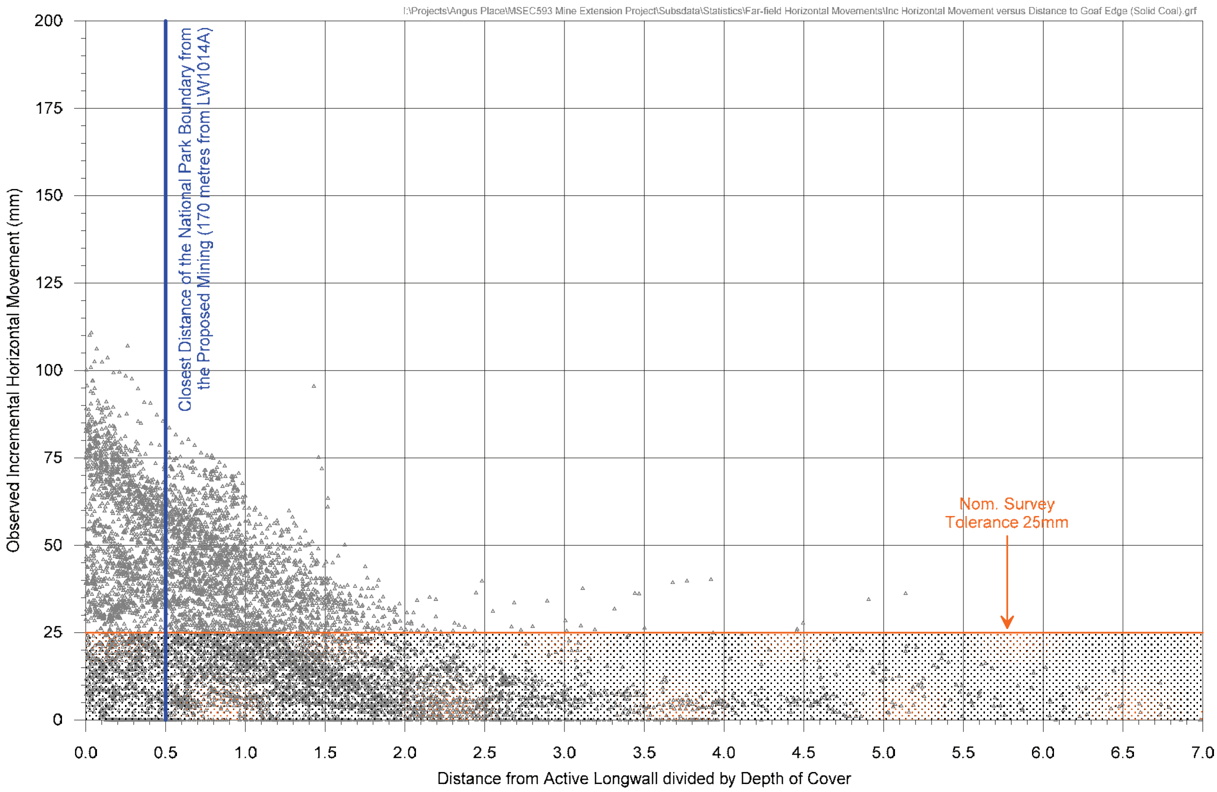


Fig. 5.25 Observed Incremental Far-Field Horizontal Movements above Solid Coal Only

It can be seen from the above figure, that far-field horizontal movements of up to 85 mm have been measured at an equivalent distance of the National Park boundary from the proposed longwalls, i.e. at distances greater than 0.5 times the depth of cover (as indicated by the vertical blue line in the above figure).

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 kilometres north of Appin Colliery Longwall 703. The depth of cover in this location was around 575 metres and, therefore, this represents an equivalent distance of 5.1 times the depth of cover.

Absolute far-field horizontal movements themselves do not result in impacts on natural or built features. The potential for impacts result from the differential horizontal movements (i.e. strain). Far-field horizontal movements tend to be bodily movements towards the extracted goaf area which are accompanied by very low levels of strain.

This is illustrated in Fig. 4.3, which shows that the strains measured outside the 26.5 degree angle of draw line at Angus Place and Springvale Collieries. The maximum observed strains were 1.3 mm/m tensile and 0.5 mm/m compressive, with the strains otherwise being typically less than 1 mm/m. The experience at Angus Place and Springvale Collieries show that these low level strains outside of the 26.5 degree angle of draw line do not result in any noticeable cracking in the surface soils.

It is not expected, therefore, that there would be any adverse impacts within the National Park resulting from the far-field horizontal movements, even if the actual movements exceeded the maxima that has been previously observed at similar distances elsewhere NSW Coalfields by a factor of 2 times.

The streams within the National Park could experience small valley related upsidence and closure movements. The sections of Carne Creek and Drainage Line 3 within the National Park are located at minimum distances of 750 metres north-east of LW1014A and LW1017, respectively, at their closest points to the proposed longwalls. The nearest ephemeral tributary within the National Park is located 220 metres north-east of LW1014A, at its closest point.

The valley closure movements measured outside the extents of mining (i.e. above solid coal) in the NSW Coalfields are illustrated in Fig. 5.26. The majority of the available monitoring data comes from the Southern Coalfield, with the higher movements occurring in the large river valleys, including along the Nepean, Cataract and Georges Rivers.

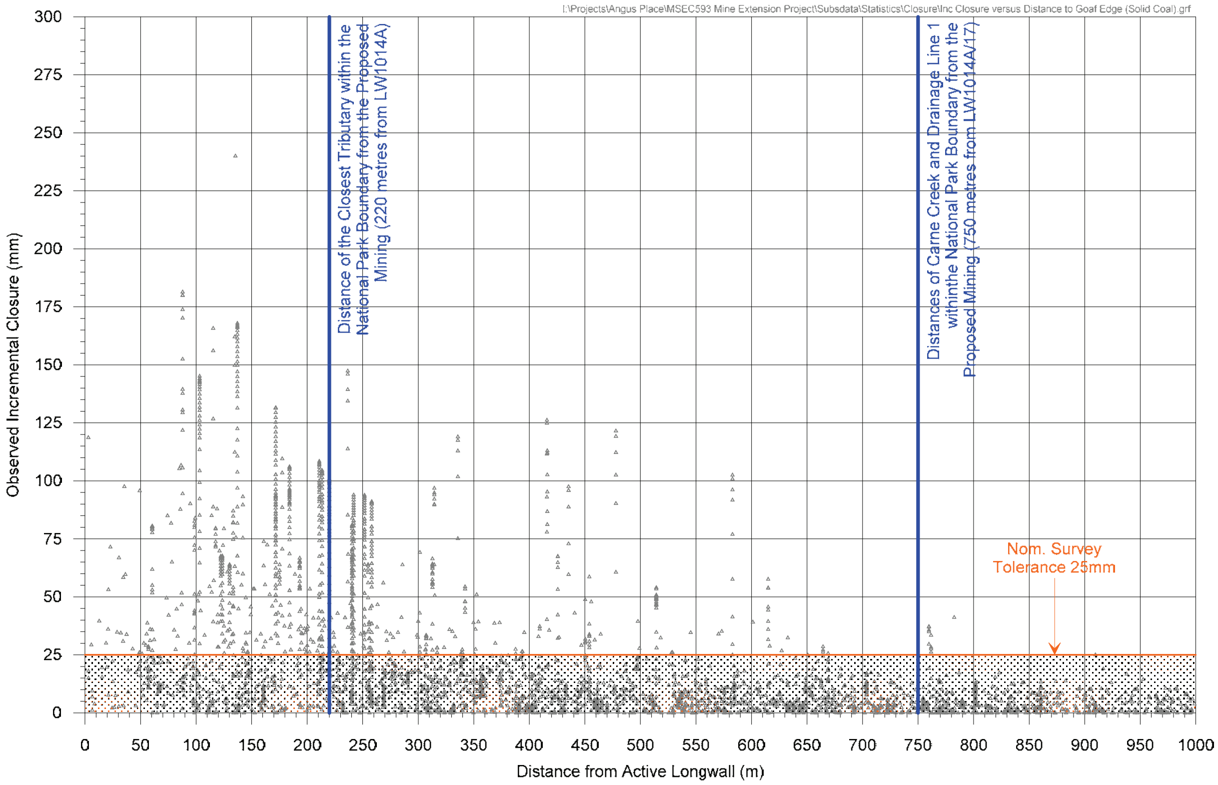


Fig. 5.26 Observed Incremental Valley Closure Movements above Solid Coal Only

It can be seen from the above figure, that closure movements of up to 40 mm have been measured at an equivalent distance as the sections of Carne Creek and Drainage Line 3, within the National Park, from the proposed longwalls. Also, closure movements of up to 150 mm have been measured at an equivalent distance as the nearest tributary within the National Park from the proposed longwalls.

The furthest valley closure 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 800 metres, which occurred at the Cataract Dam Closure Lines near Bulli Colliery.

The magnitudes of valley related movements are dependent on a number of factors, including the distance from the side of the active panel, the distance from the end of the active panel, the magnitude of subsidence above the active panel and the height of the valley. The 2002 ACARP method (Waddington and Kay, 2002) can be used to predict the valley related upsidence and closure movements for the streams within the National Park based on these factors.

The maximum predicted upsidence and closure within the sections of Carne Creek and Drainage Line 3 within the National Park, based on the 2002 ACARP method, are both less than 20 mm. It is noted, that these predictions are expected to be conservative, as the 2002 ACARP method is based on upper bound prediction curves which have been drawn over all the available monitoring data from the NSW Coalfields.

Even if the actual closures along the sections of Carne Creek and Drainage Line 3, within the National Park, were similar to the maximums observed at these distances elsewhere in the NSW Coalfields, i.e. 40 mm closure, it would still be expected that the compressive strains in the bases of the valleys would be less than 0.5 mm/m. The fracturing of bedrock is typically not observed where the compressive strains are less than 2 mm/m.

It is not expected, therefore, that there would be any fracturing in the beds of Carne Creek and Drainage Line 3, within the National Park, even if the actual valley related movements exceeded those predicted by a factor of 2 times.

The ephemeral tributaries within the National Park located closest to the proposed longwalls could experience small valley related movements. The compressive strains are expected to be similar to those observed in tributaries located at similar distances from previously extracted longwalls in the NSW Coalfields. The distribution of measured compressive strains for drainage lines which were located more than 170 metres outside the extents of previously extracted longwalls in the NSW Coalfields is provided in Fig. 5.27. The results are based on valleys which have effective heights less than 30 metres and bay lengths greater than 10 metres.

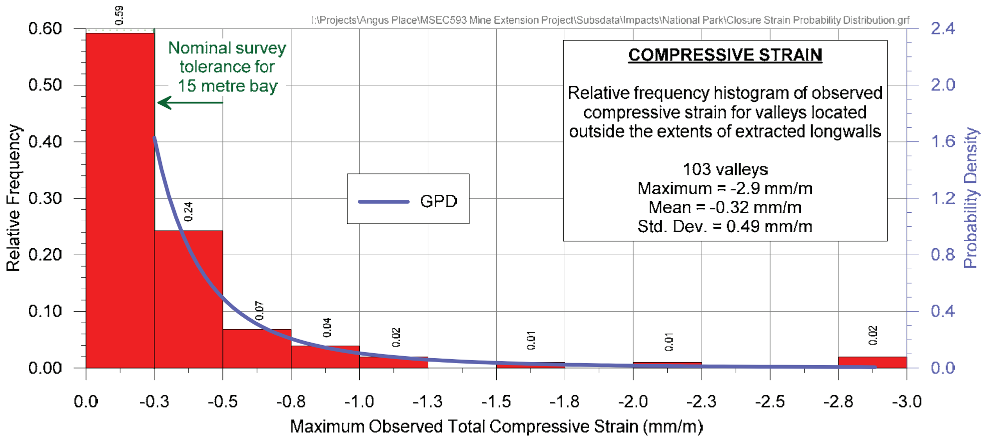


Fig. 5.27 Distribution of Closure Strains for Drainage Lines Located More than 170 metres Outside the Extents of Previously Extracted Longwalls in the NSW Coalfields

It can be seen from the above figure, that the drainage lines located more than 170 metres outside the extents of the previously extracted longwalls typically experience compressive strains less than 2 mm/m. The maximum observed compressive strain for this dataset was 2.8 mm/m

As described previously, fracturing of bedrock is generally not observed where the compressive strains are less than 2 mm/m. It is possible, therefore, that minor and isolated fracturing could occur in the bedrock of the tributaries that are located closest to the proposed longwalls. It would not be expected, however, that these fractures would result in any adverse impacts on the surface water flows or quality. This is supported by the Planning and Assessment Commission (PAC) report for the Bulli Seam Operations (PAC, 2010) which stated that:-

> "*Limited measurements suggest a threshold total compressive strain value for total diversion of flow in sandstone environments of the order of 7 mm/m, however the database is too small to be reliable at this point in time*".

It is also supported by the extensive experience of longwall mining in the NSW Coalfields where only minor and isolated fractures have been experienced in streams at the distance of the National Park from the proposed longwalls.

The furthest distance of an observed fracture from longwall mining was at the base of Broughtons Pass Weir, which was located approximately 415 metres from Appin Colliery Longwall 401. Another minor fracture was also recorded in the upper Cataract River, approximately 375 metres 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.

Whilst there have been impacts observed on standing pool water levels outside the extents of longwall mining, in almost all these cases the streams were directly mined beneath at the point of impact, or directly mined beneath immediately upstream or downstream of the impact site.

The furthest known impact on a standing pool water level, where the stream was not directly mined beneath, occurred along the Georges River at West Cliff Colliery, where the controlling rock bar was located at a distance of 40 metres from the end of Longwall 33. It should then be highlighted that, whilst the river was not directly mined beneath, the longwalls mined beneath the valley side and up to the river.

The furthest measured distances to far-field horizontal and valley closure movements (i.e. above survey tolerance) and the furthest distances to observed fracturing and impacts on standing pools (when the stream is located above solid coal) have been illustrated in Fig. 5.28.

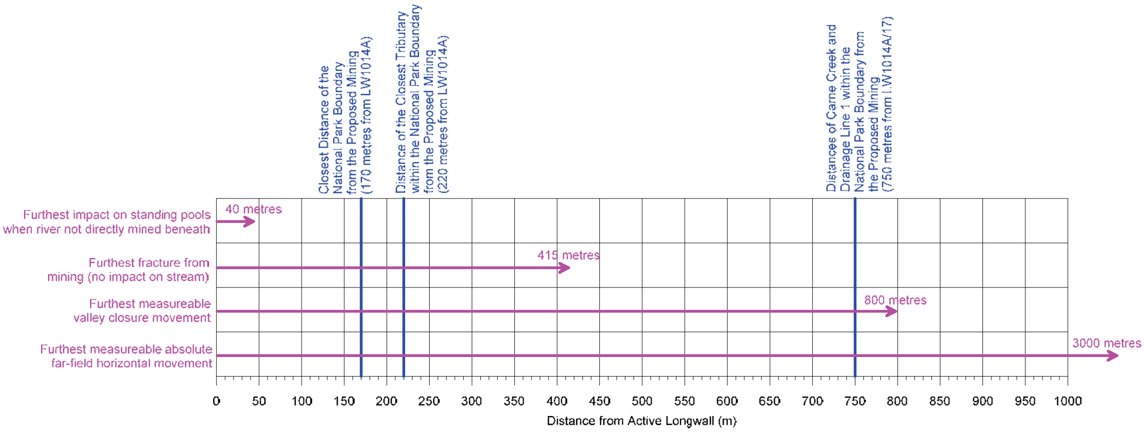


Fig. 5.28 Furthest Measureable Far-field and Valley Related Movements and Furthest Observed Impacts on Streams Located Entirely Above Solid Coal

In summary, it is not anticipated that the National Park would experience any adverse surface impacts due to the far-field horizontal movements resulting from the proposed mining. The valley related movements could result in minor and isolated fracturing within the ephemeral tributaries located within 400 metres of the proposed longwalls, however, no adverse impacts are anticipated on the surface water flows and qualities. No fracturing or adverse surface impacts are anticipated along the sections of Carne Creek and Drainage Line 3 within the National Park, as these are located more than 750 metres from the proposed longwalls.

Further discussions on the potential impacts are provided by the specialist surface water consultant in the report by *RPS* (2014a), the specialist ground water consultants in the reports by *RPS* (2014b) and *CSIRO* (2013), and the specialist ecology consultant in the report by *RPS* (2014c).

The longwalls are proposed to be extracted towards the National Park which allows for an adaptive management approach. The far-field movements can be monitored, as longwalls are progressively mined towards the National Park, allowing the 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 longwalls, allowing the impact assessments to be continually reviewed based on the available monitored data,
- Visually monitor the smaller streams to the north of the active subsidence zone, after the completion of each of the longwalls, to identify any fracturing or other 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 close 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 the appropriate actions for each of the triggers, which could include the refinement of the longwalls which 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 Colliery, 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 at mining within 2 kilometres of the National Park boundary and a further three longwalls prior to mining within 900 metres of the 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.

5.16. State Forests

The Extension 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 consultant in the report by *RPS* (2014a), the specialist ground water consultants in the reports by *RPS* (2014b) and *CSIRO* (2013), and the specialist ecology consultant in the report by *RPS* (2014c).

5.17. Natural Vegetation

The vegetation within the Extension Area comprises undisturbed natural bush, which can be seen from the aerial photograph in Fig. 1.2. A detailed survey of the natural vegetation has been undertaken and is described and assessed in the report prepared by *RPS* (2014c).

5.18. Other Natural Features Considered Significant

The *Birds Rock Flora Reserve* is located within the Extension Area, as shown in Drawing Nos. MSEC593-01 and MSEC593-02. The potential impacts on this site include changes in surface water drainage (refer to Section 5.4), surface cracking (refer to Sections 4.5 and 5.9), and fracturing and spalling of the exposed rock formations (refer to Section 5.8). Further impact assessments are provided by the other specialised consultants on the project.

The *Spanish Steps* is a four-wheel drive access track down to the Wolgan River. This feature is located outside the Extension Area, around 500 metres west of the proposed LW1013B. At this distance, it is unlikely that this feature would experience any adverse impacts, even if the predictions were exceeded by a factor of 2 times.

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

6.1. Public Utilities

As listed in Table 2.1, there were no Public Utilities identified within the Extension 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

6.2.1. Descriptions of the Unsealed Roads

There are unsealed roads located across the Extension Area which are shown in Drawing No. MSEC593-10. Photograph of the typical unsealed roads are provided in Fig. 6.1.

Fig. 6.1 Photographs of the Unsealed Roads

There are circular concrete drainage culverts in some locations where the unsealed roads cross the drainage lines within the Extension Area.

6.2.2. Predictions for the Unsealed Roads

The unsealed roads are located across the Extension Area and, therefore, could experience subsidence movements up to the maxima described in Chapter 4.

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

6.2.3. Impact Assessments for the Unsealed Roads

It is expected, at these magnitudes of predicted curvatures and strains, that cracking and heaving of the unsealed road surfaces would occur as each of the proposed longwalls mine beneath them. It is expected, however, that the unsealed roads could be maintained in safe and serviceable condition throughout the mining period using normal road maintenance techniques.

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

6.2.4. Impact Assessments for the Unsealed Roads Based on Increased Predictions

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, the incidence of cracking, stepping and heaving of the unsealed surfaces would increase directly above the proposed longwalls. It would be expected, however, that any impacts could still be repaired using normal road maintenance techniques.

6.3. Public Amenities

As listed in Table 2.1, there were no Public Amenities identified within the Extension Area.

6.4. Fences

The fences are located across the Extension Area and, therefore, could experience subsidence movements up to the maxima described in Chapter 4.

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

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

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 locations and details of the registered groundwater bores in the vicinity of the proposed longwalls were obtained from the Department of Natural Resources using the *Natural Resource Atlas* website (NRAtlas, 2014).

There were four registered groundwater bores identified directly above the proposed longwalls and further bores identified in the vicinity of the Extension Area, with the locations shown in Drawing No. MSEC593-10. The authorised uses of these bores are for monitoring or dewatering. The registered groundwater bores located within the Extension Area are owned by the colliery.

Discussions on the potential impacts on the groundwater resources are provided by the specialised groundwater consultants in the reports by *RPS* (2014b) and *CSIRO* (2013).

6.6. Industrial, Commercial or Business Establishments

As listed in Table 2.1, there were no Industrial, Commercial or Business Establishments identified within the Extension Area.

6.7. Mining Infrastructure

The exploration drill holes are located directly above the proposed longwalls and, therefore, could experience subsidence movements up to the maxima described in Chapter 4. It is likely, therefore, that fracturing and shearing would occur in the drill holes as the result of mining. It is recommended that the exploration drill holes are grouted and capped prior to being directly mined beneath.

There are a number of services which are proposed to be constructed to support the mining activities, including an air shaft compound, powerlines, switch yards, water pipelines and ground water bore compounds. The locations of these services are shown in Drawing No. MSEC593-10. Management plans will be developed by the colliery for these proposed services so that they can be maintained in safe and serviceable conditions throughout the mining period.

6.8. Archaeological Sites

6.8.1. Descriptions of the Archaeological Sites

There are no lands within the Extension Area declared as an Aboriginal Place under the *National Parks and Wildlife Act 1974*. There are a number of archaeological sites which have been identified within and in the vicinity of the Extension Area which are shown in Drawing No. MSEC593-10. A summary of the archaeological sites located within the Extension Area, based on the 26.5 degree angle of draw line, is provided in Table 6.1 below.

Table 6.1 Archaeological Sites within the Extension Area

Site Reference	Location	Description
45-1-0084	Above the proposed LW1007	Rock Shelter with Deposit
45-1-0137	150 metres west of the proposed LW1006	Rock Shelter with Deposit
45-1-2756 (same as 45-1-2757)	Above the proposed LW1019	Rock Shelter with Art and Grinding Groove

There are also other archaeological sites which are located in the vicinity of the proposed longwalls. The sites which are located outside the Extension Area, but are within 600 metres from the extents of the proposed longwalls, include Sites 45-1-0144, 45-1-0145, 45-1-0146, 45-1-0149, 45-1-0150, 45-1-0153 and 45-1-0156, which are all rock shelters with deposits, and 45-1-2689 which is a stone arrangement.

Detailed descriptions of the archaeological sites within the Extension Area are provided by *RPS* (2014d).

6.8.2. Predictions for the Archaeological Sites

A summary of the maximum predicted total conventional subsidence parameters for the archaeological sites within the Extension Area is provided in Table 6.2. The predicted tilts and curvatures are the maxima at any time during or after the extraction of the approved and proposed longwalls.

Table 6.2 Maximum Predicted Total Conventional Subsidence Parameters for the Archaeological Sites within the Extension Area

Site Reference	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})
45-1-0084	1800	8	0.10	0.20
45-1-0137	20	< 0.5	< 0.01	< 0.01
45-1-2756/2757	800	8	0.05	0.10
Remaining Sites	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted conventional strains for Sites 45-1-0084 and 45-1-2756/2757, based on applying a factor of 10 to the maximum predicted conventional curvatures, are 1 mm/m tensile and 2 mm/m compressive. Non-conventional movements can also occur as a result of, amongst other things, anomalous movements. The analysis of strains measured during the previous longwall mining at Angus Place and Springvale Collieries is provided in Section 4.3, which includes the strains resulting from both conventional and non-conventional anomalous movements.

The maximum predicted conventional strains for the remaining sites are less than 0.5 mm/m tensile and compressive (i.e. in the order of survey tolerance).

6.8.3. Impact Assessments for the Archaeological Sites

The maximum predicted curvatures for Sites 45-1-0084 and 45-1-2756/2757 are 0.10 km^{-1} hogging and 0.20 km^{-1} sagging, which represent minimum radii of curvature of 10 kilometres and 5 kilometres, respectively. The maximum predicted conventional strains for these sites, based on applying a factor of 10 to the maximum predicted conventional curvatures, are around 1 mm/m tensile and 2 mm/m compressive.

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

The predicted curvatures and conventional strains are similar to the movements 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). This suggests that the likelihood of any significant physical impacts on Sites 45-1-0084 and 45-1-2756/2757, resulting from the extraction of the proposed longwalls, is relatively low.

The experience from the Southern Coalfield indicates that the likelihood of significant physical impacts on rock shelters is relatively low. Further assessments of the potential impacts on the rock shelters are provided in a report by *RPS* (2014d).

The remaining sites are predicted to experience vertical subsidence of 20 mm or less. Whilst these sites could experience very low level subsidence, they would not be expected to experience any significant conventional tilts, curvatures or strains. These sites are also located along the sides of ridge lines and, therefore, are not expected to experience any valley related upsidence movements or compressive strains due to valley closure movements. Further assessments of the potential impacts on the rock shelters are provided in a report by *RPS* (2014d).

6.9. State Survey Control Marks

The locations of the state survey control marks in the vicinity of the proposed longwalls are shown in Drawing No. MSEC593-10. The locations and details of the survey control marks were obtained from the *Land and Property Management Authority* using the *Six Viewer* (2013).

A summary of the survey control marks which were identified within the Extension Area is provided in Table 6.3 below.

Table 6.3 Survey Control Marks Located within the Extension Area

Survey Mark	Status	Horizontal Class / Order (GDA94)	Vertical Class / Order (AHD71)
SS 21307	Not Found in Database	U / U	LC / L3
SS 21308	Not Found in Database	U / U	LC / L3
SS 21309	Found Intact	E / 5	LC / L3
SS 21310	Found Intact	E / 5	LC / L3
SS 35258	Not Found in Database	U / U	U / U
TS 6278	Found Intact - Birds Rock (P)	2A / 0	LC / L3

There were six survey control marks identified within the Extension Area, of which, only two having coordinated positions and five having surveyed levels.

The survey control marks located directly above the proposed mining area could experience subsidence movements up to the maxima described in Chapter 4. The survey control marks located further afield, up to 3 kilometres outside the extents of the proposed longwalls, could be affected by far-field horizontal movements. Far-field horizontal movements and the methods used to predict such movements are described further in Section 4.4.

It may be necessary on the completion of the longwalls, when the ground has stabilised, to re-coordinate any survey control marks that are required for future use. Consultation between Centennial and the Survey Infrastructure and Geodesy Officer at the Department of Lands will be required to ensure that the required survey control marks are resurveyed at the appropriate time.

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.

APPENDIX B. REFERENCES

References

Centennial (2008). *Notification under SMP Approval Condition 13(e) of Observed Subsidence Impact Over Longwall 940 –Angus Place Colliery*. Letter from Centennial to the Department of Primary Industries dated 22nd September 2008.

CSIRO (2013). *Angus Place and Springvale Colliery Operations Groundwater Assessment*. Commonwealth Scientific and Industrial Research Organisation (CSIRO), dated 2013.

DMR (1992). *Geological Series Sheet 8930 and 8931 (Edition 1)*. Department of Mineral Resources, 1992.

DP&I (2008). *Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield – Strategic Review*. Department of Planning NSW, July 2008. Proceedings of the Australian Geomechanics Society - Engineering Geology of the Newcastle-Gosford Region, The University of Newcastle, February 1995.

Forster (1995). *Impact of Underground Mining in Engineering Geology of the Newcastle-Gosford Region*. Forster, I., R.

Gale (2008). *Aquifer inflow prediction above longwall panels*. Gale, W., J. SCT Operations. ACARP Research Project C13013, published September 2008.

Goldney et at (2010). *Determining Whether or Not a Significant Impact Has Occurred on Temperate Highland Peat Swamps on Sandstone within the Angus Place Colliery Lease on The Newnes Plateau*. Goldney, D., Mactaggart, B., Merrick, N. Report prepared for the Department of the Environment, Water, Heritage and the Arts, January 2010.

Holla (1991). *Mining Subsidence in New South Wales - 3. Surface Subsidence Prediction in the Western Coalfield.* Department of Mineral Resources.

IC (2011). *Understanding Swamp Conditions - Field Inspection Report - September 2010 to November 2010*. Illawarra Coal, April 2011.

Kratzsch, H., (1983). *Mining Subsidence Engineering*, Published by Springer - Verlag Berlin Heidelberg New York.

Mills, K. (1998). *Subsidence Mechanisms about Longwall Panels*.

Mills, K. (2003). *WRS1 monitoring results – End of Longwall 9*. SCT Operations Report: MET2659.

Mills, K. (2007). Subsidence Impacts on River Channels and Opportunities for Control. SCT Operations Report: MET2659.

McNally, et al (1996). *Geological Factors influencing Longwall-Induced Subsidence*. McNally, G.H., Willey, P.L. and Creech, M. Symposium on Geology in Longwall mining, 12-13 November 1996, Eds G.H. McNally and C.R. Ward, pp 257-267.

Mills, K. and Huuskes, W. (2004). *The Effects of Mining Subsidence on Rockbars in the Waratah Rivulet at Metropolitan Colliery*. Proc. 6th Triennial Conference, *Subsidence Management Issues,* Mine Subsidence Technological Society, Maitland.

NRAtlas, (2014). *Natural Resource Atlas* website, viewed on the 7th January 2014. The Department of Natural Resources. http://nratlas.nsw.gov.au/

PAC (2010). *Bulli Seam Operations – PAC Report*. The Planning and Assessment Commission for the NSW Government, July 2010.

Palaris (2013a). *Stratigraphic Setting – Angus Place and Springvale Collieries*. Palaris Pty Ltd. Document No. CEY1535-01 (Version 2), January 2013.

Palaris (2013b). *Geological Structure Zones in Angus Place and Springvale Mine Extension Areas*. Palaris Pty Ltd. Document No. CEY1504-01 (Version 3), January 2013.

Patton and Hendron (1972). *General Report on Mass Movements*. Patton F.D. & Hendron A.J.. Proc. 2nd Intl. Congress of International Association of Engineering Geology, V-GR1-V-GR57.

Peng and Chiang (1984). *Longwall Mining*. Wiley, Peng S.S. & Chiang H.S. New York, pg 708.

Richardson and Ryan (2007). *The Ecology of Subsidence – Upland Swamps in the Southern Coalfield*. Richardson, M., and Ryan, D. Biosis Research. Proceedings of the Mine Subsidence Technological Society 7th Triennial Conference on Mine Subsidence, 26-27th November 2007, pp 219 to 231.

RPS (2012). *Swamp Groundwater Impact Case Study*. RPS Aquaterra Pty Ltd. Technical Memorandum dated 28th November 2012. Job No. S188D, Doc. No. 002a.

RPS (2014a). *Angus Place Mine Extension Project - Surface Water Impact Assessment*. Report No. S187D/021a, dated January 2014.

RPS (2014b). *Angus Place Mine Extension Project - Groundwater Impact Assessment*. Report No. S187B/015a, dated January 2014.

RPS (2014c). *Angus Place Mine Extension Project Flora and Fauna Assessment*. Report No. PR110328, dated January 2014.

RPS (2014d). *Cultural Heritage Impact Assessment – Angus Place Extension Project*. RPS Australia East Pty Ltd. Report No. PR111285 Revision D, dated January 2014.

Singh and Kendorski (1981). *Strata Disturbance Prediction for Mining Beneath Surface Water and Waste Impoundments*. Singh, M., M., Kendorski, F., S. Proceedings of the 1st Annual Conference on Ground Control in Mining, Morgantown WV, July 1981.

Six Viewer (2013). Spatial Information Exchange, accessed on the 11th February 2013. Land and Property Information. https://www.six.nsw.gov.au/wps/portal/

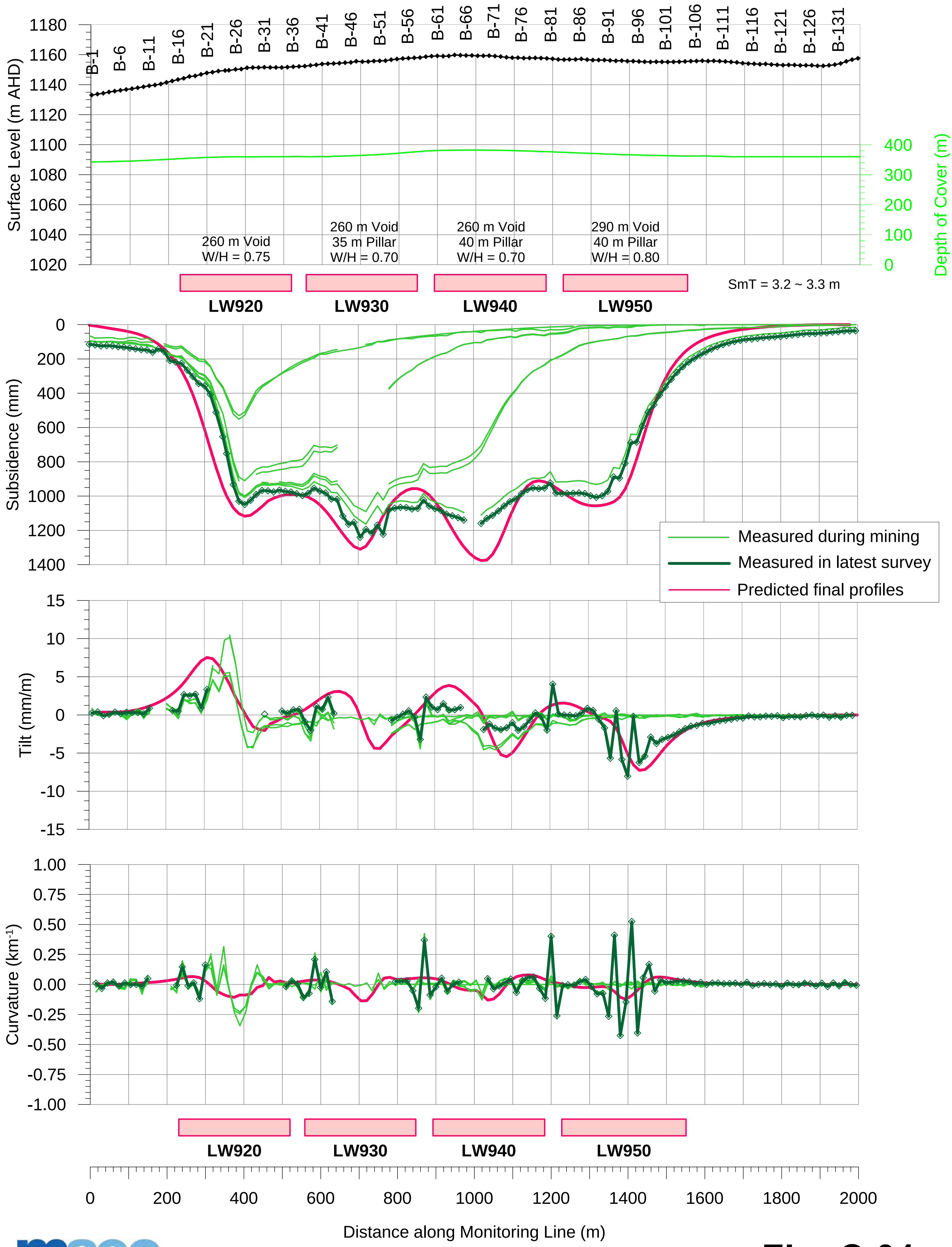
Tomkins and Humphreys (2006). *Evaluating the Effects of Fire and Other Catastrophic Events on Sediment and Nutrient Transfer within SCA Special Areas*. Humphreys, G., S., and Tomkins; M. Sydney Catchment Authority - Macquarie University collaborative research project. Technical Report 2.

Waddington and Kay (2002). *Management Information Handbook on the Undermining of Cliffs, Gorges and River Systems*. ACARP Research Projects Nos. C8005 and C9067, September 2002.

Whittaker and Reddish (1989). *Subsidence – Occurrence, Prediction and Control.* Whittaker, B.N. and Reddish, D.J. Elsevier.

APPENDIX C. COMPARISONS BETWEEN OBSERVED AND PREDICTED PROFILES OF SUBSIDENCE, TILT AND CURVATURE

Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the B-Line at Angus Place Colliery



msec

Fig. C.01

Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the LW19 to LW24 Line at Angus Place Colliery

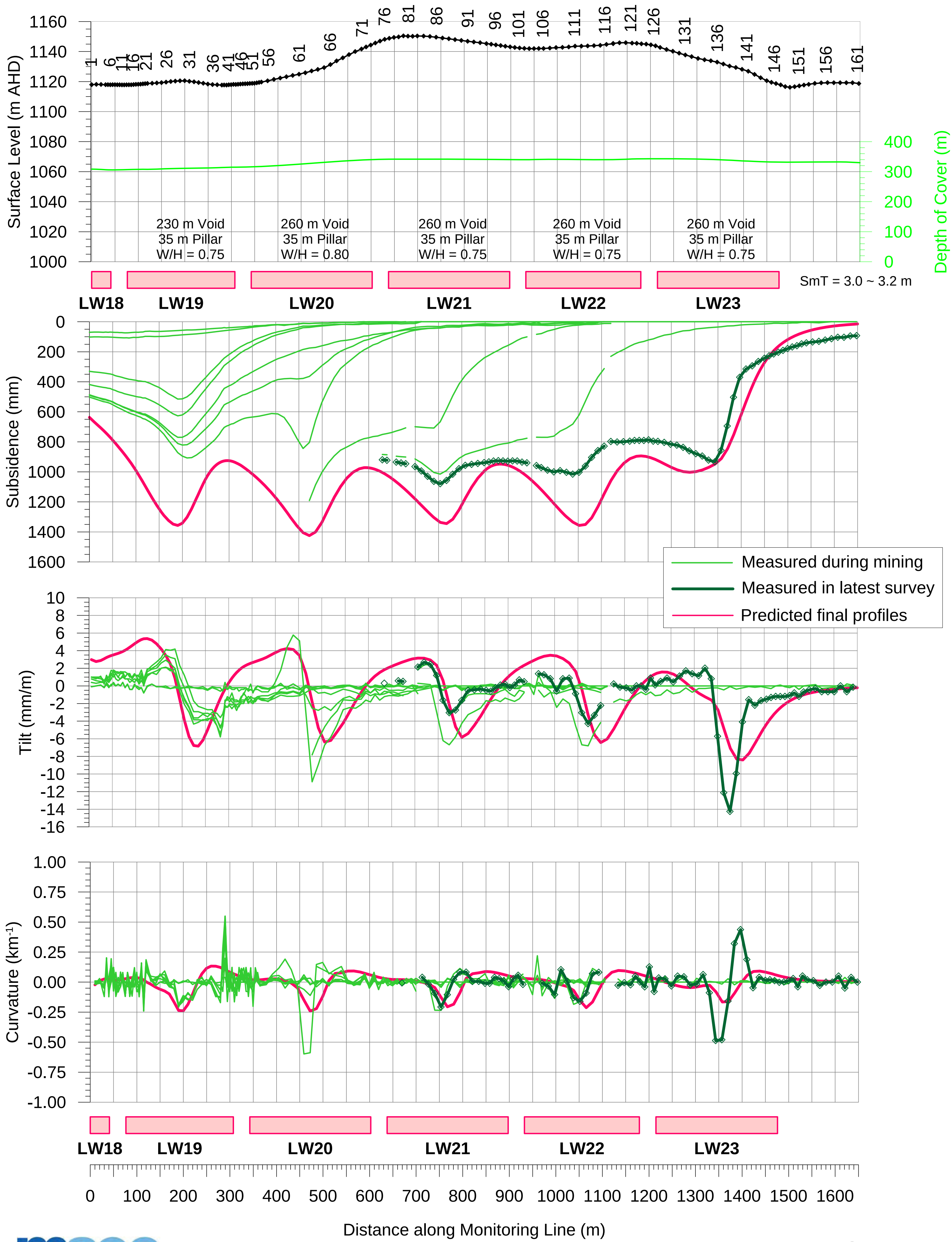
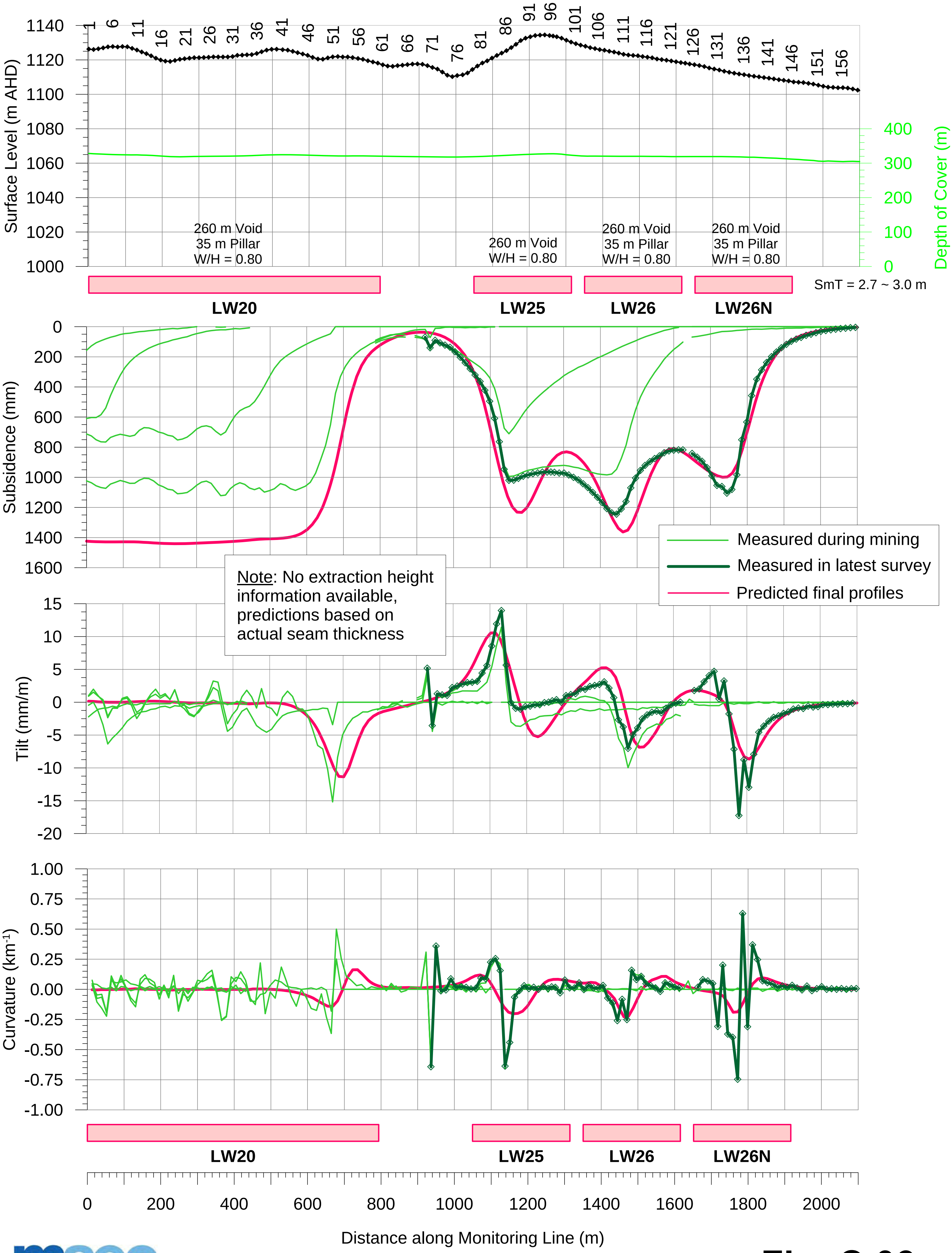


Fig. C.02

I:\Projects\Angus Place\MSEC593 Mine Extension Project\Subsdata\Calibration\Angus Place\Fig. C.03 - LW20 and LW25 to LW26N Line.grf.....02-Apr-14

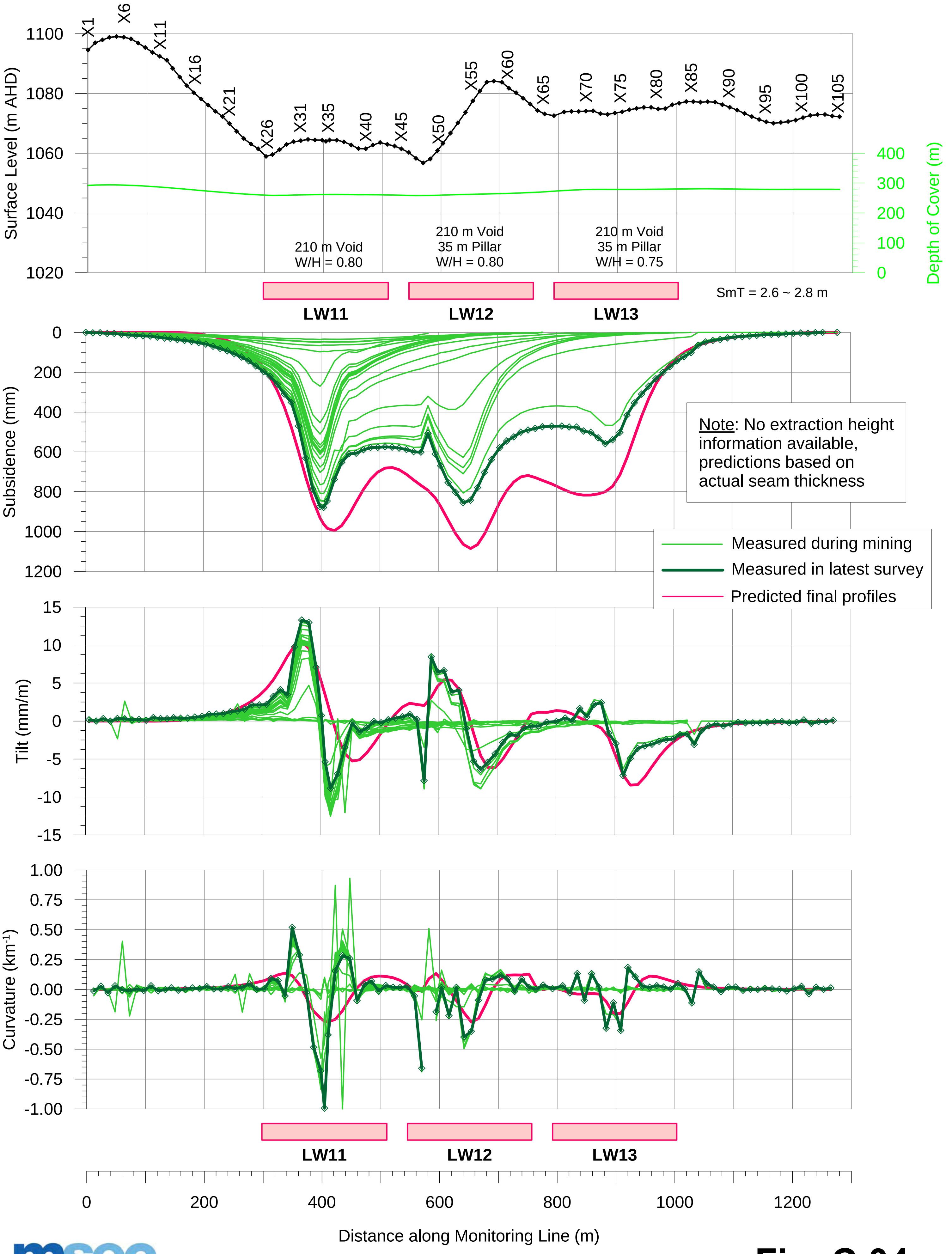
Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the LW20 and LW25 to LW26N Line at Angus Place Colliery



msec

Fig. C.03

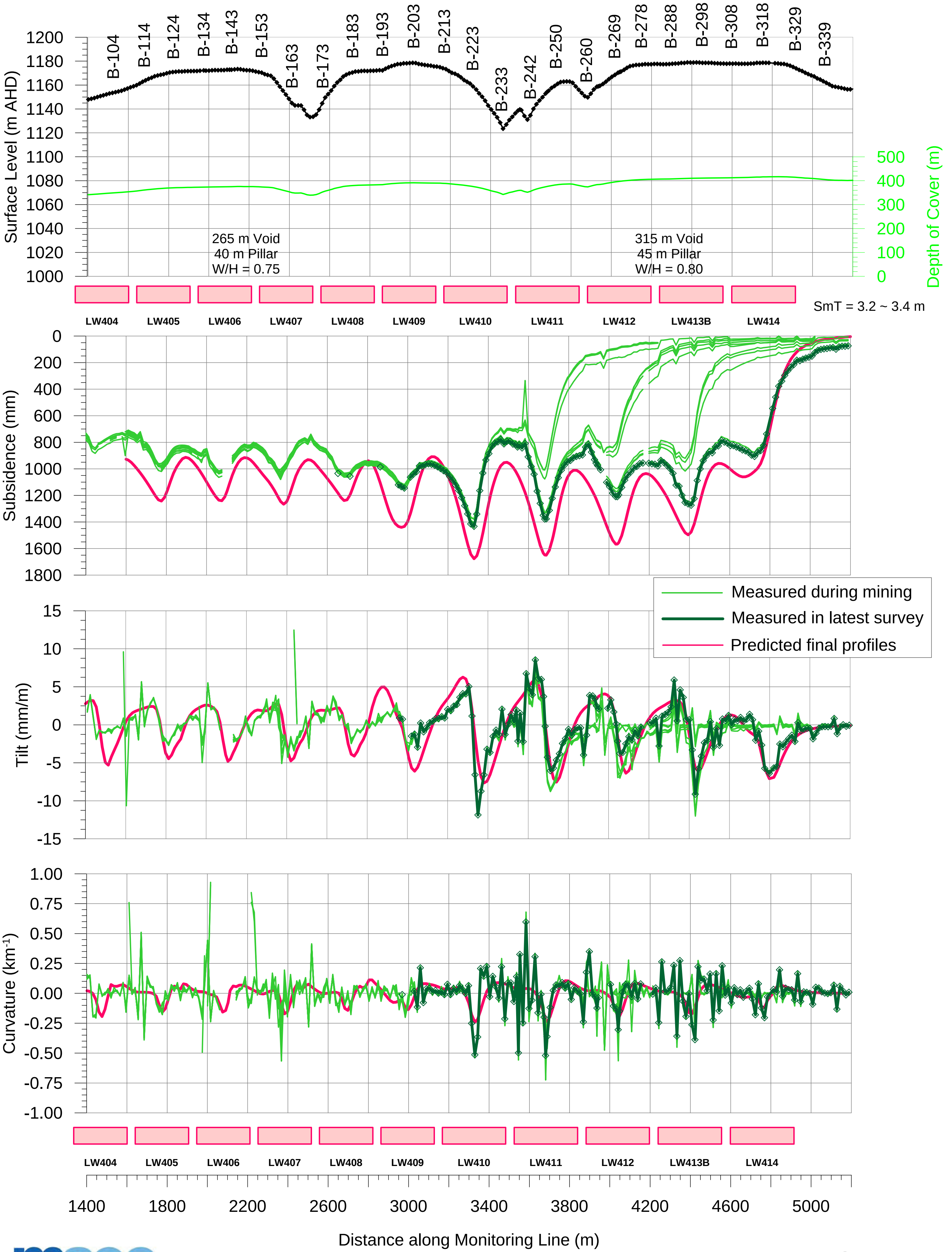
Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the X-Line at Angus Place Colliery



msec

Fig. C.04

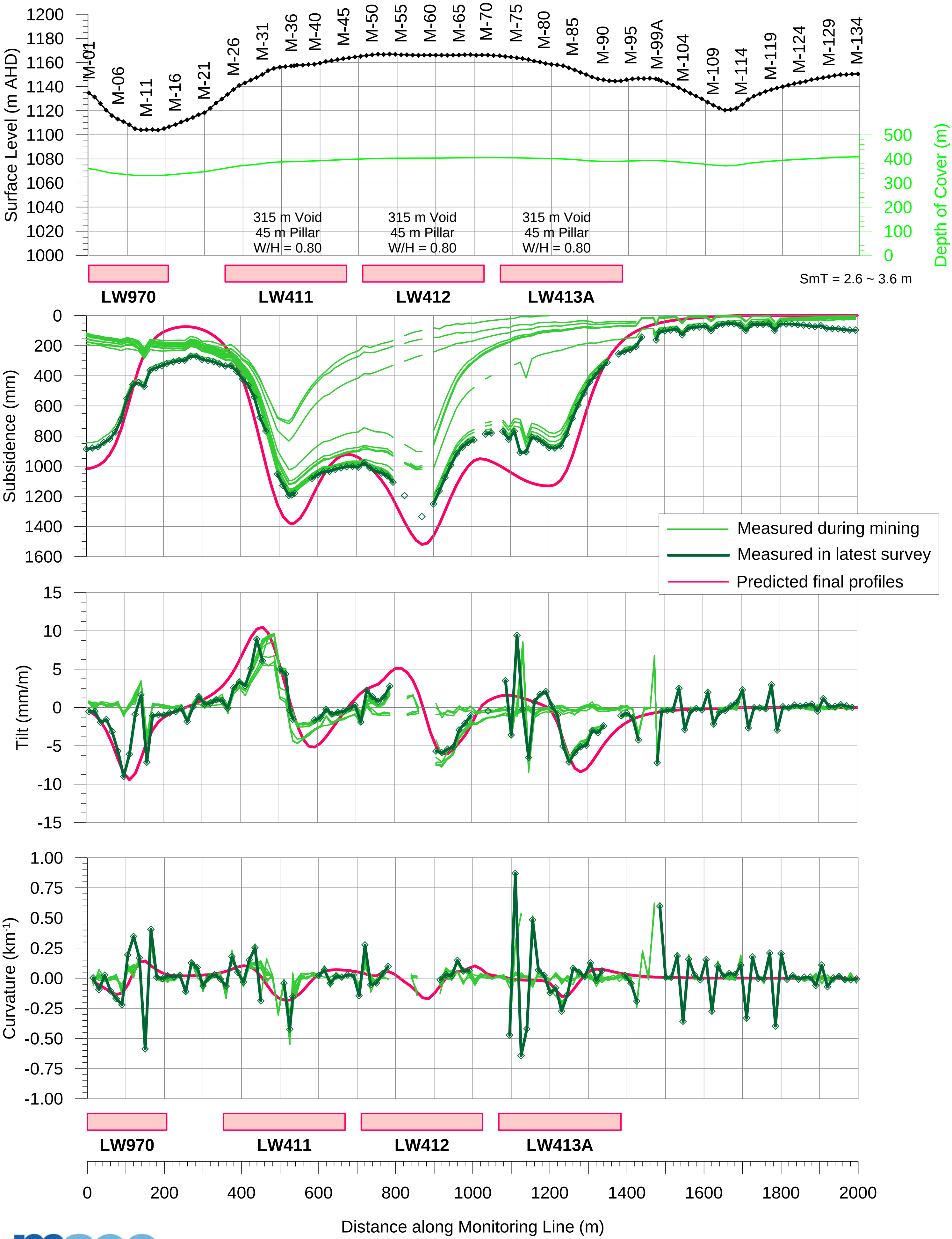
Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the B-Line at Springvale Colliery



msec

Fig. C.05

Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the M-Line at Springvale Colliery



msec

Fig. C.06

I:\Projects\Angus Place\MSEC593 Mine Extension Project\Subsdata\Calibration\Springvale\Fig. C.07 - EWS-Line.grf.....02-Apr-14

Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the EWS-Line at Springvale Colliery

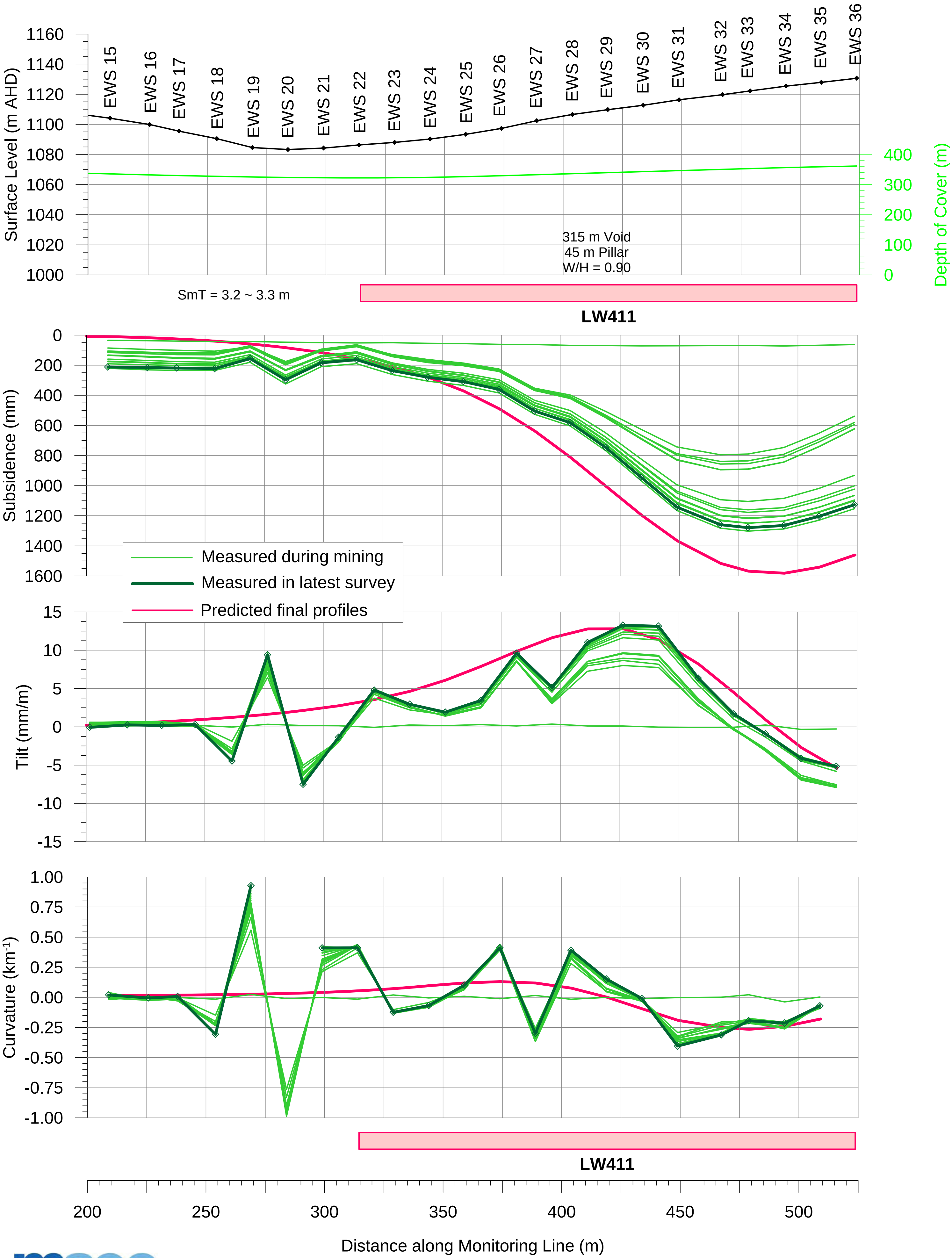
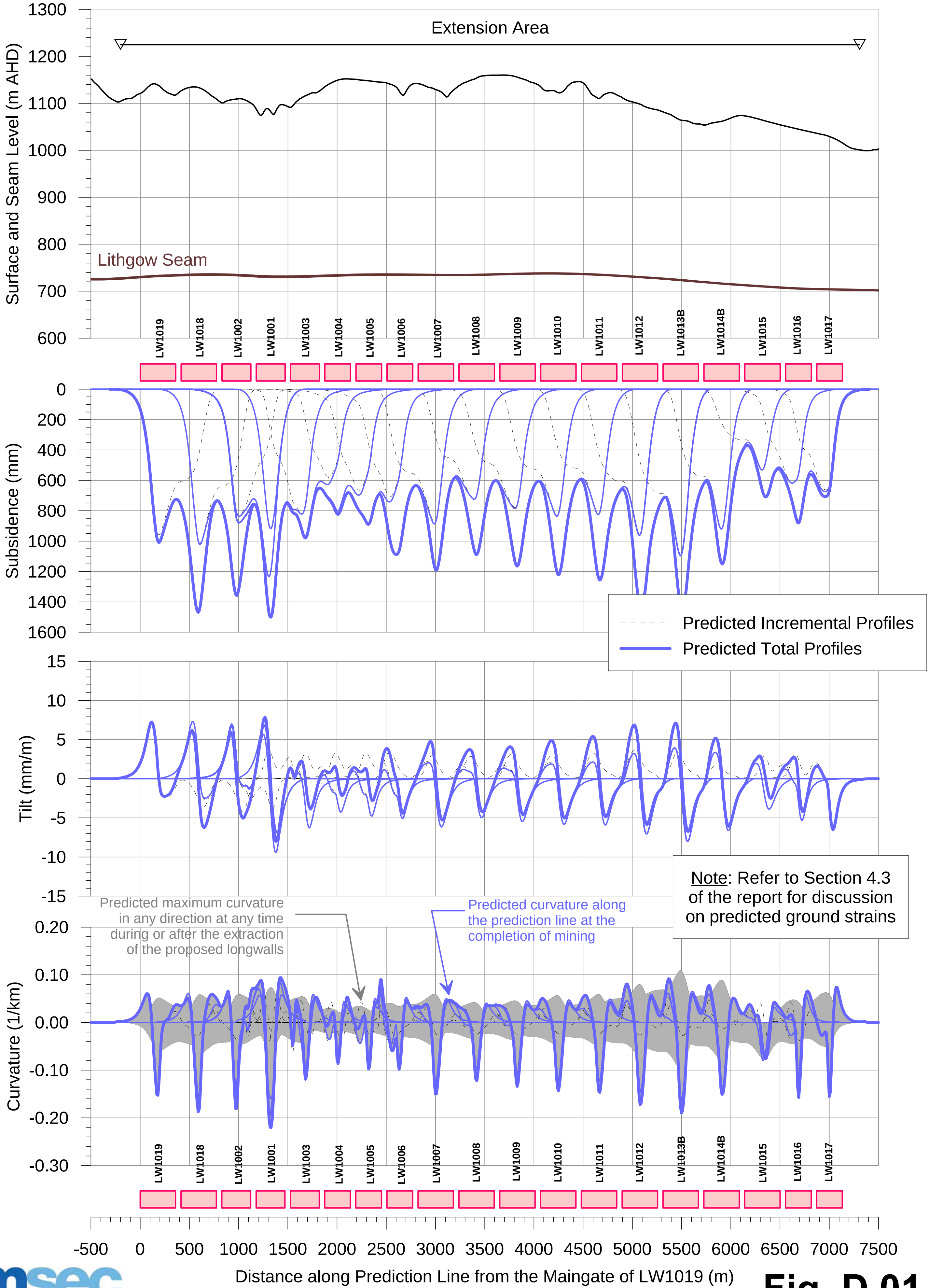


Fig. C.07

APPENDIX D.   FIGURES

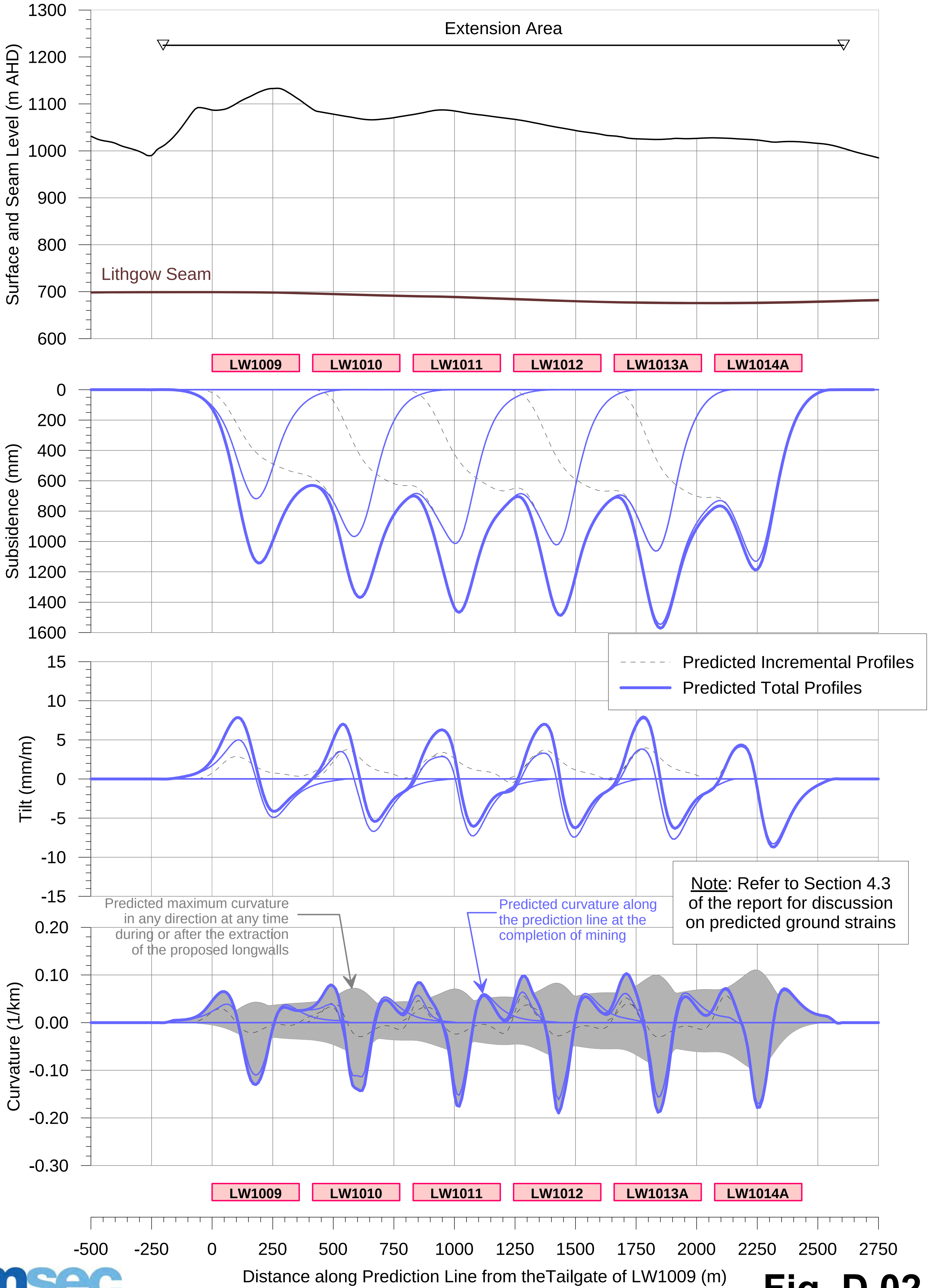
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line A1 Resulting from the Extraction of LW1001 to LW1019



msec

Fig. D.01

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line A2 Resulting from the Extraction of LW1001 to LW1019



msec

Fig. D.02

Predicted Profiles of Subsidence, Upsidence and Closure along the Wolgan River Resulting from the Extraction of LW1001 to LW1019

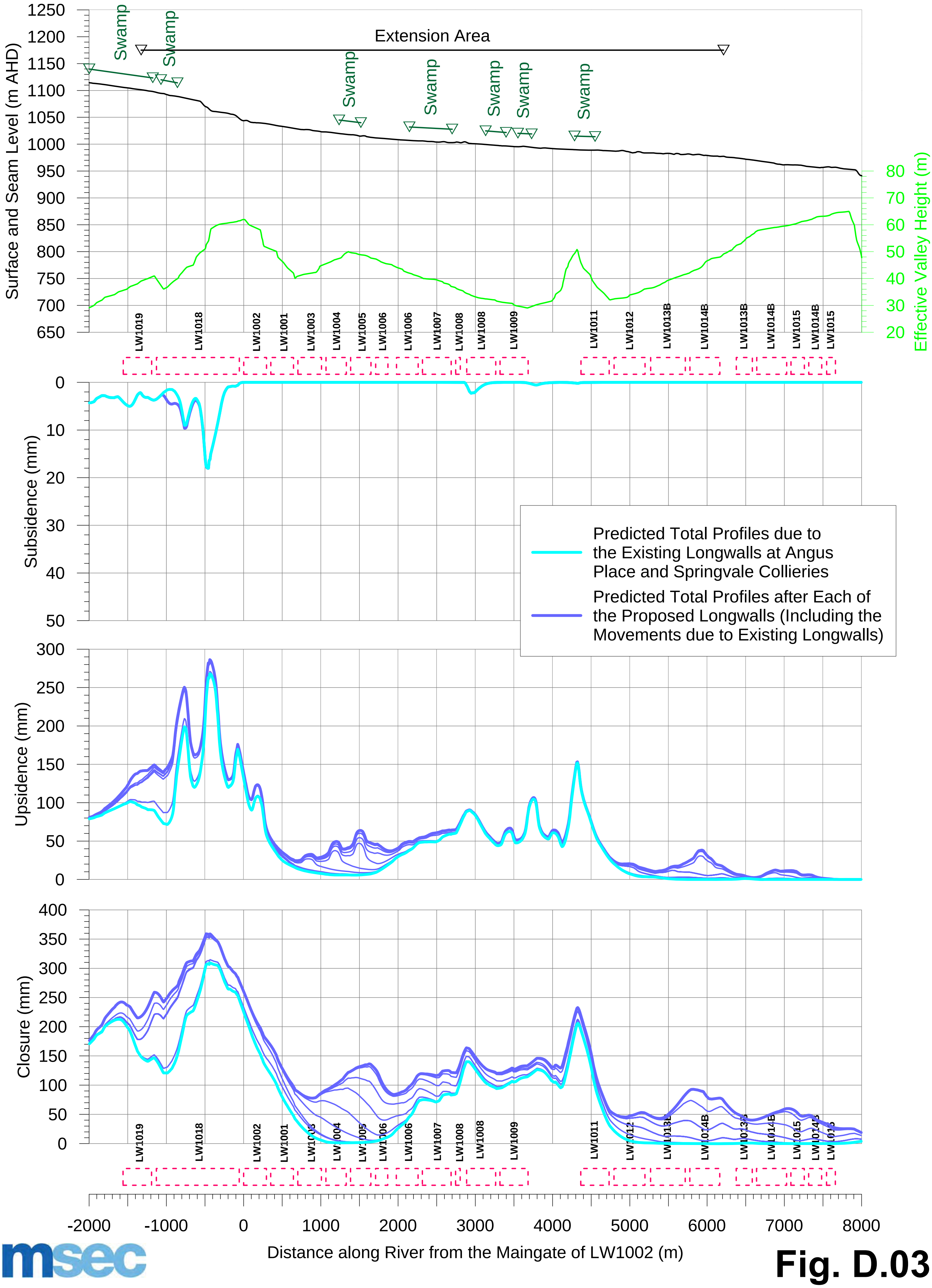


Fig. D.03

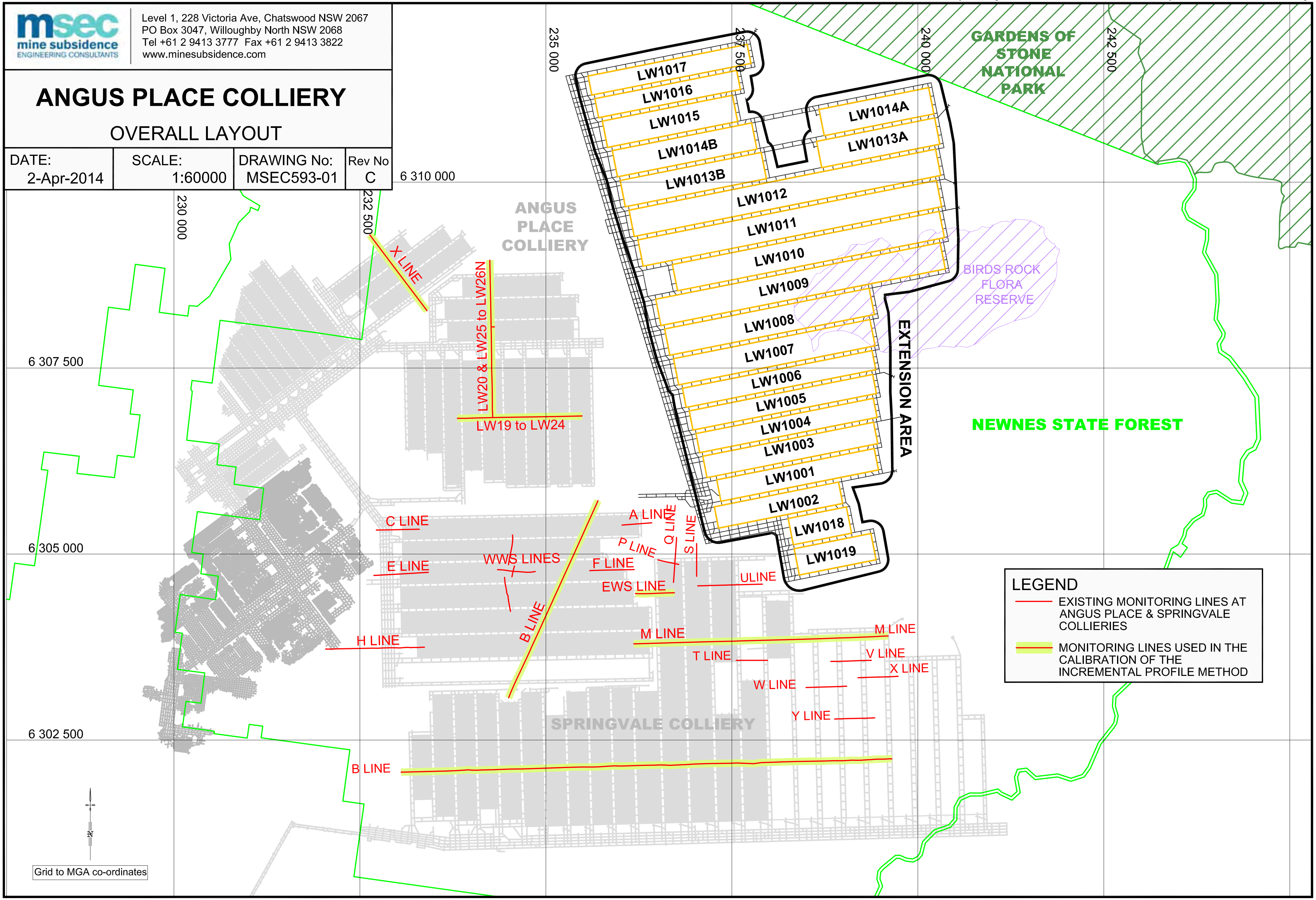
APPENDIX E. DRAWINGS

msec mine subsidence ENGINEERING CONSULTANTS
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com

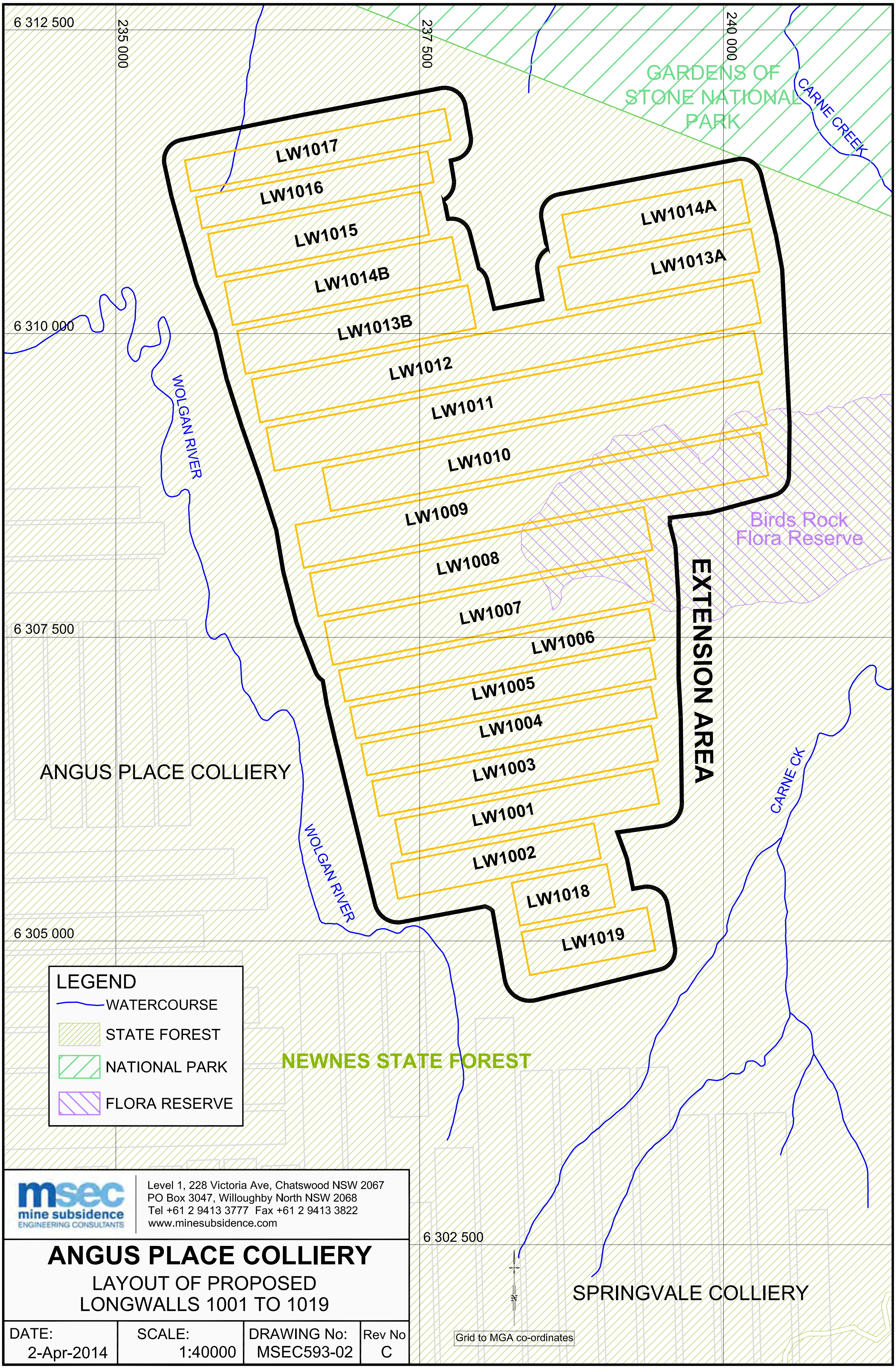
ANGUS PLACE COLLIERY

OVERALL LAYOUT

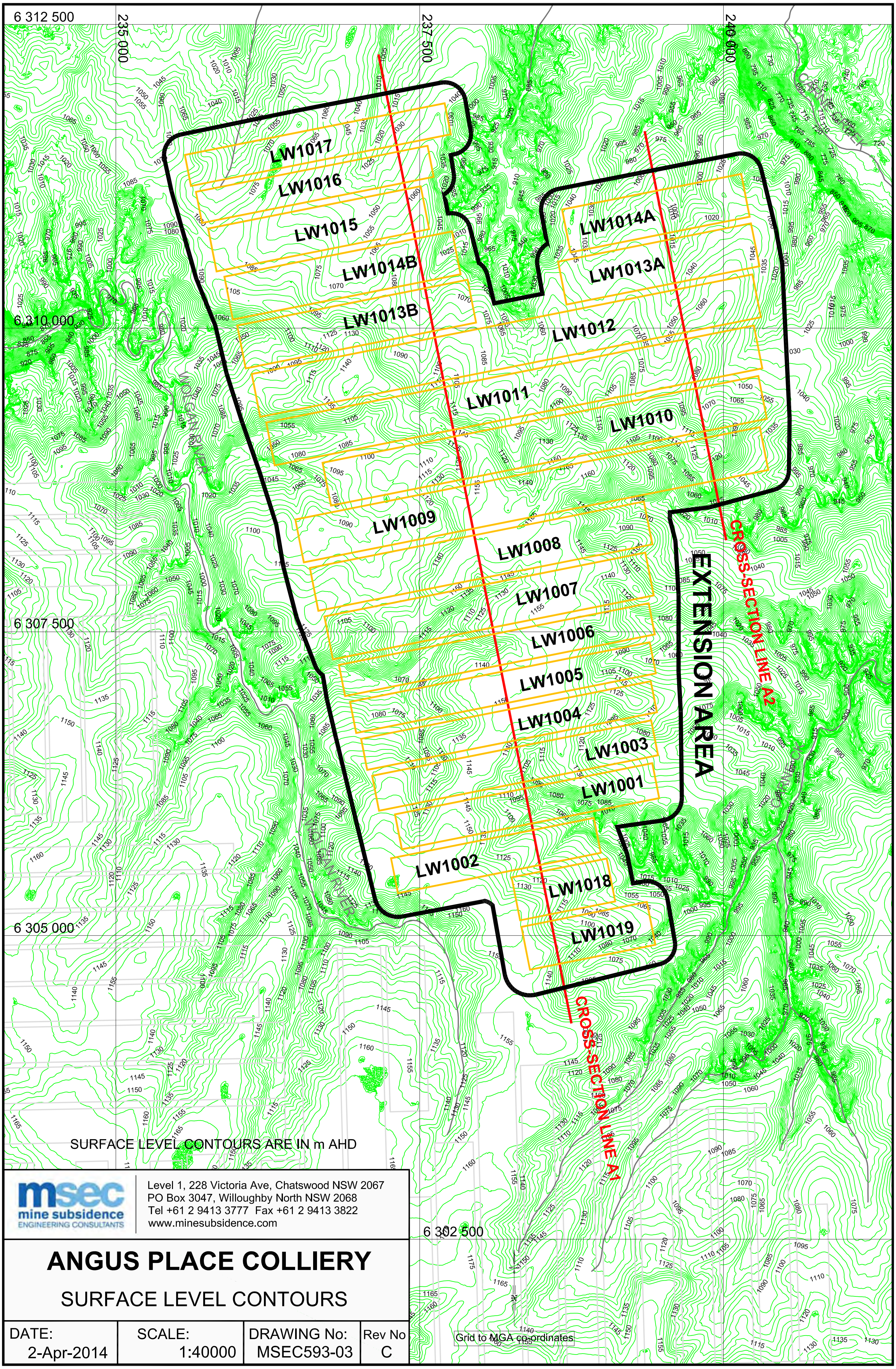
DATE:	SCALE:	DRAWING No:	Rev No
2-Apr-2014	1:60000	MSEC593-01	C



I:\Projects\Angus Place\MSEC593 Mine Extension Project\AutoCAD\MSEC593-02.dwg



I:\Projects\Angus Place\MSEC593 Mine Extension Project\AutoCAD\MSEC593-03.dwg



msec
mine subsidence
ENGINEERING CONSULTANTS

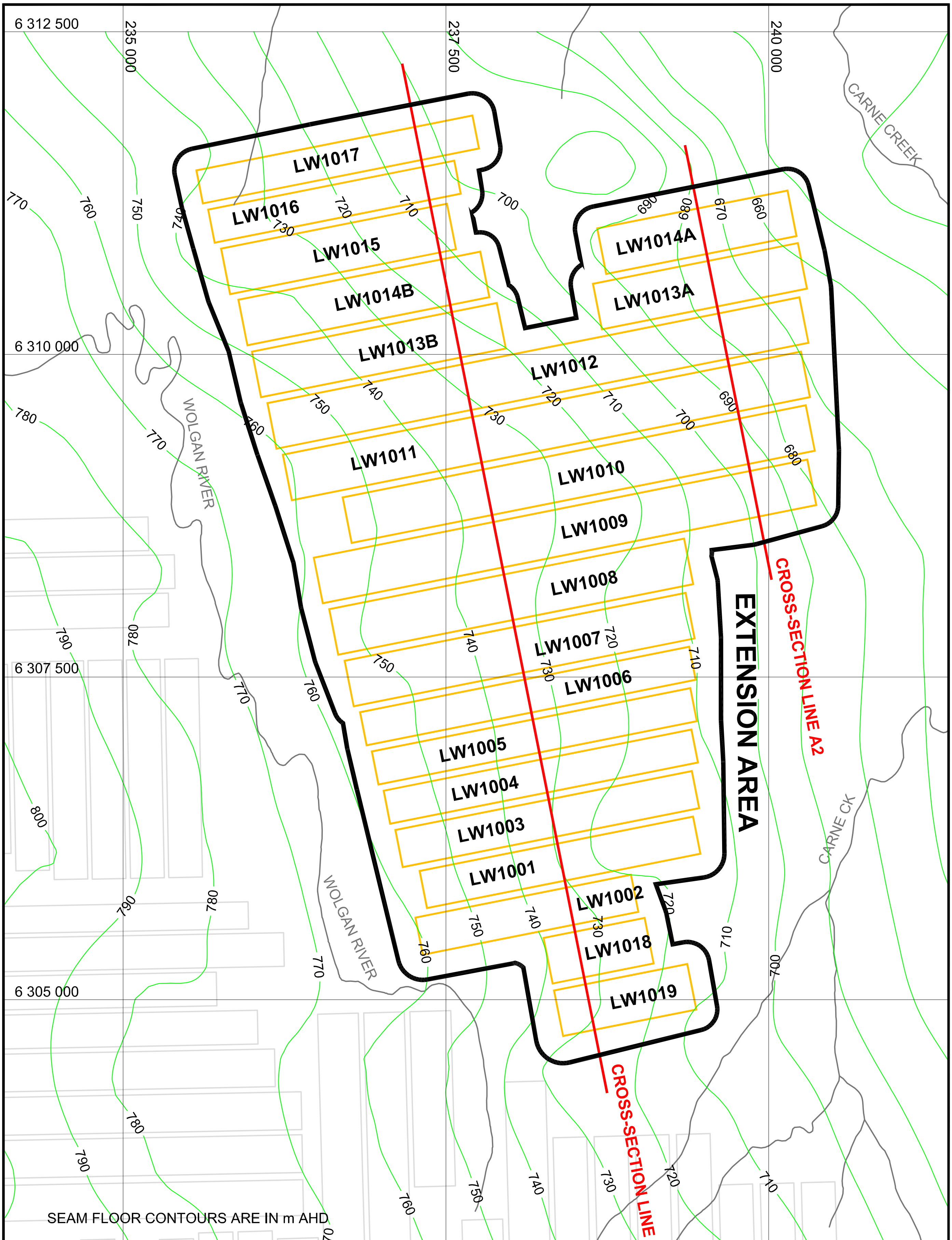
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com

ANGUS PLACE COLLIERY

SURFACE LEVEL CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
2-Apr-2014	1:40000	MSEC593-03	C

I:\Projects\Angus Place\MSEC593 Mine Extension Project\AutoCAD\MSEC593-04.dwg



msec mine subsidence ENGINEERING CONSULTANTS

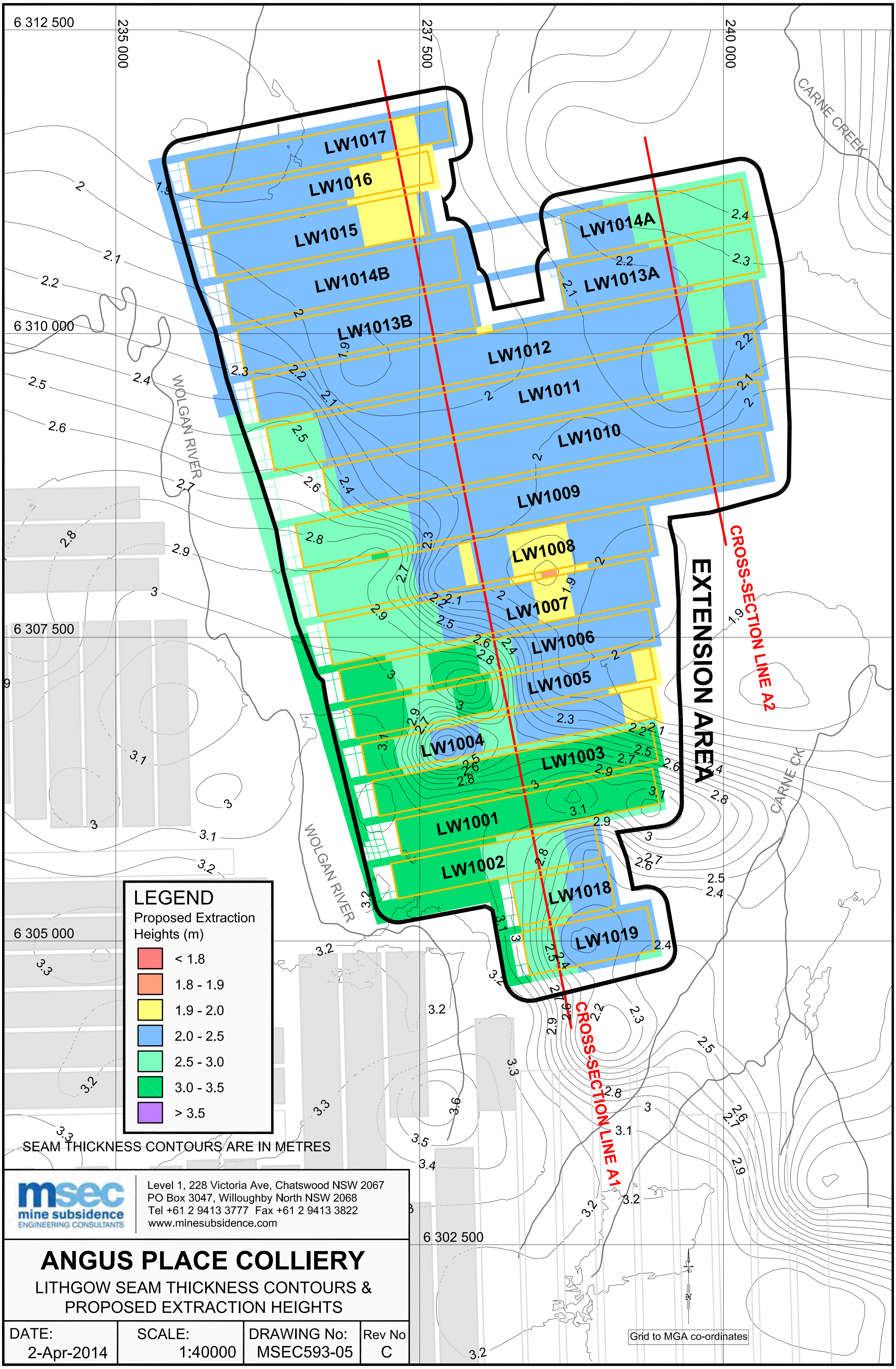
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com

ANGUS PLACE COLLIERY

LITHGOW SEAM FLOOR CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
2-Apr-2014	1:40000	MSEC593-04	C

I:\Projects\Angus Place\MSEC593 Mine Extension Project\AutoCAD\MSEC593-05.dwg



LEGEND

Proposed Extraction Heights (m)

- < 1.8
- 1.8 - 1.9
- 1.9 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- > 3.5

SEAM THICKNESS CONTOURS ARE IN METRES

msec mine subsidence ENGINEERING CONSULTANTS

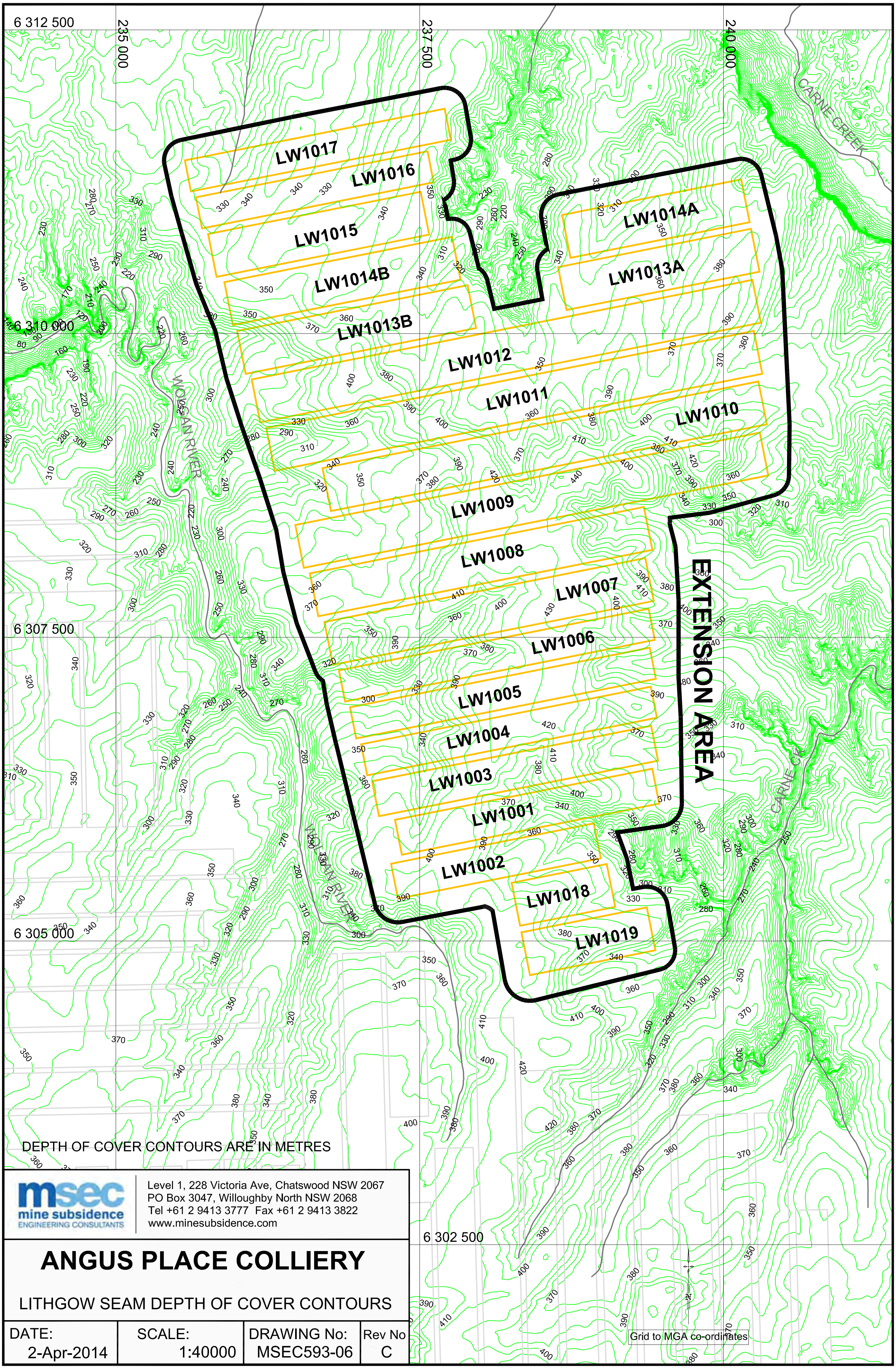
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com

ANGUS PLACE COLLIERY

LITHGOW SEAM THICKNESS CONTOURS & PROPOSED EXTRACTION HEIGHTS

DATE:	SCALE:	DRAWING No:	Rev No
2-Apr-2014	1:40000	MSEC593-05	C

I:\Projects\Angus Place\MSEC593 Mine Extension Project\AutoCAD\MSEC593-06.dwg



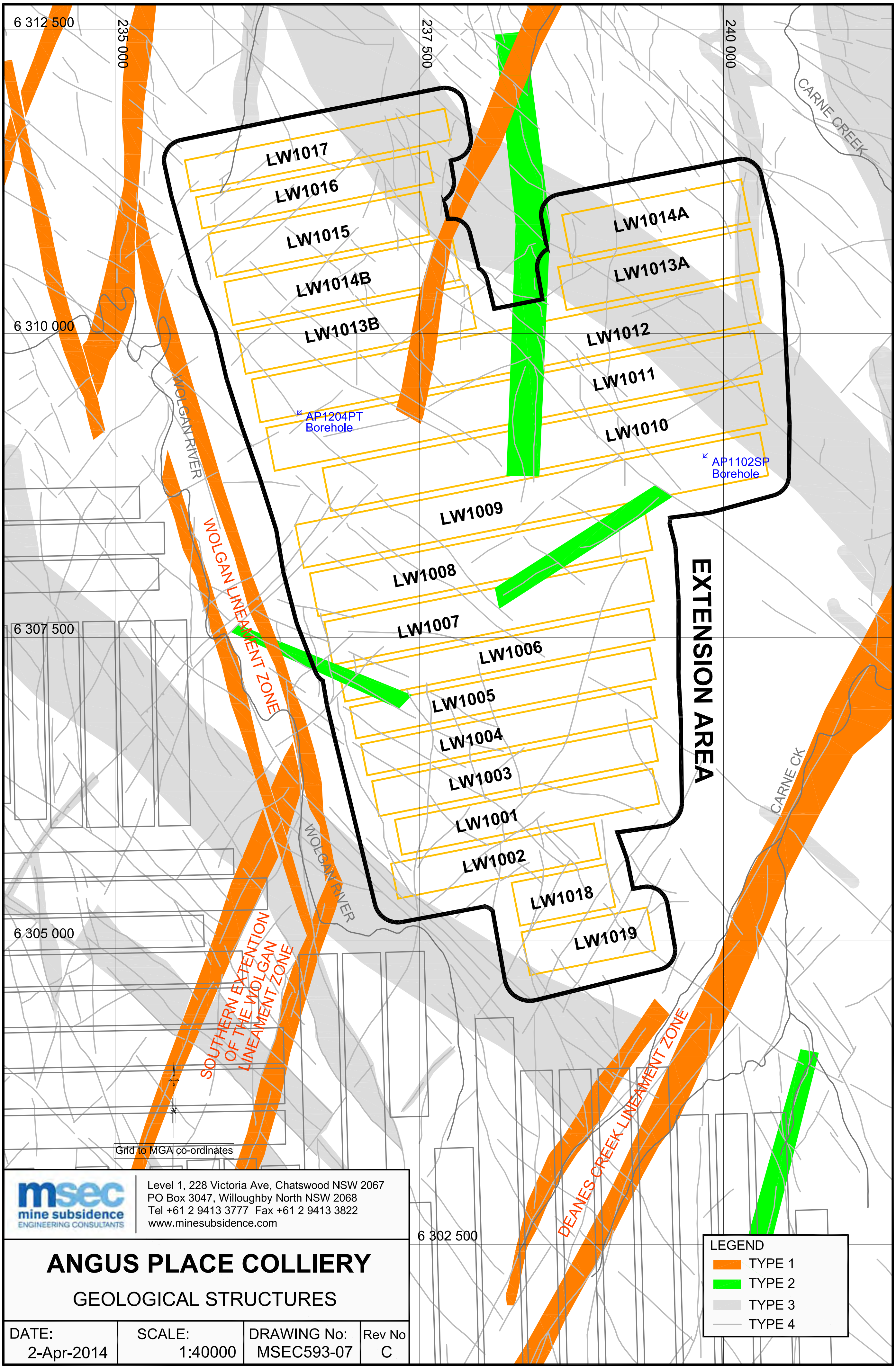
msec mine subsidence ENGINEERING CONSULTANTS
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com

ANGUS PLACE COLLIERY

LITHGOW SEAM DEPTH OF COVER CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
2-Apr-2014	1:40000	MSEC593-06	C

I:\Projects\Angus Place\MSEC593 Mine Extension Project\AutoCAD\MSEC593-07.dwg



msec mine subsidence ENGINEERING CONSULTANTS

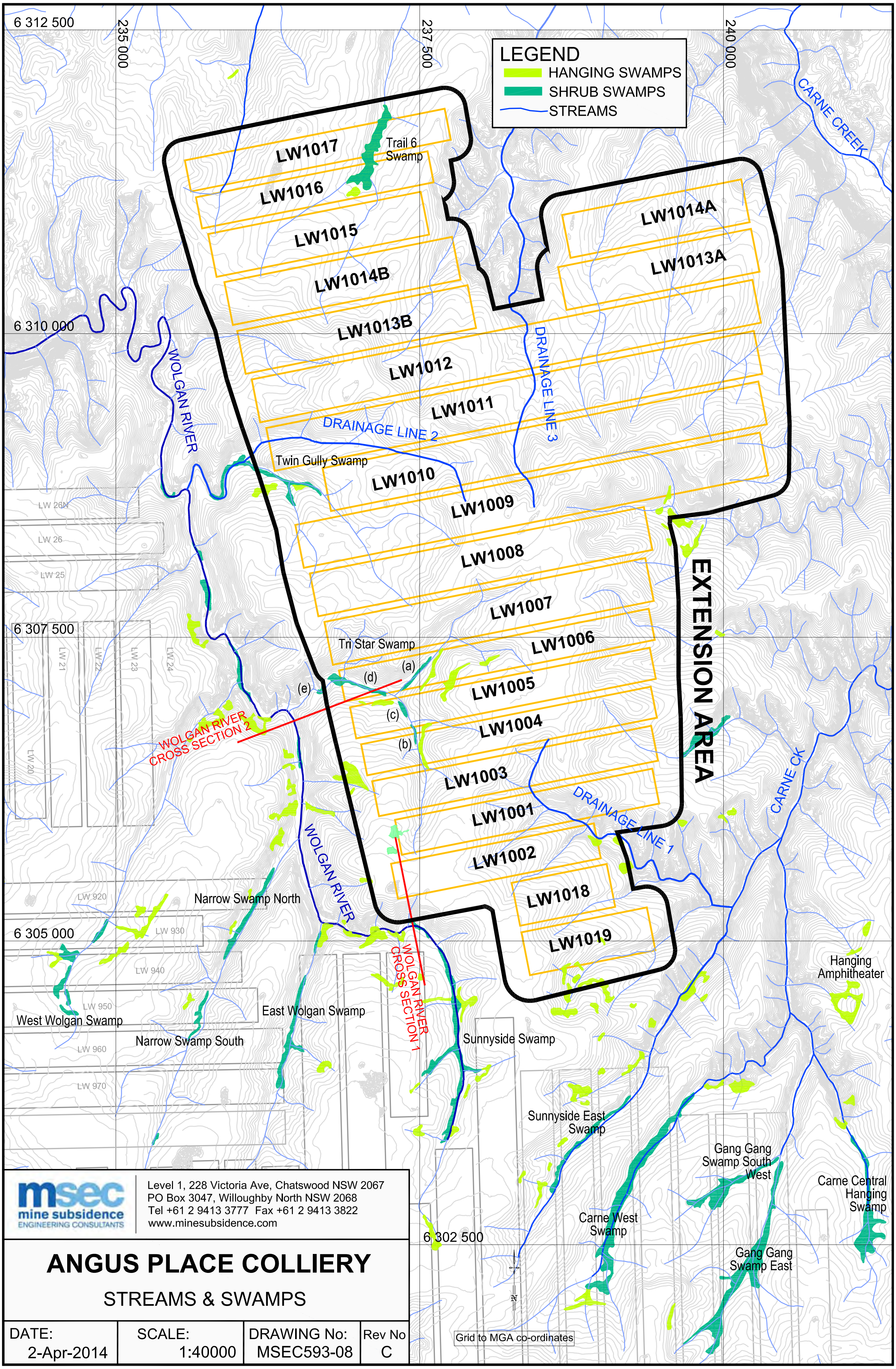
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com

ANGUS PLACE COLLIERY

GEOLOGICAL STRUCTURES

DATE:	SCALE:	DRAWING No:	Rev No
2-Apr-2014	1:40000	MSEC593-07	C

I:\Projects\Angus Place\MSEC593 Mine Extension Project\AutoCAD\MSEC593-08.dwg



msec mine subsidence ENGINEERING CONSULTANTS

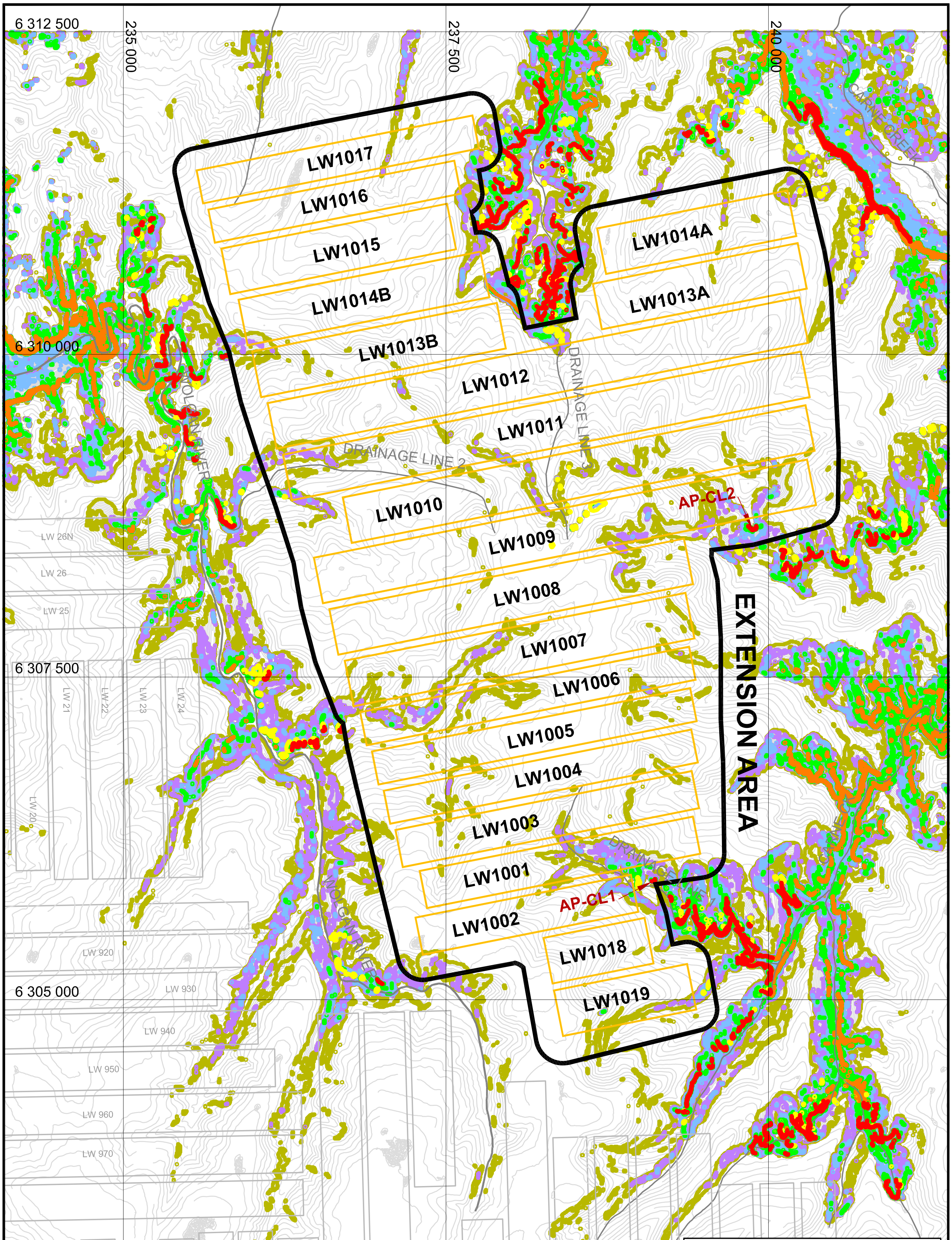
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com

ANGUS PLACE COLLIERY

STREAMS & SWAMPS

DATE:	SCALE:	DRAWING No:	Rev No
2-Apr-2014	1:40000	MSEC593-08	C

I:\Projects\Angus Place\MSEC593 Mine Extension Project\AutoCAD\MSEC593-09.dwg



Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com

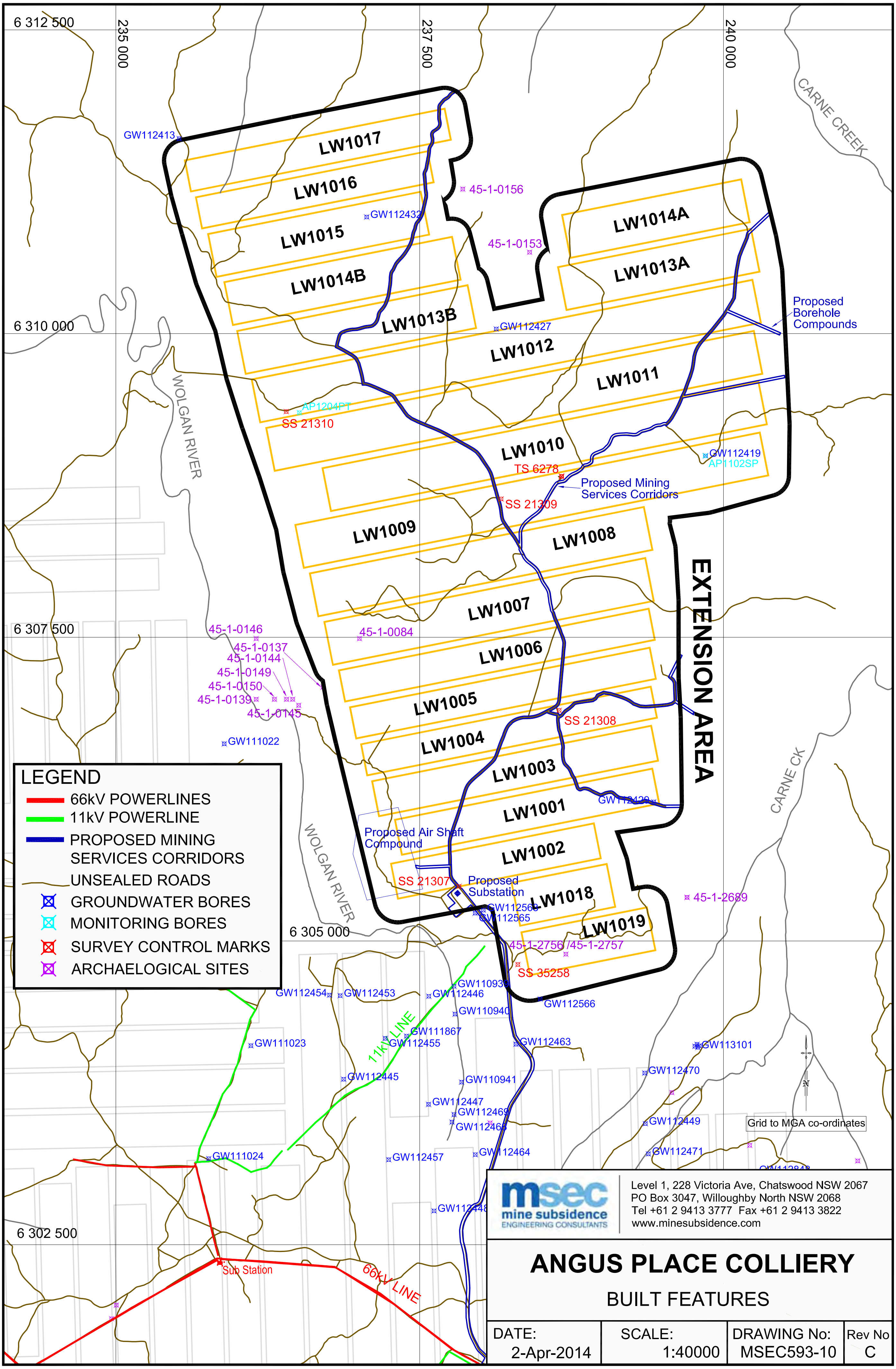
ANGUS PLACE COLLIERY

CLIFFS, MINOR CLIFFS, PAGODAS & STEEP SLOPES

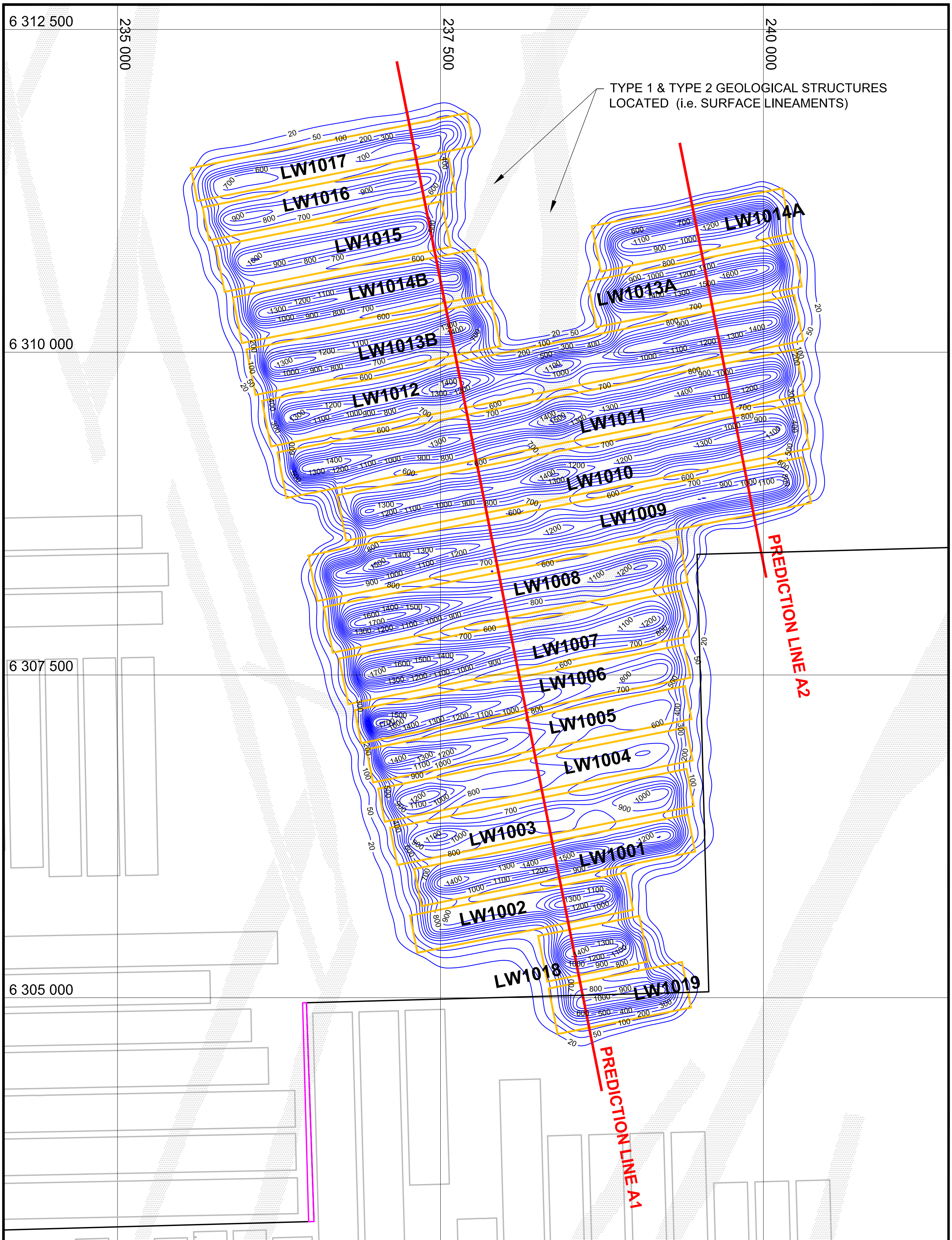
DATE:	SCALE:	DRAWING No:	Rev No
2-Apr-2014	1:40000	MSEC593-09	C

LEGEND
- STEEP SLOPES WITH GRADE 1:3 TO 1:2
- STEEP SLOPES WITH GRADE 1:2 TO 1:1.5
- STEEP SLOPES WITH GRADE 1:1.5 TO 1:1
- STEEP SLOPES WITH GRADE 1:1 TO 2:1
- PAGODAS
- MINOR CLIFFS
- CLIFFS
- SURFACE LEVEL CONTOURS

I:\Projects\Angus Place\MSEC593 Mine Extension Project\AutoCAD\MSEC593-10.dwg



I:\Projects\Angus Place\MSEC593 Mine Extension Project\AutoCAD\MSEC593-11.dwg



PREDICTED SUBSIDENCE CONTOURS ARE IN MILLIMETRES (mm)

msec mine subsidence ENGINEERING CONSULTANTS

Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com

ANGUS PLACE COLLIERY

PREDICTED TOTAL SUBSIDENCE CONTOURS DUE TO LW1001 TO LW1019

DATE:	SCALE:	DRAWING No:	Rev No
2-Apr-2014	1:40000	MSEC593-11	C