APPENDIX A

Subsidence Assessment

ILLAWARRA COAL:

Dendrobium Mine – Plan for the Future: Coal for Steelmaking

Subsidence Predictions and Impact Assessments for the Natural and Built Features
in Support of the Environmental Impact Statement Application

DOCUMENT REGISTER

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Report produced to: Support the Environmental Impact Statement Application to be issued to the Department of Planning and Environment.

Previous reports: WKA77 (January 2001) – Dendrobium Mine Project – Report on the Prediction of Mining Subsidence Parameters and the Assessment of Impacts on Surface Infrastructure – Longwalls 1 to 18 (In support of the EIS).

MSEC311 (Revision D) – The Prediction of Subsidence Parameters and the Assessment of Mine Subsidence Impacts on Natural Features and Surface Infrastructure Resulting from the Extraction of Proposed Longwalls 6 to 10 in Area 3A and Future Longwalls in Areas 3B and 3C at Dendrobium Mine (October 2007).

MSEC459 (Revision B) – Subsidence Predictions and Impact Assessments for Natural Features and Surface Infrastructure in Support of the SMP Application (September 2012).

MSEC856 (Rev. C) – Review of the Subsidence Predictions and Impact Assessments for Natural and Built Features in Dendrobium Area 3B based on Observed Movements and Impacts during Longwalls 9 and 10 (December 2015).

Background reports available at *www.minesubsidence.com*[1]:

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

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

South32 Illawarra Coal (IC) operates Dendrobium Mine (the Mine), which is located in the Southern Coalfield of New South Wales. IC has completed the extraction of longwalls in Areas 1, 2, 3A and is currently extracting longwalls in Area 3B at the Mine. The future longwalls in the approved Areas 3B and 3C are the subject of separate Subsidence Management Plan Applications.

IC proposes to continue its underground coal mining operations at the Mine by extracting longwalls in Areas 5 and 6, referred to collectively as *Dendrobium Mine – Plan for the Future: Coal for Steelmaking* (the Project). The longwalls in Area 5 are located in the Bulli Seam and the longwalls in Area 6 are located in the Wongawilli Seam. The layouts of the proposed longwalls in these mining areas are shown in Drawing No. MSEC856-02, in Appendix E. This subsidence report has been prepared to support the Environmental Impact Statement for the proposed longwalls in Areas 5 and 6.

The predicted subsidence parameters for the existing and proposed longwalls have been obtained using the Incremental Profile Method (IPM). This method has been reviewed and re-calibrated based on the updated ground monitoring and LiDAR data from Longwalls 6 to 8 in Area 3A and Longwalls 9 to 13 in Area 3B. The re-calibrated model provides predictions of vertical subsidence for longwalls in the Wongawilli Seam up to 30 % greater than predicted for longwalls in the Bulli Seam. This increased subsidence is due to the higher pillar compression resulting from the thicker coal seam.

The IPM has also been reviewed using a numerical model based on Universal Distinct Element Code (UDEC). The profiles of vertical subsidence obtained from the UDEC model reasonably match those predicted using the IPM, with the magnitudes being within ±15 %. The maximum predicted tilts and curvatures obtained from the UDEC model are similar to or slightly less than maximum predicted values based on the IPM. It is not considered necessary, therefore, to further calibrate the IPM based on the outcomes of the numerical model.

The maximum predicted subsidence parameters for the proposed longwalls in Area 5 are: 2050 mm vertical subsidence, 25 mm/m tilt (i.e. 2.5 % or 1 in 40) and 0.50 km^{-1} hogging (i.e. 2.0 km minimum radius) and 0.60 km^{-1} sagging curvature (i.e. 1.7 km minimum radius). The maximum predicted subsidence parameters for the proposed longwalls in Area 6 are: 2450 mm vertical subsidence, 20 mm/m tilt (i.e. 2.0 % or 1 in 50), 0.30 km^{-1} hogging curvature (i.e. 3.3 km minimum radius) and 0.50 km^{-1} sagging curvature (i.e. 2.0 km minimum radius).

The *Study Area* is defined as the surface area that is likely to be affected by the extraction of the proposed longwalls in Areas 5 and 6. The extent of the Study Area has been calculated, as a minimum, as the surface area enclosed by the greater of the 35° angle of draw from the extents of the proposed longwalls and by the predicted 20 mm subsidence contour due to the extraction of the proposed longwalls. Other features that could be subjected to far-field or valley related movements and could be sensitive to such 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 m from the proposed longwalls, have been assessed.

Natural and built features have been identified within or in the vicinity of the Study Area, including the Avon River, Cordeaux River, Wongawilli Creek, Donalds Castle Creek, drainage lines, cliffs, minor cliffs, steep slopes, swamps, disused railway corridor, Picton Road, unsealed tracks, gas pipelines, 330 kV transmission line, 33 kV powerline, Avon and Cordeaux Reservoirs and associated dam walls, Aboriginal heritage sites, historical heritage sites, survey control marks, buildings and other structures.

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 Avon River, Cordeaux River, Donalds Castle Creek and Wongawilli Creek are all located outside the extents of the proposed longwalls. These streams are predicted to experience less than 20 mm vertical subsidence due to the proposed mining in Areas 5 and 6. The maximum predicted total closures for these streams within the Study Area are 200 mm for the Avon River, 80 mm for the Cordeaux River, 210 mm for Donalds Castle Creek and less than 20 mm for Wongawilli Creek. Donalds Castle Creek is predicted to experience additional closure of 200 mm due to the Project longwall mining only.

  Fracturing could occur along these streams at distances up to approximately 400 m from the proposed longwalls. The potential for Type 3 impacts (i.e. fracturing in a rockbar or upstream pool resulting in reduction in standing water level based on current rainfall and surface water flow) has been considered low, with the affected pools and channels within the Study Area being approximately 7 % for the Avon River, less than 5 % for the Cordeaux River and 9 % for Donalds Castle Creek. As Wongawilli Creek is located more than 600 m from the proposed longwalls, Type 3 impacts are considered unlikely along this creek due to the proposed mining.

- Unnamed drainage lines are located directly above the proposed longwalls in Areas 5 and 6. These streams are typically first and second order but the lower reaches of AR19, AR31, AR32, DC8 and LA13 are third order. The drainage lines have exposed bedrock with some standing pools. There are also other controlling features including boulderfields, riffle zones and debris accumulations.

  Selected stream features have been mapped by IC and identified based on factors including: rockbar size, pool length, pool width, pool depth, pool volume, step height and waterfall height. The longwalls have been setback by distances of 50 m to 100 m from the selected stream features to reduce the potential for impacts. These setbacks have been applied by IC to pools with volume greater than 100 m^3 and waterfalls with greater than 5 m with a pool at the base of the step.

  The sections of the drainage lines located directly above the proposed longwalls are expected to experience the full range of predicted movements. There is potential for locally increased ponding due to the mining-induced tilt along AR31, DC9 and CR31 upstream of the chain pillars and where these streams exit the proposed mining areas. There could also be localised tilt-induced ponding areas along the other drainage lines where the natural gradients are low immediately upstream of the longwall chain pillars.

  It is expected that fracturing of the bedrock would occur along the sections of the drainage lines that are located directly above the proposed longwalls. Fracturing can also occur outside the extents the proposed longwalls, with fracturing possible at distances up to approximately 400 m. Surface water flow diversions are likely to occur along the sections of drainage lines that are located directly above and adjacent to the proposed longwalls.

- A cliff is defined as a continuous rockface having a minimum height of 10 m, a minimum length of 20 m and a minimum slope of 2 to 1, i.e. having a minimum angle to the horizontal of 63°. There are 40 cliffs that have been identified directly above the proposed longwalls in Area 5. There are no cliffs located directly above the proposed longwalls in Area 6. There are 46 additional cliffs that are located outside the extents of the proposed longwalls and within the 35° angles of draw.

  The cliffs located directly above the proposed longwalls could experience fracturing and, where the exposed rock face is marginally stable, could result in cliff instabilities. It has been estimated that between 7 % and 10 % of the total length, or between 3 % and 5 % of the total face area of the cliffs located directly or partially above the proposed longwalls in Area 5 would be impacted. This represents a total length of impact of approximately 150 m to 220 m, or a total face area of impact of approximately 800 m^2 to 1400 m^2.

  Isolated rock falls could occur at some of the cliffs located outside the extents of the proposed longwalls, which would represent less than 1 % of the affected cliffs. It is estimated that these impacts would affect a total length of less than 20 m or a face area of less than 100 m^2.

- Rock outcrops and steep slopes are located across the Study Area. These features predominately occur along the alignments of the streams. These features are expected to experience the full range of predicted movements. The potential impacts include tension cracks at the tops of the rock outcrops and steep slopes, buckling of the bedrock at the bottoms of the rock outcrops, and compression ridges at the bottoms of the steep slopes.

  The surface deformations are expected to be similar to those previously observed at the Mine, having crack widths up to approximately 400 mm, but typically in the order of 100 mm to 150 mm in width. It is possible, therefore, that remediation may be required in some areas, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface.

- There are 37 upland swamps that have been identified partially or entirely within the Study Area based on the 35° angle of draw and 9 additional swamps that are located partially or entirely within the Study Area based on the 600 m boundary.

  There are 26 upland swamps that are partially or entirely located above the proposed longwalls and these swamps are expected to experience the full range of predicted movements. The remaining 20 swamps are located outside the extents of the proposed longwalls and these swamps will experience reduced levels of predicted movements.

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

Fracturing of the bedrock is expected to occur beneath the swamps that are located directly above the proposed longwalls. The soil crack and rock fracture widths due to the extraction of the proposed longwalls in Areas 5 and 6 are expected to be less, on average, than those previously measured at the Mine. The measured surface deformations were generally less than 50 mm in width (i.e. 86 % of the cases) but had widths between 50 mm and 150 mm in 8 % of cases, between 150 mm and 300 mm in 4 % of cases and greater than 300 mm in 2 % of cases.

The discussions on the potential impacts due to changes in the surface water flows, groundwater and the environmental consequences for the swamps are provided by the specialist surface water, groundwater and ecology consultants on the Project.

- The disused Maldon-Dombarton railway corridor crosses directly above the proposed longwalls in Area 5. The infrastructure associated with the corridor could be impacted, including the cuttings, embankments and drainage culverts.

- Picton Road is located outside the extents of the proposed longwalls. This road is predicted to experience less than 20 mm of vertical subsidence. It is unlikely, therefore, that the road would experience adverse impacts.

- There are unsealed tracks located across the Study Area. It is predicted that these tracks could be maintained in safe and serviceable conditions throughout the mining period using normal road maintenance techniques.

- Two natural gas pipelines are located within an easement on the western side of Picton Road. The easement crosses directly above the northern end of the proposed LW604. The gas pipelines could experience up to 900 mm vertical subsidence, 9 mm/m tilt, 0.20 km^{-1} hogging curvature and 0.08 km^{-1} sagging curvature.

  The potential impacts on the gas pipelines could be managed using management strategies similar to those adopted where similar pipelines have been directly mined beneath in the Southern Coalfield. This includes uncovering and exposing sections of the pipelines, temporarily supporting them on sandbags, monitoring and adjusting their profiles if prescribed triggers are reached.

- A 330 kV transmission line crosses directly above the proposed LW603 and LW604. There are nine transmission towers within the Study Area, of which, six are located directly above the proposed longwalls. The transmission towers are predicted to experience up to 1850 mm vertical subsidence, 18 mm/m tilt, 0.20 km^{-1} hogging curvature and 0.45 km^{-1} sagging curvature.

  The potential impacts on the 330 kV transmission line could be managed using management strategies similar to those adopted where similar transmission lines have been directly mined beneath at the Mine and elsewhere in the NSW coalfields. This includes the installation of cable rollers and cruciform bases.

- A 33 kV powerline crosses directly above the proposed LW605. This powerline comprises aerial cables supported by metal and timber poles. It is expected that the potential impacts on the 33 kV powerline could be managed with the implementation of the necessary preventive measures, such as the installation of cable rollers, guy wires or additional poles, or the adjustment of cable catenaries.

- There are circular telecommunications antennae owned by Telstra that are fixed to a power pole adjacent to the access road to the Cordeaux Dam Picnic Area. The antennae are located 30 m outside the mining area and are predicted to experience 70 mm vertical subsidence and 2 mm/m tilt. The antennae could be sensitive to the mining-induced tilt if it affects their lines of site. This can be managed by adjusting the directions of the antennae during active subsidence.

- Avon Reservoir is located to the west of the proposed longwalls in Area 5 and Cordeaux Reservoir is located to the south of the proposed longwalls in Area 6. The dam walls associated with these reservoirs are located at a minimum distance of 1 km from the proposed mining areas. The Avon and Cordeaux dams are listed on the NSW State Heritage Register.

  The dam walls are not predicted to experience measurable vertical subsidence, upsidence and closure movements. These structures could experience very low-levels of far-field horizontal movements, in the order of 20 mm, but these are not predicted to result in measurable strains. It is unlikely that the dam walls would experience adverse impacts due to the proposed longwalls, based on their distances from mining and the very low-levels of predicted movement.

  It is recommended that IC consult with WaterNSW and the Dams Safety Committee (DSC) to develop the appropriate monitoring and management strategies for the reservoirs and dam walls. These strategies could include a detailed monitoring program and Trigger Action Response Plan (TARP).

- There are 56 Aboriginal heritage sites that have been identified within the Study Area, of which, 20 sites are located directly above the proposed longwalls. The sites within the Study Area comprise one isolated find, 22 grinding groove sites and 33 rock shelter sites.

  The isolated find is located approximately 510 m outside the extents of the proposed longwalls. It is unlikely that this site would be affected by surface cracking at this distance from the mining area.

  There are 11 grinding groove sites that are located directly above the proposed longwalls and there is potential that mining-induced fracturing could develop coincident with these sites. There are 11 additional grinding groove sites that are located outside the extents of the proposed longwalls and within the Study Area. The potential for fracturing being coincident with the grinding groove sites located outside the mining area is less than that for the sites located directly above the longwalls.

  There are nine rock shelters that are located directly above the proposed longwalls and there is potential for adverse impacts at these sites. The remaining rock shelters are located outside the proposed mining area and are predicted to experience less than 20 mm vertical subsidence. There is a reduced likelihood for adverse impacts on the rock shelters that are located outside the extents of the proposed longwalls.

- The survey control marks in the vicinity of the proposed longwalls could experience small vertical subsidence and far-field horizontal movements. It may be necessary on the completion of the proposed longwalls, when the ground has stabilised, to re-establish any state survey control marks that are required for future use.

- There are 28 buildings and other structures within the Study Area for Area 6, located along Fire Road No. 6 and in the picnic area near the Cordeaux Dam. These comprise three houses, eight sheds, four toilet blocks, six barbeque shelters, one tank and six amenities structures. It is recommended that Property Subsidence Management Plans (PSMPs) be developed, in consultation with WaterNSW, for these structures.

The assessments provided in this report indicate that the levels of impact on the natural and built features can be managed by the preparation and implementation of the appropriate management strategies. It should be noted, however, that more detailed assessments of some natural and built features have been undertaken by other specialist consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

CONTENTS

LIST OF TABLES, FIGURES AND DRAWINGS

Tables

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Figures

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

Drawings

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

1.1. Background

Illawarra Coal Holdings Pty Ltd (IC), a wholly owned subsidiary of South32 Limited (South32), operates Dendrobium Mine (the Mine), which is located in the Southern Coalfield of New South Wales (NSW). The Mine is located to the west of Wollongong and the Illawarra Escarpment and to the east of the township of Bargo.

IC previously prepared an Environmental Impact Statement for the Mine that included longwalls in Areas 1, 2 and 3, referred to herein as the 2001 EIS. Mine Subsidence Engineering Consultants (MSEC), formally trading as Waddington Kay & Associates, provided the subsidence predictions and impact assessments for the proposed mining in Report No. WKA77 (January 2001), which supported the 2001 EIS. The Mine was approved by the Minister for Planning on the 20 November 2001.

The longwall layout originally adopted in the 2001 EIS for Area 3 comprised a series of ten east-west orientated longwalls. Subsequent to the 2001 EIS, Area 3 was separated into three sub-areas for mining purposes, which are referred to as Areas 3A, 3B and 3C. The existing and approved longwalls in Areas 3A and 3B and the currently proposed longwall layout within the approved Area 3C are shown in Fig. 1.1. The Area 3 approval boundary is also shown in this figure.

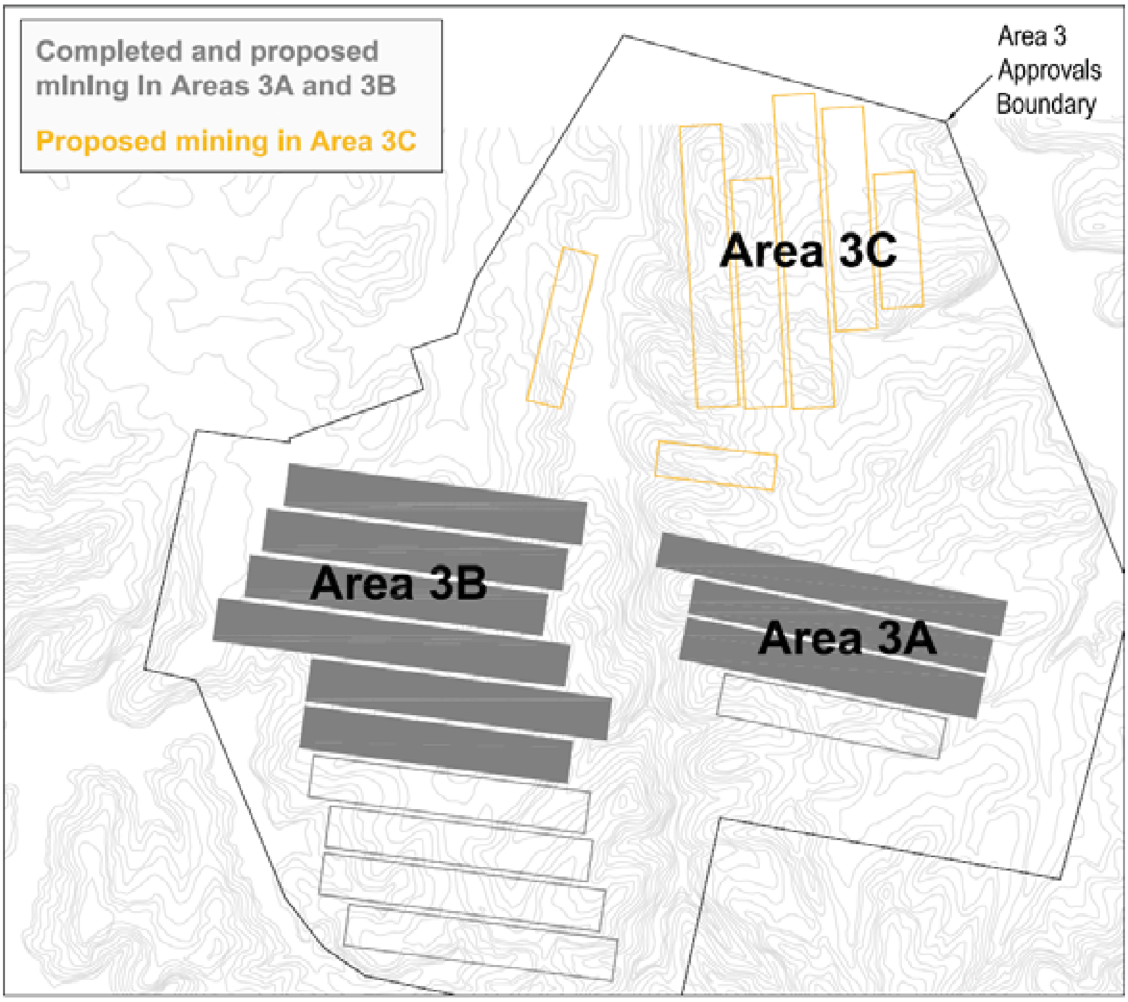

Fig. 1.1 Comparison of longwalls adopted in the 2001 EIS and the current layouts in Area 3

The layout of the existing and proposed longwalls at the Mine are also shown in Drawing No. MSEC856-01, in Appendix E. IC has completed the extraction of LW1 and LW2 in Area 1, LW3 to LW5 in Area 2, LW6 to LW8 in Area 3A and LW9 to LW14 in Area 3B at the Mine. IC has approval for the extraction of additional longwalls in Areas 3A, 3B and 3C.

IC proposes to continue its underground coal mining operations at the Mine by extracting longwalls in Areas 5 and 6, referred to collectively as *Dendrobium Mine – Plan for the Future: Coal for Steelmaking* (the Project). The layouts of the proposed longwalls in these mining areas are shown in Drawing No. MSEC856-02, in Appendix E.

The proposed longwalls and the Study Area, as defined in Section 2.2, have been overlaid on an orthophoto of the area, and is shown in Fig. 1.2.

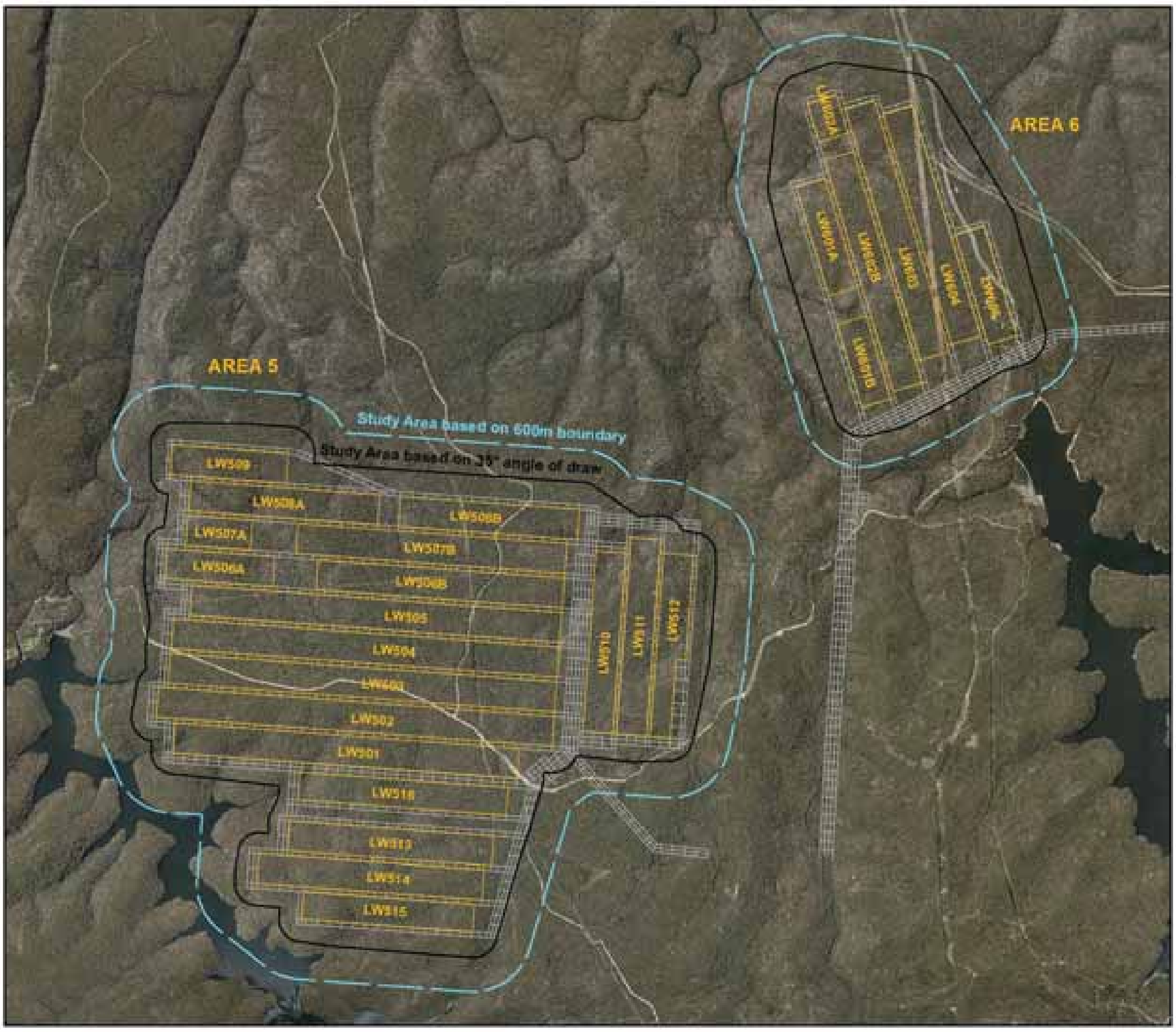

Fig. 1.2 Aerial photograph showing the proposed longwalls and the Study Area

The future longwalls in Areas 3B and 3C are the subject of separate Subsidence Management Plan Applications. The predicted subsidence movements provided in this report include the existing and future longwalls in these mining areas so that the total cumulative movements are considered.

IC is preparing an Environmental Impact Statement for the proposed longwalls in Areas 5 and 6. MSEC has been commissioned by IC to:

- prepare subsidence predictions for the proposed longwalls in Areas 5 and 6;
- identify the natural and built features in the vicinity of the proposed longwalls in Areas 5 and 6;
- provide subsidence predictions for each of these surface features;
- prepare impact assessments, in conjunction with other specialist consultants, for each of the natural and built features; and
- recommend management strategies and monitoring.

This report has been prepared to support the Environmental Impact Statement for the proposed longwalls in Areas 5 and 6 which will be submitted to the Department of Planning and Environment (DP&E).

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

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

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

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of the proposed longwalls in Areas 5 and 6.

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

This report also provides information to satisfy the Project Secretary's Environmental Assessment Requirements (SEARs) relating to subsidence, which have been summarised in Table 1.1.

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

SEARs for subsidence	Section reference
"The EIS must address the following specific issues: ***Subsidence** – including a detailed assessment of the potential conventional and non-conventional subsidence effects, subsidence impacts and environmental consequences of the development on the natural and built environments, paying particular attention to features that are considered to have significant ecological, economic, social, cultural and environmental value, taking into consideration connective fracturing above the longwall panels and recorded regional and historic subsidence;*	The maximum predicted conventional subsidence, tilt and curvatures are summarised in Chapter 4. The predicted strains based on both conventional and non-conventional movements are summarised in Section 4.4. The assessments of the potential consequences on the natural and built features are provided in the impact assessments for each of the surface features in Chapters 5 and 6. The assessment of the height of connective fracturing has been undertaken by the specialist geotechnical consultant on the Project.
*"**Water** – including:* • *an assessment of the likely impact on the quantity and quality of surface and groundwater resources, having regard to EPA's, DPI Water's and WaterNSW's requirements and recommendations (see attachment 2);* • *an assessment of the likely impacts of the development on aquifers, watercourses, swamps, riparian land, water supply infrastructure and systems including Cordeaux Dam and Avon Dam, and other water users;*	The assessments of the potential physical impacts on the streams are provided in Sections 5.2 to 5.6, with further assessments provided by the specialist surface and groundwater consultants on the Project. The assessment of the potential physical impacts on the swamps are provided in Section 5.12, with further assessments provided by the specialist surface, groundwater and ecological consultants on the Project. The assessment of the potential physical impacts on the Dam structures are provided in Section 6.8, with further assessments on the stored waters provided by the specialist groundwater consultant on the Project.
*"**Biodiversity** – including:* • *An assessment of the likely biodiversity impacts of the development, including impacts to upland swamps…"*	The assessment of the potential physical impacts on the swamps are provided in Section 5.12, with further assessments provided by the specialist surface, groundwater and ecological consultants on the Project.
*"**Heritage** – including an assessment of the likely Aboriginal and historic heritage (cultural and archaeological) impacts of the development…"*	The impact assessments for the Aboriginal and European heritage sites are provided in Sections 6.9 and 6.10, with further assessments provided by the specialist consultants on the Project.

1.2. Mining geometry

The layouts of the proposed longwalls in Areas 5 and 6 are shown in Drawings Nos. MSEC856-01 and MSEC856-02, in Appendix E. A summary of the dimensions of these longwalls is provided in Table 1.2.

Table 1.2 Geometry of the proposed longwalls

Mining Area (Seam)	Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
Area 5 (Bulli Seam)	LW501	3480	305	-
	LW502	4000	305	45
	LW503	3905	305	45
	LW504	3900	305	45
	LW505	3740	305	45
	LW506A	1090	305	44
	LW506B	2490	305	44
	LW507A	655	305	45
	LW507B	2715	305	45
	LW508A	1915	305	45
	LW508B	1810	305	45
	LW509	1170	305	45
	LW510	1830	305	-
	LW511	1990	305	35
	LW512	1855	305 / 205	35
	LW513	2065	305	-
	LW514	2275	305	45
	LW515	1725	280	45
	LW516	2105	285	-
Area 6 (Wongawilli Seam)	LW601A	1155	305	-
	LW601B	870	305	-
	LW602A	405	305	45
	LW602B	2435	305	45
	LW603	2655	305	45
	LW604	2435	305	45
	LW605	1160	305	45

It is noted that the northern part of LW512 has an overall void width of 305 m, with the last 800 m of extraction (i.e. southern end) reducing to an overall void width of 205 m. The void width of LW512 is narrowed at the southern end to reduce the potential impacts along Donalds Castle Creek, as described in Sections 3.8.1 and 5.4. Similarly, coal blocks have been provided in LW506 to LW508, LW601 and LW602 to reduce the likelihood of potential impacts on the selected stream features, as described in Sections 3.8.2 and 5.6.

The lengths of longwall extraction excluding the installation headings are approximately 9 m less than the overall void lengths provided in Table 1.2. The longwall face widths excluding the first workings are typically 295 m, except for the southern 800 m of LW512 which has a longwall face width of 195 m.

The mining in Area 3C has been approved and will be the subject of separate Subsidence Management Plan applications. The predicted mine subsidence movements for the proposed longwalls in Area 3C have been included in this report, so that the impact assessments for the natural and built features considered the cumulative movements from all current and future mining areas. The currently proposed longwalls in Area 3C have overall void lengths varying between 840 m and 2310 m, overall void widths of 255 m and 305 m and chain pillar widths of 45 m.

1.3. Surface and seam levels

The surface level contours are shown in Drawing No. MSEC856-03, in Appendix E. The proposed longwalls are located beneath the undulating land between the larger streams and lakes. The proposed longwalls in Area 5 are located to the east of Lake Avon and the Avon River and to the west of Donalds Castle Creek. The proposed longwalls in Area 6 are located to the east of the Cordeaux River and to the north of Lake Cordeaux.

The surface elevations directly above the proposed longwalls vary between 295 metres above Australian Height Datum (mAHD) and 440 mAHD in Area 5, and between 285 mAHD and 370 mAHD in Area 6.

The longwalls in Area 5 are proposed to be extracted in the Bulli Seam. The seam floor contours, seam thickness contours and depth of cover contours for the Bulli Seam are shown in Drawings Nos. MSEC856-04, MSEC856-05 and MSEC856-06, respectively.

The depths of cover above the proposed longwalls in Area 5 vary between a minimum of 250 m in the southern part of the mining area and a maximum of 390 m in the north-eastern part of the mining area. The average depth of cover within the mining area is 360 m. The thickness of the Bulli Seam varies between 2.1 m and 3.2 m within the extents of the proposed longwalls.

The longwalls in Area 6 are proposed to be extracted in the Wongawilli Seam. The seam floor contours, seam thickness contours and depth of cover contours for the Wongawilli Seam are shown in Drawings Nos. MSEC856-07, MSEC856-08 and MSEC856-09, respectively.

The depths of cover above the proposed longwalls in Area 6 vary between a minimum of 375 m in the south-western part of the mining area and a maximum of 460 m in the north-eastern part of the mining area. The average depth of cover within the mining area is 440 m.

The Wongawilli Seam is nominally 10 m thick and contains numerous bands of non-coal material. The economic section of the Wongawilli Seam is the basal 3 m to 5 m. IC has reviewed the nature of the banding in Area 6 and propose to extract a height of 3.9 m using conventional longwall mining techniques.

A summary of the target seams, the seam thickness and proposed mining heights for the proposed longwalls in Areas 5 and 6 is provided in Table 1.3. The proposed longwalls in Area 5 will extract the full thickness of the Bulli Seam. The proposed longwalls in Area 6 will extract a thickness of 3.9 m in the basal section of the Wongawilli Seam.

Table 1.3 Seam thicknesses and proposed mining heights

Area	Target seam	Seam thickness (m)	Mining height (m)
Area 5	Bulli	2.1 to 3.2	2.5 to 3.2
Area 6	Wongawilli	Nominally 10	3.9

The natural surface and the levels of the Bulli Seam in Area 5 are illustrated along Cross-sections 1 and 2 in Fig. 1.3 and Fig. 1.4, respectively. The natural surface and the levels of the Wongawilli Seam in Area 6 are illustrated along Cross-sections 3 and 4 in Fig. 1.5 and Fig. 1.6, respectively. These cross-sections have been taken through the proposed longwalls in each of the respective mining areas, as shown in Drawings Nos. MSEC856-03 to MSEC856-09, in Appendix E.

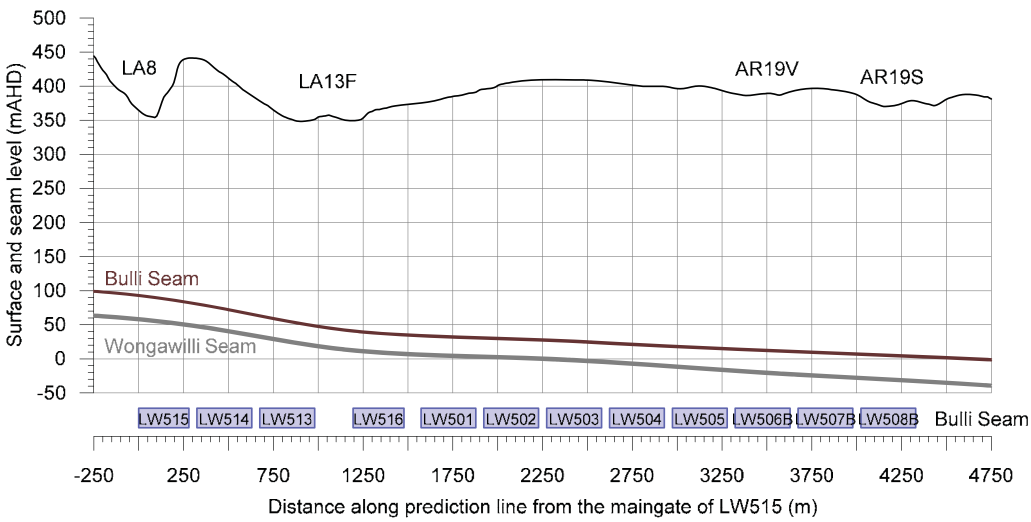

Fig. 1.3 Surface and seam levels along Cross-section 1 through the longwalls in Area 5

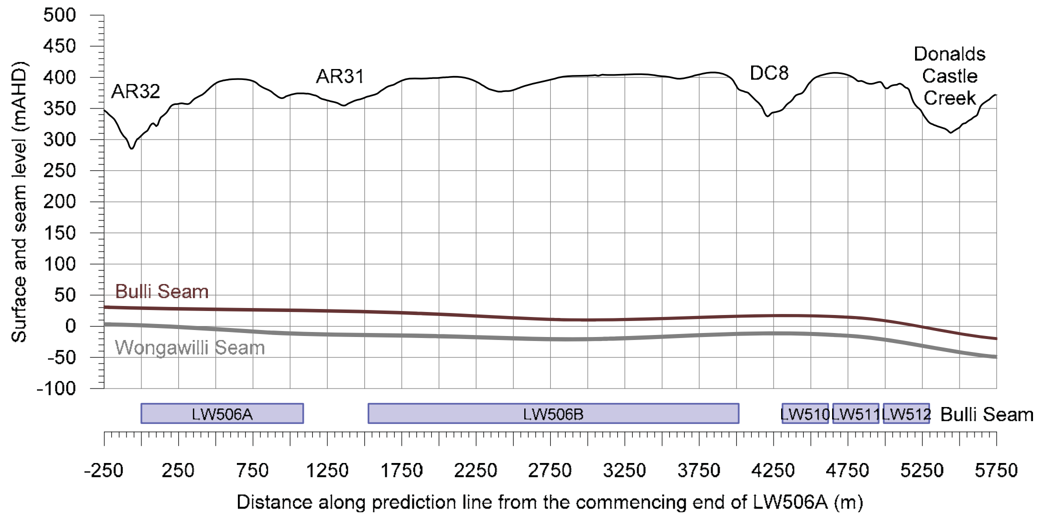

Fig. 1.4 **Surface and seam levels along Cross-section 2 through the longwalls in Area 5**

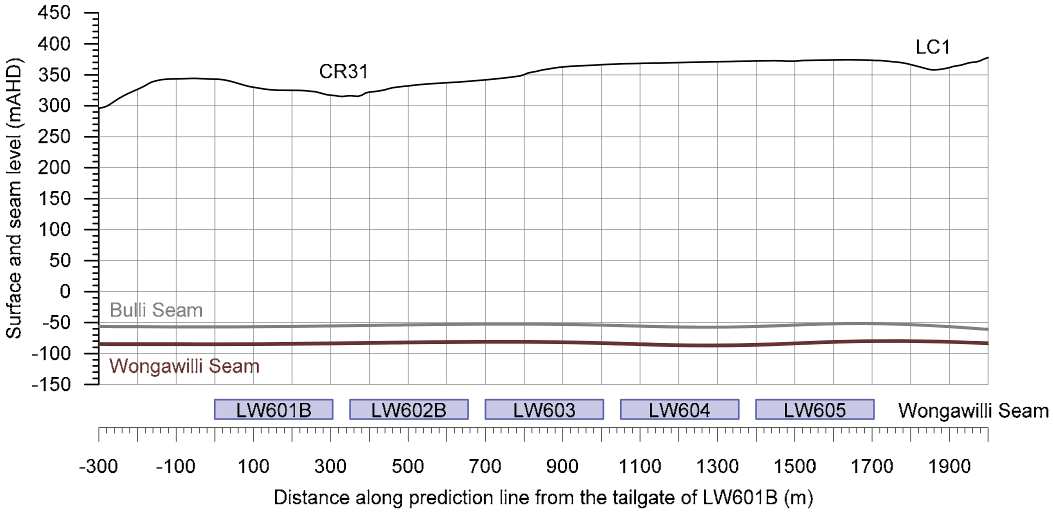

Fig. 1.5 **Surface and seam levels along Cross-section 3 through the longwalls in Area 6**

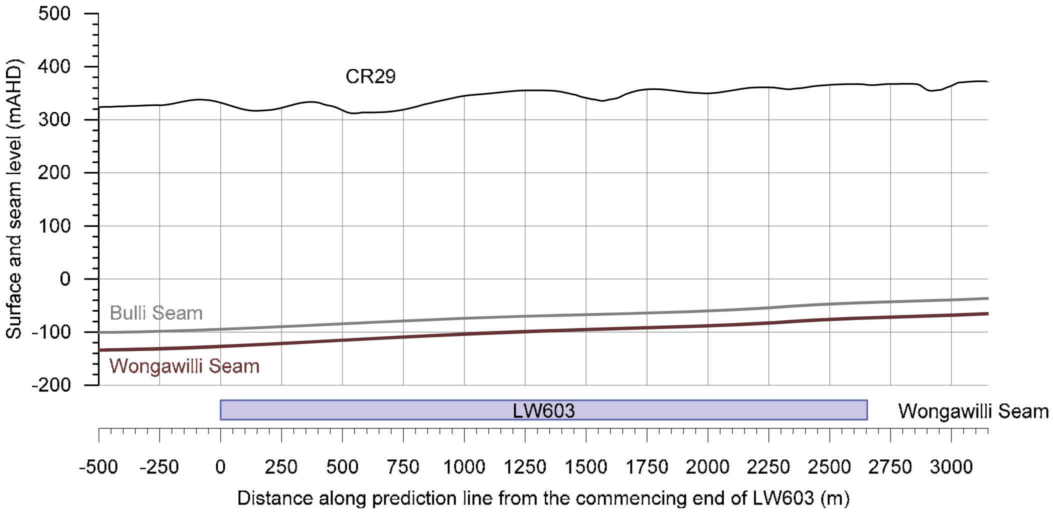

Fig. 1.6 **Surface and seam levels along Cross-section 4 through the longwalls in Area 6**

The Bulli Seam generally dips towards the north in Area 5, with an average grade of approximately 1 % (i.e. 1 in 100) over the mining area. The Wongawilli Seam generally dips towards north-north-west in Area 6, with an average grade of approximately 2 % (i.e. 1 in 50) over the mining area.

1.4. Geological details

The Mine is located in the southern part of the Sydney Basin. The landform is hilly and the region is crossed by the Avon River, the Cordeaux River and their associated creeks and tributaries. The geology mainly comprises sedimentary sandstones, shales and claystones of the Permian and Triassic Periods, which have been intruded by igneous sills. A typical stratigraphic section for Areas 5 and 6 at the Mine is provided in Fig. 1.7 (Source: IC).

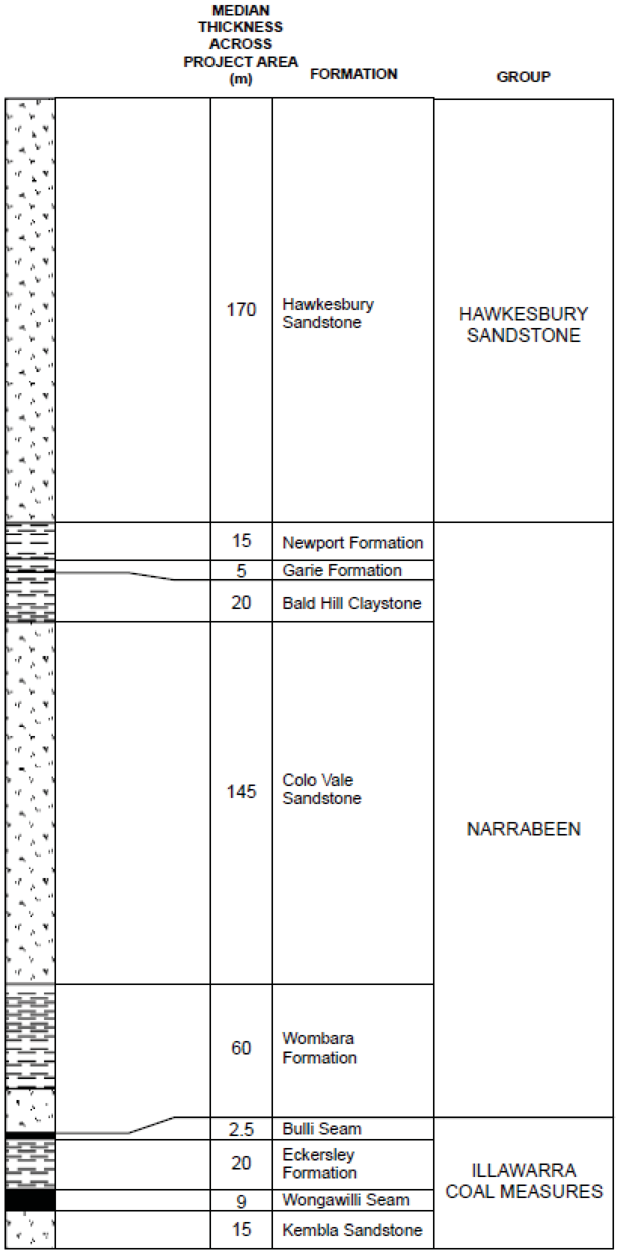

Fig. 1.7 Typical stratigraphic section for the Mine (Source: IC)

The major sedimentary units at the Mine are, from the top down, the Hawkesbury Sandstone, the Narrabeen Group and the Illawarra Coal Measures. The Wianamatta Group is only present as a very limited overlying residual in localised areas.

Hawkesbury Sandstone is the largest member in the overburden, with an average thickness of approximately 170 m within Areas 5 and 6 at the Mine. The Narrabeen Group contains the Newport Formation (sometimes referred to as the Gosford Formation), Garie Formation, Bald Hill Claystone, Colo Vale Sandstone (also referred to as Bulgo Sandstone), and the Wombarra Formation comprising Stanwell Park Claystone, Scarborough Sandstone, Wombarra Shale and Coalcliff Sandstone.

The Bulli Seam is the top unit in the Illawarra Coal Measures. The interval between the Bulli Seam and the Wongawilli Seam is known as the Eckersley Formation which consists of sandstones, shales and minor coal seams. The longwalls are proposed to be extracted from the Bulli Seam in Area 5 and from the Wongawilli Seam in Area 6 at the Mine.

The major claystone units are the Bald Hill and Stanwell Park Claystones that lie above and below the Colo Vale Sandstone and at the base of the Hawkesbury Sandstone. The Wombarra Shale will be located within the collapsed zone above the proposed longwalls.

The Mine sits at the southern end of the Nepean/Kurrajong Fault and Lapstone Monocline system. The area is therefore imprinted with the north-westerly trending structures that connect to these large scale geological features to the north. The large north-west and north-north-west displacement faults are the primary deformational set in the area. However, these faults trend north-east in the coastal fault zone. The geological structures identified within Areas 5 and 6 are shown in Drawings Nos. MSEC856-10 and MSEC856-11.

Igneous sills have intruded into the coal seams in parts of Area 5. The inferred cinder zone in the Bulli Seam extends into the eastern ends of the proposed LW501, LW513 and LW516 and the southern ends of the proposed LW510 to LW512. The inferred cinder zone in the Wongawilli Seam partially extends across the proposed mining area. However, the longwalls in Area 5 are proposed to be extracted from the overlying Bulli Seam.

There is a north-north-east to south-south-west trending fault that crosses the proposed LW501 to LW508B and LW513 to LW516. Two dykes also extend through the proposed LW508A and LW509. The locations of these structures will be better defined through the ongoing investigations and the development of the first workings. A series of north-north-west to south-south-east trending faults are located east of the proposed longwalls in Area 6. There are also east-west trending dykes located to the south of Area 6.

There are no other major faults or other geological structures that have been identified within the extents of the proposed longwalls in Areas 5 and 6. The identification of geological structures in the area will be continually refined based on the ongoing investigations and the development of first workings. The proposed mining layouts will be reviewed based on this updated geological information and, if required, will be modified to avoid the major geological features.

The surface lithology in the area can be seen in Fig. 1.8, which shows the longwalls and the Study Area overlaid on the Geological Map *Bargo 9029-3-N*, which was published by the DMR (1988), now known as the Resource Regulator. The surface lithology in Areas 5 and 6 generally comprises Hawkesbury Sandstone (Rh), with localised areas of Quaternary Alluvium (Qs).

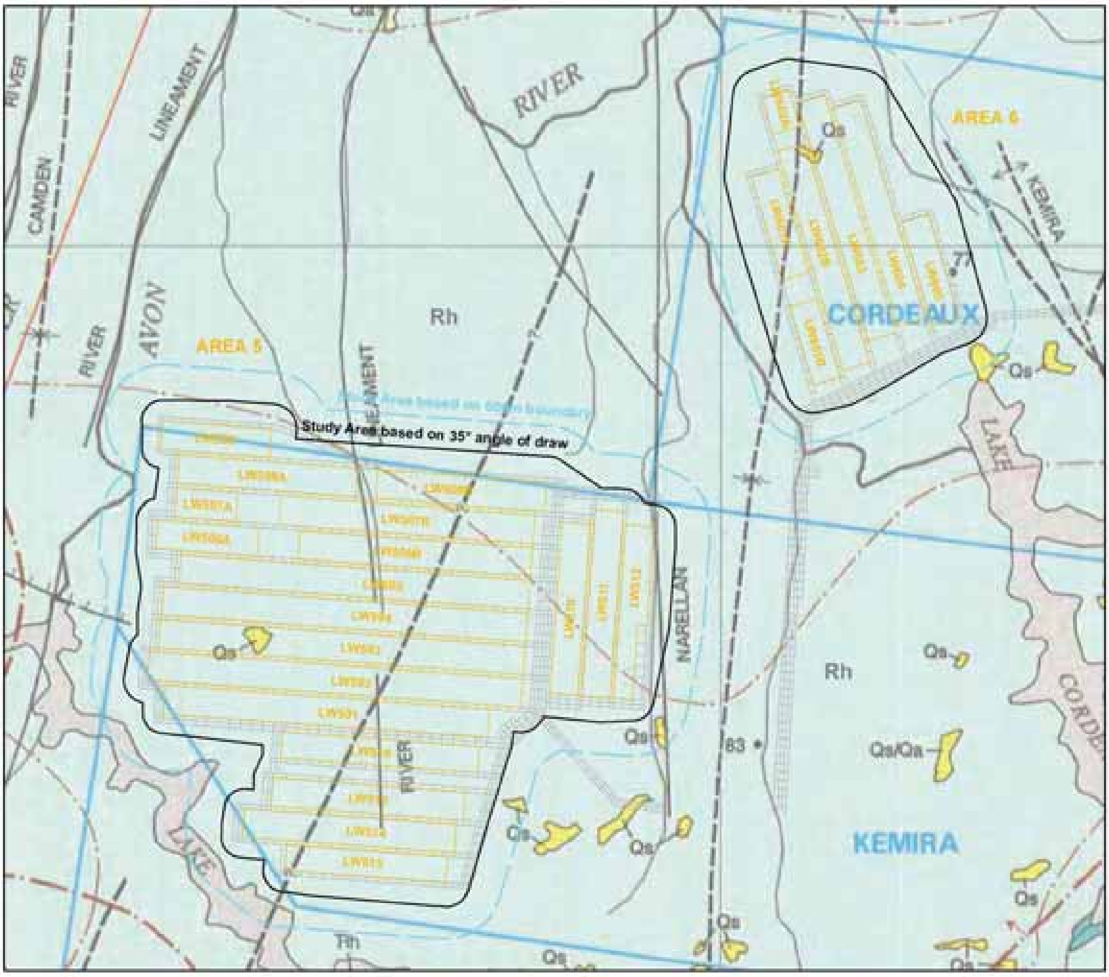

Fig. 1.8 The proposed longwalls overlaid on Geological Map *Bargo 9029-3-N* (DMR, 1988)

2.1. Definition of the Extent of the Longwall Mining Area

The *Extent of the Longwall Mining Area* is defined as the maximum extents of the longwalls (i.e. second workings) that are shown in Drawing No. MSEC856-01.

2.2. Definition of the Study Area

The *Study Area* is defined as the surface area that could be affected by the mining of the proposed longwalls in Areas 5 and 6 at the Mine. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:

- A 35° angle of draw from the extents of the proposed longwalls in Areas 5 and 6;
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, resulting from the extraction of the proposed longwalls;
- Features that could experience far-field or valley related movements and could be sensitive to such movements; and
- The natural features located within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d) of the Dendrobium Mine Development Consent.

The depths of cover contours are shown in Drawing No. MSEC856-06 for the Bulli Seam and in Drawing No. MSEC856-09 for the Wongawilli Seam. It can be seen from these drawings, that the depths of cover directly above the proposed longwalls vary between 250 m and 390 m in Area 5 and between 375 m and 460 m in Area 6. The 35° angle of draw, therefore, has been determined by drawing a line that is a horizontal distance varying between 175 m and 320 m around the limits of the secondary extraction areas.

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, has been determined using the calibrated Incremental Profile Method, which is described in Chapter 3. The predicted subsidence contours, including the 20 mm subsidence contour, is shown in Drawing No. MSEC856-22, in Appendix E. The predicted 20 mm subsidence contour is entirely located within the 35° angle of draw.

The Study Area based on the 35° angle of draw is shown in Drawings Nos. MSEC856-01 to MSEC856-21, in Appendix E. The Study Area based on a 600 m boundary around the extents of the proposed longwalls is also shown in those drawings. The features that are located within the 600 m boundary that are predicted to experience valley related movements and could be sensitive to these movements have been included in the assessments provided in this report. These features include the streams and valley infill swamps.

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

2.3. Natural and built features within the Study Area

The major natural and built features within the Study Area can be seen in the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA), called *Avon River 9029-3-S*. The proposed longwalls in Areas 5 and 6 and the Study Area have been overlaid on an extract of this CMA map in Fig. 2.1.

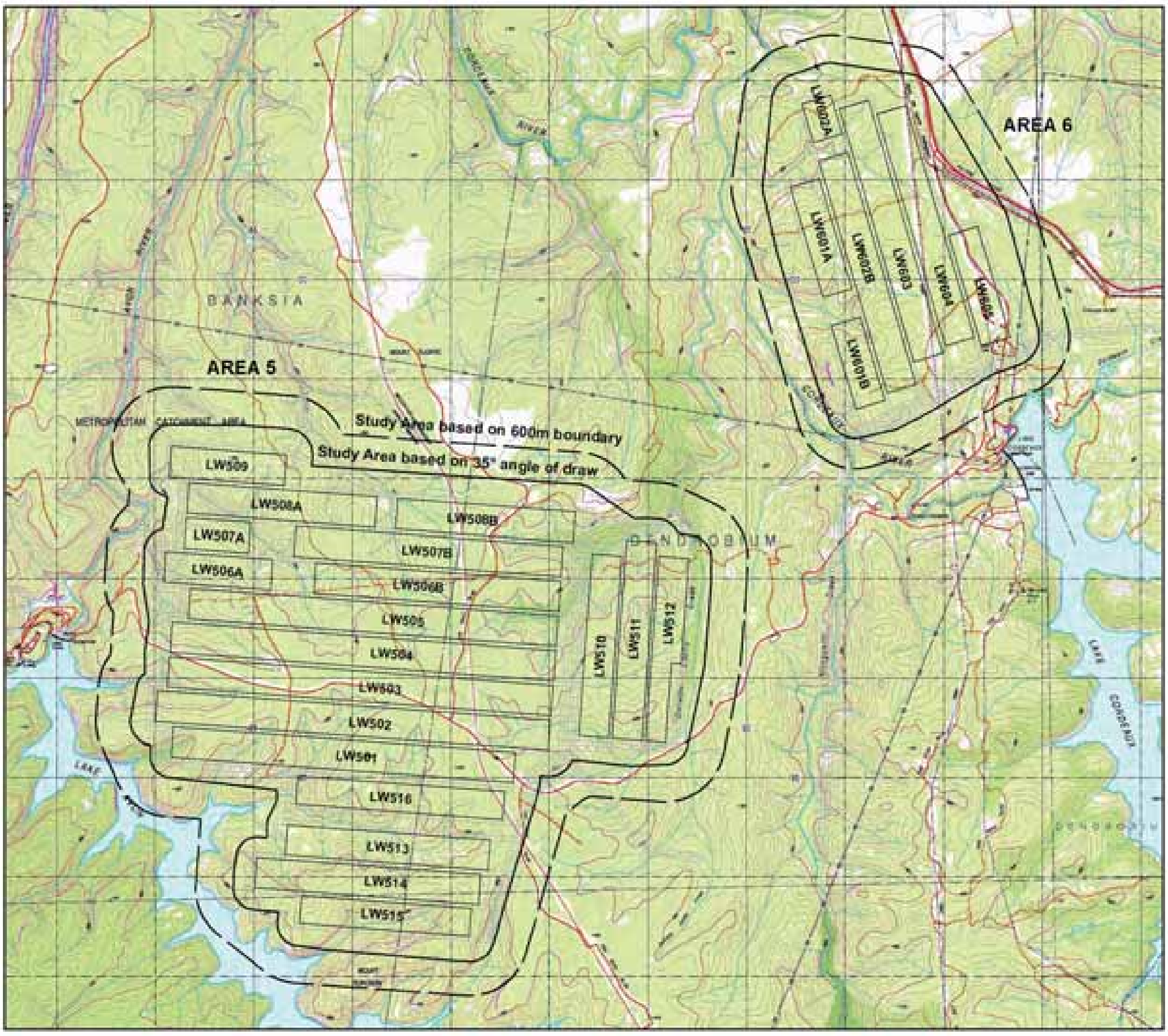

Fig. 2.1 Proposed longwalls overlaid on CMA Map *Avon River 9029-3-S*

A summary of the natural and built features located within the Study Area is provided in Table 2.1. The locations of these features are shown in Drawing Nos. MSEC856-12 to MSEC856-21, in Appendix E. The descriptions, predictions and impact assessments for the natural and built features are provided in Chapters 5 and 6. The section number references are provided in Table 2.1.

Table 2.1 Natural and built features within the Study Area

Item	Within Study Area	Section number reference
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	✓	5.1
Rivers or Creeks	✓	5.2 to 5.6
Aquifers or Known Groundwater Resources	✓	5.7
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.8
Steep Slopes	✓	5.9
Escarpments	×	
Land Prone to Flooding or Inundation	×	
Swamps, Wetlands or Water Related Ecosystems	✓	5.12
Threatened or Protected Species	✓	5.13
National Parks	×	
State Forests	×	
State Conservation Areas	✓	5.14
Natural Vegetation	✓	5.13
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	✓	6.1
Roads (All Types)	✓	6.2 & 6.3
Bridges	×	
Tunnels	×	
Culverts	✓	6.3
Water, Gas or Sewerage Infrastructure	✓	6.4
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	✓	6.5 & 6.6
Telecommunication Lines or Associated Plants	✓	6.7
Water Tanks, Water or Sewage Treatment Works	×	
Dams, Reservoirs or Associated Works	✓	6.8
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	×	
Shopping Centres	×	
Community Centres	×	
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	✓	6.12

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

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

3.1. Introduction

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

3.2. Overview of conventional subsidence parameters

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

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

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

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

3.3. Far-field movements

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

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

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

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

3.4. Overview of non-conventional subsidence movements

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

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

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

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

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

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

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

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

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

In this report, non-conventional ground movements are being included statistically in the predictions and impact assessments, by basing these on the frequency of past occurrence of both the conventional and non-conventional ground movements and impacts. The analysis of strains provided in Section 4.4 includes those resulting from both conventional and non-conventional anomalous movements. The impact assessments for the natural and built features, which are provided in Chapters 5 and 6, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

3.4.2. Non-conventional subsidence movements due to steep topography

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

Further discussions on the potential for downslope movements for the steep slopes within the Study Area are provided in Section 5.9.

3.4.3. Valley related movements

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

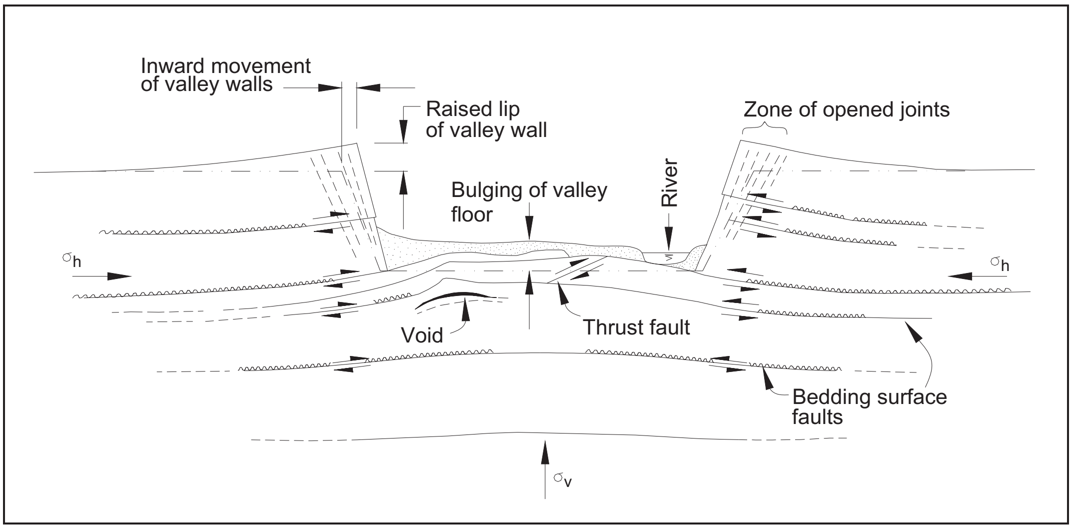

Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

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

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

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

The predicted valley related movements for the streams in the existing and approved mining Areas 2, 3A and 3B at the Mine were determined using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002), referred to as the 2002 ACARP method.

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

The predicted valley closure movements for the streams in Areas 5 and 6 have been determined using both the 2002 and 2014 ACARP methods. The maximum predicted closure movements obtained using these two methods are generally within ±25 %, which is similar to the order of accuracy of the predictive methods. The predicted closure movements obtained using the 2002 and 2014 ACARP methods can vary by more than ±25 %, away from the locations of maxima, due to the differences in how the prediction curves have been drawn over the available data, especially the low-level data well outside of mining.

The predictions based on the 2002 ACARP method can be directly compared with the predictions provided in previous MSEC subsidence reports for Areas 2, 3A and 3B at the Mine and with other case studies. This method has also been more widely used and tested than the more recent 2014 ACARP method. The assessments provided in this report, therefore, have been based on the predictions obtained using the 2002 ACARP method.

The reliability of the predicted valley related closure movements is discussed in Section 3.6.2.

The predicted strains resulting from valley related movements have been determined using the monitoring data for longwalls which have previously mined directly beneath and adjacent to streams in the Southern Coalfield, including at Dendrobium Mine. The predicted valley related strains are discussed with the impact assessments for the streams provided in Chapter 5.

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

3.5. The Incremental Profile Method

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

The database consists of detailed subsidence monitoring data from collieries in NSW including: Angus Place, Appin, Baal Bone, Bellambi, Beltana, Blakefield South, Bulli, Chain Valley, Clarence, Coalcliff, Cooranbong, Cordeaux, Corrimal, Cumnock, Dartbrook, Delta, Dendrobium, Eastern Main, Ellalong, Fernbrook, Glennies Creek, Gretley, Invincible, John Darling, Kemira, Lambton, Liddell, Mandalong, Metropolitan, Mt. Kembla, Munmorah, Nardell, Newpac, Newstan, Newvale, Newvale 2, South Bulga, South Bulli, Springvale, Stockton Borehole, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, United, West Cliff, West Wallsend, and Wyee.

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

Subsidence predictions made using the IPM use the database of observed incremental subsidence profiles, the longwall geometries, local surface and seam information and geology. The method tends to over-predict the conventional subsidence parameters (i.e. is slightly conservative) where the mining geometry and geology are within the range of the empirical database. The predictions can be further tailored to local conditions where observed monitoring data is available close to the mining area.

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

3.6. Calibration of the IPM

The use of the IPM at the Mine has been continually reviewed and refined based on the latest available ground monitoring data.

Initially, the standard model for the Southern Coalfield was used for the predictions in Areas 1, 2 and 3A at the Mine. This standard model is predominately based on the ground monitoring data for mining in the Bulli Seam in the Southern Coalfield.

The model was then calibrated for Area 3B based on the available monitoring data from the Mine at the time of the Subsidence Management Plan Application for LW9 to LW18. The calibration of the model is described in Section 3.6 of Report No. MSEC459 and was based on the monitoring data from LW3 to LW5 in Area 2 and LW6 in Area 3A at the Mine. The initial calibration of the subsidence model is referred to as the '*MSEC459 prediction curves*' in this report.

The calibrated model based on the MSEC459 prediction curves was then later reviewed based on the additional ground monitoring data collected from the Mine, which included LW7 and LW8 in Area 3A and LW9 and LW10 in Area 3B. The review of the calibrated model was discussed in Report No. MSEC792 based on the monitoring data from Areas 2, 3A and 3B.

The mine subsidence movements in Areas 2, 3A and 3B were measured using Airborne Laser Scan (ALS) / Light Detection and Ranging (LiDAR) surveys. The changes in surface level were determined by taking the differences between the measured surface levels before and after the extraction of each longwall.

It was considered that the calibrated IPM based on the MSEC459 prediction curves provided reasonable predictions in Area 2, i.e. LW3 to LW5, based on the ALS surveys. This is not unexpected, as the subsidence prediction method was calibrated using the monitoring data from LW3 to LW5 in Area 2 and LW6 in Area 3B, as described in Section 3.6 of Report No. MSEC459.

However, it was found for LW7 and LW8 in Area 3A and LW9 and LW10 in Area 3B, that the maximum observed vertical subsidence exceeded the predictions, in many locations, with these exceedances being typically up to 1.3 times those predicted. The observed subsidence directly above the tailgate chain pillars for LW7 and LW8 in Areas 3A and LW10 in Area 3B were also greater than predicted.

It was considered that the observed vertical subsidence exceeded that predicted in Areas 3A and 3B due to the higher depths of cover and wider longwall void widths, as compared with those in Area 2. This resulted in pillar compression greater than that predicted by the subsidence model based on the MSEC459 prediction curves. It is also possible that higher subsidence has developed in Area 3B, as the Coal Cliff Sandstone is not present in this area, with higher compression of the overburden occurring within the thicker Wombarra Formation above the chain pillars.

Vertical subsidence predominately develops from two components: sagging of the overburden strata above the longwall voids; and compression of the chain pillars and the immediate seam floor and roof. At higher depths of cover, the component of vertical subsidence due to pillar compression increases, but the component due to sagging of the overburden strata decreases.

The original IPM over-predicted the component of vertical subsidence due to sagging of the overburden and under-predicted the component due to pillar compression. This model therefore provided reliable predictions of vertical subsidence in Area 3A (i.e. lower depth of cover), but the predictions were exceeded in Area 3B (i.e. higher depth of cover).

The subsidence model was then further refined for Area 3B based on the latest available monitoring data from the Mine by increasing the component of vertical subsidence due to pillar compression. This resulted in the maximum predicted incremental subsidence increasing by 30 %. The latest calibration of the subsidence model is referred to as the '*MSEC792 prediction curves*' in this report.

The comparisons between the observed ground movements with those predicted using the calibrated IPM based on the MSEC792 prediction curves are provided in the following sections.

3.6.1. Review of the calibrated model based on the ALS monitoring data

The changes in surface level due to the current mining in Area 3B at the Mine are being measured using ALS and LiDAR surveys. The measured changes in surface level due to the extraction of LW9 to LW13 are shown in Fig. 3.2.

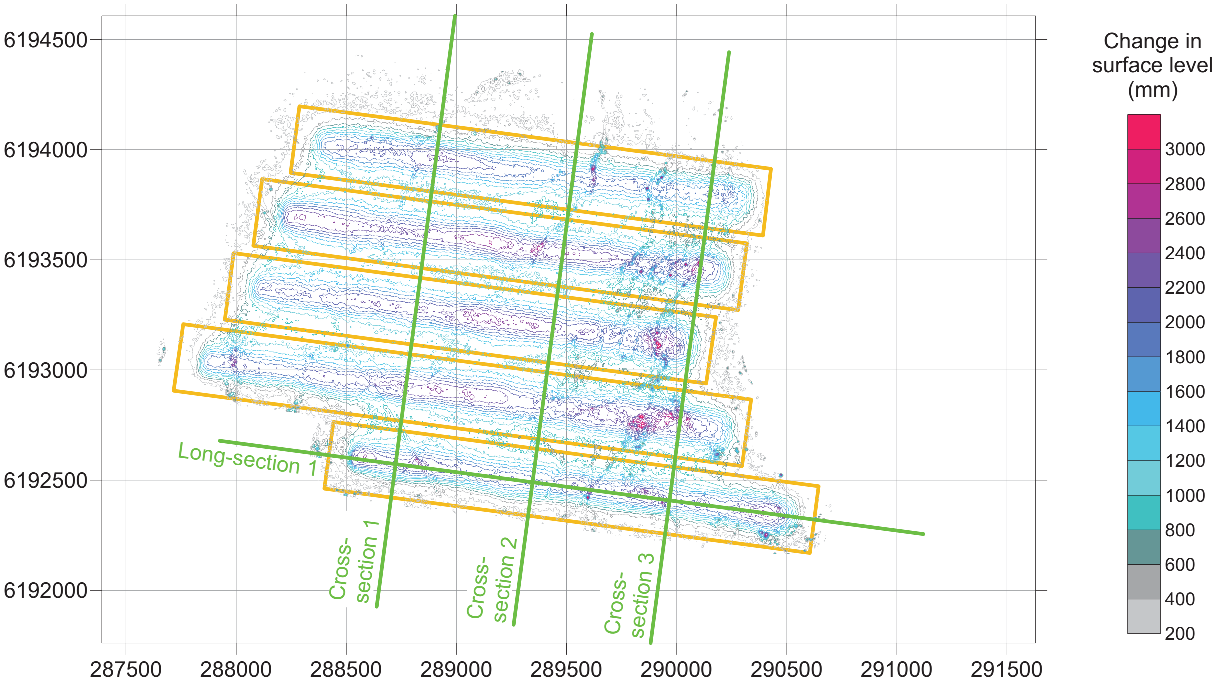

Fig. 3.2 Measured changes in surface level due to LW9 to LW13 in Area 3B

It should be noted that the contours of the measured changes in surface level, developed from the ALS / LiDAR, show the change in the heights of two surfaces defined by multiple points, not necessarily the same points. This differs from traditional subsidence contours that include both the vertical and horizontal components of the surface movements of points fixed to 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 ALS / LiDAR can contain artefacts, 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 a fixed position can be large and do not provide a true indication of the actual subsidence at a point on the ground. 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.

In comparison to traditional remote sensing topographic mapping techniques, ALS / LiDAR generally offers excellent 'vegetation penetration'. Vegetation penetration can be further enhanced by using narrower swathe angles as per the capture specifications used for mine subsidence determination at the Mine. Despite these attributes there are still limitations and ultimately if there are areas where 'light' cannot get to the ground then any optical or ALS / LiDAR system will have limitations in these locations.

The ALS / LiDAR suppliers state that the default vertical accuracy of each ALS / LiDAR dataset is around ±100 mm and, therefore, the expected accuracy of the measured vertical movements (i.e. the difference between two datasets) is around ±200 mm.

The profiles of measured (i.e. green) and predicted (i.e. red) changes in surface level along Cross-sections 1 to 3 and Long-section 1 are illustrated in Fig. 3.3 to Fig. 3.6. The predicted profiles in these figures have been obtained from the calibrated IPM based on the MSEC792 prediction curves. The locations of the sections are shown in Fig. 3.2.

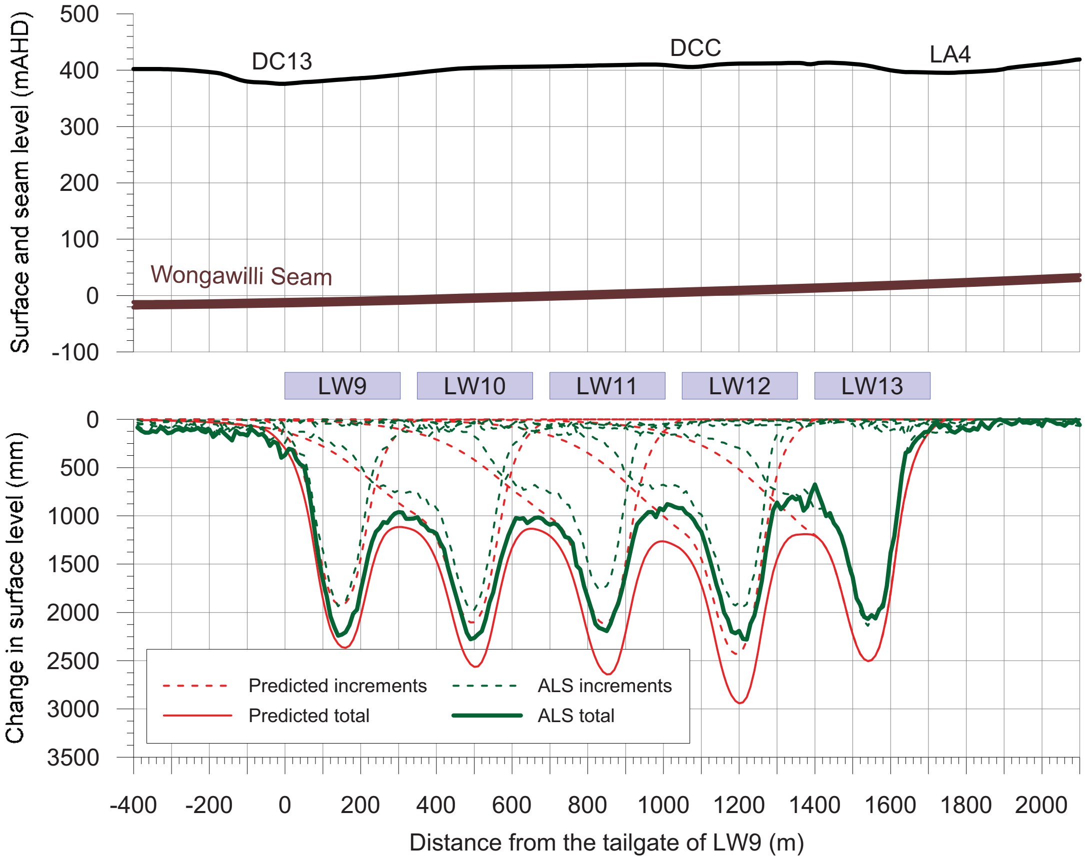

Fig. 3.3 Measured and predicted changes in surface level along Cross-section 1

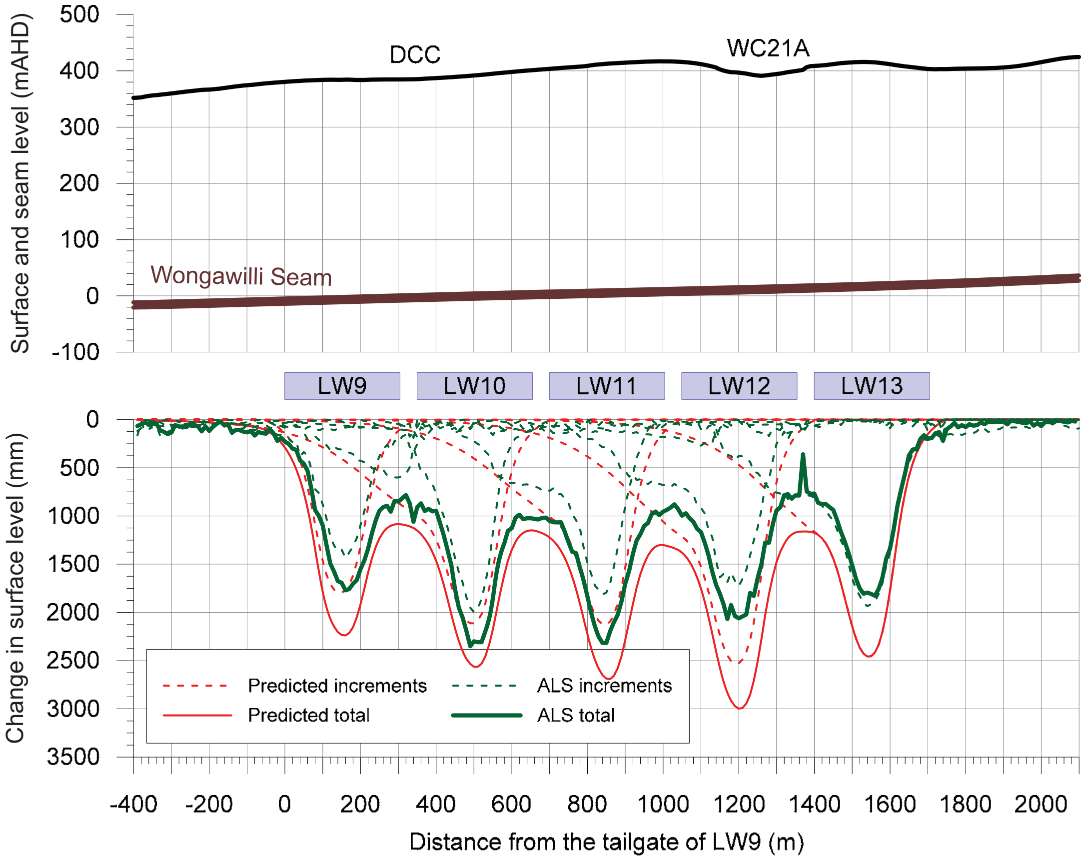

Fig. 3.4 Measured and predicted changes in surface level along Cross-section 2

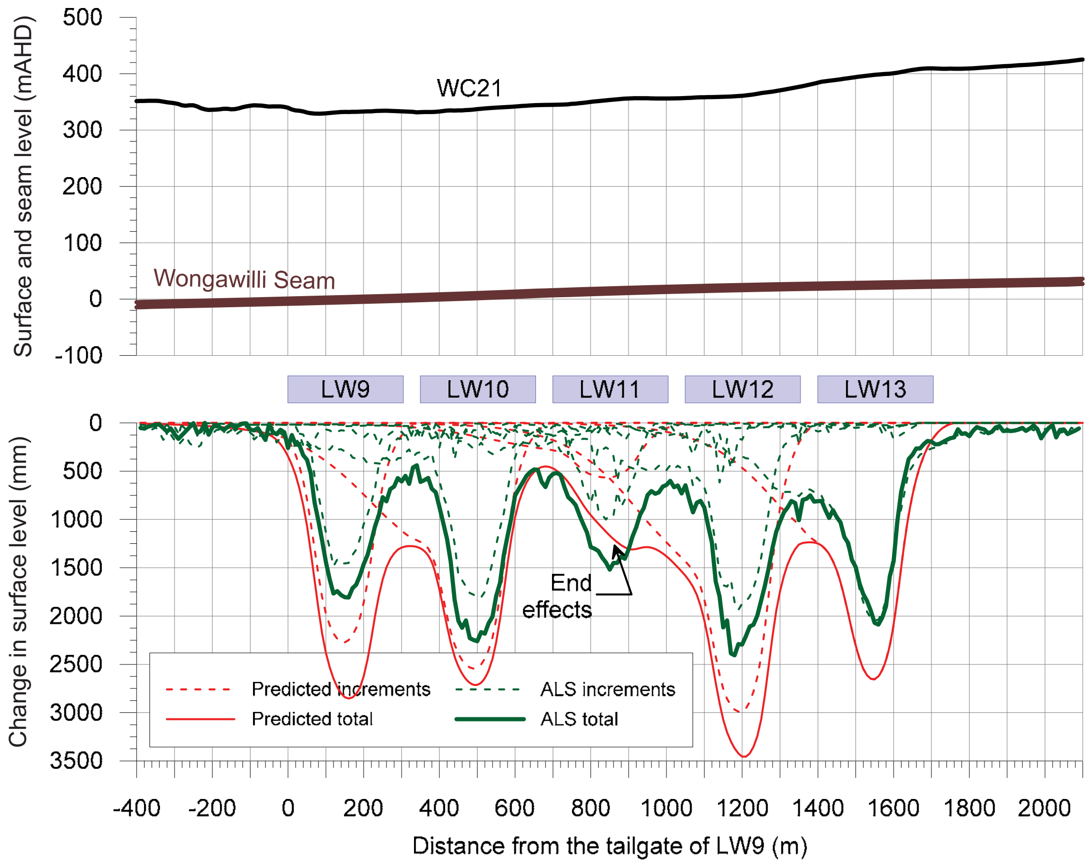

Fig. 3.5 Measured and predicted changes in surface level along Cross-section 3

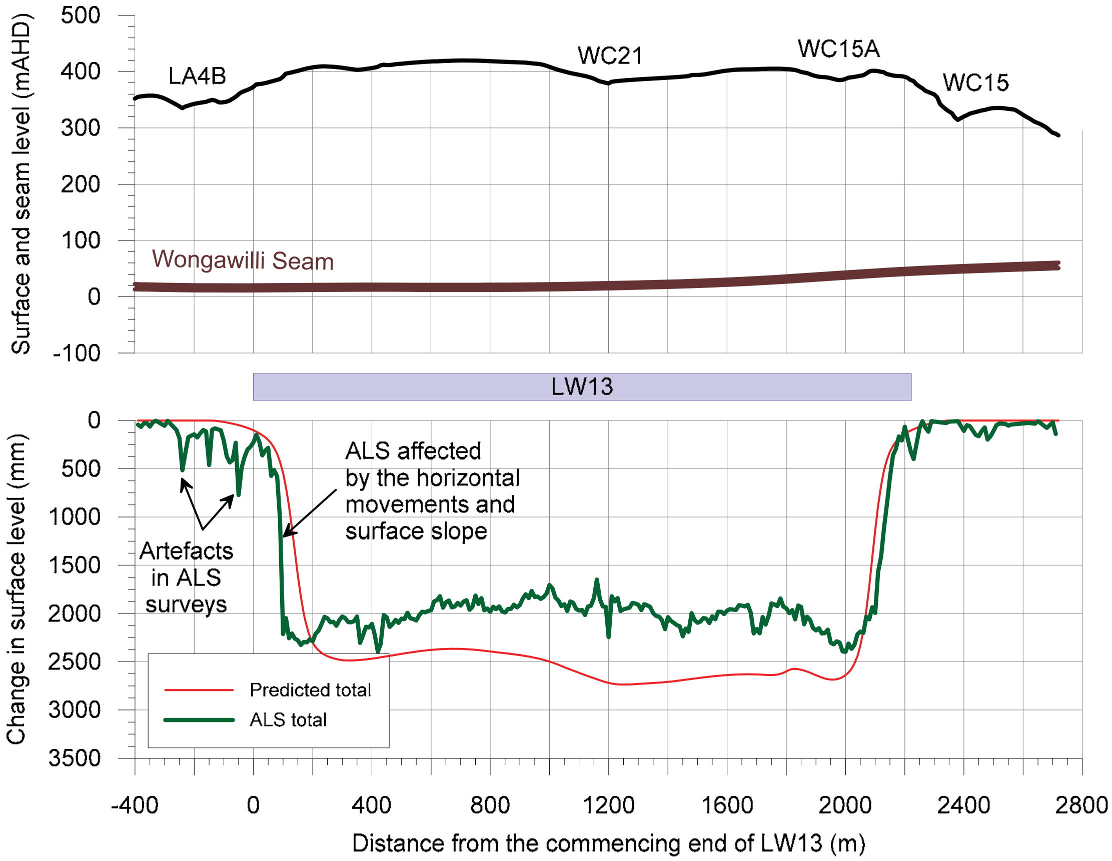

Fig. 3.6 Measured and predicted changes in surface level along Long-section 1

The profiles of the measured changes in surface level reasonably match the predicted profiles of vertical subsidence along each of the cross-sections and long-section. The maximum measured changes in surface level above each of the longwalls are less than the maximum predicted values. Also, the measured changes in surface level above each of the chain pillars are similar to but slightly less than the predicted values in these locations.

The measured change in surface level along Cross-section 3 (refer to Fig. 3.5) is slightly greater than the predicted vertical subsidence above LW11. This cross-section is located close to the finishing end of LW11 and, therefore, the predictions are influenced by the longwall end effects. The difference between the measured and predicted movements are in the order of accuracy of the measurement method.

The measured change in surface level along Long-section 1 (refer to Fig. 3.6) is greater than the predicted vertical subsidence above the commencing end of LW13 (i.e. left side of figure). However, this may be partly due to the effects of the horizontal movements on the LiDAR surveys. The ground directly above the commencing end of LW13 has moved towards the ends (i.e. following the extraction face). The natural surface dips towards the west in this location (i.e. towards the thalweg of LA4B). The mining-induced horizontal movement, therefore, results in the measured changes in level at a fixed position to be greater than the true vertical subsidence above the commencing end of LW13.

There are localised areas outside of the longwalls where the measured changes in surface level exceed the predicted vertical subsidence. However, these are artefacts of the LiDAR surveys and are not real movements.

It can be inferred from the slopes of the profiles, that the measured changes in grade are similar to the predicted tilts along each of the cross-sections and long-section. It is not possible to derive the curvature nor the horizontal movements from the LiDAR surveys.

It is considered that the ground movements measured using the LiDAR surveys are consistent with the predictions based on the calibrated IPM based on the MSEC792 prediction curves.

3.6.2. Review of the calibrated model based on the traditional ground monitoring data

The vertical subsidence and valley closure were monitored during the extraction of LW9 to LW13 in Area 3B using the Wongawilli Creek Closure Lines, Tributary Cross Lines, Donalds Castle Creek Cross Lines and Swamp Cross Lines.

The comparisons of the measured and predicted total vertical subsidence for the traditional ground monitoring lines at the completion of LW13 are illustrated in Fig. 3.7. The measured versus the predicted values are shown on the left side of this figure. The ratios of the measured to predicted values (for magnitudes greater than 50 mm) are shown on the right side of this figure. The predictions are based on the re-calibrated subsidence model using the MSEC792 prediction curves.

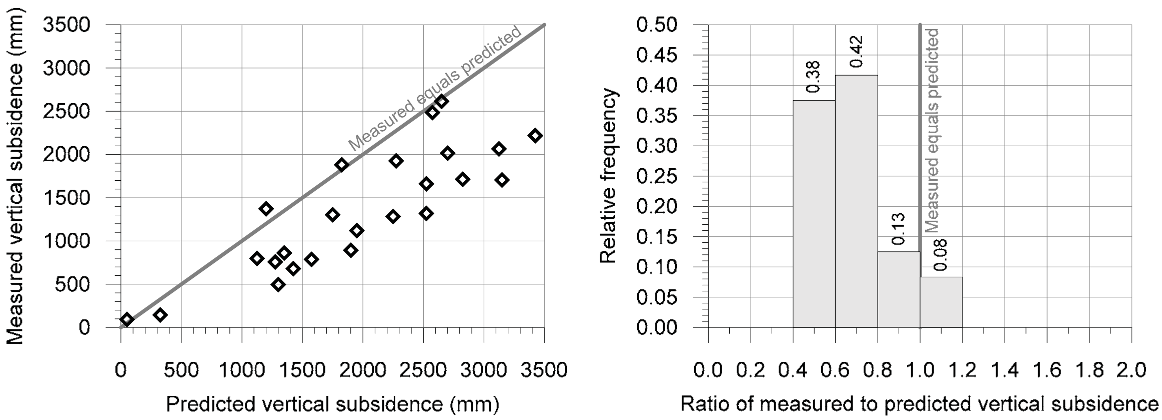

Fig. 3.7 Comparison of measured and predicted subsidence for the ground monitoring lines

The measured total vertical subsidence movements are typically less than the predicted total vertical subsidence values for each of the monitoring lines. The average ratio of the measured to predicted vertical subsidence for these monitoring lines is 0.70.

The measured total vertical subsidence movements exceed the predicted values in three of the 24 cases (i.e. 13 % of the monitoring lines). The exceedances occur where the monitoring lines are located near to or above the chain pillars and the measured movements are less than the maxima that occur directly above the longwalls. The ratios of the measured to predicted total vertical subsidence for these three monitoring lines range between 1.05 to 1.17 and, therefore, are within the order of accuracy of the predictive method for vertical subsidence of ±15 % to ±25 %.

The comparisons of the measured and predicted total closure for the traditional ground monitoring lines at the completion of LW13 are illustrated in Fig. 3.8. The measured versus the predicted values are shown on the left side of this figure. The ratios of the measured to predicted values (for magnitudes greater than 50 mm) are shown on the right side of this figure. The predictions are based on the 2002 ACARP method.

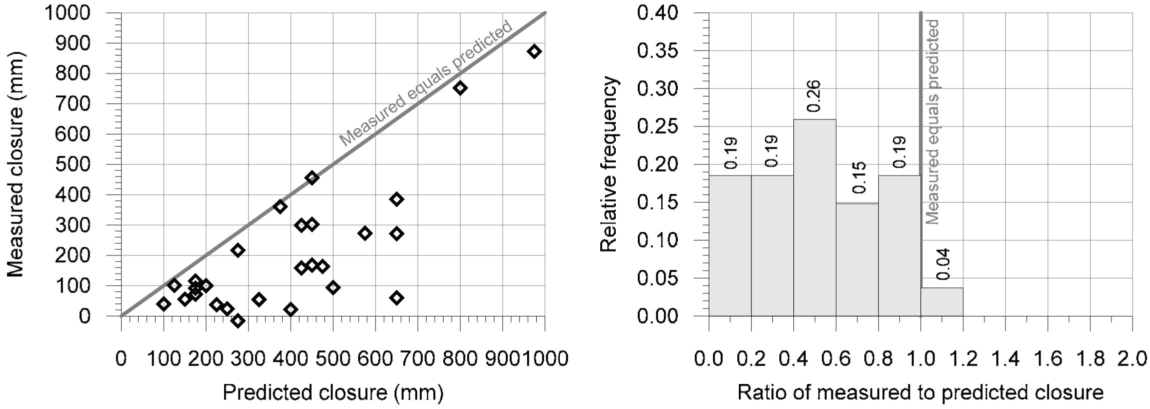

Fig. 3.8 Comparison of measured and predicted closure for the ground monitoring lines

The measured total closure movements are typically less than the predicted total closure values for each of the monitoring lines. The average ratio of the measured to predicted total closure for these monitoring lines is 0.50, i.e. the measured closures are, on average, around half of those predicted.

The measured total closure movements exceed the predicted values in one of the 28 cases (i.e. 4 % of the monitoring lines). It is noted that there were two additional cases where the measured closures exceeded the predicted values at the completion of LW12. However, the measured closures for these two cases were less than the predicted values after the completion of LW13. The ratio of the measured to predicted total closure for the remaining monitoring line is 1.03 and, therefore, is within the order of accuracy of the predictive method for valley closure of ±15 % to ±25 %.

It is considered that the calibrated prediction model based on the MSEC792 prediction curves provides adequate predictions of vertical subsidence and valley closure based on the available ground monitoring lines. The measured movements can be greater than the predicted values, in some cases, but these exceedances are expected to be within the orders of accuracy of the predictive methods of ±15 % to ±25 %.

3.6.3. Use of the calibrated IPM at Dendrobium Mine

The calibrated IPM based on the MSEC792 prediction curves has been used for the proposed longwalls in Areas 5 and 6 at the Mine, as well as the approved mining in the adjacent Area 3C.

The longwalls in Area 5 are proposed to be extracted from the Bulli Seam. The depths of cover in this mining area vary between 250 m and 390 m, with an average of approximately 360 m above the proposed longwalls. The range of depths of cover is similar to that for LW9 and LW10 in Area 3B, which vary between 330 m and 410 m, with an average of approximately 390 m. Similarly, the width-to-depth ratios for the proposed longwalls in Area 5 are similar to those for LW9 and LW10.

The thickness of the Bulli Seam in Area 5 varies between 2.1 m and 3.2 m within the extents of the proposed longwalls. This is considerably less than the thickness of the Wongawilli Seam in Area 3B, which is nominally 10 m thick.

The mine subsidence movements for the proposed longwalls in Area 5, therefore, are expected to be closer to those predicted based on the standard IPM based on the Bulli Seam prediction curves. However, the MSEC792 prediction curves have been conservatively adopted for these proposed longwalls, which is likely to over-predict the component of subsidence due to pillar compression.

The 30 % increase in the incremental vertical subsidence has not been applied for the proposed longwalls in Area 5, as this would result in a maximum total vertical subsidence of 83 % of the seam thickness. This would provide overly conservative predictions based on the extensive experience of longwall mining in the Bulli Seam that shows that the maximum achievable vertical subsidence is 65 % for single-seam mining conditions. The maximum predicted total vertical subsidence in Area 5 based on the MSEC792 prediction curves and, excluding the 30 % increase in incremental vertical subsidence, is 64 % of the seam thickness.

The longwalls in Area 6 are proposed to be extracted from the Wongawilli Seam. The depths of cover in this mining area vary between 375 m and 460 m, with an average of approximately 440 m above the proposed longwalls. The range of depths of cover is similar to but slightly greater than that for LW9 and LW10 in Area 3B. Similarly, the width-to-depth ratios for the proposed longwalls in Area 6 are similar to but slightly less than those for LW9 and LW10.

The thickness of the Wongawilli Seam at the Mine is nominally 10 m thick. IC proposed to extract the basal section of the seam with a working height of 3.9 m in Area 6. The working height in Area 6 is similar to or less than that in Area 3B, which varies between 3.9 m and 4.6 m.

The mine subsidence movements for the proposed longwalls in Area 6, therefore, are expected to be closer to those predicted based on the calibrated IPM based on the MSEC792 prediction curves. The MSEC792 prediction curves, including the 30 % increase in the incremental vertical subsidence, therefore, have been adopted for the proposed longwalls in Area 6.

3.7. Numerical model

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

The UDEC model has been derived from the *base model* that was developed for the Southern Coalfield for mining in the Bulli Seam (Barbato, 2017). The numerical model has been updated for the local stratigraphy (refer to Section 1.4) and has been calibrated for the local mining conditions using the ground monitoring data from Areas 3A and 3B at the Mine.

3.7.1. Calibration of the UDEC model for Dendrobium Mine

The widths of the longwalls in Area 3A are 250 m for LW6 and LW7 and 305 m for LW8. The average depth of cover to the Wongawilli Seam is 370 m. The width-to-depth ratios for these longwalls therefore vary between 0.68 and 0.82. The maximum mining height for the longwalls in Area 3A was 3.9 m.

The widths of the LW9 to LW13 in Area 3B are 305 m. The average depth of cover to the Wongawilli Seam is 390 m. The average width-to-depth ratio for these longwalls therefore is 0.78. The average mining heights at the cross-section considered were 3.5 m for LW9, 4.5 m for LW10 and 4.0 m for LW11 to LW13.

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

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

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

The material and joint properties have been calibrated for the local conditions using the available ground monitoring data for each mining area. The initial calibration of the numerical model using the ground monitoring data from Areas 3A and 3B at the Mine found that the *base model* (i.e. Material Type M1 and Joint Type J2) underpredicted the vertical subsidence above the longwalls and the chain pillars.

The magnitudes and the profiles of vertical subsidence obtained from the numerical model better matched those measured in Area 3A by adopting material bulk and shear moduli and joint cohesions that were 70 % of those used in the *base model*. The magnitudes and profiles better matched those measured in Area 3B by adopting material bulk and shear moduli that were 50 % of those used in the *base model*, with no changes to the joint properties. The differences in the appropriate material and joint properties adopted in the model for Areas 3A and 3B are due to the varying contributions of the components of vertical subsidence due to sagging of the overburden strata and pillar compression.

The comparison between the modelled and measured vertical subsidence are illustrated in Fig. 3.9 for Area 3A and Fig. 3.10 for Area 3B. The measured subsidence is based on the difference between the LiDAR surface levels measured prior to and after the completion of mining in each area.

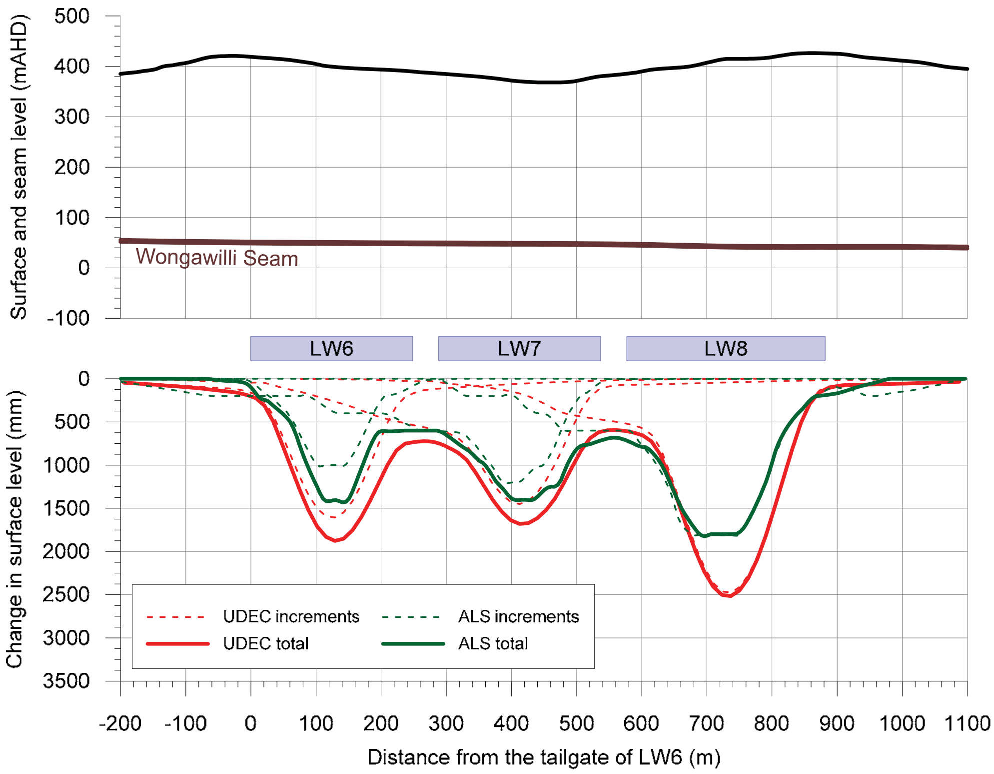

Fig. 3.9 Comparison of modelled and measured subsidence for Dendrobium Area 3A

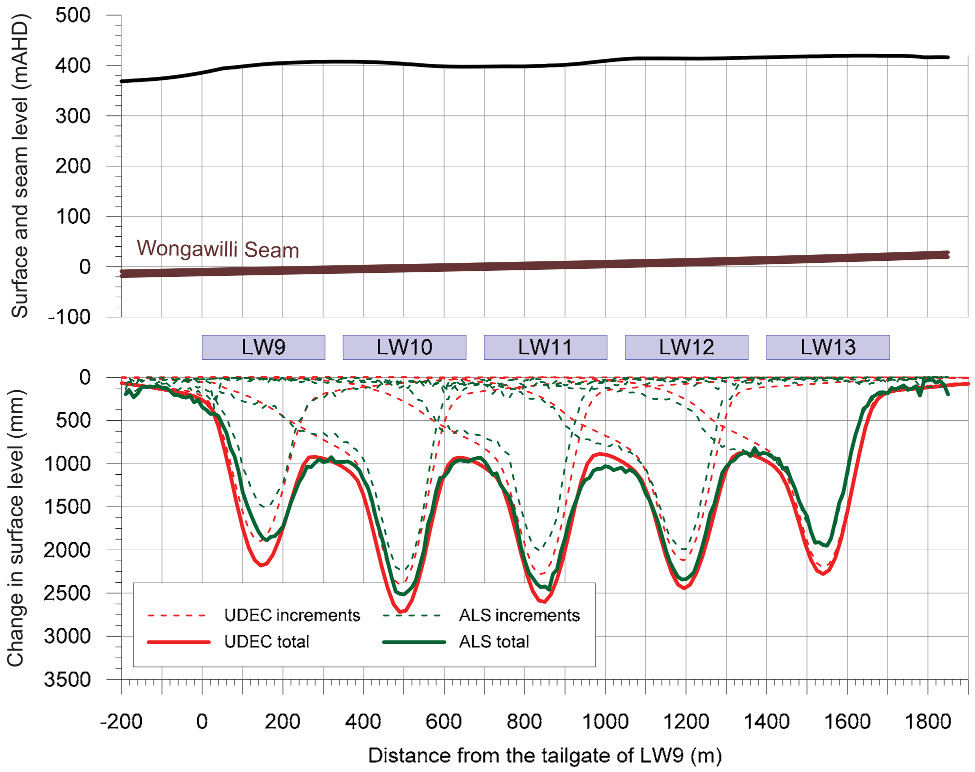

Fig. 3.10 Comparison of modelled and measured subsidence for Dendrobium Area 3B

It is considered that the profiles of vertical subsidence obtained from the UDEC model reasonably match those measured using the LiDAR surveys in Areas 3A and 3B. The numerical model slightly overpredicts the vertical subsidence for Area 3A, whereas there is a better match for Area 3B. The main difference is due to the lower depth of cover and mining height in Area 3A compared to those in Area 3B.

An extensometer was installed above the centreline of LW9. The comparison between the modelled and measured extension in the top 250 m of the overburden at the extensometer site is illustrated in Fig. 3.11.

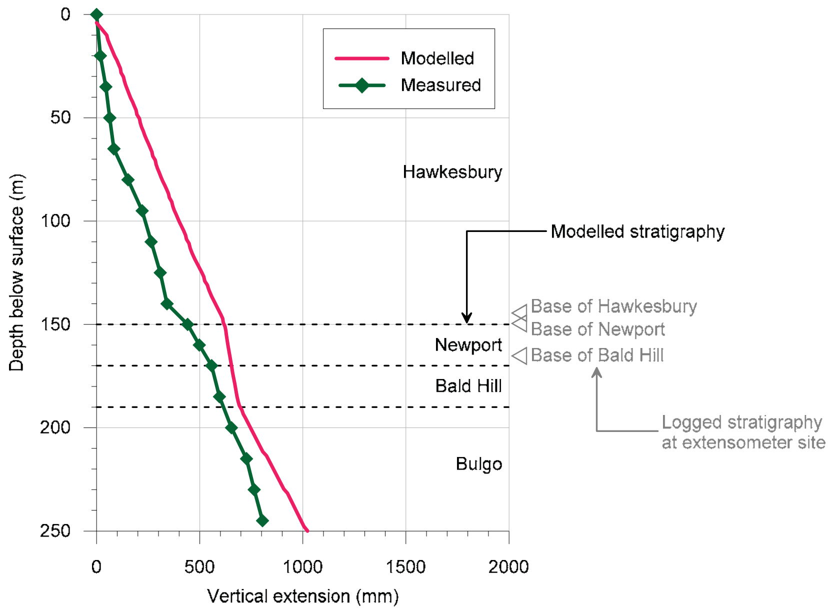

Fig. 3.11 Comparison of modelled and measured extension at the extensometer above LW9

The modelled extension in the top 250 m of the overburden reasonably matches the measured extension at the extensometer above LW9. There are slight differences in the profiles shapes which are partly due to the differences between the modelled and logged stratigraphy at the extensometer site. The total modelled extension is greater than the predicted value, as the UDEC model slightly overpredicts the vertical subsidence above LW9, as illustrated in Fig. 3.10.

The depth of cover and mining height for the proposed longwalls in Area 6 are similar to those in Area 3B. The longwalls in Area 6 and Area 3B are also both located within the Wongawilli Seam. The numerical model should therefore also provide reasonable predictions of vertical subsidence for the proposed longwalls in Area 6.

The proposed longwalls in Area 5 will be extracted from the Bulli Seam. A numerical model has not yet been developed for this area since mining has so far only occurred in the Wongawilli Seam at the Mine and, therefore, there is no local ground monitoring data to review and calibrate the model. It is then noted that the IPM is based on extensive ground monitoring data for mining in the Bulli Seam elsewhere in the Southern Coalfield.

3.7.2. UDEC model for the proposed longwalls in Area 6

The widths of the proposed LW601 to LW605 are 305 m and the solid chain pillar widths are 45 m. The edges of the numerical model have been taken as two times the longwall widths (i.e. 610 m) from the nearest longwall edges. The overall width of the model therefore is 2925 m.

The average depth of cover to the Wongawilli Seam in Area 6 is 440 m. The width-to-depth ratio of each of the proposed longwalls therefore is 0.7. The longwalls in Area 6 are proposed to extract a thickness of 3.9 m in the basal section of the Wongawilli Seam which is approximately 10 m thick.

A summary of the stratigraphy adopted in the UDEC model is provided in Table 3.1. The element sizes have been based on Block Type B1 of the *base model*, with minor adjustments to suit the depths of each stratigraphic unit.

Table 3.1 Stratigraphy adopted in the UDEC model for Area 6

Unit	Thickness (m)	Depth to base on unit (m)	Block size (H x V, m x m)
Hawkesbury Sandstone	170	170	15.0 x 10.0
Newport/Garie Formations	20	190	6.0 x 4.0
Bald Hill Claystone	20	210	6.0 x 4.0
Bulgo Sandstone	150	360	15.0 x 10.0
Wombarra Claystone	57	417	5.7 x 3.8
Bulli Coal	3	420	4.5 x 3.0
Eckersley Formation	20	440	7.5 x 5.0
Wongawilli Coal	10	450	1.5 x 1.0
Sub-Wongawilli	100	550	15.0 x 10.0

Summaries of the material and joint properties adopted in the UDEC model are provided in Table 3.2 and Table 3.3, respectively. The joint normal stiffness and shear stiffness have been taken as 30 GPa/m and 3 GPa/m, respectively. The parameter analysis of the joint stiffness properties found that the numerical model is not sensitive to these two parameters (refer to Section 6.9.4 of Barbato, 2017).

Table 3.2 Material properties adopted in the UDEC model

Unit	Density (kg/m^3)	Bulk modulus (GPa)	Shear modulus (GPa)	Cohesion (MPa)	Friction angle (deg.)	Tensile strength (MPa)
Hawkesbury Sandstone	2400	1.67	1.00	7.0	34	0.5
Newport/Garie Formations	2400	1.73	1.24	4.0	30	0.5
Bald Hill Claystone	2700	2.50	1.16	6.0	25	0.5
Bulgo Sandstone	2500	2.78	2.09	10	30	0.5
Wombarra Claystone	2600	3.45	2.48	10	25	0.5
Bulli Coal	1500	0.77	0.49	2.0	25	0.5
Eckersley Formation	2500	4.0	2.4	15	25	0.5
Wongawilli Coal	1500	0.77	0.49	2.0	25	0.5
Sub-Wongawilli	2500	4.0	2.4	15	25	0.5

Table 3.3 Joint properties adopted in the UDEC model

Unit	Cohesion (MPa)		Friction angle (deg.)	
	Peak	Residual	Peak	Residual
Hawkesbury Sandstone	2.50	1.50	25	15
Newport/Garie Formations	2.25	1.35	24	14
Bald Hill Claystone	2.75	1.65	21	13
Bulgo Sandstone	4.50	2.70	24	14
Wombarra Claystone	3.00	1.80	22	13
Eckersley Formation	4.25	2.55	22	13
Sub-Wongawilli	4.25	2.55	22	13

The modelled profiles of vertical subsidence obtained from the UDEC model for Area 6 are illustrated as the red lines in Fig. 3.12. The predicted profiles based on the IPM have also been shown as the blue lines in this figure for comparison.

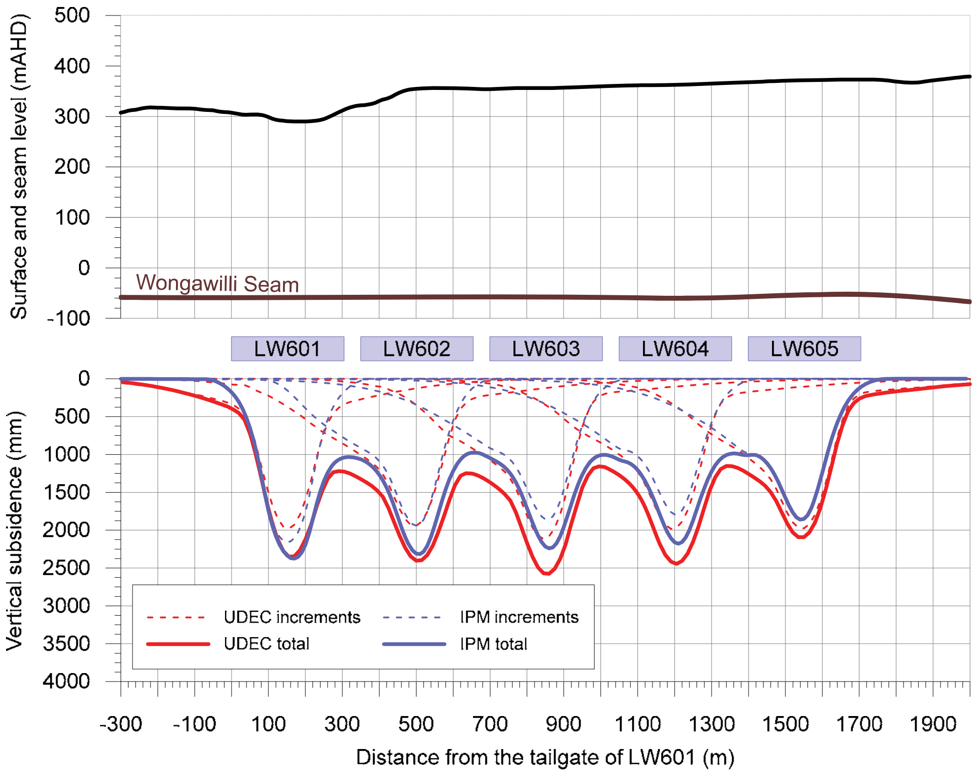

Fig. 3.12 Modelled profiles of vertical subsidence for the proposed LW601 to LW605

The profiles of vertical subsidence obtained from the UDEC model reasonably match those predicted using the IPM. The maximum vertical subsidence directly above each of the proposed longwalls are reasonably similar, with the magnitudes being within ±15 %. The numerical model predicts slightly higher vertical subsidence above each of the chain pillars compared with that obtained from the IPM.

The numerical model also predicts higher subsidence adjacent to the tailgate of LW601 and, to a lesser extent, adjacent to the maingate of LW605. This may be due to the calibration of the model based on Area 3B, where low-level subsidence was measured adjacent to LW9 (refer to Fig. 3.10). However, the accuracy of the measured changes in surface level obtained from the LiDAR surveys is in the order of ±150 mm to ±300 mm. The low-level subsidence measured adjacent to LW9, therefore, could be an artefact in the LiDAR data due to the tolerance of the measurement method.

The maximum predicted tilts and curvatures above LW601 obtained from the UDEC model are slightly less than the maximum predicted values based on the IPM. This is due to the UDEC model predicting a broader (i.e. flatter) subsidence profile above and adjacent to the longwall tailgate compared to that for the IPM.

The predicted tilts and curvatures above the remaining LW602 to LW605 obtained from the UDEC model are similar to the predicted values based on the IPM. The tilts and curvatures are similar for both models above these longwalls as the shapes of the incremental subsidence profiles are reasonable similar.

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

In addition, the potential for impacts on the natural and built features result from the differential movements (i.e. tilt and curvature) rather than from the absolute vertical subsidence. The impact assessments based on the predictions obtained from the UDEC model, therefore, are similar to the assessments based on the predictions obtained from the IPM.

The modelled profiles of vertical subsidence and horizontal movement through the overburden strata are illustrated in Fig. 3.13. The profiles have been taken through the centreline of LW603, midway between the centreline and tailgate (referred to as the quarter point) and at the tailgate of this longwall.

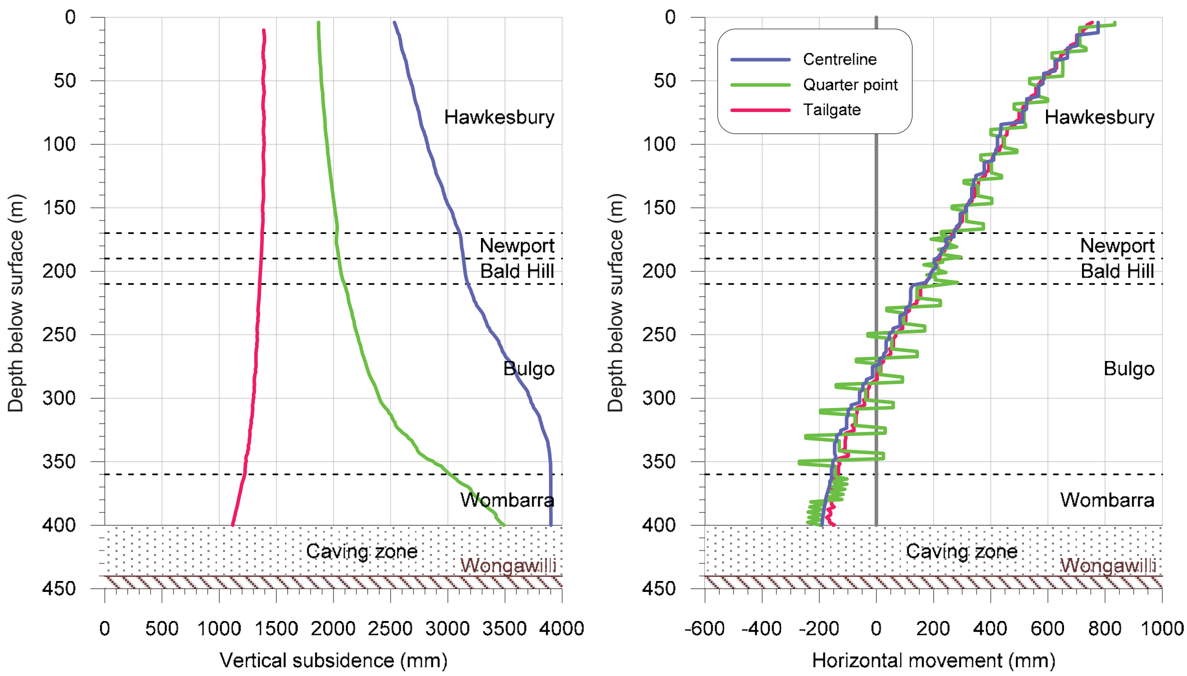

Fig. 3.13 Modelled profiles of vertical subsidence and horizontal movement through the overburden at the centreline, quarter point and tailgate of LW603

The vertical subsidence at the longwall centreline varies between 64 % of the mining height at the surface through to 100 % of the mining heights at the caving zone. The vertical subsidence adjacent to the longwall tailgate is 35 % of the mining height through most of the overburden. There is a slight reduction in vertical subsidence in the bottom part of the overburden due to the vertical dilation of the strata resulting from the rotation of the modelled elements.

The vertical strain (over a 20 m height) within the Hawkesbury Sandstone varies between approximately 2 mm/m at the surface and 5 mm/m at the base of the unit. The maximum vertical strain within the Hawkesbury Sandstone occurs at the longwall centreline with the strains reducing towards the longwall maingate and tailgate.

The vertical strain within the Bulgo Sandstone, at the longwall centreline, varies between approximately 3 mm/m at the top, 7 mm/m near mid-height and 2 mm/m at the base of the unit. The vertical strain at the quarter-points of the longwall vary between approximately 2 mm/m at the top and 16 mm/m at the base of the Bulgo Sandstone.

The vertical strain within the Wombarra Claystone varies between 8 mm/m and 16 mm/m. The maximum vertical strain occurs at the longwall quarter-points with the strains reducing towards the longwall centreline, maingate and tailgate. The vertical strains within the Newport Formation and the Bald Hill Claystone are typically less than 2 mm/m.

The horizontal shear on the bedding plane partings is approximately 100 mm within the Hawkesbury Sandstone and varies between 150 mm and 300 mm within the Bulgo Sandstone. The maximum horizontal shear occurs at the quarter point within the Bulgo Sandstone.

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

3.8. Mine design based on the major streams and critical stream features

The proposed longwalls in Areas 5 and 6 have been designed to minimise the potential impacts on the major streams and the critical stream features. The mine optimisation has been based on the potential for *Type 3* impacts. A Type 3 impact is defined as *fracturing in a rockbar or upstream pool resulting in reduction in standing water level based on current rainfall and surface water flow*.

Type 3 impacts typically occur when a stream is directly mined beneath. However, Type 3 impacts can also occur outside the extents of longwall mining. There have been five areas of Type 3 impacts outside of the previous longwall mining areas at the Mine due to the extraction of LW6 to LW8 in Area 3A and LW9 to LW13 in Area 3B.

A summary of the Type 3 impacts located outside the extents of longwall mining in Areas 3A and 3B at the Mine is provided in Table 3.4.

Table 3.4 Type 3 impacts located outside the extents of longwall mining in Areas 3A and 3B

Stream	Location	Active longwall at the time of impact	Predicted total closure at the time of Type 3 impact (mm)
Donalds Castle Creek	DC-RB33 located 115 m north of the tailgate of LW9	LW9	95
Drainage Line LA4	Rockbar 0A located 290 m south of the maingate of LW12	LW12	165
Wongawilli Creek	Pool 43a located 200 m west of LW6 and 410 m east of LW9	Reduction in standing water level after LW13	165
Drainage Line WC15	Rockbar 18 located 120 m south of the maingate of LW13	LW13	140
	Rockbars 0 and 1 located 250 m east of the finishing end of LW13	LW13	155

These Type 3 impacts occurred in the larger streams (i.e. Donalds Castle and Wongawilli Creeks) and along the lower reaches of the tributaries near the confluence with the larger streams.

3.8.1. Rivers and named creeks

The rivers and named creeks within the Study Area are the: Avon River, Cordeaux River and Donalds Castle Creek. The longwall setbacks from these streams have been determined using the rockbar impact model for the Southern Coalfield, which is described in Section 5.3.4 of Report No. MSEC459.

The rockbar model relates the likelihood of impact on rockbars with the predicted total valley closure along the stream based on the previous longwall mining experience in the Southern Coalfield. The impact model is illustrated in Fig. 3.14.

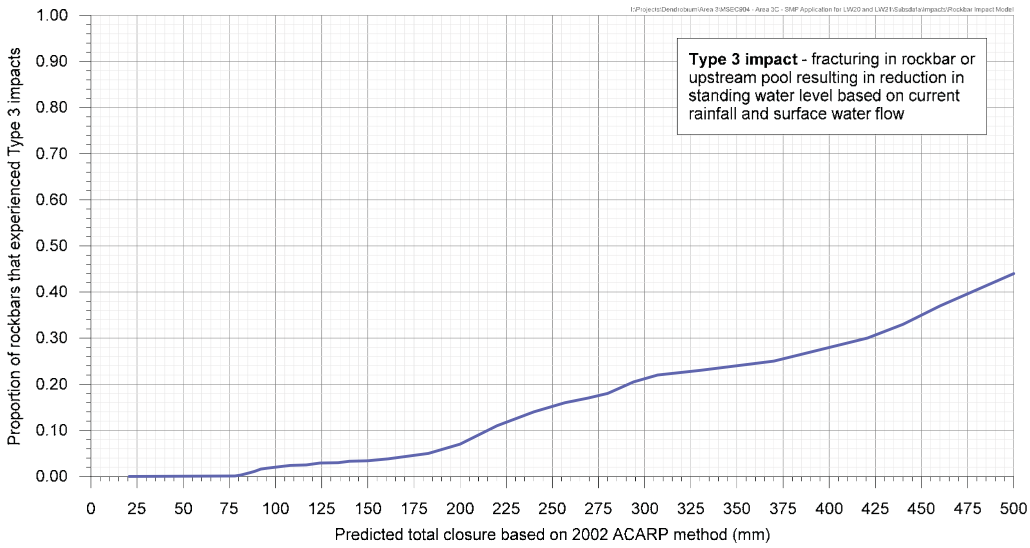

Fig. 3.14 Rockbar impact model for the Southern Coalfield

The rockbar impact model was previously used to setback the longwalls in Areas 3A and 3B from Wongawilli Creek. The longwalls were setback so that the maximum predicted closure along the creek was 200 mm and, therefore, the assessed rate of impact for the pools and channels was less than 10 %.

The extraction of LW6 to LW13 has resulted in one Type 3 impact along Wongawilli Creek, as described in Table 3.4, which was located between LW6 and LW9. The total length of creek located within a distance of 400 m of the as-extracted longwalls is 2 km. The rate of impacts along Wongawilli Creek due to the previous mining, therefore, is considered to be very low.

The proposed longwalls in Areas 5 and 6 have been setback from the Avon River, Cordeaux River and Donalds Castle Creek so that the maximum predicted additional closure is 200 mm. The predicted rate of Type 3 impacts on the rockbars and pools, therefore, is less than 10 % for the sections of the streams located within 400 m of the proposed longwalls.

Type 3 impacts have been observed at distances up to 280 m from the previously extracted longwalls at Dendrobium Mine. Fracturing (without adverse impacts on surface water flows) have been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield. Type 3 impacts are therefore not expected for the sections of the streams that are located more than 400 m from the proposed longwalls in Areas 5 and 6.

Further discussions are provided in the impact assessments for these streams in Sections 5.2 to 5.6.

3.8.2. Unnamed streams

There are many unnamed streams within Areas 5 and 6 that are tributaries to the Avon River, Cordeaux River and Donalds Castle Creek. It is not possible to develop an economically viable longwall layout to avoid all these tributaries. The proposed longwalls have therefore been designed to minimise the likelihood of potential for impacts on the selected stream features.

The unnamed streams in Areas 5 and 6 have been mapped by the IC field team. The selected stream features have been identified based on factors including: rockbar size, pool length, pool width, pool depth, pool volume, step height and waterfall height. The selected stream features in Areas 5 and 6 are outlined in the report by HEC (2019) and have been summarised in Table 5.9 and Table 5.10 in Chapter 5 of this report.

The experience in Area 3B shows that the impacts on pools along the tributaries generally occur after they have been directly mined beneath. However, pools have also been impacted along sections of the tributaries that are located outside of the longwall mining area.

The longwalls in Area 3B have been extracted directly beneath many tributaries. The majority of the data has come from Drainage Line WC21, above the eastern ends of LW9 to LW13, as large sections of the other tributaries within the longwall mining area are confined within the swamps.

The proportion of pools impacted along WC21 versus the distance from the active longwall face is illustrated in Fig. 3.15. The impacts have been grouped into: Type 3A where fracturing has directly resulted in water loss, flow diversion or change in pool water level; and Type 3B where there has been noticeable change in pool water level that is not associated with fracturing in the pool, but rather the changes in surface flow further upstream.

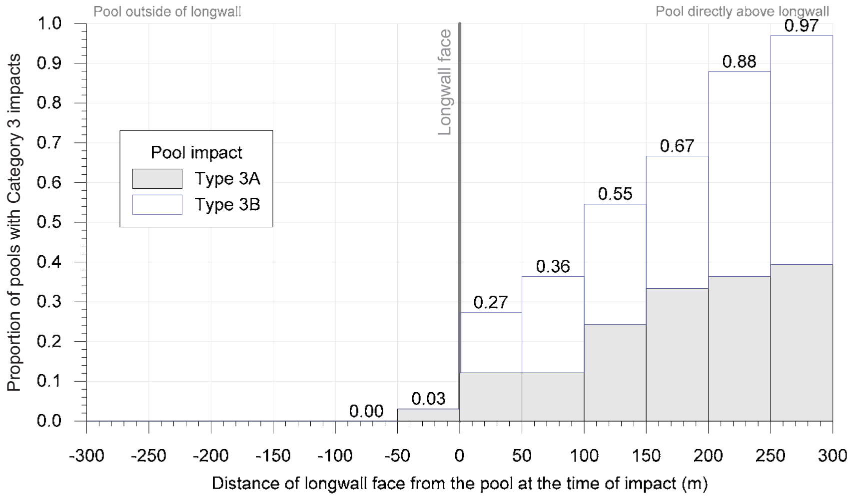

Fig. 3.15 Proportion of pools with Type 3 impacts along Drainage Line WC21 in Area 3B

There were no Type 3 impacts observed in the pools along Drainage Line WC21 prior to the longwalls approaching within 50 m of it. Type 3B impacts were observed shortly after the longwall face mined directly beneath the stream, with these impacts initially representing 27 % of pools directly mined beneath. After the longwall face had mined 250 m to 300 m beyond the stream, these impacts increased to 97 % of the pools.

Type 3 impacts have been observed at five sites located outside of the longwall mining area, as summarised in Table 3.4. However, there are also 57 other sites located outside and within 400 m of the mining area that were not impacted. It is recognised that Type 3 impacts can occur along tributaries located outside the mining area, but the proportion of affected sites is low when compared with the affected sites located directly above the mining area.

The previous experience in Area 3B suggests that the potential for Type 3 impacts on the tributaries at the Mine can be assessed as low if the longwalls mine up to but not directly beneath these streams.

The proposed longwalls in Areas 5 and 6, therefore, have been setback from the selected stream features along the tributaries by a minimum distance of 50 m, when mining on one side only. The setback distance is increased to a minimum of 100 m when mining occurs on both sides of the feature, or where it is located above a coal block, as the feature experiences subsidence from additional longwalls.

Further discussions are provided in the impact assessments for the unnamed streams in Section 5.6.

3.9. Mine layout options

The longwall layout shown in Drawings Nos. MSEC856-01 to MSEC856-22 is referred to as the *Base Case* and it has been adopted for the predictions and impact assessments provided in Chapters 4 to 6. Several alternative longwall layouts were also considered as part of the mine optimisation. Two layouts considered were the:

- *Maximum Case* – where the longwalls mine directly beneath the streams, the setbacks from the Full Supply Levels (FSLs) for the Reservoirs have been reduced from 300 m to 150 m and the setbacks from the Dam Walls have been reduced from 1000 m to 500 m; and
- *Minimum Case* – where the longwalls have been setback from the swamps by minimum distances of 50 m from the ends and 100 m for the sides. The setbacks from the streams and the FSLs of the Reservoirs are the same as the Base Case.

The comparison of the Base Case (blue) with the Maximum Case (red) is provided in Fig. 3.16 and with the Minimum Case (green) is provided in Fig. 3.17.

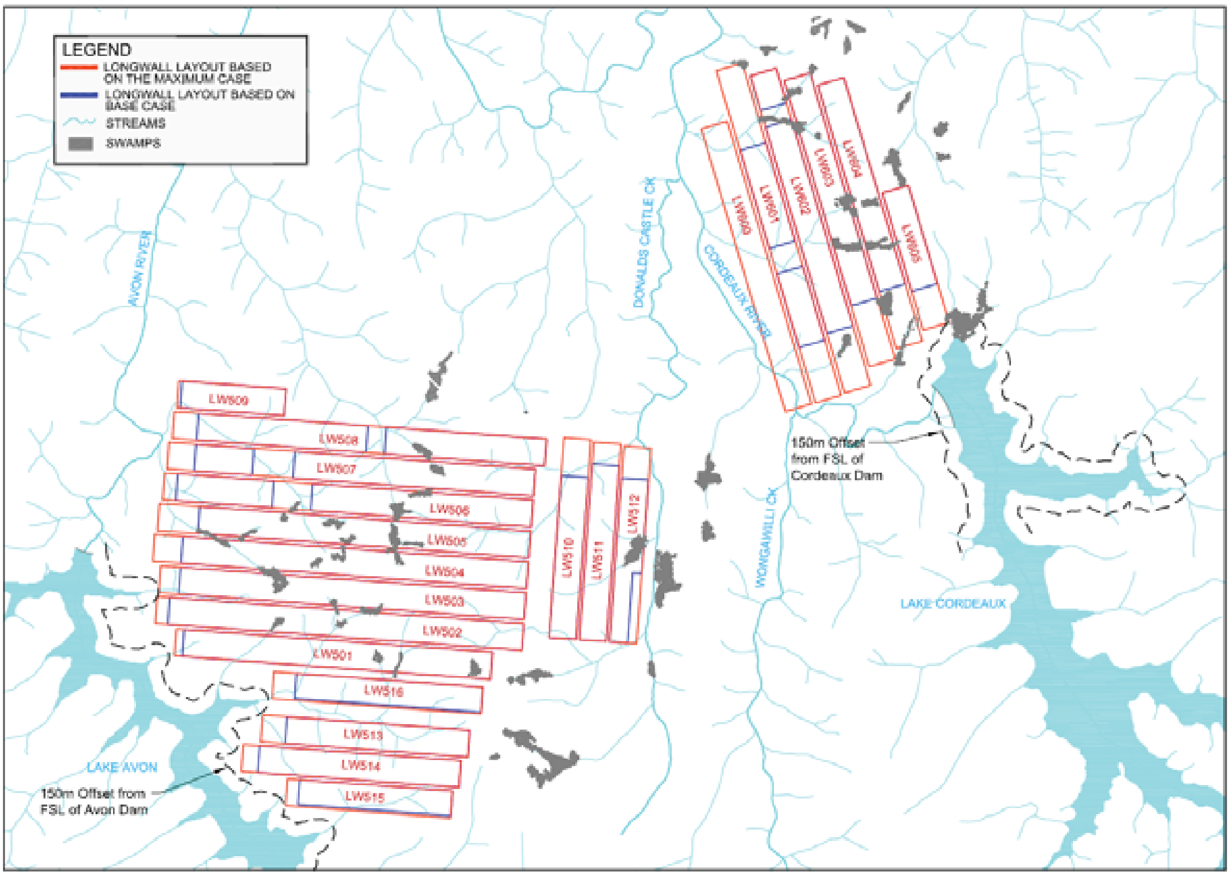

Fig. 3.16 Comparison of the Base Case (blue) and the Maximum Case (red)

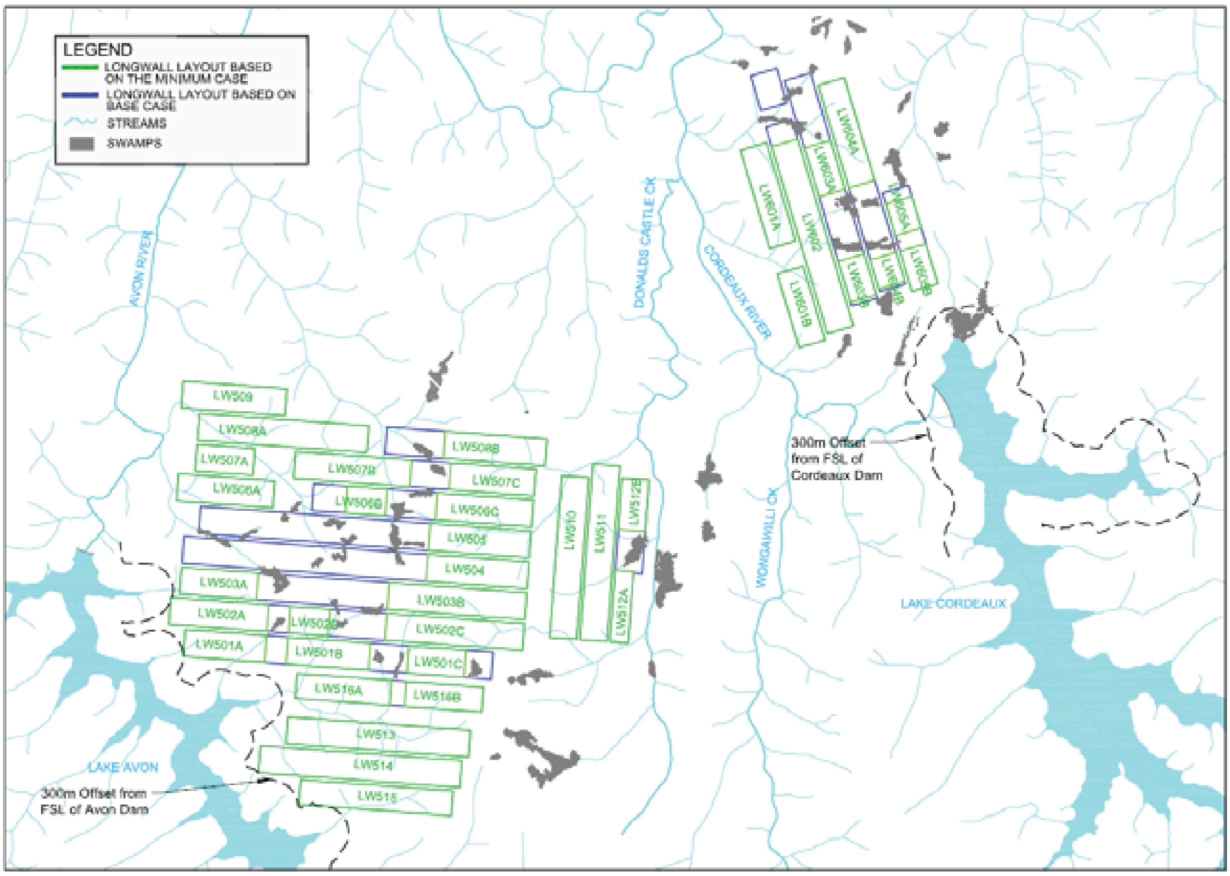

Fig. 3.17 Comparison of the Base Case (blue) and the Minimum Case (green)

The comparisons of the maximum predicted total conventional subsidence parameters for the Base Case, Maximum Case and Minimum Case are provided in Table 3.5 for Area 5 and Table 3.6 for Area 6.

Table 3.5 Comparison of maximum predicted total subsidence parameters for Area 5

Case	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})
Base Case	2050	25	0.50	0.60
Maximum Case	2200	30	0.75	0.75
Minimum Case	2050	25	0.50	0.60

Table 3.6 Comparison of maximum predicted total subsidence parameters for Area 6

Case	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})
Base Case	2450	20	0.30	0.50
Maximum Case	2700	30	0.50	0.70
Minimum Case	2350	20	0.30	0.50

The maximum predicted conventional subsidence parameters for the Maximum Case are greater than the predicted values based on the Base Case. The increase is due to the longwalls extending into areas with lower depths of cover. The values increase by up to 250 mm (i.e. 10 %) for vertical subsidence, 10 mm/m (i.e. 50 %) for tilt and 0.20 km^{-1} (i.e. 65 %) for curvature.

The maximum predicted conventional subsidence parameters for the Minimum Case are typically the same as the predicted values based on the Base Case; however, the predicted vertical subsidence in Area 6 slightly decreases. The values do not change as the maxima occur away from the coal blocks that have been introduced for the Minimum Case.

Similarly, the predicted subsidence parameters for the natural and built features above the mining areas increase for the Maximum Case and are similar to or decrease for the Minimum Case. This has been illustrated for the rivers, creeks and drainage lines in the examples below.

The predicted profiles of total closure along the Avon River, Cordeaux River and Donalds Castle Creek are shown in Fig. 3.18, Fig. 3.19 and Fig. 3.20, respectively. The profiles are shown for the Base Case (blue), Maximum Case (red) and Minimum Case (green).

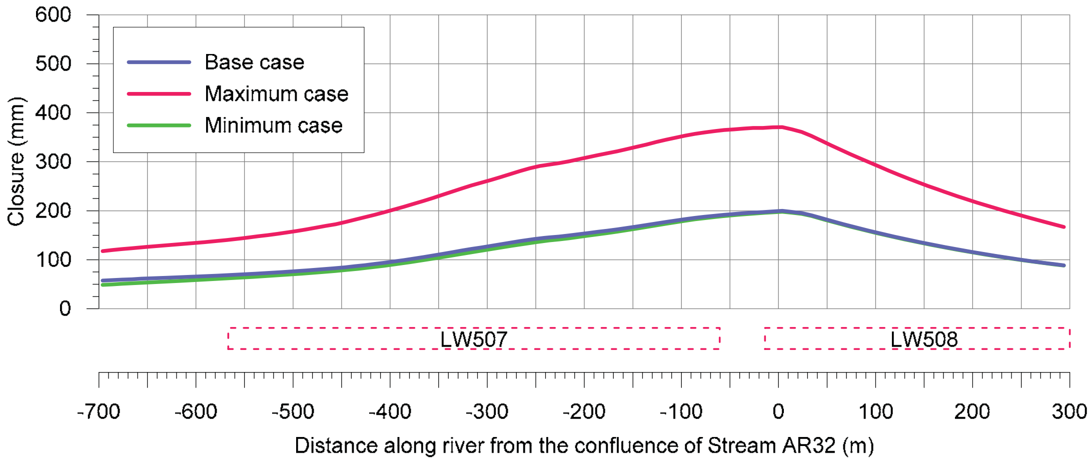

Fig. 3.18 Predicted profiles of total closure along the Avon River

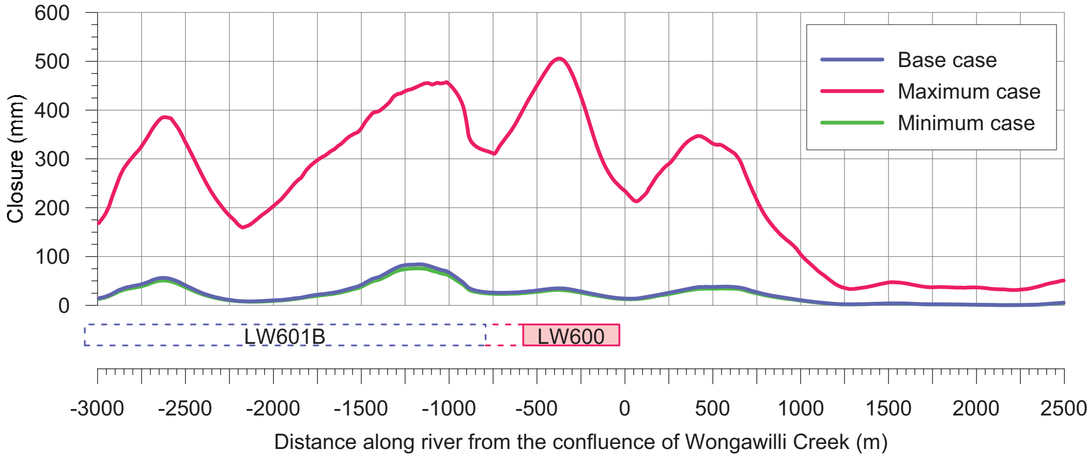

Fig. 3.19 Predicted profiles of total closure along the Cordeaux River

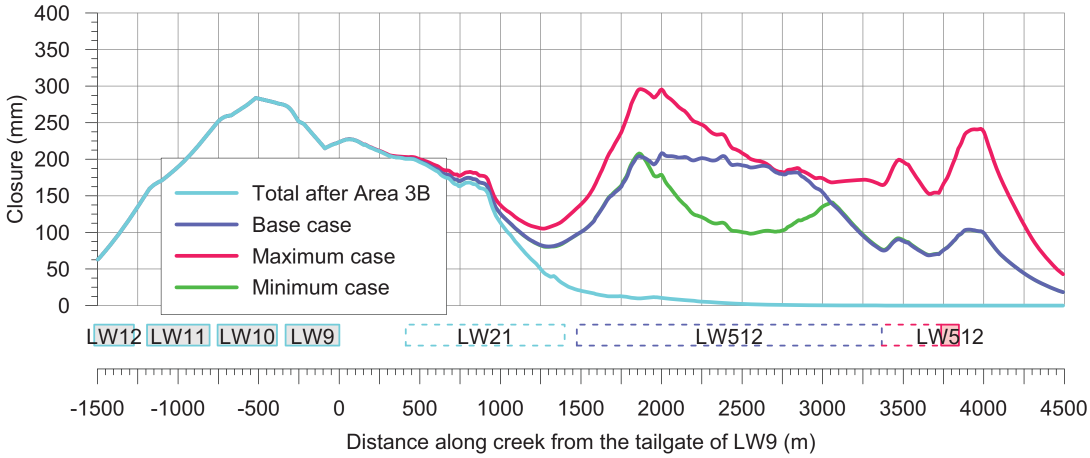

Fig. 3.20 Predicted profiles of total closure along Donalds Castle Creek

Summaries of the maximum predicted total vertical subsidence and closure along the streams, based on the Base Case, Maximum Case and Minimum Case are provided in Table 3.7 and Table 3.8, respectively. The values are the maxima anywhere along the sections of the streams located within the Study Area based on the 600 m boundary.

Table 3.7 Maximum predicted vertical subsidence for the streams based on the Base Case, Maximum Case and Minimum Case

Stream	Base Case	Maximum Case	Minimum Case
Avon River	< 20	< 20	< 20
Cordeaux River	< 20	2800	< 20
Donalds Castle Creek	< 20	90	< 20
Wongawilli Creek	< 20	70	< 20
Drainage Line AR19	1600	1700	1400
Drainage Line AR31	1950	2150	1950
Drainage Line AR32	1750	2050	< 20
Drainage Line DC8	1400	1650	1400
Drainage Line DC9	1550	1550	1350
Drainage Line DC10(C)	1450	1450	1450
Drainage Line LA13	1550	1550	1350
Drainage Line LA13A	1700	1750	1550
Drainage Line CR29	2300	2550	1850
Drainage Line CR31(C)	2300	2700	1950

Table 3.8 Maximum predicted closure for the streams based on the Base Case, Maximum Case and Minimum Case

Stream	Base Case	Maximum Case	Minimum Case
Avon River	200	375	200
Cordeaux River	80	500	80
Donalds Castle Creek	210	300	200
Wongawilli Creek	< 20	125	< 20
Drainage Line AR19	575	675	350
Drainage Line AR31	1150	1300	1150
Drainage Line AR32	425	900	250
Drainage Line DC8	800	875	775
Drainage Line DC9	625	625	475
Drainage Line DC10(C)	275	275	250
Drainage Line LA13	750	775	675
Drainage Line LA13A	1000	1200	775
Drainage Line CR29	350	950	150
Drainage Line CR31(C)	800	1200	575

The predicted vertical subsidence and closure for the Cordeaux River and Donalds Castle Creek increase considerably for the Maximum Case, as they are partially mined beneath, whereas they are located outside the mining area for the Base Case. The predicted parameters for the Avon River and Wongawilli Creek also increase, but to lesser extents, since they are located outside the mining area based on both cases.

The predicted vertical subsidence and closure for the drainage lines typically increase for the Maximum Case and decrease for the Minimum Case. The values do not change for Drainage Lines DC9 and DC10 for the Maximum Case since the mine layouts are similar in these locations.

The values for the drainage lines for the Maximum Case increase by up to 400 mm for vertical subsidence and 600 mm for closure in Area 6. The greatest changes are for Drainage Lines CR29 and CR31 in Area 6 due to the additional longwall on the western side of the mining area. The values for the streams in Area 5 increase by up to 300 mm for vertical subsidence and 475 mm for closure.

The vertical subsidence for Drainage Line AR32 is less than 20 mm for the Minimum Case since it is not directly mined beneath. This represents the greatest decrease in vertical subsidence between this case and the Base Case. Elsewhere, the values for the Minimum Case decrease up to 450 mm for vertical subsidence and 225 mm for closure.

The potential for impacts along the Avon River, Cordeaux River, Donalds Castle Creek and Wongawilli Creek for the Maximum Case are greater than those assessed for the Base Case. The reason is the proposed longwalls for the Maximum Case are located closer to these streams and partially mine beneath the Cordeaux River and Donalds Castle Creek.

The maximum predicted closures for the Avon River, Cordeaux River and Donalds Castle Creek vary between 300 mm and 500 mm for the Maximum Case. It has been assessed, using Fig. 3.14, that Type 3 impacts could affect 20 % to 45 % of the pools and channels that are located outside and within 400 m of the proposed longwalls for the Maximum Case. It is likely that the majority of the pools and channels for the sections of the Cordeaux River and Donalds Castle Creek located directly above the proposed longwalls would experience Type 3 impacts.

The potential for impacts along the Avon River, Cordeaux River, Donalds Castle Creek and Wongawilli Creek for the Minimum Case are similar to those assessed for the Base Case. The reason is these streams are located at similar distances from the proposed longwalls and the maximum predicted closures are similar for the Minimum Case and Base Case.

The potential for Type 3 impacts along the sections of named rivers and streams within 400 m of the proposed longwalls for the Base Case has been considered low, with the affected pools and channels within the Study Area being approximately 7 % for the Avon River, less than 5 % for the Cordeaux River and 9 % for Donalds Castle Creek. Type 3 impacts are considered unlikely along Wongawilli Creek due to the proposed mining layout for the Base Case, as it is located more than 600 m from the proposed longwalls.

The potential for impacts on the drainage lines for the Maximum Case are similar to but greater than those assessed for the Base Case. The reason is that these streams are directly mined beneath for both these cases. However, the proposed longwalls were setback from the identified selected stream features for the Base Case. The potential for impacts on these selected stream features is greater for the Maximum Case compared with the Base Case.

The potential for impacts on the drainage lines for the Minimum Case are less than those assessed for the Base Case. The reason is the total lengths of these streams located directly above the mining area for the Minimum Case are less those for the Base Case. The longwalls have been setback from the swamps for the Minimum Case and, therefore, the potential for impacts reduce along the streams in these locations.

4.1. Introduction

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

The predicted vertical subsidence, tilt and curvature have been obtained using the IPM, which has been calibrated based on the latest monitoring data from the Mine, as described in Section 3.6. The predicted strains have been determined by analysing the strains measured at other collieries within the NSW coalfields, where the longwall width-to-depth ratios and extraction heights are similar to those for the proposed longwalls.

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

4.2. Maximum predicted conventional subsidence, tilt and curvature

Summaries of the maximum predicted values of incremental vertical subsidence, tilt and curvature are provided in Table 4.1 for Area 5 and Table 4.2 for Area 6. The incremental parameters represent the additional movements due to the extraction of each of the proposed longwalls.

Table 4.1 Maximum predicted incremental conventional subsidence, tilt and curvature resulting from the extraction of each of the longwalls in Area 5

Longwall	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
LW501	1500	20	0.50	0.40
LW502	1500	18	0.30	0.40
LW503	1450	18	0.30	0.40
LW504	1450	18	0.35	0.40
LW505	1500	19	0.35	0.45
LW506A	1650	20	0.50	0.50
LW506B	1350	16	0.30	0.40
LW507A	1600	20	0.40	0.50
LW507B	1400	17	0.30	0.40
LW508A	1750	20	0.35	0.50
LW508B	1300	16	0.25	0.35
LW509	1600	19	0.30	0.45
LW510	1250	15	0.30	0.35
LW511	1300	16	0.25	0.40
LW512	1400	18	0.40	0.40
LW513	1500	20	0.65	0.50
LW514	1500	20	0.65	0.50
LW515	1400	20	0.55	0.45
LW516	1250	19	0.40	0.45

Table 4.2 **Maximum predicted incremental conventional subsidence, tilt and curvature resulting from the extraction of each of the longwalls in Area 6**

Longwall	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental tilt (mm/m)	Maximum predicted incremental hogging curvature (km^{-1})	Maximum predicted incremental sagging curvature (km^{-1})
LW601A	1700	17	0.25	0.35
LW601B	1850	20	0.30	0.40
LW602A	725	8	0.11	0.25
LW602B	2100	20	0.30	0.45
LW603	1950	20	0.25	0.45
LW604	1800	18	0.20	0.45
LW605	1800	17	0.20	0.40

The predicted total vertical subsidence contours resulting from the extraction of the proposed longwalls in Areas 5 and 6 are shown in Drawing No. MSEC856-22, in Appendix E. A summary of the maximum predicted values of total vertical subsidence, tilt and curvature is provided in Table 4.3. The predicted total parameters represent the accumulated movements due to the extraction of all proposed longwalls within each of the mining areas.

Table 4.3 **Maximum predicted total conventional subsidence, tilt and curvature for the proposed longwalls in Areas 5 and 6**

Area	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 5	2050	25	0.50	0.60
Area 6	2450	20	0.30	0.50

The maximum predicted vertical subsidence in Area 6 is greater than that predicted in Area 5 due to the higher mining height in the Wongawilli Seam compared to that in the Bulli Seam. The maximum predicted tilts and curvatures in Area 6 are less than those predicted in Area 5 due to the higher depths of cover.

The maximum predicted total vertical subsidence in Area 5 of 2050 mm occurs above LW507A and it represents 64 % of the proposed mining height of 3.2 m in that location. The maximum predicted total vertical subsidence in Area 6 of 2450 mm occurs above the southern end of LW602B and it represents 63 % of the proposed mining height of 3.9 m.

The maximum predicted total tilts are 25 mm/m (i.e. 2.5 %, or 1 in 40) in Area 5 and 20 mm/m (i.e. 2.0 %, or 1 in 50) in Area 6. The greatest tilts occur adjacent to the maingates of the last longwalls in the series for each of the mining areas.

The maximum predicted total curvatures in Area 5 are 0.5 km^{-1} hogging and 0.6 km^{-1} sagging, which represent minimum radii of curvature of 2.0 km and 1.7 km, respectively. The maximum predicted total curvatures in Area 6 are 0.30 km^{-1} hogging and 0.50 km^{-1} sagging, which represent minimum radii of curvature of 3.3 km and 2.0 km, respectively.

The predicted conventional subsidence parameters vary across the mining areas as the result of, amongst other factors, variations in the longwall geometry, depths of cover, seam thickness and overburden geology. To illustrate this variation, the predicted profiles of vertical subsidence, tilt and curvature have been determined along two prediction lines, the locations of which are shown in Drawing No. MSEC856-22.

The predicted profiles of total vertical subsidence, tilt and curvature along Prediction Lines 1 to 4 are shown in Figs. C.01 to C.04, in Appendix C. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines. The range of predicted curvatures in any direction, at any time during or after the extraction of the proposed longwalls, is shown by the grey shading.

4.3. Comparison of predictions with those in Areas 3A and 3B

The comparison of the maximum predicted total conventional subsidence parameters with the maxima predicted for the approved longwalls in Areas 3A and 3B is provided in Table 4.4. The predictions for each of these mining areas are based on the calibrated IPM as described in Section 3.6.

Table 4.4 Comparison of maximum predicted total subsidence parameters

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})
Area 3A	3600	50	1.4	1.4
Area 3B	3600	50	1.4	1.4
Area 5	2050	25	0.50	0.60
Area 6	2450	20	0.30	0.50

The maximum predicted subsidence parameters for the proposed longwalls in Areas 5 and 6 are less than the maxima predicted for the existing and approved longwalls in Areas 3A and 3B at the Mine. The predicted subsidence parameters for the proposed longwalls are less than the existing and approved longwalls due to the smaller proposed mining heights of up to 3.2 m in Area 5 and 3.9 m in Area 6, compared with the mining heights ranging between 3.9 m and 4.6 m in Areas 3A and 3B. Also, the width-to-depth ratios for the proposed longwalls in Areas 5 and 6 are, on average, less than the ratios for the existing and approved longwalls in Areas 3A and 3B.

4.4. Predicted strains

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

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

Adopting a linear relationship between curvature and strain provides a reasonable prediction for the 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 locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones. In the Southern Coalfield, it has been found that a factor of 15 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 proposed longwalls, based on applying a factor of 15 to the maximum predicted curvatures, are 7.5 mm/m tensile and 9 mm/m compressive for Area 5 and are 4.5 mm/m tensile and 7.5 mm/m compressive for Area 6. These strains represent typical values when the ground subsides regularly with no localised or elevated strains due to near-surface geological structures or valley closure effects. The maximum strains can be much greater than these typical values, especially in the locations of near-surface geological structures and in the bases of valleys.

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.

There are two traditional ground monitoring lines at the Mine that do not cross streams or valleys, being the SCW North and South Lines in Area 3A. The ranges of potential strains above the proposed longwalls, therefore, have been determined using these ground monitoring lines as well as data from the NSW coalfields, where the mining geometries are reasonably similar to that at the Mine.

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 in the NSW coalfields, for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls. A number of probability distribution functions were fitted to the empirical data. It was found that a *Generalised Pareto Distribution* (GPD) provided a good fit to the raw strain data.

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

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 a longwall extraction, the maximum tensile strain and the maximum compressive strain were used in the analysis (i.e. single tensile strain and single compressive strain measurement per survey bay).

4.4.1. Predicted strains for the proposed longwalls in Area 5

The comparison of the mining geometry for the proposed longwalls in Area 5 with that for the previously extracted longwalls used in the strain analysis is provided in Table 4.5. There is a total of 11 ground monitoring lines located above 20 previously extracted longwalls in the Hunter and Newcastle Coalfields.

Table 4.5 Comparison of the mine geometry for Area 5 at the Mine with the longwalls from the NSW coalfields used in the strain analysis

Parameter	Area 5 at the Mine		Longwalls used in strain analysis	
	Range	Average	Range	Average
Longwall width	205 ~ 305	305 typ.	130 ~ 220	200
Depth of cover	250 ~ 390	360	110 ~ 250	190
W/H ratio	0.78 ~ 1.1	0.85	0.8 ~ 1.2	1.07
Mining height	2.5 ~ 3.2	2.7	2.1 ~ 3.2	2.9

The range of width-to-depth ratios and mining heights for the longwall used in the strain analysis are similar to but slightly greater, on average, than the width-to-depth ratios and mining heights of the proposed longwalls in Area 5. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains resulting from the extraction of the proposed longwalls.

The histogram of the maximum measured tensile and compressive strains for survey bays located above goaf, for the selected monitoring lines from the NSW coalfields, is provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

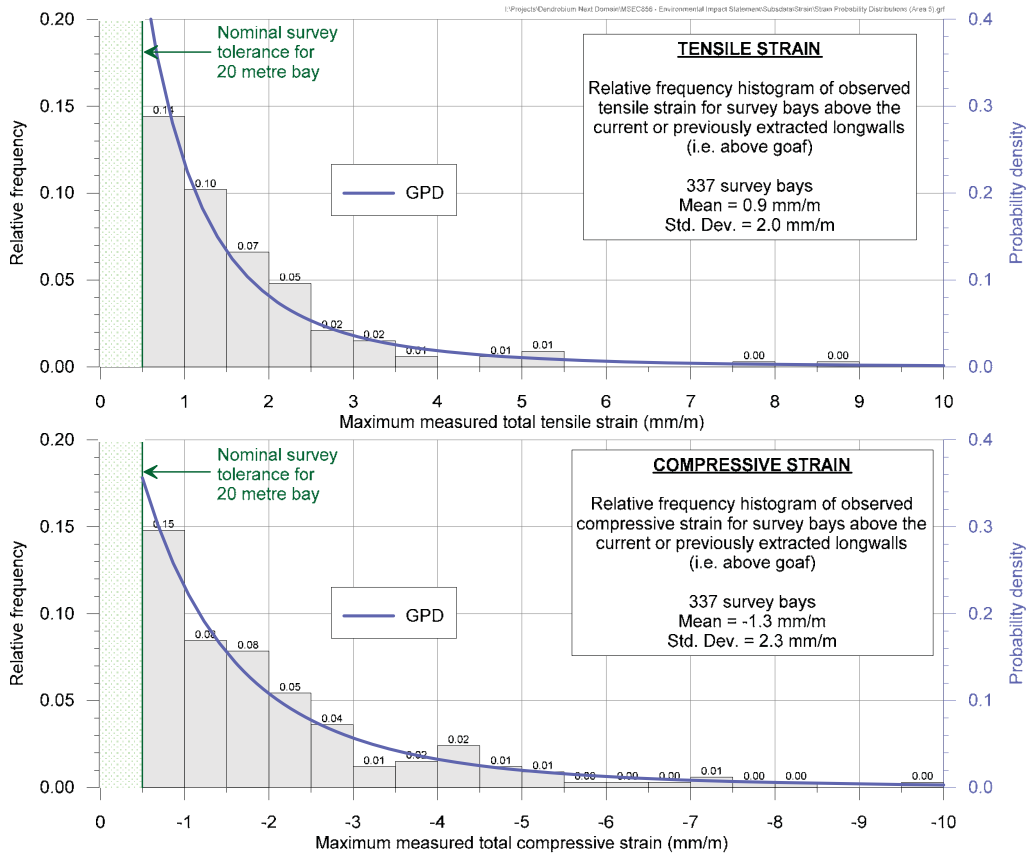

Fig. 4.1 Distributions of the measured maximum tensile and compressive strains during the extraction of previous longwalls in the NSW coalfields for bays located above goaf

The 95 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining are 4 mm/m tensile and 5 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining are 8 mm/m tensile and 11 mm/m compressive.

4.4.2. Predicted strains for the proposed longwalls in Area 6

The comparison of the mining geometry for the proposed longwalls in Area 6 with that for the previously extracted longwalls used in the strain analysis is provided in Table 4.6. There is a total of 21 ground monitoring lines located above 54 previously extracted longwalls in the Hunter and Newcastle Coalfields.

Table 4.6 Comparison of the mine geometry for Area 6 at the Mine with the longwalls from the NSW coalfields used in the strain analysis

Parameter	Area 6 at the Mine		Longwalls used in strain analysis	
	Range	Average	Range	Average
Longwall width	305	305	140 ~ 230	180
Depth of cover	375 ~ 460	440	160 ~ 370	210
W/H ratio	0.66 ~ 0.81	0.70	0.6 ~ 1.0	0.87
Mining height	3.9	3.9	3.1 ~ 4.8	4.2

The range of width-to-depth ratios and mining heights for the longwall used in the strain analysis are similar to but greater, on average, than the width-to-depth ratios and mining heights of the proposed longwalls in Area 6. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains resulting from the extraction of the proposed longwalls.

The histogram of the maximum measured tensile and compressive strains for survey bays located above goaf, for the selected monitoring lines from the NSW coalfields, is provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

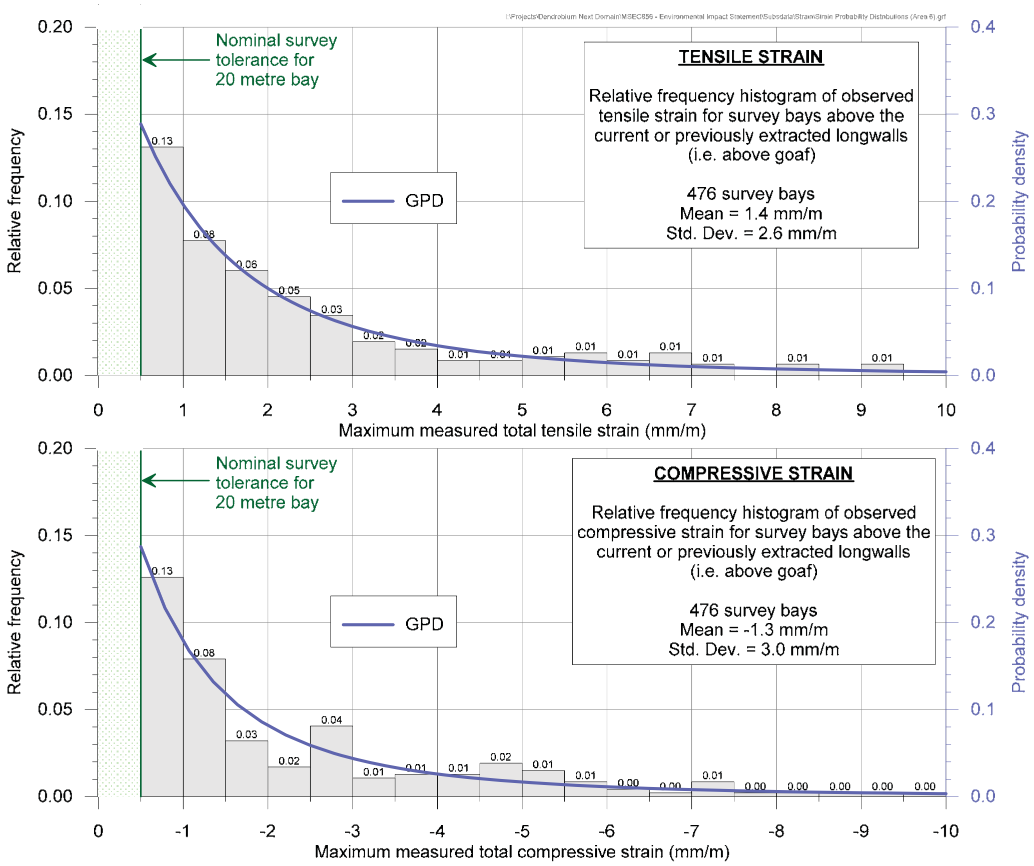

Fig. 4.2 Distributions of the measured maximum tensile and compressive strains during the extraction of previous longwalls in the NSW coalfields for bays located above goaf

The 95 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining are 6 mm/m tensile and compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining are 14 mm/m tensile and 15 mm/m compressive.

It is noted that the predicted strains in Area 6 are greater than those predicted in Area 5 based on the strain analyses, whereas they are less based on conventional movements. The reason is the strain analysis for Area 6 is based on greater mining heights than the strain analysis for Area 5.

4.5. Predicted conventional horizontal movements

The predicted conventional horizontal movements over the proposed longwalls are calculated by applying a factor to the predicted conventional tilt values. In the Southern Coalfield a factor of 15 is generally adopted, being the same factor as that used to determine the conventional strains from the conventional curvatures, and this has been found to give a reasonable correlation with measured data. This factor will vary and will be higher at low tilt values and lower at high tilt values. The application of this factor will therefore lead to over-prediction of horizontal movements where the tilts are high and under-prediction of the movements where the tilts are low.

The maximum predicted conventional tilt for the proposed longwalls is 25 mm/m. The maximum predicted conventional horizontal movement, therefore, is approximately 375 mm, i.e. 25 mm/m multiplied by a factor of 15. Greater movements can develop in incised terrain, due to the increased horizontal movements that develops in the downslope direction.

The distribution of the maximum measured horizontal movements for the 3D survey marks located directly above the longwalls in Areas 1, 2, 3A and 3B at the Mine is provided in Fig. 4.3. It can be seen from this figure, that horizontal movements have been measured up to 600 mm at the Mine, with an average measured value of approximately 300 mm.

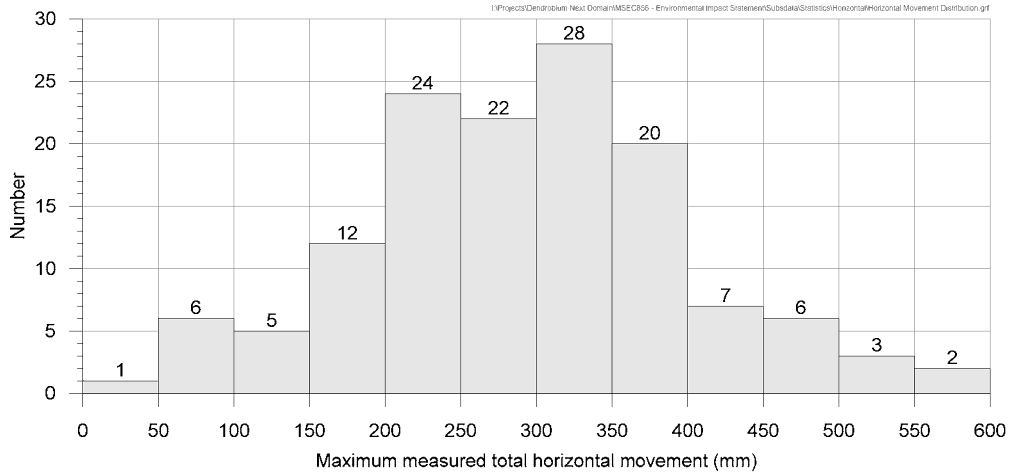

Fig. 4.3 Distribution of the maximum measured horizontal movements for the 3D marks located directly above the longwalls in Areas 1, 2, 3A and 3B at the Mine

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

4.6. Predicted far-field horizontal movements

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

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data from the Mine, as well as from other collieries in the Southern Coalfield, including Appin, Metropolitan, Tahmoor, Tower and West Cliff. 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 measured incremental far-field horizontal movements, resulting from the extraction of longwalls at Areas 1, 2, 3A and 3B at the Mine, are provided in Fig. 4.4. The observed far-field movements for other collieries in the Southern Coalfield, including the confidence levels based on fitted GPDs, have also been shown in this figure for comparison.

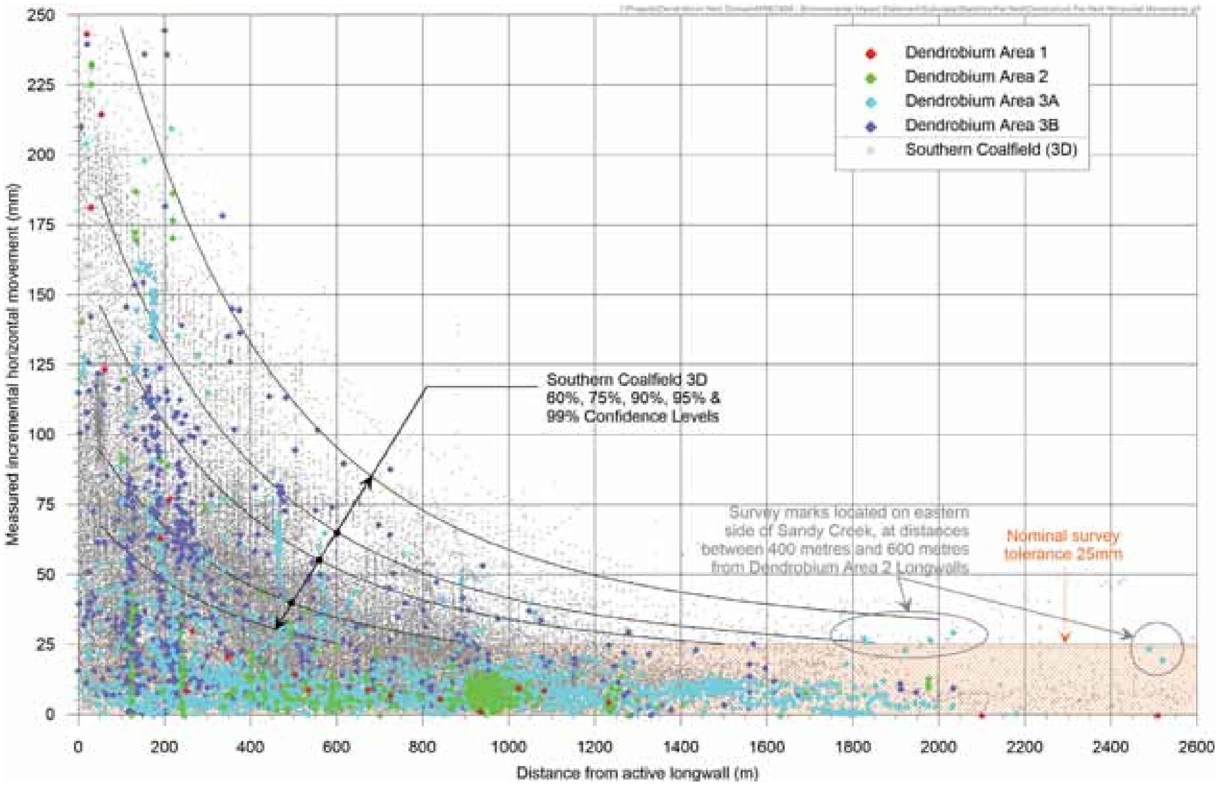

Fig. 4.4 Measured incremental far-field horizontal movements at Dendrobium Mine and elsewhere in the Southern Coalfield

As successive longwalls within a series of longwalls are mined, the magnitudes of the incremental far-field horizontal movements tend to decrease. 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 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 survey tolerance. The impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the vicinity of the Study Area are not expected to be significant, except where they occur at large structures which are sensitive to small differential movements.

4.7. Non-conventional ground movements

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

Specific predictions of upsidence, closure and compressive strain due to the valley related movements are provided for the streams in Sections 5.2 to 5.6. The impact assessments for the streams are based on both the conventional and valley related movements. The potential for non-conventional movements associated with steep topography is discussed in the impact assessments for the steep slopes provided in Section 5.9.

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

4.8. Surface deformations

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

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

Surface deformations can also develop as the result of downslope movements where longwalls are extracted beneath steep slopes. In these cases, the downslope movements can result in the development of tension cracks at the tops and on the sides of the steep slopes and compression ridges at the bottoms of the steep slopes. The impact assessments for downslope movements are provided in Section 5.9.

Fracturing of bedrock can also occur in the bases of stream valleys due to the compressive strains associated with valley upsidence and closure movements. The impact assessments for valley related movements are provided in Sections 5.2 to 5.6.

The soil crack and rock fracture widths were measured at the impact sites located above LW3 to LW5 in Area 2, LW6 to LW8 in Area 3A and LW9 to LW13 in Area 3B. The surface deformations were recorded at a total of 268 sites at the Mine. The distribution of the measured widths of these surface deformations is illustrated in Fig. 4.5.

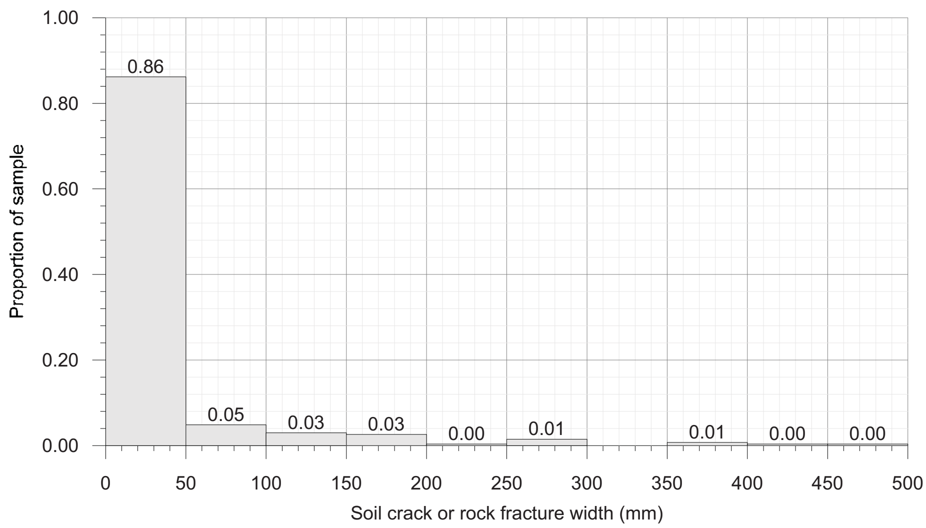

Fig. 4.5 Distribution of measured soil crack and rock fracture widths in Areas 2, 3A and 3B

The soil crack and rock fracture widths were generally less than 50 mm (i.e. 86 % of the cases). However, the widths of the surface deformations were between 50 mm and 150 mm in 8 % of cases, between 150 mm and 300 mm in 4 % of cases and greater than 300 mm in 2 % of cases. The maximum measured crack width was approximately 500 mm.

It is noted that there was a series of cracks up to 1.5 m wide located above the commencing end of LW3 (not shown in the above figure for clarity) that developed due to downslope movement on the steep slopes, the shallower depth of cover (less than 200 m at that location) and fretting of the crack edges.

The predicted mine subsidence parameters for the proposed longwalls in Areas 5 and 6 are less than those for the previously extracted longwalls in Areas 3A and 3B at the Mine, as shown in Table 4.4. The soil crack and rock fracture widths due to the extraction of the proposed longwalls, therefore, are expected to be less, on average, that those measured in Areas 3A and 3B.

4.9. Gas release

The extraction of the proposed longwalls could result in the liberation of methane and other gases. Methane, being a lighter gas, would tend to move upwards to fill the voids in the rock mass and diffuse towards the surface through any continuous cracks or fissures.

Gas emissions at the surface have typically occurred within river valleys such as the Georges, Nepean and Cataract Rivers, although some gas emissions have also been observed in smaller creeks and in water bores. Analyses of gas compositions indicate that the coal seam is not the direct and major source of the gas and that the most likely source is the Hawkesbury Sandstone (APCRC, 1997).

Gas emissions from the beds of the streams will not have time to dissolve in surface water which is present. In addition to this, gas emissions as the result of mining comprises mainly of methane which is not significantly soluble in water. The gas emissions are therefore released into the atmosphere and are unlikely to have significant impacts on water quality.

While it is possible that substantial gas emissions at the surface could result in localised vegetation die back, such observations are not common. Localised vegetation die back occurred at Tower Colliery over small areas in the base of the Cataract River Gorge, as a result of gas emissions directly above LW10 and LW14. These impacts were limited to small areas of vegetation, local to the points of emission where composting occurred. The gas emissions have declined and the affected areas have successfully revegetated.

It should also be noted that the emission of gases at the surface tends to be short-lived temporary events and result in minor impacts that are readily managed. Further discussions on the potential impact of gas emissions of flora and fauna are provided in the report by Niche (2019a).

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

5.1. Catchment Areas and Declared Special Areas

The Study Area lies entirely within the Metropolitan Catchment Area, which is a special declared area controlled by WaterNSW. The Dams Safety Committee (DSC) Notification Areas are shown in Drawings Nos. MSEC856-01 and MSEC856-02.

The western ends of the proposed LW501 to LW505, LW506A, LW507A and the western ends of LW513 to LW516 are located within the DSC Notification Area for the Avon Reservoir, also known as Lake Avon. The southern ends of the proposed LW601B, LW602B and LW603 to LW605 are located on the boundary of the DSC Notification Area for the Cordeaux Reservoir, also known as Lake Cordeaux. The descriptions, predictions and impact assessments for the Avon and Cordeaux Reservoirs are provided in Section 6.8.

The water storages in the Metropolitan Catchment Area provide the sole water supply for the Macarthur and Illawarra regions and the townships of Campbelltown, Camden, Bargo, Picton, Thirlmere, Tahmoor, The Oaks, Buxton and Oakdale, and provide approximately 20 % of the supply to the Sydney Metropolitan Area, via the Prospect Reservoir.

5.2. Avon River

5.2.1. Description of the Avon River

The Avon River is shown in Drawing No. MSEC856-12.

The Avon River is located to the west of the proposed longwalls in Area 5. The thalweg (i.e. base or centreline) of the river is located outside the 35° angle of draw but is partially located within the 600 m boundary from the proposed longwalls. The total length of river within the Study Area based on the 600 m boundary is 0.8 km.

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

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

Mining Area	Longwall	Minimum distance (m)
Area 5	LW506A	370
	LW507A	400
	LW508A	400
	LW509	360

A cross-section through the Avon River, where is it located closest to the proposed longwalls, is provided in Fig. 5.1. The 35° angle of draw and the 600 m boundary from the proposed LW509 are also shown in this figure.

The section of the Avon River within the Study Area is a fifth order perennial stream. The upper reaches of the river have been impounded by Lake Avon. The surface water flows, therefore, are controlled by the release of water from the dam. The bed of the river comprises exposed bedrock containing rockbars with standing pools. There are also other controlling features including boulderfields, riffle zones and debris accumulations.

The mapped stream features along the Avon River are shown in Drawing No. MSEC856-14.

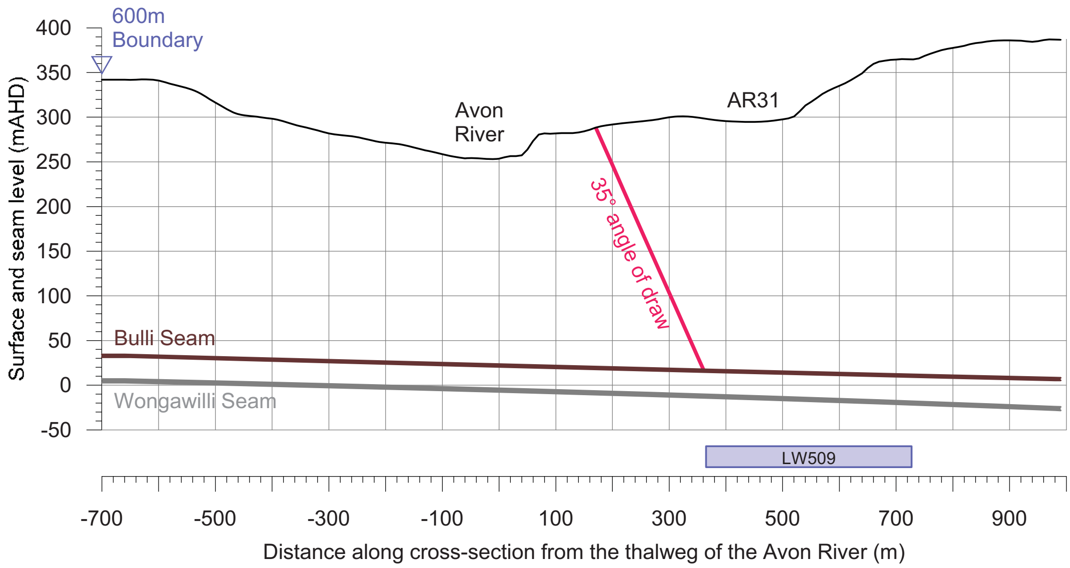

Fig. 5.1 Cross-section through the Avon River and the proposed LW509

Further descriptions of the Avon River are provided in the reports by the other specialist consultants on the Project.

5.2.2. Predictions for the Avon River

The predicted profiles of total vertical subsidence, upsidence and closure along the Avon River are shown in Fig. C.05, in Appendix C. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for the Avon River is provided in Table 5.2.

Table 5.2 Maximum predicted total vertical subsidence, upsidence and closure for the Avon River

Location	Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Avon River	LW505	< 20	< 20	< 20
	LW506B	< 20	20	60
	LW507B	< 20	60	100
	LW508B	< 20	60	150
	LW509	< 20	90	200

The Avon River is predicted to experience less than 20 mm vertical subsidence due to the extraction of the proposed longwalls. Whilst the river could experience very low-levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains. The maximum predicted valley related movements for the Avon River are 90 mm upsidence and 200 mm closure.

The Avon River could experience compressive strains due to the valley closure movements. The predicted strains have been determined based on the analysis of ground monitoring lines for valleys with similar heights located at similar distances from previously extracted longwalls in the Southern Coalfield, as for the Avon River. The maximum predicted compressive strain for the Avon River due to the extraction of the proposed longwalls is less than 2 mm/m based on the 95 % confidence level.

5.2.3. Impact assessments for the Avon River

The Avon River is predicted to experience less than 20 mm vertical subsidence due to the extraction of the proposed longwalls. Whilst the river could experience very low-levels of vertical subsidence, it is not expected to experience measurable conventional strains. That is, the strains due to the conventional ground movements are expected to be less than 0.3 mm/m.

The maximum predicted closure along the Avon River due to the proposed mining in Area 5 is 200 mm. The maximum predicted compressive strain for the river due to the valley closure effects is less than 2 mm/m based on the 95 % confidence level.

Fracturing in bedrock has been observed due to previous longwall mining where the tensile strains are greater than 0.5 mm/m or where the compressive strains are greater than 2 mm/m. It is possible, therefore, that fracturing could occur along the Avon River due to the valley related compressive strains. Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield. The furthest reported fracture outside of the previously extracted longwalls at the Mine was located approximately 290 m south of LW12 in Area 3B.

The length of the Avon River located within 400 m of the proposed longwalls is approximately 0.4 km. It is possible that minor and isolated fracturing could occur along the section of the river located closest to the proposed longwalls.

The Avon River is located at a minimum distance of 360 m from proposed longwalls in Area 5. There have been five areas of Type 3 impacts reported outside the previously extracted LW9 to LW13 in Area 3B, at distances of 115 m to 290 m from the mining area (refer to Section 3.8). However, there have been no Type 3 impacts observed at distances of 360 m or greater from the previously extracted longwalls at the Mine or elsewhere in the Southern Coalfield.

The potential for Type 3 impacts along the Avon River has been assessed using the rockbar impact model for the Southern Coalfield described in Section 3.8.1. The maximum predicted total closure for the Avon River due to the extraction of the proposed longwalls is 200 mm. The predicted rate of impact for the pools and channels along this river due to the extraction of the proposed longwalls, therefore, is in the order of 7 %.

It has been assessed that the likelihood of significant fracturing resulting in surface water flow diversions along the Avon River is very low, i.e. affecting approximately 7 % of the pools and channels along the 0.4 km section of river located within approximately 400 m of the proposed longwalls.

5.2.4. Recommendations for the Avon River

It is recommended that a Watercourse Impact Monitoring and Management Plan be developed for Area 5 at the Mine that includes monitoring and management of the Avon River.

5.3. Cordeaux River

5.3.1. Description of the Cordeaux River

The Cordeaux River is shown in Drawing No. MSEC856-12.

The Cordeaux River is located to the west and to the south of the proposed longwalls in Area 6. The thalweg (i.e. base or centreline) of the river is located outside the 35° angle of draw but it is partially located within the 600 m boundary from the proposed longwalls. The total length of river that is located within the Study Area based on the 600 m boundary is 1.4 km.

A summary of the minimum distances of the proposed longwalls from the thalweg of the Cordeaux River is provided in Table 5.3.

Table 5.3 Distances of the proposed longwalls from the thalweg of the Cordeaux River

Mining Area	Longwall	Minimum distance (m)
Area 5	LW508B	2550
	LW512	1840
Area 6	LW601A	610
	LW601B	370
	LW602B	670
	LW603	1090
	LW604	1300
	LW605	1200

A cross-section through the Cordeaux River, where is it located closest to the proposed longwalls, is provided in Fig. 5.2. The 35° angle of draw and the 600 m boundary from the proposed LW601B are also shown in this figure.

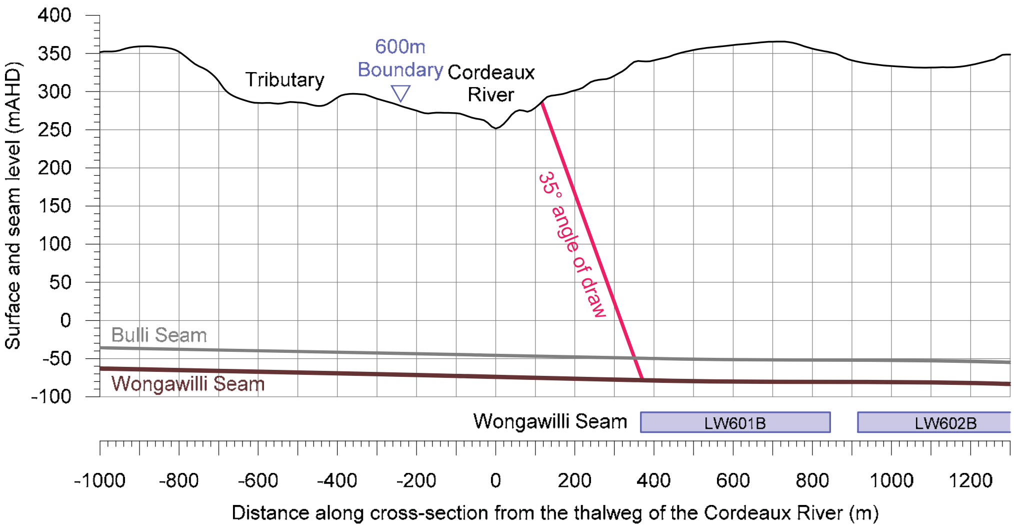

Fig. 5.2 Cross-section through the Cordeaux River and the proposed LW601B

The section of the Cordeaux River within the Study Area is a fifth order perennial stream. The upper reaches of the river have been impounded by Lake Cordeaux. The surface water flows, therefore, are controlled by the release of water from the dam. The bed of the river comprises exposed bedrock containing rockbars with standing pools. There are also other controlling features including boulderfields, riffle zones and debris accumulations.

The mapped stream features along the Cordeaux River are shown in Drawing No. MSEC856-17. Photographs of the Cordeaux River at Ryans Crossing are provided in Fig. 5.3.

Fig. 5.3 Photographs of the Cordeaux River at Ryans Crossing

The natural surface level along the Cordeaux River, within the extents of the Study Area based on the 600 m boundary, varies from approximately 255 mAHD at the upstream end to approximately 250 mAHD at the downstream end. The average natural grade within the Study Area, therefore, is approximately 4 mm/m (i.e. 0.4 %, or 1 in 250).

Further descriptions of the Cordeaux River are provided in the reports by the other specialist consultants on the Project.

5.3.2. Predictions for the Cordeaux River

The predicted profiles of vertical subsidence, upsidence and closure along the Cordeaux River are shown in Fig. C.06, in Appendix C. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for the Cordeaux River is provided in Table 5.4. The values are the maxima anywhere along the section of the river located within the Study Area, including the predicted movements due to the approved longwalls in Area 3C.

Table 5.4 Maximum predicted total vertical subsidence, upsidence and closure for the Cordeaux River

Location	Area or Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Cordeaux River	Area 3C	< 20	< 20	< 20
	LW601(A/B)	< 20	40	70
	LW602(A/B)	< 20	50	80
	LW603	< 20	50	80
	LW604	< 20	50	80
	LW605	< 20	50	80

The Cordeaux River is predicted to experience less than 20 mm vertical subsidence due to the extraction of the proposed longwalls. Whilst the river could experience very low-levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains. The maximum predicted valley related movements for the Cordeaux River are 50 mm upsidence and 80 mm closure.

The Cordeaux River could experience compressive strains due to the valley closure movements. The predicted strains have been determined based on the analysis of ground monitoring lines for valleys with similar heights located at similar distances from previously extracted longwalls in the Southern Coalfield, as for the Cordeaux River. The maximum predicted compressive strain for the Cordeaux River due to the extraction of the proposed longwalls is 2 mm/m based on the 95 % confidence level.

5.3.3. Impact assessments for the Cordeaux River

The Cordeaux River is predicted to experience less than 20 mm vertical subsidence due to the extraction of the proposed longwalls. Whilst the river could experience very low-levels of vertical subsidence, it is not expected to experience measurable conventional strains. That is, the strains due to the conventional ground movements are expected to be less than 0.3 mm/m.

The maximum predicted closure along the Cordeaux River due to the proposed mining in Area 6 is 80 mm. The maximum predicted compressive strain for the river due to the valley closure effects is 2 mm/m based on the 95 % confidence level.

Fracturing in bedrock has been observed due to previous longwall mining where the tensile strains are greater than 0.5 mm/m or where the compressive strains are greater than 2 mm/m. It is possible, therefore, that fracturing could occur along the Cordeaux River due to the valley related compressive strains. Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield. The furthest reported fracture outside of the previously extracted longwalls at the Mine was located approximately 290 m south of LW12 in Area 3B.

The length of the Cordeaux River located within 400 m of the proposed longwalls is approximately 0.25 km. It is possible that minor and isolated fracturing could occur along the section of the river located closest to the proposed longwalls.

The Cordeaux River is located at a minimum distance of 370 m from proposed longwalls in Area 6. There have been five areas of Type 3 impacts reported outside the previously extracted LW9 to LW13 in Area 3B, at distances of 115 m to 290 m from the mining area (refer to Section 3.8). However, there have been no Type 3 impacts observed at distances of 370 m or greater from the previously extracted longwalls at the Mine or elsewhere in the Southern Coalfield.

The potential for Type 3 impacts along the Cordeaux River has been assessed using the rockbar impact model for the Southern Coalfield described in Section 3.8.1. The maximum predicted total closure for the Cordeaux River due to the extraction of the proposed longwalls is 80 mm. There have been no Type 3 impacts outside of previous longwall mining at a predicted total closure of 80 mm.

It has been assessed that the likelihood of significant fracturing resulting in surface water flow diversions along the Cordeaux River is very low, i.e. affecting less than 5 % of the channels located within the Study Area. Minor fracturing could occur elsewhere along the river for distances up to approximately 400 m from the proposed longwalls.

5.3.4. Recommendations for the Cordeaux River

It is recommended that a Watercourse Impact Monitoring and Management Plan be developed for Area 6 at the Mine that includes monitoring and management of the Cordeaux River.

5.4. Donalds Castle Creek

5.4.1. Description of Donalds Castle Creek

The location of Donalds Castle Creek is shown in Drawing No. MSEC856-12.

Donalds Castle Creek is situated on the eastern side of the proposed longwalls in Area 5. The thalweg of the creek is located within both the 35° angle of draw and the 600 m boundary from the proposed longwalls. The total length of creek that is located within the Study Area based on the 600 m boundary is approximately 3.3 km.

A summary of the minimum distances of the proposed longwalls from the thalweg of Donalds Castle Creek is provided in Table 5.5.

Table 5.5 Distances of the proposed longwalls from the thalweg of Donalds Castle Creek

Mining Area	Longwall	Minimum distance (m)
Area 5	LW511	340
	LW512	50
Area 6	LW601B	1310

A cross-section through Donalds Castle Creek, where is it located closest to the proposed longwalls, is provided in Fig. 5.4. The 35° angle of draw and the 600 m boundary from the proposed LW512 are also shown in this figure.

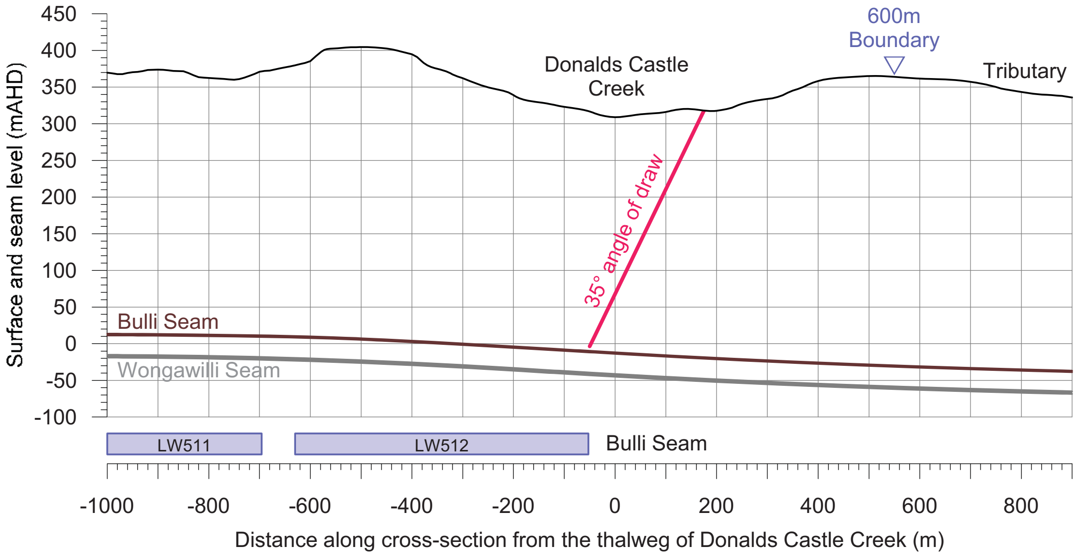

Fig. 5.4 Cross-section through Donalds Castle Creek and the proposed LW512

The upper reaches of Donalds Castle Creek are located above the completed LW9 to LW12 in Area 3B and to the west of the approved longwalls in Area 3C. The total length of creek that has been previously mined beneath is approximately 1.5 km.

The section of Donalds Castle Creek located within the Study Area is a third and fourth order perennial stream with a small base flow and increased flows for short periods of time after each significant rain event. The creek generally flows in a northerly direction and drains into the Cordeaux River to the west of the proposed longwalls in Area 6.

The bed of the creek comprises exposed bedrock containing rockbars with standing pools. There are also other controlling features including boulderfields, riffle zones and debris accumulations. The locations of the mapped stream features are shown in Drawing No. MSEC856-17.

The stream features along Donalds Castle Creek have been identified by IC (HEC, 2019). A summary of the selected stream features within the Study Area based on the 600 m boundary is provided in Table 5.6. The locations of these features are shown in Drawing No. MSEC856-17.

Table 5.6 **Selected stream features along Donalds Castle Creek**

Type	Reference	Location	Size (L x W, m^2)
Pools	P12	370 m north-east of LW511	30 x 20
	P13	340 m north-east of LW511	25 x 12
	P18	170 m north of LW512	95 x 8
	P24	50 m north of LW512	17 x 8
	P26	160 m east of LW512	30 x 15
	P36	160 m east of LW512	65 x 7
	P40	210 m east of LW512	127 x 6
	P41	220 m east of LW512	30 x 4
	P42	220 m east of LW512	45 x 3
	P43	200 m east of LW512	32 x 7
	P50	200 m east of LW512	32 x 15

Photographs of Donalds Castle Creek at the Fire Road 6 crossing are provided in Fig. 5.5.

Fig. 5.5 Photographs of Donalds Castle Creek at the Fire Road 6 Crossing

The natural surface level along Donalds Castle Creek, within the extents of the Study Area based on the 600 m boundary, varies from 335 mAHD at the upstream end to 284 mAHD at the downstream end. The average natural grade within the Study Area, therefore, is approximately 15 mm/m (i.e. 1.5 %, or 1 in 67).

Further descriptions of Donalds Castle Creek are provided in the reports by the other specialist consultants on the Project.

5.4.2. Predictions for Donalds Castle Creek

The predicted profiles of total vertical subsidence, upsidence and closure along Donalds Castle Creek are shown in Fig. C.07, in Appendix C. The predicted total profiles after the completion of the existing and approved longwalls in Areas 3B and 3C are shown as cyan lines. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for Donalds Castle Creek is provided in Table 5.7. The values are the maxima anywhere along the section of the creek located within the Study Area based on the 600 m boundary.

Table 5.7 Maximum predicted total vertical subsidence, upsidence and closure for Donalds Castle Creek

Location	Area or Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)	Maximum predicted additional closure due to the proposed longwalls only (mm)
Donalds Castle Creek	Areas 3B & 3C	< 20	80	150	-
	LW510	< 20	80	150	< 20
	LW511	< 20	80	150	80
	LW512	< 20	100	210	200

The section of Donalds Castle Creek located within the Study Area is predicted to experience less than 20 mm vertical subsidence, 100 mm upsidence and up to a maximum of 210 mm total closure due to the existing and approved longwalls in Areas 3B and 3C and the proposed longwalls in Area 5. The section of creek upstream of the Study Area has been directly mined beneath by LW9 to LW12 in Area 3B and is predicted to have experienced up to 2700 mm vertical subsidence, 370 mm upsidence and 280 mm closure.

Donalds Castle Creek is predicted to experience less than 20 mm additional vertical subsidence due to the extraction of the proposed longwalls in Areas 5 and 6. Whilst the creek could experience very low-levels of additional vertical subsidence, it is not expected to experience measurable conventional tilts or curvatures.

The additional valley related effects due to the extraction of the proposed longwalls in Areas 5 and 6 only are 90 mm upsidence and 200 mm closure. The proposed LW512 has been notched at the southern end to limit the predicted additional closure to 200 mm.

Donalds Castle Creek could experience compressive strains due to the valley closure movements. The predicted strains have been determined based on the analysis of ground monitoring lines for valleys with similar heights located at similar distances from previously extracted longwalls in the Southern Coalfield, as for Donalds Castle Creek. The maximum predicted compressive strain for Donalds Castle Creek due to the extraction of the proposed longwalls is 7 mm/m based on the 95 % confidence level.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure at the selected stream features along Donalds Castle Creek is provided in Table 5.8. The locations of these selected features are shown in Drawing No. MSEC856-17 and in Fig. C.07. The values in this table are the maximum predicted movements within the extents of each feature due to the existing and approved longwalls in Areas 3B and 3C and the proposed longwalls in Area 5.

Table 5.8 Maximum predicted total vertical subsidence, upsidence and closure at the selected stream features along Donalds Castle Creek

Stream	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Donalds Castle Creek	P12	< 20	50	100
	P13	< 20	60	100
	P18	< 20	50	70
	P24	< 20	70	90
	P26	< 20	90	180
	P36	< 20	100	200
	P40	< 20	100	200
	P41	< 20	100	190
	P42	< 20	100	170
	P43	< 20	100	150
	P50	< 20	90	110

5.4.3. Observed impacts to Donalds Castle Creek due to previous mining in Area 3B

The upper reaches of Donalds Castle Creek are located above the previously extracted LW9 and LW10 in Area 3B. Impacts were observed along the creek due to the extraction of LW9, which were described in the End of Panel Report (IC, 2014) and have been summarised as follows:

> "*Site DA3B_LW9_006: Multiple fractures and uplift on DC_RB33 at basal step of Swamp 5; up to 0.015m wide, 2m long and 0.040m of uplift. Exfoliation from the step. Associated flow diversion"*
>
> "*Site DA3B_LW9_007: Change in water appearance in DC_Pool33. Yellow/orange colour and increase in turbidity*"
>
> "*Reduction in pool water levels were observed in watercourses Donalds Castle Creek*"

There was no observable fracturing along the creek due to the extraction of LW10, as Swamp 5 overlays the creek above the extent of this longwall. There were increased rates of water level recession compared to baseline conditions within this swamp. There were no observable impacts to Donalds Castle Creek due to the subsequent extraction of LW11 and LW12 (IC, 2016 and IC, 2017).

5.4.4. Impact assessments for Donalds Castle Creek

The impact assessments for Donalds Castle Creek are provided in the following sections. The assessments provided in this report should be read in conjunction with the assessments provided in the reports by the other specialist consultants on the Project.

Potential for increased levels of ponding, flooding and scouring due to the mining-induced tilt

Donalds Castle Creek is predicted to experience less than 20 mm vertical subsidence due to the extraction of the proposed longwalls in Areas 5 and 6. Whilst the creek could experience very low-levels of vertical subsidence, it is not expected to experience measurable conventional tilts. That is, the predicted changes in grade along the creek due to the conventional movements are less than 0.5 mm/m (i.e. less than 0.05 %, or 1 in 2000).

The maximum predicted total upsidence along the section of Donalds Castle Creek located within the Study Area, due to the extraction of the existing and proposed longwalls, is 100 mm. Whilst the magnitudes of the predicted upsidence movements vary along the alignment of the creek, as illustrated in Fig. C.07, the predicted changes in grade are less than 0.5 mm/m (i.e. less than 0.05 %, or 1 in 2000).

The average natural grade of the section of Donalds Castle Creek within the Study Area is approximately 15 mm/m (i.e. 1.5 %, or 1 in 67). The predicted changes in grade due to the extraction of the proposed longwalls, therefore, are considerably less than the average natural grade. It is unlikely, therefore, that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilts.

It is possible, however, that there could be some localised changes in the levels of ponding or flooding, due to the mining-induced tilts, where the maximum changes in grade coincide with existing pools, steps or cascades along the creek. It is predicted that these changes would not result in adverse impacts on the creek since the predicted changes in grade are less than 0.05 %.

Potential for fracturing of bedrock and surface water flow diversions

Fractures and joints in bedrock and rockbars occur naturally from erosion and weathering processes and from natural valley bulging movements. Where longwall mining occurs in the vicinity of streams, mine subsidence movements can result in additional fracturing or the reactivation of the existing joints. The precise causes of these mining-induced fractures are difficult to determine as the mechanisms are complex, although the main mining-related mechanisms are conventional subsidence and valley related upsidence and closure movements.

Diversions of surface water flows also occur naturally from erosion and weathering processes and from natural valley bulging movements. Mining-induced surface water flow diversions into the strata occur where there is an upwards thrust of bedrock, resulting in a redirection of some water flows into the dilated strata beneath the creek beds. On the basis that there is no connective fracturing to any deeper storage, it is likely that any diverted surface water will re-emerge at the surface further downstream. This would occur at the limit of the mining-induced fracturing within Donalds Castle Creek.

Donalds Castle Creek is located at a minimum distance of 50 m from the proposed longwalls in Area 5. Whilst the creek could experience very low-levels of vertical subsidence, it is not expected to experience measurable conventional strains. That is, the strains due to the conventional ground movements are expected to be less than 0.3 mm/m.

The maximum predicted total closure along the section of Donalds Castle Creek located within the Study Area, due to the extraction of the existing and proposed longwalls, is 210 mm. The maximum additional closure due to the extraction of the proposed longwalls only is 200 mm.

The southern end of the proposed LW512 has been notched so as to limit the maximum predicted additional closure due to the proposed mining in Area 5 to 200 mm. The notching reduces the potential for adverse impacts along the adjacent section of the creek.

The maximum predicted compressive strain for Donalds Castle Creek due to the valley closure effects is 7 mm/m based on the 95 % confidence level. Fracturing in bedrock has been observed due to previous longwall mining where the tensile strains are greater than 0.5 mm/m or where the compressive strains are greater than 2 mm/m. Fracturing therefore could occur along Donalds Castle Creek due to the valley related compressive strains. Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield. The furthest reported fracture outside of the previously extracted longwalls at the Mine was located approximately 290 m south of LW12 in Area 3B.

The length of Donalds Castle Creek located within 400 m of the proposed longwalls is approximately 2.9 km. It is possible that fracturing could occur along the section of the creek located closest to the proposed longwalls.

The potential for Type 3 impacts along Donalds Castle Creek has been assessed using the rockbar impact model for the Southern Coalfield described in Section 3.8.1. The maximum predicted total closure for Donalds Castle Creek due to the extraction of the proposed longwalls is 210 mm. The predicted rate of impact for the pools along this creek due to the extraction of the proposed longwalls, therefore, is in the order of 9 %.

It has been assessed that the likelihood of significant fracturing resulting in surface water flow diversions along Donalds Castle Creek is very low, i.e. affecting approximately 9 % of the pools located within the Study Area.

5.4.5. Recommendations for Donalds Castle Creek

It is recommended that a Watercourse Impact Monitoring and Management Plan be developed for Area 5 at the Mine that includes monitoring and management of Donalds Castle Creek.

5.5. Wongawilli Creek

The location of Wongawilli Creek is shown in Drawing No. MSEC856-12.

Wongawilli Creek is a third order perennial stream with a small base flow and increased flows for short periods of time after each significant rain event. Pools in the creek are permanent (based on monitoring to date) and naturally develop behind the rockbars and at the sediment and debris accumulations.

Wongawilli Creek is situated to the east of the proposed longwalls in Area 5 and to the south of the proposed longwalls in Area 6. The creek is located outside the Study Area based both on the 35° angle of draw and the 600 m boundary. The minimum distances of the creek from the proposed longwalls in each of the proposed mining areas are 0.7 km from LW601B and 1.4 km from LW512.

The upper reaches of Wongawilli Creek are located between the completed longwalls in Areas 3A and 3B and between the two series of approved longwalls in Area 3C. The completed longwalls have been mined up to distances from the creek of 110 m in Area 3A and 260 m in Area 3B.

Fracturing has occurred in one pool along Wongawilli Creek due to the previous mining in Areas 3A and 3B. The impact site is located 200 m west of LW6 and 410 m east of LW9. Pool water levels below baseline conditions have been observed in this pool at low flow conditions during the mining of LW13. This site has therefore been considered a Type 3 impact.

The predicted additional vertical subsidence, upsidence and closure along Wongawilli Creek, due to the extraction of the proposed longwalls in Areas 5 and 6, are all less than 20 mm. Very low-levels of closure could develop at the northern end of the creek, at the confluence with the Cordeaux River, but it is unlikely to result in measurable strains due to its distance from the proposed longwalls.

It is unlikely, therefore, that Wongawilli Creek would experience adverse impacts due to the extraction of the proposed longwalls in Areas 5 and 6. This is supported by the observation that there have been no adverse impacts on streams at the Mine, or elsewhere in the Southern Coalfield, that have been located at distances similar to that of Wongawilli Creek from the proposed longwalls.

It is recommended that a Watercourse Impact Monitoring and Management Plan be developed for Areas 5 and 6 at the Mine that includes monitoring and management of Wongawilli Creek.

5.6. Drainage lines

5.6.1. Descriptions of the drainage lines

There are unnamed drainage lines located within the Study Area that are shown in Drawings Nos. MSEC856-12 and MSEC856-13. The drainage lines in Area 5 are tributaries to the Avon Reservoir and the Avon River in the western part of the mining area and are tributaries to Donalds Castle Creek in the eastern part of the mining area. The drainage lines in Area 6 are tributaries to the Cordeaux River.

The drainage lines located directly above the proposed longwalls are generally first and second order streams. There is a 0.7 km section of Drainage Line AR31 that is third order and is located above the western ends of the proposed LW508A and LW509. The third order section of Drainage Line LA13 also crosses above the edges of the proposed LW513 and LW516. Elsewhere, the third order sections of the drainage lines are located outside of the proposed mining areas.

The drainage lines overlying the proposed mining areas are ephemeral (HEC, 2019). The beds of the drainage lines generally comprise exposed bedrock containing rockbars with some standing pools. There are also other controlling features including boulderfields, riffle zones and debris accumulations. The locations of the mapped stream features are shown in Drawings Nos. MSEC856-14 to MSEC856-17.

Stream features along the drainage lines have been identified and mapped by IC (HEC, 2019). Summaries of the selected stream features (i.e. pools with volumes greater than 100 m^3 and waterfalls with heights greater than 5 m with a pool at the base of the step) that are located within the Study Area based on the 600 m boundary (from the downstream to the upstream end) are provided in Table 5.9 and Table 5.10. The proposed longwalls have been setback from these features to minimise the likelihood of potential impacts, as described in Section 3.8.2.

Table 5.9 Selected stream features identified along the drainage lines in Area 5

Drainage Line	Reference	Type	Location
AR19	AR19-P4	Pool	510 m north of LW509
	AR19-P6	Pool	440 m north of LW509
	AR19-P7	Pool	380 m north-east of LW509
	AR19-P8	Pool	380 m north-east of LW509
	AR19-P9	Pool	400 m north-east of LW509
	AR19-P13	Pool	420 m north-east of LW509
	AR19-P21	Pool	300 m north of LW508A
	AR19-P25	Pool	270 m north of LW508A
	AR19-P26	Pool	260 m north of LW508A
	AR19-P31	Pool	130 m north-east of LW508A
	AR19-P32	Pool	120 m north-east of LW508A
	AR19-P33	Pool	100 m from LW508A and LW508B
AR31	AR31-P1	Pool	400 m west of LW508A
	AR31-W1	Waterfall	350 m west of LW508A
	AR31-P45	Pool	100 m east of LW507A
	AR31-P52	Pool	100 m from LW506A and LW507B
	AR31-P63	Pool	100 m from LW505 and LW506B
AR32	AR32-P17	Pool	50 m west of LW506A
	AR32-ST5	Step	50 m west of LW506A
	AR32-P22	Pool	100 m south-west of LW506A
	AR32-ST8	Step	230 m west of LW505
	AR32-P31	Pool	50 m west of LW505
	AR32-ST11	Step	50 m west of LW505
DC8	DC8-RB1	Rockbar	340 m north-east of LW511
	DC8-ST1	Step	230 m north of LW511
	DC8-ST2	Step	220 m north of LW511
	DC8-P9	Pool	50 m north of LW511
	DC8-P16	Pool	50 m north of LW510
DC10(C)	DC10C-P7	Pool	110 m west of LW510 and 170 m east of LW502
LA13	LA13-P2	Pool	50 m west of LW516
	LA13-P4	Pool	100 m from LW513 and LW516
	LA13-P9	Pool	100 m from LW513 and 110 m from LW516
	LA13-P17	Pool	100 m from LW513 and LW516

Table 5.10 Selected stream features identified along the drainage lines in Area 6

Drainage Line	Reference	Type	Location
CR29	CR29-P4	Pool	400 m west of LW601A
	CR29-P9	Pool	90 m north of LW601A
	CR29-P35	Pool	130 m north of LW601A
	CR29-P37	Pool	100 m from LW602A and LW602B
CR31	CR31-P6	Pool	450 m west of LW601A
	CR31-P10	Pool	360 m west of LW601A
	CR31-P13	Pool	350 m west of LW601A
	CR31-P18	Pool	260 m west of LW601A
	CR31-P26	Pool	100 m south-west of LW601A
	CR31-P30	Pool	130 m from LW601A and 150 m from LW601B
	CR31-P32	Pool	110 m from LW601B and 150 m from LW601A
	CR31-P33	Pool	100 m north of LW601B

Photographs of Drainage Lines AR31 and AR32 are provided in Fig. 5.6 and Fig. 5.7, respectively.

Fig. 5.6 Photographs of the upper reaches of Drainage Line AR31

Fig. 5.7 Photographs of the lower reaches of Drainage Line AR32

The average natural gradients of the drainage lines typically vary between 20 mm/m (i.e. 2.0 %, or 1 in 50) and 150 mm/m (i.e. 15 %, or 1 in 7) directly above the proposed longwalls. Localised areas have natural grades greater than 300 mm/m (i.e. 30 %, or 1 in 3), where there are steps, cascades and waterfalls.

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

5.6.2. Predictions for the drainage lines

The drainage lines are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4. The site-specific subsidence predicted parameters have also been provided below for selected drainage lines located within the Study Area.

The predicted profiles of vertical subsidence, upsidence and closure along Drainage Lines AR19, AR31, AR32, DC8, DC9, DC10(C), LA13, LA13A, CR29 and CR31(C) are shown in Figs. C.08 to C.17, in Appendix C. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for the selected drainage lines is provided in Table 5.11. The values are the maxima anywhere along the sections of the drainage lines located within the Study Area.

Table 5.11 Maximum predicted total vertical subsidence, upsidence and closure for the drainage lines

Area	Drainage line	Maximum predicted total vertical subsidence (mm)	Maximum predicted total valley related upsidence (mm)	Maximum predicted total valley related closure (mm)
Area 5	AR19	1600	475	575
	AR31	1950	775	1150
	AR32	1750	400	425
	DC8	1400	500	800
	DC9	1550	525	625
	DC10(C)	1450	425	275
	LA13	1550	525	750
	LA13A	1700	875	1000
Area 6	CR29	2300	425	350
	CR31(C)	2300	675	800

The sections of the drainage lines located directly above the proposed longwalls could experience compressive strains in the order of 10 mm/m to 20 mm/m due to the predicted valley related movements. The sections of the drainage lines located within the 35° angle of draw from the proposed longwalls could experience compressive strains in the order of 2 mm/m to 5 mm/m.

The drainage lines will also experience horizontal movements along and across their alignments due to the conventional movements. A summary of the maximum predicted values of total horizontal movement along, horizontal movement across and conventional closure for the drainage lines is provided in Table 5.12. It is noted that the conventional closures are normally provided separately to the valley related closures, as the associated conventional strains are distributed across the longwalls, as opposed to the valley related compressive strains which are concentrated in the valley bases. Also, in most cases, the valley related closures and conventional closures are orientated obliquely to each other.

Table 5.12 Maximum predicted total horizontal movement along, horizontal movement across and conventional closure for the drainage lines

Area	Drainage line	Maximum predicted total horizontal movement along (mm)	Maximum predicted total horizontal movement across (mm)	Maximum predicted total conventional closure (mm)
Area 5	AR19	275	70	125
	AR31	300	200	275
	AR32	125	200	325
	DC8	125	150	250
	DC9	250	225	375
	DC10(C)	200	150	250
	LA13	250	200	250
	LA13A	250	150	275
Area 6	CR29	225	200	350
	CR31(C)	300	225	400

The maximum predicted conventional strains for the drainage lines, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 7.5 mm/m tensile and 9 mm/m compressive for Area 5 and are 4.5 mm/m tensile and 7.5 mm/m compressive for Area 6.

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

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

5.6.3. Observed impacts to drainage lines due to previous mining in Area 3B

The physical impacts observed along the drainage lines due to LW9 were described in the End of Panel Report (IC, 2014) and have been summarised below:

> *Drainage Line DC13*: impacts observed at five sites including: change in water appearance with orange precipitate from DC13_Pool20 to DC13_Pool14; multiple fractures upstream of Pool DC13_Pool20, in Rockbar DC13_RB21 and in Rockbar DC13_RB17 from less than 1 mm and up to 5 mm in width and up to 4 m in length; soil cracking downstream of DC13_RB21; and flow diversions in Pool DC13_Pool20 and upstream of Rockbar DC13_RB21.
>
> *Drainage Line WC21*: impacts observed at nine sites (including at and between Pools 10, 11, 16, 17, 18 and 19) including: multiple fractures from 3 mm and up to 20 mm in width and up to 5.5 m in length; dilation and uplift up to 20 mm; iron staining; and water loss in Pool WC21_Pool16.

The impacts observed along the drainage lines due to LW10 were described in the End of Panel Report (IC, 2015) and have been summarised below:

> *Drainage Line WC21*: impacts observed at 17 sites including: additional fracturing at the sites previously impacted by LW9; fracturing from hairline and up to 30 mm in width and up to 5.5 m in length; iron staining; dilation and uplift; and localised flow diversion upstream of Rockbar WC21_RB26 and in Pool WC21_Pool 24.

The impacts observed in the drainage lines due to LW11 were described in the End of Panel Report (IC, 2016) and have been summarised below:

> Multiple fractures, uplift and displacement in two locations along WC21, in Rockbar 27 and upstream of Pool 30. Loss of surface water flow along Watercourse WC21 in Pool 30.

The impacts observed along the drainage lines due to LW12 were described in the End of Panel Report (IC, 2017) and have been summarised below:

> Rock fractures and uplift identified at four sites along WC21, LA4 and LA4B with widths up to approximately 50 mm. Loss of surface water flow along stream LA4 and possible diversion along stream LA4B. Fracturing observed outside of mining along LA4B and WC21 at distances of 290 m and 110 m, respectively.

The environmental consequences due to the abovementioned physical impacts are described by the specialist consultant's reports attached to each of the End of Panel reports.

5.6.4. 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 in the reports by the other specialist consultants on the Project.

Potential for increased levels of ponding, flooding and scouring due to the mining-induced tilt

Mining-induced tilt can potentially result in increased levels of ponding and some minor flooding of the adjacent riparian areas in locations where the mining induced tilts oppose and are greater than the natural drainage line gradients that exist before mining. Mining can also result in an increased likelihood of scouring of the banks in the locations where the mining induced tilts considerably increase the natural drainage line gradients that exist before mining.

The maximum predicted tilt for the drainage lines within the Study Area is 25 mm/m (i.e. 2.5 %), which represents a change in grade of 1 in 40. The average natural gradients of the drainage lines typically vary between 20 mm/m (i.e. 2.0 %, or 1 in 50) and 150 mm/m (i.e. 15 %, or 1 in 7) directly above the proposed longwalls.

The maximum predicted changes in grade are similar orders of magnitude as the natural gradients along the drainage lines. The natural grades and the predicted post mining grades along the selected drainage lines are illustrated in Fig. 5.8 to Fig. 5.16.

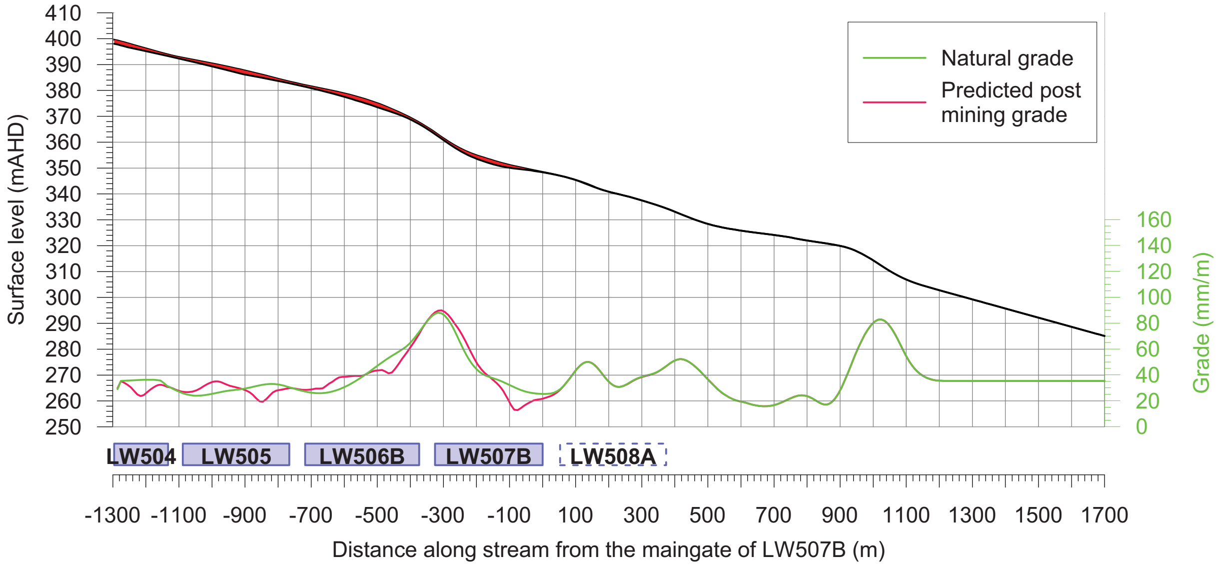

Fig. 5.8 Natural and predicted post mining surface levels along Drainage Line AR19

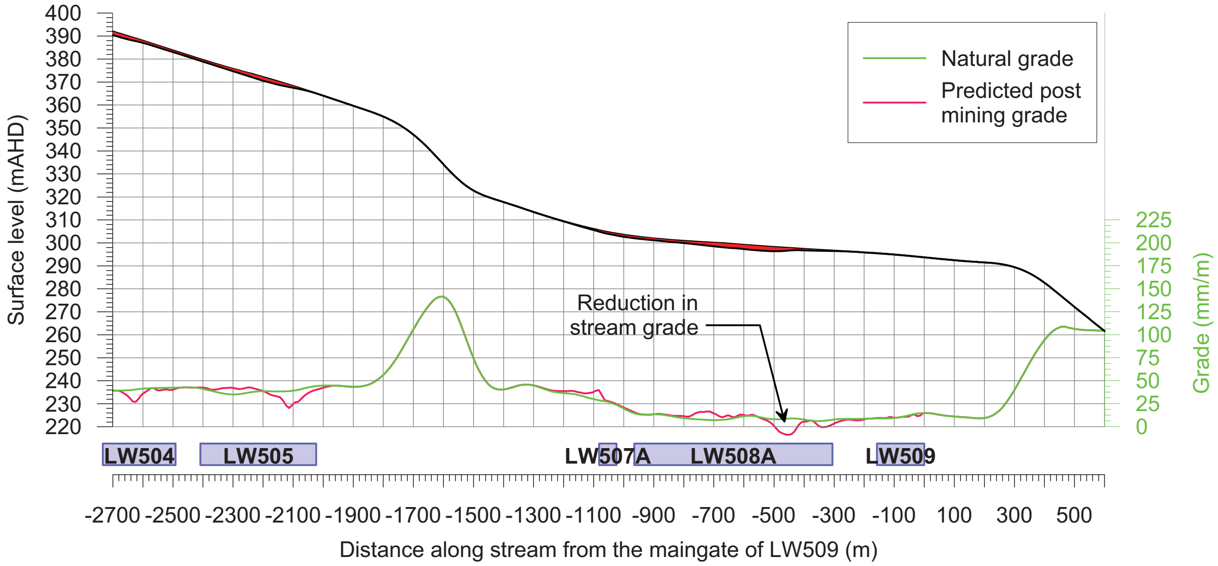

Fig. 5.9 Natural and predicted post mining surface levels along Drainage Line AR31

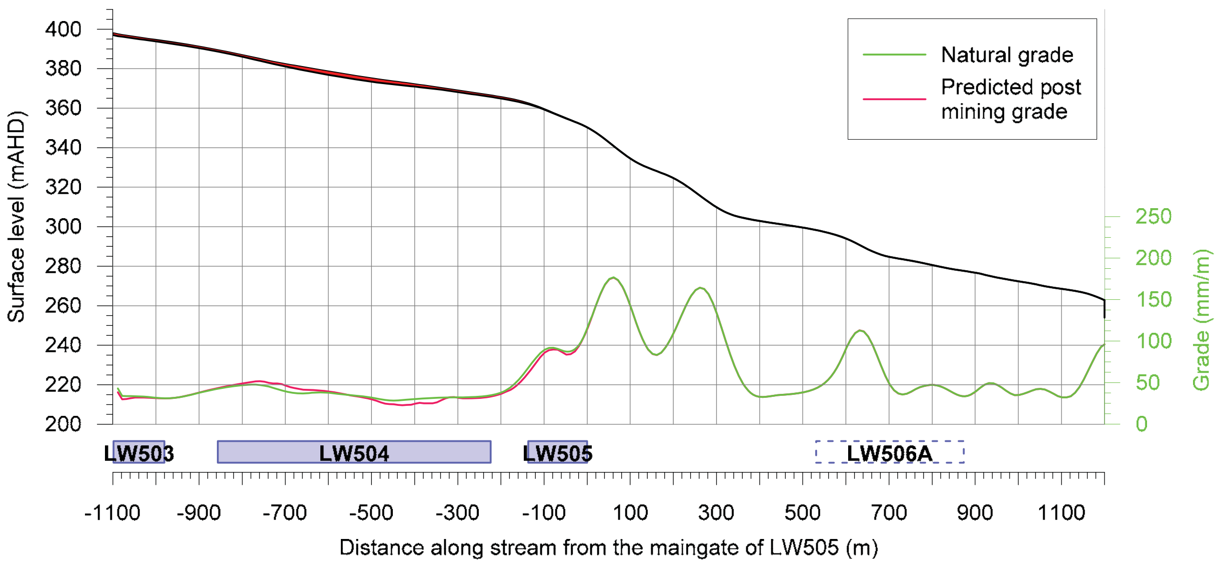

Fig. 5.10 Natural and predicted post mining surface levels along Drainage Line AR32

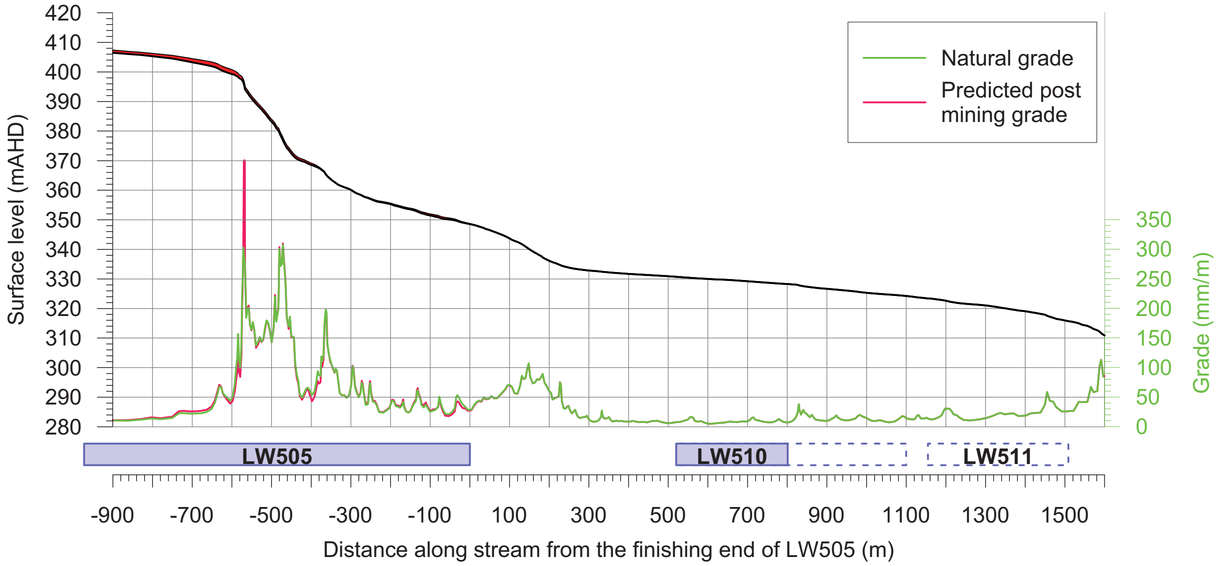

Fig. 5.11 Natural and predicted post mining surface levels along Drainage Line DC8

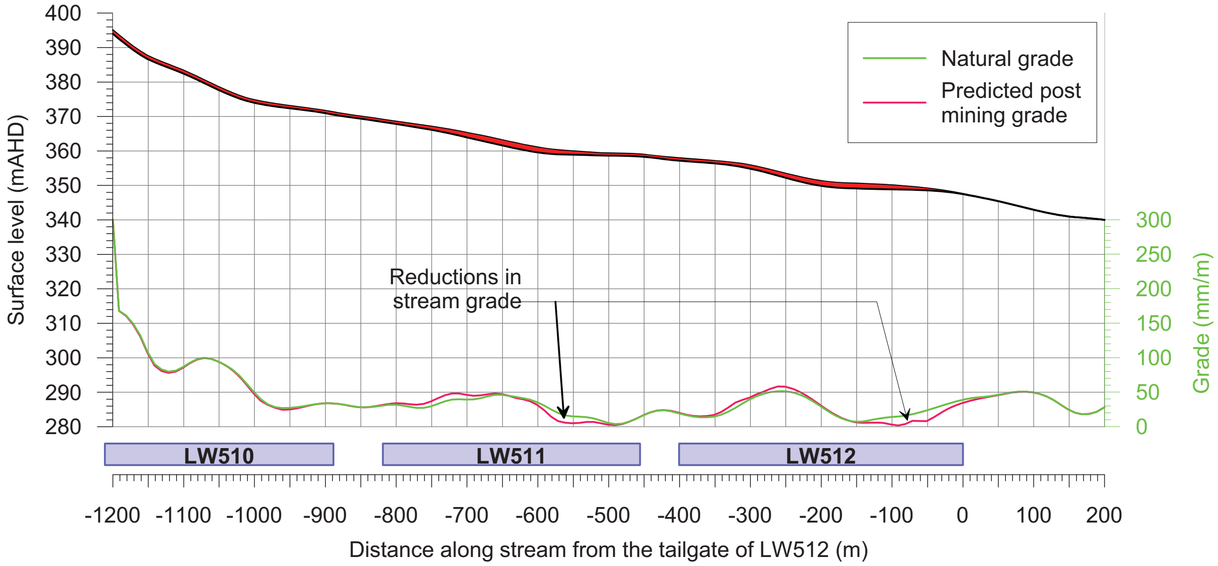

Fig. 5.12 Natural and predicted post mining surface levels along Drainage Line DC9

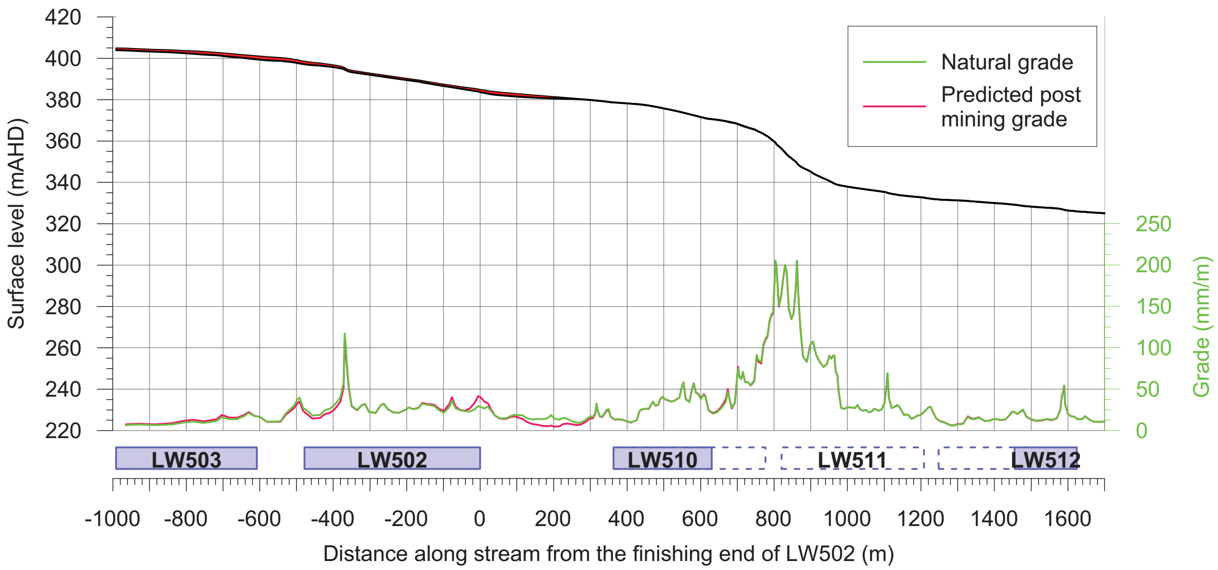

Fig. 5.13 Natural and predicted post mining surface levels along Drainage Line DC10(C)

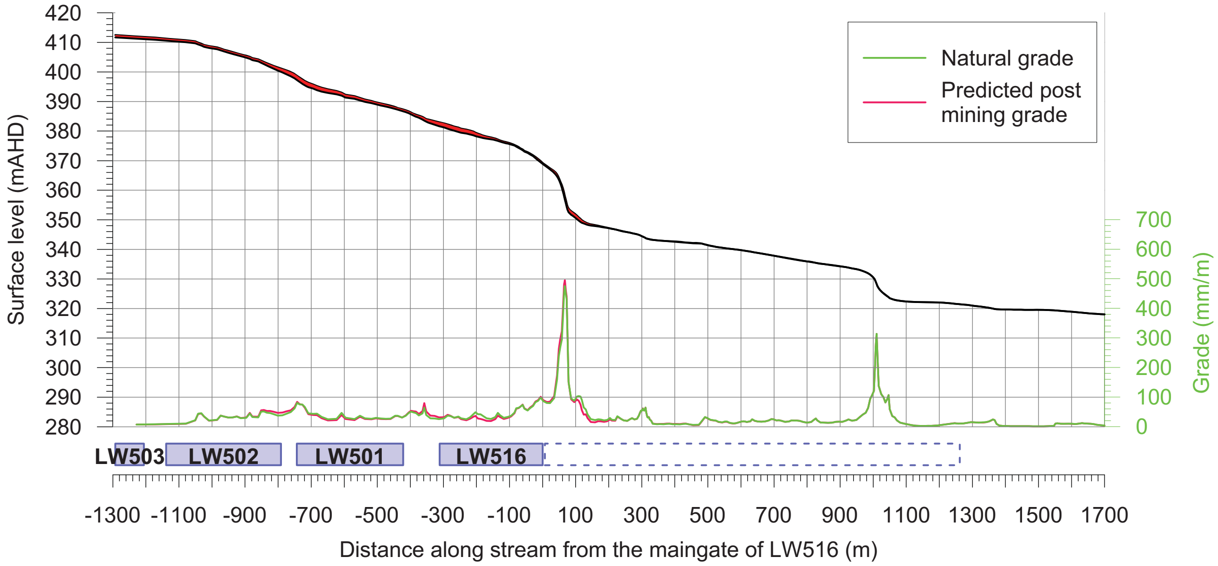

Fig. 5.14 Natural and predicted post mining surface levels along Drainage Line LA13

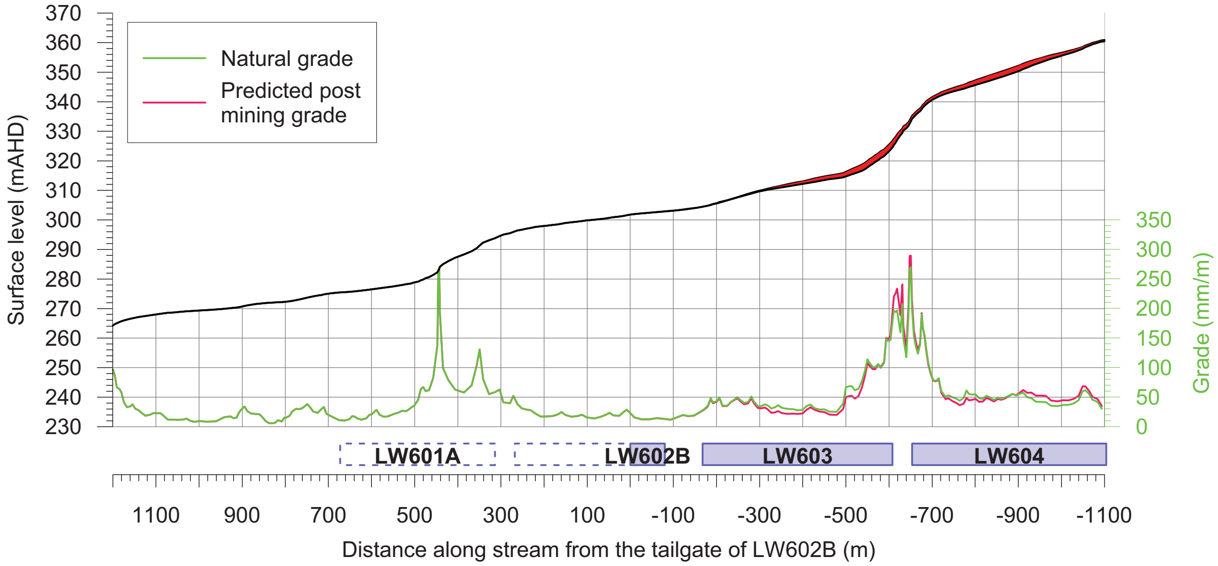

Fig. 5.15 Natural and predicted post mining surface levels along Drainage Line CR29

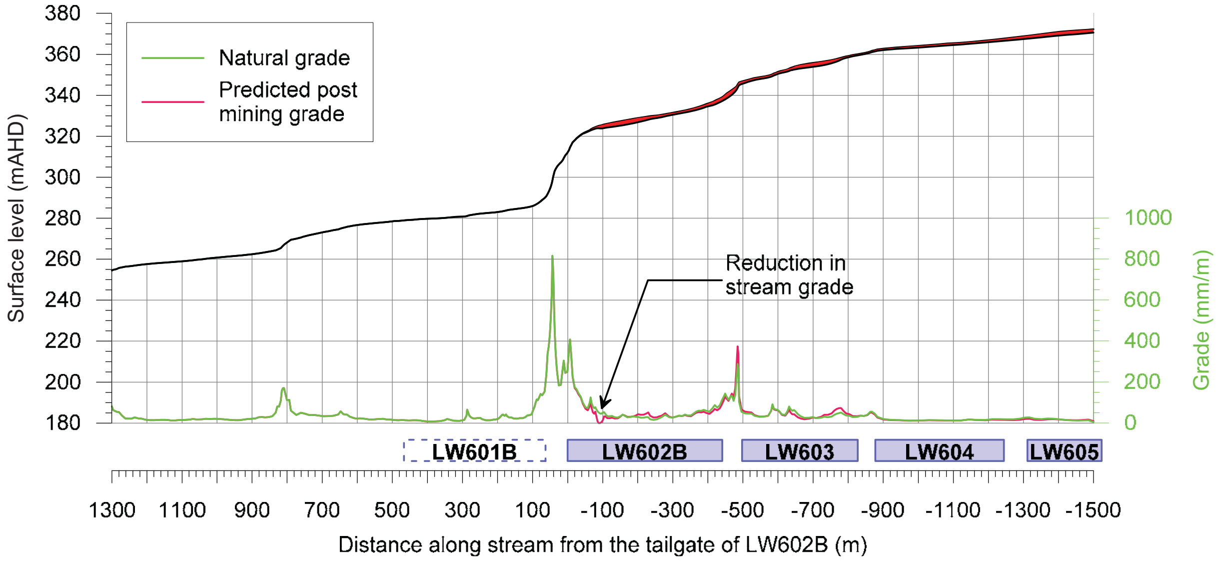

Fig. 5.16 Natural and predicted post mining surface levels along Drainage Line CR31(C)

It can be seen from Fig. 5.8 to Fig. 5.16, that there are reductions in grades along some of the drainage lines, including Drainage Lines AR31, DC9 and CR31(C). The natural and the predicted post-mining grades are small along the upper reaches of the drainage lines and in the locations where the drainage lines exit the proposed mining areas. There could be increased potentials for localised ponding upstream of these locations due to the mining-induced tilt.

It is unlikely that large-scale adverse changes in the levels of ponding or scouring of the banks along these drainage lines due to the predicted mining-induced tilt. It is possible that localised increased ponding could develop in some locations, where the natural grades are smallest and the predicted mining-induced tilts are the greatest. It is also possible, that there could be localised areas that experience increased scouring of the banks, in the locations of the predicted maximum increasing tilts, such as downstream of the longwall chain pillars.

The potential impacts of increased ponding and scouring of the drainage lines, therefore, are expected to be minor and localised.

The tributaries to the drainage lines have high natural gradients as they are located on the sides of the ridgelines. It is unlikely, therefore, that increased ponding or scouring would develop along these tributaries due to the mining-induced tilt.

Potential for cracking in the creek bed and fracturing of bedrock

Impacts have been observed along the drainage lines above the previously extracted LW9 to LW13 in Area 3B, including fracturing in the rockbars and exposed bedrock, dilation and uplift of the bedrock, iron staining, surface water flow diversions and reduction in levels of the standing pools. These impacts predominately occurred directly above the extracted longwalls. However, fracturing was also observed up to 290 m from the extracted longwalls.

The comparison of the maximum predicted subsidence parameters for the proposed longwalls in Areas 5 and 6 with the maxima predicted for the previously extracted longwalls in Area 3B is provided in Table 4.4. The predicted subsidence parameters for the proposed longwalls are less than the maxima predicted for the existing and approved longwalls due to their smaller extraction heights. The likelihood and extents of the assessed impacts on the drainage lines due to the extraction of the proposed longwalls in Areas 5 and 6, therefore, are expected to be less than that observed above the previously extracted longwalls in Area 3B.

It is expected that fracturing of the bedrock would occur along the sections of the drainage lines that are located directly above and adjacent to the proposed longwalls. Fracturing can also occur outside the extents of the proposed longwalls, with fracturing occurring at distances up to approximately 400 m.

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

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

The tributaries to the drainage lines may also experience fracturing due to the conventional ground movements. These tributaries are ephemeral and, therefore, surface water flows only occur during and for short periods after rain events. The diversion of surface water flows in these tributaries is unlikely to affect water availability due to their high natural gradients and the free draining nature of the ridgelines.

Further discussions on the environmental consequences for the drainage lines are provided by the specialist surface water and groundwater consultants on the Project.

5.6.5. Recommendations for the drainage lines

It is recommended that a Watercourse Impact Monitoring and Management Plan be developed for Areas 5 and 6 at the Mine that includes monitoring and management of the drainage lines.

5.7. Aquifers and known groundwater resources

Shallow aquifers have been identified within the Study Area and these are associated with the drainage lines and upland swamps. The potential impacts on the aquifers and groundwater resources are provided by the specialist groundwater consultant.

5.8. Cliffs

5.8.1. Descriptions of the cliffs

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

"*Cliff* — *Continuous rock face, including overhangs, having a minimum length of 20 metres, a minimum height of 10 metres and a minimum slope of 2 to 1 (>63.4º)*

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

The cliffs and minor cliffs within the Study Area have been identified from the LiDAR surface level contours and from field investigations. The locations of these features are shown in Drawing No. MSEC856-18. The cliffs and minor cliffs are predominantly located along the lower reaches of the streams including: AR31, AR32, DC8, DC10, LA6, LA7, LA8, LA10, LA13, LA14, LA15, LA17 and their associated tributaries in Area 5; and the Cordeaux River, CR29, CR31, CR35, LC1 and their associated tributaries in Area 6.

The details of the cliffs located within the Study Area (based on the 35° angle of draw) is provided in Table D.01, in Appendix D. The prefix of each cliff name indicates the stream along which it is located. A summary of the cliffs within each of the mining areas is provided in Table 5.13.

Table 5.13 Cliffs located within the Study Area

Mining area	Location	Number	Overall lengths (m)	Maximum heights (m)
Area 5	Directly or partially above the proposed longwalls	40	20 to 200	10 to 25
	Outside longwalls and within 35° angle of draw	39	20 to 165	10 to 20
Area 6	Directly above longwalls	0	-	-
	Outside longwalls and within 35° angle of draw	7	30 to 55	10 to 12

There are 40 cliffs that have been identified directly or partially above the proposed longwalls in Area 5. No cliffs have been identified directly above the proposed longwalls in Area 6. There are a further 46 cliffs that are located outside of the proposed longwalls in Areas 5 and 6 and within the 35° angles of draw.

The lengths of each of the cliffs located directly or partially above the proposed longwalls in Area 5 range between 20 m and 200 m. It is noted that the longer clifflines comprise many separate cliffs and minor cliffs and are intermittently discontinuous. The total length of cliffs located directly or partially above the proposed longwalls is approximately 2.2 km.

The lengths of each of the cliffs located outside the proposed longwalls in Area 5 and within the 35° angles of draw range between 20 m and 165 m. The total length of these cliffs is approximately 1.7 km.

The maximum heights of each of the cliffs located directly or partially above the proposed longwalls vary between 10 m and 25 m. The maximum heights of each of the cliffs located outside the proposed longwalls in Areas 5 and 6 and within the 35° angles of draw vary between 10 m and 20 m.

The cliffs have formed predominantly from Hawkesbury Sandstone, with the faces being at various stages of weathering and erosion. The cliffs have many overhangs and undercuts that are generally less than 6 m. Photographs of the typical cliffs within the Study Area are provided in Fig. 5.17.

Fig. 5.17 Typical cliffs within the Study Area

The minor cliffs are generally located outside of the proposed longwalls. The lengths of each of the minor cliffs typically range between 20 m and 100 m and have heights up to 10 m. There are also many rock outcrops and rock platforms that are located across the Study Area. The rock outcrops are generally less than 5 m in height.

5.8.2. Predictions for the cliffs

The maximum predicted total conventional subsidence parameters for each of the cliffs located within the Study Area (based on the 35° angle of draw) is provided in Table D.01, in Appendix D. A summary of the maximum predicted total vertical subsidence, tilt and curvatures for these cliffs is provided in Table 5.14. The values are the maxima within 20 m of the mapped extents of each of the cliffs.

Table 5.14 Maximum predicted total vertical subsidence, tilt and curvatures for the cliffs

Mining area	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 5	2000	25	0.50	0.50
Area 6	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted tilt for the cliffs is 25 mm/m (i.e. 2.5 %, or 1 in 40). The maximum predicted curvatures for the cliffs are 0.50 km^{-1} hogging and sagging, which represent a minimum radius of curvature of 2 km.

The maximum predicted conventional strains for the cliffs located directly or partially above the longwalls, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 7.5 mm/m tensile and compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls in Area 5 is described in Section 4.4.1. The predicted strains directly above the proposed longwalls are 4 mm/m tensile and 5 mm/m compressive based on the 95 % confidence levels.

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

The cliffs located outside the proposed longwalls and within the 35° angle of draw are predicted to experience strains typically less than 0.5 mm/m tensile and compressive.

The remaining cliffs located outside the 35° angle of draw are predicted to experience less than 20 mm vertical subsidence. Whilst these cliffs could experience very low-levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

5.8.3. Comparison of the predictions for the cliffs

Cliffs are located directly or partially above the previously extracted longwalls in Areas 1, 2 and 3A at the Mine. The comparison of the maximum predicted total subsidence parameters for the cliffs is provided in Table 5.15.

Table 5.15 Comparison of the maximum predicted subsidence parameters for the cliffs

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 1	2800	20	0.35	0.75
Area 2	1275	17	0.50	0.60
Area 3A	700	13	0.20	0.06
Area 5	2000	25	0.50	0.50
Area 6	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted subsidence parameters for the cliffs located directly above the proposed longwalls in Area 5 are similar to the range of predicted movements for the cliffs located directly above the previously extracted longwalls in Areas 1, 2 and 3A at the Mine. The maximum predicted subsidence parameters for the cliffs located in Area 6 are considerably less than the maximum predicted movements for the cliffs in the previous mining areas at the Mine.

5.8.4. Impact assessments for the cliffs

The total length of cliffs that are located directly or partially above the proposed longwalls in Area 5 is approximately 2.2 km. These cliffs are predicted to experience mine subsidence movements up to: 2000 mm vertical subsidence, 25 mm/m tilt and 0.50 km^{-1} hogging and sagging curvature.

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

The likelihood of instabilities for the cliffs located directly or partially above the proposed longwalls in Area 5 has been assessed using the previous experience of mining beneath cliffs at the Mine. The cliffs located above the previously extracted longwalls in Area 1 are the most relevant case study.

LW1 and LW2 at the Mine had void widths of 250 m and a solid chain pillar width of 50 m. The longwalls were extracted from the Wongawilli Seam, at depths of cover varying between 170 m and 320 m and were also located beneath existing bord and pillar workings in the overlying Bulli Seam, i.e. partial multi-seam mining conditions. The maximum predicted conventional curvatures, resulting from the extraction of these longwalls, were 0.35 km^{-1} hogging and 0.75 km^{-1} sagging.

These longwalls were extracted directly beneath a ridgeline and rock falls were observed in eight locations directly above mining. The total length of disturbance resulting from the extraction of LW1 and LW2 was approximately 135 m to 175 m. The total plan length of ridgeline located directly above the longwalls was between approximately 1800 m to 2000 m. It should be noted that there are two levels of cliffs in some locations and, therefore, the total length of cliffline is greater than the total plan length of the ridgeline.

The length of ridgeline disturbed due to the extraction of LW1 and LW2 was, therefore, estimated to be between 7 % and 10 % of the total plan length of ridgeline directly above the longwalls. The length of rockfalls that occurred due to the extraction of LW1 and LW2 was, however, less than the length of disturbed ridgeline.

Based on the experience in Area 1 at the Mine, it has been estimated that between 7 % and 10 % of the total length, or between 3 % and 5 % of the total face area of the cliffs located directly or partially above the proposed longwalls in Area 5 would be impacted. This represents a total length of impact of approximately 150 m to 220 m, or a total face area of impact of approximately 800 m^2 to 1400 m^2.

The remaining cliffs located outside the extents of the proposed longwalls and within the 35° angle of draw are predicted to experience vertical subsidence of less than 100 mm. These cliffs are predicted to experience only low-levels of tilt, curvature and strain. Rock falls could occur at some of the cliffs located outside the extents of the proposed longwalls, which would represent less than 1 % of the affected cliffs. It is estimated that these impacts would affect a total length of less than 20 m or a face area of less than 100 m^2.

It is unlikely that the cliffs located outside the 35° angle of draw would experience adverse impacts due to their distances outside of the mining areas. This is based on the extensive experience of mining near to but not directly beneath cliffs in the NSW coalfields, where no large cliff falls have occurred when the cliffs are located completely outside the angle of draw from mining. It is still possible, but unlikely, that rock falls could occur due to mining, natural processes, or both.

5.8.5. Recommendations for the cliffs

It is recommended that a Landscape Management Plan be developed for Areas 5 and 6 to monitor and manage any impacts that result from cliff instabilities.

5.9. Rock outcrops and steep slopes

5.9.1. Descriptions of the rock outcrops and steep slopes

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

The areas identified as having steep slopes are shown in Drawing No. MSEC856-18.

The steep slopes within the Study Area have been identified within the alignments of the streams. The slopes are steepest along the lower reaches of the streams, outside the extents of the proposed longwalls, with natural grades up to approximately 1 in 1 (i.e. 45° or 100 %). The steep slopes located directly above the proposed longwalls have natural grades typically of up to 1 in 1.5 (i.e. 34°, or 67 %).

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

Photographs of typical rock outcropping located within the Study Area are provided in Fig. 5.18.

Fig. 5.18 Typical rock outcropping within the Study Area

5.9.2. Predictions for the rock outcrops and steep slopes

The rock outcrops and steep slopes are located across the Study Area and are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted values of total vertical subsidence, tilt and curvatures for the rock outcrops and steep slopes is provided in Table 5.16.

Table 5.16 Maximum predicted total vertical subsidence, tilt and curvatures for the rock outcrops and steep slopes

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Rock outcrops and steep slopes	2450	25	0.50	0.60

The maximum predicted tilt for the rock outcrops and steep slopes is 25 mm/m (i.e. 2.5 %, or 1 in 40). The maximum predicted curvature for these features are 0.50 km^{-1} hogging and 0.60 km^{-1} sagging, which represent minimum radii of curvature of 2 km and 1.7 km, respectively.

The maximum predicted conventional strains for the rock outcrops and steep slopes, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 7.5 mm/m tensile and 9 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted strains directly above the proposed longwalls, based on the 95 % confidence levels, are 4 mm/m tensile and 5 mm/m compressive in Area 5, and 6 mm/m tensile and compressive in Area 6.

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

5.9.3. Comparison of predictions for the rock outcrops and steep slopes

Rock outcrops and steep slopes are located directly above the previously extracted longwalls in Areas 1, 2, 3A and 3B at the Mine. The comparison of the maximum predicted total subsidence parameters for these features is provided in Table 5.17.

Table 5.17 Comparison of the maximum predicted subsidence parameters for the rock outcrops and steep slopes

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 1	2800	20	0.35	0.75
Area 2	1275	17	0.50	0.60
Area 3A	3600	50	1.4	1.4
Area 3B	3600	50	1.4	1.4
Area 5	2050	25	0.50	0.60
Area 6	2450	20	0.30	0.50

The maximum predicted subsidence parameters for the rock outcrops and steep slopes located in Areas 5 and 6 are similar to the predicted movements for these features located directly above the previously extracted longwalls in Area 1 at the Mine. The maximum predicted subsidence parameters for these features are less than the maximum predicted movements for Areas 3A and 3B at the Mine.

5.9.4. Impact assessments for the rock outcrops and steep slopes

The maximum predicted tilt for the rock outcrops and steep slopes within the Study Area is 25 mm/m (i.e. 2.5 %, or 1 in 40). The predicted changes in grade are very small when compared to the natural surface grades, which are greater than 1 in 3. It is unlikely, therefore, that the mining-induced tilts would result in an adverse impact on the stability of the rock outcrops or steep slopes.

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

The maximum predicted total curvatures for the rock outcrops and steep slopes within the Study Area are 0.50 km^{-1} hogging and 0.60 km^{-1} sagging. The maximum predicted curvatures and strains for these features are similar to those predicted to have occurred for LW1 and LW2, which mined directly beneath a ridgeline comprising cliffs, rock outcrops and steep slopes. The impacts observed from this case study, therefore, can be used to provide an indication of the potential impacts on the rock outcrops and steep slopes located within the Study Area.

LW1 and LW2 mined directly beneath a ridgeline where steep slopes had natural surface gradients of up to 1 in 1 (i.e. 100 %, or an angle to the horizontal of 45°). A number of surface cracks were observed along the steep slopes located directly above LW1 and LW2 which are shown in Fig. 5.19.

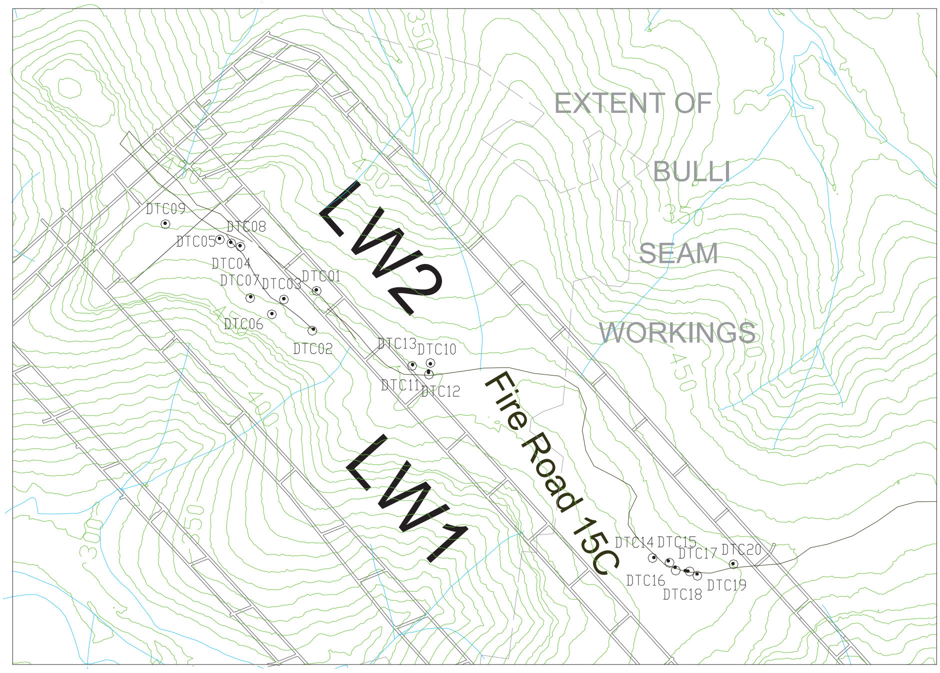

Fig. 5.19 Locations of observed surface cracking above LW1 and LW2 at the Mine

The largest surface cracks observed in Area 1 at the Mine occurred along the top of the ridgeline, having widths of up to 400 mm, which were associated with downslope movement of the surface soils. Additional surface cracks, typically in the order of 100 mm to 150 mm in width, were also observed further down the ridgeline and the steep slopes.

Photographs of the surface cracking at the Mine are provided in Fig. 5.20.

Fig. 5.20 Surface tension cracking due to downslope movements at the Mine

It is expected, therefore, that the downslope movement of the ground would also occur along rock outcrops and steep slopes within the Study Area. The steep slopes are heavily vegetated and natural erosion due to soil instability (i.e. natural downslope movements) was not readily apparent from the site investigations undertaken. If tension cracks were to develop, due to the extraction of the proposed longwalls, it is possible that soil erosion could occur if these cracks were left untreated.

It is possible, therefore, that some remediation might be required, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the surface soils in the longer term. Similarly, where cracking restricts the passage of vehicles along the tracks and fire trails that are required to be open for access, it is recommended that these cracks are treated in the same way.

5.9.5. Recommendations for the rock outcrops and steep slopes

It is recommended that a Landscape Management Plan be developed for Areas 5 and 6 to monitor and manage any impacts on the rock outcrops and steep slopes.

5.10. Escarpments

There are no escarpments located within the Study Area. The *Illawarra Escarpment* is located more than 12 km to the east of the proposed longwalls. At this distance, the escarpment is not expected to experience measurable mine subsidence movements or adverse impacts due to the extraction of the proposed longwalls.

5.11. Land prone to flooding and inundation

The catchment areas of the streams within the Study Area are relatively small and the land drains freely into the Avon Reservoir, the Avon River, Donalds Castle Creek and the Cordeaux River. There are no major flood prone areas identified within the Study Area. The predicted changes in the surface levels of the streams, resulting from the extraction of the proposed longwalls, will have only a marginal effect on their natural gradients, and hence, on their discharge characteristics.

5.12. Swamps, wetlands and water related ecosystems

5.12.1. Descriptions of the swamps

The locations of the upland swamps are shown in Drawing No. MSEC856-12. The locations and extents of the upland swamps have been interpreted from detailed aerial photogrammetry and site inspections.

There are 37 upland swamps that have been identified partially or entirely within the Study Area based on the 35° angle of draw and 9 additional swamps that are located partially or entirely within the Study Area based on the 600 m boundary. There are 26 upland swamps that are partially or entirely located above the proposed longwalls and the remaining 20 swamps are located outside the extents of the proposed longwalls.

The details of the upland swamps located within the Study Area is provided in Table D.02, in Appendix D. A summary of these swamps is provided in Table 5.18.

Table 5.18 Upland swamps within the Study Area

Location	Total number located within the Study Area based on 35° angle of draw	Total number located within the Study Area based on 600 m boundary	Number located directly above the proposed longwalls	Number located outside the proposed longwalls
Area 5	25	28	21	7
Area 6	12	18	5	13
Total	37	46	26	20

The upland swamps can be categorised into two geomorphological types, the *valley infill* swamps that form within the drainage lines, and *headwater* swamps that form within relatively low sloped areas of weathered Hawkesbury Sandstone where hillslope aquifers exist.

Photographs of a typical valley infill swamp are provided in Fig. 5.21, showing Swamp Den104. Photographs of typical headwater swamps are provided in Fig. 5.22, showing Swamp Den99 (left side) and Swamp Den105 (right side).

Fig. 5.21 Photographs of Swamp Den104 (valley infill swamp)

Fig. 5.22 Photographs of Swamps Den99 and Den105 (headwater swamps)

Further descriptions of the swamps are provided in the report by the specialist ecology consultant on the Project.

5.12.2. Predictions for the swamps

The maximum predicted total conventional subsidence parameters for each of the swamps located within the Study Area is provided in Table D.02, in Appendix D. A summary of the maximum predicted total vertical subsidence, tilt and curvatures for these swamps is provided in Table 5.19. The values are the maxima within 20 m of the mapped extents of each of the swamps.

Table 5.19 Maximum predicted total vertical subsidence, tilt and curvatures for the swamps

Mining area	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 5	1800	19	0.40	0.40
Area 6	2300	18	0.20	0.45

The maximum predicted tilt for the swamps is 19 mm/m (i.e. 1.9 %, or 1 in 53). The maximum predicted curvatures for the swamps are 0.40 km^{-1} hogging and 0.45 km^{-1} sagging, which represent minimum radii of curvatures of 2.5 km and 2.2 km, respectively.

The maximum predicted conventional strains for the swamps located directly or partially above the longwalls, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 6 mm/m tensile and 7 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted strains directly above the proposed longwalls, based on the 95 % confidence levels, are 4 mm/m tensile and 5 mm/m compressive in Area 5, and 6 mm/m tensile and compressive in Area 6.

The valley infill swamps are located along the alignments of the streams and, therefore, could experience valley related effects. Some headland swamps are located on the valley sides and these could also experience part of the valley related effects.

The maximum predicted upsidence and closure for each of the swamps located within the Study Area is provided in Table D.02, in Appendix D. It is noted that the conventional closures are provided separately to the valley related closures, as the associated conventional strains are distributed across the longwalls, as opposed to the valley related compressive strains which are concentrated in the valley bases. Also, in most cases, the valley related closures and conventional closures are orientated obliquely to each other.

A summary of the maximum predicted upsidence, valley closure and conventional closure for the swamps is provided in Table 5.20. The values are the maxima along the alignments of the streams within the extents of the swamps.

Table 5.20 Maximum predicted additional upsidence and closure for the swamps

Location	Maximum predicted total upsidence (mm)	Maximum predicted total valley related closure (mm)	Maximum predicted total conventional closure (mm)
Area 5	525	575	275
Area 6	350	350	200

The predicted valley related movements provided in the above table are the maxima which occur in the bases of the streams within the extents of the swamps. The headwater swamps are located partly up the valley sides and, therefore, in these cases the predicted upsidence and closure movements for these swamps are less than the maxima provided in the above table.

The valley infill swamps located directly above the proposed longwalls could experience compressive strains in the order of 10 mm/m to 20 mm/m due to the predicted valley related movements. The swamps located within the 35° angle of draw from the proposed longwalls could experience compressive strains in the order of 2 mm/m to 5 mm/m.

5.12.3. Previous experience of mining beneath swamps

Discussions on the previous experience of mining beneath swamps at the Mine and at other nearby collieries are provided below. These discussions relate to the reported physical impacts, which include surface cracking and fracturing of bedrock at the swamps. The detailed discussions on the environmental consequences are provided by the other specialist consultants on the Project.

- *Area 2*

  LW4 and LW5 were extracted directly beneath Swamp Den01, which is both a headwater and valley infill swamp located along Drainage Line A2-14. Cracking was observed within the extent of the swamp in three locations and fracturing was observed in the downstream rockbar. A photograph of the fracturing in the downstream rockbar is provided in Fig. 5.23.

Fig. 5.23 Photograph of the fracturing in the rockbar downstream of Swamp Den01 (Source: IC)

  Whilst reductions in groundwater levels in the soil were observed in the swamp and the upstream hillslope aquifer, the groundwater levels have responded to significant recharge events. Based on the observations to date, there has been no erosion or other physical changes observed within Swamp Den01 resulting from the mining in Area 2.

- *Area 3A*

  LW7 was extracted directly beneath Swamp Den12, which is a headwater swamp located on the valley side of Drainage Line WC17. One fracture was identified in a rock outcrop after mining beneath this swamp. Regular monitoring has been undertaken and, to date, no erosion or other physical changes in the swamp have been observed. Four piezometers have been installed in and around the swamp to measure shallow groundwater levels within the sediments above the sandstone bedrock. One of the piezometers has measured a reduction in the groundwater level, two of the piezometers show no change and one is providing poor quality data.

- *Area 3B*

  LW9 was extracted directly beneath Swamp 5, which is a valley infill swamp located along the alignment of Donalds Castle Creek. The impacts to this swamp were described in the End of Panel Report (IC, 2014) which stated "*Site DA3B_LW9_006: Multiple fractures and uplift on DC_RB33 at basal step of Swamp 5; up to 0.015m wide, 2m long and 0.040m of uplift. Exfoliation from the step. Associated flow diversion" and "TARP triggers in relation to shallow groundwater levels (reduction and recession rates) in Swamps 1a, 1b and Swamp 5 were also reported during Longwall 9 extraction*".

  Impacts were also observed to the swamps due to the extraction of LW10 to LW13 which were described in each of the End of Panel Reports (IC, 2015, 2016, 2017 and 2018). The groundwater levels were lower than baseline and recession rates greater than baseline for Swamps 3, 5, 10 and 11. Soil moisture levels below baseline were also reported in Swamps 5 and 11.

- *Elouera and other collieries*

  Elouera Colliery LW1 to LW10 mined beneath a total of 10 swamps, which includes both valley infill and headwater swamps. Erosion was identified in Swamp 18 after bushfires in the summer of 2001 to 2002, which was then followed by a series of storm events. Swamp 19 was also impacted by these bushfires.

  An investigation into the potential effects of longwall mining on these swamps, as well as other swamps on the Woronora Plateau, was undertaken by Tomkins and Humphreys (2006) and the report 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 report also stated that:

  > "*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*".

5.12.4. Impact assessments for the swamps

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

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

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

The maximum predicted tilt for the swamps within the Study Area is 19 mm/m (i.e. 1.9 %, or 1 in 53). The mining-induced tilts are small when compared with the natural gradients within the swamps. This is illustrated in Fig. 5.8 to Fig. 5.16, which show the natural and predicted post-mining grades along the drainage lines and, hence, for the valley infill swamps. These figures show that the predicted post-mining grades are generally similar to the natural grades and that there are no predicted reversals in grade in the locations of the swamps. The headwater swamps are located on the sides of the valleys and, therefore, natural gradients are greater than those along the drainage lines.

It is unlikely, therefore, that there would be large-scale adverse changes in the levels of ponding or scouring of the swamps based on the predicted vertical subsidence and tilt.

Further discussions on the potential impacts due to changes in surface water flows and storage are provided by the specialist surface water consultant in the report by Hydro Engineering and Consulting (2019) and the specialist ecology consultant in the reports by Cardno (2019) and Niche (2019a).

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 that are located outside the extents of the proposed longwalls (8 in Area 5 and 13 in Area 6) are predicted to generally 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 significant fracturing.

Fracturing has been observed in streams located outside the extents of previously extracted longwalls in the NSW coalfields. Fracturing has been observed up to 400 m from longwalls; however, these have occurred within large valleys and have not resulted in adverse impacts. Hence, it is possible that 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 adverse surface impacts on these swamps.

The swamps that 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 bedrock beneath these swamps.

The estimated fracture widths in the topmost bedrock beneath the swamps, based on the maximum predicted conventional tensile strains between 4 mm/m and 6 mm/m and based on a typical joint spacing of 10 m, are in the order of 40 mm to 60 mm. In some cases, a series of smaller fractures, rather than one single fracture, would develop in the topmost bedrock. Fracturing would only be visible at the surface where the bedrock is exposed, or where the thickness of the overlying sediment is relatively shallow.

The distribution of soil cracks and rock fractures in Areas 2, 3A and 3B is illustrated in Fig. 4.5. The measured surface deformations were generally less than 50 mm in width (i.e. 86 % of the cases). However, the widths of the surface deformations were between 50 mm and 150 mm in 8 % of cases, between 150 mm and 300 mm in 4 % of cases and greater than 300 mm in 2 % of cases. The maximum measured crack width was approximately 500 mm which was the result of downslope movement along a steep slope.

The soil crack and rock fracture widths due to the extraction of the proposed longwalls in Areas 5 and 6 are expected to be less, on average, than those previously measured at the Mine due to the lower predicted mine subsidence movements.

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

The valley related upsidence movements could result in the dilation of the strata beneath the valley infill swamps. It has been observed that the depth of fracturing and dilation of the uppermost bedrock, resulting from valley related movements, is generally in the order of 10 m to 15 m (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 valley infill 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 discussions on the potential impacts due to changes in the surface water flows, groundwater and the environmental consequences are provided by the specialist surface water, groundwater and ecology consultants on the Project.

5.12.5. Recommendations for the swamps

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

- Install subsidence monitoring lines in the vicinity of the swamps to measure the subsidence movements during mining. The locations of the 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 of the mining to the swamps;
- Compare the observed ground movements with those predicted during active subsidence and at the completion of each longwall;
- Establish appropriate surface water and groundwater monitoring programs for the swamps, based on the recommendations from the specialist surface and groundwater consultants on the Project; and
- Develop a Trigger Action Response Plan (TARP), based on the ground, visual, surface water and groundwater monitoring programs. Similar TARPs have been established for swamps which have been previously mined beneath at the Mine.

Management plans have been developed for the swamps which have been previously mined beneath at the Mine. It is recommended, that the existing management strategies and the methods of remediation are reviewed, based on the assessments provided in this report and the reports by other specialist consultants.

5.13. Flora and fauna

The land above the proposed longwalls consists of undisturbed native bush, as shown in Fig. 1.2. Only limited clearing has been undertaken for the tracks, fire trails and the easements within the Study Area. The descriptions of the flora and fauna within the Study Area are provided by the specialist ecology consultant on the Project.

The potential for impacts on the natural vegetation are dependent on the surface cracking, changes in surface water and changes in groundwater. The assessment of the physical impacts due to the proposed longwalls are provided in Sections 4.8 and 5.1 to 5.12. The assessments of the environmental consequences have been provided by the other specialist consultants on the Project.

5.14. State Conservation Areas

The Upper Nepean State Conservation Area is shown in Drawing No. MSEC856-01. The conservation area is partially located within the Study Area for Area 5 and it is located outside and to the west of the Study Area for Area 6.

The surface area of the Upper Nepean State Conservation Area that is located within the Study Area is 16.1 hectares (ha) based on the 35° angle of draw and is 70.9 ha based on the 600 m boundary. The conservation area is located outside the extents of the proposed longwalls. The boundary of the Upper Nepean State Conservation Area is located just north of the maingate of the proposed LW508B. The boundary of the conservation area is located at a distance of 900 m from LW602A, at its closest point to the proposed longwalls in Area 6.

The maximum predicted vertical subsidence within the boundary of the Upper Nepean State Conservation Area is 100 mm. The surface area of the conservation area that is located within the predicted limit of vertical subsidence (i.e. 20 mm subsidence contour) is less than 0.2 ha. There is a ridgeline where the Upper Nepean State Conservation Area is located adjacent to the proposed LW508B. Low-level vertical subsidence could therefore extend further into the conservation area due to the presence of this ridgeline.

Surface cracking could occur on the sides of this ridgeline due to the horizontal movements towards the mining area and in the downslope direction. The surface crack widths within the Upper Nepean State Conservation Area could have widths in the order of 25 mm to 50 mm. The surface cracking on the side of the ridgeline could occur within a distance of 50 m to 100 m of the maingate of LW508B.

The tributaries within the Upper Nepean State Conservation Area located closest to the proposed mining area could also experience valley related upsidence and closure movements. Fracturing could occur up to approximately 400 m from the proposed longwalls. The total length of the tributaries that are located within the conservation area and within 400 m of the proposed longwalls is less than 0.5 km.

Whilst fracturing has been observed up to around 400 m from longwall mining in the Southern Coalfield, these have occurred within large and incised valleys. The tributaries within the Upper Nepean State Conservation Area that are located closest to the proposed mining area are near the top of the ridgeline (i.e. upper reaches with small valley heights) and, therefore, it is less likely that mining-induced fracturing would occur at these distances from the longwalls.

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

6.1. Railway infrastructure

6.1.1. Description of the disused railway corridor

There are no operating railways within the Study Area. The disused Maldon-Dombarton Railway Corridor crosses the proposed longwalls in Area 5. The location of this corridor is shown in Drawing No. MSEC856-19. At the time of abandoning the work, the major earthworks had been completed, but no tracks or associated equipment had been installed. Any future plans for the corridor remain uncertain and are the subject of continuing review.

The locations of the cuttings and embankments along the disused railway corridor are shown in Drawing No. MSEC856-19. Photographs of the disused railway corridor and cutting are provided in Fig. 6.1, the embankment are provided in Fig. 6.2 and the drainage culvert are provided in Fig. 6.3.

Fig. 6.1 Photographs of the disused railway corridor and cutting

Fig. 6.2 Photographs of the embankment

Fig. 6.3 Photographs of drainage culvert

6.1.2. Predictions for the disused railway corridor

The predicted profiles of vertical subsidence, tilt and curvature along the disused railway corridor are shown in Fig. C.18, in Appendix C. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines. The predicted total profiles after the completion of the approved longwalls in Area 3B are shown as cyan lines.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the disused railway corridor is provided in Table 6.1. The values are the maxima anywhere along the section of the corridor located within the Study Area.

Table 6.1 Maximum predicted total vertical subsidence, tilt and curvature for railway corridor

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Railway corridor	1450	14	0.20	0.30

The maximum predicted tilt for the disused railway corridor is 14 mm/m (i.e. 1.4 %, or 1 in 71). The maximum predicted curvatures for the corridor are 0.20 km^{-1} hogging and 0.30 km^{-1} sagging, which represent minimum radii of curvatures of 5 km and 3.3 km, respectively.

The maximum predicted conventional strains for the disused railway corridor, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 3 mm/m tensile and 4.5 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls in Area 5 is described in Section 4.4.1. The predicted strains directly above the proposed longwalls are 4 mm/m tensile and 5 mm/m compressive based on the 95 % confidence levels.

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

6.1.3. Comparison of the predictions for the disused railway corridor

The disused railway corridor crosses directly above LW10 to LW18 in Area 3B. The comparison of the maximum predicted total subsidence parameters for the disused railway corridor is provided in Table 6.2.

Table 6.2 Comparison of the maximum predicted total subsidence parameters for the disused railway corridor

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 3B	3000	25	0.40	0.50
Area 5	1450	14	0.20	0.30

The maximum predicted subsidence parameters for the section of the disused railway corridor that is located within the Study Area are less than the maximum predicted values for the section that is located above the completed and approved longwalls in Area 3B.

The predicted subsidence parameters for the proposed longwalls are less, due to the mining heights along the alignment of the railway, of 2.5 m to 2.7 m in Area 5, being less than the mining heights of 3.9 m to 4.6 m in Area 3B. The proposed longwalls will also be extracted from the Bulli Seam and, therefore, there is less subsidence due to pillar compression when compared to that for the current mining in the Wongawilli Seam.

6.1.4. Impact assessments for the disused railway corridor

The formation and ballast have been constructed, however, there is no track along the section of the disused railway corridor within the Study Area. The other associated infrastructure above the proposed longwalls are a cutting, embankment and drainage culvert.

The maximum predicted tilt for the disused railway corridor is 14 mm/m (i.e. 1.4 %, or 1 in 71). The predicted changes in grade are very small and unlikely to adversely impact on the surface water drainage along the corridor. The maximum predicted tilt is also considerably less than the as-built grades of the cutting and embankment, which are in the order of 1 in 1 and, therefore, is unlikely to result in adverse impacts on the stability of these features.

The maximum predicted curvatures and strains for the disused railway corridor could be sufficient to result in cracking in the cutting and embankment. These features have relatively flat batters, in the order of 1 in 1 and, therefore, is it unlikely that their stability would be adversely impacted. The cutting is stabilised to some extent by vegetation and the embankment is stabilised by boulders and large rocks.

Whilst the surface cracking in the cutting and embankment are not expected to be extensive, it is possible that soil erosion channels could develop at the larger cracks if these were left untreated. Surface cracking can be identified in the cutting and embankment by visual inspections during active subsidence.

The predicted final tilt at the drainage culvert is 5 mm/m (i.e. 0.5 %, or 1 in 200). The mining-induced tilt could adversely impact the serviceability of the drainage culvert, by reducing or reversing the as-built grade and potentially affecting the flow of water through it. If increased ponding were to occur upstream of the culvert, it may be necessary to reconstruct or relevel it.

The maximum predicted subsidence parameters and, hence, the potential for impacts on the section of the disused railway corridor within Area 5 are less than those for the section within Area 3B. There have been no impacts on the disused railway corridor, other than minor cracking, buckling and increased ponding, due to the extraction of LW9 and LW13 in Area 3B. It is expected, therefore, that the disused railway corridor would only experience minor impacts due to the extraction of the proposed longwalls in Area 5, similar to that previously observed along the corridor.

If the railway were to be completed prior to active subsidence, the track and associated infrastructure could be managed using strategies similar to that adopted for the Main Southern Railway at Appin and Tahmoor Collieries. The management strategies could include the installation of rail expansion switches, zero toe load clips and real-time rail stress monitoring during active subsidence.

6.1.5. Recommendations for the disused railway corridor

It is recommended that periodic visual inspections of the disused railway corridor are undertaken during active subsidence. The larger surface cracking in the embankment and cutting should be remediated if there is potential for long term erosion. With the appropriate management strategies in place, it is unlikely that there would be more than negligible impacts on the use of the corridor due to the proposed mining.

If the railway were to be completed prior to active subsidence, a management plan should be developed similar to the approved management plans for the Main Southern Railway at Appin and Tahmoor Collieries. The plan should include preventive measures and monitoring during active subsidence so that the railway could be maintained in safe and serviceable conditions during and after the mining period.

6.2. Picton Road

Picton Road is located outside and to the east of the proposed longwalls in Area 6. This road is 160 m from LW604 at its closest point to the proposed longwalls. The total length of Picton Road located within the Study Area based on the 35° angle of draw is approximately 1.5 km. The location of this road is shown in Drawing No. MSEC856-19.

The section of Picton Road within the Study Area comprises a single carriageway with a flexible asphalt pavement and grass verges. Photographs of this road at the intersection with the access road to the Cordeaux Dam picnic area are provided in Fig. 6.4.

Fig. 6.4 Picton Road at the intersection with the access road to the Cordeaux Dam Picnic Area

Picton Road is predicted to experience less than 20 mm vertical subsidence due to the proposed longwalls. Whilst the road could experience very low-levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains.

The road crosses the upper reaches of a drainage line approximately 0.4 km east of the maingate of the proposed LW604. Only low-level valley related effects would be expected along this small drainage line at this distance from the proposed mining area.

Roads and Maritime Services (RMS) is proposing to widen Picton Road to four lanes. The widened road would still be predicted to experience less than 20 mm vertical subsidence and only low-level valley related effects, due to its distance from the proposed mining area.

It is unlikely, therefore, that Picton Road would experience adverse impacts due to the proposed longwalls.

It is recommended that a Picton Road Management Plan be developed, in consultation with RMS, that includes ground monitoring and periodic visual inspections of the road during the extraction of LW604 and LW605. The management plan could be developed similar to the approved plan for the M1 Princes Motorway near Metropolitan Colliery.

6.3. Unsealed roads and tracks

There are unsealed fire trails and four-wheel drive tracks located across the Study Area, which are used by WaterNSW and other groups for access to the catchment, fire-fighting and other activities. The locations of the unsealed roads and tracks are shown in Drawing No. MSEC856-19. A photograph of a typical track within the Study Area is provided in Fig. 6.5.

Fig. 6.5 Photograph of a typical track within the Study Area

There are small drainage culverts located across the Study Area associated with the unsealed fire trails and four-wheel drive tracks. The culverts comprise small concrete pipes which are located at the drainage line crossings.

The unsealed roads and tracks are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted mine subsidence parameters within the Study Area was provided in Chapter 4.

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

It is expected that cracking, rippling and stepping of the unsealed road surfaces would occur as each of the proposed longwalls mine beneath them. The predicted subsidence parameters for the proposed longwalls are less than those predicted for the previously extracted longwalls in Areas 3A and 3B. The potential impacts on the unsealed roads and tracks within the Study Area, therefore, are expected to be less than the levels of impacts that occurred for the road and tracks previously mined beneath at the Mine.

The surface cracking and stepping along the unsealed roads and tracks in Areas 3A and 3B typically varied between 50 mm and 300 mm, with widths and heights greater than 300 mm in some locations. The sizes and extents of the surface deformations are dependent on how they manifest. In some cases, the impacts comprise a series of smaller cracks and, in other cases, the deformations concentrate as a single larger crack. The impacts on the unsealed roads and tracks were repaired by regrading and recompacting the road surfaces. Examples of the impacts on unsealed roads and tracks in Areas 3A and 3B are provided in Fig. 6.6 (Source: IC).

Fig. 6.6 Impacts along the unsealed roads and tracks above LW6 in Area 3A (left side) and above LW11 in Area 3B (right side) (Source: IC)

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

6.4. Gas infrastructure

6.4.1. Description of the gas infrastructure

There are two natural gas pipelines owned by Jemena Gas Pipeline that are located within an easement on the western side of Picton Road. The easement crosses directly above the northern end of the proposed LW604. The total length of the easement located directly above the longwall is approximately 0.9 km. The locations of the gas pipelines are shown in Drawing No. MSEC856-19.

The Eastern Gas Pipeline is located on the western side of the easement and was constructed in the year 2000. This pipeline is a fully welded steel pipeline, 450 mm in diameter, laid below ground with a minimum cover of 600 mm. The second gas pipeline located on the eastern side of the easement was completed prior to 1976 and forms part of the Sydney Region Trunk Distribution System. This pipeline is a fully welded steel pipeline, 864 mm in diameter, which is laid below ground with a minimum cover of 800 mm.

The sections of these pipelines located further to the north of the Study Area, within the Appin and Campbelltown Mine Subsidence Districts, were designed to accommodate mine subsidence movements. However, it is understood that the sections of the pipelines that are located within the Study Area have not been designed for mine subsidence.

6.4.2. Predictions for the gas infrastructure

The predicted profiles of vertical subsidence, tilt and curvature along the gas pipeline easement are shown in Fig. C.19, in Appendix C. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the gas pipeline easement is provided in Table 6.3. The values are the maxima anywhere along the section of the easement located within the Study Area.

Table 6.3 Maximum predicted total vertical subsidence, tilt and curvature for the gas pipeline easement

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Gas pipeline easement	900	9	0.20	0.08

The maximum predicted tilt for the gas pipeline easement is 9 mm/m (i.e. 0.9 %, or 1 in 110). The maximum predicted curvatures for the easement are 0.20 km^{-1} hogging and 0.08 km^{-1} sagging, which represent minimum radii of curvatures of 5 km and 13 km, respectively.

The maximum predicted conventional strains for the gas pipeline easement, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 3 mm/m tensile and 1 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls in Area 6 is described in Section 4.4.2. The predicted strains directly above the proposed longwalls are 6 mm/m tensile and compressive based on the 95 % confidence levels.

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

6.4.3. Impact assessments for the gas infrastructure

The gas pipelines are under pressure and, therefore, are not adversely affected by vertical subsidence or tilt. The pipelines are direct buried and, therefore, could experience the full range of predicted curvatures and strains due to the proposed longwalls. Without mitigation measures, the mining-induced bending and axial loads have the potential to reduce the allowable operating pressures of the pipelines.

These natural gas pipelines have been previously directly mined beneath by LW404 to LW407 at Appin Colliery and by LW30 to LW35 at West Cliff Colliery. The predicted curvatures for the sections of the pipelines located above these previously extracted longwalls were between 0.05 km^{-1} and 0.10 km^{-1} and, therefore, are similar orders of magnitude as those predicted for the sections of the pipelines located within the Study Area. The measured strains were typically between 1 mm/m and 2 mm/m, however, localised and elevated compressive strains between 5 mm/m and 18 mm/m occurred at the stream crossings.

Numerical analyses of the sections of the natural gas pipelines at Appin and West Cliff Collieries were undertaken prior to active subsidence. It was found that the pipelines could accommodate the conventional mine subsidence movements without having to reduce the allowable operating pressures. However, these pipelines could not accommodate the localised compressive strains at the stream crossings. The potential impacts on these pipelines were managed by:

- uncovering and exposing the sections of the pipelines located within the larger stream valleys;
- temporarily supporting on sandbags to isolate them from the mining induced ground movements;
- monitoring the mine subsidence movements using a ground monitoring line;
- monitoring the pipe stresses using strain gauges; and
- the implementation of a Trigger Action Response Plan (TARP) where preventive measures are undertaken when prescribed triggers have been reached, such as adjusting the profiles of the pipelines using sandbags or by reducing the operating pressures.

The sections of the natural gas pipelines within the Study Area follow a ridgeline and do not cross any large streams. It is unlikely, therefore, that these pipelines would experience elevated compressive strains due to valley related effects. However, the pipelines could still experience localised and elevated strains due to anomalous movements.

These pipelines may be able accommodate the conventional ground movements due to the proposed longwalls based on the experience at Appin and West Cliff Collieries. It is recommended, however, that a numerical analysis of the natural gas pipelines is undertaken based on the predicted subsidence movements. If the numerical analysis were to find that the pipelines could not accommodate the predicted mine subsidence movements, then the potential impacts could be managed using similar strategies to those adopted at Appin and West Cliff Collieries.

6.4.4. Recommendations for the gas infrastructure

It is recommended that a numerical analysis of the natural gas pipelines be undertaken based on the predicted mine subsidence movements due to the proposed longwalls. It is also recommended that management strategies are developed, in consultation with the pipeline owners, which could include: the installation of a ground monitoring line along the pipeline route; the preparation of a TARP; and the development of preventive measures if prescribed triggers are reached, such as locally uncovering the affected sections of pipeline.

It is predicted that the natural gas pipelines within the Study Area could be maintained in safe and serviceable conditions, with the implementation of suitable management strategies.

6.5. 330 kV transmission line

6.5.1. Descriptions of the 330 kV transmission line

The Avon-to-Macarthur 330 kV transmission line (Line 17) owned by TransGrid crosses directly above the proposed LW603 and LW604 in Area 6. This transmission line is also located above the completed LW6 to LW8 in Area 3A and above the approved longwalls in Area 3C. The location of the 330 kV transmission line is shown in Drawing No. MSEC856-19.

There are nine transmission towers (Refs. T22 to T30) that are located within the Study Area based on the 35° angle of draw. Six of these towers (Refs. T23 to T28) are located directly above the proposed longwalls in Area 6. All towers within the Study Area are suspension towers with pile footings. Photographs of a typical transmission tower are provided in Fig. 6.7.

Fig. 6.7 330 kV transmission tower

6.5.2. Predictions for the 330 kV transmission line

The predicted profiles of vertical subsidence, tilt along and tilt across the alignment of the 330 kV transmission line are shown in Fig. C.20, in Appendix C. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines. The predicted total profiles after the completion of the approved longwalls in Area 3C are shown as cyan lines.

A summary of the maximum predicted values of total vertical subsidence, tilt along the alignment and tilt across the alignment of the 330 kV transmission line is provided in Table 6.4. The values are the maxima anywhere along the transmission line (i.e. not necessarily at the tower locations) within the Study Area.

Table 6.4 Maximum predicted total subsidence and tilt for the 330 kV transmission line

Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)
LW602B	< 20	< 0.5	< 0.5
LW603	500	5	11
LW604	1800	6	17
LW605	1850	7	18

The maximum predicted total subsidence for the 330 kV transmission line of 1850 mm occurs above the proposed LW604. The maximum predicted conventional tilts are 7 mm/m (i.e. 0.7 %, or 1 in 143) along the alignment and 18 mm/m (i.e. 1.8 %, or 1 in 56) across the alignment of the transmission line.

There are nine transmission towers that are located within the Study Area based on the 35° angle of draw. A summary of the maximum predicted vertical subsidence, tilt and curvature at each of the tower locations is provided in Table 6.5. The values are the maxima within a distance of 20 m from the centre of each tower resulting from the extraction of the proposed longwalls.

Table 6.5 Maximum predicted total subsidence and tilt for the 330 kV transmission line

Tower	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
T22	< 20	< 0.5	< 0.01	< 0.01
T23	1200	15	0.20	0.08
T24	1100	3.5	0.09	0.09
T25	1200	7.5	0.17	0.04
T26	1850	11	0.08	0.35
T27	1750	18	0.07	0.45
T28	625	13	0.20	0.03
T29	< 20	< 0.5	< 0.01	< 0.01
T30	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted total tilt at the transmission tower locations is 18 mm/m (i.e. 1.8 %, or 1 in 56). The maximum predicted horizontal movement of the ground associated with the maximum predicted tilt is 270 mm. The maximum predicted horizontal movement at the tops of the transmission towers (assuming a height of 50 m) therefore is 1.2 m.

The maximum predicted conventional strains for the transmission towers, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 3 mm/m tensile and 7 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls in Area 6 is described in Section 4.4.2. The predicted strains directly above the proposed longwalls are 6 mm/m tensile and compressive based on the 95 % confidence levels.

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

A summary of the maximum predicted values of total opening and closure between the tops of the transmission towers is provided in Table 6.6. The values are the maxima that occur at any time during or after the completion of the proposed longwalls.

Table 6.6 **Maximum predicted total opening and total closure movements between the tops of the 330 kV transmission towers**

Span	Maximum predicted transient or total opening (mm)	Maximum predicted transient or total closure (mm)	Final predicted opening (+ve) or closure (-ve) after the completion of all proposed longwalls (mm)
T22 to T23	+150	-100	+150
T23 to T24	+375	-125	-125
T24 to T25	+375	-250	-30
T25 to T26	+575	-275	+100
T26 to T27	+375	-775	-300
T27 to T28	+70	-525	+70
T28 to T29	+125	-60	+125

The maximum predicted total differential movements between the tops of the transmission towers are +575 mm opening and -775 mm closure. These values are transient and occur as the extraction face of LW604 mines directly beneath the transmission towers. The maximum predicted final movements at the completion of mining are 150 mm opening and 300 mm closure.

6.5.3. Comparisons of the predictions for the 330 kV transmission line

The 330 kV transmission line crosses above the completed LW6 to LW8 and the proposed LW19 in Area 3A at the Mine. The transmission line is also located above the approved longwalls in Area 3C. The comparison of the maximum predicted total conventional subsidence parameters for the 330 kV transmission line is provided in Table 6.7. The values are the maxima anywhere along the transmission line (i.e. not just at the tower locations).

Table 6.7 **Comparison of the maximum predicted total subsidence parameters for the 330 kV transmission line**

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Area 3A	2150	18	5	0.17	0.50
Area 3C	3050	14	25	0.50	0.70
Area 6	1850	7	18	0.20	0.45

The maximum predicted vertical subsidence, tilts and curvatures for the section of the 330 kV transmission line located within the Study Area are similar to the maximum predicted values in Area 3A and are less than the maximum predicted values in Area 3C. It is noted that the maximum tilt in Area 3A is along the alignment of the transmission line, whereas the maximum tilt in Area 6 is across its alignment.

6.5.4. Impact assessments for the 330 kV transmission line

The maximum predicted total differential movements between the tops of the transmission towers are 575 mm opening and 775 mm closure. It is noted that these values are transient movements as the extraction face of LW604 mines directly beneath the tower locations. The predicted total differential movements between the tops of the towers are greater than that measured between the transmission towers above the completed LW6 to LW8 in Area 3B of 136 mm opening and 407 mm closure.

It is recommended that the predicted movements of the tops of the transmission towers are reviewed by TransGrid to assess the potential impacts on the cable catenaries and the subsequent loads induced into the towers. If adverse impacts are predicted due to the mining-induced horizontal movements and tilt, then the potential impacts could be managed with the installation of cable rollers on these towers.

The predicted strains directly above the proposed longwalls in Area 6 are 6 mm/m tensile and compressive based on the 95 % confidence levels. The predicted changes in the k-point distances (i.e. spacing between the tower legs at the pile connections) based on an 8 m span, therefore, are 48 mm opening and closure. If mitigation measures are not implemented, then these predicted changes in k-point distances will induce loads into the transmission tower frames and into the pile foundations.

The measured changes in k-point distances for the transmission towers located above the completed LW6 to LW8 in Area 3A were very small, in the order of ±1 mm, due to the construction of cruciform bases that constrained the movements of the tower legs.

Another 330 kV transmission line is located above the completed LW30 to LW35 at West Cliff Colliery and only one tower had a cruciform base installed. The measured changes in the k-point distances for the five suspension towers without cruciform bases were between 6 mm opening and 4 mm closure. The transmission towers did not experience adverse impacts due to the mining at West Cliff Colliery.

The predicted changes in k-point distances for the transmission towers within the Study Area are considerably greater than those measured at West Cliff Colliery, where cruciform bases were not installed on the suspension towers. The predicted changes in k-point distances are closer to those predicted for the transmission towers in Area 3A at the Mine, if cruciform bases had not been installed.

It is recommended that TransGrid undertake a structural analysis of the transmission towers within the Study Area based on the predicted ground movements. If adverse impacts on the transmission tower frames or pile foundations are predicted, then these could be managed with the installation of cruciform bases, similar to that undertaken for the transmission towers in Area 3A.

With the implementation of the appropriate management strategies, it is predicted that the 330 kV transmission line could be maintained in a safe and serviceable condition throughout the mining period, similar to that during the extraction of the completed longwalls in Area 3A.

6.5.5. Recommendations for the 330 kV transmission line

It is recommended that the predicted subsidence parameters for the 330 kV transmission line are provided to TransGrid to assess the potential impacts due to mining. It is also recommended that management strategies are developed, in consultation with TransGrid, which could include the installation of cable rollers, the construction of cruciform bases, the provision of monitoring points on the tower bases and tops and the development of a Trigger Action Response Plan (TARP).

6.6. 33 kV powerline

6.6.1. Descriptions of the 33 kV powerline

A 33 kV powerline owned by Endeavour Energy crosses directly above the proposed LW605 in Area 6. This powerline line is also located above the completed LW6 and LW7 in Area 3A and the approved mining in Area 3C. The location of the 33 kV powerline is shown in Drawing No. MSEC856-19.

The 33 kV powerline comprises aerial copper conductors supported by metal and timber poles. Photographs of the powerline within the Study Area are provided in Fig. 6.8.

Fig. 6.8 33 kV powerline

6.6.2. Predictions for the 33 kV powerline

The predicted profiles of vertical subsidence, tilt along and tilt across the alignment of the 33 kV powerline are shown in Fig. C.21, in Appendix C. The predicted total profiles after the extraction of each of the proposed longwalls are shown as the blue lines. The predicted total profiles after the completion of the approved longwalls in Area 3C are shown as cyan lines.

A summary of the maximum predicted values of total vertical subsidence, tilt along the alignment and tilt across the alignment of the 33 kV powerline is provided in Table 6.8. The values are the maxima anywhere along the powerline (i.e. not necessarily at the pole locations) within the Study Area.

Table 6.8 Maximum predicted total subsidence and tilt for the 33 kV powerline

Longwall	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)
LW604	< 20	< 0.5	< 0.5
LW605	1850	15	18

The maximum predicted total subsidence for the 33 kV powerline of 1850 mm occurs directly above the proposed LW605. The maximum predicted conventional tilts are 15 mm/m (i.e. 1.5 %, or 1 in 67) along the alignment and 18 mm/m (i.e. 1.5 %, or 1 in 56) across the alignment of the powerline.

The maximum predicted total tilt in any direction is 25 mm/m (i.e. 2.5 %, or 1 in 40). The maximum predicted horizontal movement of the ground associated with the maximum predicted tilt is 375 mm. The maximum predicted horizontal movement at the tops of the poles (assuming a height of 15 m) therefore is 750 mm.

6.6.3. Comparisons of the predictions for the 33 kV powerline

The 33 kV powerline crosses above the completed LW6 and LW7 in Area 3A at the Mine. The powerline is also located above the approved longwalls in Area 3C. The comparison of the maximum predicted total conventional subsidence parameters for the 33 kV powerline is provided in Table 6.9. The values are the maxima anywhere along the powerline (i.e. not just at the pole locations).

Table 6.9 Comparison of the maximum predicted total subsidence parameters for the 33 kV powerline

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt along alignment (mm/m)	Maximum predicted total tilt across alignment (mm/m)
Area 3A	1550	5	10
Area 3C	3450	30	25
Area 6	1850	15	18

The maximum predicted vertical subsidence and tilts for the section of the 33 kV powerline located within the Study Area are greater than the maximum predicted values in Area 3A and are less than the maximum predicted values in Area 3C. Whilst the predicted movements above the proposed longwalls are greater than the predicted values above the existing longwalls in Area 3A, it is predicted that similar management strategies could be used to manage the potential impacts.

6.6.4. Impact assessments for the 33 kV powerline

The maximum predicted tilt in any direction for the 33 kV powerline is 25 mm/m (i.e. 2.5 %, or 1 in 40). A rule of thumb used by some electrical engineers is that the tops of the poles may displace up to two pole diameters horizontally before remediation works are considered necessary. Based on pole heights of 15 m and pole diameters of 250 mm, the maximum tolerable tilt at the pole locations is in the order of 20 mm/m.

It is possible, therefore, that the 33 kV powerline could experience adverse impacts resulting from the extraction of the proposed LW605. It is recommended that preventive measures are implemented, if required, which could include the installation of cable rollers, guy wires or additional poles, or the adjustment of cable catenaries.

Extensive experience of mining beneath powerlines in the NSW coalfields, where the mine subsidence movements were similar to those predicted for the proposed longwalls, indicates that incidences of impacts is very low and of a minor nature. Some remedial measures have been required, in the past, which included adjustments to cable catenaries, pole tilts and to short span cables.

6.6.5. Recommendations for the 33 kV powerline

It is recommended that the predicted movements are provided to Endeavour Energy so that the necessary preventive measures can be developed, which may include the installation of cable rollers, guy wires or additional poles, or the adjustment of cable catenaries. It is recommended that the powerlines are visually monitored during active subsidence, to maintain them in safe and serviceable conditions at all times.

6.7. Telecommunications services

There are circular telecommunications antennae owned by Telstra that are fixed to a power pole adjacent to the access road to the Cordeaux Dam Picnic Area. The locations of these services are shown in Drawings Nos. MSEC856-19 and MSEC856-21.

The antennae are located outside the mining area, approximately 30 m east of the maingate of LW605. The maximum predicted subsidence effects are 70 mm vertical subsidence and 2 mm/m tilt. The antennae could be sensitive to the mining-induced tilt if it affects their lines of site. This can be managed by adjusting the directions of the antennae during active subsidence.

It is recommended that the predicted movements are provided to Telstra so that the necessary management measures can be developed.

6.8. Dams, reservoirs or associated Works

6.8.1. Descriptions of the reservoirs

Areas 5 and 6 at the Mine are located within the Metropolitan Special Area. The proposed mining is located near two reservoirs. The Avon Reservoir, also known as Lake Avon, is located to the west of the proposed longwalls in Area 5. The Cordeaux Reservoir, also known as Lake Cordeaux, is located to the south of the proposed longwalls in Area 6. These reservoirs are shown in Drawing No. MSEC856-01.

The Avon and Cordeaux Reservoirs are two of the four reservoirs that form part of the Upper Nepean Scheme. These reservoirs supply water to the Macarthur and Illawarra regions, the Wollondilly Shire and Metropolitan Sydney (WaterNSW, 2017). These dams are State significant heritage items that are listed on the NSW State Heritage Register (Niche, 2019b).

Avon Reservoir

The Avon Reservoir has been formed within the valley of the Avon River. The overall size of the reservoir is 10.5 km^2 and the total operating capacity is 146,700 ML (WaterNSW, 2017). The Full Supply Level (FSL) of the reservoir is 320.2 mAHD.

The Avon Dam Wall is located to the west of the proposed mining in Area 5 and it is shown in Drawing No. MSEC856-19. A summary of the minimum distances of the proposed longwalls in Area 5 from the Avon Dam Wall is provided in Table 6.10. The longwalls in Area 5 are extracted in sequence towards and then away from the dam wall.

Table 6.10 Distances of the proposed longwalls from the Avon Dam Wall

Location	Longwall	Minimum distance (m)
Avon Dam Wall	LW501	1340
	LW502	1000
	LW503	1000
	LW504	1000
	LW505	1200
	LW506A	1110
	LW507A	1470
	LW508A	1730
	LW509	1910

The proposed LW501 to LW507A and LW513 to LW516 are partially located within the Dams Safety Committee (DSC) Notification Area for the Avon Reservoir. The proposed longwalls are located at a minimum distance of 300 m from the stored water when the reservoir is filled to the FSL.

The Avon Reservoir was constructed in 1927. The Avon Dam Wall is a mass gravity structure constructed using Hawkesbury Sandstone Blocks embedded in concrete. The dam wall has a blue metal and sandstone concrete facing on the upstream side and sandstone concrete facing on the downstream side (WaterNSW, 2015a). Avon Dam was strengthened in 1971 by buttressing its downstream face with a rockfill embankment.

The overall length of the dam crest is 223 m and the maximum height is 72 m. The radius of curvature of the dam wall in plan is 366 m. An elevation and a cross-section of the Avon Dam Wall are provided in Fig. 6.9 and Fig. 6.10, respectively. A photograph of the dam wall is provided in Fig. 6.11.

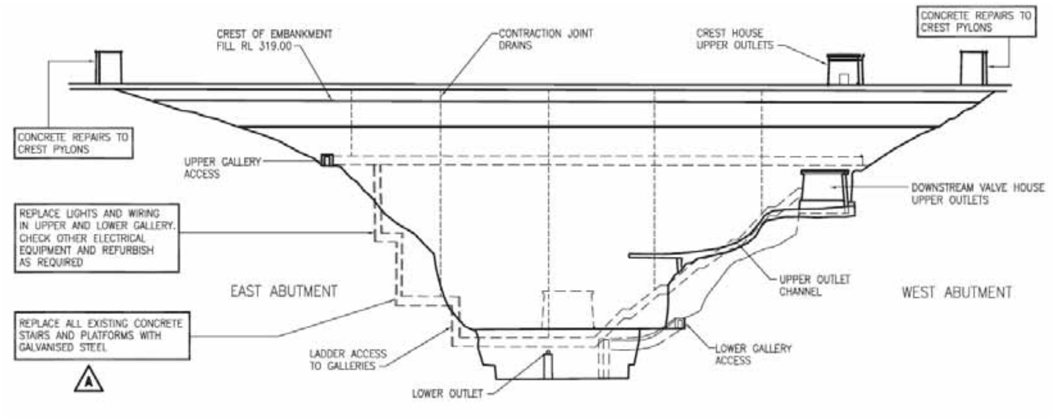

Fig. 6.9 Elevation of the Avon Dam Wall (Source: WaterNSW, 2015a)

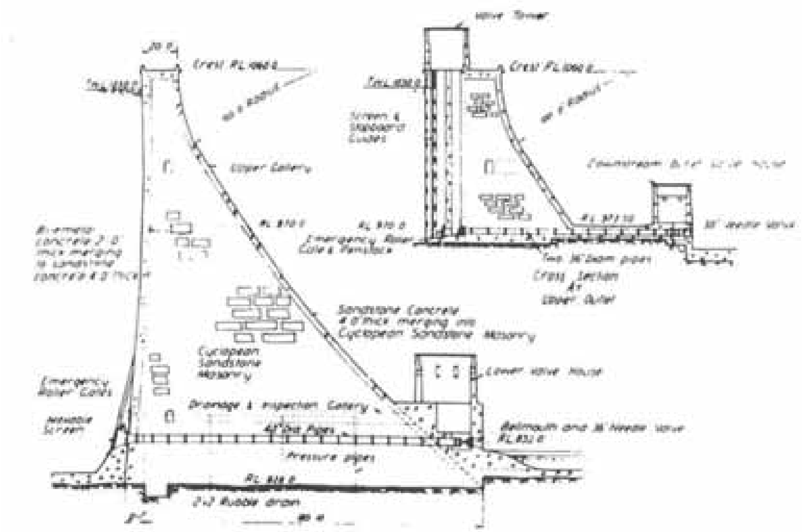

Fig. 6.10 Cross-section of the Avon Dam Wall (Source: WaterNSW, 2015a)

Fig. 6.11 Avon Dam Wall

The dam wall is founded on Hawkesbury Sandstone. The foundation has been pressure grouted forming a grout curtain with a depth up to 7.5 m. The foundation was re-grouted and additional drainage was installed between 1958 and 1964.

The base of the Avon River valley and, hence, the reservoir extends into the Newport Formation and the Bald Hill Claystone. The sides of the valley comprise Hawkesbury Sandstone. Thrust faulting has been identified along the river, as well as an anticlinal fold, which has been interpreted to be the result of natural valley bulging (WaterNSW, 2015a).

The geological structures identified at seam and surface level are shown in Drawings Nos. MSEC856-10 and MSEC856-11. A north-east to south-west trending dyke has been identified at the surface that is located to the north-east of the Avon Reservoir and dam wall. There are also north-east to south-west trending faults identified at seam level that are projected to intersect the reservoir approximately 2 km to 4 km upstream of the dam wall.

A section through the Avon Dam Wall and the proposed LW504 is provided in Fig. 6.12. The section has been taken through the dam wall where it is closest to the proposed mining.

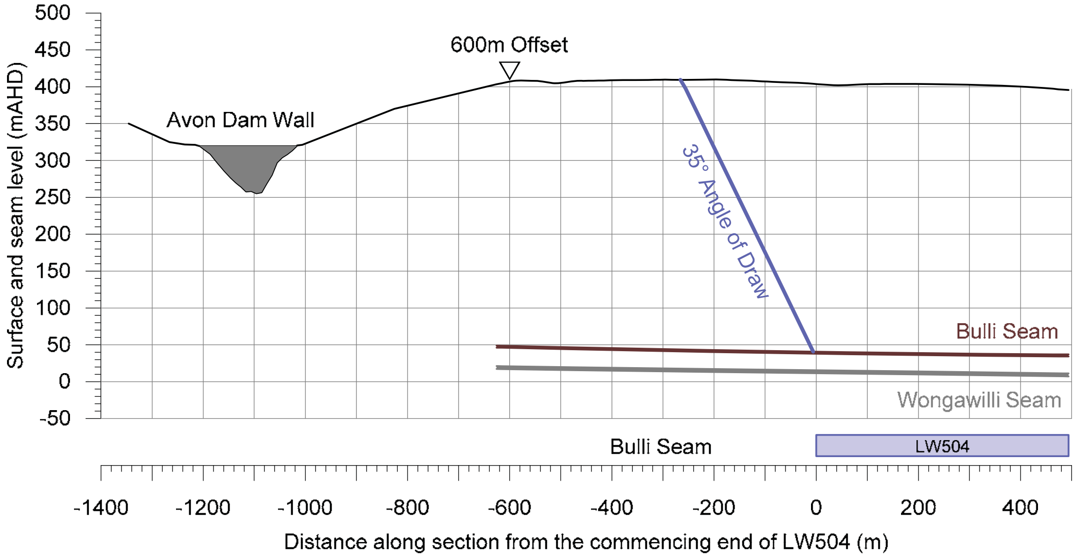

Fig. 6.12 Section through the Avon Dam Wall

The effective valley height is used to determine the predicted valley related effects. This parameter has been determined based on the recommendations outlined in ACARP Research Projects Nos. C8005 and C9067 (Waddington and Kay, 2002). The effective valley height in the location of the Avon Dam Wall has been taken as the average heights of the two valley sides, within distances equal to half the depth of cover from the extents of the dam wall, above the base of the Avon River. The effective valley height in the location of the Avon Dam Wall is 104 m.

Cordeaux Reservoir

The Cordeaux Reservoir has been formed within the valley of the Cordeaux River. The overall size of the reservoir is 7.8 km^2 and the total operating capacity is 93,640 ML (WaterNSW, 2017). The Full Supply Level (FSL) of the reservoir is 303.9 mAHD.

The stored water in the main reservoir is impounded by the Cordeaux Dam Wall, which is located at the northern end and closest to the proposed mining in Area 6. The dam wall is shown in Drawing No. MSEC856-19. A summary of the minimum distances of the proposed longwalls in Area 6 from the Cordeaux Dam Wall is provided in Table 6.11. The stored waters in the southern part of the reservoir are impounded by the Upper Cordeaux No.1 and No. 2 Dam Walls, which are located more than 9 km from the proposed longwalls.

Table 6.11 Distances of the proposed longwalls from the Cordeaux Dam Wall

Location	Longwall	Minimum distance (m)
Cordeaux Dam Wall	LW601B	1310
	LW602B	1110
	LW603	1160
	LW604	1180
	LW605	1080

The southern ends of the proposed LW601B and LW605 extend into the DSC's Notification Area for the Cordeaux Reservoir. The stored water is located at a minimum distance of 600 m from LW605, at its closest point to the proposed longwalls, when the reservoir is filled to the FSL.

The Cordeaux Reservoir was constructed between 1917 and 1926. The Cordeaux Dam Wall is a mass gravity structure constructed using Hawkesbury Sandstone blocks embedded in concrete. The dam wall has a blue metal and sandstone concrete facing on the upstream side and a sandstone concrete facing on the downstream side (WaterNSW, 2015b).

The overall length of the dam crest is 405 m and the maximum height is 57 m. The radius of curvature of the dam wall in plan is 875 m. An elevation and a cross-section of the Cordeaux Dam Wall are provided in Fig. 6.13 and Fig. 6.14, respectively. Photographs of the dam wall are provided in Fig. 6.15.

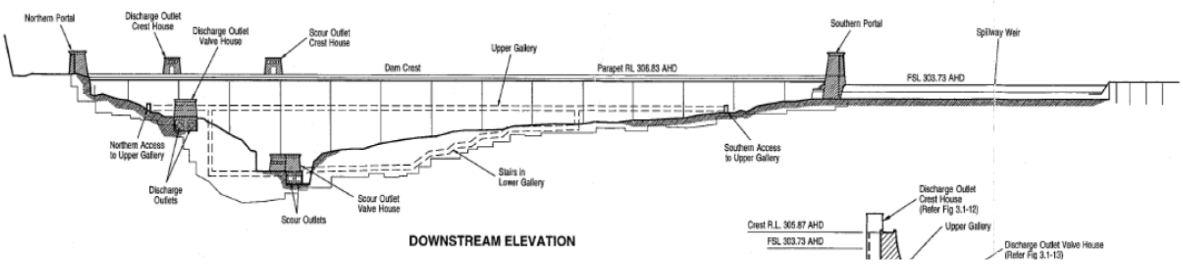

Fig. 6.13 Elevation of the Cordeaux Dam Wall (Source: WaterNSW, 2015b)

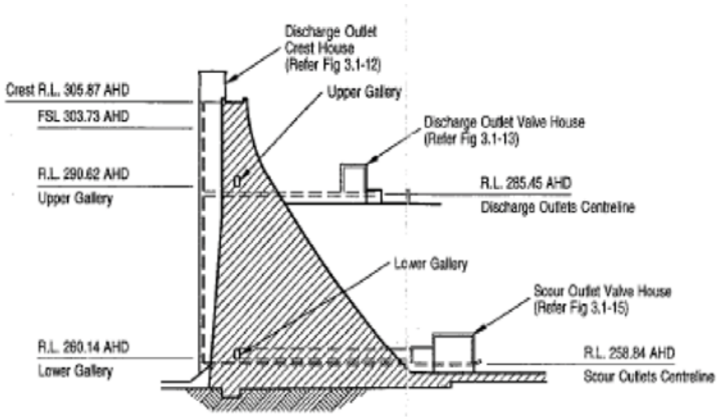

Fig. 6.14 Cross-section of the Cordeaux Dam Wall (Source: WaterNSW, 2015b)

Fig. 6.15 Cordeaux Dam Wall

The dam wall is founded on Hawkesbury Sandstone. The foundation has been pressure grouted forming a grout curtain with a depth up to 10 m to 20 m. The foundation was re-grouted and additional drainage was installed between 1977 and 1978.

The geological structures identified at seam and surface level are shown in Drawings Nos. MSEC856-10 and MSEC856-11. There are two east-west orientated dykes identified at seam level and, if these were projected to the surface, they would intersect with the Cordeaux Dam Wall. There are also east-west trending faults identified at seam level and, if these were projected to the surface, they would intersect the reservoir approximately 1 km to 2 km upstream of the dam wall.

A section through the Cordeaux Dam Wall and the proposed LW605 is provided in Fig. 6.16. The section has been taken through the dam wall where it is located closest to the proposed mining in Area 6.

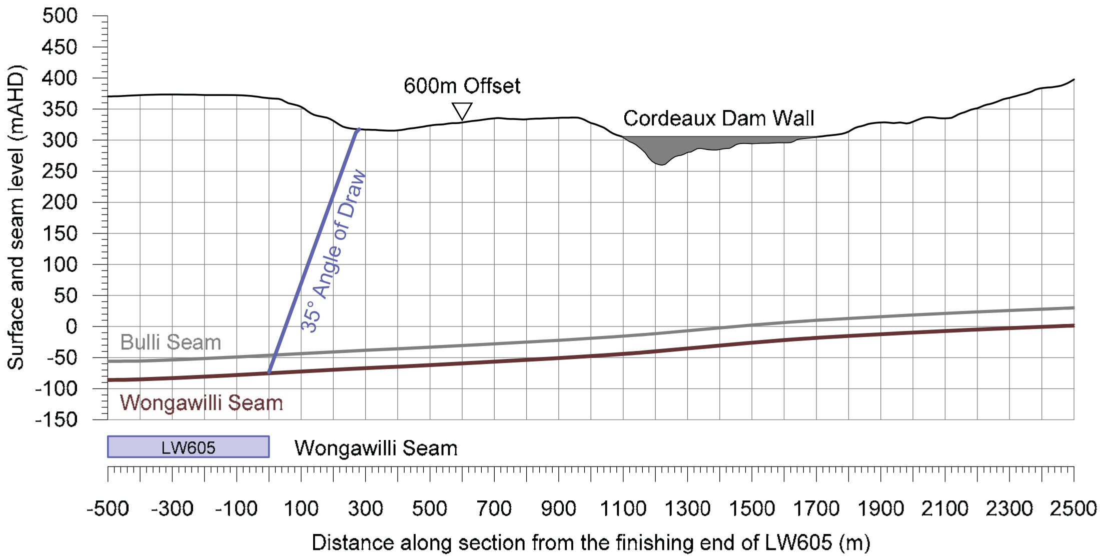

Fig. 6.16 Section through the Cordeaux Dam Wall

The effective valley height is used to determine the predicted valley related effects. This parameter has been determined based on the recommendations outlined in ACARP Research Projects Nos. C8005 and C9067 (Waddington and Kay, 2002). The effective valley height in the location of the Cordeaux Dam Wall has been taken as the average heights of the two valley sides, within distances equal to half the depth of cover from the extents of the dam wall, above the base of the Cordeaux River. The effective valley height in the location of the Cordeaux Dam Wall is 72 m.

WaterNSW is proposing to extend the Cordeaux Reservoir. The discussions on the proposed Lower Cordeaux Reservoir are provided in Section 6.13.

6.8.2. Predictions for the reservoirs

A summary of the maximum predicted vertical subsidence, upsidence and closure at the Avon and Cordeaux Dam Walls is provided in Table 6.12. The values are the total movements due to the mining of all longwalls in Areas 5 and 6.

Table 6.12 Maximum predicted total vertical subsidence, upsidence and closure for the Avon and Cordeaux Dam Walls

Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Avon Dam Wall	< 20	< 20	20
Cordeaux Dam Wall	< 20	< 20	< 20

The maximum predicted vertical subsidence for the Avon and Cordeaux Dam Walls are both less than 20 mm. Whilst the dam walls could experience very low-levels of vertical subsidence, they are not expected to experience measurable conventional tilts, curvatures or strains.

The predicted closure effects are 20 mm at the Avon Dam Wall and less than 20 mm at the Cordeaux Dam Wall. These predicted values have been obtained using the 2002 ACARP method (Waddington and Kay, 2002).

The predicted valley closure effects for the Avon and Cordeaux Dam Walls have been further refined based on a statistical analysis of total valley closure movements measured in the Southern Coalfield. The analysis is based on the valley closures measured for monitoring lines across valleys with effective heights between 50 m and 100 m for previously extracted longwalls at Appin, Dendrobium, Metropolitan, Tahmoor, Tower and West Cliff Collieries.

The measured total valley closure versus the distance from the nearest longwall is illustrated in Fig. 6.17. The mean and 95 % confidence level for the data have been shown in this figure, which have been determined by binning the measured data and fitting Generalised Pareto Distributions (GPDs). It is noted that there is limited data for distances greater than 1000 m from the nearest longwalls and, therefore, the tails of the fitted mean and 95 % confidence levels become less reliable with increasing distance.

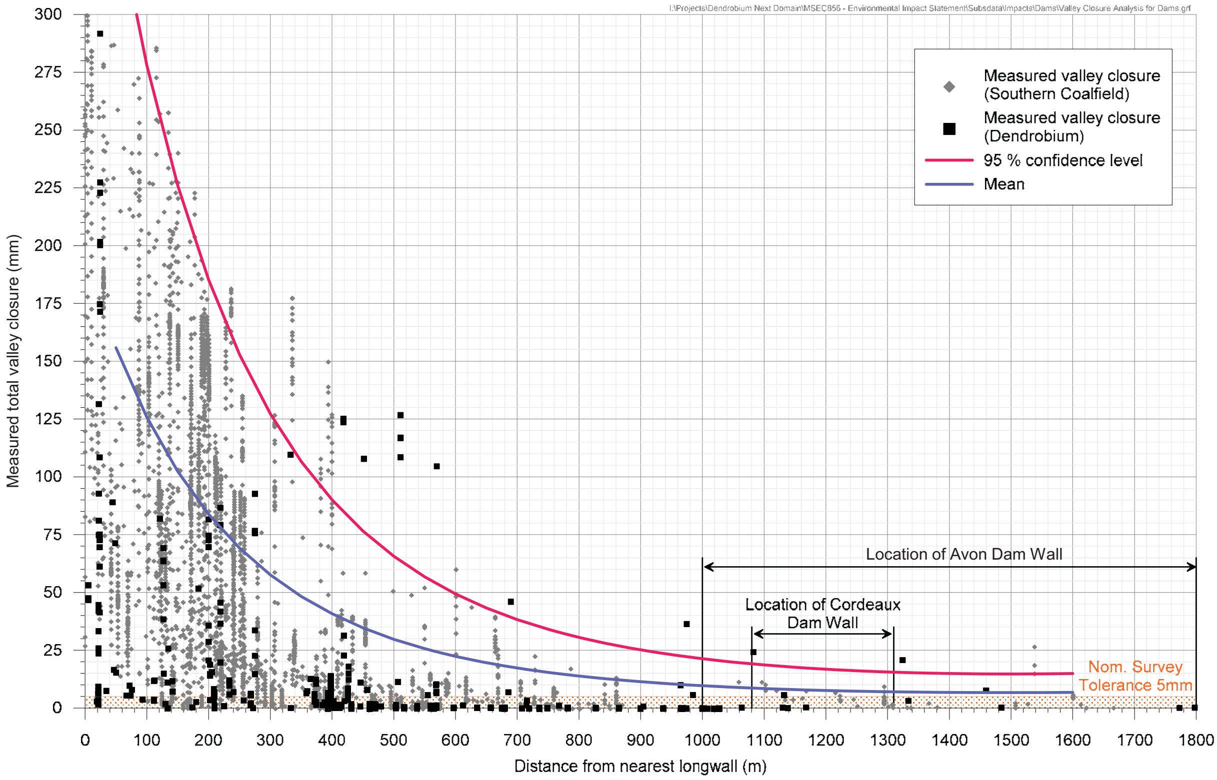

Fig. 6.17 Measured total valley closure versus distance from nearest longwall

The relative locations of the Avon and Cordeaux Dam Walls are shown in Fig. 6.17. The predicted total valley closure for the dam walls, due to the proposed mining in Areas 5 and 6, are both 20 mm based on the 95 % confidence level.

6.8.3. Previous experience of mining near the reservoirs

The longwalls at the Mine have been extracted near the Upper Cordeaux No. 2 reservoir. The dam wall is located approximately 1.5 km west of LW1 in Area 1 and approximately 0.9 km from LW3 in Area 2 at the mine. The Upper Cordeaux No. 2 reservoir is shown in Drawing No. MSEC856-01.

The mine subsidence movements at the Upper Cordeaux No. 2 reservoir were measured by the, then, Sydney Catchment Authority (SCA) using 3D survey marks located on and around the dam wall. The latest available survey, Survey No. 9a, was carried out in April 2010, during the extraction of LW6 in Area 2. The results of this survey were provided in the monitoring report by the SCA (2010).

The maximum measured movements at the Upper Cordeaux No. 2 dam wall were ±1 mm vertical, +3 mm horizontal in the downstream direction and ±1 mm in the east and west directions. The SCA monitoring report states that:

> *"The centre of the dam crest is at its maximum downstream position near July of each year and maximum upstream position near January of each year. This change is very probably caused by the overall change in dam wall temperature as well as the change in the temperature gradient across the dam wall section. The water storage level has remained within 0.1m of FSL since April 2005 and so has no significant effect on deflection. Towards the right bank the movement on the crest is generally smaller and more complex due to the reduced height and the changing curvature of the dam wall. The several cracks in this section of the dam wall may also be influencing how the dam wall moves as it expands and contracts. The fact that both ground and dam wall are vertically stable reduces the likelihood that mining is a factor in the measured horizontal movement."*

The detailed ground monitoring data indicated that the measured movements were very small and were within the order of survey tolerance. That is, the mining-induced movements at the Upper Cordeaux No. 2 dam wall were not measurable above the seasonal variations.

A numerical analysis of the effects of mining on the Upper Cordeaux No. 2 Dam Wall was carried out by WorleyParsons (2006). A series of non-linear 3D finite element analyses were performed based on the predicted effects due to the mining in Area 2 at the Mine. It was assessed that the pre-existing vertical cracks in the dam wall would open up allowing small leakages based on the predicted valley closure and opening effects.

The numerical analyses found that "*the dam performance under the full supply level will be within the acceptance criteria except for the potential crack of 56 % across the dam width based on a full head uplift pressure across 2/3 of the dam width. This crack extent will probably be within the acceptable limit should a linear uplift pressure distribution [be] assumed at the dam to rock interface*" (WorleyParsons, 2006).

6.8.4. Impact assessments for the reservoirs

The proposed longwalls are located at a minimum distance of 1 km from both the Avon and Cordeaux Dam Walls. The predicted vertical and horizontal movements at the Cordeaux and Avon Reservoirs and their associated dam walls are very small and are unlikely to be measurable.

The previously extracted longwalls in Areas 1 and 2 at the Mine have been mined to within 0.9 km of the Upper Cordeaux No. 1 and No. 2 Dam Walls. The detailed ground monitoring indicated that the measured movements were very small and were within the order of survey tolerance. The previous mining has not resulted in adverse impacts on these structures.

It is unlikely, therefore, that the Avon and Cordeaux Dam Walls and the associated reservoirs would experience adverse impacts due to the extraction of the proposed longwalls in Areas 5 and 6. The longwall series in Areas 5 and 6 are progressively mined towards the Avon and Cordeaux Dam Walls. This allows the movements at these structures to be measured and reviewed as the mining progresses towards them.

6.8.5. Recommendations for the reservoirs

It is recommended that IC consult with the WaterNSW and the DSC to develop the appropriate monitoring and management strategies of the reservoirs and dam walls. These strategies could include a detailed monitoring program and Trigger Action Response Plan (TARP).

6.9. Aboriginal heritage sites

6.9.1. Descriptions of the Aboriginal heritage sites

The locations of the Aboriginal heritage sites are shown in Drawing No. MSEC856-20. The details of the heritage sites have been provided by *Niche Environment and Heritage* (Niche, 2019c).

There are 43 Aboriginal heritage sites that have been identified within the Study Area based on the 35° angle of draw. There are 13 additional sites that are located within the Study Area based on the 600 m boundary which could experience valley related movements and could be sensitive to these movements and, therefore, have been included in the assessments.

The details of the Aboriginal heritage sites located within the Study Area is provided in Table D.03, in Appendix D. A summary of these sites is provided in Table 6.13.

Table 6.13 Aboriginal heritage sites identified within the Study Area

Type	Total number located within the Study Area	Number located directly above longwalls in Area 5	Number located directly above longwalls in Area 6	Number located outside the proposed longwalls
Isolated finds	1	0	0	1
Grinding groove sites	22	8	3	11
Rock shelters	33	7	2	24
Total	56	15	5	36

Further details on the Aboriginal heritage sites are provided in the report by Niche (2019c).

6.9.2. Predictions for the Aboriginal heritage sites

The maximum predicted total conventional subsidence parameters for each of the Aboriginal heritage sites located within the Study Area is provided in Table D.03, in Appendix D. A summary of the maximum predicted total vertical subsidence, tilt and curvatures for these sites is provided in Table 6.14. The values are the maxima within 20 m of the identified locations of each of the sites.

Table 6.14 **Maximum predicted total vertical subsidence, tilt and curvatures for the Aboriginal heritage sites within the Study Area**

Type	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Isolated find	< 20	< 0.5	< 0.01	< 0.01
Grinding groove sites	2150	16	0.30	0.40
Rock shelters	1650	20	0.60	0.45

The isolated find is predicted to experience less than 20 mm vertical subsidence. Whilst this site could experience very low-levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains.

The maximum predicted tilt for the grinding groove sites is 16 mm/m (i.e. 1.6 %, or 1 in 63). The maximum predicted curvatures for these sites are 0.30 km^{-1} hogging and 0.40 km^{-1} sagging, which represent minimum radii of curvatures of 3.3 km and 2.5 km, respectively.

The maximum predicted tilt for the rock shelters is 20 mm/m (i.e. 2.0 %, or 1 in 50). The maximum predicted curvatures for these sites are 0.60 km^{-1} hogging and 0.45 km^{-1} sagging, which represent minimum radii of curvatures of 1.7 km and 2.2 km, respectively.

The maximum predicted conventional strains for the Aboriginal heritage sites located directly above the longwalls, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 9 mm/m tensile and 7 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted strains directly above the proposed longwalls, based on the 95 % confidence levels, are 4 mm/m tensile and 5 mm/m compressive in Area 5, and 6 mm/m tensile and compressive in Area 6.

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

The grinding groove sites and rock shelters are located along the alignments of streams and, therefore, could experience valley related effects. A summary of the maximum predicted upsidence and closure along the streams in the locations of the Aboriginal heritage sites is provided in Table 6.15. The values provided in this table are the predicted upsidence and closure effects along the streams at the site locations.

Table 6.15 **Maximum predicted total upsidence and closure for the streams in the locations of the Aboriginal heritage sites**

Type	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Grinding groove sites	450	700
Rock shelters	550	800

The maximum predicted compressive strains due to valley closure effects along the streams in the locations of the Aboriginal heritage sites above the proposed longwalls range between 10 mm/m and 20 mm/m.

6.9.3. Review of the assessed and observed impacts for the Aboriginal heritage sites due to LW9 to LW13

There are six rock shelters located directly above the previously extracted LW9 to LW12 in Area 3B. There are no grinding groove sites located directly above LW9 to LW12 or within the 35° angle of draw from these previously extracted longwalls.

The impact assessments for the rock shelters provided in Report No. MSEC459 stated that:

> *"…the likelihoods of impacts on these sites are expected to be similar to those previously experienced where shelters were directly mined beneath in the Southern Coalfield"* where *"approximately 10 % of the shelters have been affected by fracturing of the strata or shear movements along bedding planes and that none of the shelters have collapsed (Sefton, 2000)"*

Impacts were observed to one of the rock shelters due to the extraction of LW9, which was described in the End of Panel Report (IC, 2014) and has been summarised below:

> "*Site 52-2-2208: Minor expansion and extension of vertical cracking in horizontal bedding plane observed. While rock cracking has occurred, it is considered to be minor and unlikely to lead to water seepage or rock falls at Dendrobium 1. There is no art on the shelter walls and the archaeological deposit was not impacted by this crack.*"

There were no additional impacts reported on this site or the other rock shelters due to the extraction of LW10 to LW13. It is considered that the physical impacts observed to the rock shelter site are consistent with the assessed potential for impacts outlined in Report No. MSEC459. Further discussions on the environmental consequences for this site are provided by the specialist Aboriginal heritage consultant.

6.9.4. Impact assessments for the Aboriginal heritage sites

The impact assessments for the Aboriginal heritage sites provided in this report should be read in conjunction with the assessments provided by Niche (2019c).

Isolated find

The isolated find (Ref. 52-2-3204) is located approximately 510 m west of the proposed longwalls in Area 5. At this distance, this site is not expected to experience measurable conventional tilts or curvatures. The site could experience small far-field horizontal movements, in the order of 50 mm to 100 mm. However, it is not predicted that these absolute horizontal movements would result in measurable strains.

It is unlikely that cracking in the surface soils would occur in the location of the isolated find, due to its distance from the proposed longwalls. It is not expected, therefore, that the isolated find would experience adverse impacts due to the proposed mining.

Grinding groove sites

There are 22 grinding groove sites identified within the Study Area, of which, eight sites are located directly above the proposed longwalls in Area 5 (Refs. 52-2-1566, 52-2-1592, 52-2-1758, 52-2-1779, 52-2-4465, 52-2-4466, 52-2-4467 and 52-2-4468) and a further three sites are located directly above the proposed longwalls in Area 6 (Refs. 52-2-1456, 52-2-1465 and 52-2-1466).

The 11 grinding groove sites located directly above the proposed longwalls are formed in exposed bedrock platforms along the alignments of the streams. The areas of the platforms range between 4 m by 2 m through to 40 m by 12 m.

The extraction of the proposed longwalls is likely to result in fracturing of the exposed bedrock along the streams. The fracturing is expected to predominately occur directly above the proposed longwalls and, to lesser extents, outside the longwalls and within the 35° angle of draw. Minor and isolated fracturing could occur up to approximately 400 m from the proposed longwalls.

It is extremely difficult to assess the likelihood that fracturing would be coincident with the grinding groove sites themselves, as this is dependent on the localised response of the bedrock to the mining-induced ground movements. The potential for impacts on the grinding groove sites has been based on the previous experience of mining longwalls directly beneath these types of sites in the Southern Coalfield.

The potential for adverse impacts on the grinding groove sites located directly above the proposed longwalls has been assessed as *unlikely* for each of these sites. However, it is possible that these sites could be impacted by fracturing of the bedrock due to the proposed mining.

The remaining grinding groove sites are located outside the extents of the proposed longwalls and are predicted to experience less than 50 mm vertical subsidence. Whilst these sites could experience low-levels of vertical subsidence, they are not expected to experience measurable conventional tilts, curvatures or strains. The grinding groove sites located outside the extents of the proposed longwalls could experience compressive strains due to valley closure movements in the order of 2 mm/m.

The potential for adverse impacts on the grinding groove sites located outside the extents of the proposed longwalls has been assessed as *rare* for each of these sites. However, it is possible that some of these sites could be impacted by fracturing of the bedrock due to the proposed mining.

Further assessments of the potential impacts on the grinding groove sites are provided by Niche (2019c).

Rock shelters

There are 33 rock shelters identified within the Study Area, of which, seven sites are located directly above the proposed longwalls in Area 5 (Refs. 52-2-1567, 52-2-1747, 52-2-1759, 52-2-1780, 52-2-1782, 52-2-3955 and Dendrobium ACHA Shelter-2) and a further two sites are located directly above the proposed longwalls in Area 6 (Refs. 52-2-1464 and 52-2-4469).

The nine rock shelters located directly above the proposed longwalls comprise block fall and cavernous weathering in exposed Hawkesbury Sandstone along ridgelines. The sizes of the shelters vary between 5 m and 14 m wide, between 2.6 m and 3.5 m deep, and between 1.6 m and 4.8 m high.

The extraction of the proposed longwalls is likely to result in fracturing of the exposed bedrock along the ridgelines and, where the rock is marginally stable, could then result in rockfalls or instabilities. The fracturing and rock falls could adversely impact the rock shelters located directly above the proposed longwalls.

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

It has been assessed that between 7 % and 10 % of the total length, or between 3 % and 5 % of the total face area, of the cliffs located directly or partially above the proposed longwalls would be impacted by the extraction of these longwalls.

The potential for adverse impacts on the rock shelters located directly above the proposed longwalls has been assessed as *unlikely* for each of these sites. However, it is possible that these sites could experience fracturing resulting in spalling or rock falls.

The remaining rock shelters are located outside the extents of the proposed longwalls and are typically predicted to experience less than 20 mm vertical subsidence. However, Sites Refs. 52-2-1752 and 52-2-1735 are predicted to experience vertical subsidence of 50 mm and 100 mm, respectively.

Whilst the 24 sites located outside of the longwalls could experience low-levels of vertical subsidence, they are generally not expected to experience significant conventional tilts, curvatures or strains. The rock shelters are also not expected to experience the valley related upsidence or compressive strains due to valley closure, as these occur near the valley base, rather than along the valley sides.

Sites Refs. 52-2-1752 and 52-2-1735 are located outside but adjacent to the proposed mining area. The remaining rock shelters located outside the extents of the proposed longwalls are at distances ranging between 80 m and 600 m from the proposed mining area. There have been no reported impacts on rock shelters in the Southern Coalfield at similar distances from previous longwall mining. It is predicted, therefore, that it is unlikely that there would be adverse impacts on the rock shelters located outside the extents of the proposed longwalls.

Further assessments of the potential impacts on the rock shelters are provided by Niche (2019c).

6.10. Historical heritage sites

The Avon and Cordeaux Dams are State significant heritage items that are listed on the NSW State Heritage Register (Niche, 2019b). The descriptions, predictions and impact assessments for the reservoirs, dam walls and associated infrastructure are provided in Section 6.8.

6.11. Survey control marks

The locations of the survey control marks are shown in Drawing No. MSEC856-20. The locations and details of the survey control marks were obtained from the *Land and Property Management Authority* using the *SCIMS Online* website (SCIMS, 2017).

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

The survey control marks located outside the Study Area are also expected to experience small amounts of subsidence and small far-field horizontal movements. It is possible that the survey control marks could be affected by far-field horizontal movements at distances of 1 km to 2 km outside the proposed longwalls. Far-field horizontal movements and the methods used to predict such movements are described further in Sections 3.3 and 4.6.

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

6.12. Buildings and other structures

6.12.1. Descriptions of the buildings and other structures

The detailed map of the buildings and other structures are shown in Drawing No. MSEC856-21. The location of this map is indicated in Drawing No. MSEC856-19.

There are 28 structures that are within the Study Area based on the 35° angle of draw for Area 6. These structures are located along Fire Road No. 6 and are in the picnic area near the Cordeaux Dam. The structures are located within the catchment area and are owned by WaterNSW.

The details of the structures are provided in Table D.04, in Appendix D. The buildings comprise single-storey timber framed structures supported on piers, with weatherboard cladding and corrugated metal roof sheeting. The other structures include sheds, tanks and amenities.

6.12.2. Predictions for the buildings and other structures

The maximum predicted total conventional subsidence parameters for each of the buildings and other structures located within the Study Area is provided in Table D.04, in Appendix D. A summary of the maximum predicted total vertical subsidence, tilt and curvatures for these structures is provided in Table 6.16. The values are the maxima within 20 m of the identified locations of each of the structures.

Table 6.16 Maximum predicted total vertical subsidence, tilt and curvatures for the buildings and other structures

Type	Number	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Houses	3	100	3.5	0.06	< 0.01
Sheds	8	1800	13	0.10	0.40
Toilet blocks	4	40	0.5	< 0.01	< 0.01
BBQ shelters	6	100	1.5	0.02	0.01
Tanks	1	1750	11	0.04	0.35
Other	6	200	6	0.10	< 0.01
All	28	1800	13	0.10	0.40

The maximum predicted tilt for the structures is 13 mm/m (i.e. 1.3 %, or 1 in 77). The maximum predicted curvatures for these structures are 0.10 km^{-1} hogging and 0.40 km^{-1} sagging, which represent minimum radii of curvatures of 10 km and 2.5 km, respectively.

The maximum predicted conventional strains for the structures located directly above the longwalls, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 1.5 mm/m tensile and 6.0 mm/m compressive. The distribution of the predicted strains due to the extraction of the proposed longwalls is described in Section 4.4. The predicted strains directly above the proposed longwalls in Area 6 are 6 mm/m tensile and compressive, based on the 95 % confidence levels.

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

6.12.3. Impact assessments for the buildings and other structures

House Ref. S_22 is located above the maingate of the proposed LW605. This structure is predicted to experience 100 mm vertical subsidence and 3.5 mm/m tilt. These low-level movements could result in minor serviceability impacts, such as door swings or issues with gutter and wet area drainage. The mining-induced curvatures and strains could result in minor impacts to the finishes, such as cracking of the plasterboard linings or movement of the cladding. It is unlikely that the structure would experience structural impacts due to the low-levels of predicted movement and the flexible construction comprising a timber frame on piers.

The remaining two houses (Refs. S_01 and S_02) are located outside the extents of the proposed longwalls. These structures are predicted to experience less than 20 mm vertical subsidence. It is unlikely, therefore, that these two houses would experience adverse impacts.

Shed Ref. S_24 is located directly above the proposed LW605. It is possible that this structure could experience adverse impacts. However, only minor impacts are predicted due to its small size and flexible construction. These impacts could be remediated using normal building maintenance techniques.

The remaining seven sheds (Refs. S_04 to S_07, S_19, S_20 and S_23) and garage (Ref. S_21) are located adjacent to the maingate of the proposed LW605 or outside the extents of mining. These structures are predicted to experience up to 275 mm of vertical subsidence. It is unlikely that these sheds would experience adverse impacts due to the low-levels of predicted movement, small sizes and flexible constructions.

The four toilet blocks (Refs. S_09 and S_16 to S_18) are located outside the extents of the proposed longwalls. These structures are predicted to experience up to 40 mm vertical subsidence. Whilst these structures could experience low-levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains. It is unlikely, therefore, that the toilet blocks would experience adverse impacts.

The six barbeque shelters (Refs. S_10, S_11, S_14, S_15, S_27 and S_28) are located adjacent to the finishing end of the proposed LW605 and outside the extents of mining. These structures are predicted to experience up to 100 mm vertical subsidence. It is unlikely that these shelters would experience adverse impacts due to the low-levels of predicted movement, small sizes and flexible constructions.

The water tank (Ref. S_25) is located directly above the proposed LW605. This structure is predicted to experience 1750 mm vertical subsidence and 11 mm/m tilt. The changes in grade could affect the levels of the stored water and, therefore, it may be necessary to re-level after mining. It is unlikely that the tank itself would be adversely impacted by the mining-induced curvatures and strains, due to its small size, flexible construction and being founded above the natural ground. It is possible that the pipes associated with the tank could be adversely impacted due to differential movements between the tank and the ground.

The remaining structures are located outside the mining area and are predicted to experience less than 20 mm vertical subsidence. It is unlikely, therefore, that these remaining structures would experience adverse impacts due to the proposed mining.

6.12.4. Recommendations for the buildings and other structures

It is recommended that Property Subsidence Management Plans (PSMPs) be developed, in consultation with WaterNSW, for the buildings and other structures located within the Study Area.

6.13. Known future developments

WaterNSW has advised IC that the following infrastructure are part of a number of options for future water supply: Lower Cordeaux Reservoir and Dam Wall, Burrawang to Avon Dam Tunnel, Avon Dam to the New Lower Cordeaux Dam Tunnel and Lower Cordeaux to Broughtons Pass Weir Tunnel.

The indicative locations of the potential infrastructure were provided in a letter sent by WaterNSW to IC in February 2018 (WaterNSW, 2018) and these have been reproduced in Fig. 6.18. The potential impacts of mining on any future reservoir, dam wall and tunnels are dependent on what is constructed, how it is constructed and whether they are constructed before or after longwall mining.

The potential Lower Cordeaux Reservoir is shown by the yellow hatching in Fig. 6.18. The potential reservoir FSL extends along the Cordeaux River, Donalds Castle Creek, Wongawilli Creek and their tributaries. It is partially located above the proposed longwalls in Area 6. The total surface area of the potential reservoir above the extent of secondary extraction is approximately 200,000 m^2 (i.e. 20 ha). The potential reservoir is also located adjacent to but outside the proposed longwalls in Area 5.

The extraction of the proposed longwalls will result in surface cracking and fracturing. These surface deformations will predominately occur directly above the proposed longwalls and, to lesser extents, outside the longwalls and within the 35° angle of draw. Minor and isolated fracturing could occur up to approximately 400 m from the proposed longwalls. The fracturing can result in iron staining and increased permeability in the near-surface strata. The proposed longwalls will also affect the permeability of the overburden.

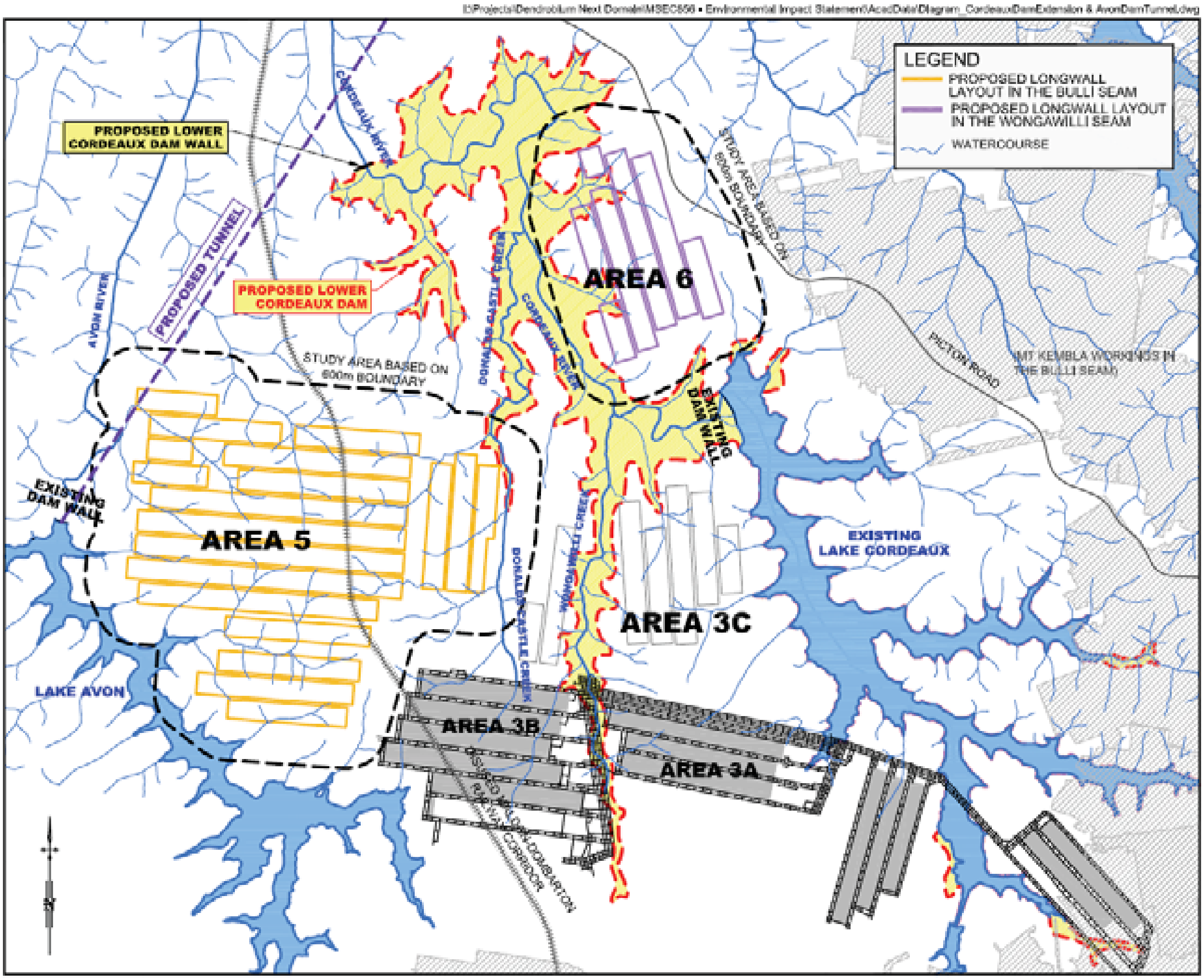

Fig. 6.18 Future WaterNSW infrastructure

The potential Lower Cordeaux Dam Wall is located on the Cordeaux River approximately 2.8 km west of the proposed longwalls in Area 6 and approximately 3.7 km north of the proposed longwalls in Area 5. At these distances, the potential dam wall is not expected to experience measurable far-field horizontal or valley related effects.

The indicative location of the potential Avon Dam to the Lower Cordeaux Dam Tunnel is shown by the dashed magenta line in Fig. 6.18. The potential tunnel crosses the north-western corner of Area 5, however, the final alignment would be subject to any future planning.

The potential tunnel could be affected by fracturing and horizontal shear along the bedding plane horizons due to the proposed mining in Area 5. The potential tunnel should be designed to accommodate these movements if it were to be constructed prior to mining. The predicted mine subsidence movements will depend on the final alignment of any tunnel and whether it is constructed before or after mining.

It is recommended that WaterNSW develop management strategies, in consultation with IC, to manage the potential impacts on any future infrastructure, should it be built.

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

Glossary of terms and definitions

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

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

Shear deformations — The horizontal displacements that are measured across monitoring lines and these can be described by various parameters including; horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.

Strain — The change in the horizontal distance between two points divided by the original horizontal distance between the points, i.e. strain is the relative differential displacement of the ground along or across a subsidence monitoring line. Strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation.

Tensile Strains are measured where the distance between two points or survey pegs increases and **Compressive Strains** where the distance between two points decreases. Whilst mining induced **strains** are measured **along** monitoring lines, ground **shearing** can occur both vertically, and horizontally **across** the directions of the monitoring lines.

Sub-critical area — An area of panel smaller than the critical area.

Subsidence — The vertical movement of a point on the surface of the ground as it settles above an extracted panel, but, 'subsidence of the ground' in some references can include both a vertical and horizontal movement component. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of *millimetres (mm)*. Sometimes the horizontal component of a peg's movement is not measured, but in these cases, the horizontal distances between a particular peg and the adjacent pegs are measured.

Super-critical area — An area of panel greater than the critical area.

Tilt — The change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the horizontal distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.

Uplift — An increase in the level of a point relative to its original position.

Upsidence — Upsidence results from the dilation or buckling of near surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.

APPENDIX B. REFERENCES

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APPENDIX C.   FIGURES

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Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to mining in Area 5

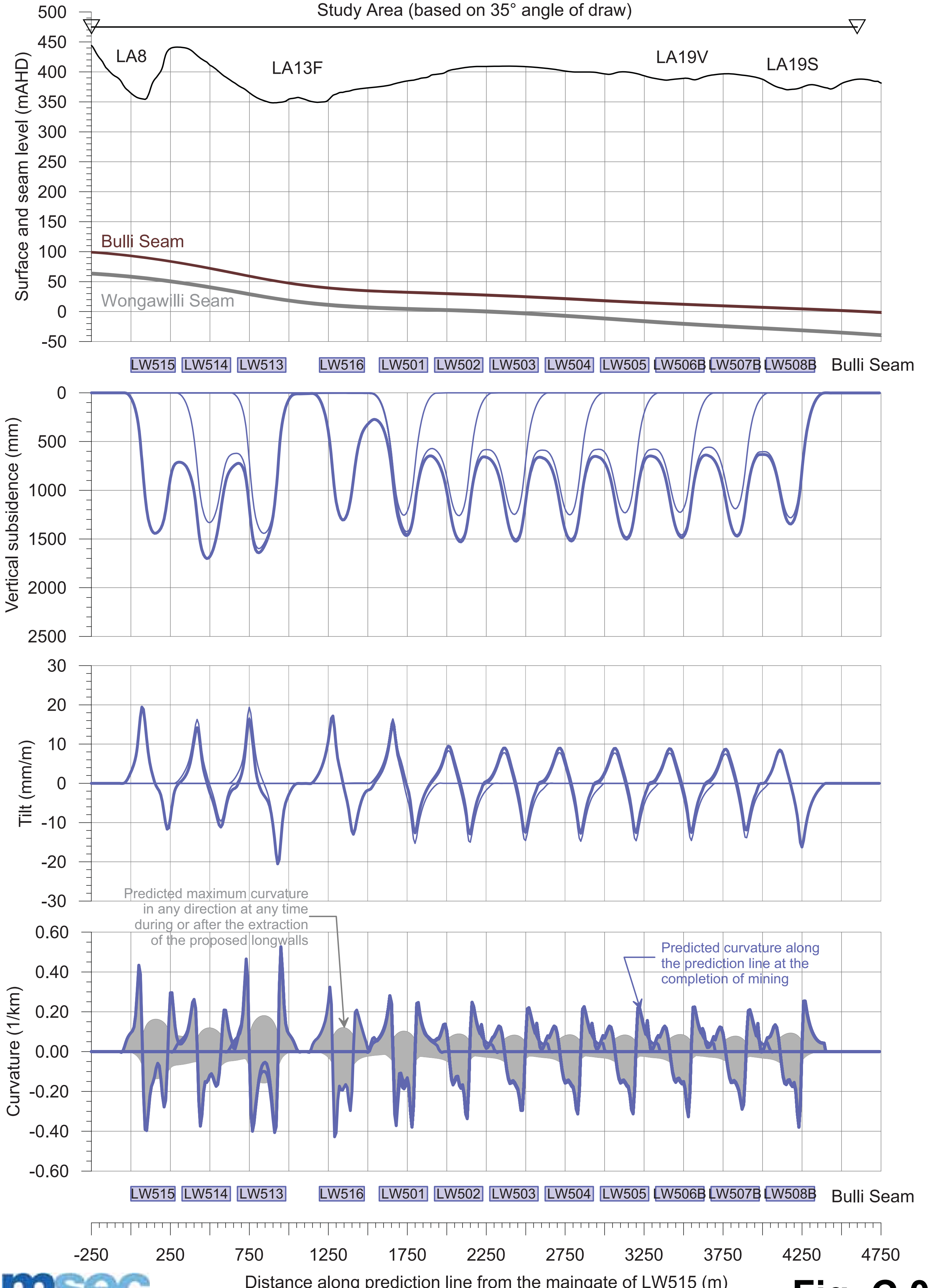

Fig. C.01

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to mining in Area 5

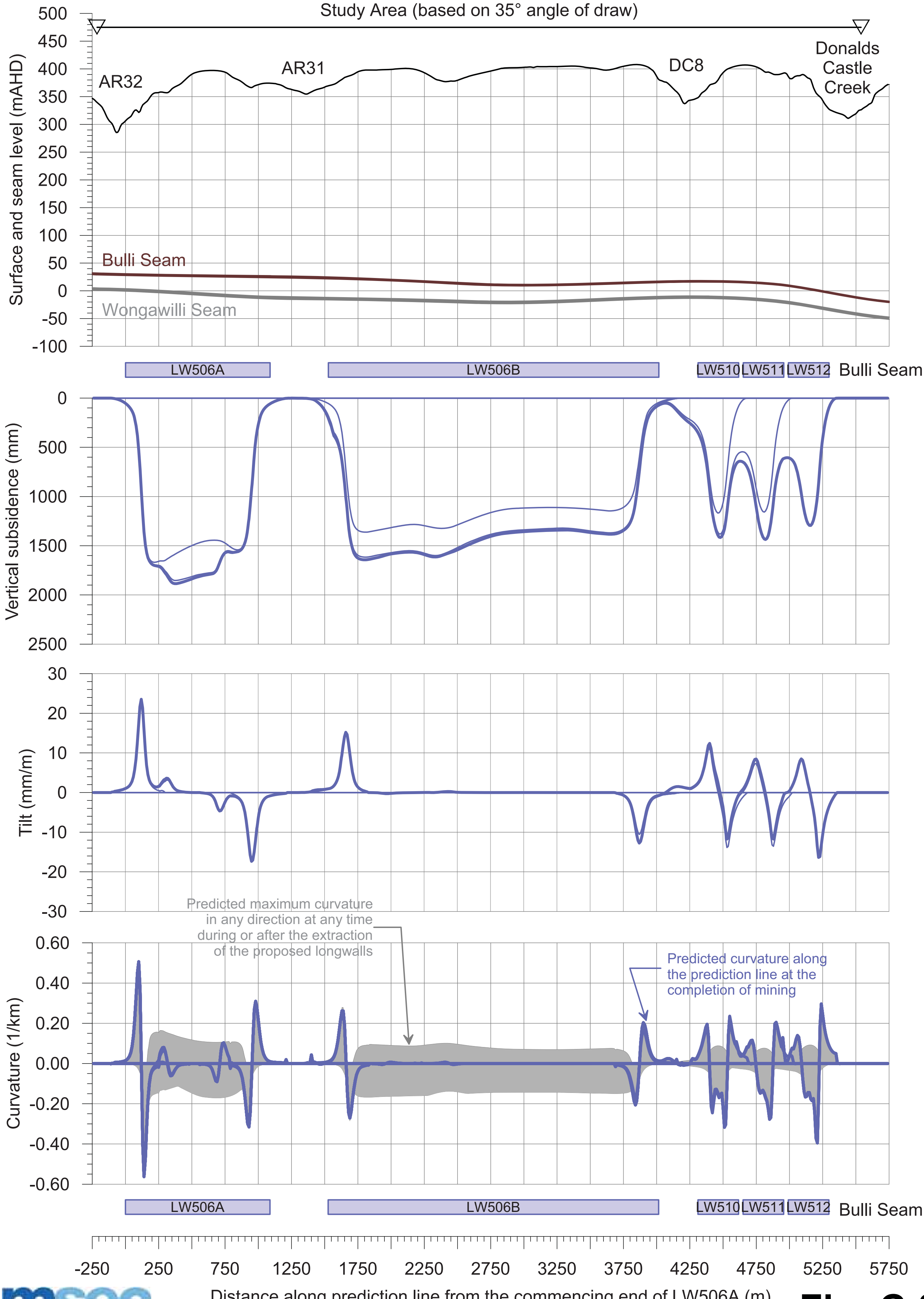

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Fig. C.02

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 3 due to mining in Area 6

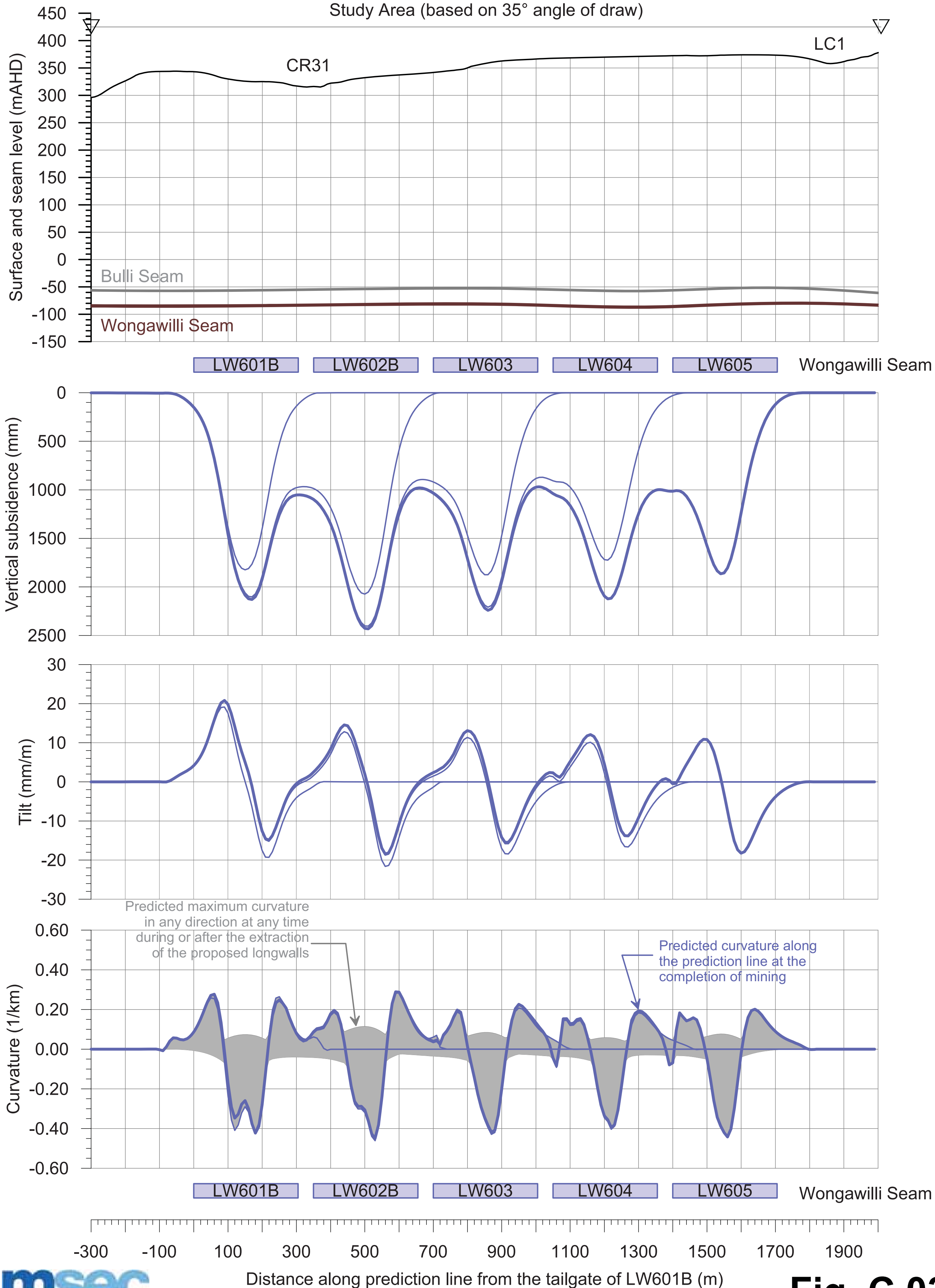

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Fig. C.03

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 4 due to mining in Area 6

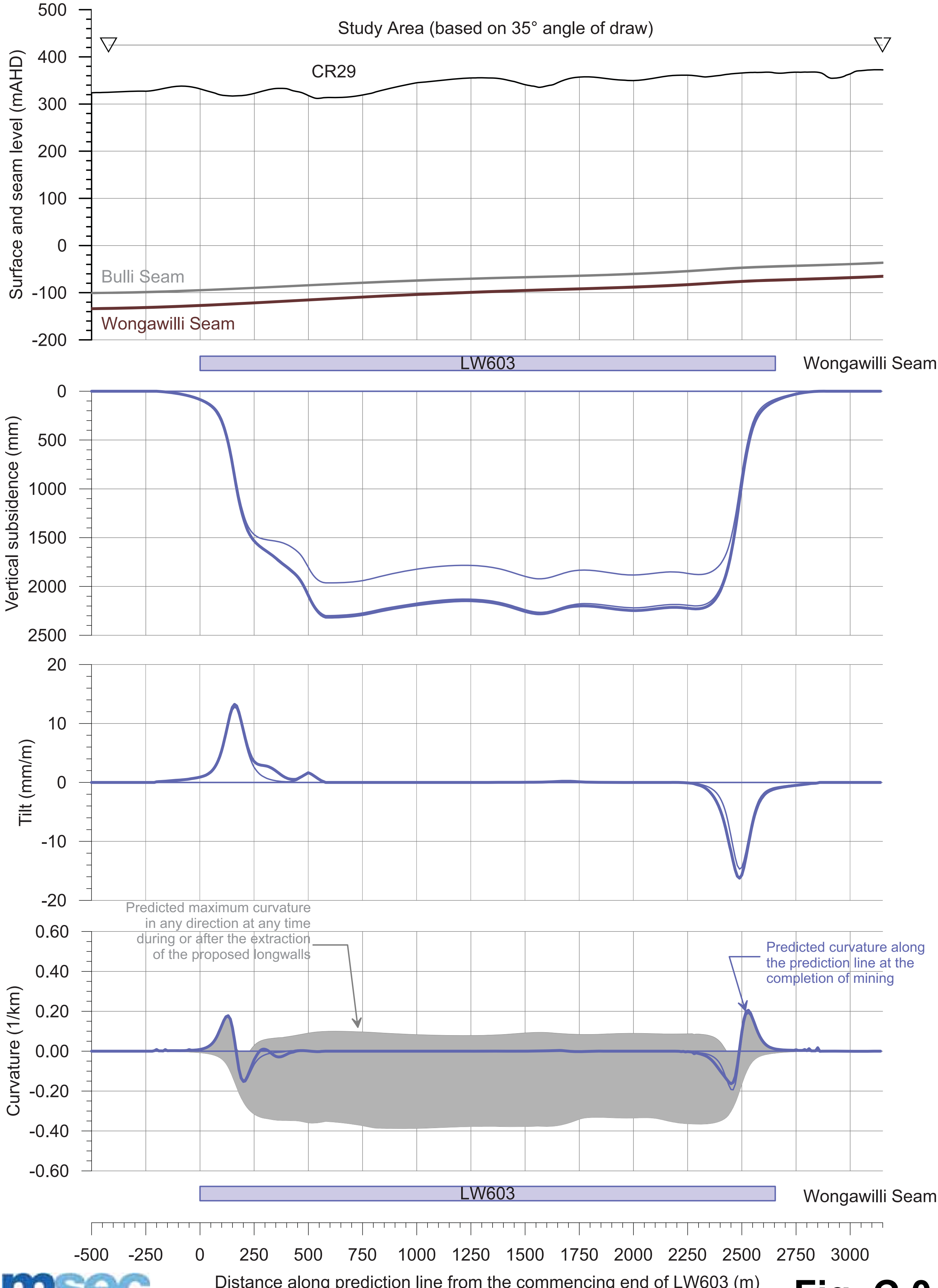

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Fig. C.04

Predicted profiles of vertical subsidence, upsidence and closure along the Avon River due to mining in Area 5

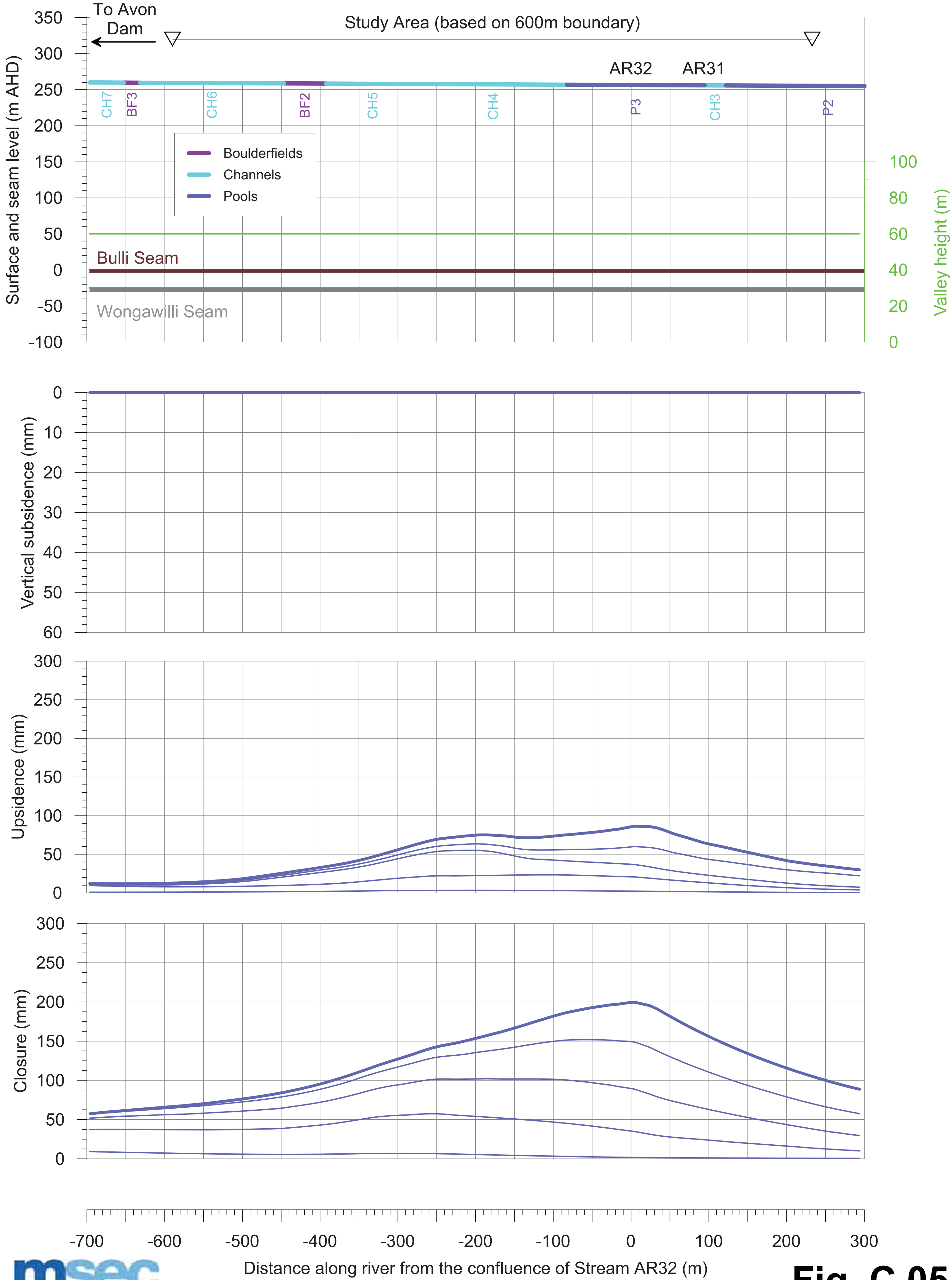

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Fig. C.05

Predicted profiles of vertical subsidence, upsidence and closure along the Cordeaux River due to mining in Areas 3C and 6

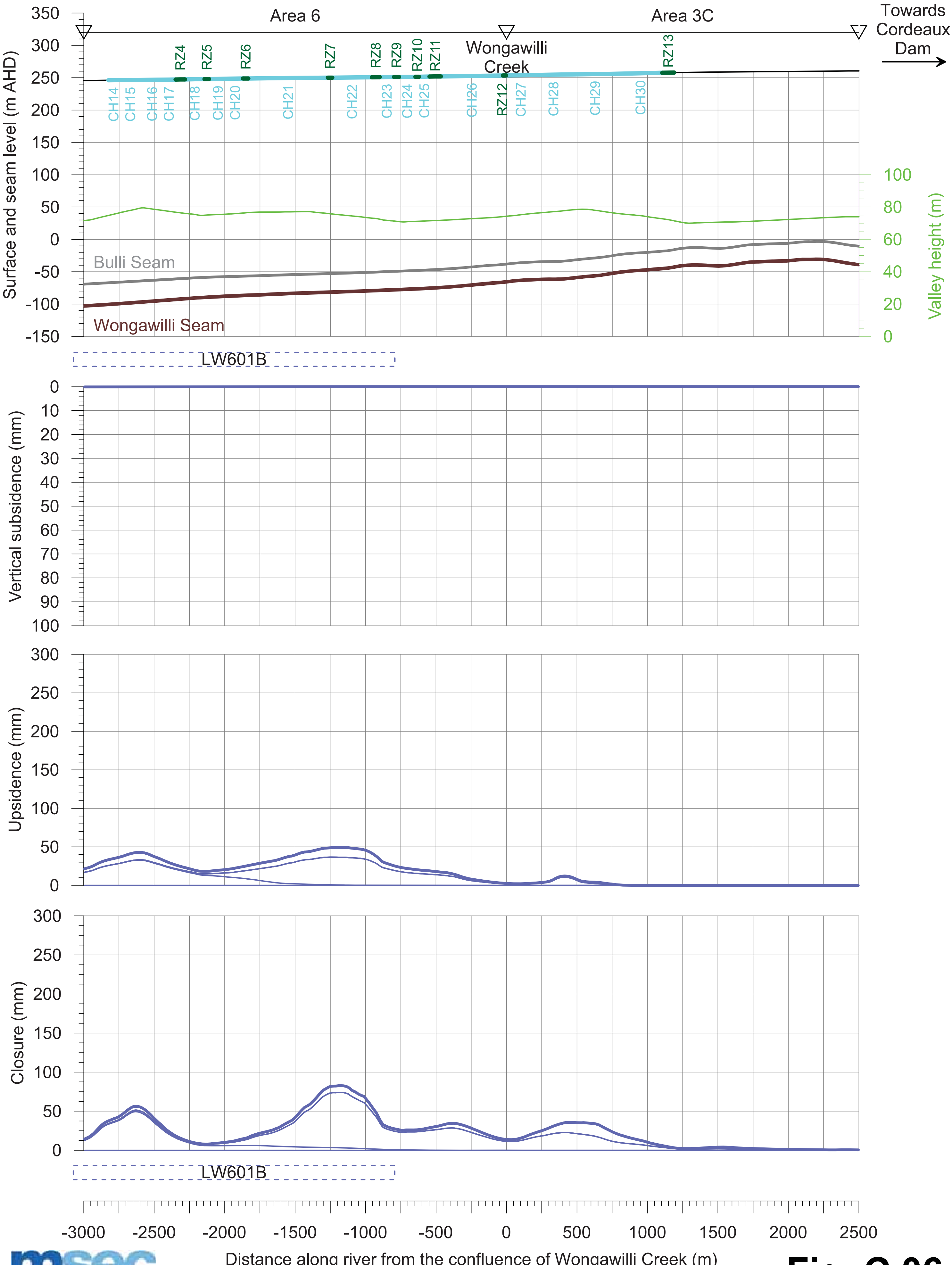

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Fig. C.06

Predicted profiles of vertical subsidence, upsidence and closure along Donalds Castle Creek due to mining in Areas 3B, 3C and 5

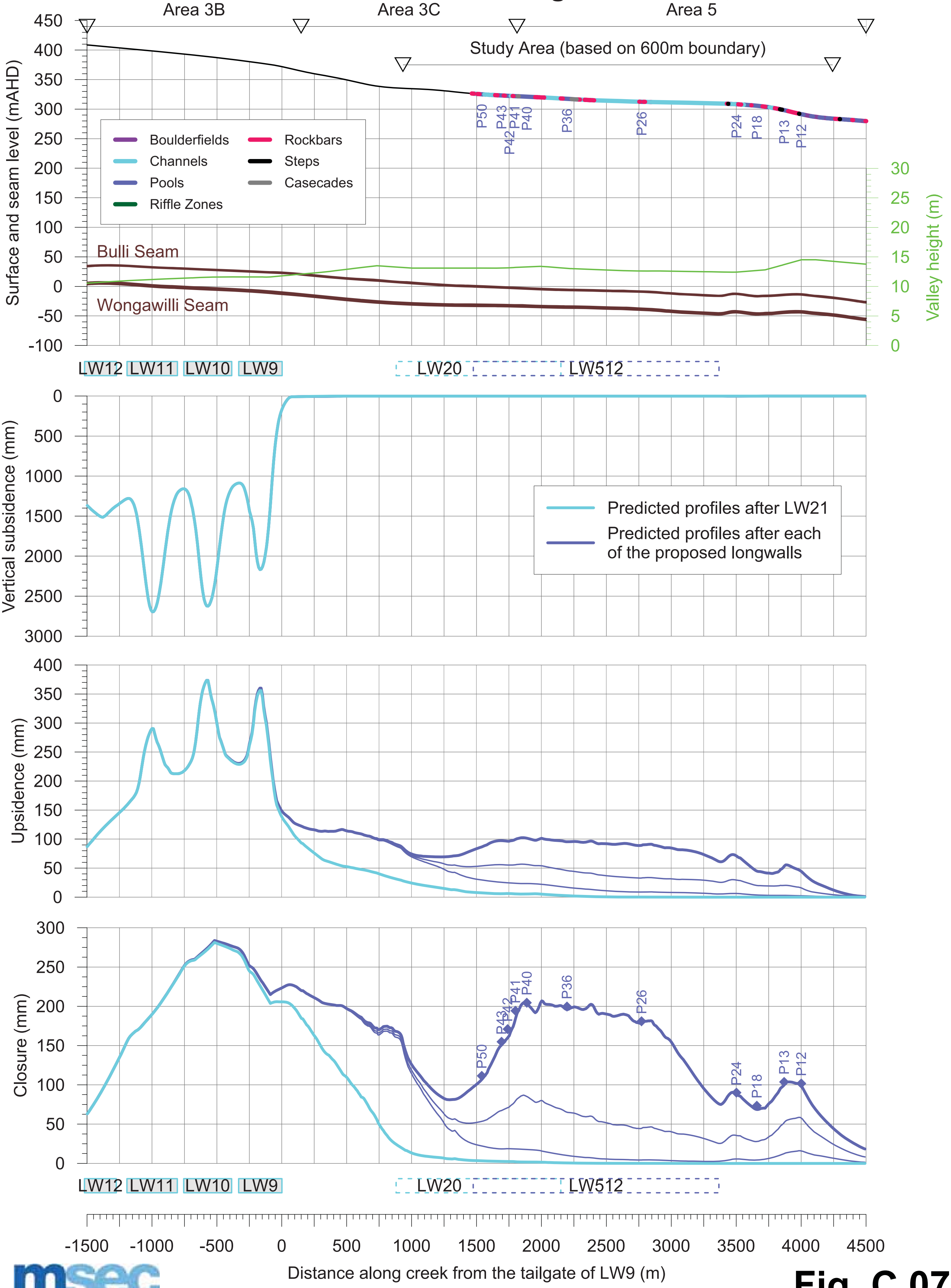

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Fig. C.07

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line AR19 due to mining in Area 5

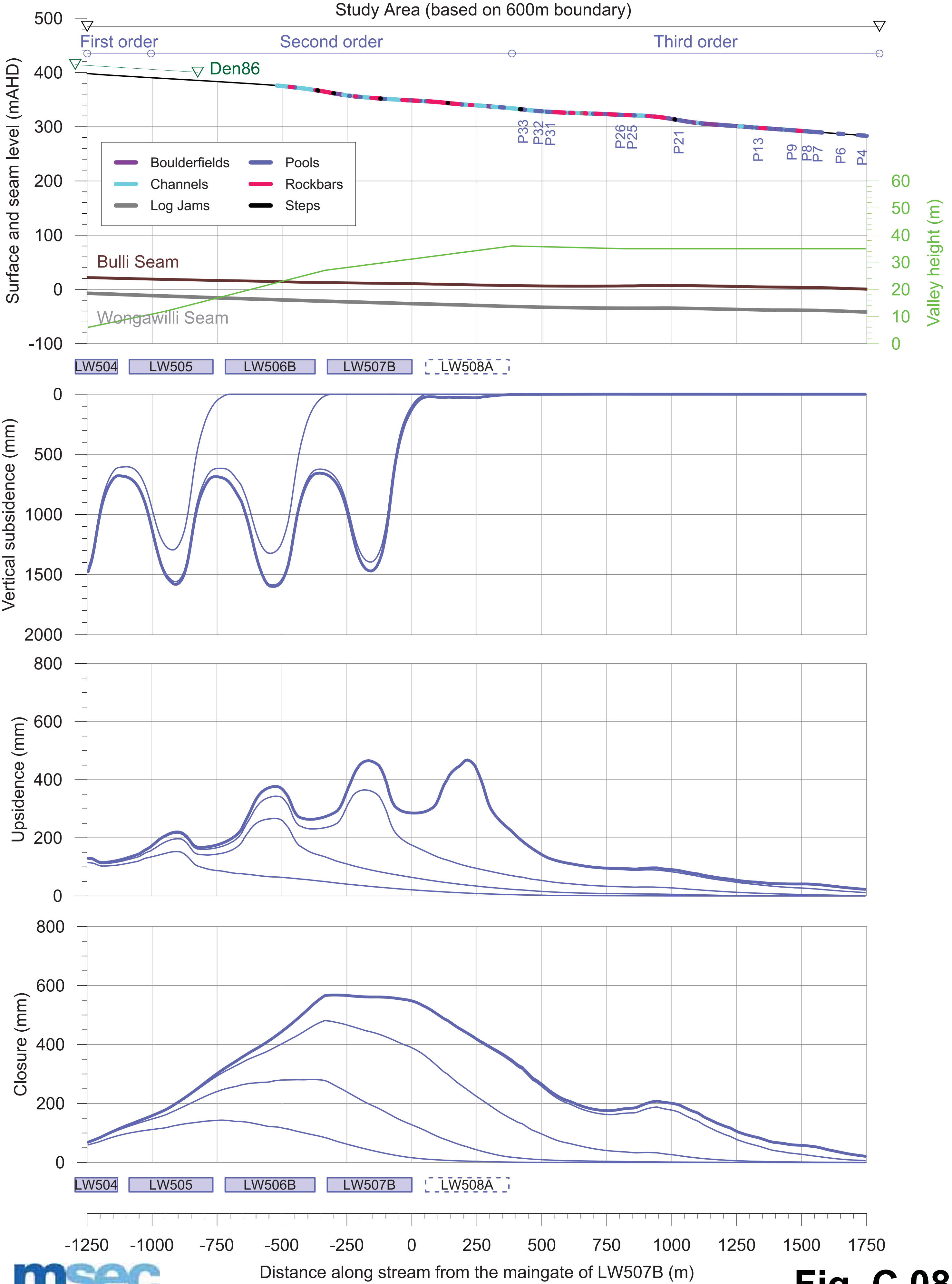

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Fig. C.08

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line AR31 due to mining in Area 5

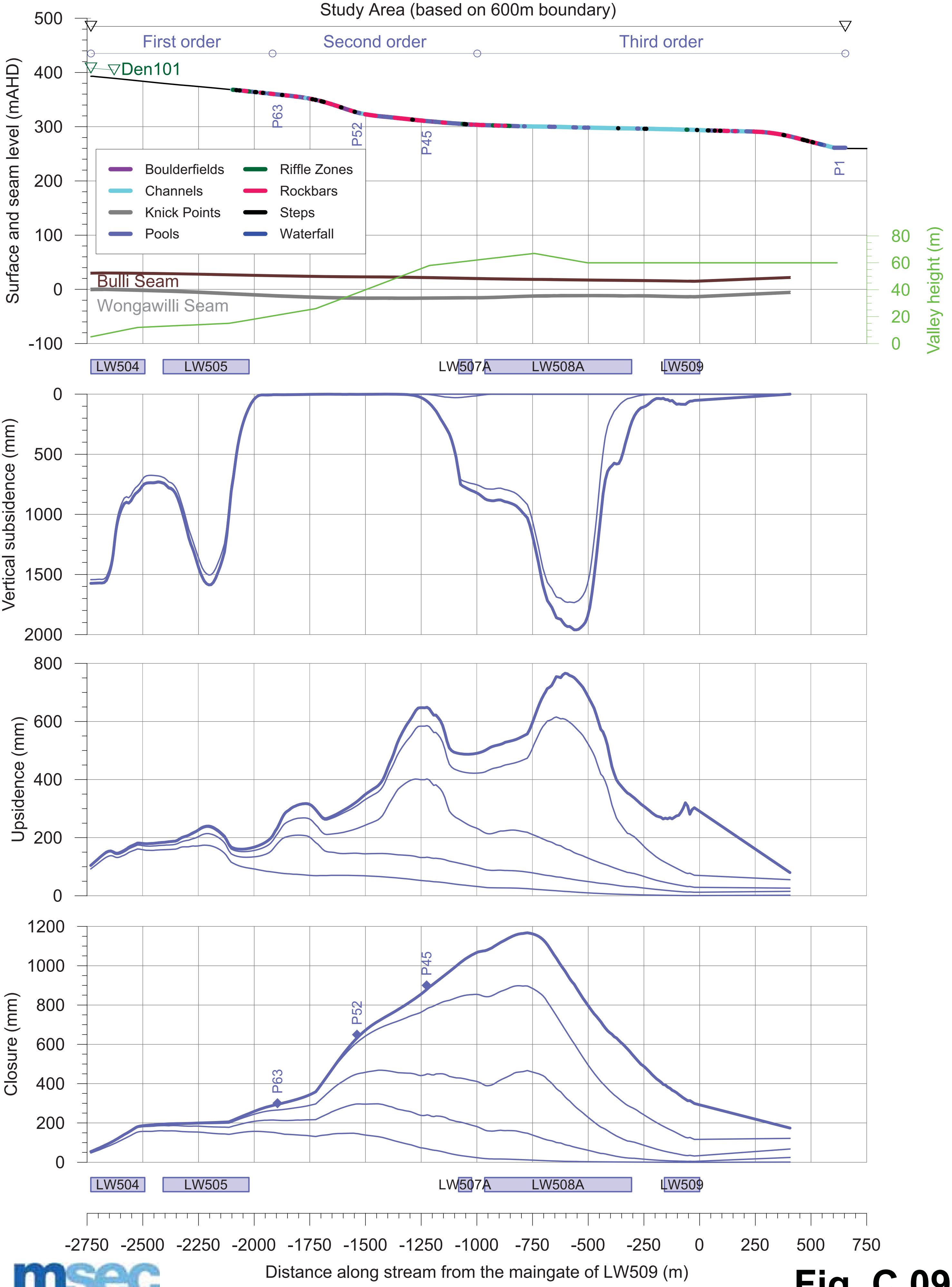

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Fig. C.09

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line AR32 due to mining in Area 5

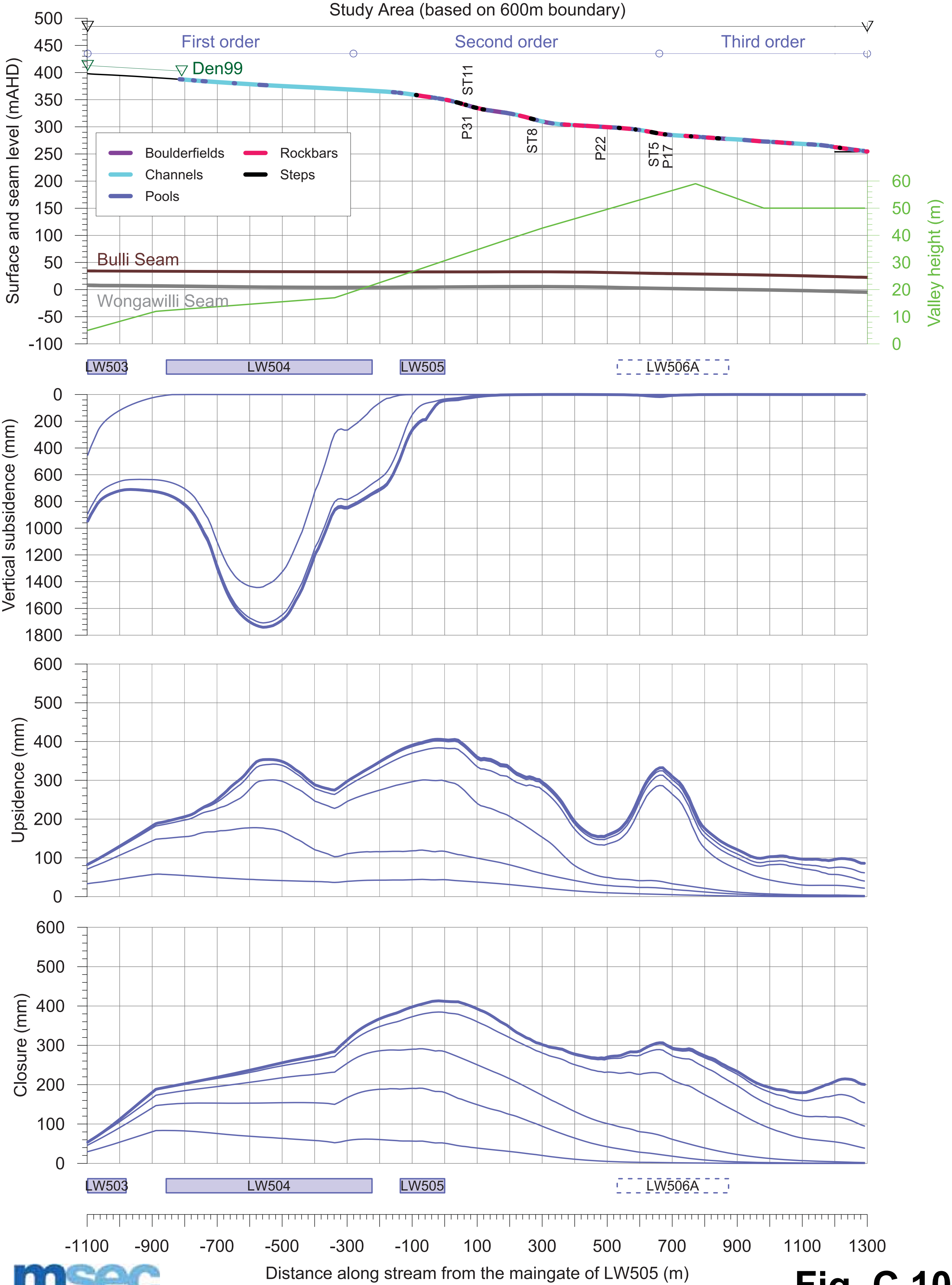

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Fig. C.10

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line DC8 due to mining in Area 5

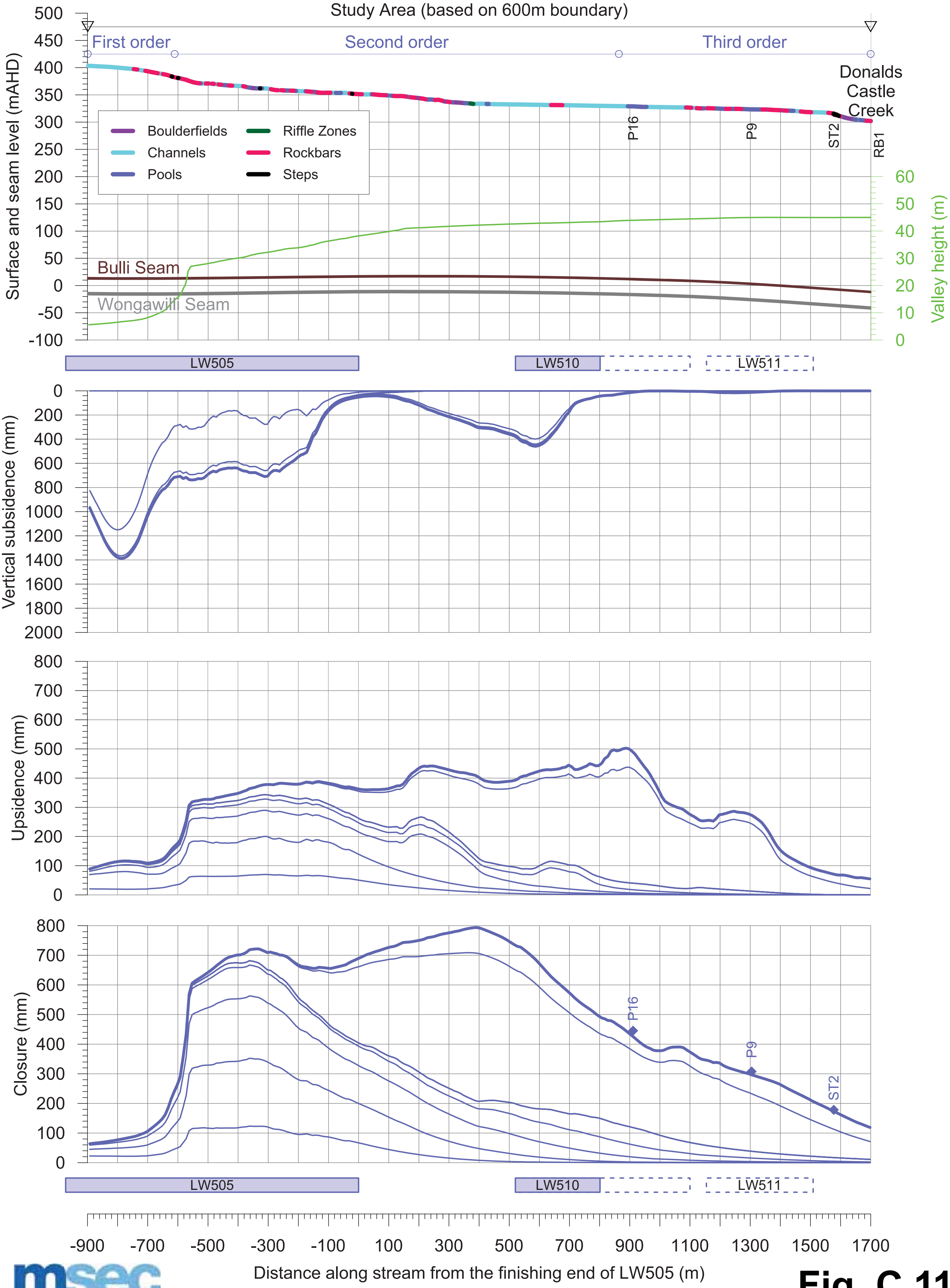

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Fig. C.11

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line DC9 due to mining in Area 5

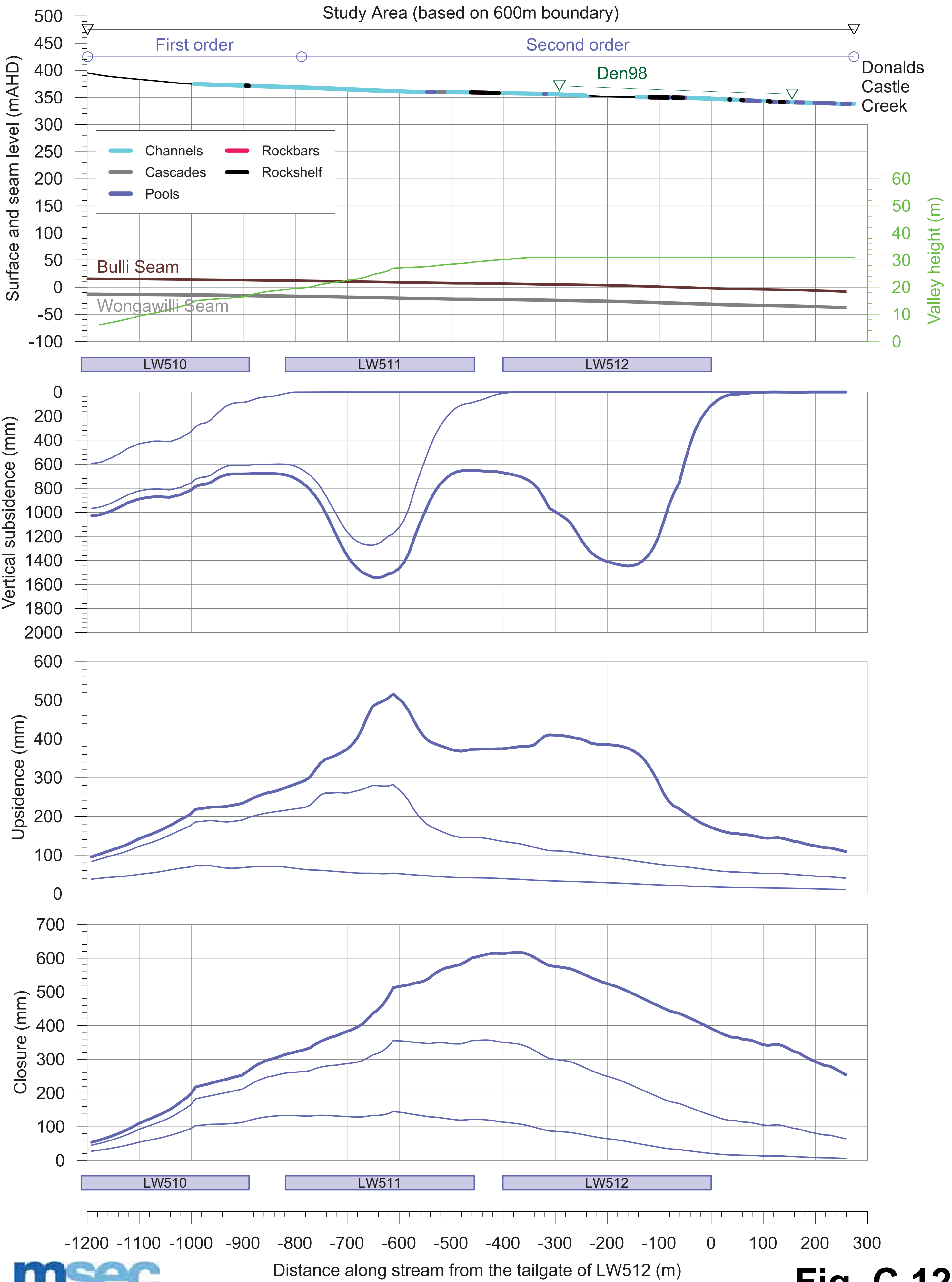

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Fig. C.12

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line DC10(C) due to mining in Area 5

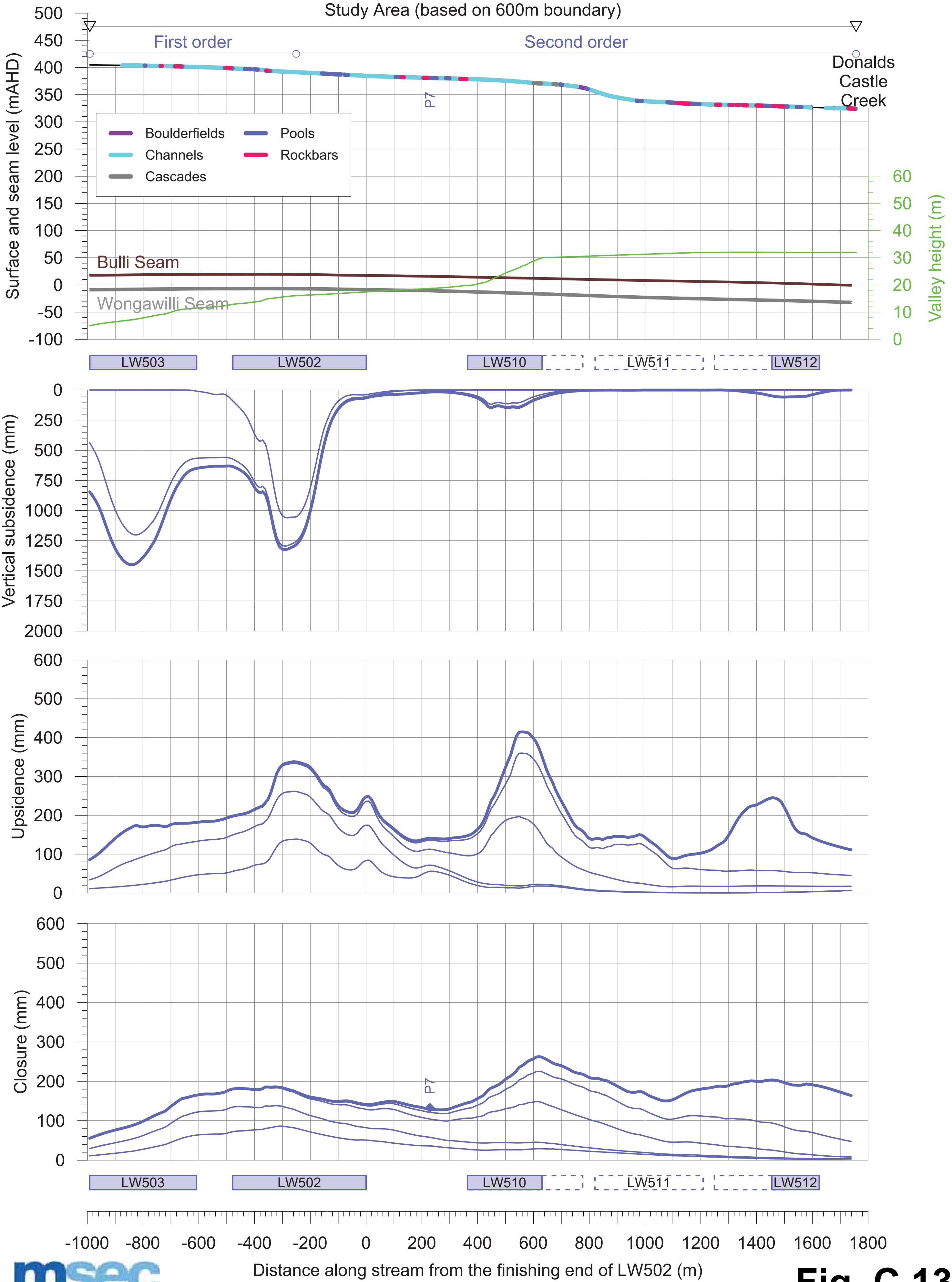

Fig. C.13

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line LA13 due to mining in Area 5

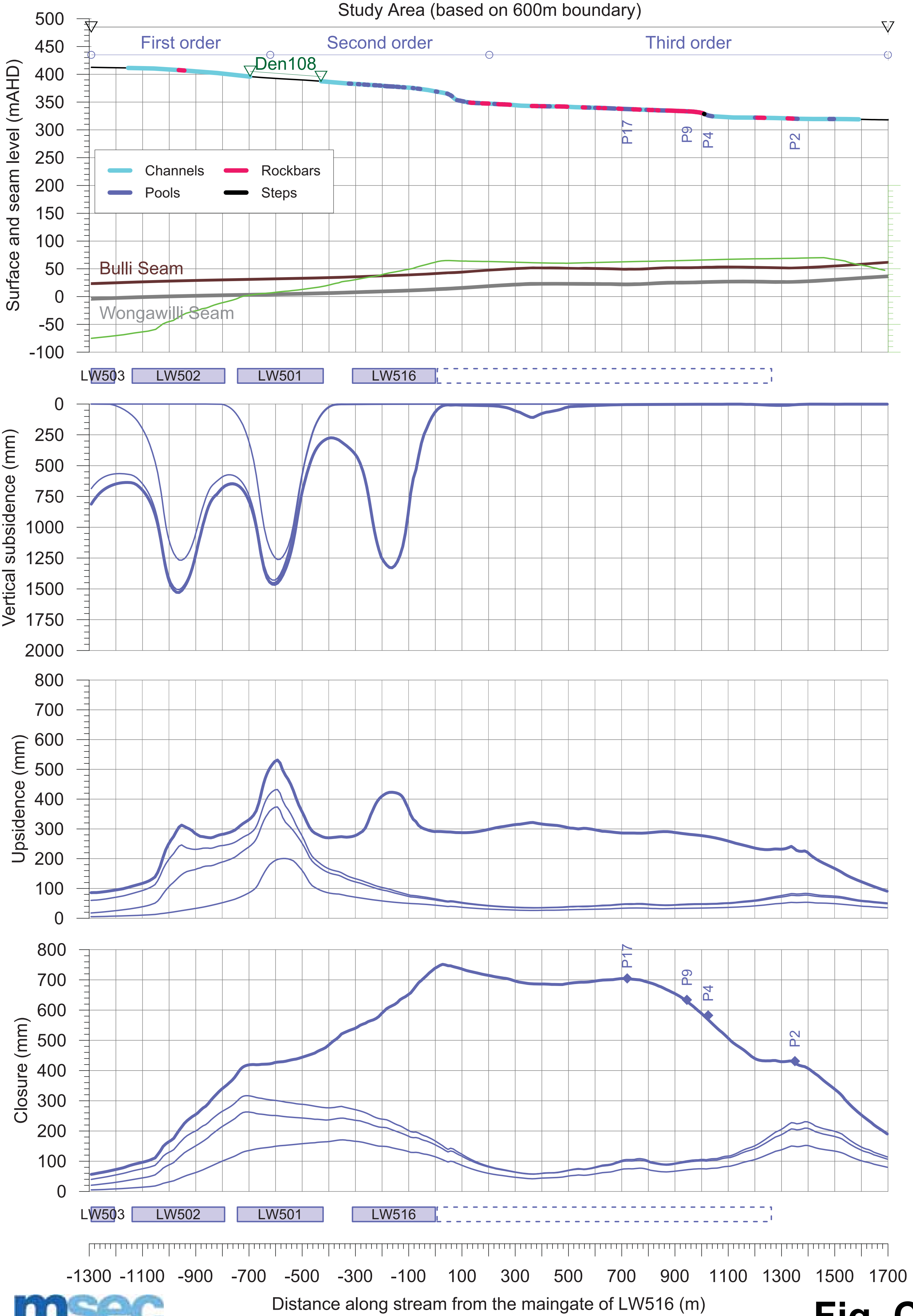

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Fig. C.14

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line LA13A due to mining in Area 5

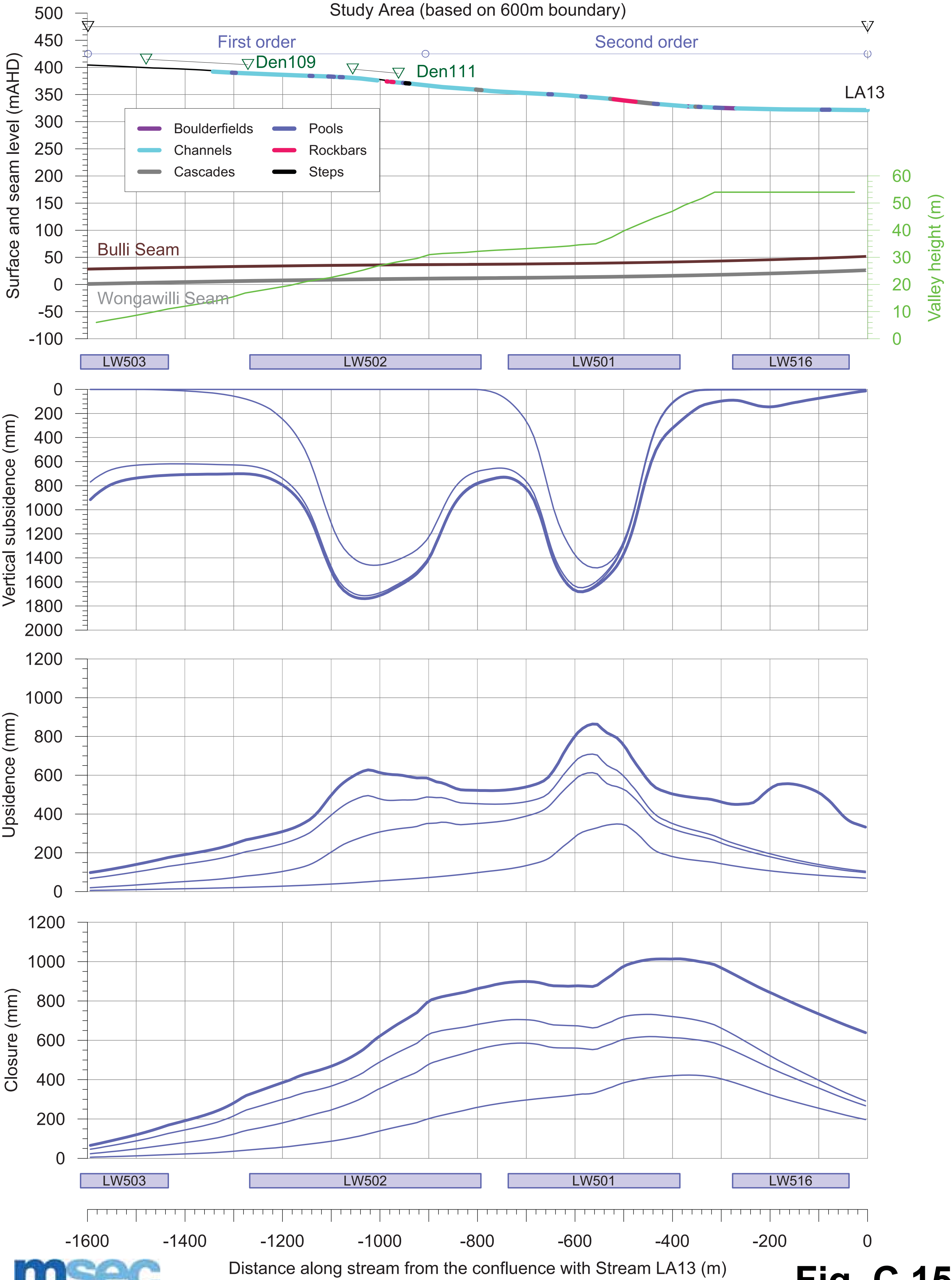

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Fig. C.15

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line CR29 due to mining in Area 6

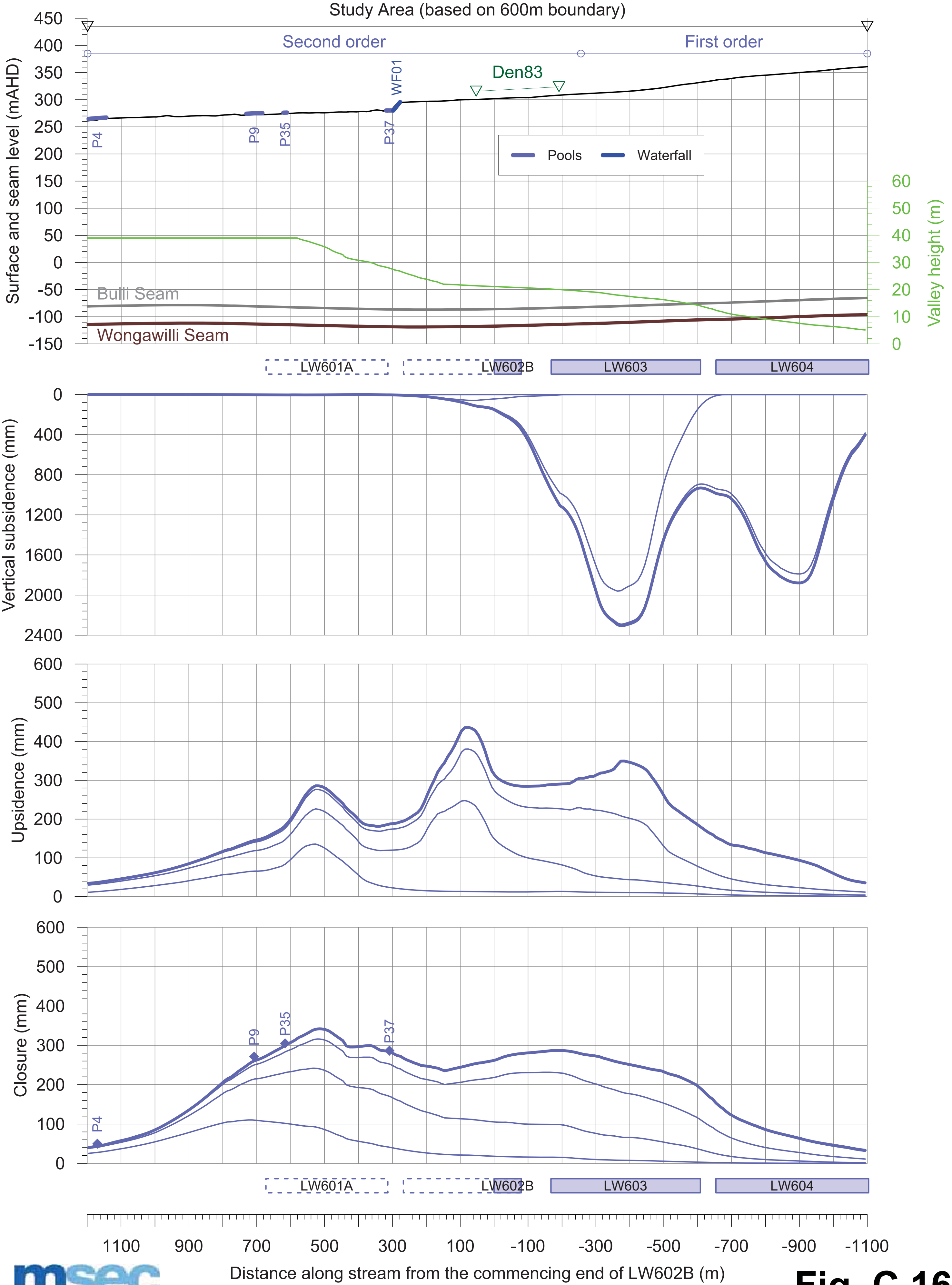

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Fig. C.16

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line CR31(C) due to mining in Area 6

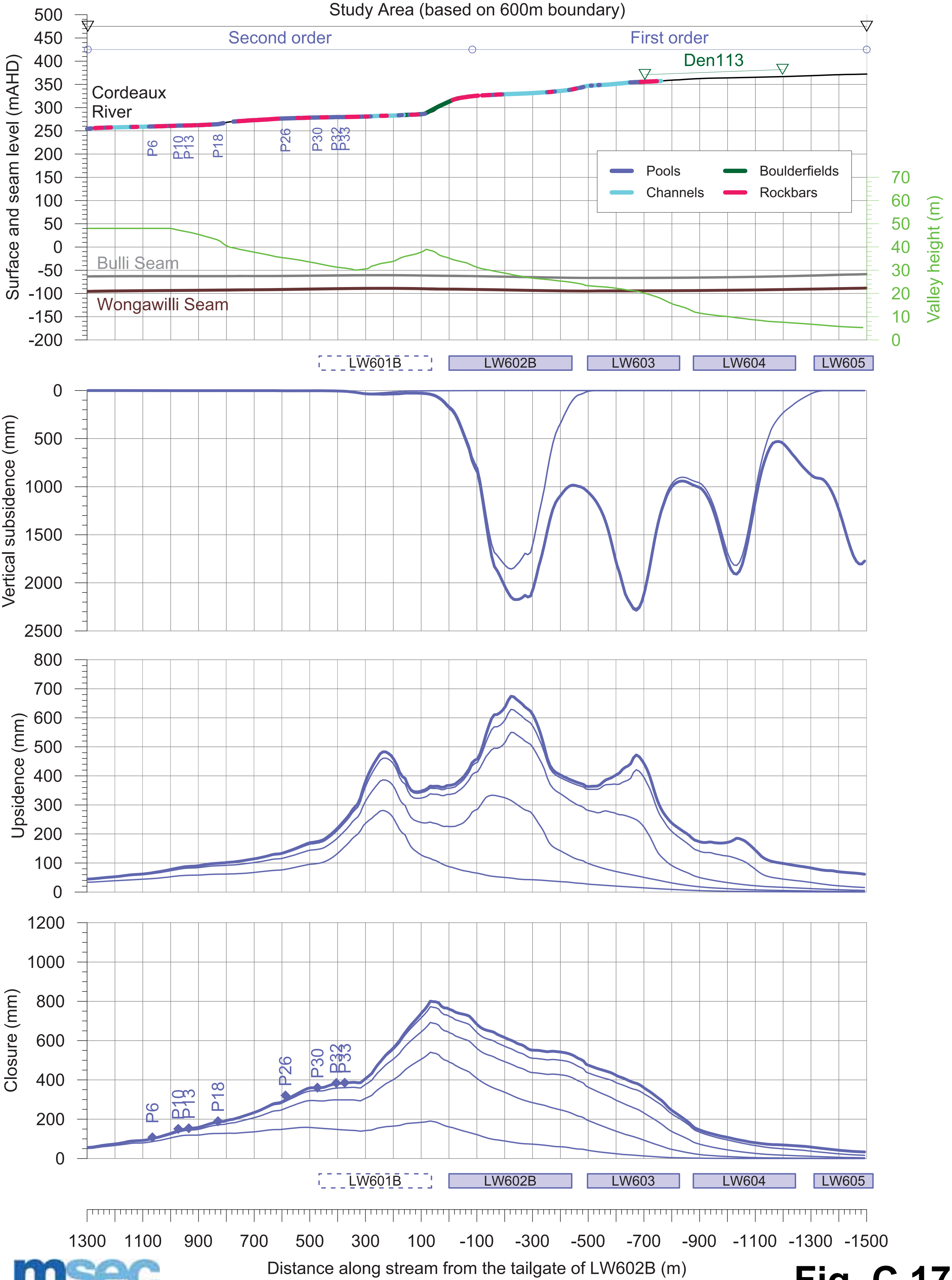

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Fig. C.17

I:\Projects\Dendrobium Next Domain\MSEC856 - Environmental Impact Statement\Subsdata\Impacts\Railway\Fig. C.18 - Railway Corridor.grf

Predicted profiles of vertical subsidence, tilt and curvature along the disused railway corridor due to mining in Area 5

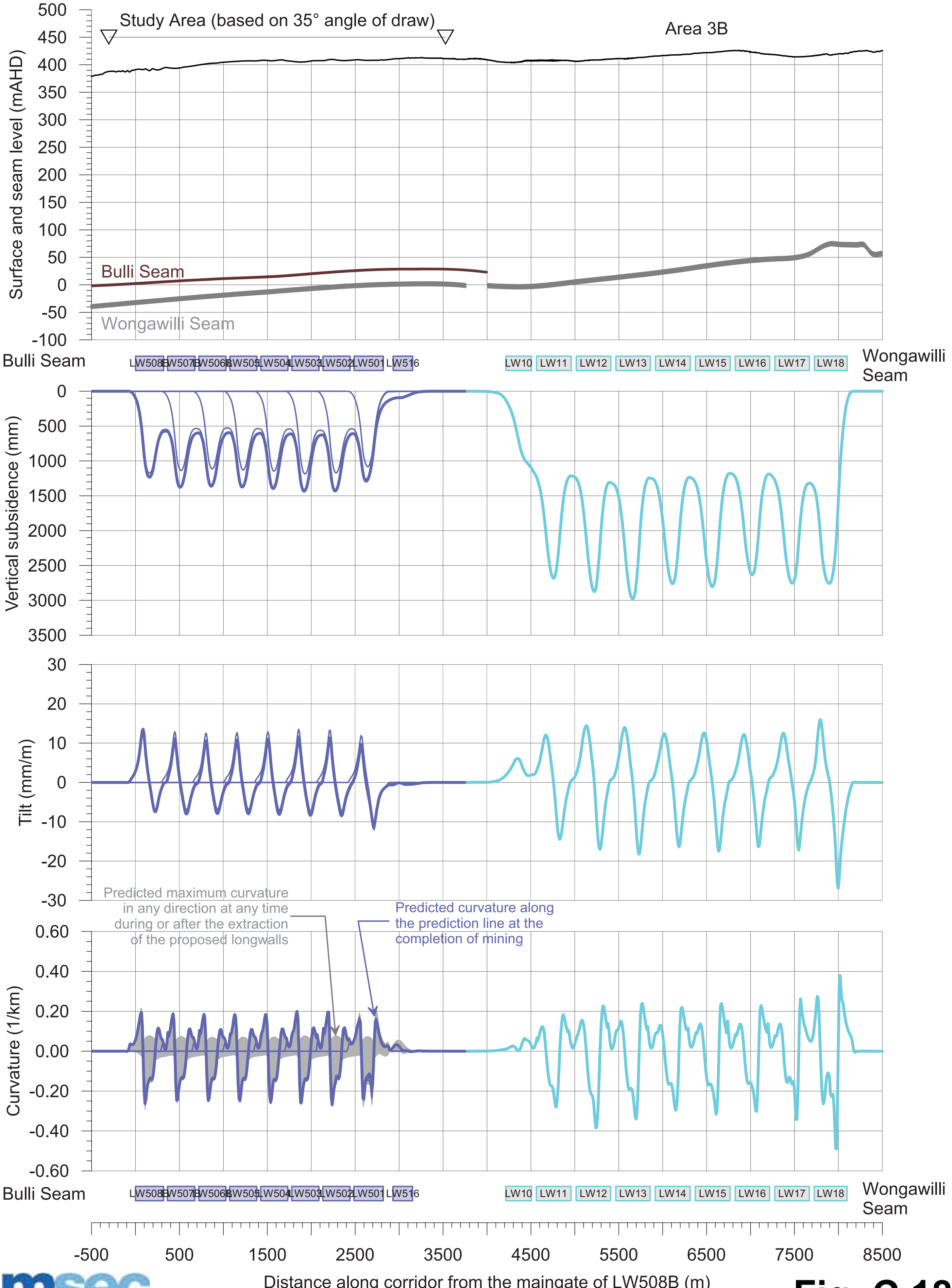

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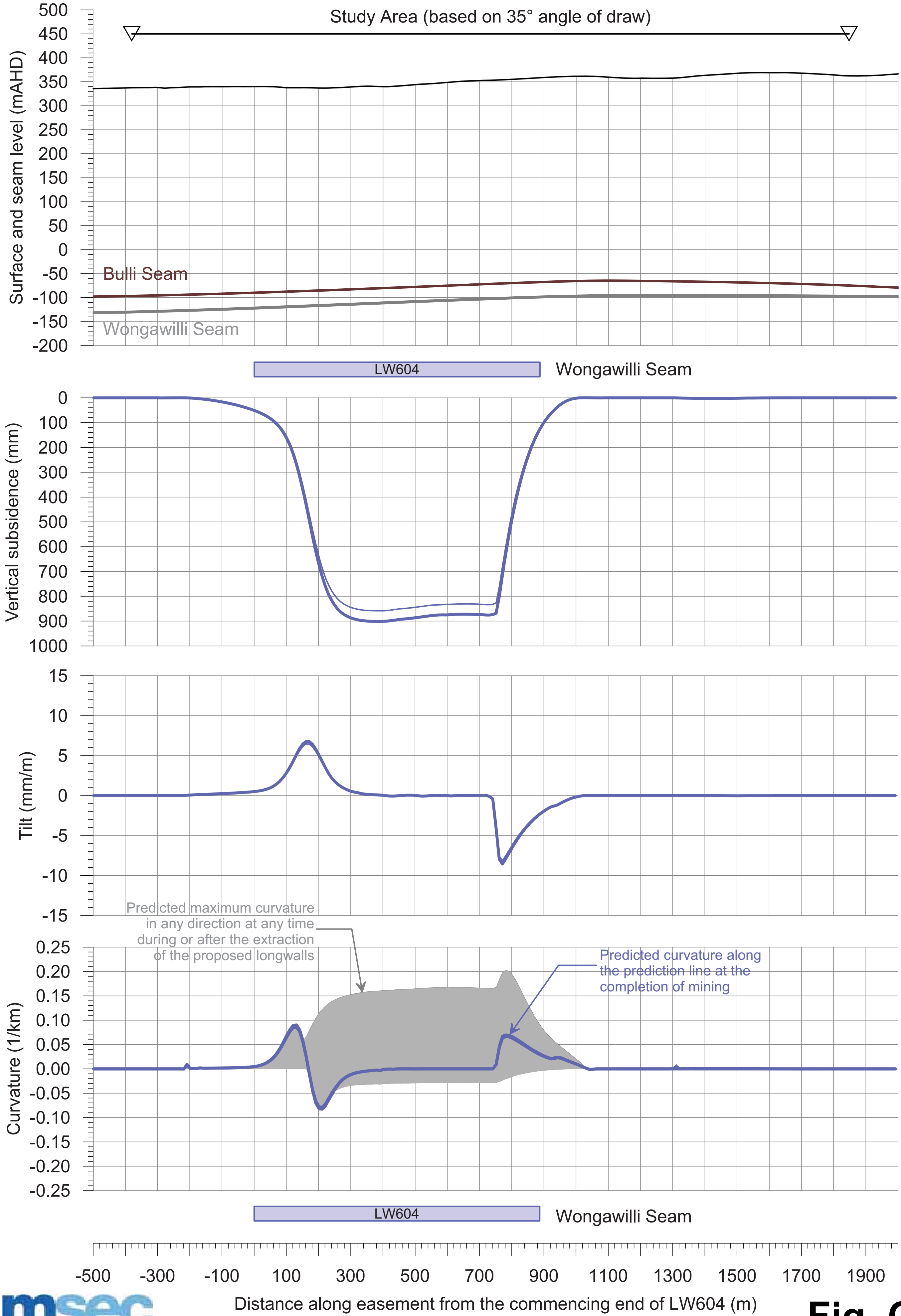
Fig. C.18

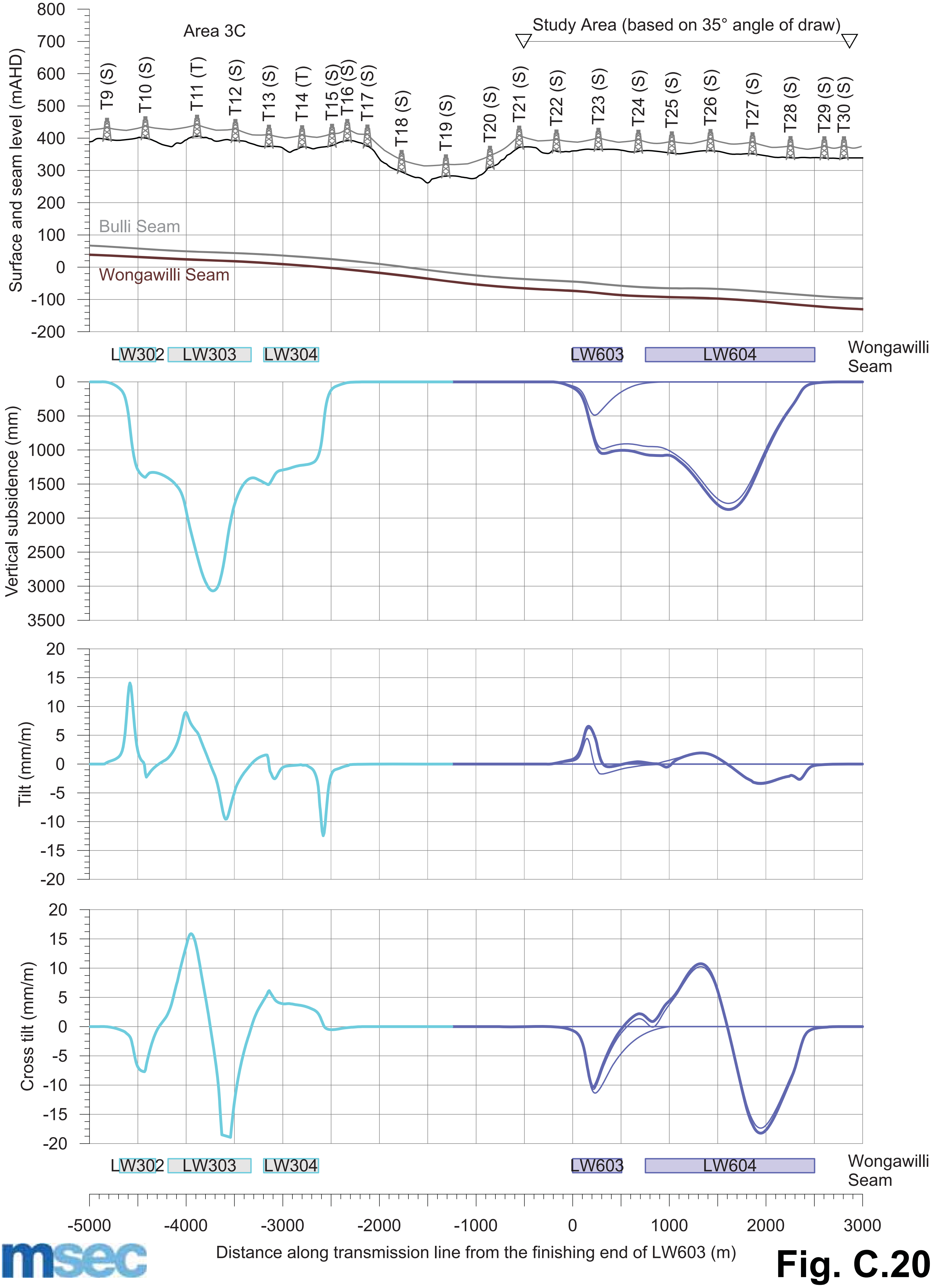
Predicted profiles of vertical subsidence, tilt and curvature along the gas pipeline easement due to mining in Area 6



msec

Fig. C.19

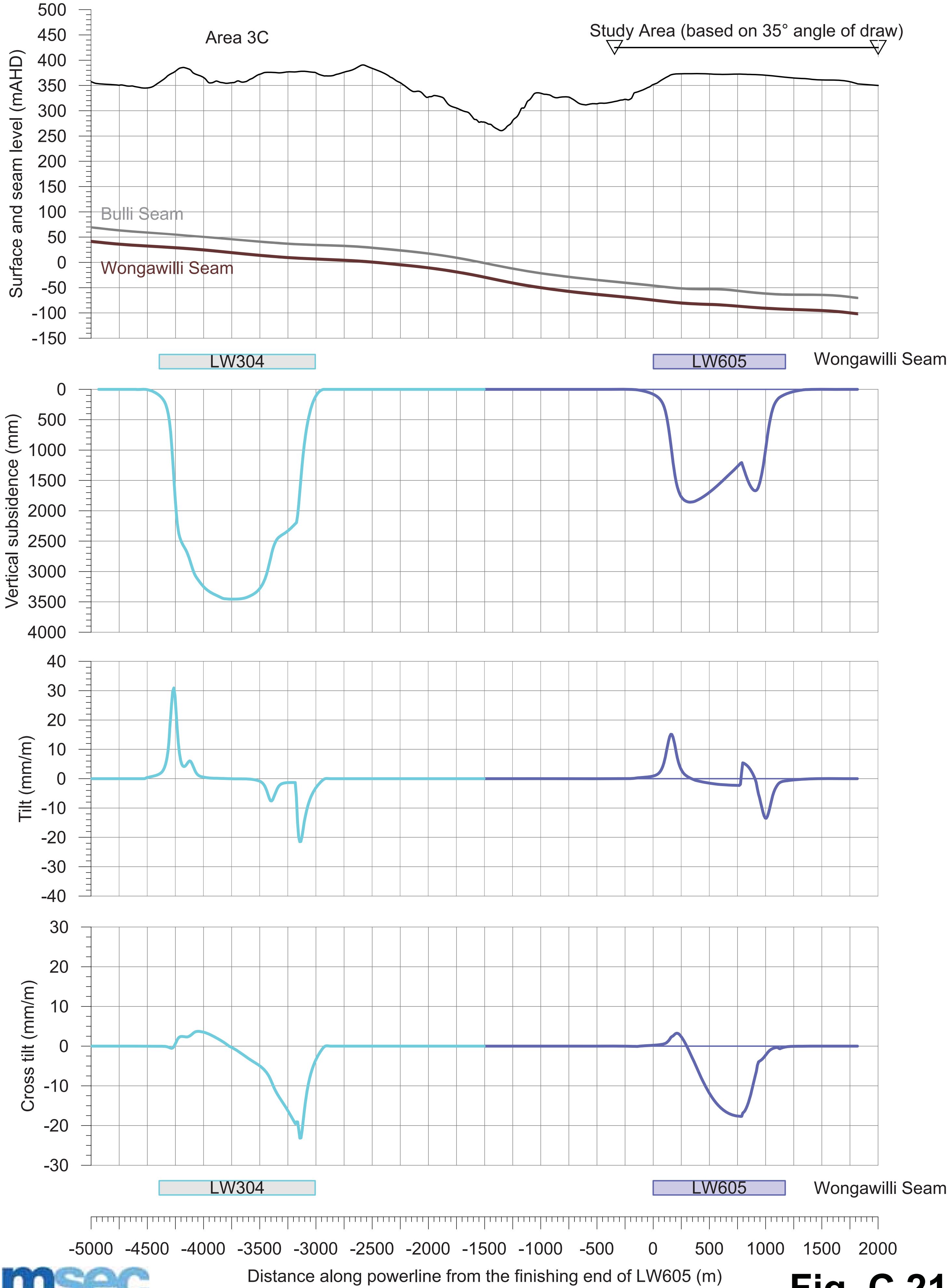
Predicted profiles of vertical subsidence, tilt along and tilt across the 330 kV transmission line due to mining in Areas 3C and 6



msec

Fig. C.20

Predicted profiles of vertical subsidence, tilt along and tilt across the 33 kV powerline due to mining in Areas 3C and 6



msec

Fig. C.21

APPENDIX D. TABLES

Table D.01 - Details and maximum predicted subsidence parameters for the cliffs within the Study Area

Area	Cliff ID	Overall Length (m)	Maximum Height (m)	Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (1/km)	Maximum predicted total sagging curvature (1/km)
Area 5	AR31-CF1	55	20	100m south of LW508A	70	< 0.5	< 0.01	< 0.01
Area 5	AR31A-CF1	45	12	Directly above LW508A	1950	19.0	0.40	0.40
Area 5	AR31A-CF2	90	20	Directly above LW508A	2000	10.0	0.18	0.35
Area 5	AR31A1-CF1	20	10	Directly above LW508A	1650	15.0	0.13	0.45
Area 5	AR32-CF1	25	10	170m north-west of LW504	< 20	< 0.5	< 0.01	< 0.01
Area 5	AR32-CF2	30	10	50m west of LW506A	30	0.5	0.02	< 0.01
Area 5	AR32-CF3	35	10	140m west of LW506A	< 20	< 0.5	< 0.01	< 0.01
Area 5	AR32-CF4	25	10	10m west of LW506A	60	1.0	0.02	< 0.01
Area 5	AR32-CF5	20	10	80m west of LW506A	< 20	< 0.5	< 0.01	< 0.01
Area 5	AR32-CF6	35	10	110m west of LW506A	< 20	< 0.5	< 0.01	< 0.01
Area 5	AR32-CF7	35	10	150m west of LW506A	< 20	< 0.5	< 0.01	< 0.01
Area 5	AR32-CF8	25	12	30m north of LW506A	< 20	< 0.5	< 0.01	< 0.01
Area 5	AR32-CF9	55	15	30m west of LW507A	40	1.0	< 0.01	< 0.01
Area 5	AR32A-CF1	30	10	Directly above LW506A	1050	10.0	0.30	0.08
Area 5	AR32A-CF2	20	13	Directly above LW506A	1350	25.0	0.50	0.50
Area 5	AR32A-CF3	30	10	Directly above LW506A	1300	20.0	0.45	0.50
Area 5	DC8-CF1	20	10	Directly above LW505	725	5.5	0.16	0.02
Area 5	DC8-CF2	40	15	Partially above LW506B	650	2.5	0.07	0.03
Area 5	DC8-CF3	25	15	Directly above LW506B	625	2.0	0.06	0.04
Area 5	DC8-CF4	150	20	Directly above LW506B	625	6.0	0.10	0.10
Area 5	DC8-CF5	40	10	30m east of LW506B	60	0.5	0.03	< 0.01
Area 5	DC8-CF6	90	10	40m west of LW510	325	2.0	0.03	0.03
Area 5	DC8-CF7	25	10	Directly above LW510	1050	12.0	0.25	0.05
Area 5	DC8A-CF1	65	10	Directly above LW511	1250	15.0	0.25	0.35
Area 5	DC8D-CF1	20	10	40m esst of LW505	70	0.5	0.02	< 0.01
Area 5	DC10-CF1	40	10	Directly above LW512	1300	14.0	0.10	0.40
Area 5	DC10-CF2	25	10	Directly above LW512	1150	8.0	0.12	0.15
Area 5	LA6_CF5	20	11	70m south-east of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA6_CF6	20	11	70m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA6_CF7	20	10	70m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA6_CF8	20	10	170m south of LW515	< 20	< 0.5	< 0.01	< 0.01

Table D.01 - Details and maximum predicted subsidence parameters for the cliffs within the Study Area

Area	Cliff ID	Overall Length (m)	Maximum Height (m)	Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (1/km)	Maximum predicted total sagging curvature (1/km)
Area 5	LA6_CF9	20	13	180m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA6_CF10	20	11	200m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA6_CF11	20	10	250m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA7_CF1	20	10	250m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA8_CF1	40	11	Directly above LW514	675	2.0	0.13	0.06
Area 5	LA8_CF2	45	11	Directly above LW515B	800	5.0	0.30	0.08
Area 5	LA8_CF3	45	13	Directly above LW515	950	11.0	0.40	0.10
Area 5	LA8_CF4	20	10	Directly above LW515	1100	13.0	0.35	0.11
Area 5	LA8_CF5	35	12	Directly above LW515	1200	13.0	0.35	0.20
Area 5	LA8_CF6	90	14	Directly above LW515	1400	13.0	0.35	0.30
Area 5	LA8_CF7	25	13	80m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA8_CF8	90	12	100m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA8_CF9	40	13	Directly above LW515	1400	12.0	0.16	0.30
Area 5	LA8_CF10	175	15	Directly above LW515	1450	13.0	0.18	0.35
Area 5	LA8_CF11	30	10	150m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA8_CF12	20	10	170m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA8_CF13	20	10	210m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA8_CF14	20	12	220m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA8_CF15	20	12	240m south of LW515	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA8A_CF1	20	10	Directly above LW515	475	15.0	0.40	0.04
Area 5	LA8A_CF2	20	12	Directly above LW515	625	16.0	0.35	0.04
Area 5	LA8A_CF3	20	13	Directly above LW515	350	10.0	0.25	0.02
Area 5	LA10-CF1	35	13	80m south-west of LW514	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA10-CF2	45	14	110m south-west of LW514	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA13-CF1	20	10	90m south of LW516	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA13-CF2	25	11	30m south of LW516	20	1.5	0.07	< 0.01
Area 5	LA13-CF3	165	15	170m west of LW516	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA13A-CF1	35	10	Partially above LW501	300	8.5	0.25	0.02
Area 5	LA13A-CF2	35	12	Partially above LW501	350	7.0	0.20	0.08
Area 5	LA13A-CF3	100	12	Partially above LW516	100	3.0	0.11	0.02
Area 5	LA13A-CF4	45	11	Directly above LW516	100	2.0	0.07	0.02

Table D.01 - Details and maximum predicted subsidence parameters for the cliffs within the Study Area

Area	Cliff ID	Overall Length (m)	Maximum Height (m)	Location	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (1/km)	Maximum predicted total sagging curvature (1/km)
Area 5	LA13A-CF5	30	12	Partially above LW516	70	1.5	0.03	< 0.01
Area 5	LA13A-CF6	30	10	100m south of LW501	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA14-CF1	25	12	Directly above LW501	1600	11.0	0.14	0.35
Area 5	LA14-CF2	75	12	Directly above LW501	1600	7.5	0.14	0.19
Area 5	LA14-CF3	25	10	Directly above LW501	1200	18.0	0.35	0.35
Area 5	LA14-CF4	25	10	Directly above LW501	950	18.0	0.35	0.25
Area 5	LA15-CF1	40	12	Directly above LW501	1500	17.0	0.35	0.40
Area 5	LA15-CF2	85	12	Directly above LW501	950	16.0	0.35	0.12
Area 5	LA15-CF3	200	25	Partially above LW501	100	1.5	0.04	< 0.01
Area 5	LA15-CF4	140	12	Partially above LW501	90	1.5	0.03	0.01
Area 5	LA15-CF5	80	11	30m west of LW501	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA15-CF6	20	10	140m west of LW501	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA15-CF7	65	12	160m west of LW501	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA15-CF8	50	12	200m west of LW501	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA15-CF9	40	14	220m west of LW501	< 20	< 0.5	< 0.01	< 0.01
Area 5	LA17-CF1	60	10	Directly above LW503	900	14.0	0.25	0.20
Area 5	LA17-CF2	70	10	Partially above LW503	125	2.0	0.05	< 0.01
Area 6	CR-CF1	55	12	150m west of LW601	< 20	< 0.5	< 0.01	< 0.01
Area 6	CR29-CF1	50	10	30m west of LW602	< 20	< 0.5	< 0.01	< 0.01
Area 6	CR29-CF2	30	10	170m north of LW601	< 20	< 0.5	< 0.01	< 0.01
Area 6	CR29-CF3	30	10	170m north-west of LW601	< 20	< 0.5	< 0.01	< 0.01
Area 6	CR31-CF1	50	10	280m west of LW601	< 20	< 0.5	< 0.01	< 0.01
Area 6	CR35-CF1	35	10	240m south-west of LW601	< 20	< 0.5	< 0.01	< 0.01
Area 6	LC1-CF1	30	10	240m east of LW605	< 20	< 0.5	< 0.01	< 0.01
				Maximum	**2000**	**25.0**	**0.50**	**0.50**

Table D.02 - Details and maximum predicted subsidence parameters for the swamps within the Study Area

Area	Swamp Ref.	Centroid Easting (MGA)	Centroid Northing (MGA)	Type	Location above or outside of longwalls	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (1/km)	Maximum predicted total sagging curvature (1/km)	Valley Height (m)	Maximum predicted total valley related upsidence (mm)	Maximum predicted total valley related closure (mm)	Maximum predicted total conventional closure (mm)
Area 5	Den01b	288160	6194155	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	5	< 20	20	< 20
	Den02	289445	6195065	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	30	50	90	< 20
	Den85	288110	6194985	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	5 to 15	30	40	< 20
	Den86	286550	6196490	Headwater	Above	1600	14	0.25	0.40	5 to 15	225	250	225
	Den97	286870	6197535	Headwater	Above	1350	9	0.13	0.17	5 to 15	200	200	90
	Den98	289265	6196420	Valley Infill	Outside	1450	19	0.40	0.40	30	400	575	200
	Den99	285210	6196095	Headwater	Above	1650	14	0.30	0.40	5 to 10	200	200	100
	Den100	286770	6197040	Headwater	Above	1050	12	0.25	0.04	0 to 5	80	90	125
	Den101	285930	6196350	Headwater	Above	1750	15	0.30	0.40	5	80	80	< 20
	Den102	286030	6196530	Headwater	Above	1400	10	0.15	0.13	No valley	-	-	-
	Den103	285860	6196715	Headwater	Above	1700	17	0.30	0.40	10 to 15	150	225	< 20
	Den104	285405	6196865	Valley Infill	Above	80	4	0.08	< 0.01	20	275	300	< 20
	Den105	285305	6196775	Headwater	Above	1150	19	0.30	0.40	No valley	-	-	-
	Den106	287455	6195075	Headwater	Outside	1250	13	0.20	0.30	No valley	-	-	-
	Den107	286325	6195175	Headwater	Above	1450	15	0.09	0.35	5 to 10	175	175	125
	Den108	286595	6195135	Valley Infill	Above	1450	15	0.30	0.40	20 to 25	525	525	150
	Den109	286285	6195730	Headwater	Above	900	7	0.18	0.04	10 to 15	225	250	60
	Den110	285875	6195785	Headwater	Above	1150	11	0.25	0.06	5 to 10	125	125	70
	Den111	285950	6195580	Valley Infill	Above	1750	9	0.13	0.40	15 to 20	325	325	70
	Den114	285235	6195590	Headwater	Above	1600	10	0.15	0.18	15 to 20	300	325	< 20
	Den120	287035	6197320	Headwater	Above	1400	12	0.20	0.30	5	70	70	150
	Den121	284605	6196505	Valley Infill	Above	1500	15	0.30	0.35	15 to 30	400	425	275
	Den122	284895	6196585	Headwater	Above	1300	10	0.19	0.07	5 to 15	225	225	150
	Den123	285670	6196275	Headwater	Above	1750	11	0.16	0.19	No valley	-	-	-
	Den124	289600	6196090	Valley Infill	Outside	< 20	< 0.5	< 0.01	< 0.01	35 to 40	125	325	< 20
	Den126	288035	6197970	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	No valley	-	-	-
	Den127	290080	6197250	Valley Infill	Outside	< 20	< 0.5	< 0.01	< 0.01	5 to 10	< 20	< 20	< 20
	Den137	286970	6198190	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	No valley	-	-	-
Area 6	Den83	291320	6201095	Headwater/Valley Infill	Above	2300	17	0.20	0.45	20	275	275	50
	Den112	292190	6200770	Headwater	Outside	50	1	0.02	< 0.01	5 to 10	20	30	< 20
	Den113	291670	6200320	Headwater	Above	2250	18	0.20	0.45	10 to 20	350	350	200
	Den115	291625	6198750	Headwater	Outside	30	< 0.5	0.02	< 0.01	5 to 10	30	30	< 20
	Den116	292085	6199195	Headwater	Outside	100	2	0.03	< 0.01	5 to 25	100	100	< 20
	Den117	291650	6199855	Headwater	Above	2250	15	0.20	0.45	10 to 15	250	300	150
	Den118	291040	6201585	Valley Infill	Above	1250	13	0.18	0.25	20	175	175	50
	Den119	290480	6201905	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	5 to 10	< 20	30	< 20
	Den128	291260	6201850	Headwater	Above	20	< 0.5	0.01	< 0.01	5 to 10	40	40	< 20
	Den129	292290	6201480	Valley Infill	Outside	< 20	< 0.5	< 0.01	< 0.01	5 to 20	30	40	< 20
	Den130	292705	6201170	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	No valley	-	-	-
	Den131	292235	6198560	Valley Infill	Outside	< 20	< 0.5	< 0.01	< 0.01	10 to 25	60	90	< 20
	Den132	292960	6198975	Valley Infill	Outside	< 20	< 0.5	< 0.01	< 0.01	5 to 20	< 20	20	< 20
	Den133	291750	6202320	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	No valley	-	-	-
	Den134	290755	6202070	Valley Infill	Outside	< 20	< 0.5	< 0.01	< 0.01	5 to 10	< 20	20	< 20
	Den135	291355	6202310	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	No valley	-	-	-
	Den136	291650	6202120	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	No valley	-	-	-
	Den138	292725	6200860	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	No valley	-	-	-
					Maximum	**2300**	**19**	**0.40**	**0.45**		**525**	**575**	**275**

Table D.03 - Details and maximum predicted subsidence parameters for the Aboriginal heritage sites within the Study Area

Area	Reference	Type	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (1/km)	Maximum predicted total sagging curvature (1/km)
Area 5	52-2-1566	Grinding Groove Site	650	13.0	0.20	0.17
Area 5	52-2-1567	Rock Shelter	275	6.0	0.12	0.02
Area 5	52-2-1568	Grinding Groove Site	40	1.0	0.03	< 0.01
Area 5	52-2-1577	Grinding Groove Site	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1592	Grinding Groove Site	1250	11.0	0.20	0.25
Area 5	52-2-1729	Grinding Groove Site	< 20	< 0.5	0.03	< 0.01
Area 5	52-2-1730	Grinding Groove Site	30	1.5	0.06	< 0.01
Area 5	52-2-1733	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1735	Rock Shelter	100	3.5	0.07	0.04
Area 5	52-2-1736	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1737	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1739	Grinding Groove Site	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1747	Rock Shelter	800	2.0	0.10	0.05
Area 5	52-2-1752	Rock Shelter	50	1.0	0.02	< 0.01
Area 5	52-2-1753	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1754	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1755	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1756	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1757	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1758	Grinding Groove Site	325	3.5	0.10	0.01
Area 5	52-2-1759	Rock Shelter	625	17.0	0.35	0.05
Area 5	52-2-1761	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1775	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1776	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1778	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-1779	Grinding Groove Site	1150	10.0	0.18	0.06
Area 5	52-2-1780	Rock Shelter	1650	10.0	0.12	0.18
Area 5	52-2-1781	Grinding Groove Site	20	1.0	0.06	< 0.01
Area 5	52-2-1782	Rock Shelter	1250	20.0	0.60	0.45
Area 5	52-2-3204	Isolated Find	< 20	< 0.5	< 0.01	< 0.01

Table D.03 - Details and maximum predicted subsidence parameters for the Aboriginal heritage sites within the Study Area

Area	Reference	Type	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (1/km)	Maximum predicted total sagging curvature (1/km)
Area 5	52-2-3730	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 5	52-2-3955	Rock Shelter	1050	12.0	0.25	0.04
Area 5	52-2-4465	Grinding Groove Site	950	8.0	0.20	0.05
Area 5	52-2-4466	Grinding Groove Site	725	1.5	0.07	0.06
Area 5	52-2-4467	Grinding Groove Site	1250	11.0	0.30	0.25
Area 5	52-2-4468	Grinding Groove Site	600	3.0	0.11	0.02
Area 5	Dendrobium ACHA Shelter-2	Rock Shelter	775	20.0	0.50	0.20
Area 6	52-2-1278	Grinding Groove Site	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1279	Grinding Groove Site	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1450	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1451	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1452	Grinding Groove Site	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1453	Grinding Groove Site	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1456	Grinding Groove Site	1700	16.0	0.25	0.05
Area 6	52-2-1457	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1459	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1460	Grinding Groove Site	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1461	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1462	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1464	Rock Shelter	875	6.0	0.13	0.09
Area 6	52-2-1465	Grinding Groove Site	1850	15.0	0.20	0.16
Area 6	52-2-1466	Grinding Groove Site	2150	16.0	0.12	0.40
Area 6	52-2-1467	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-1474	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-3635	Rock Shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	52-2-4469	Rock Shelter	200	4.0	0.08	0.03
		Maximum	**2150**	**20.0**	**0.60**	**0.45**

Table D.04 - Details and maximum predicted subsidence parameters for the buildings and other structures within the Study Area

Area	Reference	Type	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (1/km)	Maximum predicted total sagging curvature (1/km)
Area 6	S_01	House	< 20	< 0.5	< 0.01	< 0.01
Area 6	S_02	House	< 20	< 0.5	0.02	< 0.01
Area 6	S_03	Garage	< 20	< 0.5	0.02	< 0.01
Area 6	S_04	Shed	< 20	< 0.5	0.02	< 0.01
Area 6	S_05	Shed	< 20	< 0.5	0.02	< 0.01
Area 6	S_06	Shed	< 20	< 0.5	0.02	< 0.01
Area 6	S_07	Shed	< 20	< 0.5	0.02	< 0.01
Area 6	S_08	Pool	< 20	< 0.5	0.02	< 0.01
Area 6	S_09	Toilet block	40	0.5	< 0.01	< 0.01
Area 6	S_10	Barbecue shelter	90	1.0	< 0.01	0.01
Area 6	S_11	Barbecue shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	S_12	Awning	< 20	< 0.5	< 0.01	< 0.01
Area 6	S_13	Information shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	S_14	Barbecue shelter	< 20	< 0.5	< 0.01	< 0.01
Area 6	S_15	Barbecue shelter	70	1.0	< 0.01	< 0.01
Area 6	S_16	Toilet block	< 20	< 0.5	< 0.01	< 0.01
Area 6	S_17	Toilet block	< 20	< 0.5	< 0.01	< 0.01
Area 6	S_18	Toilet block	< 20	< 0.5	< 0.01	< 0.01
Area 6	S_19	Shed	275	8.0	0.10	< 0.01
Area 6	S_20	Shed	250	6.5	0.10	< 0.01
Area 6	S_21	Garage	200	6.0	0.10	< 0.01
Area 6	S_22	House	100	3.5	0.06	< 0.01
Area 6	S_23	Shed	125	4.0	0.08	< 0.01
Area 6	S_24	Shed	1800	13.0	0.04	0.40
Area 6	S_25	Tank	1750	11.0	0.04	0.35
Area 6	S_26	Telecom tower	80	3.0	0.07	< 0.01
Area 6	S_27	Barbecue shelter	80	1.5	0.02	< 0.01
Area 6	S_28	Barbecue shelter	100	1.5	0.02	0.01
		Maximum	**1800**	**13.0**	**0.10**	**0.40**

APPENDIX E. DRAWINGS

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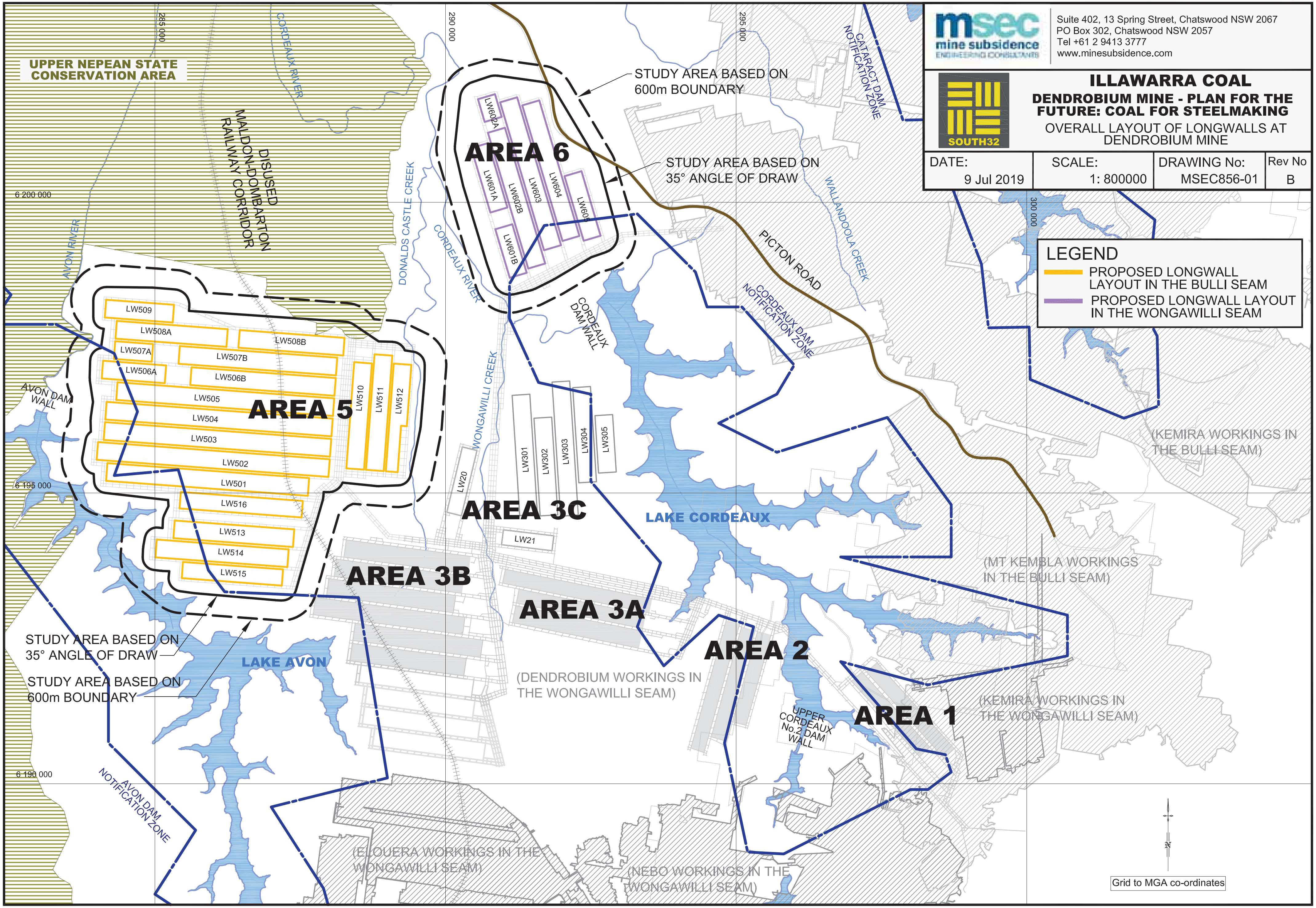

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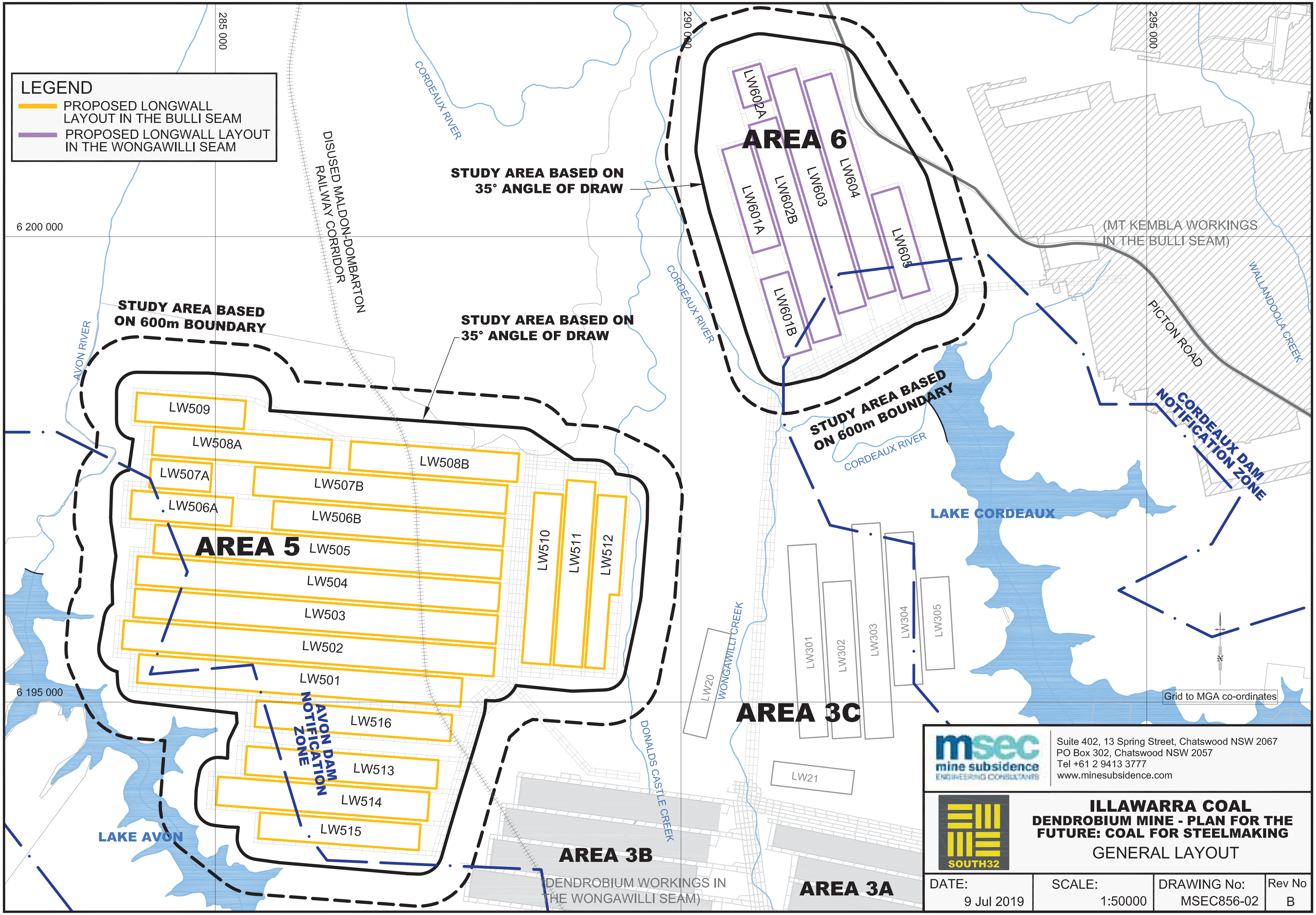

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SOUTH32

ILLAWARRA COAL
DENDROBIUM MINE - PLAN FOR THE FUTURE: COAL FOR STEELMAKING
GENERAL LAYOUT

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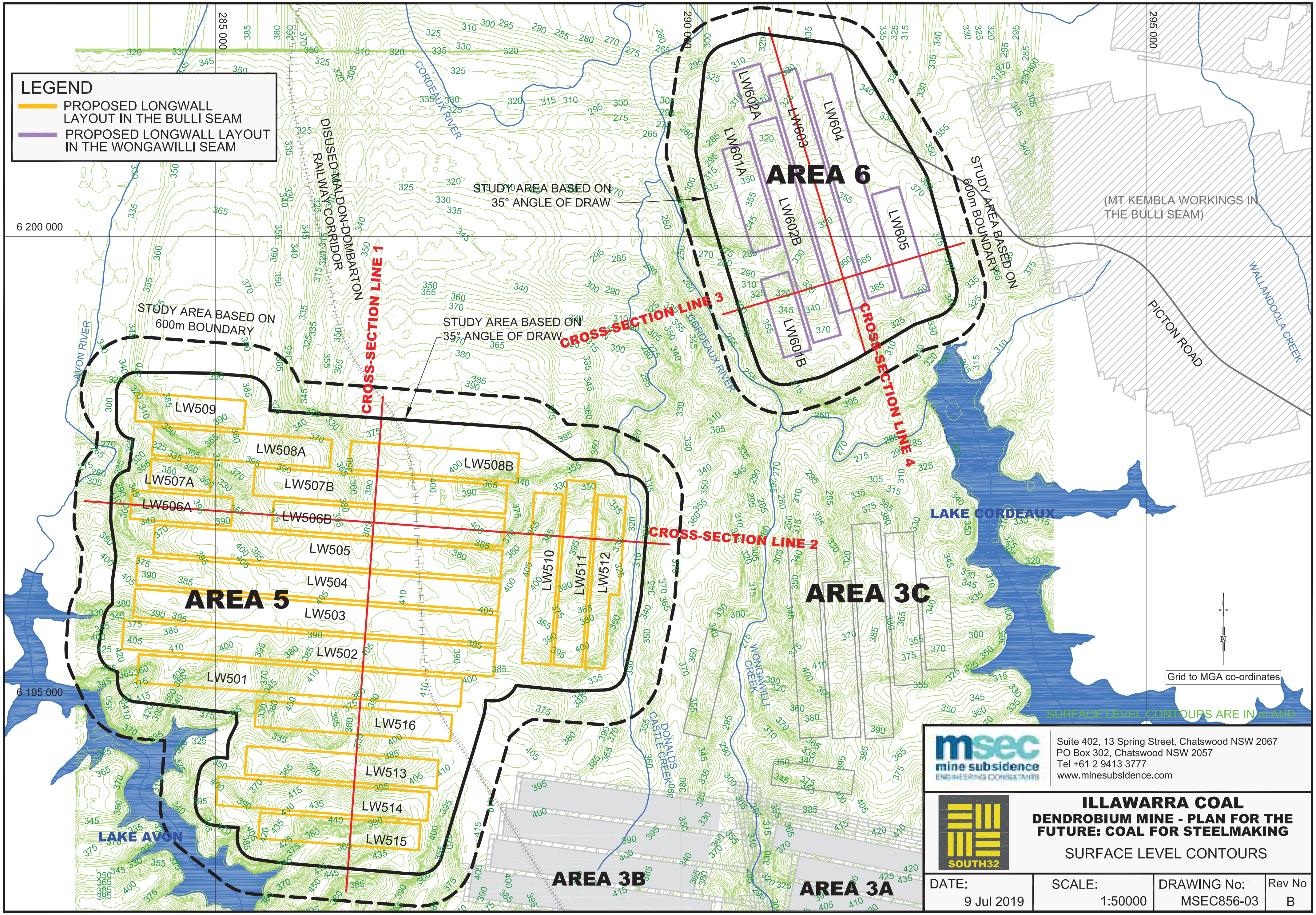

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DENDROBIUM MINE - PLAN FOR THE FUTURE: COAL FOR STEELMAKING

SURFACE LEVEL CONTOURS

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9 Jul 2019	1:50000	MSEC856-03	B

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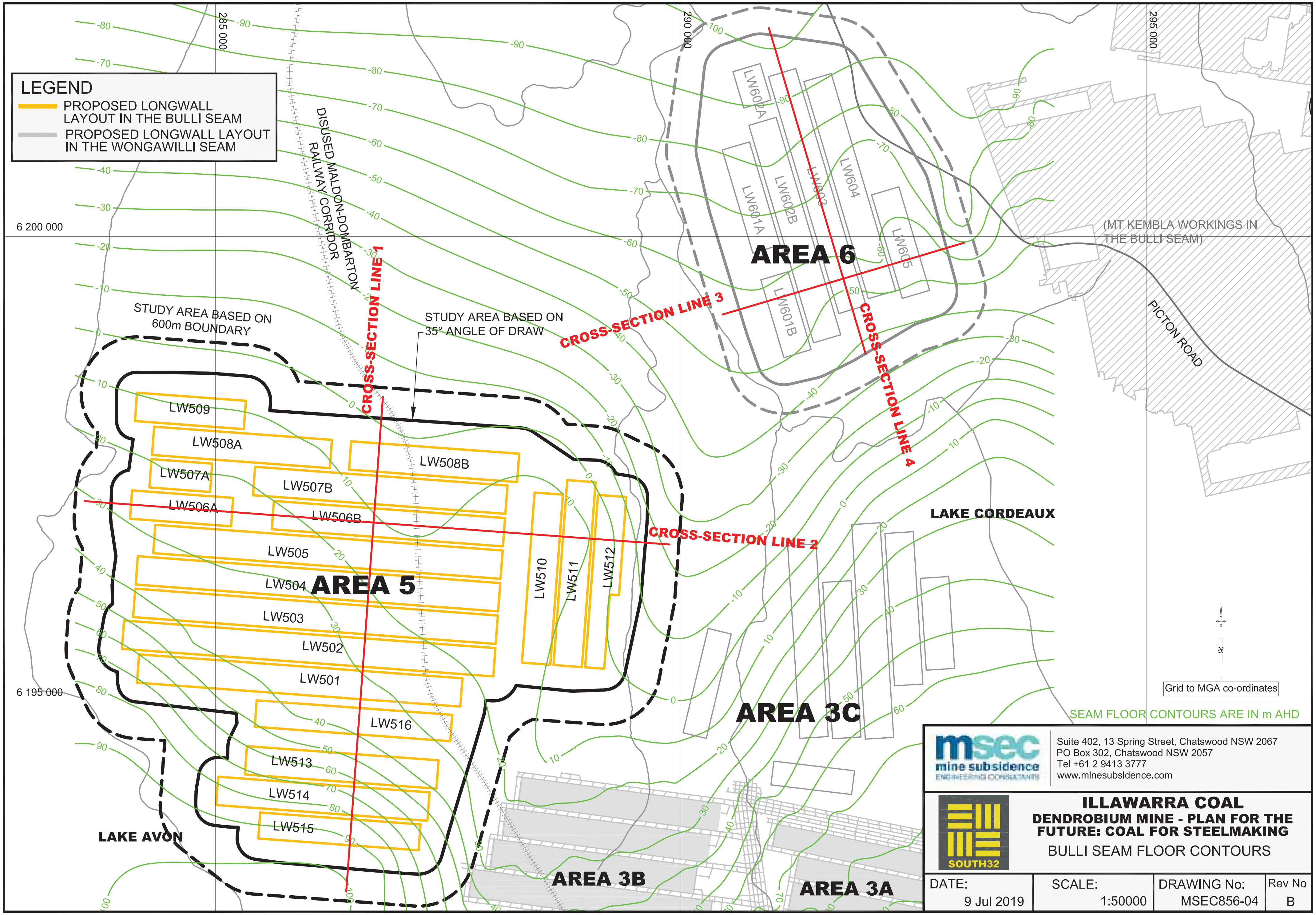

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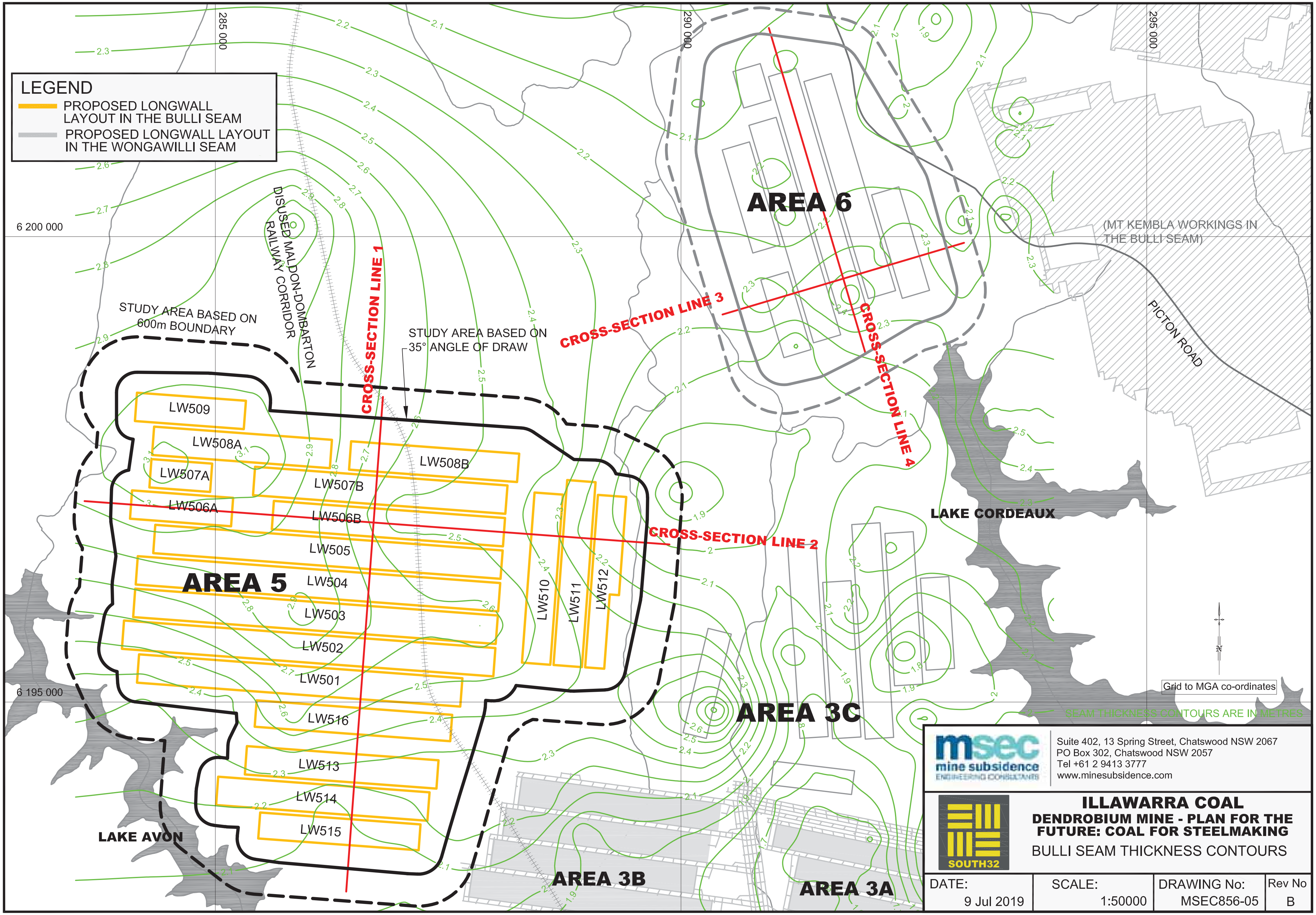

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DENDROBIUM MINE - PLAN FOR THE FUTURE: COAL FOR STEELMAKING
BULLI SEAM THICKNESS CONTOURS

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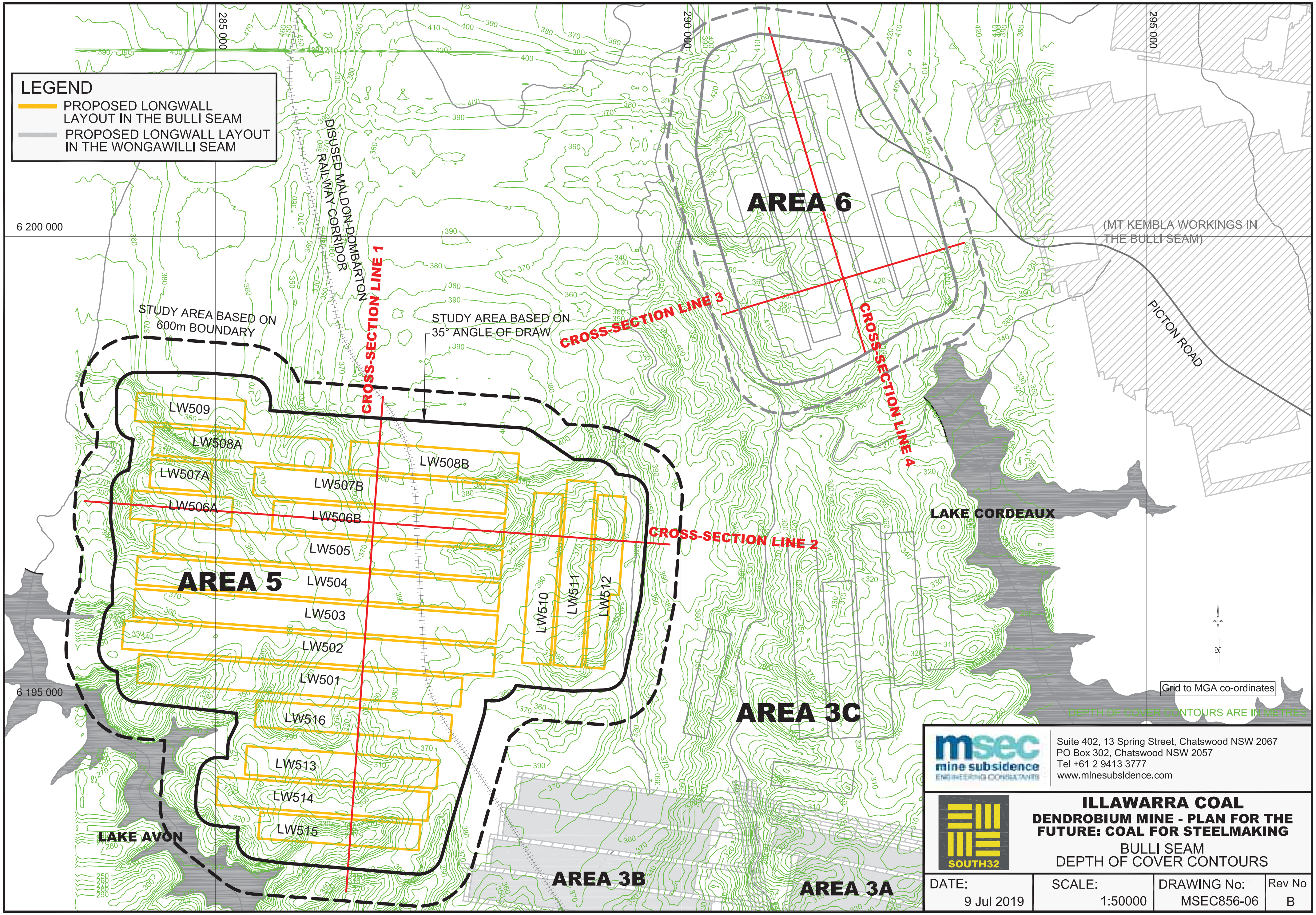

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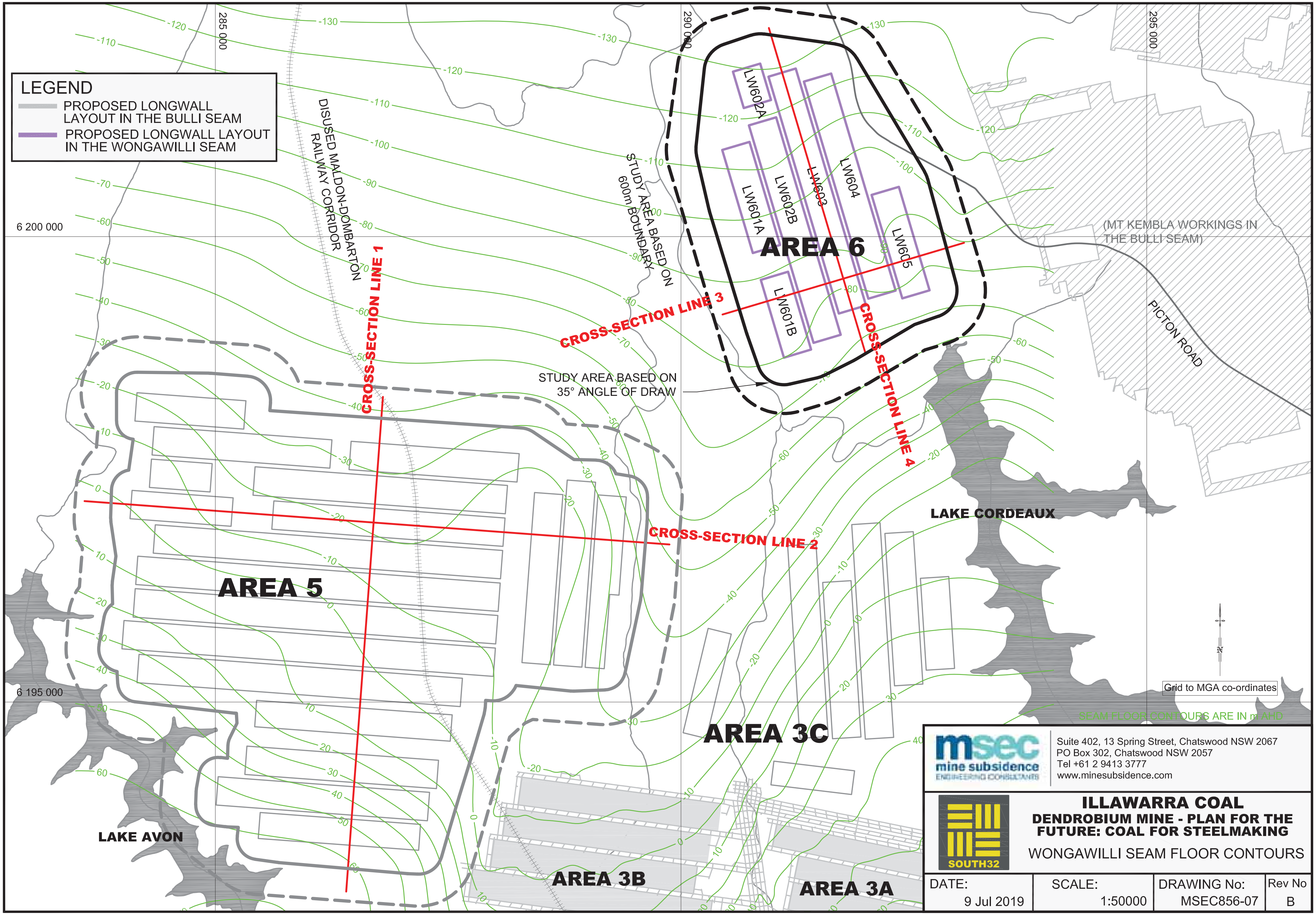

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ILLAWARRA COAL

DENDROBIUM MINE - PLAN FOR THE FUTURE: COAL FOR STEELMAKING

WONGAWILLI SEAM FLOOR CONTOURS

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