

CENTENNIAL COAL:

Springvale 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 416 to 432
and 501 to 503 in the Lithgow Seam

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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 Springvale Colliery (Springvale), which is located in the western coalfield of New South Wales. Centennial is seeking approval to extract the proposed Longwalls 416 to 432 and 501 to 503 in the Lithgow Seam, which is referred to as the *Springvale Colliery Mine Extension Project*. The layout of the proposed longwalls is shown in Drawing Nos. MSEC594-01 and MSEC594-02, 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 Springvale Colliery Mine Extension Project for the continuation of mining at Springvale beyond 28 September 2014.

Specific objectives of the Project are as follows:

- *Design the Project in accordance with the principles of ecologically sustainable development;*
- *Extract up to 4.5 million tonnes per annum (Mtpa) of run of mine (ROM) coal from the Lithgow Seam;*
- *Development of underground access headings and roadways from the current mining area initially eastwards then to the south and south-west as illustrated on Figure 2;*
- *Secondary extraction by longwall mining;*
- *Process ROM coal through a crusher and screening plant at Springvale pit top;*
- *Install and/or operate ancillary surface infrastructure for ventilation, electricity, water, materials supply, environmental monitoring and communications;*
- *Progressively rehabilitate any disturbed areas;*
- *Continue to operate 24 hours per day seven days per week;*
- *Employment to a full time workforce of up to 310 persons comprising 280 existing personnel and up to an additional 30 full time employees; and*
- *Transfer of the operational management of coal processing and distribution infrastructure to Springvale Coal Services.”*

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

- provide subsidence predictions for the proposed Longwalls 416 to 432 and 501 to 503,
- 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 LW416 to LW432 and LW501 to LW503 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, unsealed tracks, electrical infrastructure, 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 widths of the proposed longwalls have also been narrowed, so as to reduce the potential impacts on the 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 to the west of the proposed longwalls, outside the Extension Area, above the previously extracted longwalls at the colliery. 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 Buralow Formation of the Triassic Narrabeen Group, with sandstone bedrock outcropping in some locations.

The river is predicted to experience less than 20 mm subsidence, 65 mm upsidence and 75 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 unlikely that fracturing would occur in the bed of the Wolgan River resulting from the extraction of the proposed longwalls. If any fracturing were to occur in the river, it would be expected to be isolated and minor in nature.

- *Carne Creek* is located directly above the proposed LW416 to LW419. The section of creek located above the proposed longwalls is generally confined within *Sunnyside East Swamp*. The assessed impacts on the shrub swamps are described further below.
- 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 Buralow 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 valley of Carne Creek and the tributaries to Carne Creek and Marrangaroo 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 some cliffs and 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.

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 rock formations which are located 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 rock formations would represent less than 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 18°) and 1 in 2 (i.e. 50 % or 27°), with isolated areas having natural grades up to 1 in 1.5 (i.e. 67 % or 34°).

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. The shrub swamps located within the Extension Area include *Sunnyside East Swamp*, *Carne West Swamp*, *Gang Gang Swamp South West*, *Gang Gang Swamp East*, *Pine Swamp*, *Pine Upper Swamp*, *Paddys Creek Swamp* and *Marrangaroo 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. There are around 20 hanging swamps located within the Extension Area.

The shrub swamps are predicted to experience subsidence up to 1650 mm, tilts up to 13 mm/m, and curvatures up to 0.20 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 1500 mm, tilts up to 13 mm/m, and curvatures up to 0.20 km⁻¹ hogging and 0.35 km⁻¹ 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.

- 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.
- The electrical infrastructure within the Extension Area includes a 66 kV powerline, an 11 kV powerline and a 66 kV/11 kV substation. Experience of mining beneath powerlines in the NSW Coalfields, at similar depths of cover, indicates that incidences of impacts are very low and readily repairable. Whilst impacts on the substation are not anticipated, it is recommended that the predictions are provided to *Ausgrid*, so that the plant associated with the substation can be reviewed based on the predicted movements.
- There are a number of services which are proposed to be constructed to support the mining activities, including 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 five artefact scatter and stone arrangement sites, three grinding groove sites, one rock shelter, and one scarred tree. There are also two additional artefact scatter sites which are located outside the Extension Area but are within 600 metres of the proposed longwalls.

The artefact scatter and stone arrangement sites can potentially be affected by cracking of the surface soils as a result of mine subsidence movements. It is unlikely, however, that the scattered artefacts or isolated finds themselves would be impacted by surface cracking.

One grinding groove site is located directly above the proposed longwalls. It is possible that fracturing of the bedrock could occur in the vicinity of this site. Preventive measures could be implemented, if required, including slotting of the bedrock around the site to isolate it from the ground curvatures and strains. It is possible, however, that the preventive measures could result in greater impacts on the site than those which would have occurred as a result of mine subsidence movements.

The two remaining grinding groove sites are located 120 metres and 200 metres outside the extents of the proposed longwalls. It is unlikely that these sites would experience any adverse impacts resulting from the proposed mining.

The rock shelter is located around 200 metres from the proposed longwalls. At this distance, it is unlikely that this site would experience any adverse impacts resulting from the proposed mining.

It is unlikely that the scarred tree would be adversely impacted as a result of the proposed mining, based on the extensive experience of mining beneath trees at similar depths of cover and similar surface gradients.

- 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.

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Drawings

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

<i>Drawing No.</i>	<i>Description</i>	<i>Revision</i>
MSEC594-01	Overall Layout	A
MSEC594-02	Layout of Proposed Longwalls 416 to 432 and 501 to 503	A
MSEC594-03	Surface Level Contours	A
MSEC594-04	Lithgow Seam Floor Contours	A
MSEC594-05	Lithgow Seam Thickness Contours and Proposed Extraction Heights	A
MSEC594-06	Lithgow Seam Depth of Cover Contours	A
MSEC594-07	Geological Structures	A
MSEC594-08	Streams and Swamps	A
MSEC594-09	Cliffs, Minor Cliffs, Pagodas and Steep Slopes	A
MSEC594-10	Built Features	A
MSEC594-11	Predicted Total Subsidence Contours due to Longwalls 401 to 432 and 501 to 503	A

1.1. Background

Centennial Coal Pty Limited (Centennial) operates Springvale Colliery (Springvale), which is located in the western coalfield of New South Wales. Centennial is seeking approval to extract the proposed Longwalls 416 to 432 and 501 to 503 (LW416 to LW432 and LW501 to LW503) in the Lithgow Seam, which is referred to as the *Springvale Colliery Mine Extension Project*. The layout of the proposed longwalls is shown in Drawing Nos. MSEC594-01 and MSEC594-02, in Appendix E.

The location of the project application area is shown in Fig. 1.1, which has been reproduced from the project briefing paper provided by Centennial (2012). The proposed longwalls have also been overlaid on an orthophoto of the area, which is shown in Fig. 1.2.

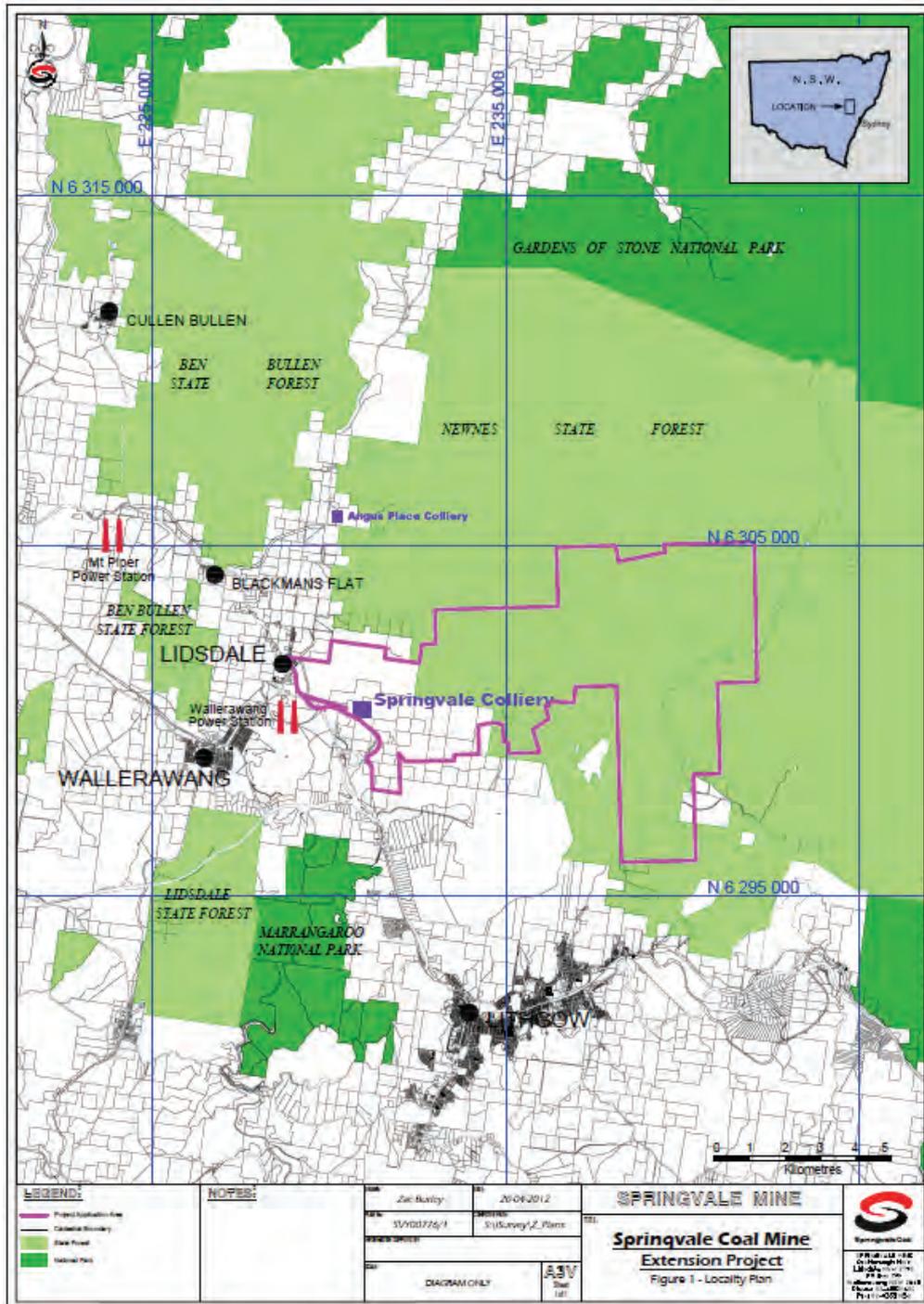


Fig. 1.1 Location Plan (Centennial, 2012)

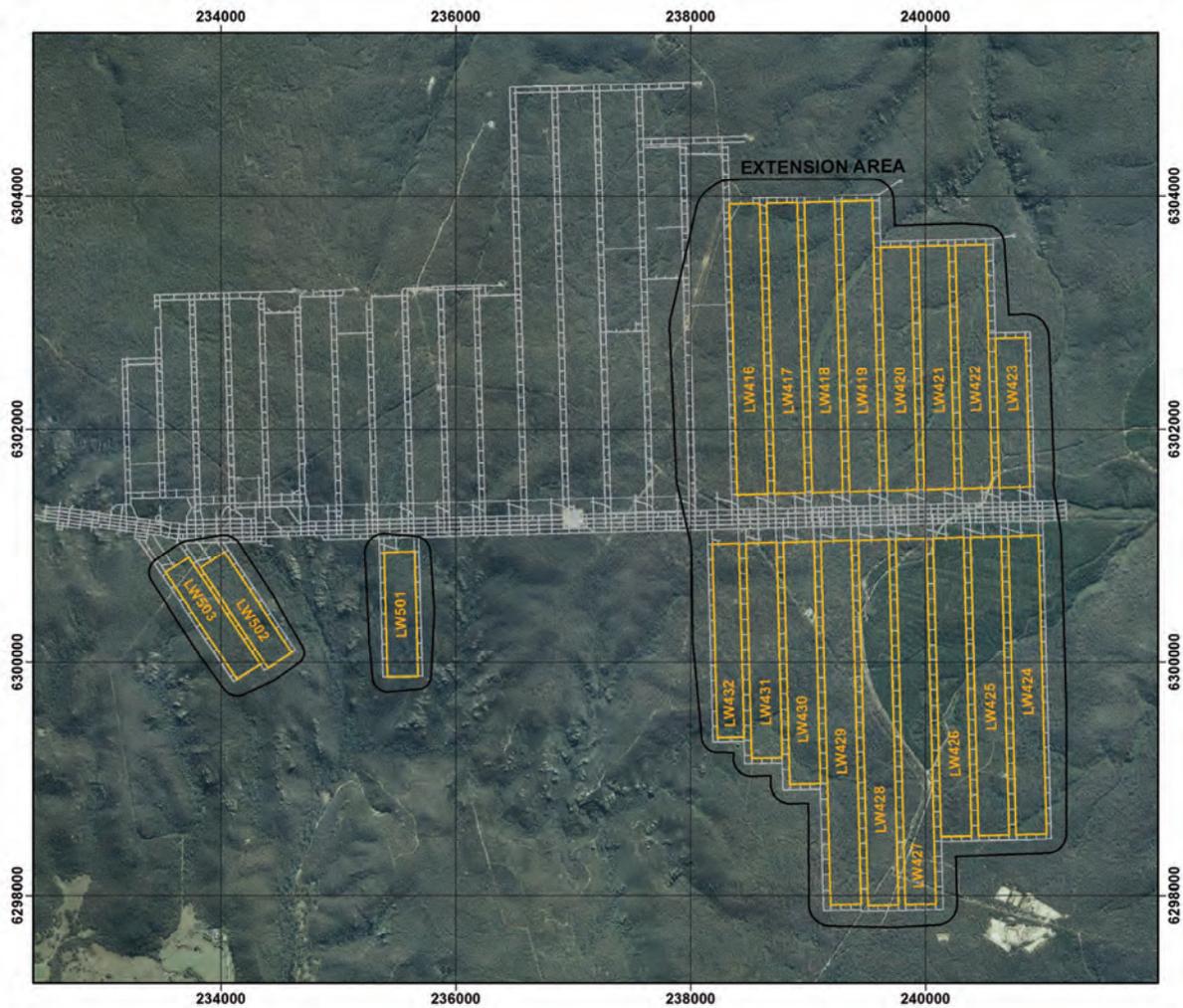


Fig. 1.2 Aerial Photograph Showing Locations of the Proposed LW416 to LW432 and LW501 to LW503

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 Springvale Colliery Mine Extension Project for the continuation of mining at Springvale beyond 28 September 2014.

Specific objectives of the Project are as follows:

- *Design the Project in accordance with the principles of ecologically sustainable development;*
- *Extract up to 4.5 million tonnes per annum (Mtpa) of run of mine (ROM) coal from the Lithgow Seam;*
- *Development of underground access headings and roadways from the current mining area initially eastwards then to the south and south-west as illustrated on Figure 2;*
- *Secondary extraction by longwall mining;*
- *Process ROM coal through a crusher and screening plant at Springvale pit top;*
- *Install and/or operate ancillary surface infrastructure for ventilation, electricity, water, materials supply, environmental monitoring and communications;*
- *Progressively rehabilitate any disturbed areas;*
- *Continue to operate 24 hours per day seven days per week;*
- *Employment to a full time workforce of up to 310 persons comprising 280 existing personnel and up to an additional 30 full time employees; and*
- *Transfer of the operational management of coal processing and distribution infrastructure to Springvale Coal Services.”*

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

- provide subsidence predictions for the proposed LW416 to LW432 and LW501 to LW503,
- 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
<p><i>“The EIS must address the following specific issues:</i></p> <ul style="list-style-type: none"> • <i>Subsidence – including a detailed quantitative and qualitative assessment of the potential conventional and non-conventional subsidence impacts of the development that includes:</i> <ul style="list-style-type: none"> ➤ <i>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;</i> ➤ <i>accurate predictions of the potential subsidence effects and impacts of the development, including a robust sensitivity analysis of these predictions;</i> ➤ <i>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</i> ➤ <i>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);”</i> <p><i>“In addition, the EIS must include:”</i></p> <ul style="list-style-type: none"> • <i>“a detailed assessment of the key issues specified below, and any other significant issues identified in this risk assessment, which includes:”</i> <ul style="list-style-type: none"> ➤ <i>“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”</i> 	<p>Table 2.1 provides a summary of the natural and built features identified in the area; and Chapters 5 and 6 provide details of these features.</p> <p>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.</p> <p>Chapters 5 and 6 provide the impact assessments for each of the natural and built features.</p> <p>Chapters 5 and 6 provide discussions and recommendations for the existing and proposed management strategies for the natural and built features.</p> <p>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.</p>

1.2. Mining Geometry

The LW416 to LW432 and LW501 and LW503 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)
LW416	2495	261	45
LW417	2495	261	58
LW418	2495	261	58
LW419	2495	261	58
LW420	2095	261	58
LW421	2095	261	58
LW422	2095	261	58
LW423	1285	261	58
LW424	2560	261	-
LW425	2560	261	58
LW426	2560	261	58
LW427	3135	261	58
LW428	3135	261	58
LW429	3120	261	58
LW430	2080	261	58
LW431	1850	261	58
LW432	1660	229	58
LW501	1070	261	-
LW502	1035	243	-
LW503	1105	236	35

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 S1, S2 and S3 in Fig. 1.3, Fig. 1.4 and Fig. 1.5, respectively. The location of this cross-section is shown in Drawing Nos. MSEC594-03 to MSEC594-05.

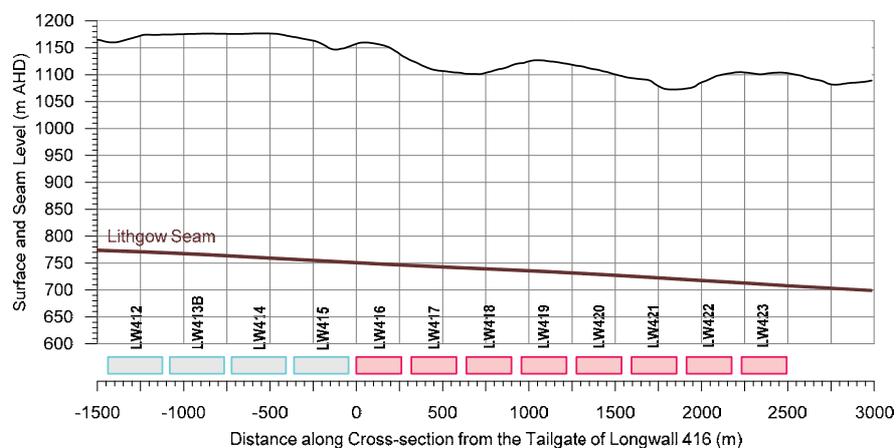


Fig. 1.3 Surface and Seam Levels along Cross-section S1

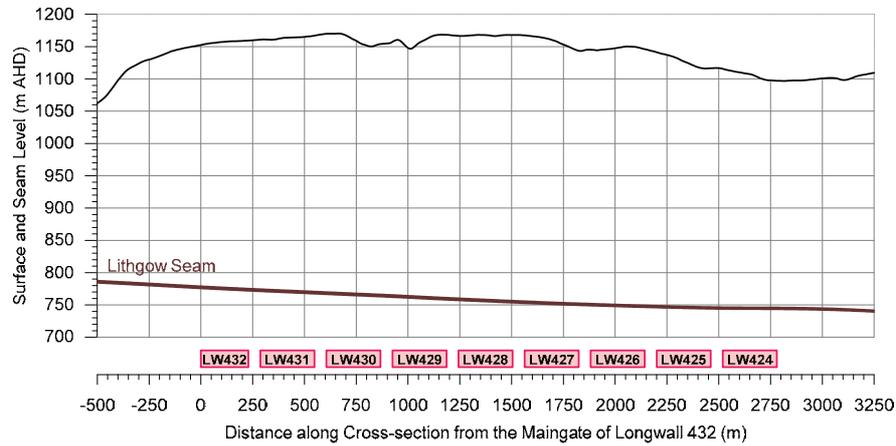


Fig. 1.4 Surface and Seam Levels along Cross-section S2

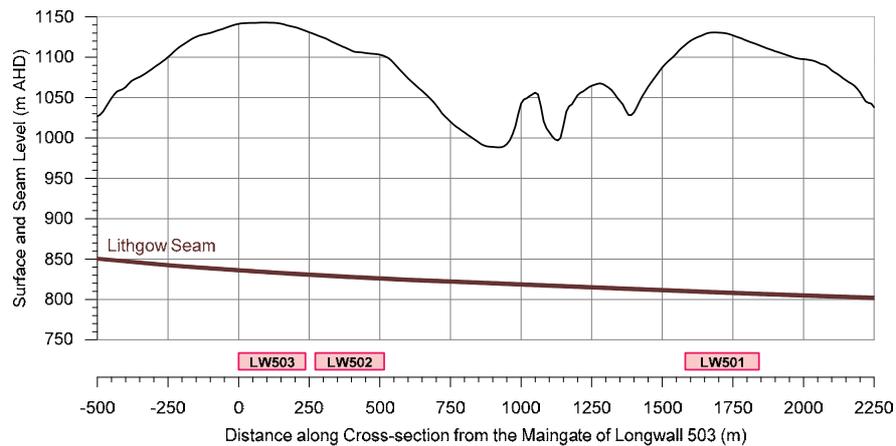


Fig. 1.5 Surface and Seam Levels along Cross-section S3

The surface level contours in the vicinity of the proposed longwalls are shown in Drawing No. MSEC594-03. The land above the northern part of the mining area naturally drains towards Carne Creek, and the land above the southern part of the mining area naturally drains towards Marrangaroo 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 1000 mAHD above the commencing (southern) ends of the proposed LW501 and LW502, to a high point of approximately 1175 mAHD above the proposed LW426 to LW428.

The seam floor contours, seam thickness contours and depth of cover contours for the Lithgow Seam are shown in Drawings Nos. MSEC594-04, MSEC594-05, and MSEC594-06, 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 180 metres above the commencing (southern) ends of the proposed LW501 and LW502, and a maximum of 420 metres above the northern end of the proposed LW416 and the southern ends of the proposed LW417 and LW419.

The seam floor within the mining area generally dips from the south-west towards the north-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 2.0 metres and 3.4 metres. The proposed extraction heights are shown in Drawing No. MSEC594-05.

1.4. Geological Details

Springvale lies in the south-western part of the western coalfield of the Sydney Basin. A typical stratigraphic section is provided in Fig. 1.6 (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.

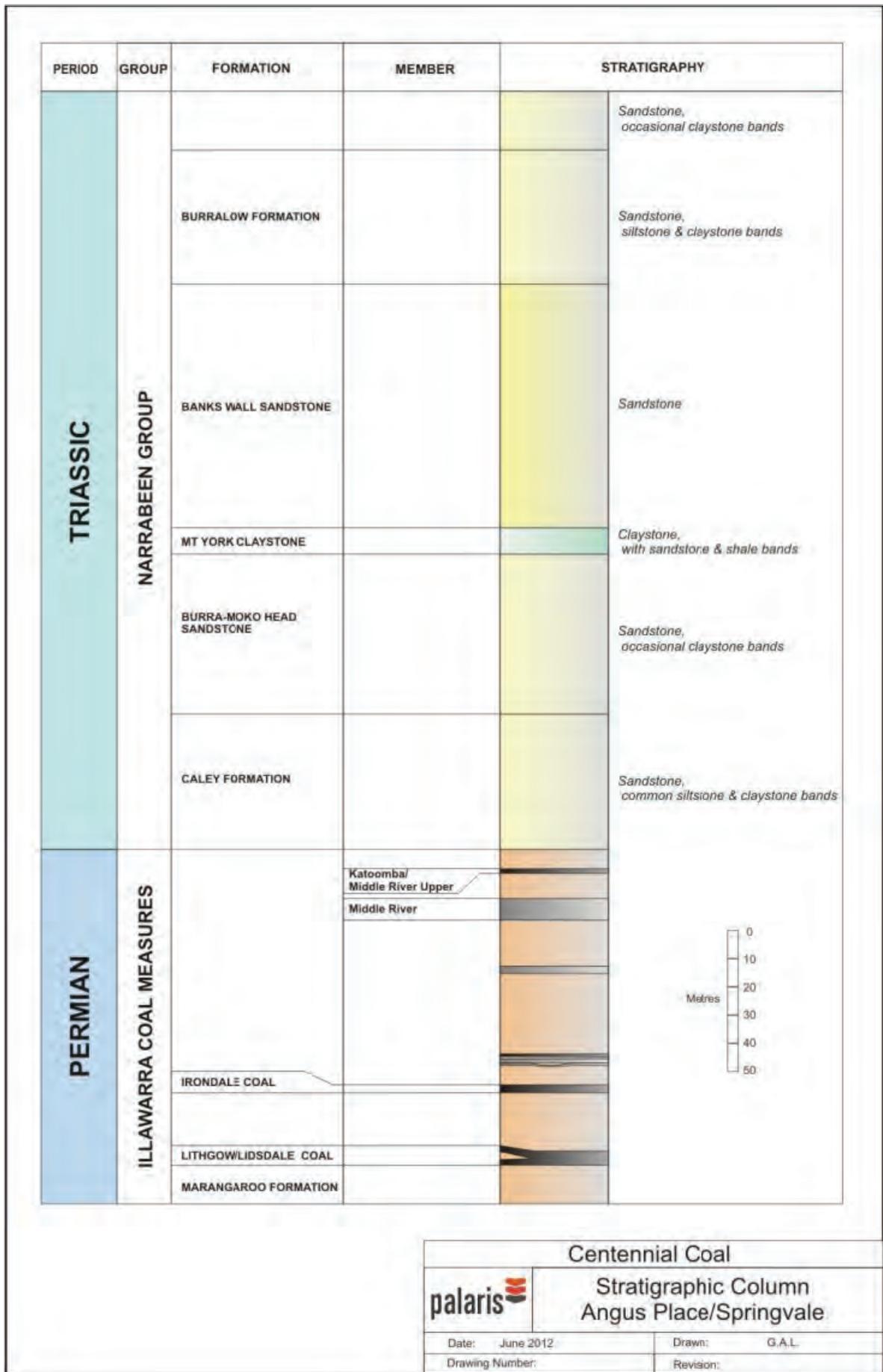


Fig. 1.6 Typical Stratigraphic Section (Palaris, 2013a)

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. 1.7 (Palaris, 2013a). These boreholes are positioned north of the Extension Area, at Angus Place Colliery, and the locations are indicated in Drawing No. MSEC594-01.

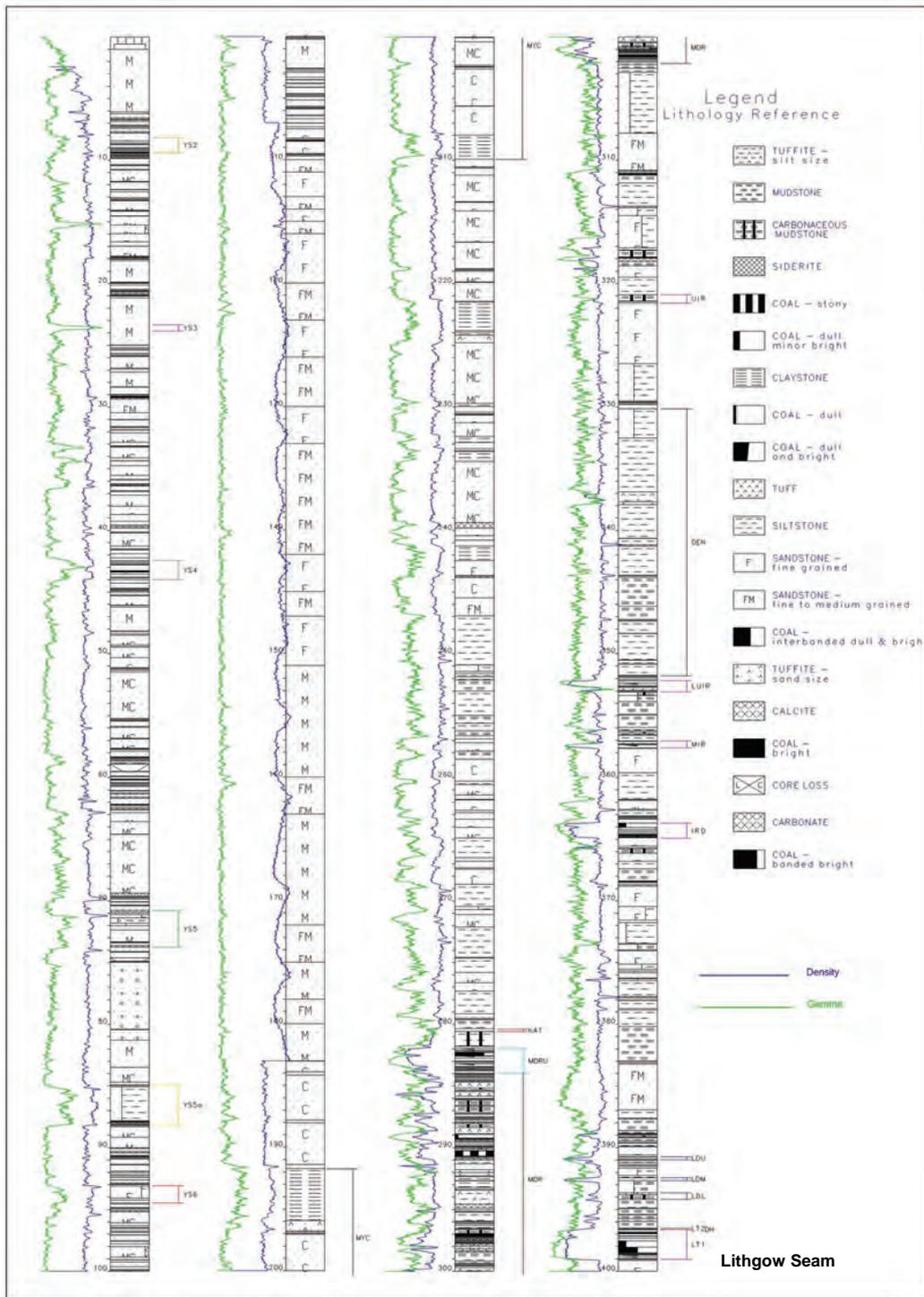


Fig. 1.7 Composite Graphic Section – Boreholes AP1102SP and AP1204PT (Palaris, 2013a)

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. 1.8, which shows the proposed longwalls overlaid on the *Geological Series Sheets 8830 and 8831*, 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 Buralow Formation of the Triassic Narrabeen Group (Tn).

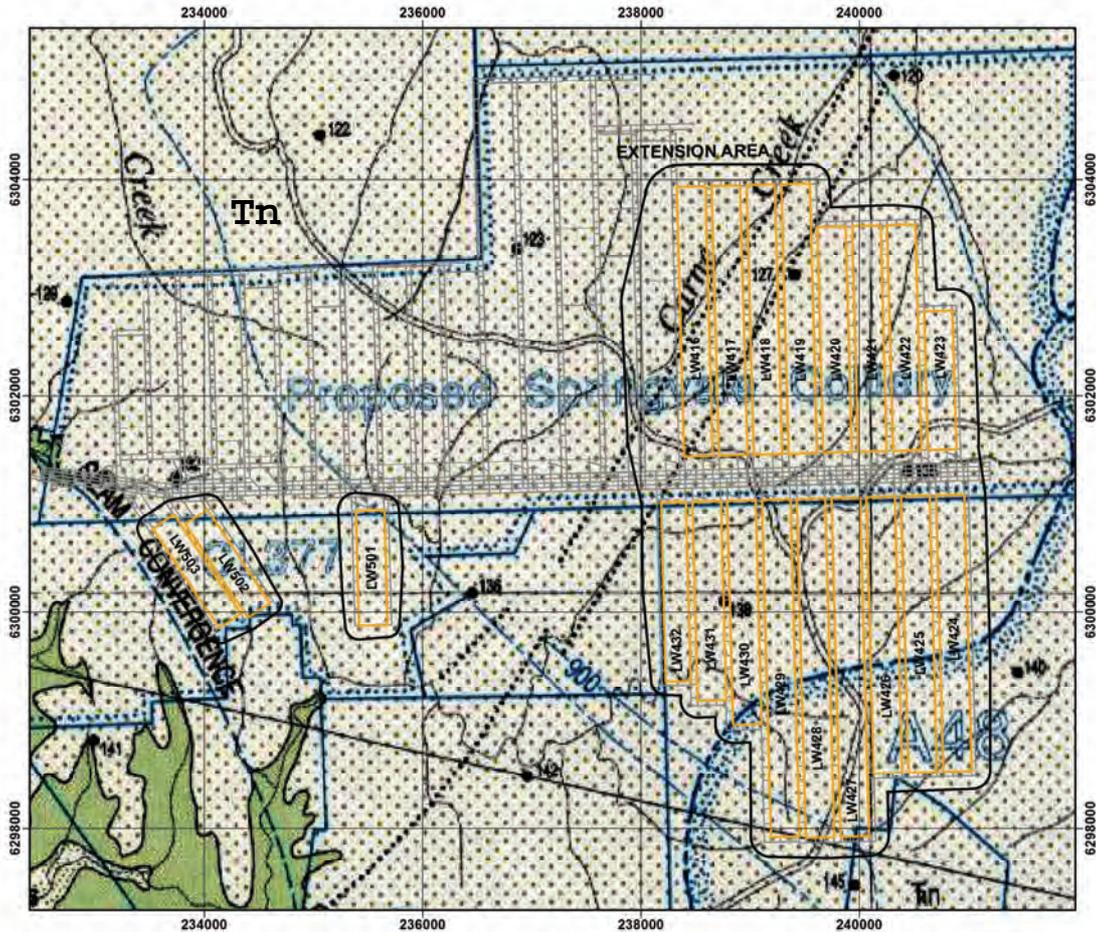


Fig. 1.8 Proposed Longwalls Overlaid on Geological Map Series Sheets 8830 and 8831

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. MSEC594-07. 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 are two *Type 1* structures which have been identified within the extents of the proposed longwalls, which are collectively referred to as the *Deanes Creek Lineament Zone*. The NNE trending surface lineaments are coincident with Carne Creek and an associated tributary above the proposed LW416 to LW419. The eastern arm of the *Deanes Creek Lineament Zone* also extends past the western side of the proposed LW432.

The southern extensions of the Wolgan Lineament are located either side of the proposed LW501 and to the east of the proposed LW502 and LW503. As described in the report by Palaris (2013b) that “*Surface relief, although present above these longwall blocks, does not appear to be part of any structure controlled lineament system*”.

There are two *Type 2* structures which have been identified within the extents of the proposed longwalls. One is a NNE surface lineament coincident with a tributary to Carne Creek above the proposed LW422, and the other is a NE surface lineament coincident with a tributary to Marrangaroo Creek above the proposed LW430 and LW431.

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 LW416 to LW432 and LW501 to LW503 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 LW416 to LW432 and LW501 to LW503, 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. MSEC594-06. 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 180 metres above the commencing (southern) ends of LW501 and LW502, and a maximum of 420 metres above the northern end of LW416 and the southern ends of LW417 and LW419. The 26.5 degree angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 90 metres and 210 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 LW416 to LW432 and LW501 to LW503, 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. MSEC594-13, 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 Drawings Nos. MSEC594-01 and MSEC594-02.

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 features and items of surface infrastructure 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 8830 and 8831. The proposed longwalls and the Extension Area have been overlaid on an extract of this CMA map in Fig. 2.1.

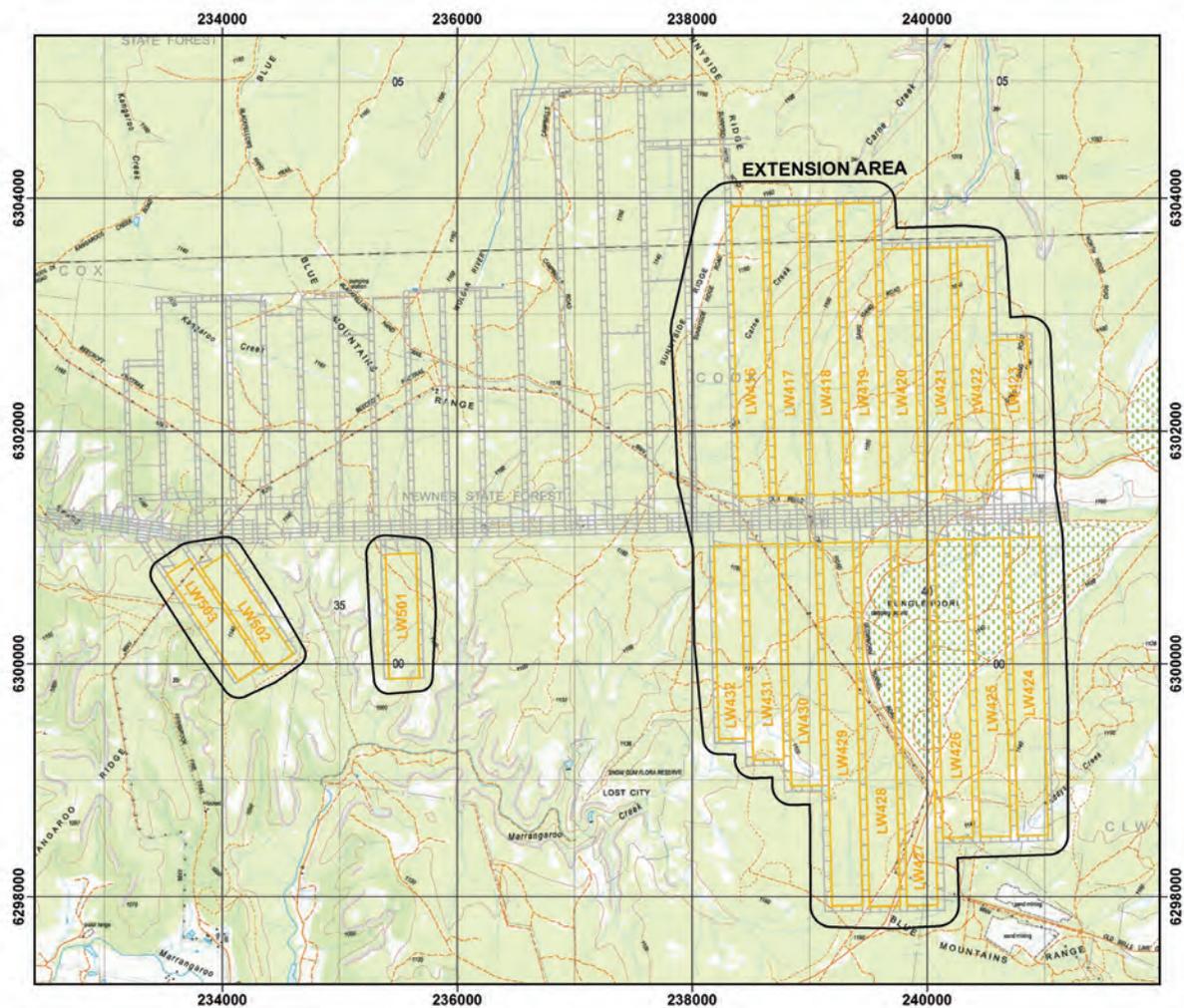


Fig. 2.1 Proposed LW416 to LW432 and LW501 to LW503 Overlaid on CMA Map Series Sheets 8830 and 8831

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 Drawings Nos. MSEC594-08 and MSEC594-10. 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	Item	Within Extension Area	Section Number
NATURAL FEATURES			FARM LAND AND FACILITIES		
Drinking Water Catchment Areas or Declared Special Areas	x		Agricultural Utilisation or Agricultural Suitability of Farm Land	x	
Streams	✓	5.2 to 5.4	Farm Buildings or Sheds	x	
Aquifers or Known Groundwater Resources	✓	5.5	Tanks	x	
Springs or Groundwater Seeps	✓	5.6	Gas or Fuel Storages	x	
Sea or Lake	x		Poultry Sheds	x	
Shorelines	x		Glass Houses	x	
Natural Dams	x		Hydroponic Systems	x	
Cliffs or Pagodas	✓	5.7	Irrigation Systems	x	
Steep Slopes	✓	5.9	Fences	✓	6.7
Escarpments	x		Farm Dams	x	
Land Prone to Flooding or Inundation	x	5.11	Wells or Bores	✓	6.8
Swamps or Wetlands	✓	5.12	Any Other Farm Features	x	
Water Related Ecosystems	✓	5.13			
Threatened or Protected Species	✓	5.14	INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Lands Defined as Critical Habitat	x		Factories	x	
National Parks	x	5.15	Workshops	x	
State Forests	✓	5.16	Business or Commercial Establishments or Improvements	x	
State Recreation or Conservation Areas	x		Gas or Fuel Storages or Associated Plants	x	
Natural Vegetation	✓	5.17	Waste Storages or Associated Plants	x	
Areas of Significant Geological Interest	x		Buildings, Equipment or Operations that are Sensitive to Surface Movements	x	
Any Other Natural Features Considered Significant	x		Surface Mining (Open Cut) Voids or Rehabilitated Areas	x	
			Mine Related Infrastructure Including Exploration Bores and Gas Wells	✓	6.10
PUBLIC UTILITIES			Any Other Industrial, Commercial or Business Features	x	
Railways	x				
Roads (All Types)	✓	6.2	AREAS OF ARCHAEOLOGICAL SIGNIFICANCE		
Bridges	x			✓	6.11
Tunnels	x		AREAS OF HISTORICAL SIGNIFICANCE		
Culverts	✓	6.2		x	
Water, Gas or Sewerage Infrastructure	x		ITEMS OF ARCHITECTURAL SIGNIFICANCE		
Liquid Fuel Pipelines	x			x	
Electricity Transmission Lines or Associated Plants	✓	6.3	PERMANENT SURVEY CONTROL MARKS		
Telecommunication Lines or Associated Plants	x			✓	6.12
Water Tanks, Water or Sewage Treatment Works	x		RESIDENTIAL ESTABLISHMENTS		
Dams, Reservoirs or Associated Works	x	6.4	Houses	x	
Air Strips	x	6.5	Flats or Units	x	
Any Other Public Utilities	x		Caravan Parks	x	
			Retirement or Aged Care Villages	x	
PUBLIC AMENITIES			Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	x	
Hospitals	x		Any Other Residential Features	x	
Places of Worship	x				
Schools	x		ANY OTHER ITEM OF SIGNIFICANCE		
Shopping Centres	x			x	
Community Centres	x		ANY KNOWN FUTURE DEVELOPMENTS		
Office Buildings	x			x	
Swimming Pools	x				
Bowling Greens	x				
Ovals or Cricket Grounds	x				
Race Courses	x				
Golf Courses	x				
Tennis Courts	x				
Any Other Public Amenities	x				

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 LW416 to LW432 and LW501 to LW503 varies between 180 metres and 420 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.

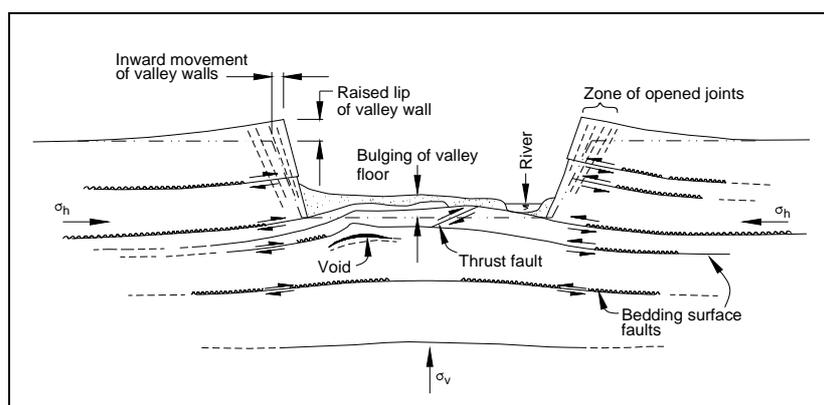


Fig. 3.1 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

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 Springvale 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 0.7 and 0.9, but were typically within the range of 0.75 to 0.85.

The proposed LW416 to LW431 have overall void widths of 261 metres and have chain pillar widths of 58 metres. The depths of cover directly above these proposed longwalls varies between a minimum of 290 metres and a maximum of 420 metres, but are typically within the range of 350 metres to 400 metres. The width-to-depth ratios for these proposed longwalls vary between 0.6 and 0.9, but are typically within the range of 0.65 and 0.75 and, therefore, are less than those for the previously extracted longwalls at Angus Place and Springvale Collieries.

The proposed LW432 and LW501 to LW503 have void widths of 229 metres to 261 metres and chain pillar widths of 35 metres or 58 metres. The depths of cover above these proposed longwalls varies between a minimum of 180 metres and a maximum of 400 metres, but are typically in the range of 250 metres to 350 metres. The width-to-depth ratio for these proposed longwalls are typically between 0.7 to 1.0 and, therefore, are similar to but 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 LW416 to LW432 and LW501 to LW503.

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.

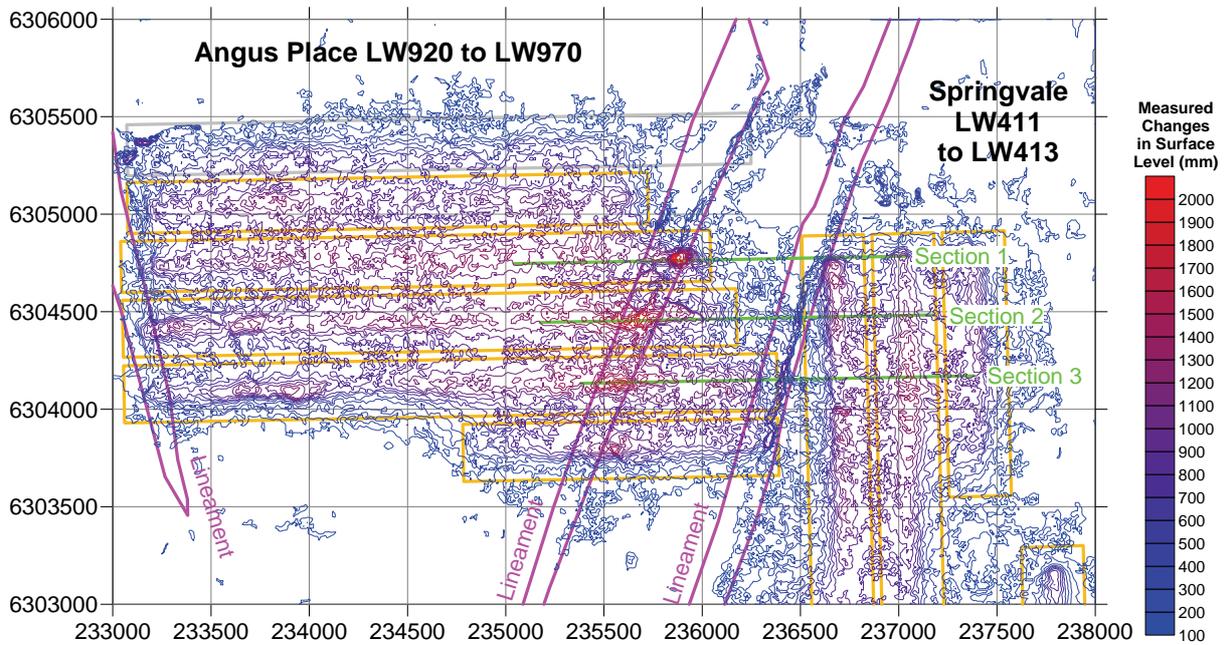


Fig. 3.2 Observed Changes in Surface Level based on LiDAR Surveys 2005 and 2012

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.

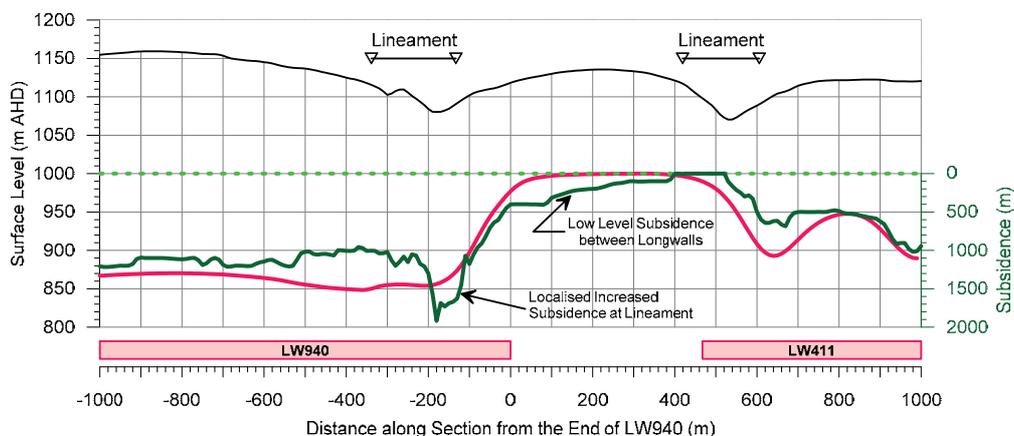


Fig. 3.3 Observed Changes in Surface Level and Predicted Subsidence along Section 1

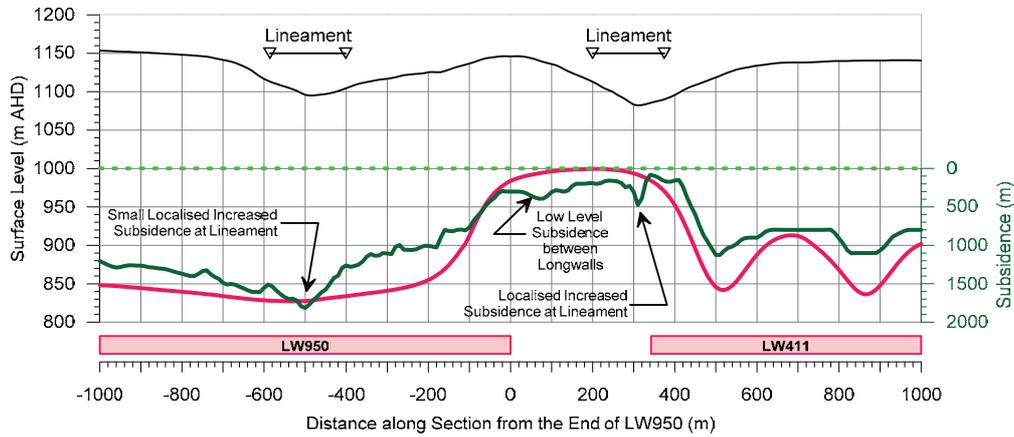


Fig. 3.4 Observed Changes in Surface Level and Predicted Subsidence along Section 2

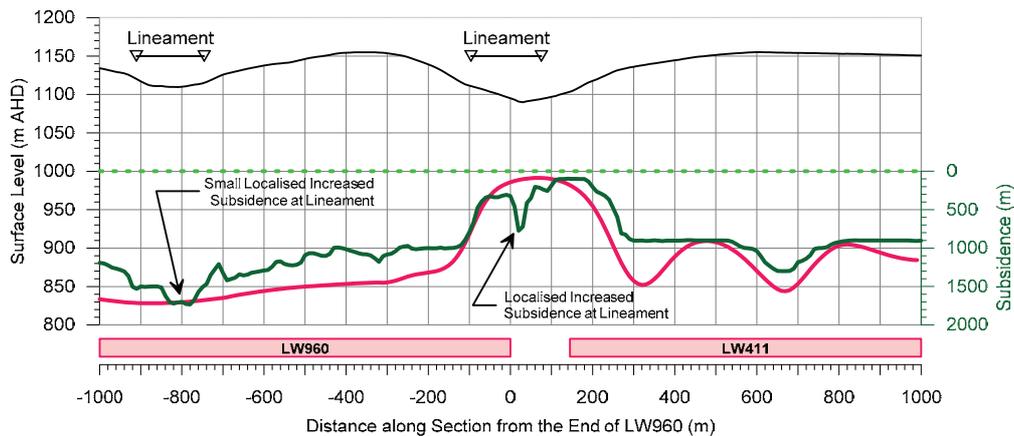


Fig. 3.5 Observed Changes in Surface Level and Predicted Subsidence along Section 3

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. MSEC594-07. 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 LW416 to LW419 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.

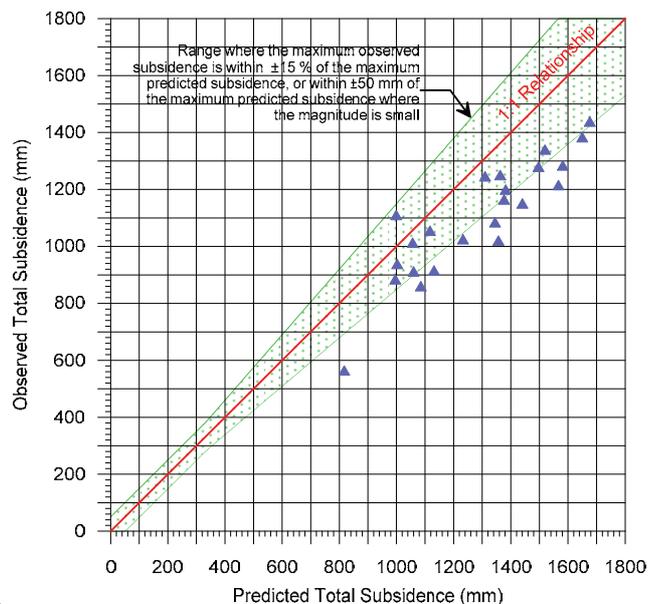


Fig. 3.6 Comparisons between Maximum Observed and Maximum Predicted Total Subsidence Directly Above the Previously Extracted Longwalls at Angus Place and Springvale Collieries

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 the 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.

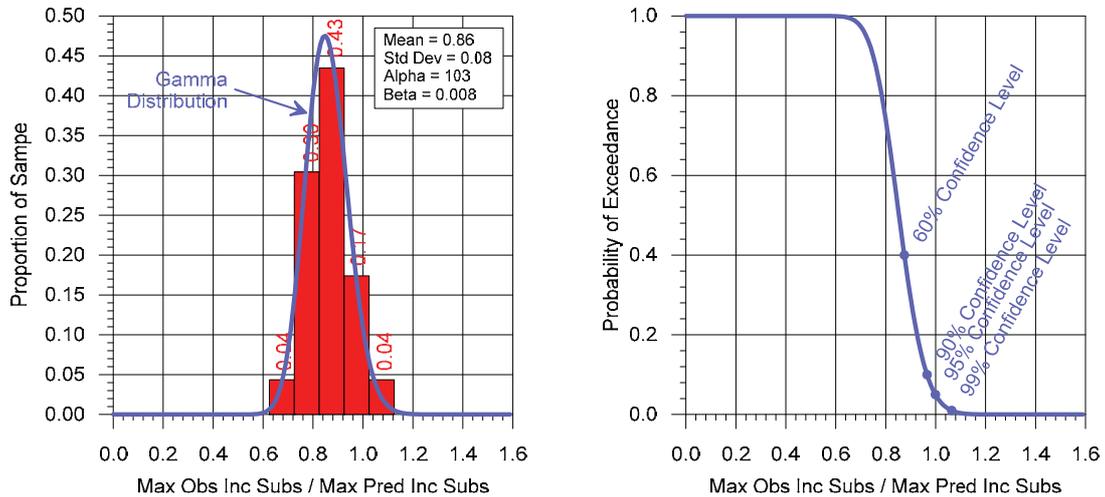


Fig. 3.7 Distribution of the Ratio of the Maximum Observed to Maximum Predicted Total Subsidence for Previously Extracted Longwalls at Angus Place and Springvale Collieries

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.

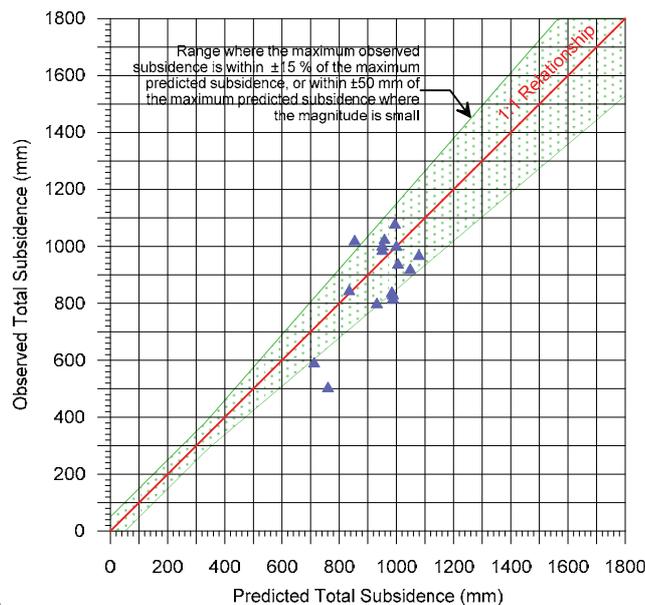


Fig. 3.8 Comparisons between Observed and Predicted Total Subsidence Directly Above the Chain Pillars for the Previously Extracted Longwalls at Angus Place and Springvale Collieries

It can be seen from the above figure, that the observed total subsidence were typically within $\pm 15\%$ 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).

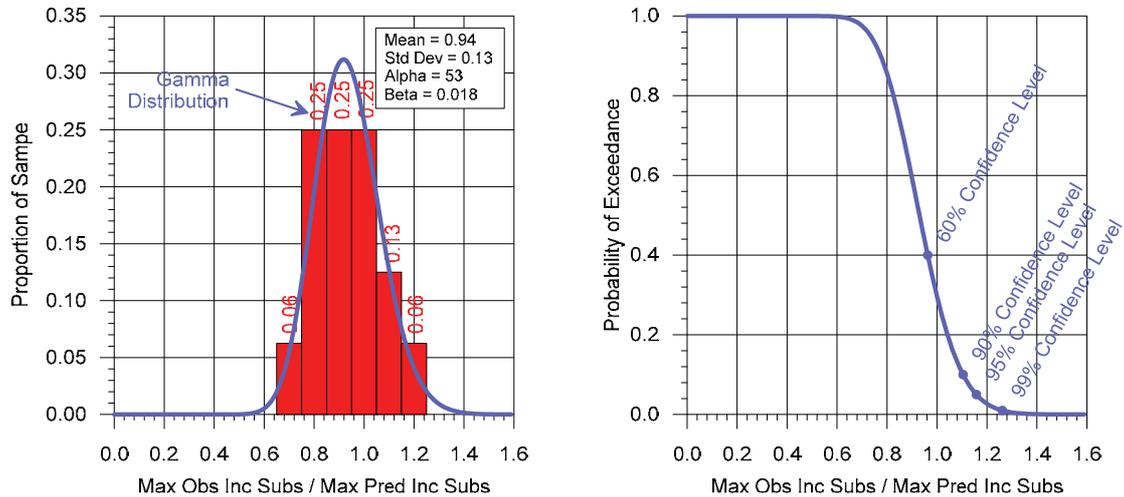


Fig. 3.9 Distribution of the Ratio of the Observed to Predicted Total Subsidence Above the Chain Pillars for Previously Extracted Longwalls at Angus Place and Springvale Collieries

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.

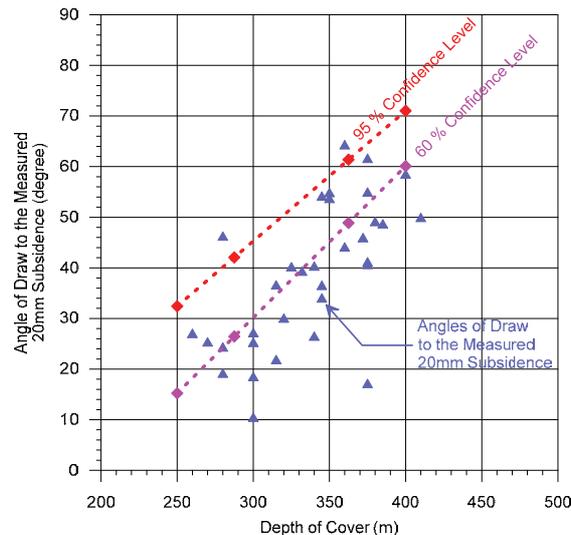


Fig. 3.10 Distribution of the Angles of Draw to the Measured 20 mm Subsidence for Previously Extracted Longwalls at Angus Place and Springvale Collieries

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 and 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.

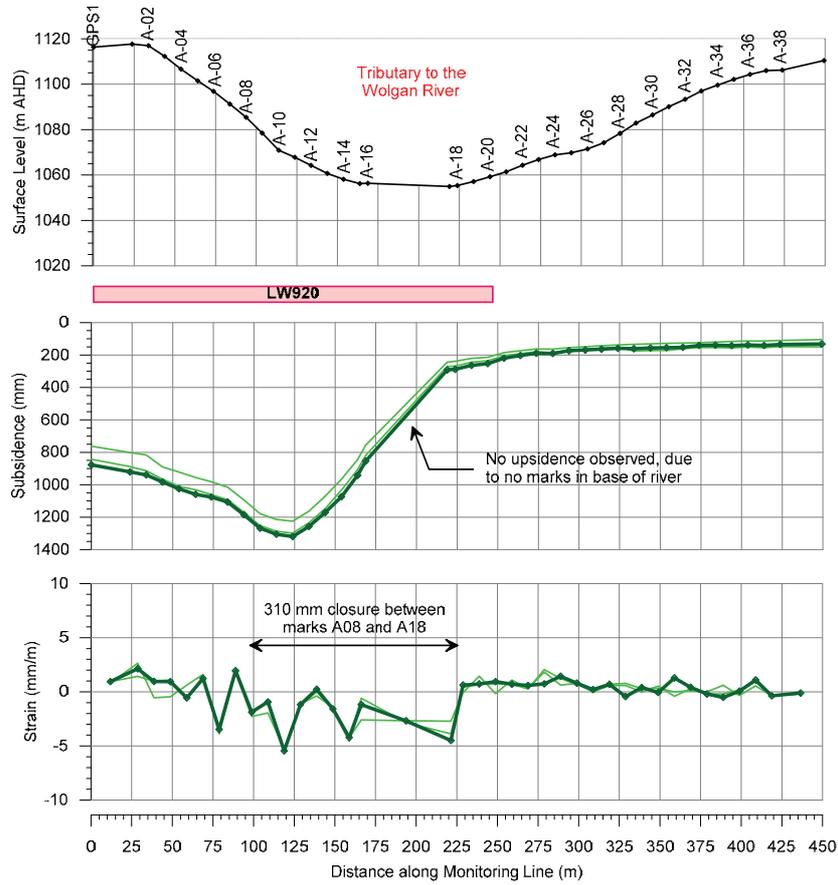


Fig. 3.11 Observed Closure along the A-Line at Angus Place Colliery

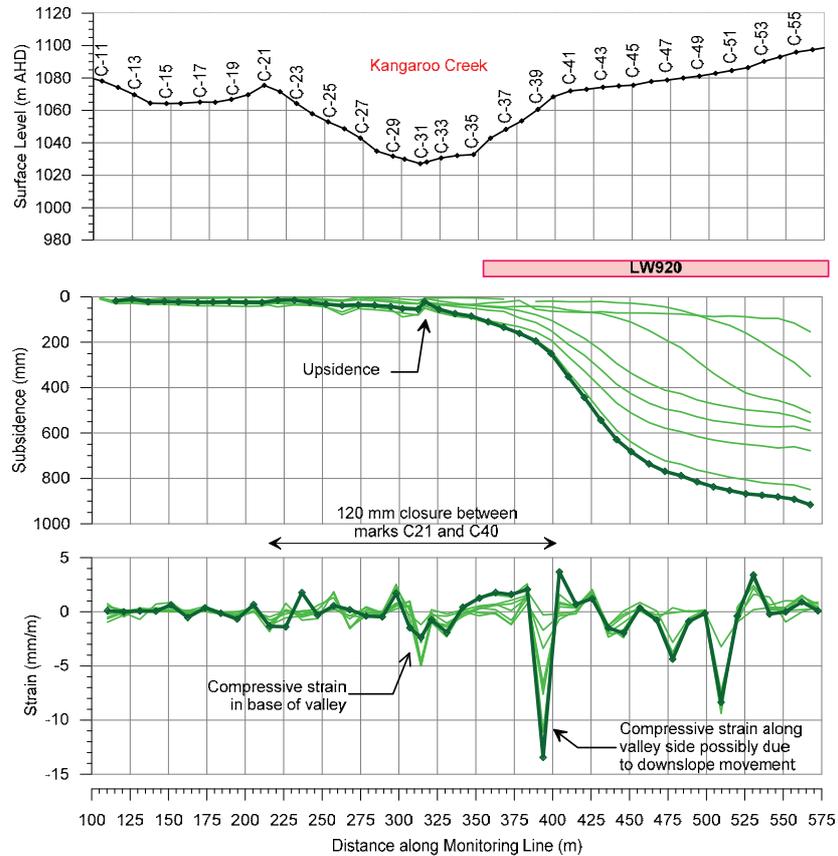


Fig. 3.12 Observed Closure along the C-Line at Angus Place Colliery

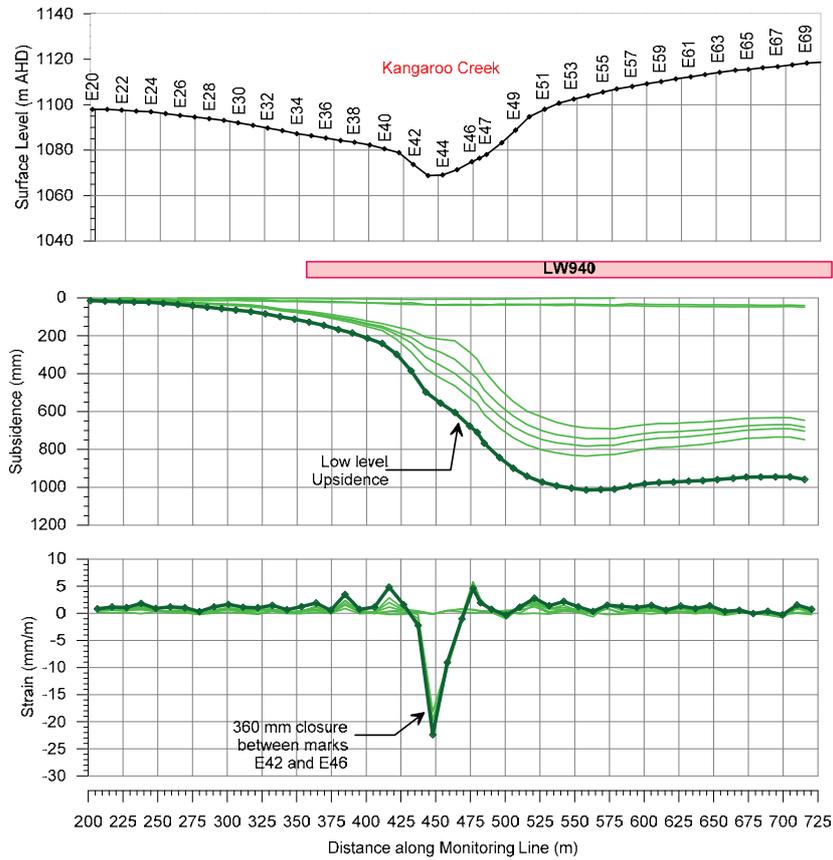


Fig. 3.13 Observed Closure along the E-Line at Angus Place Colliery

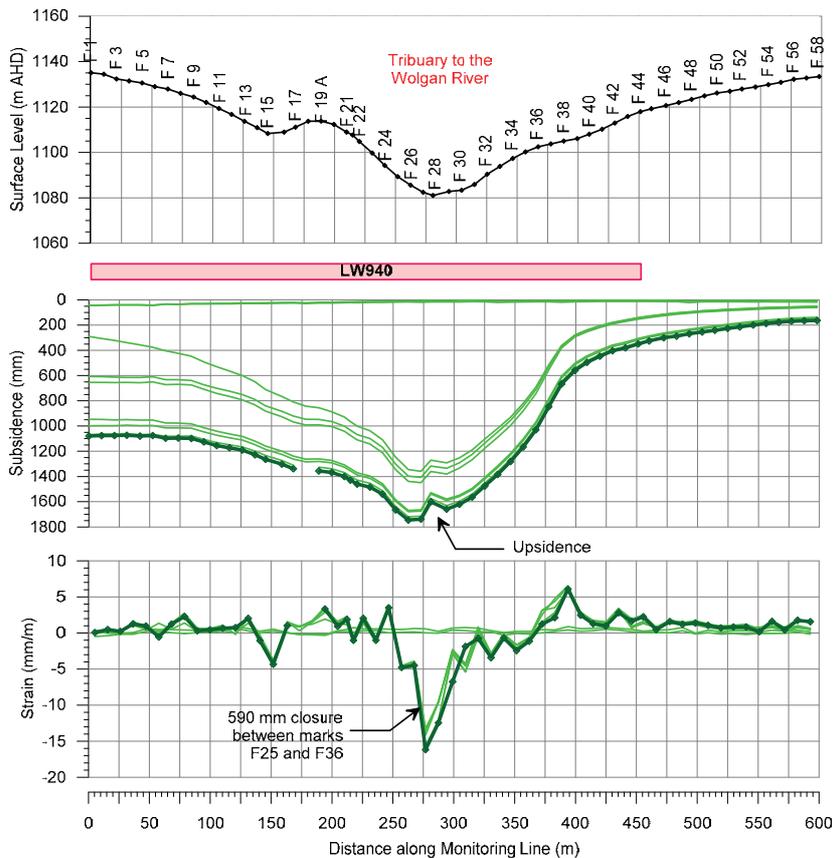


Fig. 3.14 Observed Closure along the F-Line at Angus Place Colliery

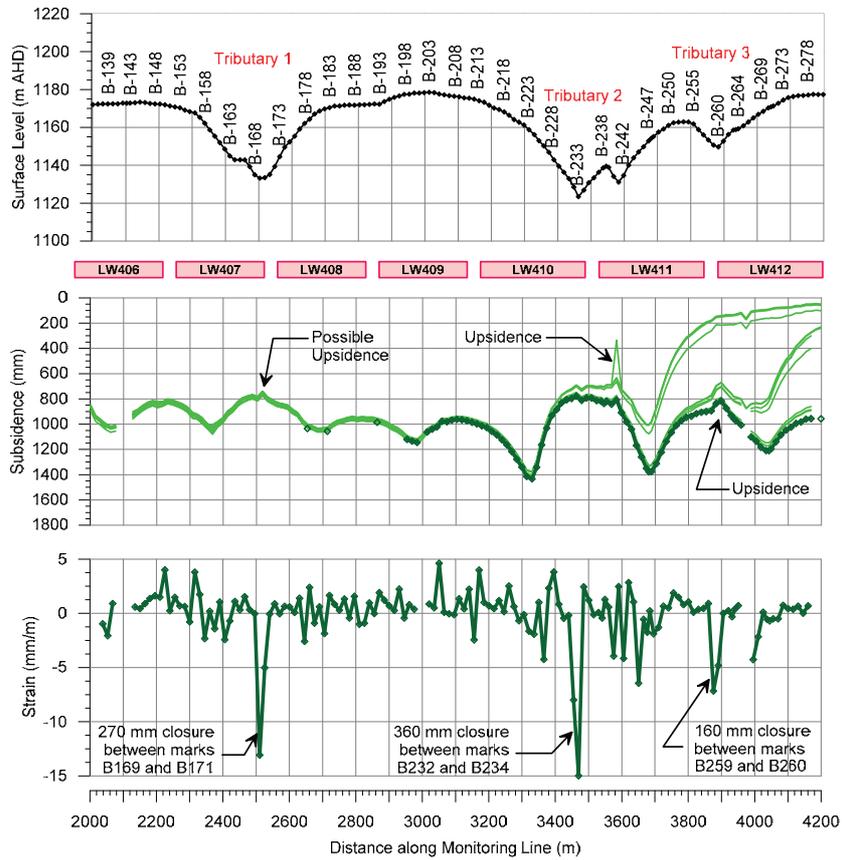


Fig. 3.15 Observed Closure along the B-Line at Springvale Colliery

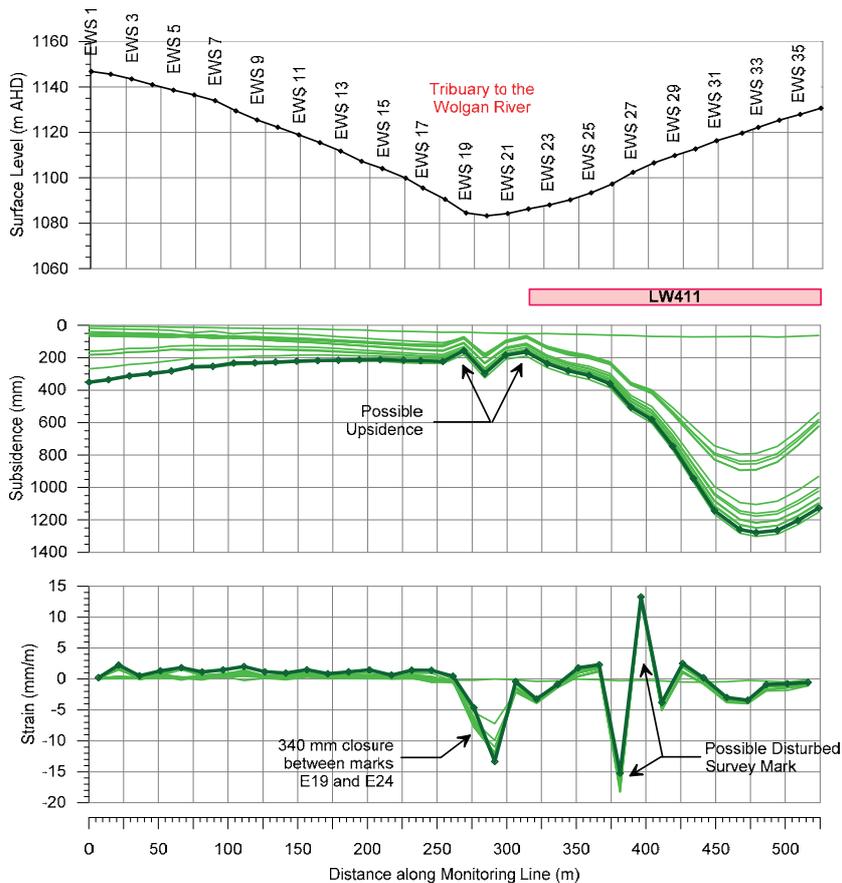


Fig. 3.16 Observed Closure along the EWS-Line at Springvale Colliery

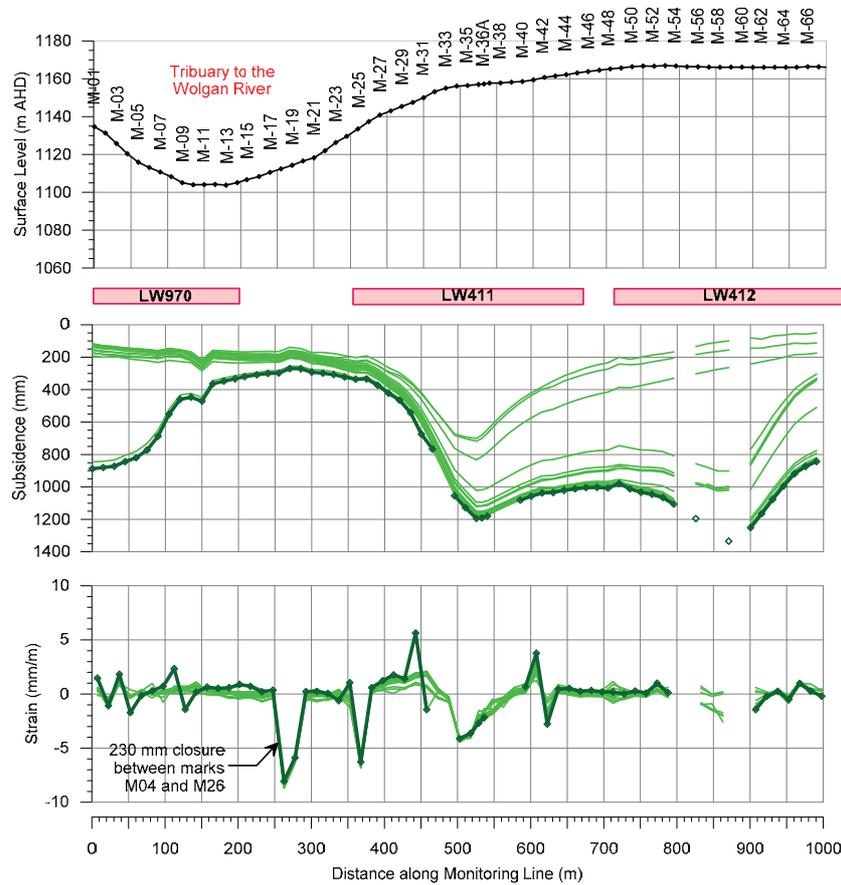


Fig. 3.17 Observed Closure along the M-Line at Springvale Colliery

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 LW416 to LW432 and LW501 to LW503 in the Lithgow Seam at Springvale 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

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})
LW416	1000 (1250)	9	0.10	0.15
LW417	950 (1200)	9	0.10	0.20
LW418	950 (1150)	9	0.10	0.20
LW419	900 (1150)	9	0.10	0.20
LW420	950	8	0.10	0.15
LW421	900 (950)	8	0.10	0.15
LW422	800 (1000)	8	0.10	0.20
LW423	650	5	0.05	0.10
LW424	700	6	0.10	0.10
LW425	850	7	0.10	0.15
LW426	850	7	0.10	0.15
LW427	800	6	0.10	0.15
LW428	900	7	0.10	0.15
LW429	1000	8	0.10	0.20
LW430	950 (1150)	9	0.15	0.20
LW431	1150 (1400)	13	0.15	0.35
LW432	950	10	0.20	0.20
LW501	1350	20	0.60	0.60
LW502	1300	20	0.50	0.55
LW503	1050	12	0.25	0.30

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 approved longwalls and proposed LW416 to LW432 and LW501 to LW503 are shown in Drawing No. MSEC594-11. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature, for each of the mining areas, 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 provided 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

Longwalls	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km ⁻¹)	Maximum Predicted Total Conventional Sagging Curvature (km ⁻¹)
LW416 to LW423	1200 (1450)	10	0.15	0.20
LW424 to LW432	1350 (1650)	13	0.20	0.35
LW501	1350	25	0.60	0.60
LW502 and LW503	1650	25	0.60	0.60

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 1650 mm which represents around 50 % of the extraction height of 3.3 metres. The maximum predicted localised subsidence at the surface lineaments is also 1650 mm, which represents around 52 % of the extraction height of 3.15 metres in this location.

The maximum predicted total conventional tilt is 25 mm/m (i.e. 2.5 %), which represents a change in grade of 1 in 40. The maximum predicted total conventional curvatures are 0.60 km⁻¹ hogging and sagging, which represents a minimum radius of curvature of 1.7 kilometres.

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 1, 2 and 3, the locations of which are shown in Drawing No. MSEC594-11.

The predicted profiles of conventional subsidence, tilt and curvature along Prediction Lines S1, S2 and S3, resulting from the extraction of the proposed longwalls, are shown in Figs. D.01, D.02 and D.03, 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 completion of the approved LW415, are shown as the solid cyan 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 line, 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 longwalls, based on applying a factor of 10 to the maximum predicted conventional curvatures, are:

- 1.5 mm/m tensile and 2 mm/m compressive for LW416 to LW423,
- 2 mm/m tensile and 3.5 mm/m compressive for LW424 to LW432, and
- 6 mm/m tensile and compressive for LW501 to LW503.

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 LW404 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 LW416 to LW431 are typically between 0.65 and 0.75, which are less than those for the previously extracted longwalls at Angus Place and Springvale Collieries. The width-to-depth ratios for the proposed LW432 and LW501 to LW503 are typically between 0.70 and 1.0, which are similar to those for the previously extracted longwalls at the collieries.

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 LW416 to LW432 and LW501 to LW503. 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.

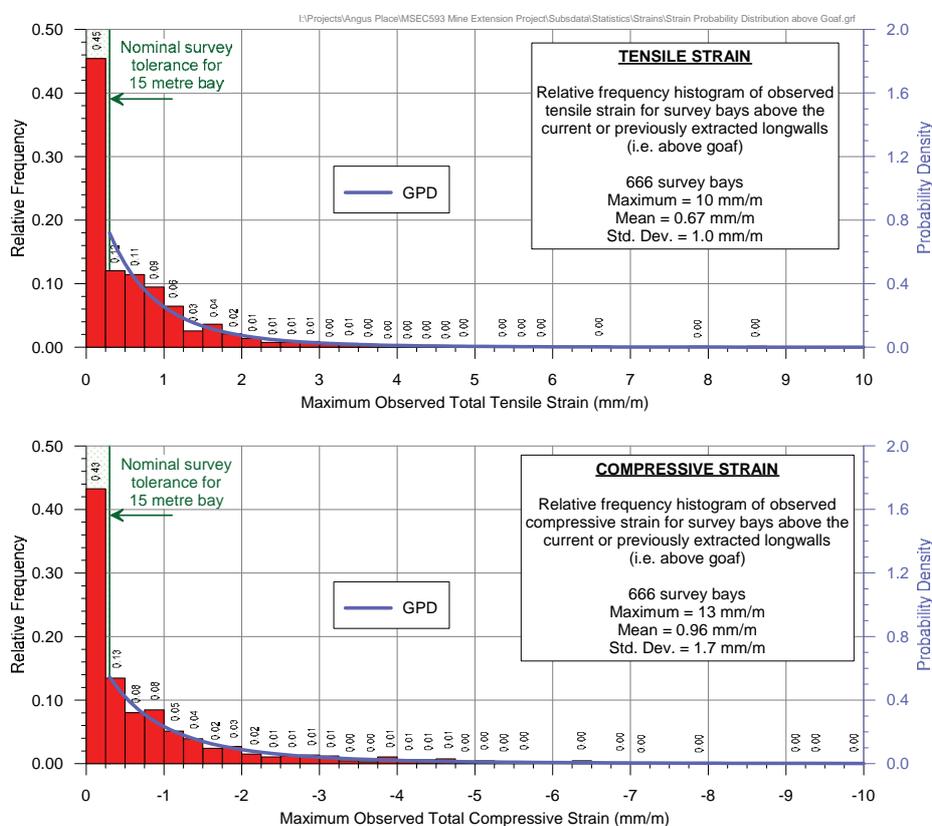


Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located Directly Above Goaf at Angus Place and Springvale Collieries

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.

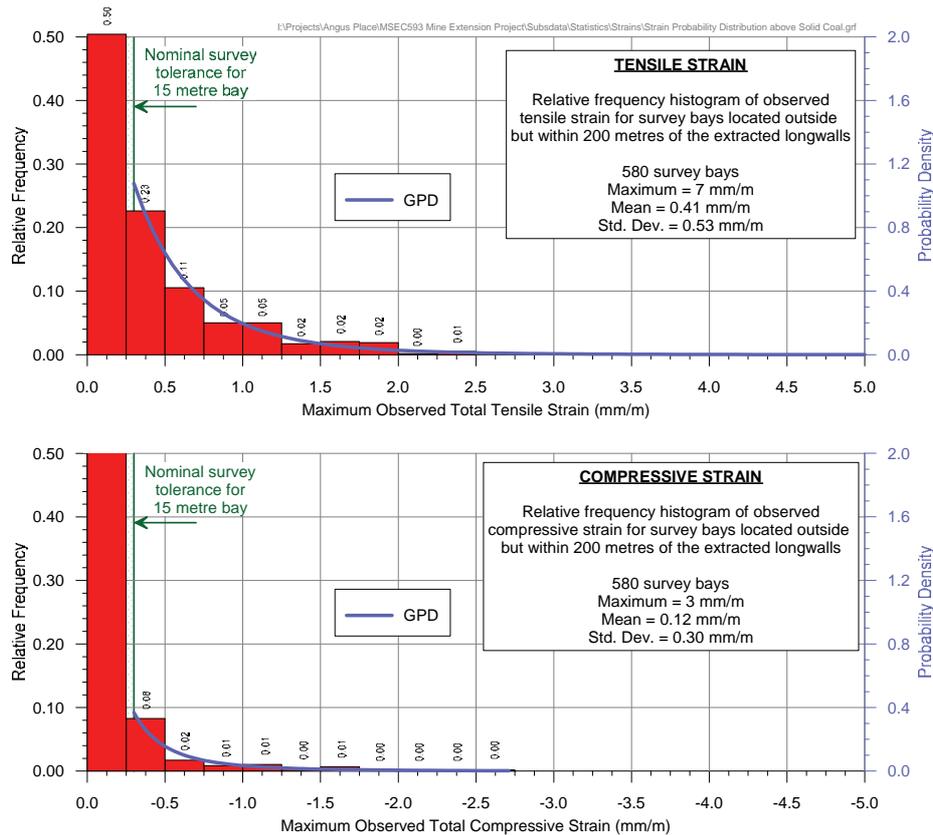


Fig. 4.2 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located Above Solid Coal at Angus Place and Springvale Collieries

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 outside the 26.5 degree angle of draw line for the previous longwalls at Angus Place and Springvale Collieries, 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.

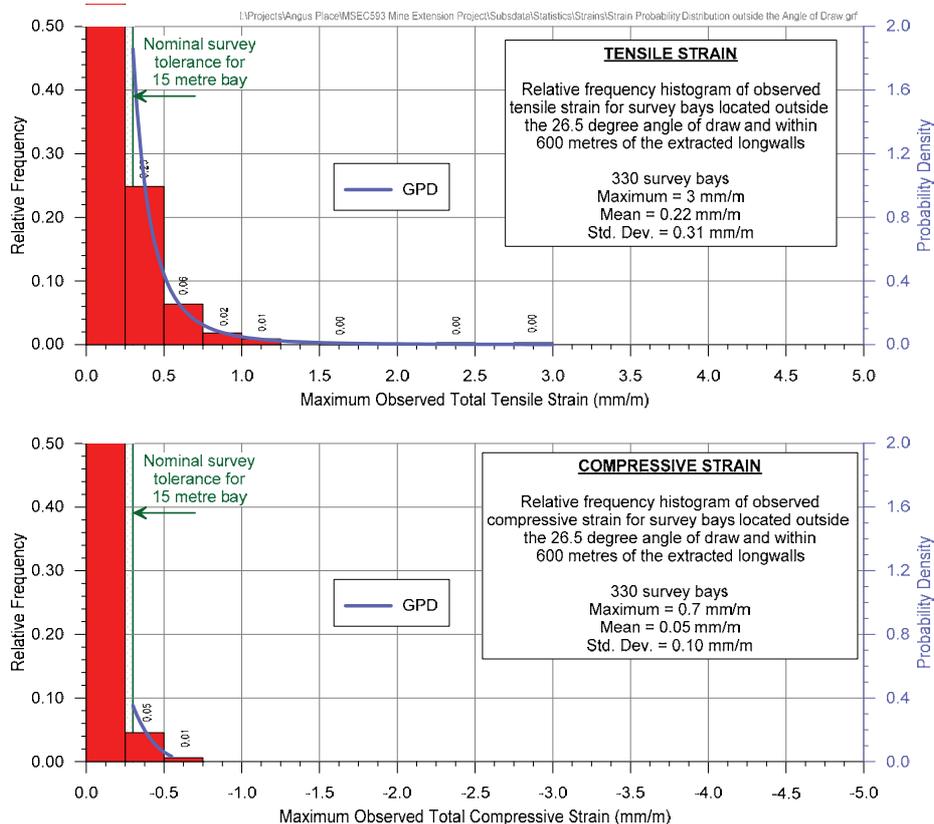


Fig. 4.3 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located Outside the Angle of Draw at Angus Place and Springvale Collieries

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.

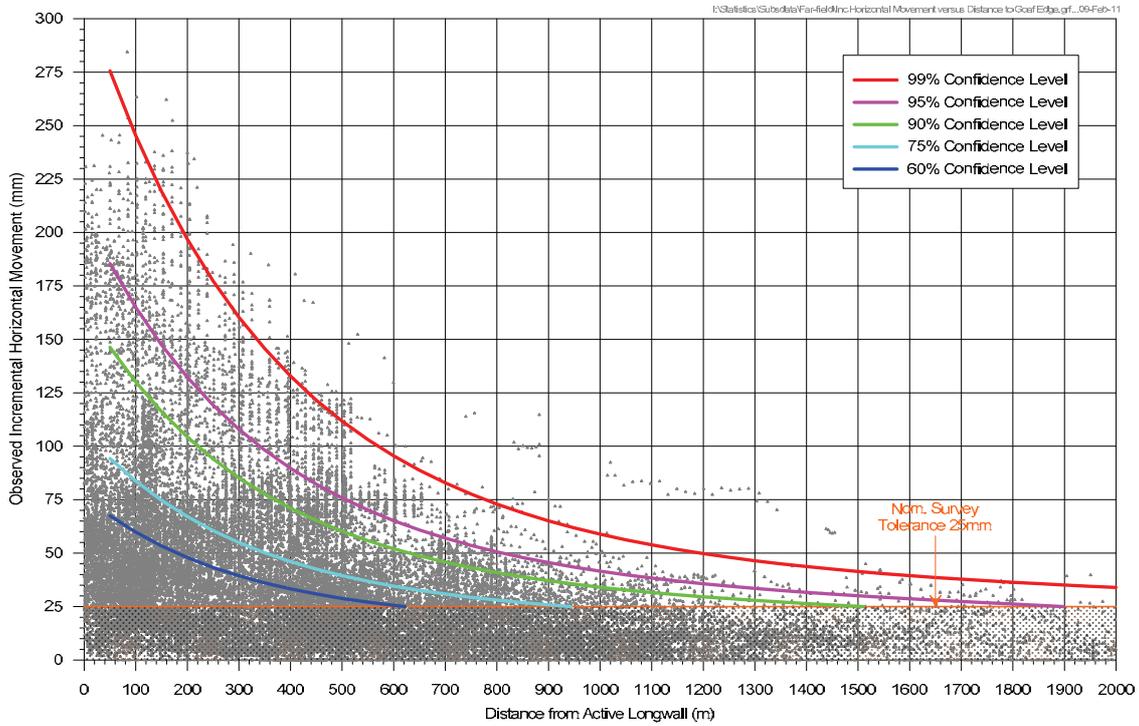


Fig. 4.4 Observed Incremental Far-Field Horizontal Movements above Goaf or Solid Coal

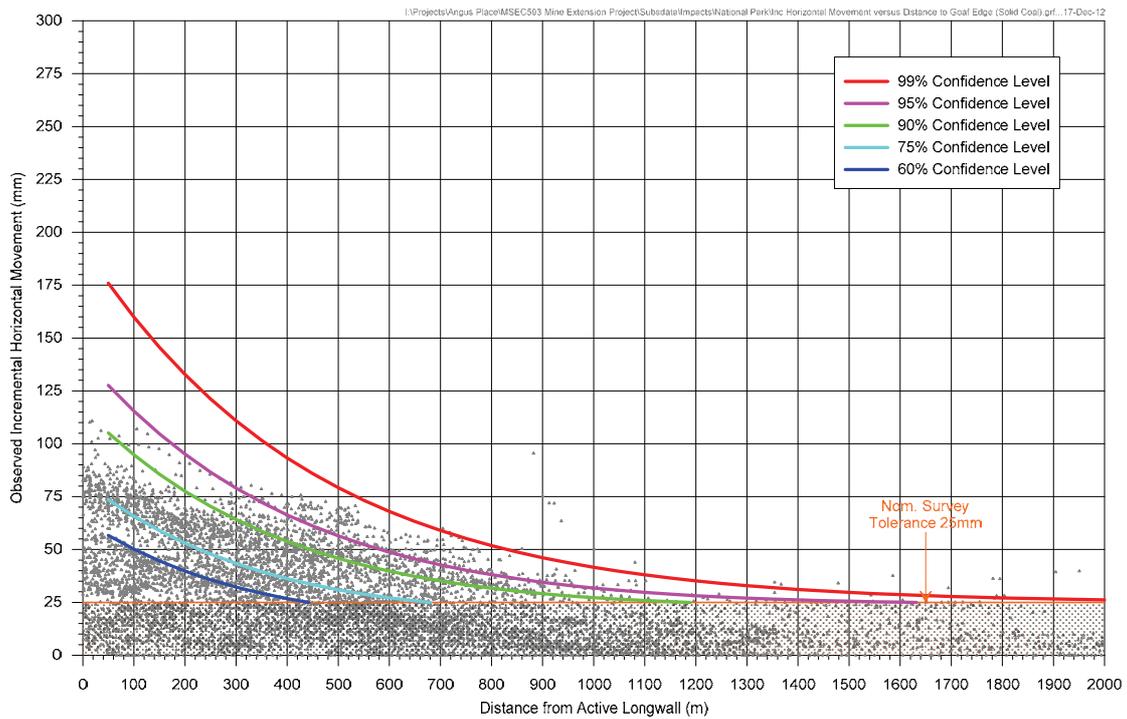


Fig. 4.5 Observed Incremental Far-Field Horizontal Movements above Solid Coal Only

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 be 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 above Angus Place LW920 (after Centennial)

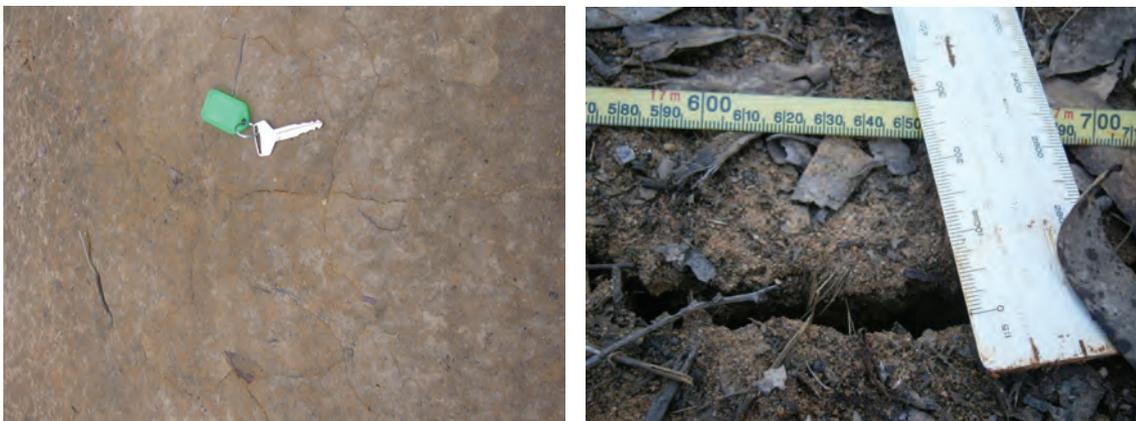


Fig. 4.7 Photographs of Surface Cracking in Kangaroo Creek Road above Angus Place LW950 (LHS) and LW960 (RHS) (after Centennial)

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.

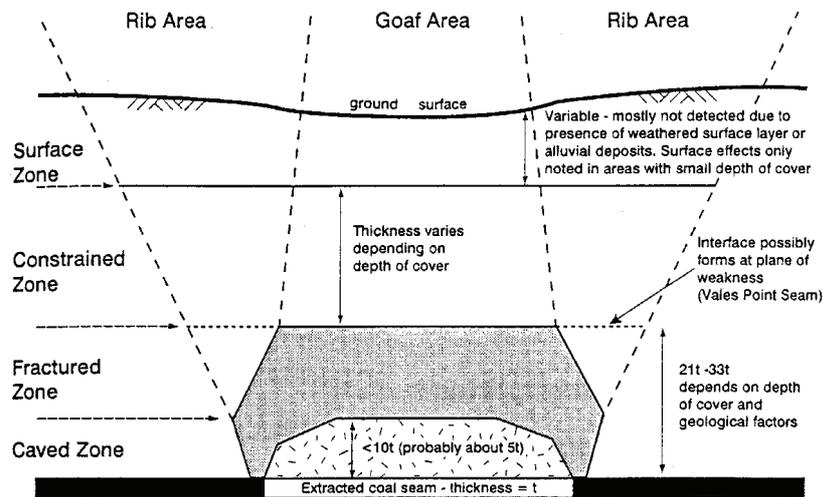


Fig. 4.8 Zones in the Overburden according to Forster (1995)

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

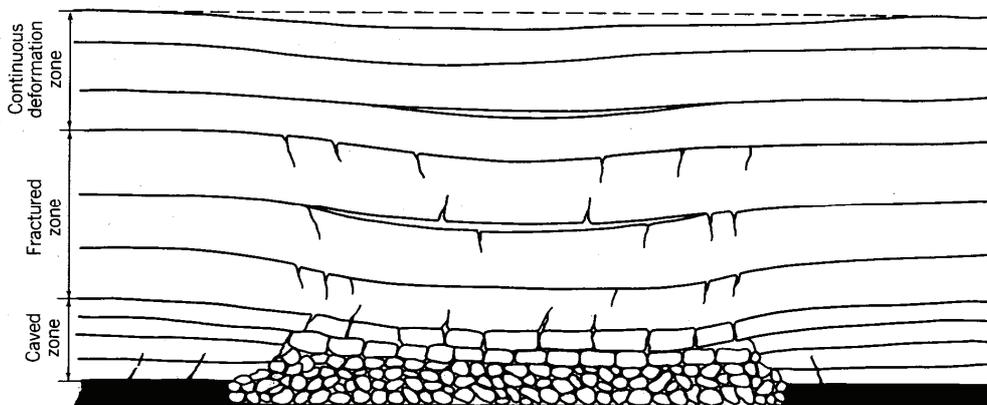


Fig. 4.9 Zones in the Overburden According to Peng and Chiang (1984)

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.

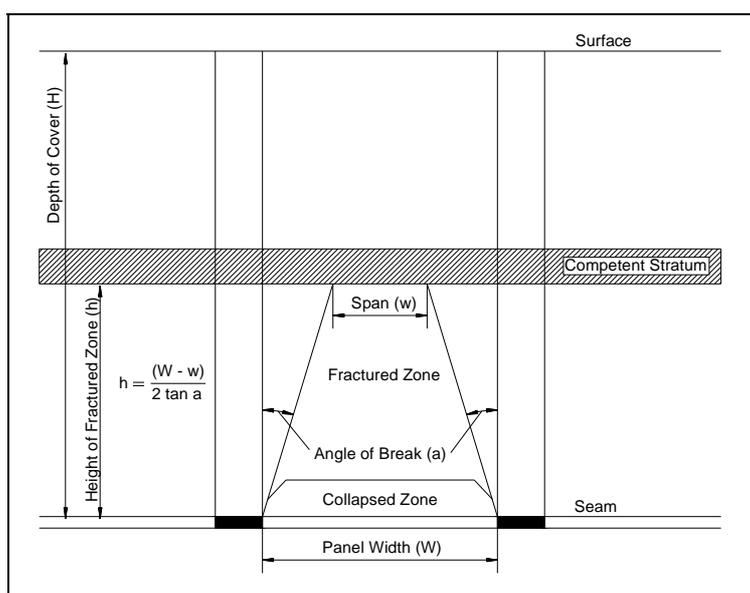


Fig. 4.10 Theoretical Model Illustrating the Development and Limit of the Fractured Zone

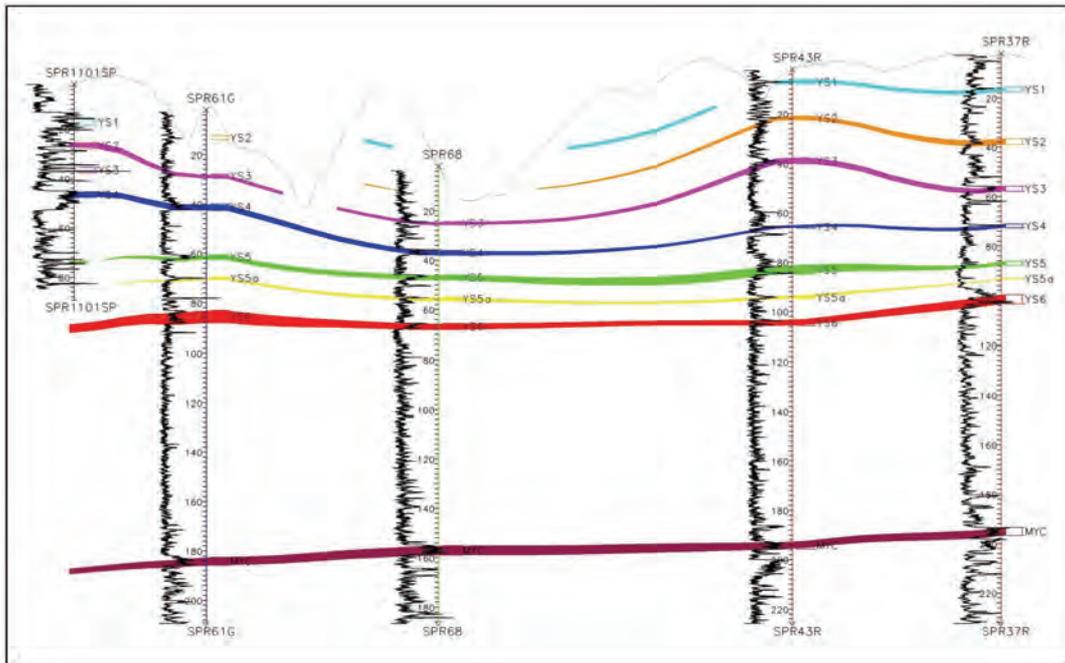


Fig. 4.12 Claystone Units in the Narrabeen Group (Palaris, 2013a)

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 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. MSEC594-08. It can be seen from this drawing, that the river is located to the west of the proposed longwalls, outside the Extension Area, above the previously extracted longwalls at the colliery. The river has been included in the assessments provided in this report, as it is likely to experience additional valley related movements, due to the proposed mining, and could be sensitive to these movements.

The Wolgan River commences above the previously extracted longwalls at Springvale Colliery and generally flows in a northerly direction on the eastern side of the existing 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 Wolgan River is located 460 metres west of LW416, at its closest point to the proposed longwalls. The total length of the Wolgan River located within a distance of 600 metres from the extents of the proposed longwalls is approximately 0.9 kilometres.

The previously extracted longwalls at Springvale Colliery have been partially extracted beneath the upper reaches of the Wolgan River. The previously extracted longwalls at Angus Place Colliery have been extracted up to 150 metres from the centreline of the river.

The Wolgan River is a perennial stream with small base surface water flows derived from the shrub swamps and hill slope aquifers. The bed of the river comprises surface soils derived from the Burrellow 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 Extraction Area.

Further descriptions of the Wolgan River are provided by the specialist surface water consultant in the report by RPS (2013a).

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.04, in Appendix D. The predicted total profiles after the completion of the existing longwalls at Springvale Colliery 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.

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 5.1. 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 5.1 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 LW401 to LW415 at Springvale Colliery	40	270	330
Total Movements after the Extraction of the Proposed Longwalls (Including the Movements due to the Existing Longwalls at Springvale Colliery)	40	320	400
Additional Movements due to the Extraction of the Proposed LW416 to LW432 Only (Excluding the Movements due to the Existing Longwalls)	< 20	65	75

It is noted, that the maxima due to the extraction of the proposed longwalls only are located 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 additional compressive strains due to valley related movements.

The section of the Wolgan River within the Extension Area has experienced around 3 mm/m compressive strain, due to the extraction of the existing longwalls, based on the results along the M-Line. It is expected, therefore, that the river will experience around 0.5 mm/m to 1 mm/m additional compressive strain due to valley related movements, resulting from the extraction of the proposed longwalls.

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 (2013a).

The Wolgan River is predicted to experience less than 20 mm of additional vertical subsidence due to the extraction of the proposed longwalls. While it is possible that the river could experience very low levels of subsidence, it would not be expected to experience any measurable conventional tilts, curvatures or ground strains.

The additional compressive strains due to the valley closure movements along the Wolgan River, resulting from the extraction of the proposed longwalls, are expected to be around 0.5 mm/m to 1 mm/m. Fracturing of sandstone is rarely observed where compressive strains are less 2 mm/m.

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.

The Wolgan River is located at a distance of 460 metres west of LW416, at its closest point to the proposed longwalls. It is unlikely, therefore, that fracturing would occur in the river as a result of the proposed mining. If any fracturing were to occur in the river, it would be expected to 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 valley related movements, due to the extraction of the proposed longwalls only, are 65 mm upsidence and 75 mm closure. It has also been predicted that the river has already experienced valley related movements up to 270 mm upsidence and 330 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. In this case, it would still be unlikely that the river would experience any adverse impacts as a result of the conventional subsidence movements.

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 460 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 at 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

5.3.1. Description of Carne Creek

The location of Carne Creek is shown in Drawing No. MSEC594-08.

Carne Creek commences above the proposed longwalls and flows in a northerly direction to where it drains into the Wolgan River, approximately 18 kilometres north of the proposed longwalls. The total length of the creek located directly above the proposed longwalls is approximately 2 kilometres.

The section of Carne Creek located directly above the proposed longwalls is generally confined within *Sunnyside East Swamp*, which is described further in Section 5.12.1. Outside the extents of this shrub swamp, the creek has shallow incisions into the natural surface soils which are derived from the Buralool Formation of the Triassic Narrabeen Group, with isolated sandstone outcropping in some locations.

The creek is ephemeral upstream of *Sunnyside East Swamp* and has small base surface water flows downstream of the swamp. The natural gradients along Carne Creek, directly above the proposed longwalls, typically varies between 25 mm/m (i.e. 2.5 %, or 1 in 40) and 100 mm/m (i.e. 10 %, or 1 in 10), with an average natural gradient of around 50 mm/m (i.e. 5 %, or 1 in 20).

Photographs of Carne Creek, within the extents of Sunnyside East Swamp, are provided in Fig. 5.1.



Fig. 5.2 Photographs of Carne Creek within the Extents of Sunnyside East Swamp

Further descriptions of Carne Creek are provided by the specialist surface water consultant in the report by *RPS* (2013a). Further descriptions of *Sunnyside East Swamp* are provided by the specialist ecology consultant in the report by *RPS* (2013c).

5.3.2. Predictions for Carne Creek

The predicted profiles of subsidence, upsidence and closure along Carne Creek, resulting from the extraction of the existing and proposed longwalls, are shown in Fig. D.05, in Appendix E. The predicted total profiles after the completion of the approved longwalls at Springvale Colliery 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 Carne Creek is shown in Fig. D.05, 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 Carne Creek, after the extraction of the existing and proposed longwalls, is provided in Table 5.1. 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 Carne Creek Resulting from the Extraction of the Approved and Proposed Longwalls

Case	Maximum Predicted Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Total Movements after the Extraction of the Approved Longwalls at Springvale Colliery	1100	100	300
Total Movements after the Extraction of the Proposed Longwalls (Including the Movements due to the Approved Longwalls at Springvale Colliery)	1400	750	1000
Additional Movements due to the Extraction of the Proposed LW416 to LW432 Only (Excluding the Movements due to the Approved Longwalls)	1375	725	875

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 approved 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 approved longwalls.

The compressive strains along Carne Creek, resulting from the valley closure movements, are expected to be similar to those measured 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 in Section 5.4.2.

It is expected that Carne Creek will experience compressive strains due to valley related movements between 5 mm/m and 15 mm/m. The greatest compressive strains are expected to occur where the creek is located near the centrelines of the proposed longwalls, and less where the creek is located near the chain pillars.

5.3.3. Impact Assessments for Carne Creek

The impact assessments for the section of Carne Creek located within the extents of *Sunnyside East Swamp* are covered in Section 5.12.5. The impact assessments for the sections of the creek located outside the extents of the shrub swamp are covered in Section 5.4.3.

Further discussions on the potential impacts on Carne Creek are provided by the specialised surface water consultant in the report by *RPS* (2013a).

5.3.4. Recommendations for Carne Creek

It is recommended that Carne Creek is periodically visually monitored during the extraction of the proposed longwalls. The assessed impacts on the creek 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 Carne Creek resulting from the extraction of the proposed longwalls.

5.4. Drainage Lines

5.4.1. Description of the Drainage Lines

The location of the unnamed drainage lines are shown in Drawing No. MSEC594-08.

The drainage lines in the northern part of the Extension Area drain into Carne Creek, and the drainage lines in the southern part of the Extraction Area drain into Marrangaroo Creek. Photographs of typical drainage lines within the Extension Area are provided in Fig. 5.3.



Fig. 5.3 Photographs of Typical Drainage Lines
(Courtesy of Centennial)

The drainage lines have shallow incisions into the natural surface soils which are derived from the Buralow 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.

Further descriptions of the drainage lines are provided by the specialist surface water consultant in the report by RPS (2013a).

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 compressive strains along the drainage lines, resulting from the valley closure movements, are expected to be similar to those measured 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 which are 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. 5.4. 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.

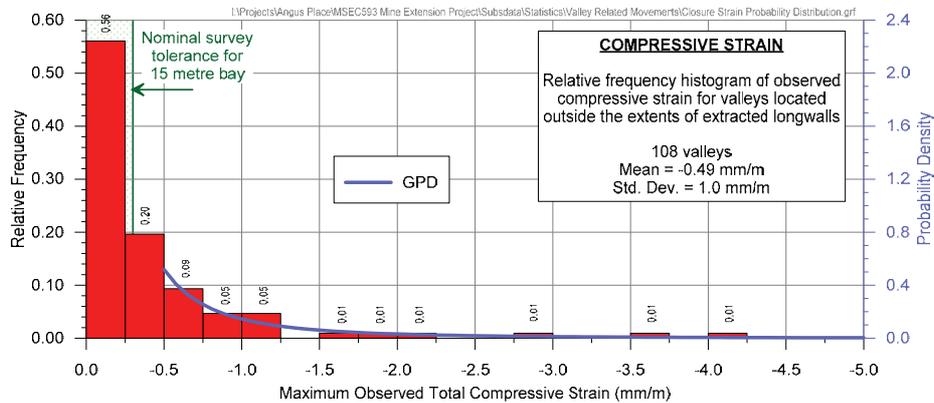


Fig. 5.4 Distribution of Measured Closure Strains for Drainage Lines Located Outside the Extents of Previously Extracted Longwalls in the NSW Coalfields

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 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 (2013a).

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 25 mm/m (i.e. 2.5 %), which represents a change in grade of 1 in 40. 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. 5.12 to Fig. 5.18, in Section 5.12.5, which show the natural grades and the predicted post mining grades along the alignments of the drainage lines through the shrub swamps.

It can be seen from these figures, that the predicted post mining grades are similar to the natural grades along the 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, in the order of 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 streams.

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 (2013a).

Potential for Cracking in the Stream 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, beneath the surface soils, 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 sections of the drainage lines downstream of the shrub 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 stream 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 (2013a), RPS (2013b) 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 predicted changes in grade along the drainage lines would generally be less than 25 mm/m, which is less than the natural grades which typically vary between 25 mm/m and 300 mm/m. There could be localised increased ponding along the drainage lines, in some locations, where the natural grades are relatively flat just upstream of the chain pillars.

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 Carne Creek and 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 (2013b).

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 (2013b).

5.7. Cliffs

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. MSEC594-09.

The cliffs, minor cliffs and pagodas have been identified within the valley of Carne Creek and the tributaries to Carne Creek and Marrangaroo 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. It is noted, that the cliff along the western valley side of Carne Creek extends just inside the 26.5 degree angle of draw line and is located around 160 metres north of the LW419, at its closest point to the proposed longwalls. There are also some minor cliffs and pagoda complexes identified within the 26.5 degree angle of draw line, but outside the extents of the proposed longwalls.

Photograph of typical cliffs and pagodas in the vicinity of the proposed longwalls are provided in Fig. 5.5 and Fig. 5.6, respectively.



Fig. 5.5 Photograph of Typical Cliffs Outside the Extents of the Proposed Longwalls (Courtesy of Centennial)



**Fig. 5.6 Photograph of Typical Pagodas
(Courtesy of Centennial)**

5.7.2. Predictions and Impact Assessments for the Cliffs, Minor Cliffs and Pagodas

The cliffs are generally located outside the 26.5 degree angle of draw line from the limit of extraction for the proposed longwalls. There is only one cliff which partially extends just inside the 26.5 degree angle of draw line and is located at a minimum distance of 160 metres from the proposed longwalls.

Whilst the cliffs closest to the proposed longwalls could experience low levels of vertical subsidence, they are 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.

There are some minor cliffs and pagoda complexes located within the 26.5 degree angle of draw line, but outside the extents of the proposed longwalls. These features 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 minor 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 less than 0.5 mm/m are unlikely to have any adverse impacts on the minor cliffs or pagodas.

The cliffs, minor cliffs and pagodas 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.

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.

It is unlikely, therefore, that the cliffs, minor cliffs and pagodas 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 that some minor rock falls have been observed outside the extents of extracted longwalls, these have been isolated and possibly due to natural causes.

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

If the actual subsidence movements exceeded those predicted by a factor of 2 times, the likelihood of impacts on the cliffs, minor cliffs and pagodas 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.

5.7.4. 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.

Photographs of typical rock outcropping within the Extension Area are provided in Fig. 5.7.



Fig. 5.7 Photograph of Typical Rock Outcropping (Courtesy of Centennial)

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 steep slopes within the Extension Area are shown in Drawing No. MSEC594-09.

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 18°) and 1 in 2 (i.e. 50 % or 27°), with isolated areas having natural grades up to 1 in 1.5 (i.e. 67 % or 34°).

The surface soils along the steep slopes are derived from weathered sandstone from the Triassic Narrabeen Group (Tn), as can be inferred from Fig. 1.8. 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 25 mm/m (i.e. 2.5 %, or 1 in 40) 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. 5.8.



Fig. 5.8 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 50 mm/m (i.e. 5 %), which represents a change in grade of 1 in 20. 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 within the Extension Area naturally drains towards the Wolgan River in the western part of the Extraction Area, and towards Carne Creek in the eastern part of the Extraction 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* (2013a).

5.12. Swamps

5.12.1. Descriptions of the Swamps

The locations of the swamps within the Extension Area are shown in Drawing No. MSEC594-08. 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.

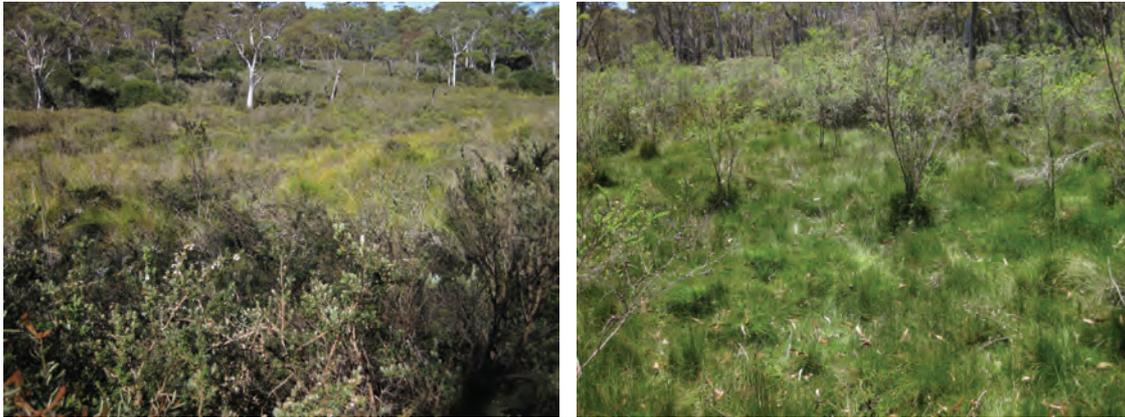
The *shrub swamps* develop in the bases of natural valleys and are formed from the accumulation of sediments along relatively flat sections of the drainage lines. These swamps have dense peat layers which overlie the shallow surface soils derived from the Triassic Narrabeen Sandstone group. Some swamps 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. 5.9 and Fig. 5.10.



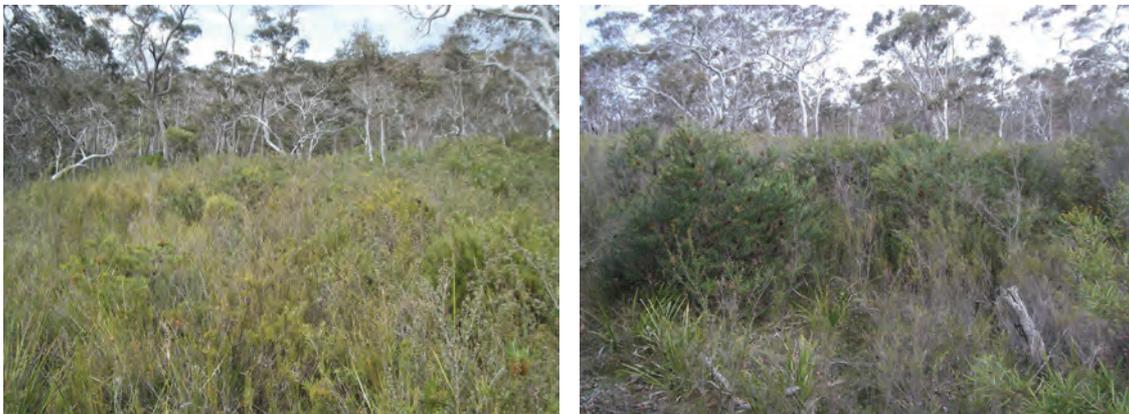
**Fig. 5.9 Photographs of Sunnyside East Swamp (Shrub Swamp)
(Courtesy of Centennial)**



**Fig. 5.10 Photographs of Marrangaroo Creek Swamp (Shrub Swamp)
(Courtesy of Centennial)**

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. 5.11.



**Fig. 5.11 Photographs of Typical Hanging Swamps
(Courtesy of Centennial)**

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 (2013c).

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 5.4 and Table 5.5, 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 5.4 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Shrub 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)
Sunnyside Swamp	50 <i>Total</i> < 20 <i>Additional</i>	< 0.5	< 0.01	< 0.01
Sunnyside East Swamp	1350	9	0.15	0.20
Carne West Swamp	1350	9	0.15	0.20
Gang Gang Swamp South West	1250	9	0.15	0.20
Gang Gang Swamp East	1150	9	0.09	0.20
Pine Upper Swamp	1050	7	0.07	0.15
Pine Swamp	900	6	0.06	0.10
Paddys Creek Swamp	950	9	0.15	0.15
Marrangaroo Creek Upper Swamp	1050	8	0.08	0.20
Marrangaroo Creek Swamp	1650	13	0.20	0.35
Nine Mile Swamp	< 20	< 0.5	< 0.01	< 0.01

Table 5.5 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)
Sunnyside East Catchment	1450	9	0.15	0.20
Carne West Catchment	1350	9	0.10	0.20
Gang Gang Catchment	900	6	0.07	0.04
Pine Catchment	1050	7	0.07	0.15
Paddys Creek Catchment	350	5	0.04	0.02
Marrangaroo Creek Catchment	1500	13	0.20	0.35
Catchment above LW503	650	9	0.15	0.20

The maximum predicted conventional curvatures for the swamps are 0.20 km⁻¹ hogging and 0.35 km⁻¹ sagging, which represent minimum radii of curvature of 5 kilometres and 3 kilometres, respectively. The maximum predicted conventional strains for the swamps, based on applying a factor of 10 to the maximum predicted conventional curvatures, are 2 mm/m tensile and 3.5 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 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 5.6. Discussions on the method and the reliability of the prediction method for valley related movements are provided in Section 3.8.

Table 5.6 Maximum Predicted Total Upsidence and Closure for the Shrub Swamps

Swamp	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
Sunnyside Swamp	320 <i>Total</i> 65 <i>Additional</i>	400 <i>Total</i> 75 <i>Additional</i>
Sunnyside East Swamp	750	1000
Carne West Swamp	450	600
Gang Gang Swamp South West	200	300
Gang Gang Swamp East	250	350
Pine Upper Swamp	250	350
Pine Swamp	350	500
Paddys Creek Swamp	100	150
Marrangaroo Creek Upper Swamp	200	250
Marrangaroo Creek Swamp	250	300
Nine Mile Swamp	75	100

It is noted, that Sunnyside Swamp is predicted to experience 320 mm total upsidence and 400 mm total closure resulting from the extraction of both the approved and proposed longwalls. The predicted additional movements at this swamp, due to the extraction of the proposed longwalls only, are 65 mm upsidence and 75 mm closure.

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 15 mm/m, as described in Section 5.4.2. The additional compressive strains due to valley closure movements for the Sunnyside Swamp and the remaining shrub swamps which are located outside the extents of the proposed longwalls are predicted to be less than 2 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 5.7.

Table 5.7 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 widths of the proposed longwalls have also been narrowed, so as to reduce the potential impacts on the 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 5.8 below.

Table 5.8 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 5.9 below.

Table 5.9 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
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 detectable 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

The previously extracted LW404 to LW409 at Springvale Colliery had overall void widths of 265 metres and chain pillar widths of 40 metres. These longwalls were mined at depths of cover typically between 300 metres and 380 metres, with an average depth of cover around 360 metres. The width-to-depth ratios of LW404 to LW409 were typically within the range of 0.70 to 0.85 (i.e. subcritical to critical in width).

The overall void widths of the subsequently extracted LW410 to LW414 were increased to 315 metres, which allowed the coal to be mined more cost effectively. These longwalls were mined at depths of cover typically between 320 metres and 420 metres, with an average depth of cover around 390 metres. The width-to-depth ratios for LW410 to LW414 were typically in the range of 0.75 to 1.0 (i.e. critical in width).

Following the impacts observed at four swamps at Angus Place and Springvale Collieries, a number of investigations were undertaken into their potential causes. As described in the previous section, the findings from the report by Goldney et al (2010) indicates that the impacts were the result of the combination of mine water discharge, erosion from nearby roads, as well as a mine subsidence ground movements, but the proportion of this could not be quantified.

Centennial conducted a review of the subsidence ground monitoring results for all of the extracted longwalls at Springvale Colliery, which found that the subsidence observed above later extracted LW410 to LW414 (as well as LW415) were significantly greater than those observed above the earlier extracted LW1 and LW401 to LW409. The review concluded that the general increases in the observed subsidence were the result of the mine geometry changes.

Centennial recognises the importance of the Newnes Plateau swamps and, in consultation with Government Departments, has reviewed the mine design options so to reduce the potential for future impacts on the swamps. The options reviewed included:-

- Adopting bord and pillar mining methods, however, this was not considered viable due to the greater depths of cover within the mining area, which typically vary between 350 metres and 400 metres, and due to the geotechnical environment,
- Shortening longwalls or stepping longwalls around the swamps, but this was also not considered economically viable due to the much higher development costs and discontinuity of mining operations, and
- Narrowing the longwall widths and/or increasing the chain pillar widths, which was considered the most viable and economical option.

Centennial proposes to reduce the overall void widths of LW416 to LW432 and LW501 to LW503 back to 261 metres, or less, and to increase the chain pillar widths to 58 metres. The width-to-depth ratios for the proposed longwalls are typically within the range of 0.65 and 0.75, which are less than those for the previously extracted LW410 to LW414, due to the narrower void widths and higher depths of cover.

The depths of cover beneath the swamps within the Extension Area are typically between 340 metres and 370 metres for the shrub swamps, and typically between 360 metres and 390 metres for the hanging swamps. The longwall width-to-depth ratios beneath these swamps, therefore, are typically within the ranges of 0.70 to 0.75 (i.e. generally subcritical in width) for the shrub swamps and 0.65 to 0.70 for the hanging swamps (i.e. subcritical in width).

The changes in the mine geometry have resulted in the predicted subsidence parameters for the proposed LW416 to LW432 and LW501 to LW503 reducing by around 20 % to 30 % when compared to equivalent longwalls having void widths similar to those for the previously extracted LW410 to LW414. It is noted that further reductions in the void widths do not result in linear reductions in the predicted subsidence parameters. That is, for longwall width-to depth ratios less than 0.7 (i.e. subcritical), the subsidence parameters reduce at a diminishing rate for ongoing reductions in the overall void widths.

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, groundwater consultant and ecology consultant in the reports by RPS (2013a), RPS (2013b) and CSIRO (2013), and RPS (2013c), respectively.

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 13 mm/m (i.e. 1.3 %, or 1 in 75) for both the shrub swamps and 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. 5.12 to Fig. 5.18, which show the natural grades and the predicted post mining grades along the alignments of the drainage lines through the shrub swamps.

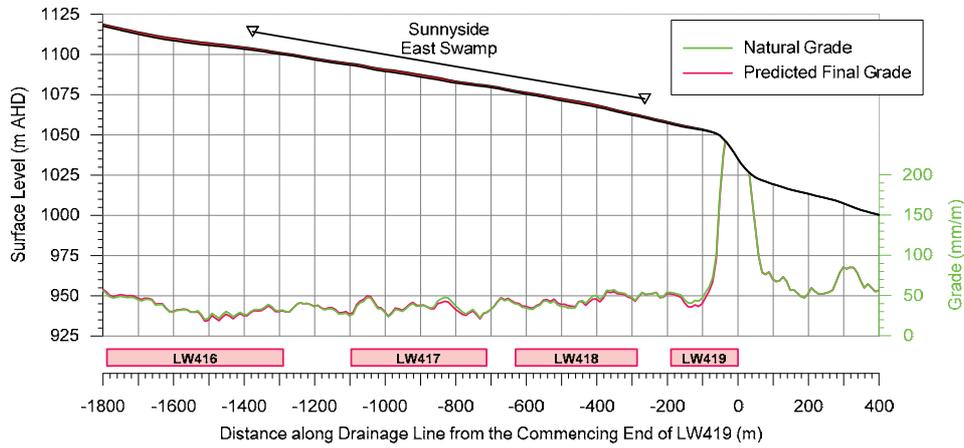


Fig. 5.12 Natural and Predicted Post Mining Levels and Grades for Sunnyside East Swamp

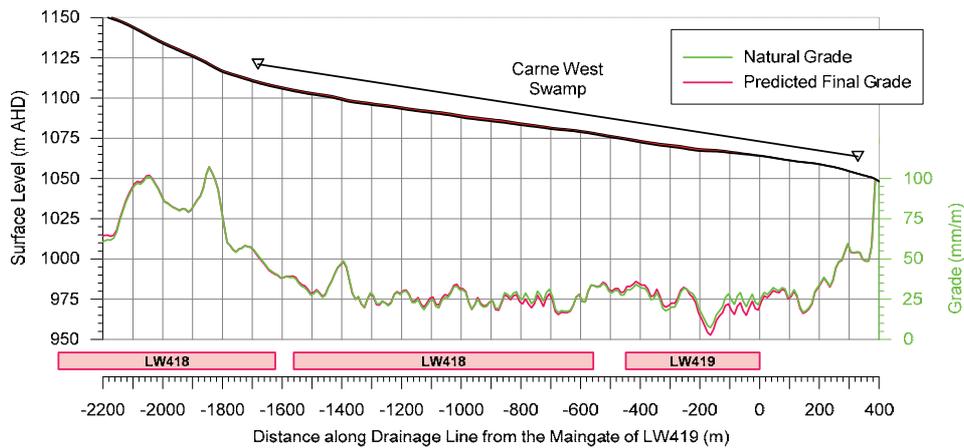


Fig. 5.13 Natural and Predicted Post Mining Levels and Grades for Carne West Swamp

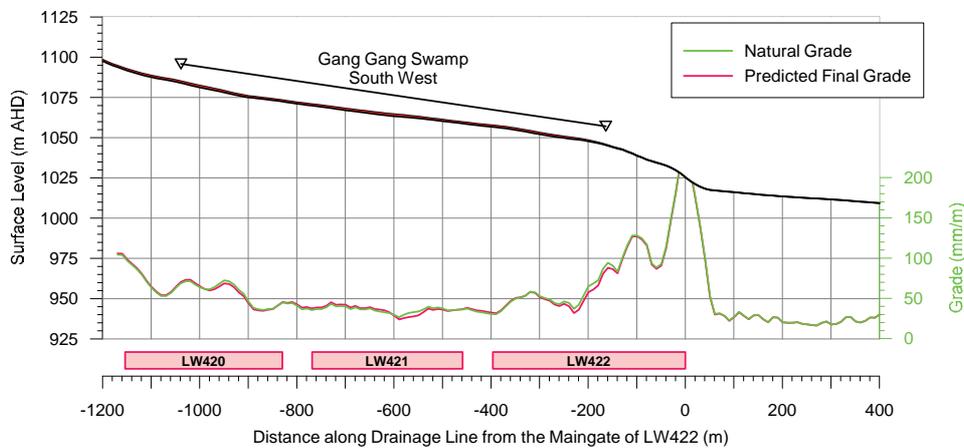


Fig. 5.14 Natural and Predicted Post Mining Levels and Grades for Gang Gang Swamp South West

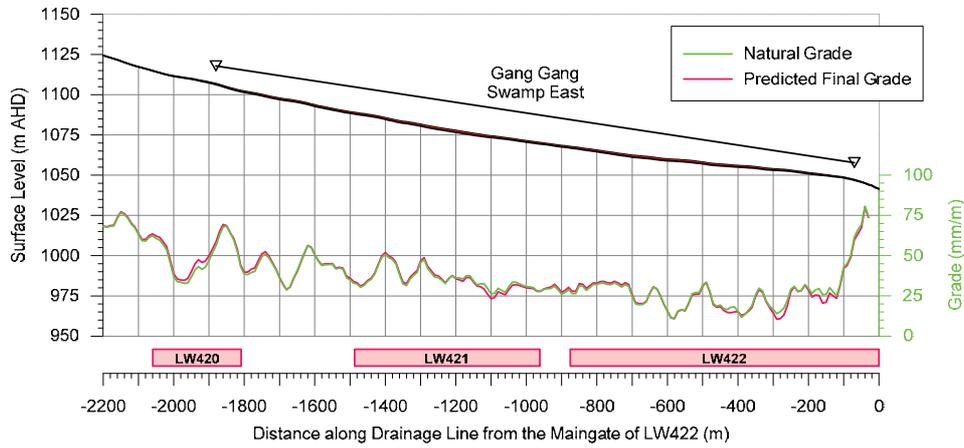


Fig. 5.15 Natural and Predicted Post Mining Levels and Grades for Gang Gang Swamp East

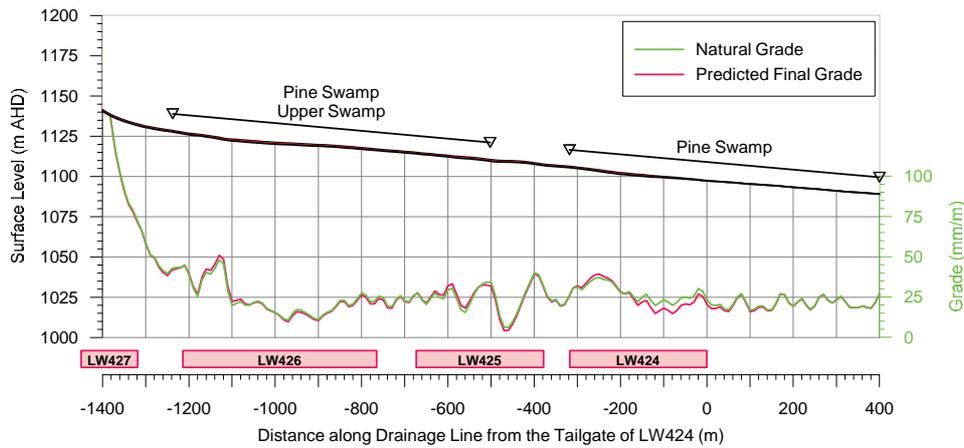


Fig. 5.16 Natural and Predicted Post Mining Levels and Grades for Pine Upper and Pine Swamps

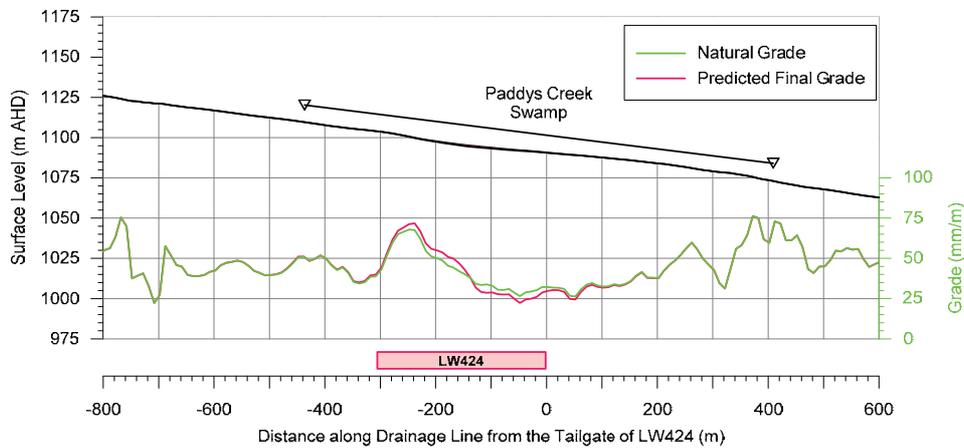


Fig. 5.17 Natural and Predicted Post Mining Levels and Grades for Paddys Creek Swamp

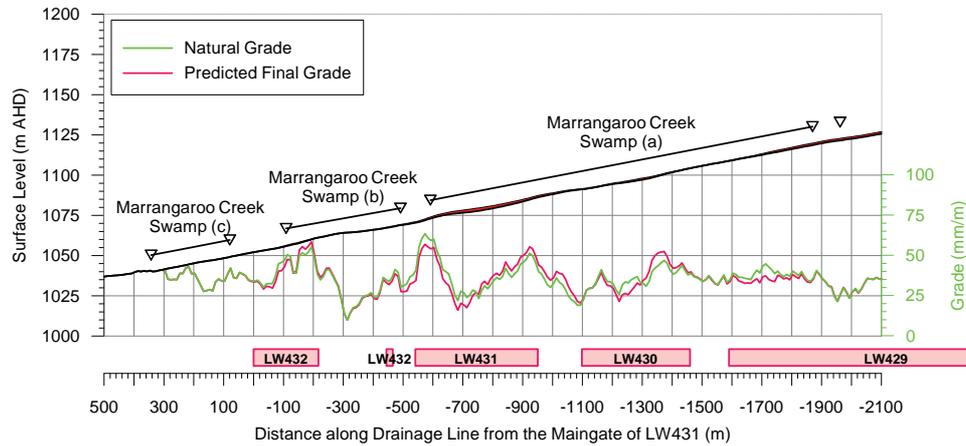


Fig. 5.18 Natural and Predicted Post Mining Levels and Grades for Marrangaroo Creek Upper and Marrangaroo Creek Swamps

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.

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 (2013a) and the specialist ecology consultant in the report by RPS (2013c).

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 Sunnyside Swamp and Nine Mine Swamp, 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 350 metres and 400 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 overlie 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 consultant in the reports by RPS (2013b) and CSIRO (2013).

The width-to-depth ratios for the proposed LW416 to LW431 are typically between 0.65 and 0.75, which are less than those for the previously extracted longwalls at Angus Place and Springvale Collieries. 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 or less than 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 (2013a) and the specialist ecology consultant in the report by RPS (2013c).

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 26 mm/m (i.e. 2.6 %, or 1 in 40) for the shrub swamps and 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 greater than 100 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* (2013a), the specialist ground water consultant in the reports by *RPS* (2013b) and *CSIRO* (2013), and the specialist ecology consultant in the report by *RPS* (2013c).

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* (2013c).

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* (2013c).

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* is located more than 7 kilometres north of the proposed longwalls. At this distance, the National Park will not experience any measurable subsidence movements resulting from the extraction of the proposed LW416 to LW432 and LW501 to LW503.

5.16. State Forests

The Extension Area is located within the *Newnes State Forest* which is managed by Forests 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 surface water consultant, groundwater consultant and ecology consultant in the reports by *RPS (2013a)*, *RPS (2013b)* and *CSIRO (2013)*, and *RPS (2013c)*, respectively.

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 (2013c)*.

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. MSEC594-12. Photographs 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. Electrical Infrastructure

6.3.1. Description of the Electrical Infrastructure

The locations of the electrical infrastructure within the Extension Area are shown in Drawing No. MSEC594-10. The electrical infrastructure is owned by Ausgrid.

There is a 66 kV powerline which crosses the proposed LW431 to LW427 and an 11 kV powerline which crosses the proposed LW430 and LW431. These powerlines comprise aerial cables supported by timber poles. A 66 kV/11 kV substation is also located above the proposed LW430.

Centennial also proposes to construct trenched power cables and associated infrastructure to supply the ground water bore compounds.

6.3.2. Predictions for the Electrical Infrastructure

The predicted profiles of conventional subsidence, tilt along the alignments, and tilt across the alignment of the 66 kV powerline are shown in Fig. D.06, in Appendix D. The predicted profiles along the 11 kV powerline are similar to those shown in this figure above the proposed LW430 and LW431. Summaries of the maximum predicted subsidence, tilts along and tilts across the alignments of the 66 kV powerline and the 11 kV powerline are provided in Table 6.1 and Table 6.2, respectively. The values provided in these tables are the maxima within the Extension Area, based on the 26.5 degree angle of draw line from the extents of the proposed longwalls.

Table 6.1 Maximum Predicted Total Conventional Subsidence, Tilt Along and Tilt Across the Alignment of the 66 kV Powerline

Case	Maximum Predicted Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Tilt Across Alignment (mm/m)
Total Movements after the Extraction of the Approved Longwalls at Springvale Colliery	1150	7.0	5.5
Total Movements after the Extraction of the Proposed Longwalls (Including the Movements due to the Approved Longwalls at Springvale Colliery)	1175	7.0	6.0
Additional Movements due to the Extraction of the Proposed LW416 to LW432 Only (Excluding the Movements due to the Approved Longwalls)	1175	5.5	4.0

Table 6.2 Maximum Predicted Total Conventional Subsidence, Tilt Along and Tilt Across the Alignment of the 11 kV Powerline

Case	Maximum Predicted Subsidence (mm)	Maximum Predicted Total Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Total Conventional Tilt Across Alignment (mm/m)
Total Movements after the Extraction of the Approved Longwalls at Springvale Colliery	1200	7.5	6.0
Total Movements after the Extraction of the Proposed Longwalls (Including the Movements due to the Approved Longwalls at Springvale Colliery)	1200	7.5	6.0
Additional Movements due to the Extraction of the Proposed LW416 to LW432 Only (Excluding the Movements due to the Approved Longwalls)	1100	6.0	3.0

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 approved 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 approved longwalls.

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the substation is provided in Table 6.3. The predicted tilts provided in this table are the maxima after the completion of any or all 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 6.3 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Substation

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})
Substation	1100	3.0	0.05	0.05

The maximum predicted conventional strains for the substation, based on applying a factor of 10 to the maximum predicted conventional curvatures, are 0.5 mm/m tensile and 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 future electrical services constructed and owned by Centennial could experience subsidence movements up to the maxima described in Chapter 4.

6.3.3. Impact Assessments for the Electrical Infrastructure

The maximum predicted total tilts for the powerlines are 7 mm/m (i.e. 0.7 %, or 1 in 140) for the 66 kV powerline, and 7.5 mm/m (i.e. 0.8 %, or 1 in 135) for the 11 kV powerline. The maximum predicted additional tilts, due to the extraction of the proposed longwalls only, are 5.5 mm/m (i.e. 0.6 %, or 1 in 180) for the 66 kV powerline, and 6 mm/m (i.e. 0.6 %, or 1 in 165) for the 11 kV powerline

A rule of thumb used by some electrical engineers is that the tops of the poles may displace up to 2 pole diameters horizontally before remediation works are considered necessary. Based on pole heights of 15 metres and pole diameters of 250 mm, the maximum tolerable tilt at the pole locations is in the order of 33 mm/m.

It is unlikely, therefore, that the 66 kV powerline or the 11 kV powerline would experience any adverse impacts resulting from the extraction of the proposed longwalls. Extensive experience of mining beneath powerlines in the NSW Coalfields, at similar depths of cover, indicates that incidences of impacts are very low and readily repairable. Some minor remedial measures have been required, in the past, which included adjustments to cable catenaries, pole tilts and to consumer cables which connect between the powerlines and building structures.

The maximum predicted tilt for the substation is 3.0 mm/m (i.e. 0.3 %, or 1 in 330), which is very small (i.e. less than 1 %) and, therefore, unlikely to adversely affect the transformers or other associated infrastructure.

The maximum predicted hogging and sagging curvatures for the substation are both 0.05 km^{-1} , which represents a minimum radius of curvature of 20 kilometres. The maximum predicted conventional strains are 0.5 mm/m tensile and compressive. It is unlikely, at these magnitudes of movement, that the substation would be adversely affected by the proposed mining.

Whilst impacts are not anticipated, it is recommended that the predictions are provided to *Ausgrid*, so that the plant associated with substation can be reviewed based on the predicted movements.

The future electrical services constructed and owned by Centennial will be designed to accommodate the predicted subsidence movements.

6.3.4. Impact Assessments for the Electrical Infrastructure Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum tilts at the powerlines would be 14 mm/m (i.e. 1.4 %, or 1 in 70) for the 66 kV powerline, and 15 mm/m (i.e. 1.5 %, or 1 in 65) for the 11 kV powerline. In this case, the tilts at the powerlines would still be less than the tolerable tilt, which is in the order of 33 mm/m. The maximum tilt at the substation would be 6 mm/m (i.e. 0.6 %, or 1 in 115), which is still less than 1 % and, therefore, unlikely to adversely affect the transformers or other associated infrastructure.

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, the potential impacts on the substation would increase. It is recommended, therefore, that the review of the designs by the substation engineers should also include assessments of the substations based on increased predictions.

6.3.5. Recommendations for the Electrical Infrastructure

It is recommended that the predicted mine subsidence movements for the electrical infrastructure are provided to *Ausgrid*, so that any necessary preventive measures can be developed. It is also recommended that a Trigger Action Response Plan (TARP) is developed for the substation, in consultation with *Ausgrid*.

6.4. Dams, Reservoirs and Associated Works

There are no dams, reservoirs or associated works within the Extension Area. The Lithgow Water Supply Dam is located around 3 kilometres south of the proposed longwalls. At this distance, the dam is not expected to experience any measurable subsidence movements. It is unlikely, therefore, that the dam would experience adverse impacts, even if the predictions were exceeded by a factor of 2 times.

6.5. Air Strips

There are no active air strips within the Extension Area. There is a disused air strip located adjacent to Sunnyside Ridge Road immediately to the west of the proposed longwalls. If this air strip were to be used in the future, it may be necessary to repair the larger surface cracking or heaving which develop as a result of the mine subsidence movements.

6.6. Public Amenities

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

6.7. 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.

6.8. Registered Ground Water Bores

The locations of the registered groundwater bores in the vicinity of the proposed longwalls are shown in Drawing No. MSEC594-10. The locations and details of these bores were obtained from the Department of Natural Resources using the *Natural Resource Atlas* website (NRAtlas, 2012).

A summary of the three registered groundwater bores identified within the Extension Area is provided in Table 6.4.

Table 6.4 Details of the Registered Groundwater Bores within the Extension Area

Ref.	Location	Ownership	Authorised Purposes
GW111025	Above LW502	Angus Place Colliery	Dewatering
GW111866	Above LW417	Private	Monitoring
GW111868	Above LW420	Private	Monitoring

Discussions on the potential impacts on the groundwater resources are provided by the specialised groundwater consultant in the report by RPS (2013b) and CSIRO (2013).

6.9. Industrial, Commercial or Business Establishments

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

6.10. 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 powerlines, switch yards, water pipelines and ground water bore compounds. The locations of these services are shown in Drawing No. MSEC594-10. 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.

6.11. Archaeological Sites

6.11.1. 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. MSEC594-10. 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 6.5 below.

Table 6.5 Archaeological Sites within the Extension Area

Site Reference	Location	Description
45-1-0002	Above the chain pillar between the proposed LW428 and LW429	Grinding Groove
45-1-0005	Above the main headings, 120 metres north of the proposed LW426	Grinding Groove
45-1-0051	Above the proposed LW422	Artefact Scatter
45-1-0065	200 metres east of the proposed LW424	Grinding Groove and Shelter with Deposit
45-1-0184	Above the proposed LW424	Artefact Scatter
45-1-2578	Above the proposed LW430	Stone Arrangement
45-1-2600	Above the approved LW415	Scarred Tree
45-1-2669	Above the proposed LW425	Artefact Scatter
45-1-2739	20 metres east of the proposed LW419	Isolated Find

There are also two additional artefact scatter sites (Refs. 45-1-0052 and 45-1-0185) which are located outside the Extension Area but are within 600 metres of the proposed longwalls.

Detailed descriptions of the archaeological sites within the Extension Area are provided by *RPS* (2013d).

6.11.2. 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 6.6. The predicted tilts and curvatures are the maxima at any time during or after the extraction of the approved and proposed longwalls.

Table 6.6 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})
45-1-0002	900	3	0.04	0.03
45-1-0005	50	< 0.5	< 0.01	< 0.01
45-1-0051	1050	5	0.08	0.06
45-1-0065	25	< 0.5	< 0.01	< 0.01
45-1-0184	500	9	0.15	0.06
45-1-2578	950	5	0.10	0.04
45-1-2600	800	6	0.04	0.07
45-1-2669	1000	6	0.07	0.09
45-1-2739	150	2	0.04	< 0.01

The maximum predicted conventional strains for the archaeological sites, based on applying a factor of 10 to the maximum predicted conventional curvatures, are 1.5 mm/m tensile and 1 mm/m compressive for the artefact scatter and stone arrangement sites, and 0.5 mm/m tensile and compressive for the grinding groove sites and the scarred tree.

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.

6.11.3. Impact Assessments for the Artefact Scatter and Stone Arrangement Sites

There are five sites within the Extension Area comprising artefact scatters or stone arrangements, being Sites 45-1-0051, 45-1-0184, 45-1-2578, 45-1-2669, and 45-1-2739.

The maximum predicted total tilt for the opens sites is 9 mm/m (i.e. 0.9 %), which represents a change in grade of 1 in 110. It is unlikely that these sites would experience any adverse impacts resulting from the mining induced tilts.

These sites can potentially be affected by cracking of the surface soils as a result of mine subsidence movements. It is unlikely, however, that the scattered artefacts or isolated finds themselves would be impacted by surface cracking. It is possible, however, that if remediation of the surface was required after mining, that these works could potentially impact these sites.

It is recommended that Centennial seek the required approvals from the appropriate authorities, in the event that remediation of the surface is required in the locations of the artefact scatter and stone arrangement sites.

Further assessments of the potential impacts on the artefact scatter and stone arrangement sites are provided in a report by *RPS* (2013d).

6.11.4. Impact Assessments for the Grinding Groove Sites

There are three sites within the Extension Area comprising grinding grooves, being Sites 45-1-0002, 45-1-0005, and 45-1-0065.

Site 45-1-0002 is located above the chain pillar between the proposed LW428 and LW429. The predicted maximum curvatures at this site are 0.04 km^{-1} hogging and 0.03 km^{-1} sagging, which represent minimum radii of curvature of 25 kilometres and than 33 kilometres, respectively. The maximum predicted conventional strains for this site, based on applying a factor of 10 to the maximum predicted conventional curvatures, are around 0.5 mm/m tensile and compressive.

Fracturing in bedrock has been observed in the past, as a result of longwall mining, where tensile strains were greater than 0.5 mm/m or where compressive strains were greater than 2 mm/m. It is possible, therefore, that fracturing of the bedrock could occur in the vicinity of Site 45-1-0002.

Preventive measures could be implemented at Site 45-1-0002, if required, including slotting of the bedrock around the site to isolate it from the ground curvatures and strains. It is possible, however, that the preventive measures could result in greater impacts on the site than those which would have occurred as a result of mine subsidence movements. Further discussions on preventive measures for this site are provided in the report by *RPS* (2013d).

Sites 45-1-0005, and 45-1-0065 are located at distances of 120 metres and 200 metres, respectively, outside the extents of the proposed longwalls. While it is possible that these sites could experience very low levels of subsidence, they would not be expected to experience any measurable conventional tilts, curvatures or ground 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. It is unlikely, therefore, that Sites 45-1-0005, and 45-1-0065 would experience any adverse impacts resulting from the proposed mining, even if the predictions were exceeded by a factor of 2 times.

Further assessments of the potential impacts on the grinding groove sites are provided in the report by *RPS* (2013d).

6.11.5. Impact Assessments for the Rock Shelter

There is one site within the Extension Area comprising a rock shelter, being Site 45-1-0065. This site is located around 200 metres east of the proposed LW424. At this distance, the site is predicted to experience around 25 mm of vertical subsidence. While it is possible that the site could experience very low levels of subsidence, it would not be expected to experience any measurable conventional tilts, curvatures or ground strains.

The rock shelter is located along the side of a ridge line and, therefore, is not expected to experience any valley related upsidence movements or compressive strains due to valley closure movements.

It is unlikely, therefore, that the rock shelter would experience any adverse impacts resulting from the proposed mining, even if the predictions were exceeded by a factor of 2 times.

Further assessments of the potential impacts on the rock shelter are provided in a report by *RPS* (2013d).

6.11.6. Impact Assessments for the Scarred Tree

There is one scarred tree identified within the Extension Area, being Site 45-1-2600.

It has been found, from past longwall mining experience, that the incidence of impacts on trees is extremely rare. Impacts on trees have only been previously observed where the depths of cover were extremely shallow, in the order of 50 metres or less, or on very steeply sloping terrain, in the order of 1 in 1 or greater.

The depths of cover above the proposed longwalls are greater than 300 metres and the natural surface gradients are typically less than 1 in 1. It is unlikely, therefore, that the scarred tree would be adversely impacted as a result of the extraction of the proposed longwalls, even if the predictions were exceeded by a factor of 2 times.

Further assessments of the potential impacts on the scarred tree are provided in a report by RPS (2013d).

6.12. State Survey Control Marks

The locations of the state survey control marks in the vicinity of the proposed longwalls are shown in Drawing No. MSEC594-10. 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 6.7 below.

Table 6.7 Survey Control Marks Located within the Extension Area

Survey Mark	Status	Horizontal Class / Order (GDA94)	Vertical Class / Order (AHD71)
SS 18529	N/A	B / 2	LC / L3
SS 19176	N/A	B / 3	LC / L3
SS 21304	Not Found	U / U	LC / L3
SS 21305	Found Intact	E / 5	LC / L3
SS 21306	Not Found	U / U	LC / L3
SS 21311	Found Intact	E / 5	LC / L3
SS 24519	Found Intact	E / 5	U / U
SS 35254	Found Intact	E / 5	U / U
SS 35255	Found Intact	E / 5	U / U
SS 35256	Found Intact	E / 5	U / U
SS 35257	Not Found	U / U	U / U

There were 11 survey control marks identified within the Extension Area, of which, eight having coordinated positions and six 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 <i>millimetres (mm)</i> , 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 <i>1/kilometres (km⁻¹)</i> , but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in <i>kilometres (km)</i> . 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	<p>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.</p> <p>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.</p>
Sub-critical area	An area of panel smaller than the critical area.
Subsidence	<p>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 <i>millimetres (mm)</i>.</p> <p>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.</p>
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 <i>millimetres per metre (mm/m)</i> . 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 <i>millimetres (mm)</i> , 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

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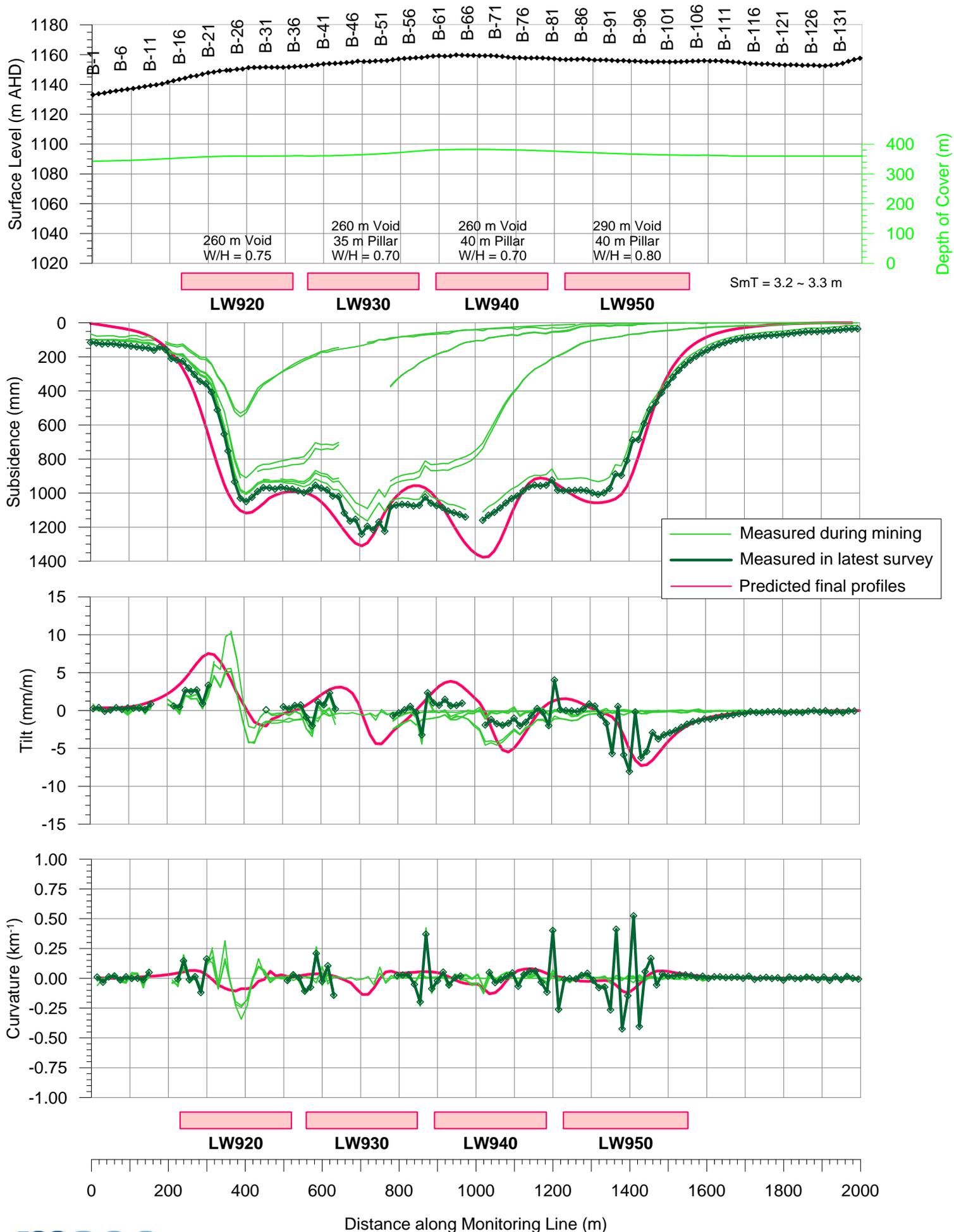
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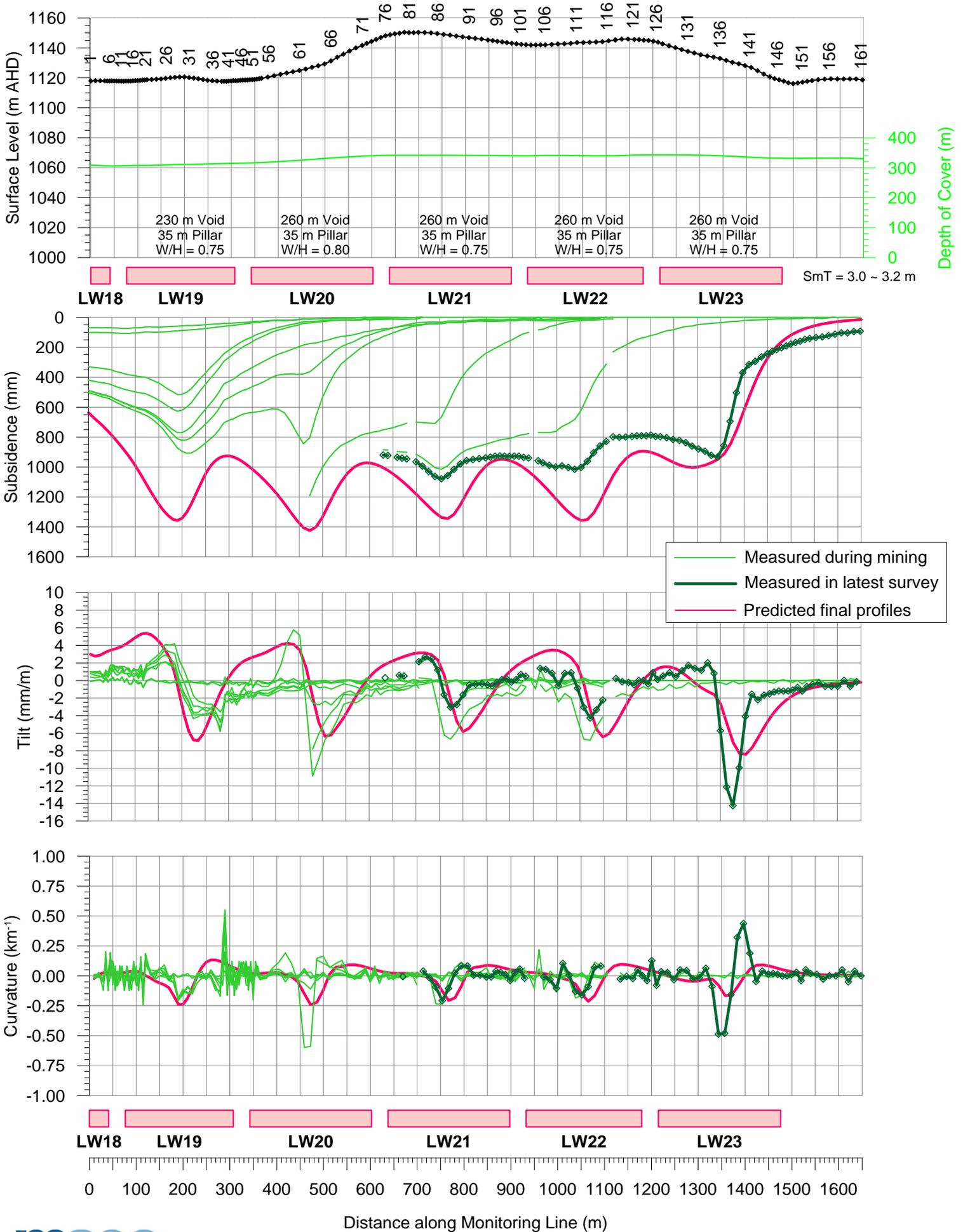
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APPENDIX C. COMPARISONS BETWEEN OBSERVED AND PREDICTED PROFILES OF SUBSIDENCE, TILT AND CURVATURE

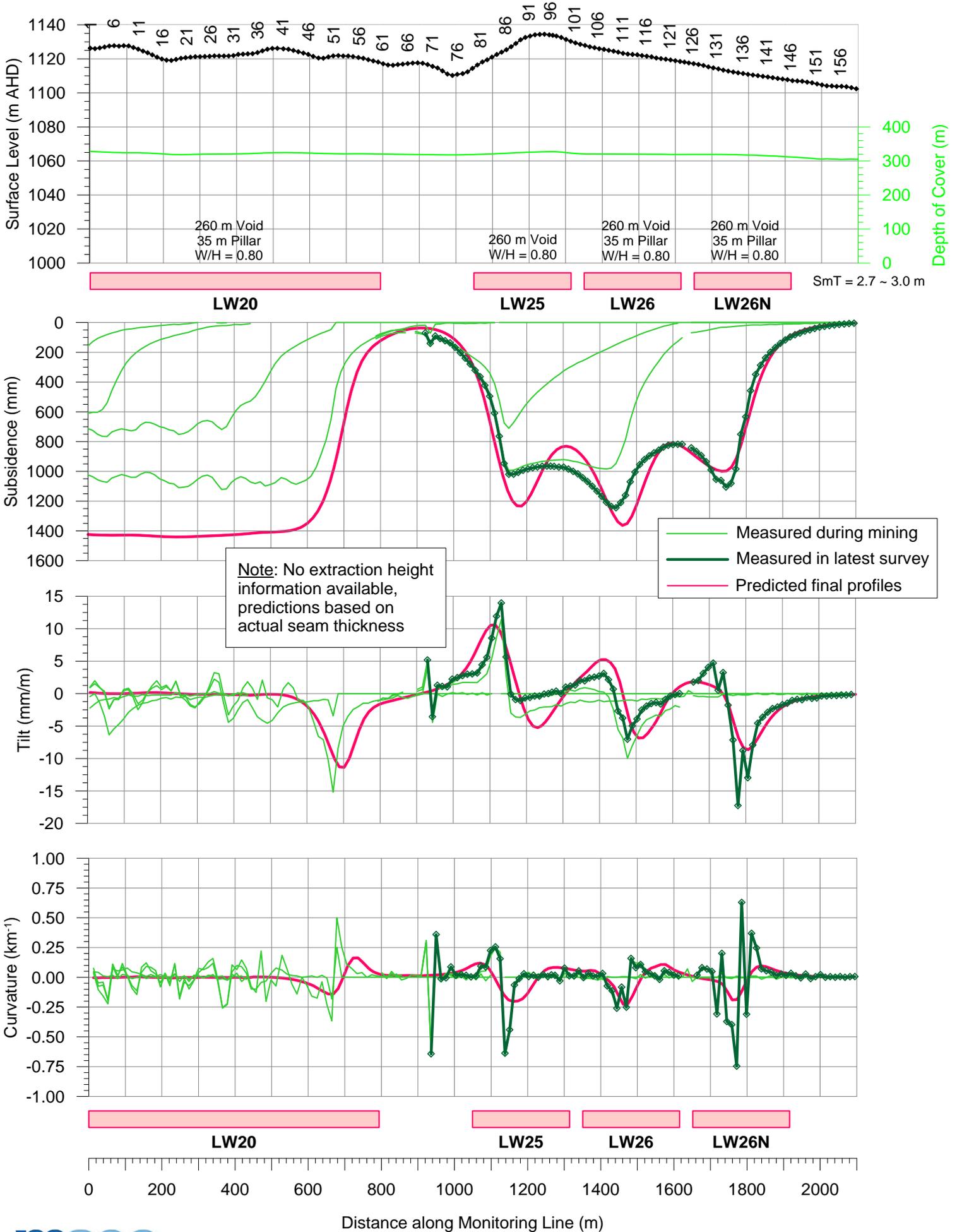
Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the B-Line at Angus Place Colliery



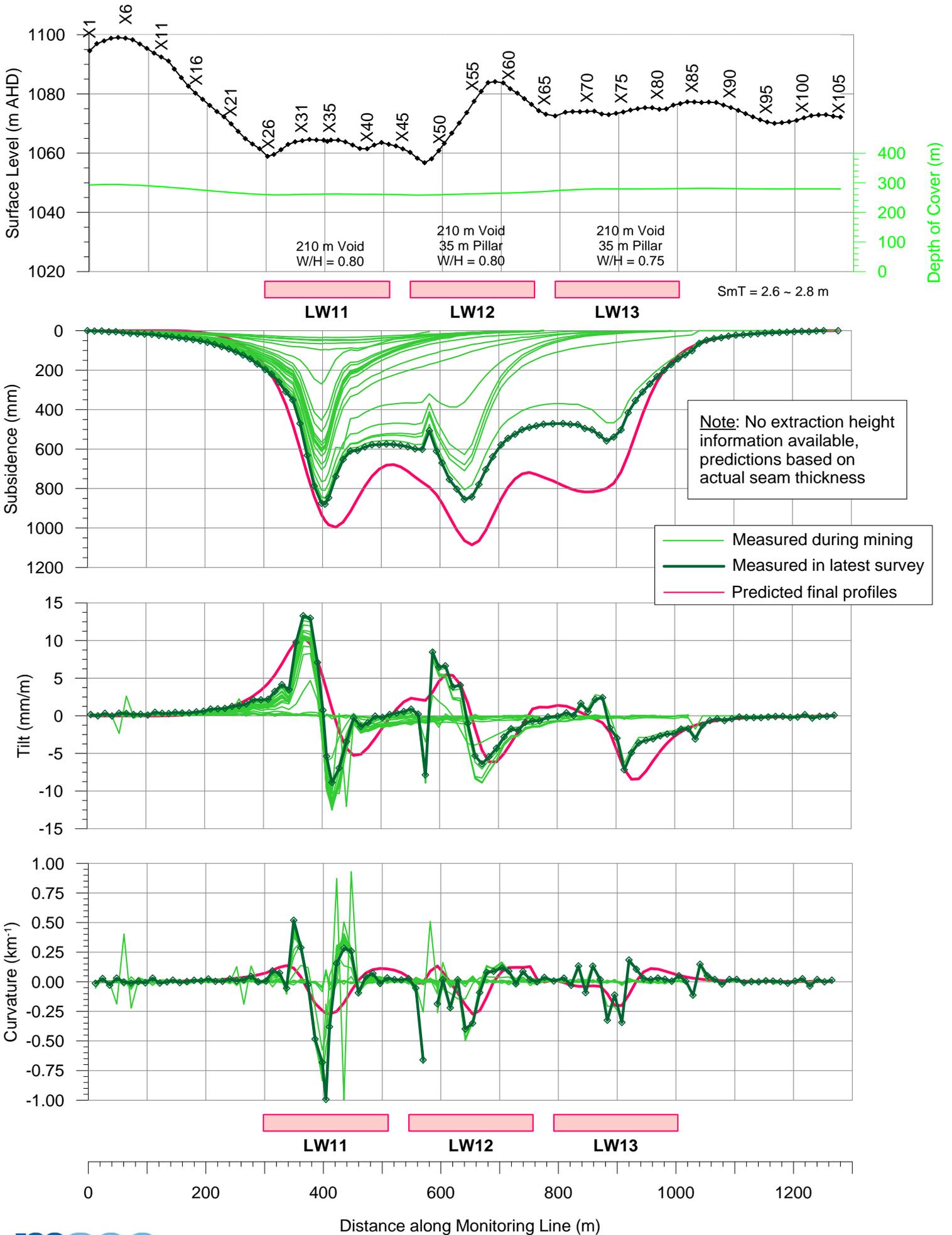
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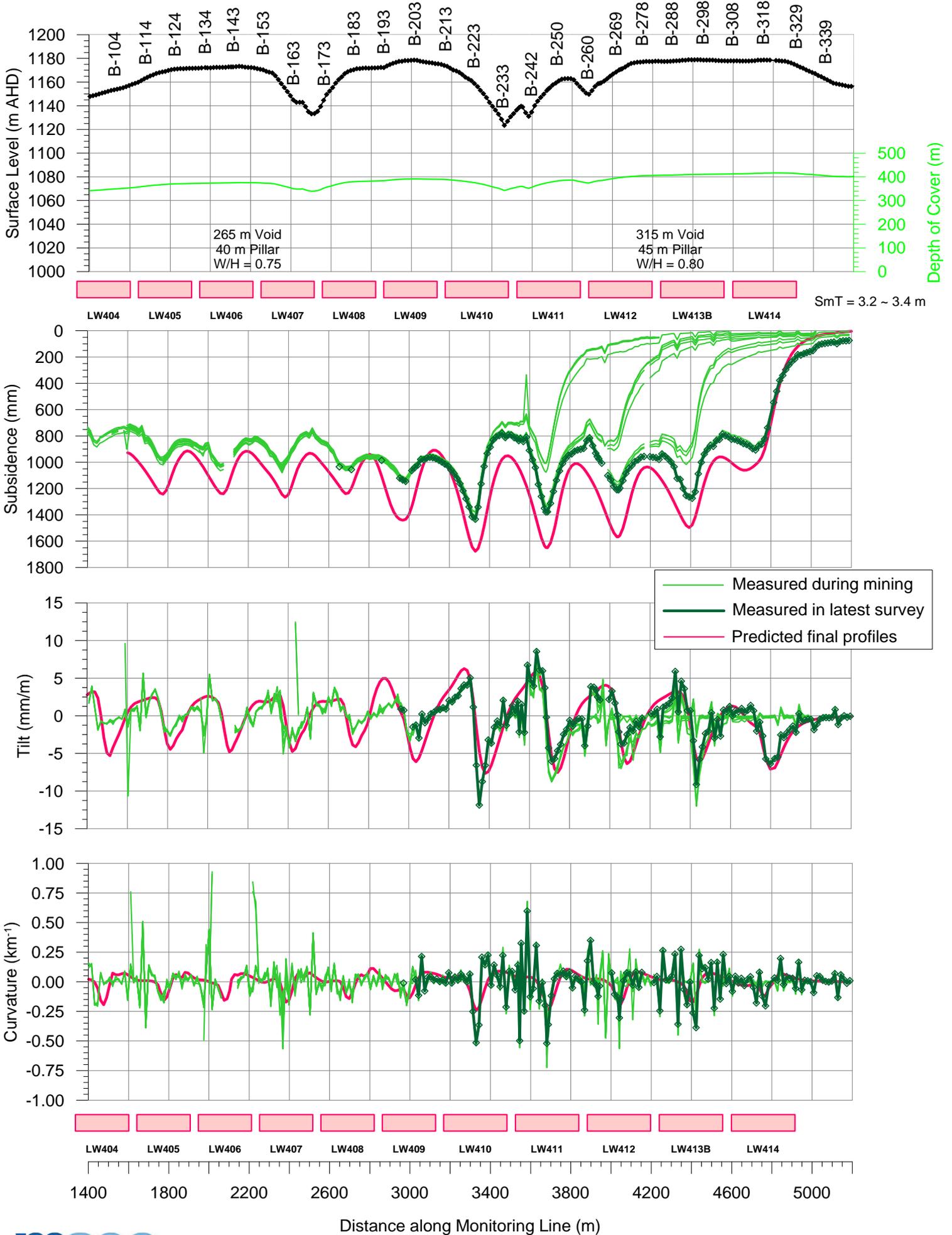
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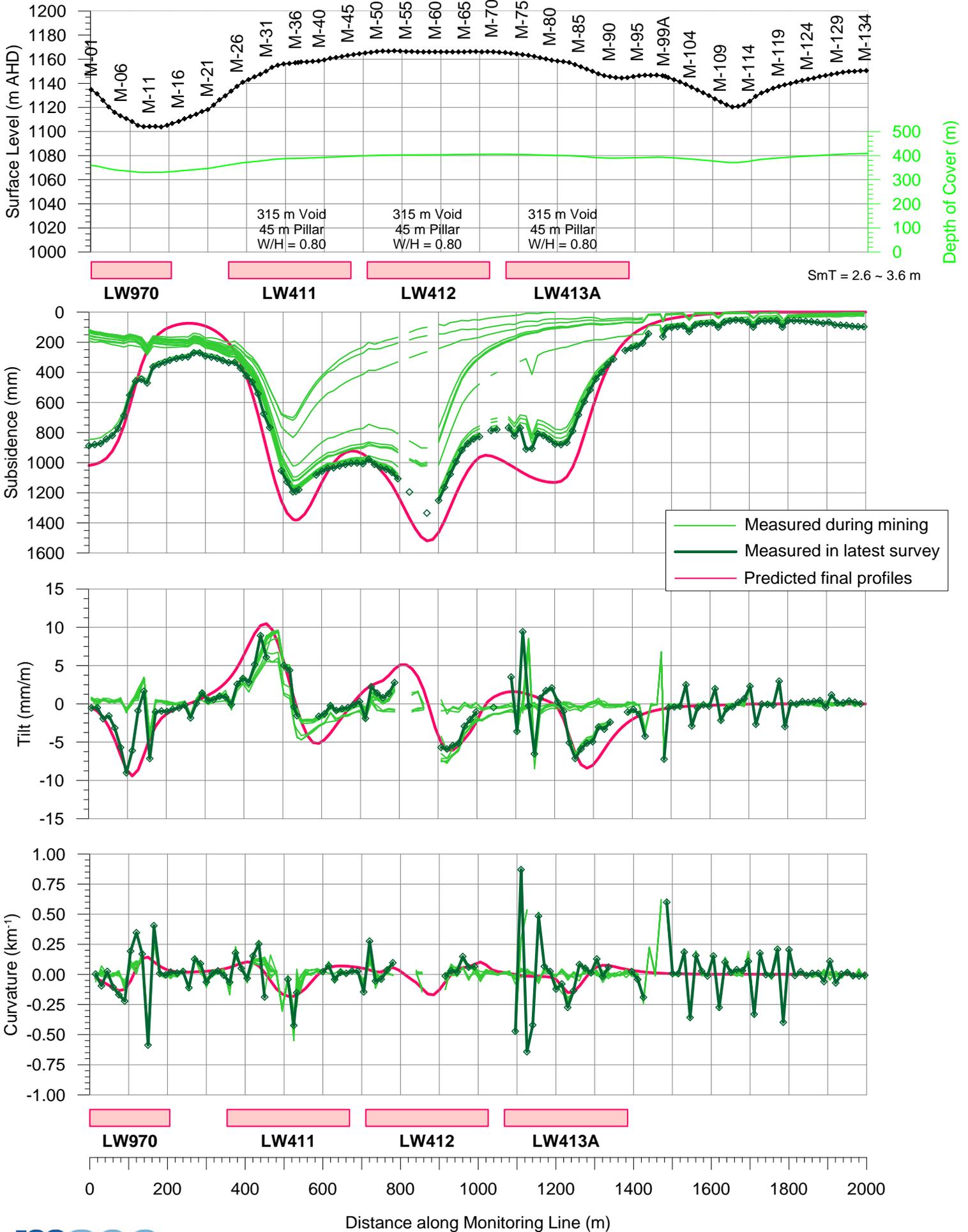
Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the X-Line at Angus Place Colliery



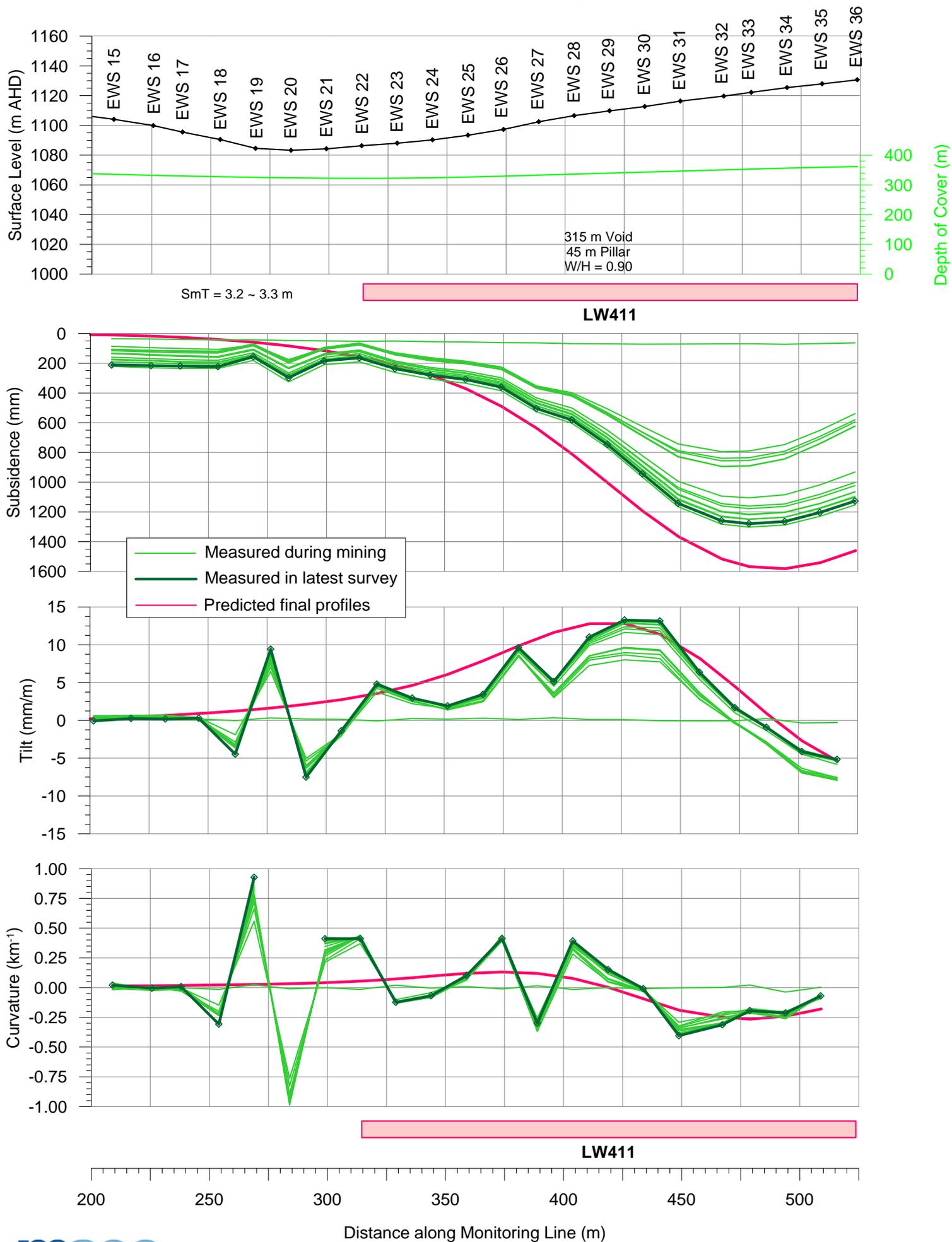
Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the B-Line at Springvale Colliery



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

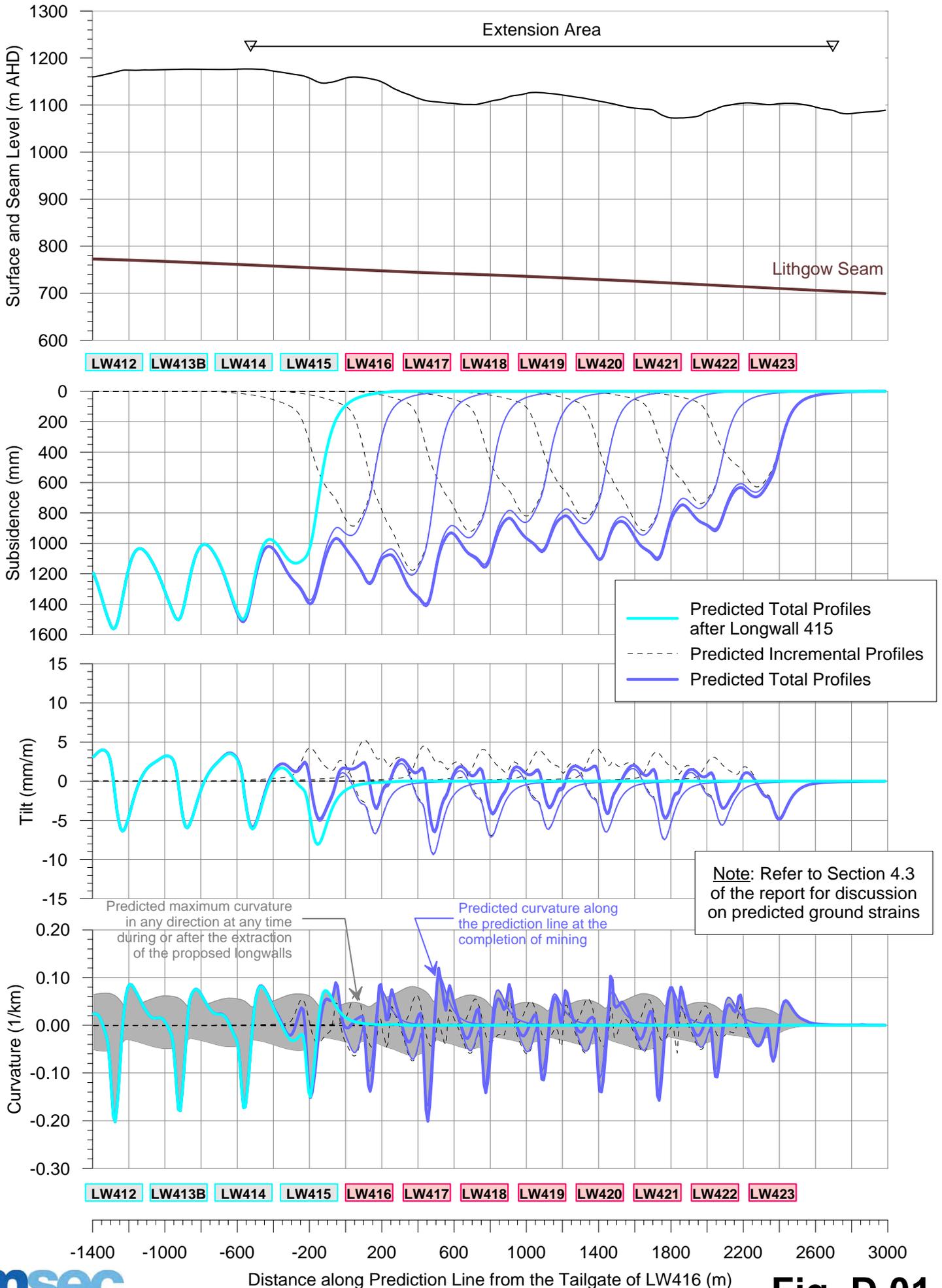


Observed and Predicted Profiles of Total Subsidence, Tilt and Curvature along the EWS-Line at Springvale Colliery

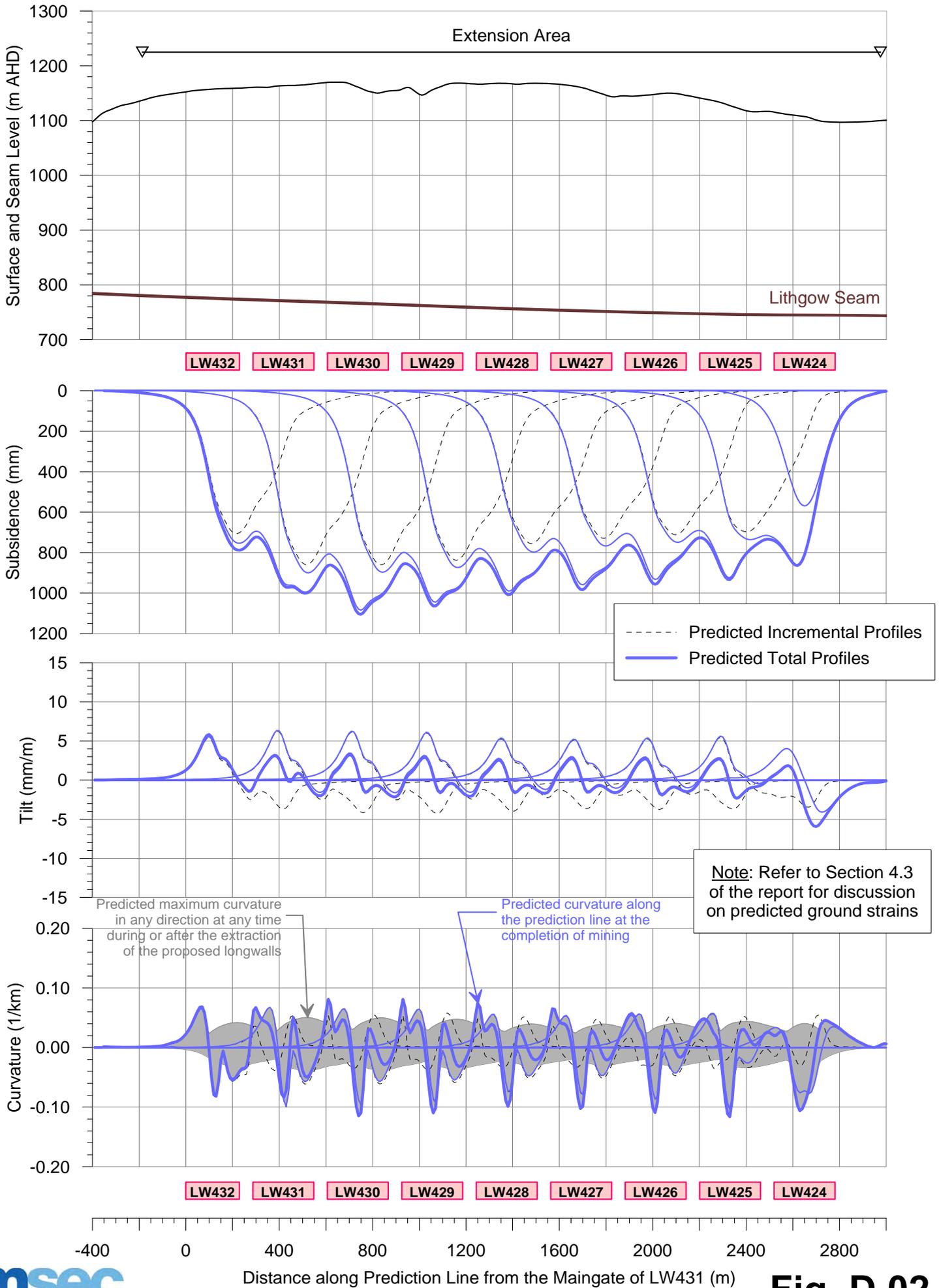


APPENDIX D. FIGURES

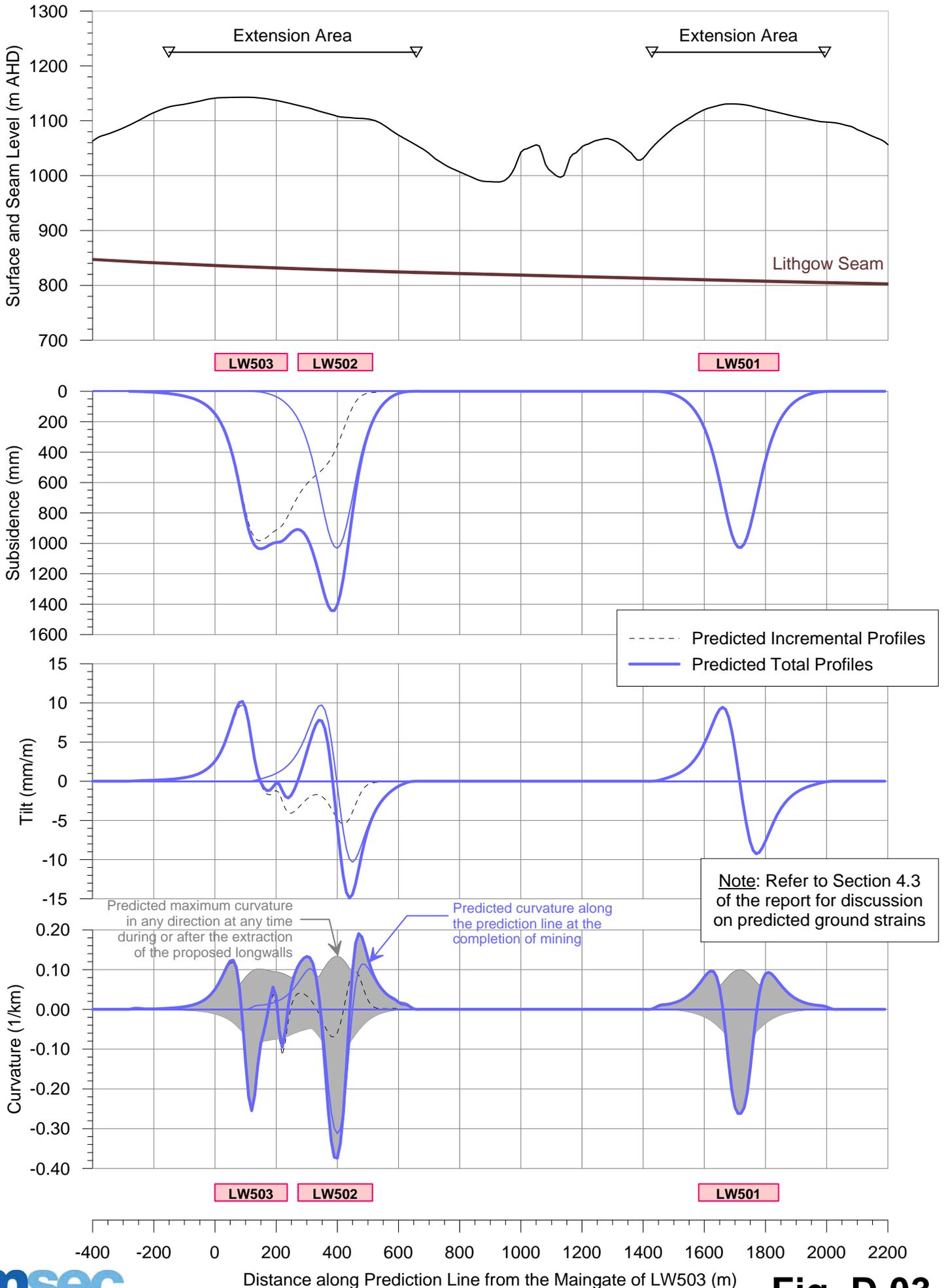
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line S1 Resulting from the Extraction of Longwalls 401 to 423



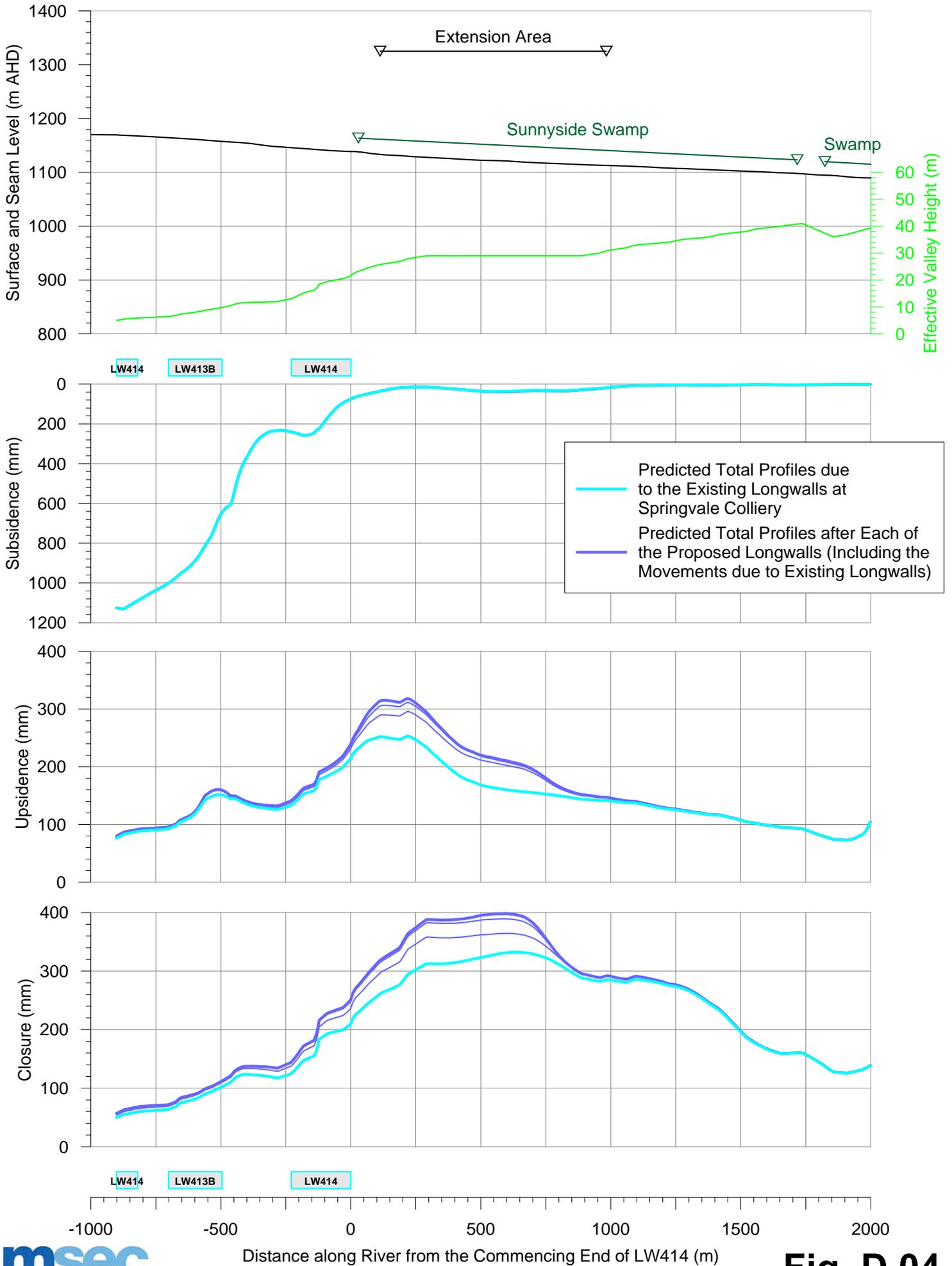
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line S2 Resulting from the Extraction of Longwalls 424 to 431



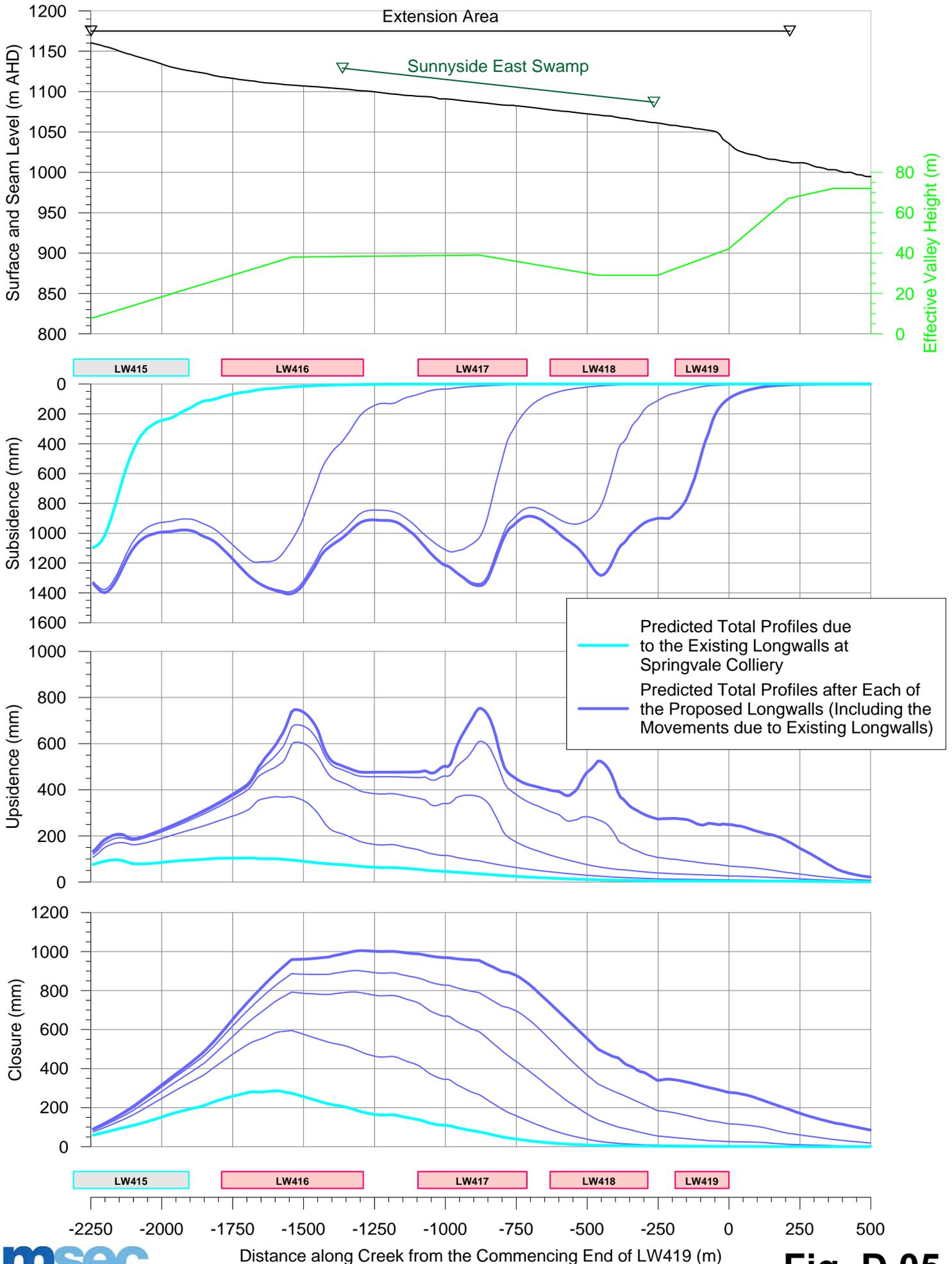
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line S3 Resulting from the Extraction of Longwalls 501 to 503



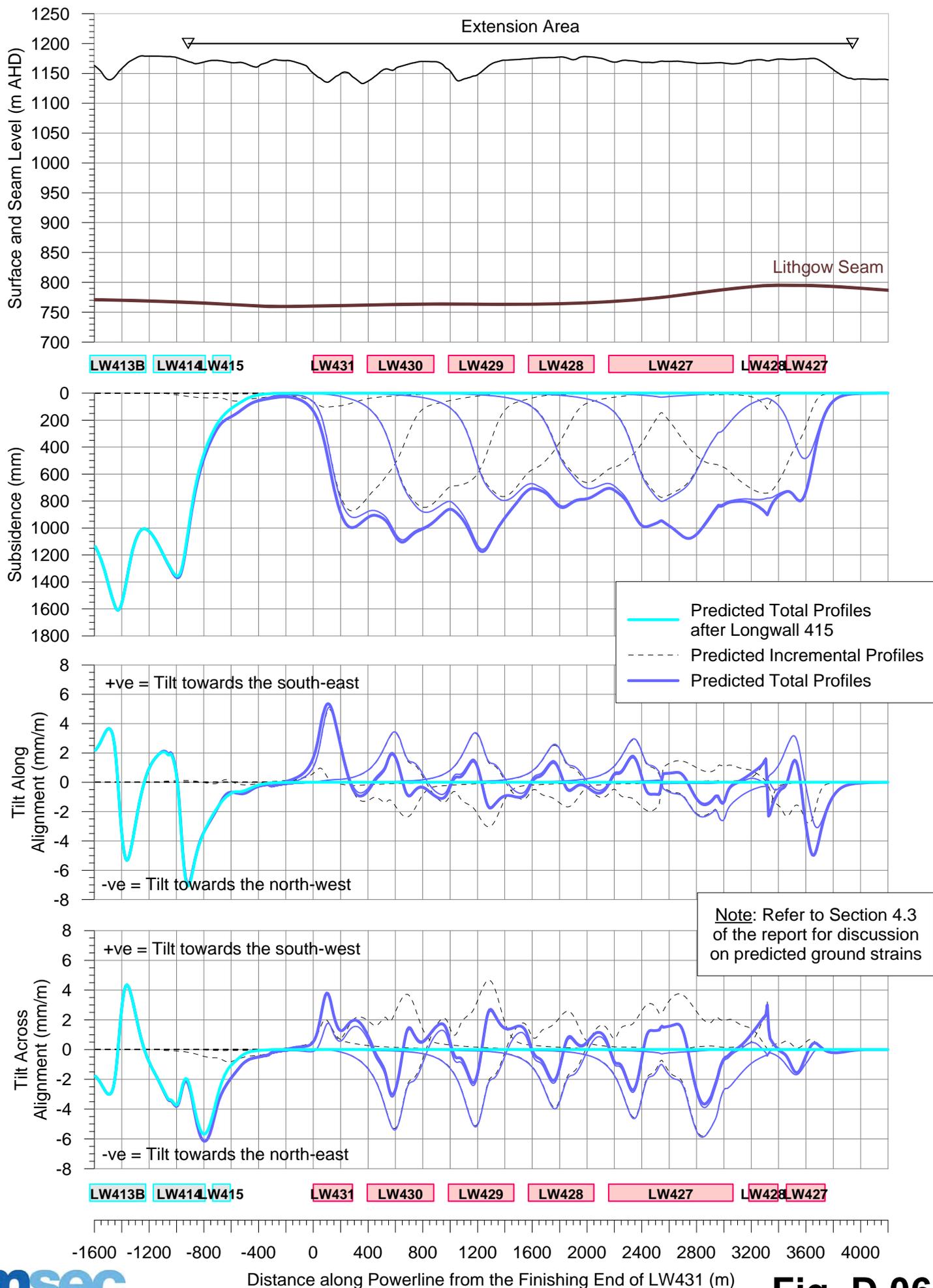
Predicted Profiles of Subsidence, Upsidence and Closure along the Wolgan River Resulting from the Extraction of LW401 to LW432



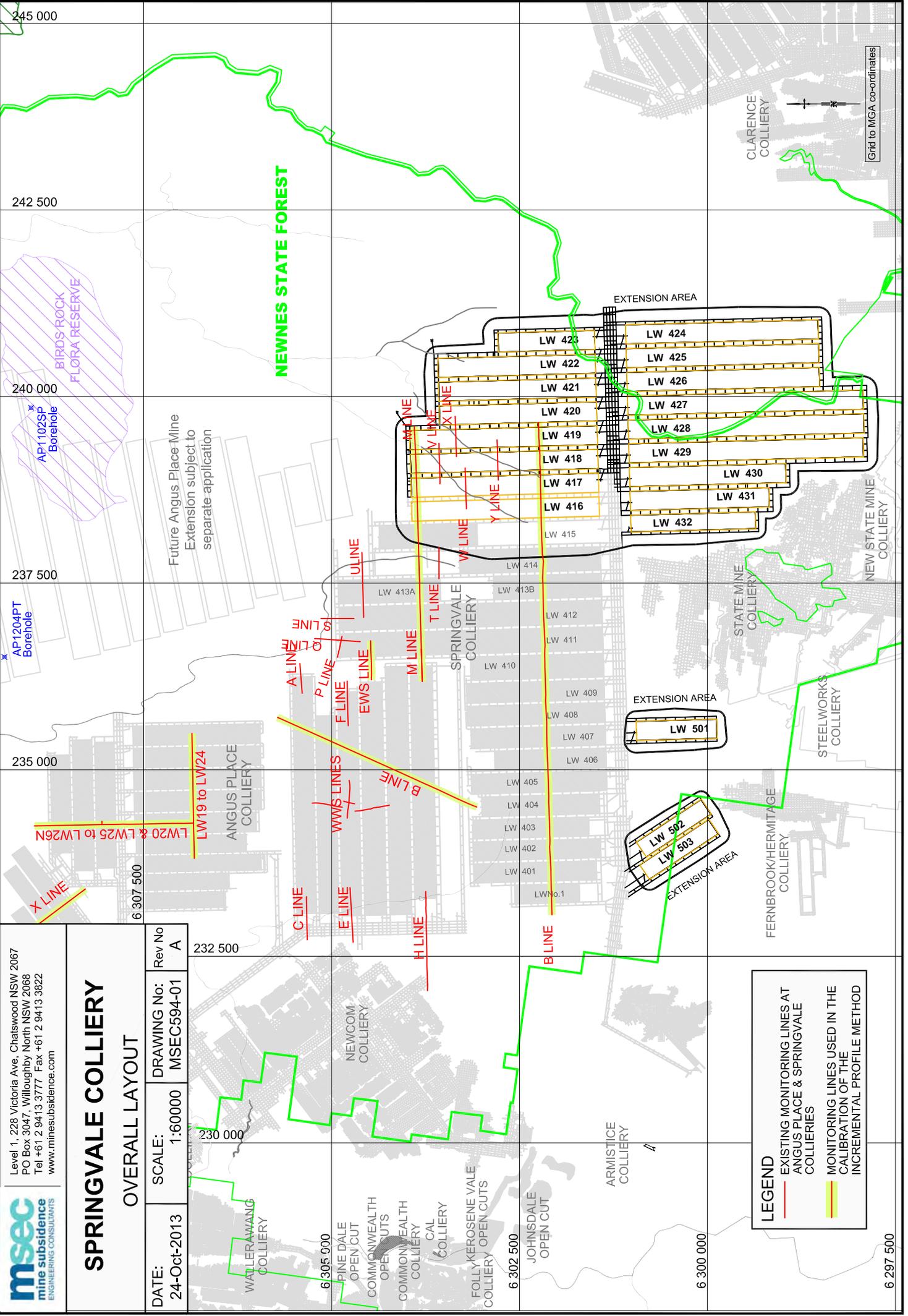
Predicted Profiles of Subsidence, Upsidence and Closure along Carne Creek Resulting from the Extraction of LW401 to LW432



Predicted Profiles of Conventional Subsidence, Tilt Along and Tilt Across the 66 kV Powerline Resulting from the Extraction of Longwalls 401 to 423



APPENDIX E. DRAWINGS



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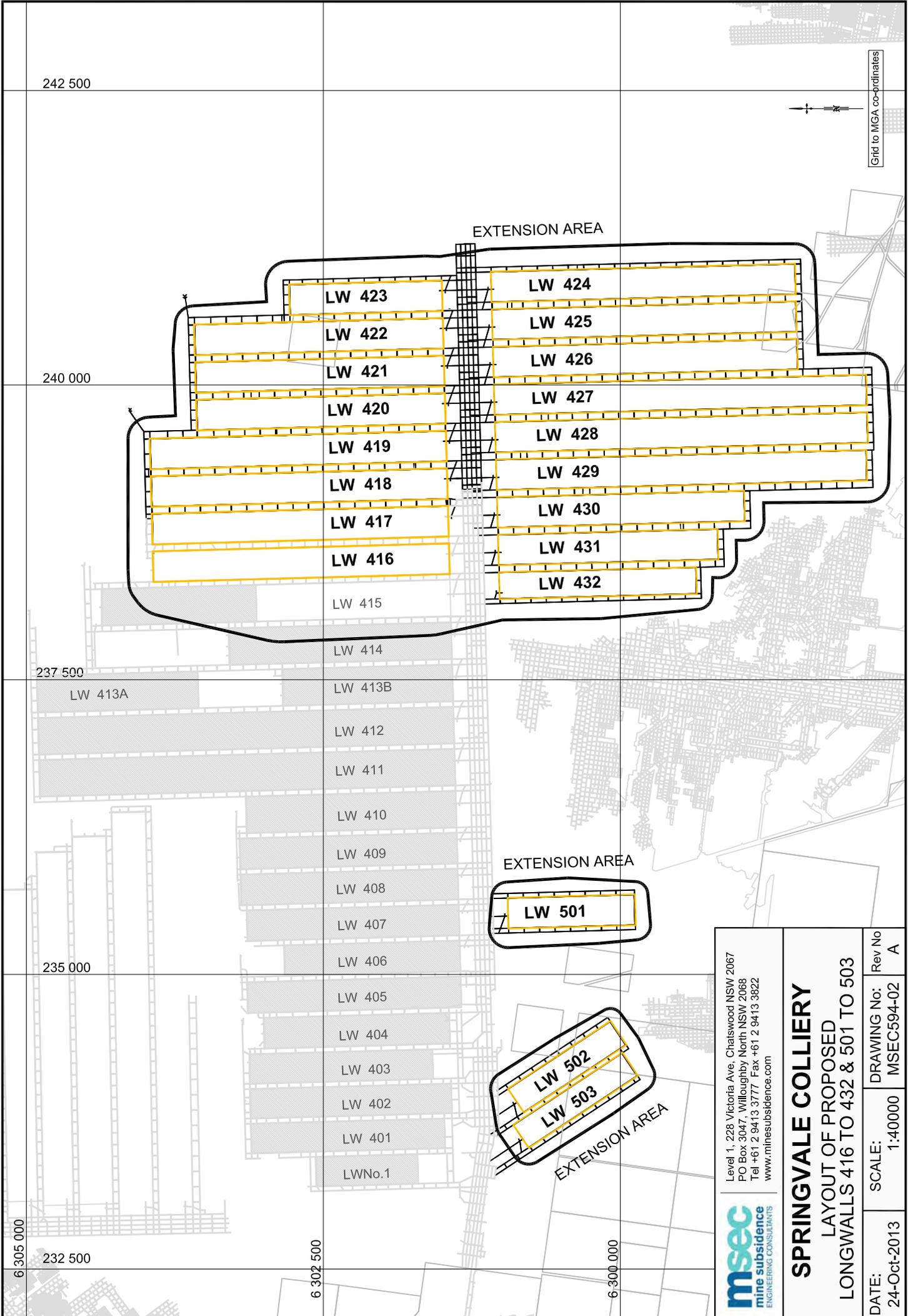


SPRINGVALE COLLIERY

OVERALL LAYOUT

DATE:	24-Oct-2013	SCALE:	1:60000	DRAWING No:	MSEC594-01	Rev No	A
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LEGEND
EXISTING MONITORING LINES AT ANGUS PLACE & SPRINGVALE COLLIERIES
MONITORING LINES USED IN THE CALIBRATION OF THE INCREMENTAL PROFILE METHOD

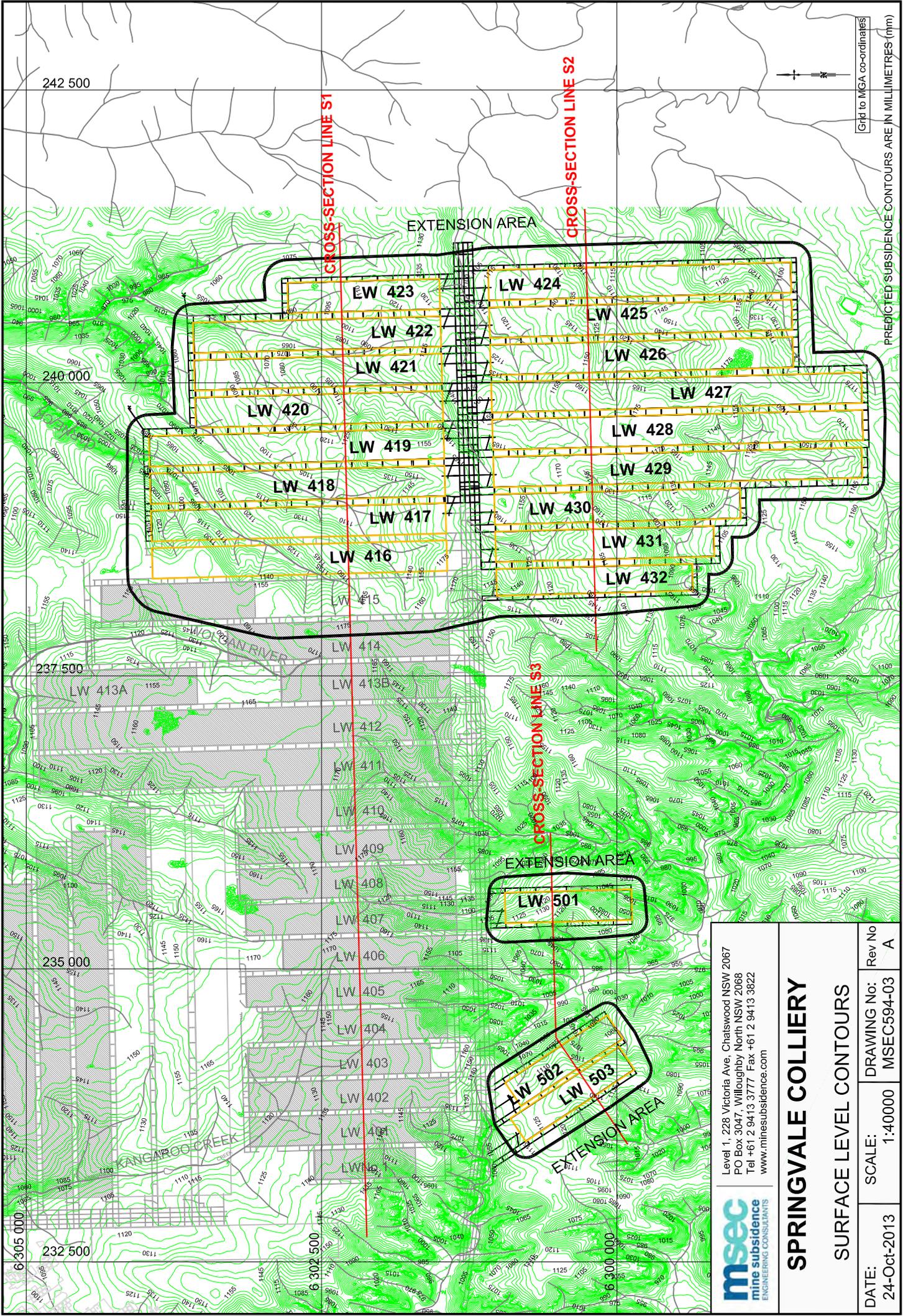


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SPRINGVALE COLLIERY
 LAYOUT OF PROPOSED
 LONGWALLS 416 TO 432 & 501 TO 503

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Grid to MGA co-ordinates

PREDICTED SUBSIDENCE CONTOURS ARE IN MILLIMETRES (mm)

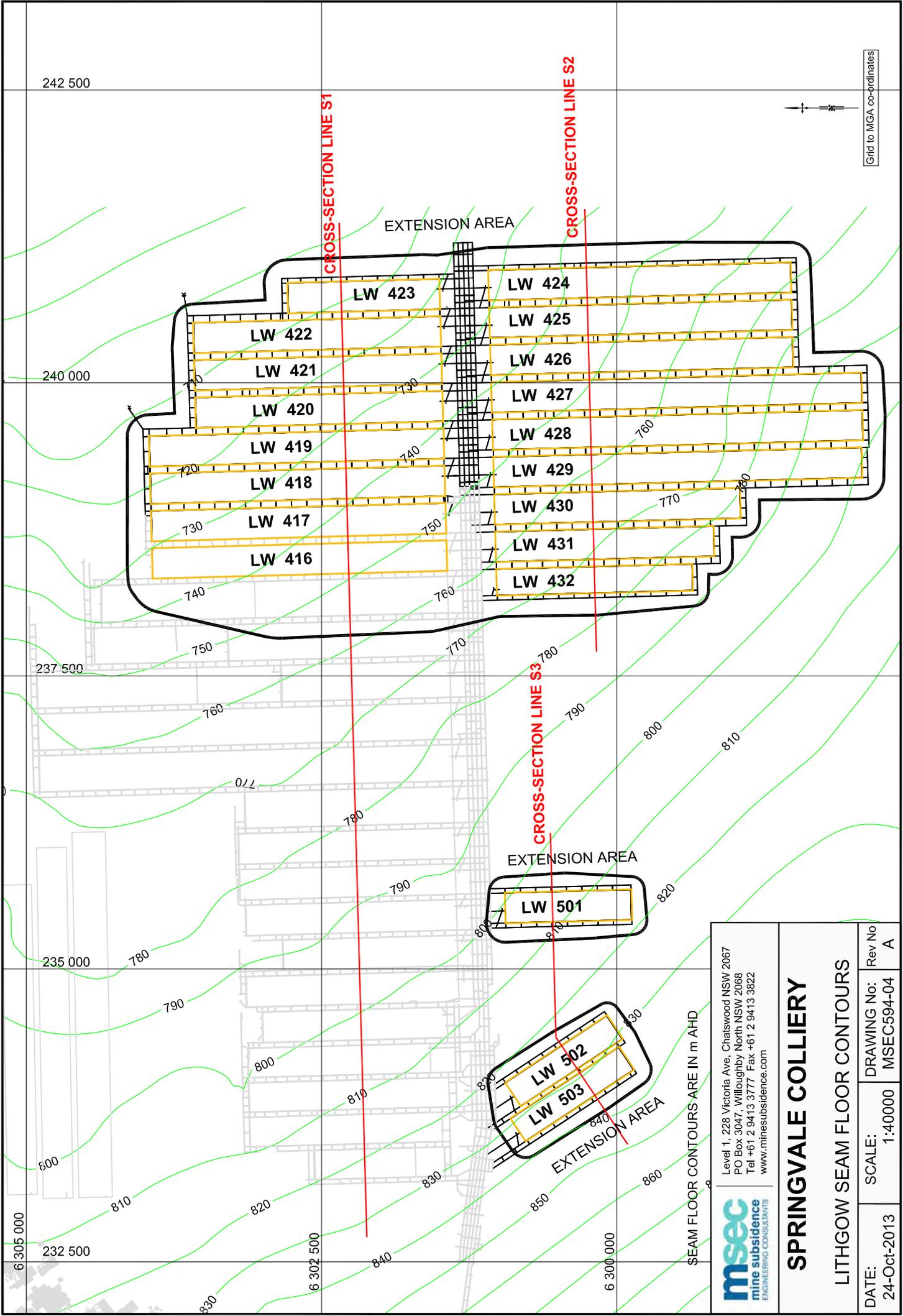
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SURFACE LEVEL CONTOURS

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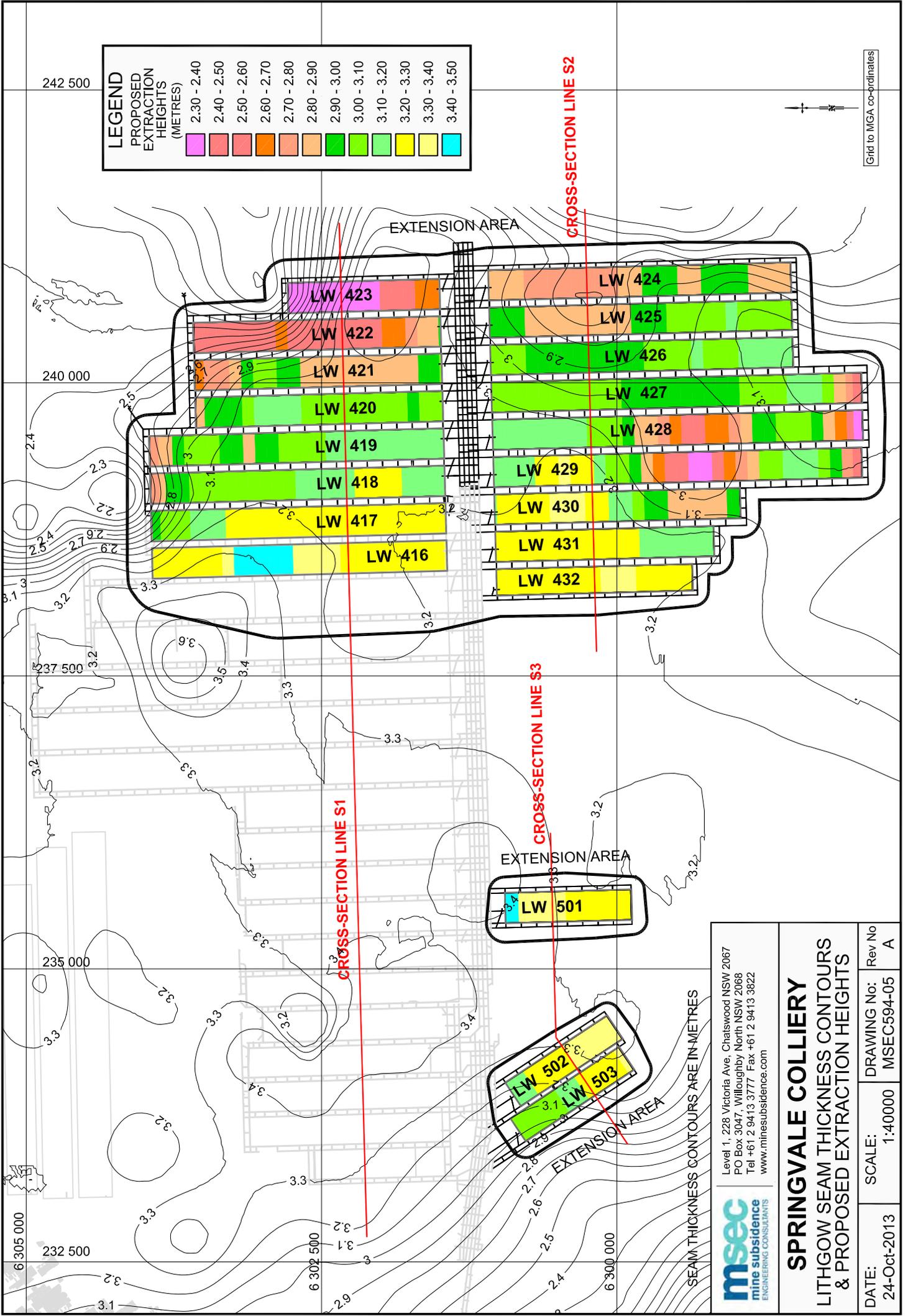
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SPRINGVALE COLLIERY
LITHGOW SEAM FLOOR CONTOURS

DATE: 24-Oct-2013	SCALE: 1:40000	DRAWING No: MSEC594-04	Rev No A
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SEAM FLOOR CONTOURS ARE IN m AHD



LEGEND	PROPOSED EXTRACTION HEIGHTS (METRES)
[Pink]	2.30 - 2.40
[Light Red]	2.40 - 2.50
[Red]	2.50 - 2.60
[Orange]	2.60 - 2.70
[Light Orange]	2.70 - 2.80
[Light Green]	2.80 - 2.90
[Green]	2.90 - 3.00
[Light Green]	3.00 - 3.10
[Yellow-Green]	3.10 - 3.20
[Yellow]	3.20 - 3.30
[Light Yellow]	3.30 - 3.40
[Cyan]	3.40 - 3.50

Grid to MGA co-ordinates

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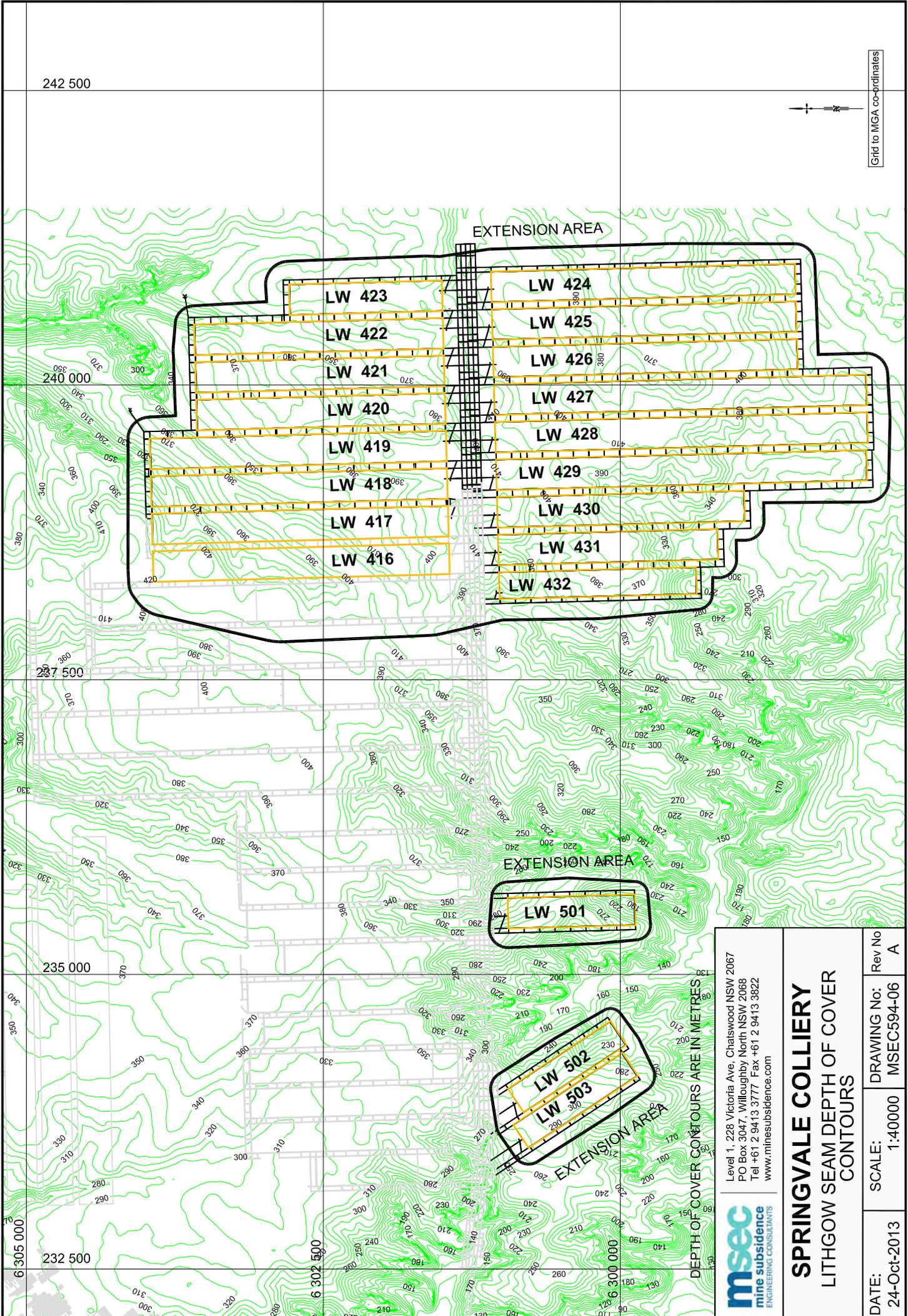
SPRINGVALE COLLIERY
LITHGOW SEAM THICKNESS CONTOURS & PROPOSED EXTRACTION HEIGHTS

DATE: 24-Oct-2013	SCALE: 1:40000	DRAWING No: MSEC594-05	Rev No A
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SEAM THICKNESS CONTOURS ARE IN METRES

242 500

Grid to MGA co-ordinates



235 000

232 500

6 302 500

6 300 000

DEPTH OF COVER CONTOURS ARE IN METRES

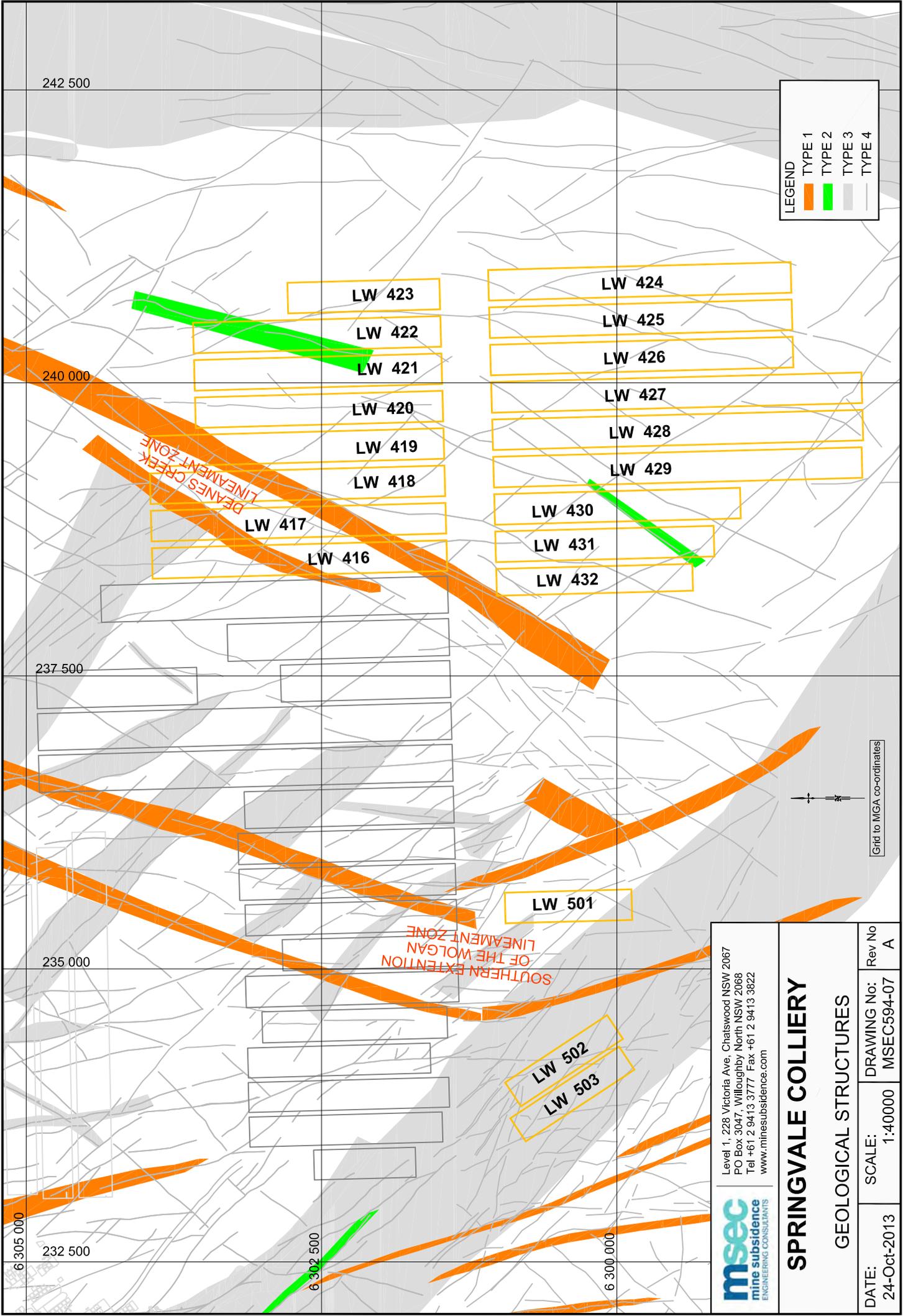
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LITHGOW SEAM DEPTH OF COVER CONTOURS

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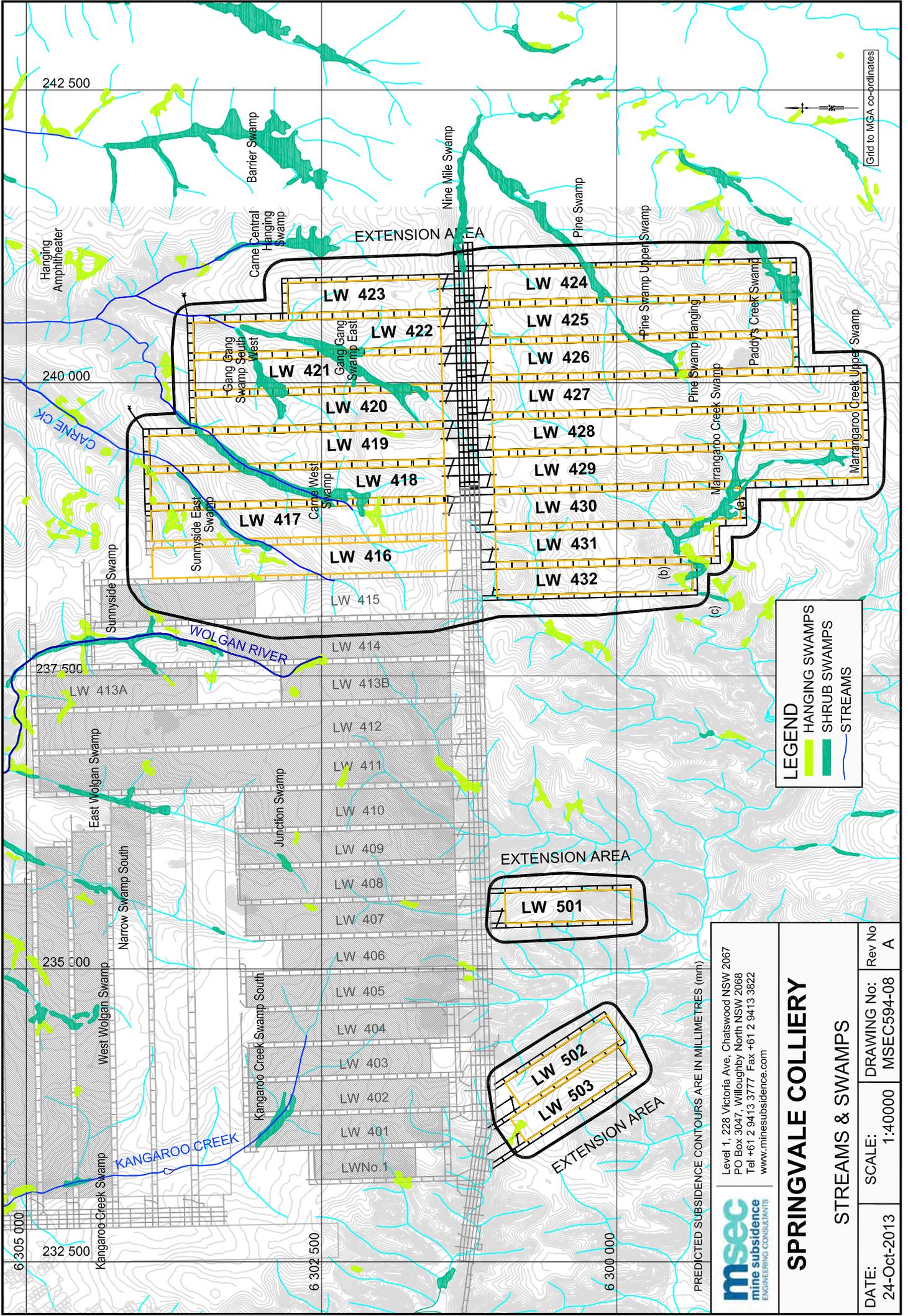


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SPRINGVALE COLLIERY
GEOLOGICAL STRUCTURES

DATE: 24-Oct-2013	SCALE: 1:40000	DRAWING No: MSEC594-07	Rev No A
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LEGEND

- HANGING SWAMPS
- SHRUB SWAMPS
- STREAMS

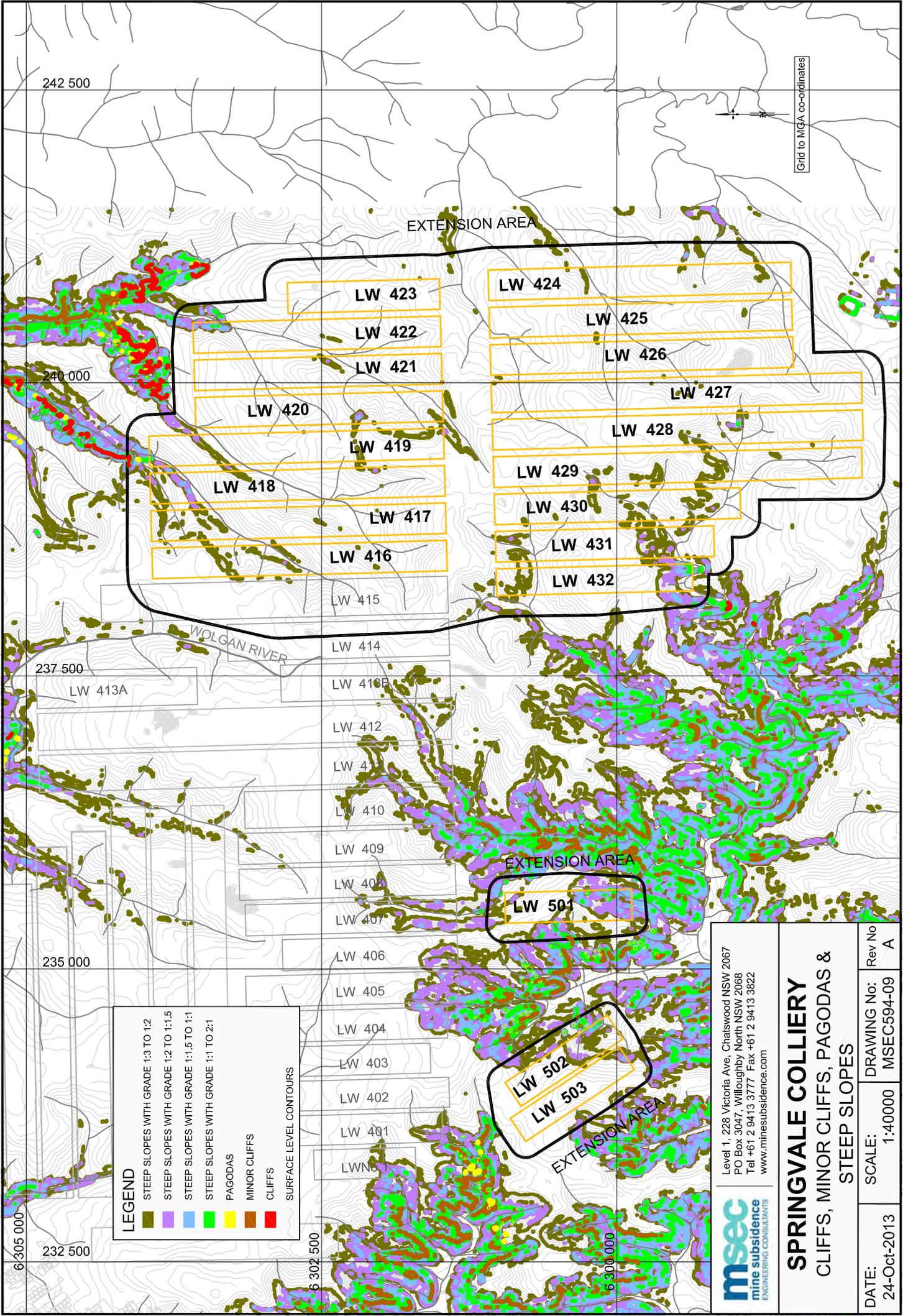
Predicted subsidence contours are in millimetres (mm)

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		DRAWING No:	MSEC594-08
DATE:	SCALE:	1:40000	
24-Oct-2013			

STREAMS & SWAMPS

Grid to MGA co-ordinates



LEGEND

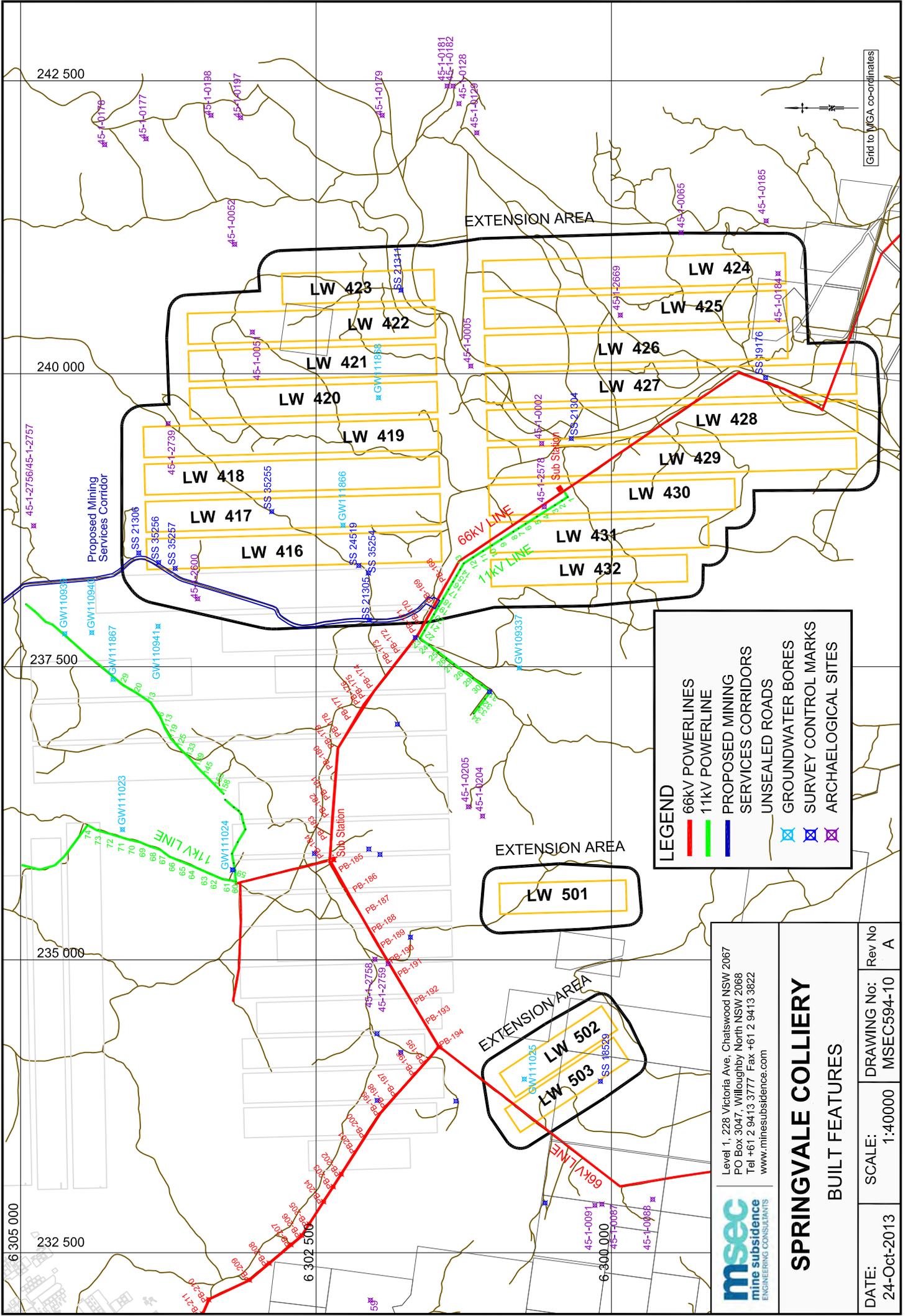
- STEEP SLOPES WITH GRADE 1:3 TO 1:2
- STEEP SLOPES WITH GRADE 1:2 TO 1:1.5
- STEEP SLOPES WITH GRADE 1:1.5 TO 1:1
- STEEP SLOPES WITH GRADE 1:1 TO 2:1
- PAGODAS
- MINOR CLIFFS
- CLIFFS
- SURFACE LEVEL CONTOURS

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SPRINGVALE COLLIERY
 CLIFFS, MINOR CLIFFS, PAGODAS &
 STEEP SLOPES

DATE: 24-Oct-2013	SCALE: 1:40000	DRAWING No: MSEC594-09	Rev No: A
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Grid to WGA co-ordinates

LEGEND

- 66kV POWERLINES
- 11kV POWERLINE
- PROPOSED MINING SERVICES CORRIDORS
- UNSEALED ROADS
- GROUNDWATER BORES
- SURVEY CONTROL MARKS
- ARCHAEOLOGICAL SITES

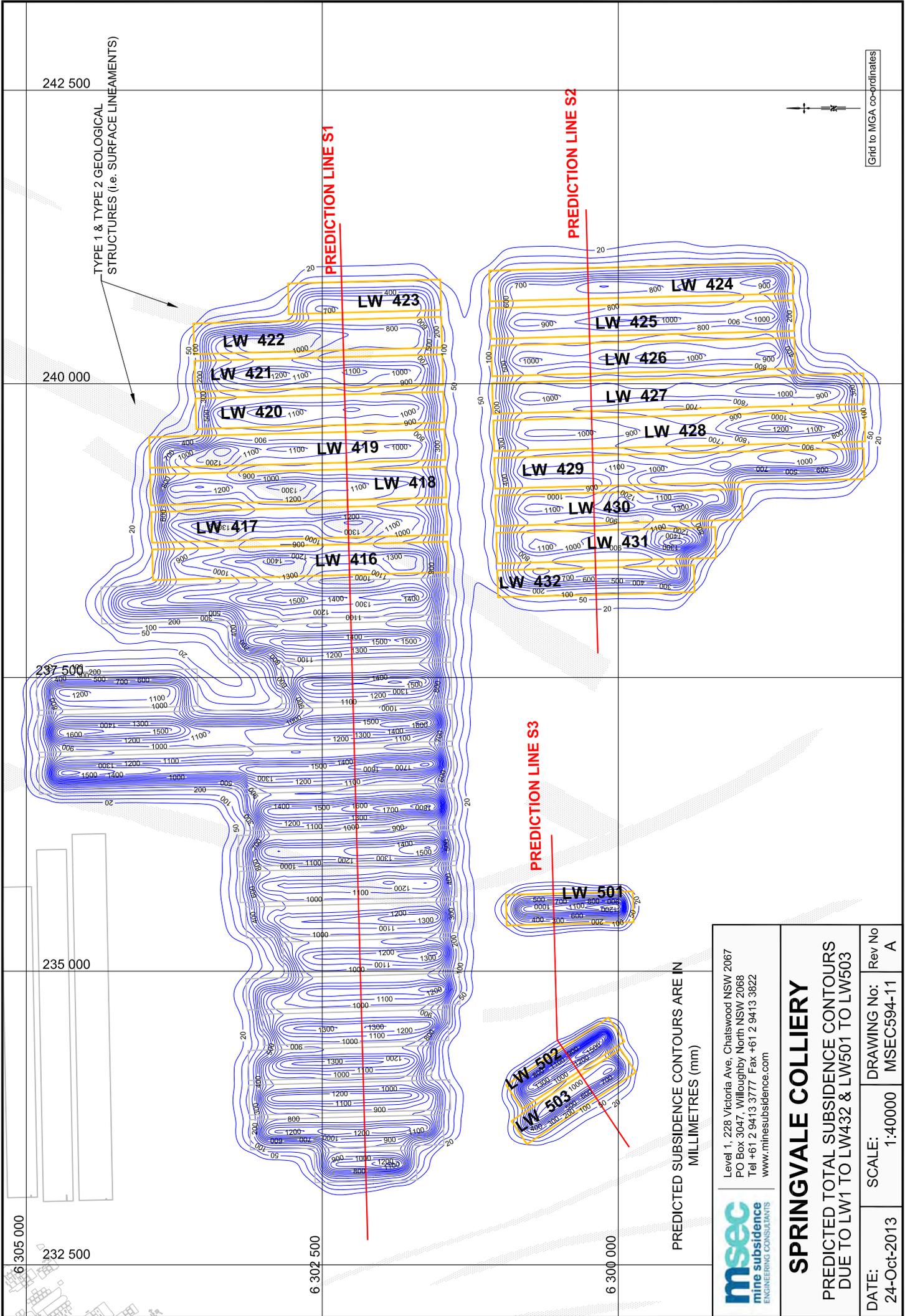
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SPRINGVALE COLLIERY

BUILT FEATURES

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24-Oct-2013	1:40000	MSEC594-10	A



Grid to MGA co-ordinates

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SPRINGVALE COLLIERY

PREDICTED TOTAL SUBSIDENCE CONTOURS
DUE TO LW1 TO LW432 & LW501 TO LW503

DATE:	SCALE:	DRAWING No:	Rev No
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