APPENDIX A

Subsidence Assessment

ILLAWARRA METALLURGICAL COAL:

Dendrobium Mine Extension Project

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

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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).

MSEC1181 (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).

MSEC856 (Rev. B) – 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 (July 2019).

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

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

IMC previously submitted an Environmental Impact Statement (EIS) seeking an extension of underground coal mining operations at the Dendrobium Mine by extracting longwalls in proposed Areas 5 and 6. Mine Subsidence Engineering Consultants (MSEC) prepared the Report No. MSEC856 (Rev. B) which provided subsidence predictions and impact assessments in support of that application. The longwall layout adopted in the previous EIS and Report No. MSEC856 is referred to as the Previous Layout in this report.

IMC is now preparing a new EIS based on a revised longwall layout in Area 5 and excluding longwall mining in Area 6 (the Project). The revised layout of the proposed longwalls in Area 5 is shown in Drawing No. MSEC1181-02, in Appendix E, and is referred to as the Revised Layout in this report. This subsidence report has been prepared to support the EIS for the revised longwalls in Area 5.

The predicted subsidence effects for the existing and proposed longwalls have been obtained using the Incremental Profile Method (IPM). This method has been reviewed and re-calibrated based on the updated ground monitoring and LiDAR data from LW6 to LW8 in Area 3A and LW9 to LW16 in Area 3B. The re-calibrated model provides predictions of vertical subsidence for longwalls up to 30 % greater than the standard IPM model for the Bulli 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 also similar to the 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 effects for the proposed longwalls in Area 5 are: 2000 mm vertical subsidence, 25 mm/m tilt (i.e. 2.5 % or 1 in 40), 0.50 km^{-1} hogging curvature (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 effects for the Revised Layout in Area 5 are the same or slightly less than the maximum predicted values based on the Previous Layout in Area 5. The reason is that the longwall widths, chain pillar widths, depths of cover and proposed mining heights remain the same.

While the maximum predicted subsidence effects remain the same, the extent of the longwall mining area within Area 5 has been reduced. The surface area located directly above the proposed longwalls and the chain pillars between the longwalls in Area 5 is 1520 hectares (ha) based on the Previous Layout and 792 ha based on the Revised Layout. The extents of the natural and built features affected by subsidence, based on the Revised Layout, therefore, are less than that based on the Previous Layout.

The *Study Area* is defined as the surface area that is likely to be affected by the extraction of the proposed longwalls in Area 5. 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 these effects have also been considered 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, Donalds Castle Creek, unnamed streams, cliffs, minor cliffs, steep slopes, swamps, a disused railway corridor, unsealed tracks, Avon and Cordeaux Reservoirs and associated dam walls, Aboriginal heritage sites, historical heritage sites and survey control marks.

A summary of the locations and maximum predicted subsidence effects for the natural and built features, based on the Previous and Revised Layouts, is provided below in Table 1. The values in this table for the Previous Layout include both Areas 5 and 6.

Table 1 Maximum predicted subsidence effects for the natural and built features based on the Previous and Revised Layouts

Feature type	Parameter	Name	Previous Layout (i.e. Previous Area 5 and Area 6)	Revised Layout (i.e. Revised Area 5)
Named streams	Total length of stream within 600 m of the longwalls (km)	Avon River	0.8	0.0
		Cordeaux River	1.4	0.0
		Donalds Castle Creek	3.3	0.0
		Wongawilli Creek	0.0	0.0
	Maximum predicted additional closure due to the longwalls (mm)	Avon River	200	30
		Cordeaux River	80	< 20
		Donalds Castle Creek	200	30
		Wongawilli Creek	< 20	< 20
Unnamed streams	Total length directly above the longwalls (km)	Third order	0.9	0.0
		First and second order	34	14
	Maximum predicted total closure due to the longwalls (mm)	Third order	1150	325
		First and second order	1000	750
Key stream features	Number located within the Study Area	-	45	15
	Maximum predicted total closure (mm)	-	700	300
Cliffs	Number located directly above longwalls	-	40	12
	Total length located directly or partially above longwalls (km)	-	2.2	0.8
	Maximum predicted total vertical subsidence (mm)	-	2000	1600
Rock outcrops and steep slopes	Maximum predicted total vertical subsidence (mm)	-	2450	2000
Upland swamps	Number directly or partially above longwalls	-	26	15
	Number within the 600 m boundary	-	46	22
	Maximum predicted total vertical subsidence (mm)	-	2300	1950
Dam walls	Minimum distance from the longwalls (km)	Avon Dam Wall	1.0	1.0
		Cordeaux Dam Wall	1.1	> 4
	Maximum predicted total closure (mm)	Avon Dam Wall	20	10
		Cordeaux Dam Wall	20	< 3
Aboriginal heritage sites	Number directly or partially above longwalls	Isolated finds	0	0
		Grinding groove sites	11	3
		Rock shelters	9	3
	Maximum predicted total vertical subsidence (mm)	Isolated finds	< 20	< 20
		Grinding groove sites	2150	1550
		Rock shelters	1650	1750

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 and Donalds Castle Creek are located at minimum distances of 900 m and 700 m, respectively, from the proposed longwalls in Area 5. The Cordeaux River and Wongawilli Creek are located more than 1.9 km from the proposed longwalls. At these distances, the named streams are not predicted to experience measurable conventional subsidence effects.

  The sections of the Avon River and Donalds Castle Creek located closest to the proposed mining area could experience low-level valley-related effects. However, it is considered unlikely that the named streams would experience adverse physical impacts (i.e. fracturing or mining-induced surface water diversions) based on their distances from the proposed mining area.

- Unnamed streams are located across the Study Area. There are first and second order streams located directly above the proposed mining area. The revised longwalls in Area 5 have avoided mining beneath third order sections of the unnamed streams. The longwalls have also avoided the key stream features along the unnamed streams including pools with volumes greater than 100 m^3 and waterfalls with heights greater than 5 m and with a pool at the base of the step.

  The unnamed streams that are located directly above or adjacent to the proposed longwalls have been labelled AR19, AR31, AR32, DC8, DC9, DC10, LA12, LA13, LA14, LA15 and LA17. The streams have exposed bedrock with some standing pools. There are also other controlling features including boulderfields, riffle zones and debris accumulations.

  The total length of the third order sections of the streams within the 35° angle of draw and the 600 m boundary are approximately 1.3 km and 2.2 km, respectively. Fracturing could occur along the third order sections of the streams located within 400 m of the proposed mining area. The potential for Type 3 impacts has been based on the experience from mining in Area 3B. It has been assessed that approximately 15 % of the stream controlling features (i.e. rockbars, steps and other controlling features) located within 400 m of the proposed longwalls could experience Type 3 impacts. This represents approximately five rockbars along the third order sections of the streams.

  The first and second order sections of the streams located directly above the proposed longwalls are expected to experience the full range of predicted subsidence effects. There is potential for locally increased ponding due to the mining-induced tilt along streams DC8 and, to lesser extents, the other first and second order streams. There could be localised tilt-induced ponding areas along the unnamed streams where the natural gradients are low immediately upstream of the longwall chain pillars or upstream of the perimeter of the proposed mining area.

  It is expected that fracturing of bedrock would occur along the sections of the streams that are located directly above the proposed longwalls. Fracturing can also occur outside the extents of 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 streams 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 12 cliffs that have been identified directly above the proposed longwalls in Area 5. There are also 32 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, this 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 60 m to 80 m, or a total face area of impact of approximately 300 m^2 to 500 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 Dendrobium 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 15 upland swamps that have been identified partially or entirely above the proposed longwalls in Area 5. There are an additional five swamps that are located outside of the proposed mining area and within the 35° angle of draw and an additional two swamps located within the 600 m boundary.

  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 predicted mining-induced tilt or vertical subsidence.

  Fracturing of 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 Area 5 are expected to be similar to but, on average, less than those previously observed at the Dendrobium Mine. The measured surface deformations were generally less than 50 mm in width (i.e. 79 % of the cases) but had widths between 50 mm and 150 mm in 15 % of cases, between 150 mm and 300 mm in 5 % of cases and greater than 300 mm in approximately 1 % 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.

- 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.

- Avon Reservoir is located to the west of the proposed longwalls in Area 5. The Avon Dam wall is 1 km from LW505 at its closest point to the proposed mining area. Cordeaux Reservoir is located to the east of Area 5 and its dam wall is more than 4 km from the proposed mining area. The Avon and Cordeaux dams are listed on the NSW State Heritage Register.

  The Avon and Cordeaux dam walls are not predicted to experience measurable vertical subsidence, upsidence or closure movements. The Avon Dam Wall could experience low-level far-field horizontal movements; however, they are not expected 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 IMC consult with WaterNSW and Dams Safety NSW 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 Plans.

- There are 31 Aboriginal heritage sites that have been identified within the Study Area, of which, six sites are located directly above the proposed longwalls. The sites within the Study Area comprise one isolated find, 13 grinding groove sites and 17 rock shelter sites.

  The isolated find is located approximately 500 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 three 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 nine 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 three 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 they are typically 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.

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

CONTENTS

Tables

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

Figures

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

Drawings

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

1.1. Background

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

IMC has carried out underground longwall mining in Areas 1, 2, 3A and 3B at the Dendrobium Mine. This includes LW1 and LW2 in Area 1, LW3 to LW5 in Area 2, LW6 to LW8 in Area 3A and LW9 to LW16 in Area 3B. IMC has approval for the extraction of additional longwalls in these mining areas including LW17 (currently active) and LW18 in Area 3B and LW19 in Area 3A and it proposes to mine LW20 to LW23 in Area 3C. The layouts of the existing, approved and proposed longwalls at the Dendrobium Mine are shown in Drawing No. MSEC1181-01, in Appendix E.

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

IMC previously submitted an Environmental Impact Statement (EIS) seeking an extension to its underground coal mining operations at the Dendrobium Mine by extracting longwalls in proposed Areas 5 and 6. Mine Subsidence Engineering Consultants (MSEC) prepared the Report No. MSEC856 (Rev. B) which provided subsidence predictions and impact assessments in support of that application. The longwall layout adopted in the previous EIS and Report No. MSEC856 is referred to as the Previous Layout in this report.

IMC is now preparing a new EIS based on a revised longwall layout which includes a reduction in the extent of Area 5 and removes longwall mining in Area 6. The revised mine plan is referred to as the Dendrobium Mine Extension Project (the Project). The layout of the proposed longwalls in Area 5 is shown in Drawings Nos. MSEC1181-01 and MSEC1181-02. The revised longwall layout in Area 5 is also referred to as the Revised Layout in this report.

A comparison of the Previous Layout (i.e. black outlines) and Revised Layout (i.e. orange outlines) is provided in Fig. 1.1.

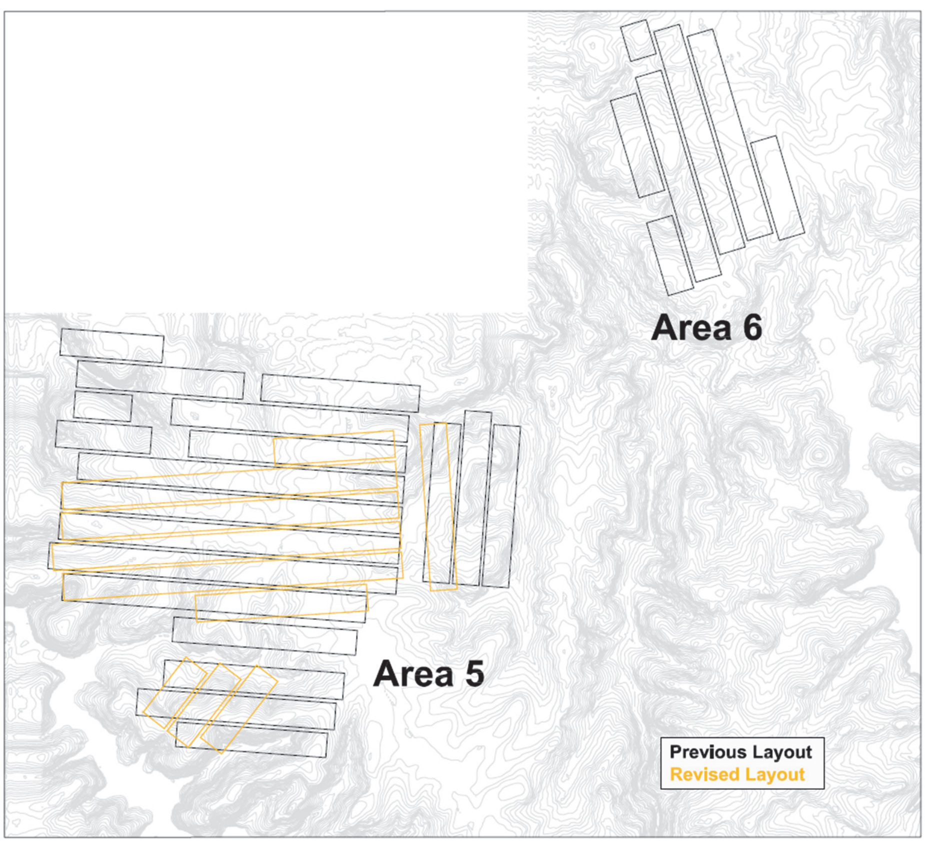

Fig. 1.1 Comparison between the Previous Layout and Revised Layout

The surface area located directly above the proposed longwalls and the chain pillars between the longwalls is approximately 1895 hectares (ha) based on the Previous Layout (i.e. Areas 5 and 6) and 792 ha based on the Revised Layout (i.e. Area 5 only). The surface above the mining area therefore reduces by approximately 1103 ha or 58 %.

The currently proposed longwalls in Area 5 and the Study Area, as defined in Section 2.2, have been overlaid on an orthophoto of the area and are shown in Fig. 1.2.

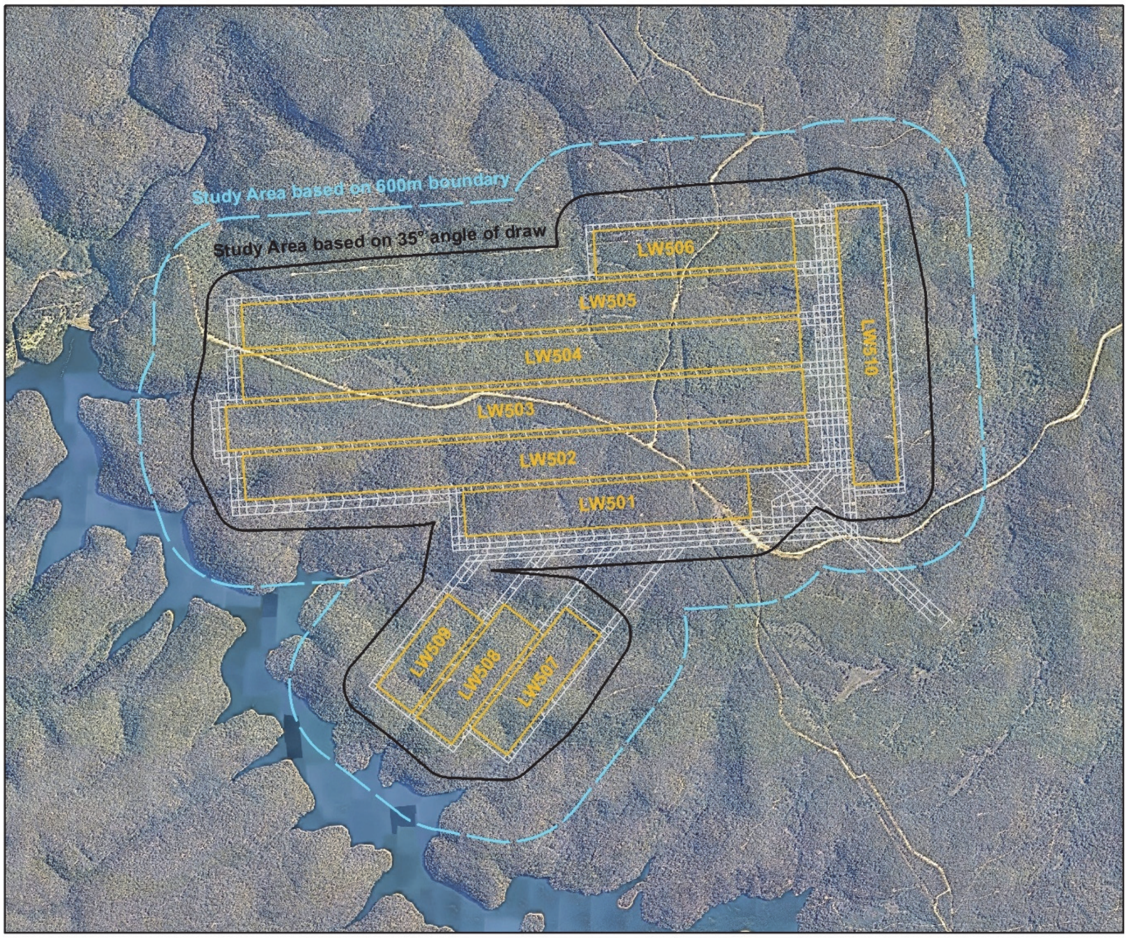

Fig. 1.2 Aerial photograph showing the proposed longwalls and the Study Area

MSEC has been commissioned by IMC to:

- prepare updated subsidence predictions for the proposed longwalls in Area 5;
- identify the natural and built features in the vicinity of the proposed longwalls in Area 5;
- 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 EIS for the revised longwalls in Area 5 which will be submitted to the NSW Department of Planning, Industry and Environment (DPIE).

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

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

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

Chapter 4 provides the maximum predicted subsidence effects due to the mining of the currently proposed longwalls in Area 5.

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) (DPIE, 2021) relating to subsidence, which have been summarised in Table 1.1.

Table 1.1 Secretary's Environmental Assessment Requirements relating to subsidence

SEARs (DPIE, 2021) relating to subsidence	Section reference
"2. Subsidence *– including:"*	
"- a review of the local and regional geological setting, including identification and characterisation of geological structures and lineaments within the proposed mining area;"	Refer to Section 1.4 and Drawing No. MSEC1181-07.
"- a detailed review of the status of historical mine workings in the vicinity of the proposed development;"	There are no historic workings located above or within 600 m of Area 5. Longwall mining is being carried out in Area 3B located more than 1 km away with active mining located more than 4 km away. Comparison of measured and predicted subsidence effects in Area 3B are provided in Sections 3.7.1 and 3.7.2.
"- an assessment of the likely conventional and non-conventional subsidence effects and subsidence impacts of the development;"	The maximum predicted subsidence effects are provided in Chapter 4. The subsidence model has been reviewed and calibrated based on monitoring data from the Dendrobium Mine (refer Section 3.7) and a numerical model (refer Section 3.8). The predicted strains are based on statistical analyses of ground monitoring data that includes anomalous movements. A comparison of measured and predicted valley-related closure at the Dendrobium Mine is provided in Section 3.7.2. The predicted far-field horizontal movements are based on monitoring data from Dendrobium Mine and elsewhere in the Southern Coalfield (refer Section 4.6). The subsidence predictions for the natural and built features are provided in Chapters 5 and 6 and they include both conventional and non-conventional effects including anomalous, valley-related and far-field effects.
"- assessment of the potential consequences of subsidence-related effects and impacts on the natural and built environment, paying particular attention to those features that are considered to have significant ecological, economic, social, cultural or environmental value, taking into consideration connective fracturing above the longwall panels and recorded regional and historical subsidence;"	The predictions and 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 assessments consider the measured movements and the observed impacts from previous longwall mining at the Dendrobium Mine and elsewhere in the Southern Coalfield. The assessment of the height of connective fracturing has been undertaken by the specialist geotechnical consultant on the Project.

SEARs (DPIE, 2021) relating to subsidence	Section reference
***"3. Water** – including:"*	
"- an assessment of the likely impacts of the development on aquifers, watercourses, swamps, riparian land, groundwater dependent ecosystems, water supply infrastructure and systems including Cordeaux Dam and Avon Dam, basic landholder rights and other water users. The significance of water-related features must be considered individually for the purpose of impact assessment;"	The predictions and assessments of the potential physical impacts on the streams are provided in Sections 5.2 and 5.3, 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 5.9, 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 6.3, with further assessments on the stored waters provided by the specialist groundwater consultant on the Project.
***"5. Heritage** – including:"*	
"- an assessment of the likely impacts of the development on Aboriginal cultural heritage values…"	The predictions and assessments of the potential physical impacts on the Aboriginal heritage sites are provided in Section 6.4, with further assessments provided by the specialist heritage consultant on the Project.
"- an assessment of the likely impacts of the development on the historic heritage significance of the site and adjacent areas…"	The predictions and assessments of the potential physical impacts on the Avon and Cordeaux Dams are provided in Section 6.3, with further assessments provided by the specialist heritage consultant on the Project.

1.2. Mining geometry

The layout of the proposed longwalls in Area 5 is shown in Drawings Nos. MSEC1181-01 and MSEC1181-02, 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 in Area 5

Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
LW501	1970	305	-
LW502	3890	305	42
LW503	3990	305	42
LW504	3860	305	42
LW505	3835	305	42
LW506	1380	305	42
LW507	1050	305	-
LW508	985	305	42
LW509	800	305	42
LW510	1910	305	-

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 295 m.

The mining in Area 3C has been approved and is 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.

1.3. Surface and seam levels

The surface level contours are shown in Drawing No. MSEC1181-03, 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 east of Lake Avon and the Avon River and west of Donalds Castle Creek.

The surface levels directly above the proposed longwalls in Area 5 vary between a minimum of 335 metres above Australian Height Datum (mAHD) at the northern end of LW509 and a maximum of 440 mAHD at the southern end of LW507.

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. MSEC1181-04, MSEC1181-05 and MSEC1181-06, respectively.

The depths of cover above the proposed longwalls in Area 5 vary between a minimum of 250 m at the southern extent of the proposed mining area and a maximum of 400 m in the north-eastern part of the mining area. The average depth of cover above the proposed longwalls is 360 m.

The thickness of the Bulli Seam varies between a minimum of 2.1 m at the southern extent of the proposed mining area and a maximum of 3.2 m near the mid-length of LW505. The longwalls will mine a minimum thickness of 2.4 m.

A summary of the ranges of the depth of cover, seam thickness and proposed mining heights for the proposed longwalls in Area 5 is provided in Table 1.3.

Table 1.3 Seam thicknesses and proposed mining heights

Location	Depth of cover (m)	Seam thickness (m)	Mining height (m)
LW501 to LW510	250 to 400 (360 average)	2.1 to 3.2 (2.6 average)	2.4 to 3.2 (2.6 average)

The levels of the natural surface and the Bulli Seam in Area 5 are illustrated along Cross-sections 1 to 4 in Fig. 1.3 to Fig. 1.6, respectively. The locations of these cross-sections are shown in Drawings Nos. MSEC1181-03 to MSEC1181-05, in Appendix E.

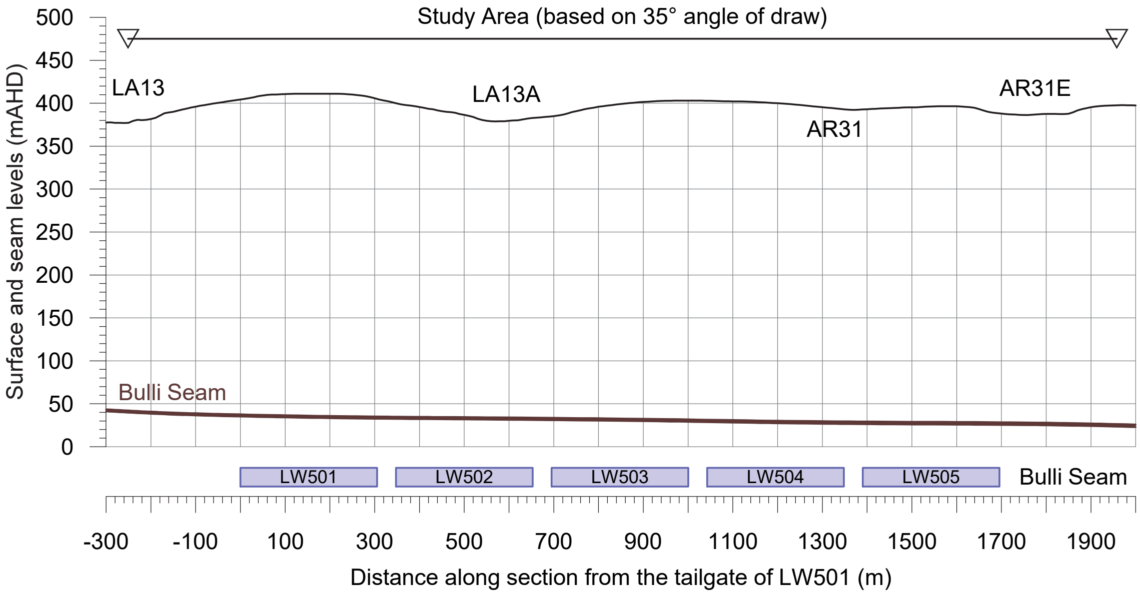

Fig. 1.3 Surface and seam levels along Cross-section 1 through the proposed LW501 to LW505

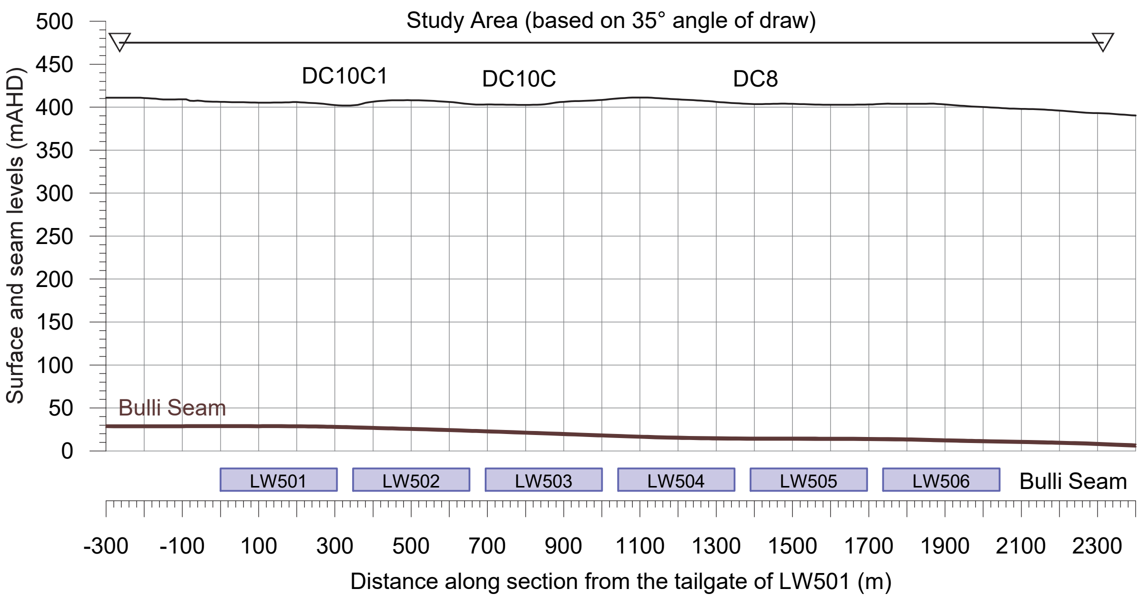

Fig. 1.4 Surface and seam levels along Cross-section 2 through the proposed LW501 to LW506

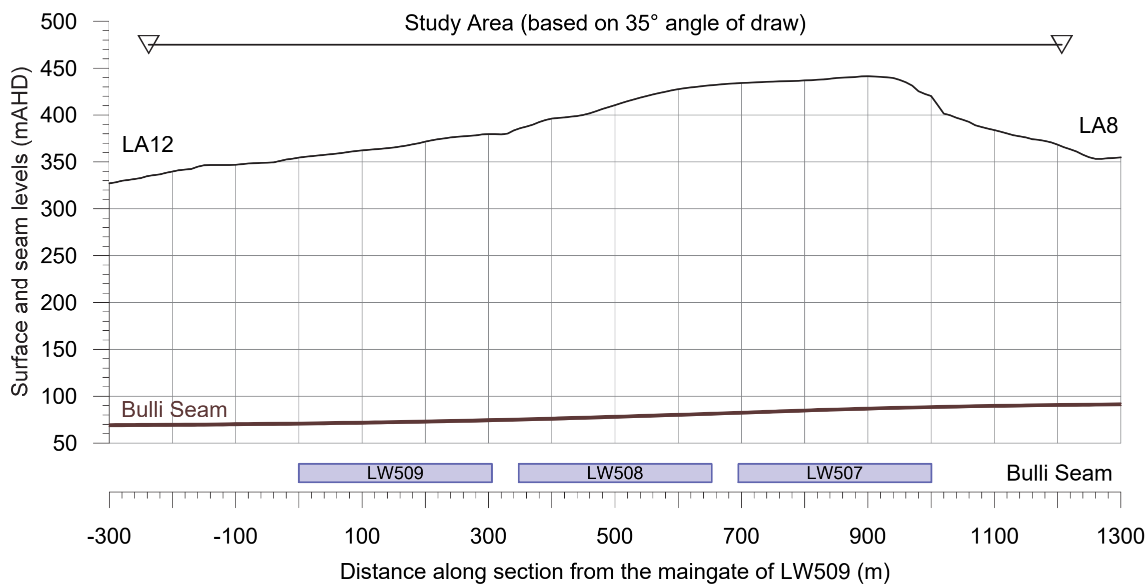

Fig. 1.5 Surface and seam levels along Cross-section 3 through the proposed LW507 to LW509

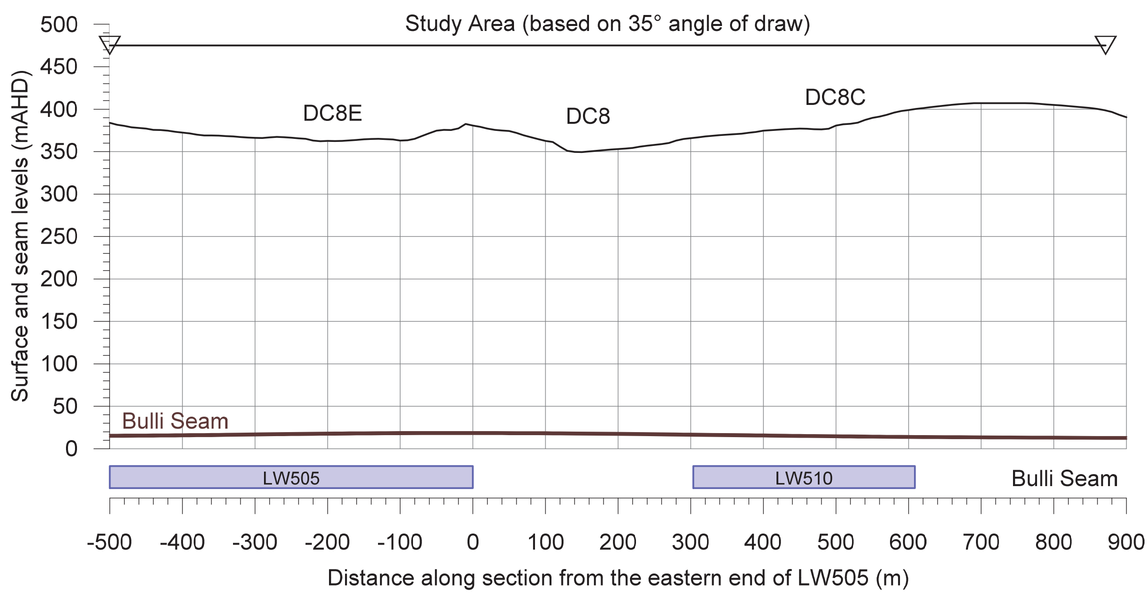

Fig. 1.6 Surface and seam levels along Cross-section 4 through the longwalls in Area 5

The Bulli Seam generally dips towards the north to north-east in Area 5 with an average grade of approximately 1 % (i.e. 1 in 100) within the proposed mining area. A north-south orientated syncline is located at the eastern ends of LW504 to LW506. The seam dip across the main axis of the syncline is up to approximately 1.5 % (i.e. 1 in 67).

1.4. Geological details

The Dendrobium 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 the Dendrobium Mine is provided in Fig. 1.7 (Source: IMC). A geological long-section through Areas 1, 2, 3A, 3B and 5 at the Mine is presented in the Groundwater Assessment report for the Project and it has been reproduced in Fig. 1.8 (Source: Watershed HydroGeo, 2022).

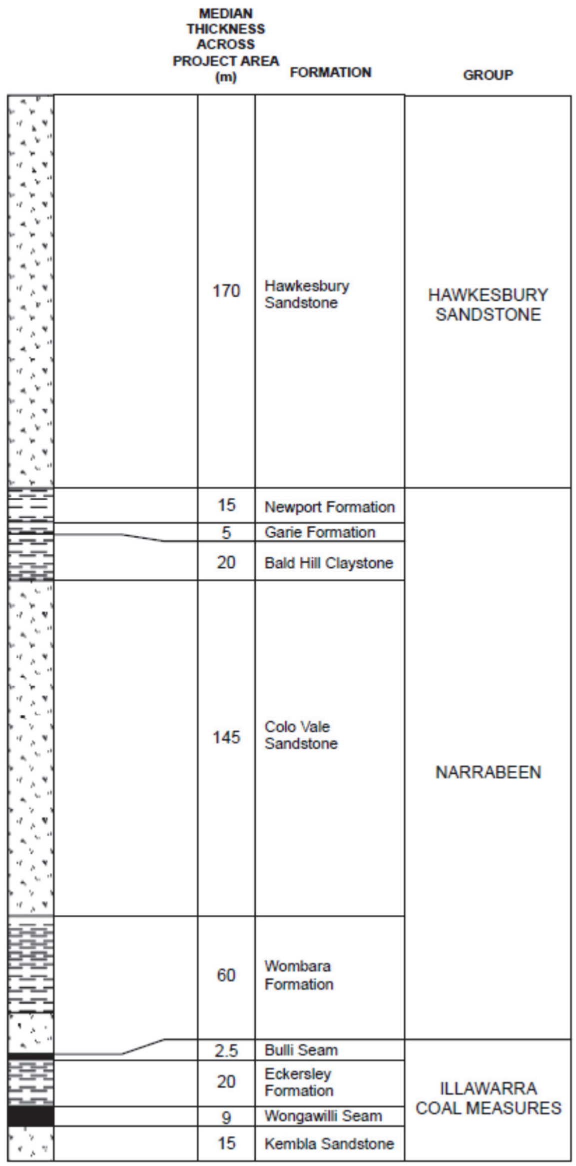

Fig. 1.7 Typical stratigraphic section for the Dendrobium Mine (Source: IMC)

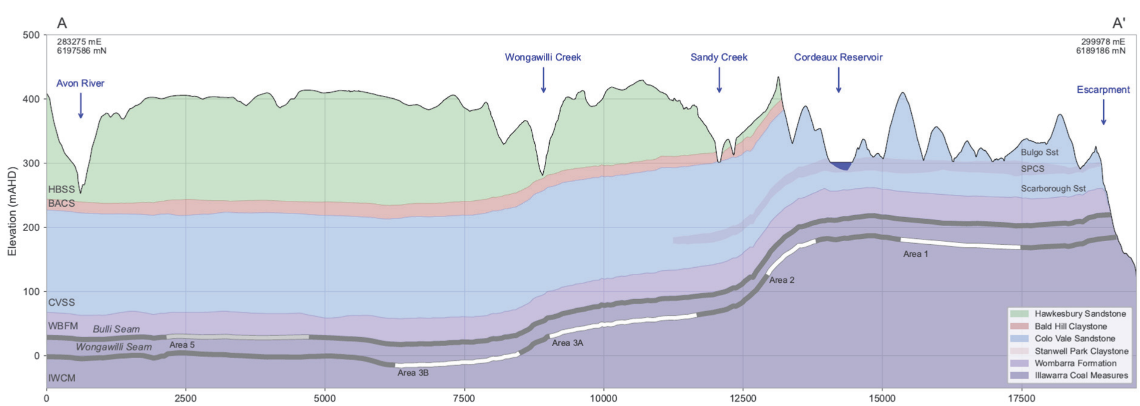

Fig. 1.8 Geological long-section through Areas 1, 2, 3A, 3B and 5 (Source: Watershed HydroGeo, 2022)

The major sedimentary units at the Dendrobium 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 Area 5 at the Dendrobium 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 proposed longwalls are proposed to be extracted from the Bulli Seam.

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 overburden lithology and thicknesses of the strata layers in Area 5 are reasonably similar to those in Area 3B, as illustrated in Fig. 1.8. However, the longwalls in Area 5 are proposed to be mined in the Bulli Seam whereas the existing longwalls in the other mining areas have been extracted from the Wongawilli Seam. The immediate seam roof in Area 5 therefore comprises the Wombarra Claystone and the immediate seam roof in the other mining areas comprise the Eckersley Formation.

The Dendrobium 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 at seam level are shown in Drawing No. MSEC1181-07.

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 end of the proposed LW501 and the southern end of the proposed LW510. The inferred cinder zone is also located adjacent to the western end of the proposed LW506 and the northern end of the proposed LW507.

There is a north-north-east to south-south-west trending fault that crosses the proposed LW501 to LW506 and LW508. There are dykes located north-west and south-east of the proposed mining area. The locations of these structures will be better defined through the ongoing investigations and the development of the first workings. A north-south orientated syncline is located at the eastern ends of LW504 to LW506.

A review was carried out on the effects of geological structures on the measured surface subsidence above LW9 to LW13 in Area 3B (MSEC, 2019). The available monitoring data suggest that there was no apparent increase in the subsidence measured in the mapped locations of the lineaments, minor faults and dykes. Similarly, there was no apparent increase in the subsidence measured along the minor seam folds (i.e. synclines and anticlines). There also does not appear to be an association between the observed surface impacts and the mapped lineaments, minor faults, dykes and minor seam folds.

IMC has advised that the surface lineaments, minor faults and dykes located above and near to the proposed longwalls in Area 5 are similar to those mapped in Area 3B. It is considered unlikely, therefore, that these structures would adversely affect the subsidence predictions and assessed impacts for the proposed longwalls.

The maximum predicted subsidence in Area 5 represents 65 % of the proposed mining height (refer to Section 4.2). Extensive experience of longwall mining in the Bulli Seam shows that the maximum achievable vertical subsidence is 65 % of the mining height for single-seam mining conditions. It is considered unlikely, therefore, that the geological structures in Area 5 would cause increased subsidence since the maximum predicted subsidence already represents the maximum achievable.

The predicted strains for Area 5 have been based on statistical analysis of monitoring data (refer Section 4.4) which include the measured localised effects due to near-surface geological features and due to no known causes (i.e. anomalies). Surface lineaments are often coincident with the valleys and the predicted strains in Area 5 consider the increased compressive strains due to valley closure effects.

There are no other major faults or other geological structures that have been identified within the extents of the proposed longwalls. 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 layout 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. 1.9, which shows the proposed longwalls and the Study Area overlaid on the Geological Map *Bargo 9029-3-N*, which was published by the Department of Mineral Resources (DMR, 1988), now known as the NSW Resources Regulator. The surface lithology in Area 5 generally comprises Hawkesbury Sandstone (Rh), with localised areas of Quaternary Alluvium (Qs).

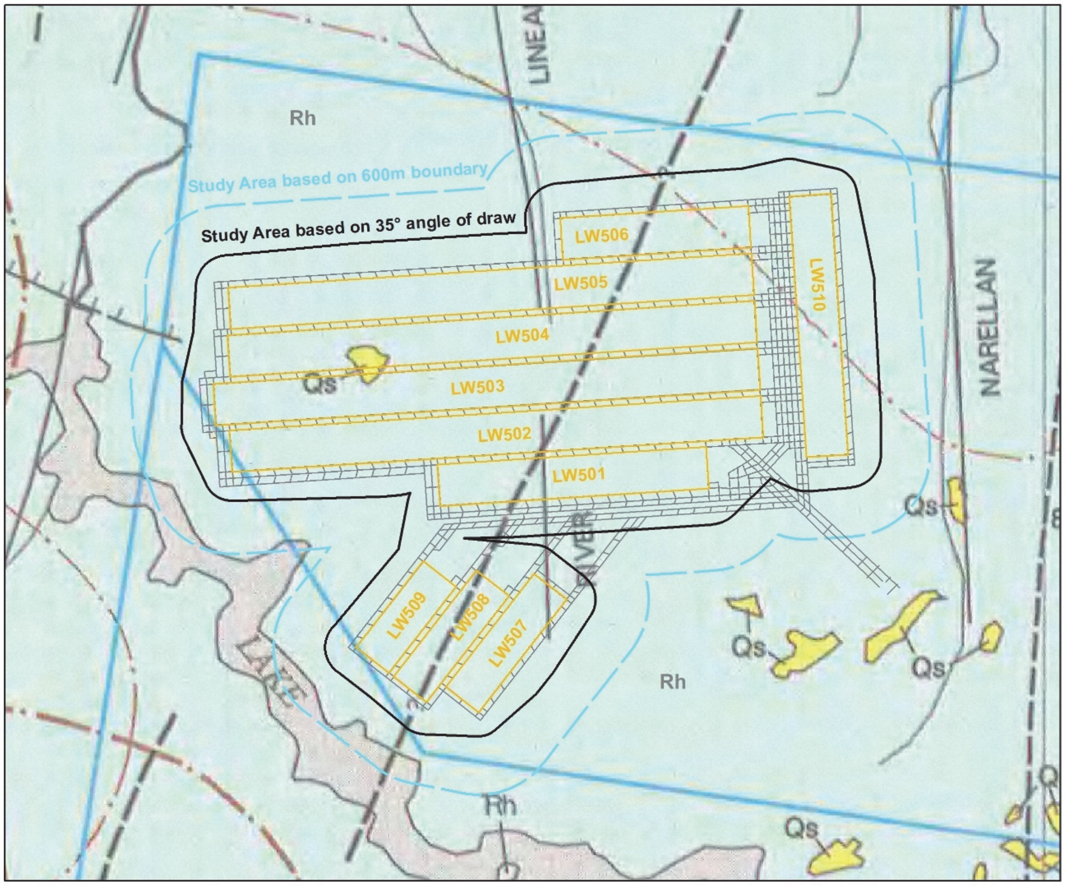

Fig. 1.9 The proposed longwalls overlaid on Geological Map *Bargo 9029-3-N* (DMR, 1988)

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. MSEC1181-01.

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 Area 5 at the Dendrobium 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 Area 5;
- 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 for the Bulli Seam are shown in Drawing No. MSEC1181-06. The depths of cover directly above the proposed longwalls vary between 250 m and 400 m. The 35° angle of draw, therefore, has been determined by drawing a line that is a horizontal distance varying between 175 m and 280 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 (IPM), which is described in Chapter 3. The predicted subsidence contours, including the 20 mm subsidence contour, are shown in Drawing No. MSEC1181-16, 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. MSEC1181-01 to MSEC1181-15, 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 effects 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 effects. The surface features that could be sensitive to such movements have been identified and have also been included in the assessments provided in this report. These features include the 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 Area 5 and the Study Area have been overlaid on an extract of this CMA map in Fig. 2.1.

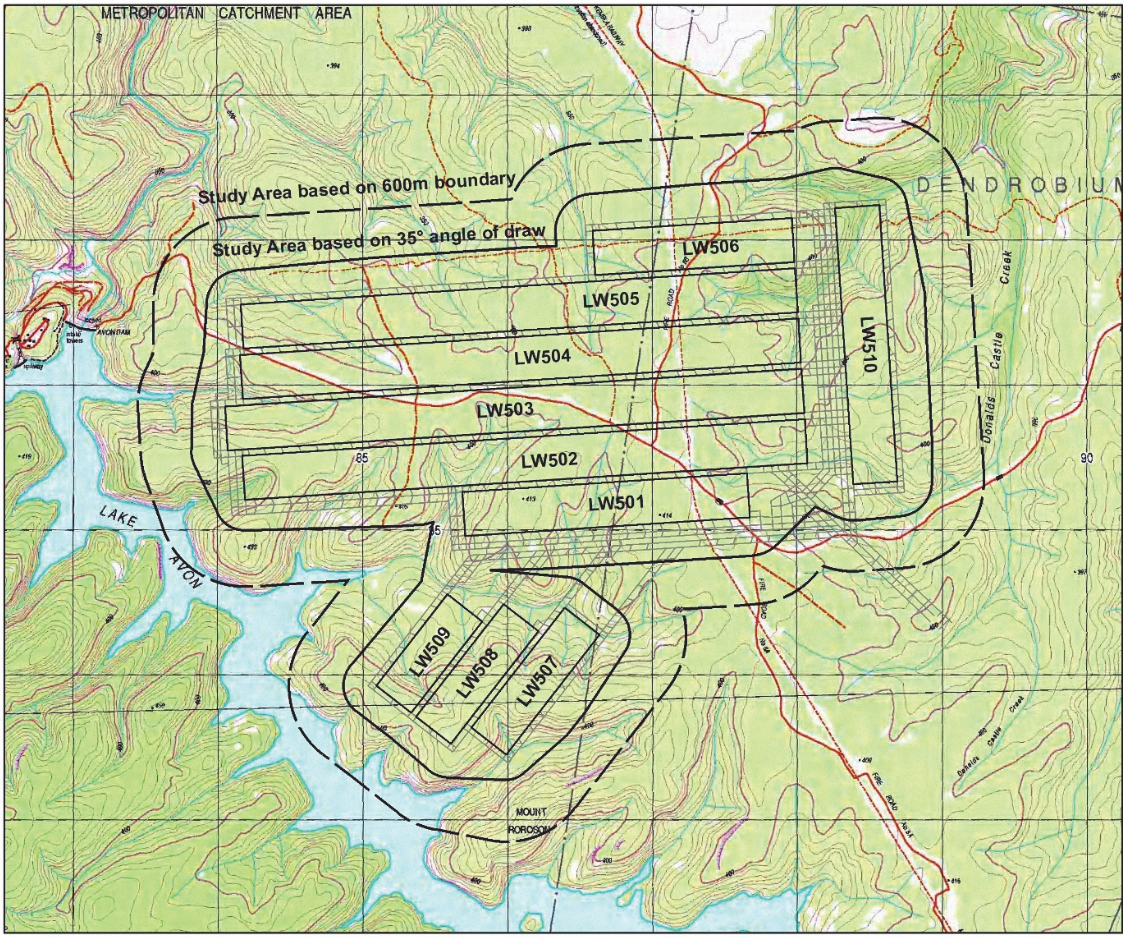

Fig. 2.1 Proposed longwalls overlaid on CMA Map *Avon River 9029-3-S*

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. MSEC1181-08 to MSEC1181-16, 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 & 5.3
Aquifers or Known Groundwater Resources	✓	5.4
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.5
Steep Slopes	✓	5.6
Escarpments	×	
Land Prone to Flooding or Inundation	×	
Swamps, Wetlands or Water Related Ecosystems	✓	5.9
Threatened or Protected Species	✓	5.10
National Parks	×	
State Forests	×	
State Conservation Areas	✓	5.11
Natural Vegetation	✓	5.10
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	✓	6.1
Roads (All Types)	✓	6.2
Bridges	×	
Tunnels	×	
Culverts	✓	6.2
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	×	
Telecommunication Lines or Associated Plants	×	
Water Tanks, Water or Sewage Treatment Works	×	
Dams, Reservoirs or Associated Works	✓	6.3
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	×	
Shopping Centres	×	
Community Centres	×	
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

Item	Within Study Area	Section number reference
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	×	
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	✓	6.4 & 6.5
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.6
RESIDENTIAL ESTABLISHMENTS		
Houses	×	
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	✓	6.7

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

3.1. Introduction

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

Subsidence *effects* represent the movement of the surface including the vertical and horizontal components at a point or differential movements between two points. Subsidence *impacts* refer to deformations or physical responses including surface cracking, rock fracturing, etc. Environmental *consequences* represent changes due to the subsidence impacts including diversion of surface water flows, adverse changes to ecology or heritage, adverse impacts on serviceability of built features, etc.

3.3. Overview of conventional subsidence effects

The normal ground movements resulting from the extraction of longwalls are referred to as conventional or systematic subsidence effects. These 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.

  While 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 effects which result from the extraction of each longwall. The **cumulative** subsidence, tilts, curvatures and strains are the accumulated effects which result from the extraction of a series of longwalls. The **total** subsidence, tilts, curvatures and strains are the final effects 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.

3.4. 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, greater 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.

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

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

- 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.

3.5.1. 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.

3.5.2. 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 5.6.

3.5.3. 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.

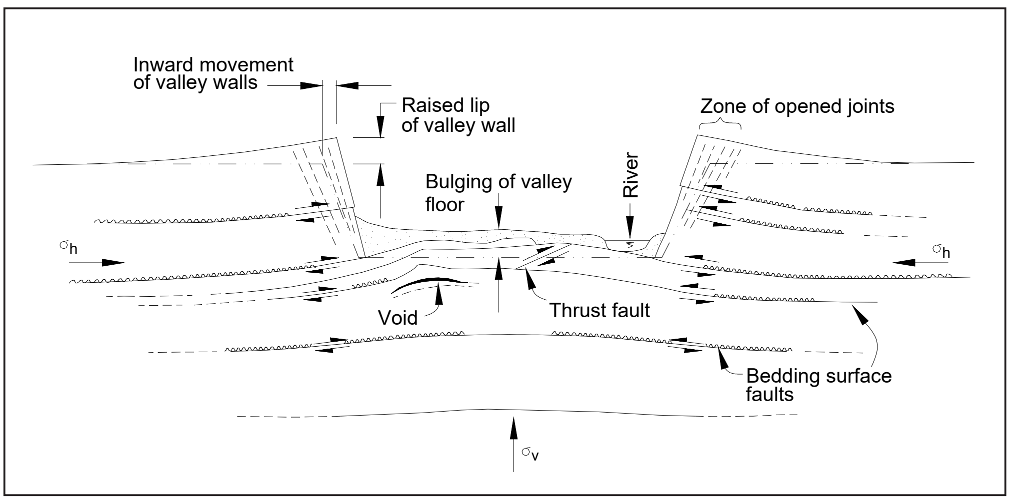

Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

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 effects for the streams in the existing and approved mining Areas 2, 3A and 3B at the Dendrobium 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 Area 5 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 Dendrobium 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 3.7.2.

The predicted strains resulting from valley-related effects 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*.

3.6. The Incremental Profile Method

The predicted conventional subsidence effects for the proposed longwalls have been determined using the Incremental Profile Method (IPM), which has been developed by MSEC. The method is an empirical model based on a large database of 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 effects (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*.

3.7. Calibration of the IPM

The use of the IPM at the Dendrobium 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 Dendrobium 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 Dendrobium 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 Dendrobium 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 Dendrobium 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 Dendrobium 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 for mining in the Wongawilli Seam at the Mine is referred to as the '*MSEC792 prediction curves*' in this report.

The comparisons between the measured ground movements in Area 3B with those predicted using the calibrated IPM based on the MSEC792 prediction curves are provided in the following sections.

3.7.1. 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 Dendrobium Mine are being measured using ALS and LiDAR surveys. The measured changes in surface level due to the extraction of LW9 to LW16 are shown in Fig. 3.2. The extent of the latest ALS survey covers the area above LW13 to LW16 and, therefore, the contours are not shown above the earlier longwalls.

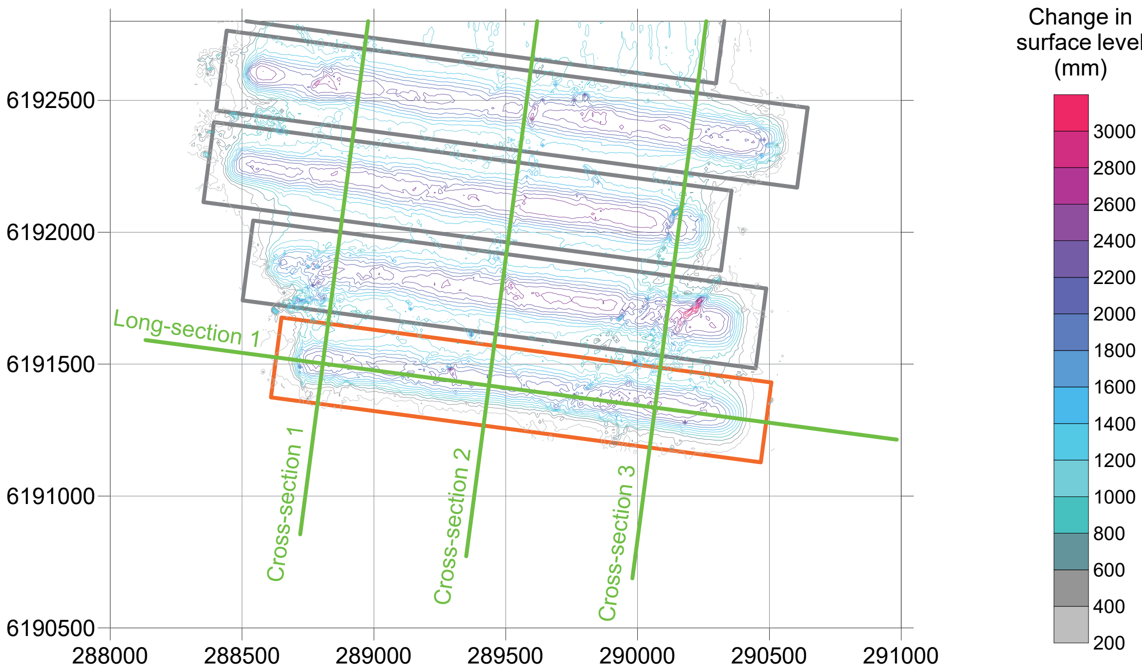

Fig. 3.2 Measured changes in surface level due to LW9 to LW16 in Area 3B

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 Dendrobium 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, respectively. 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.

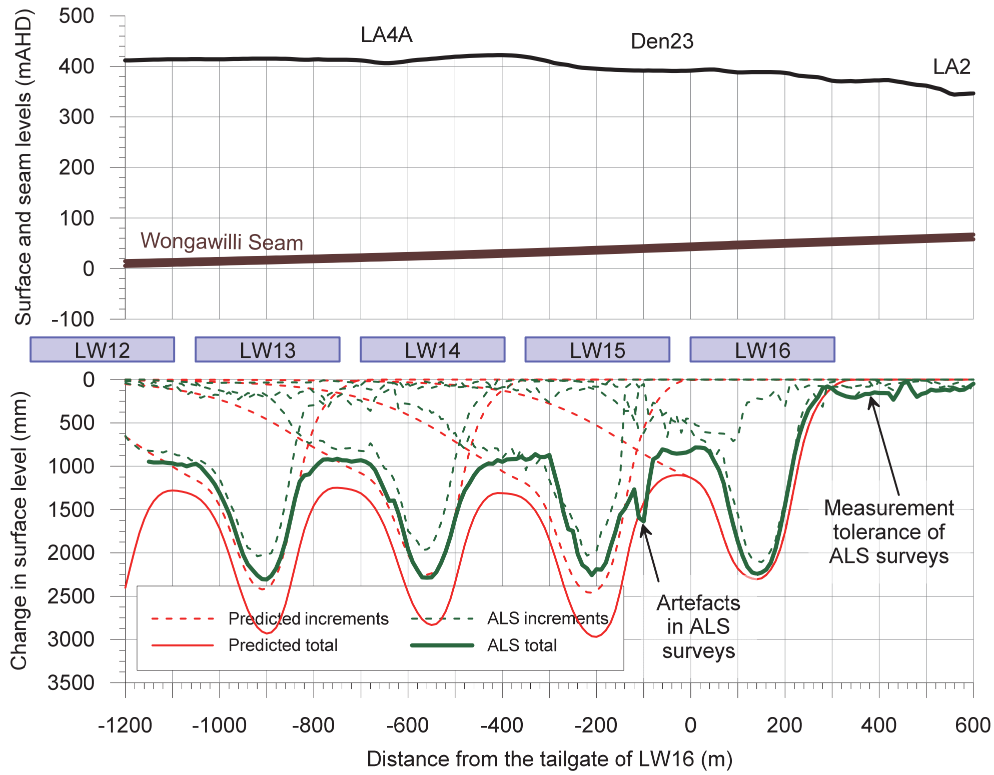

Fig. 3.3 Measured and predicted changes in surface level along Cross-section 1

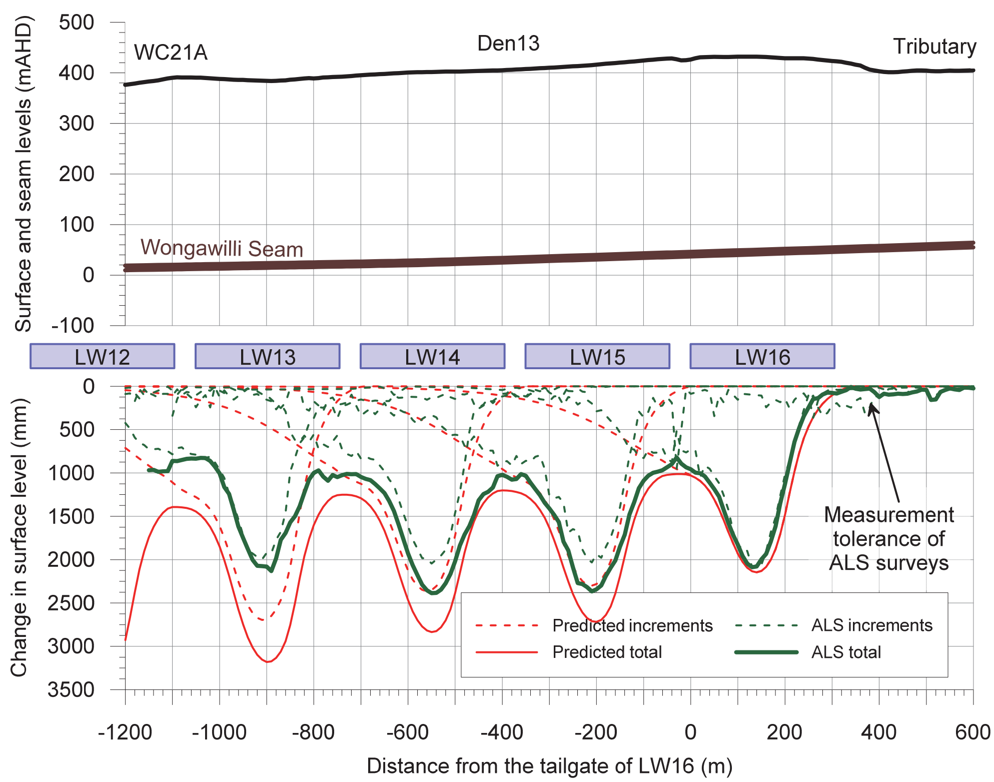

Fig. 3.4 Measured and predicted changes in surface level along Cross-section 2

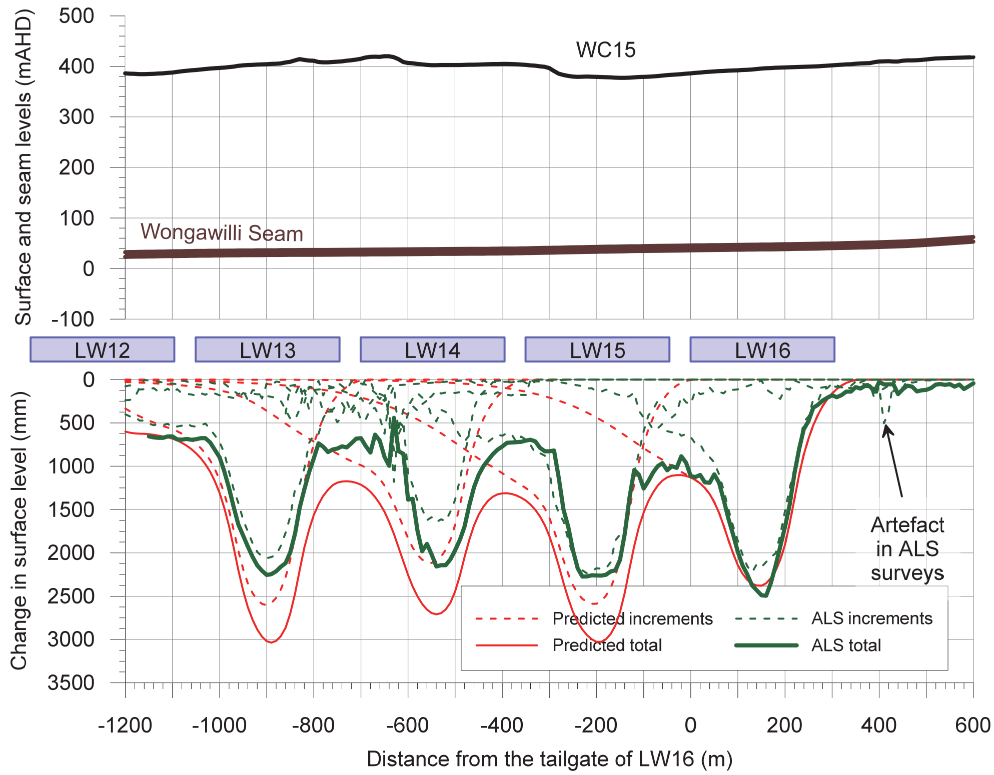

Fig. 3.5 Measured and predicted changes in surface level along Cross-section 3

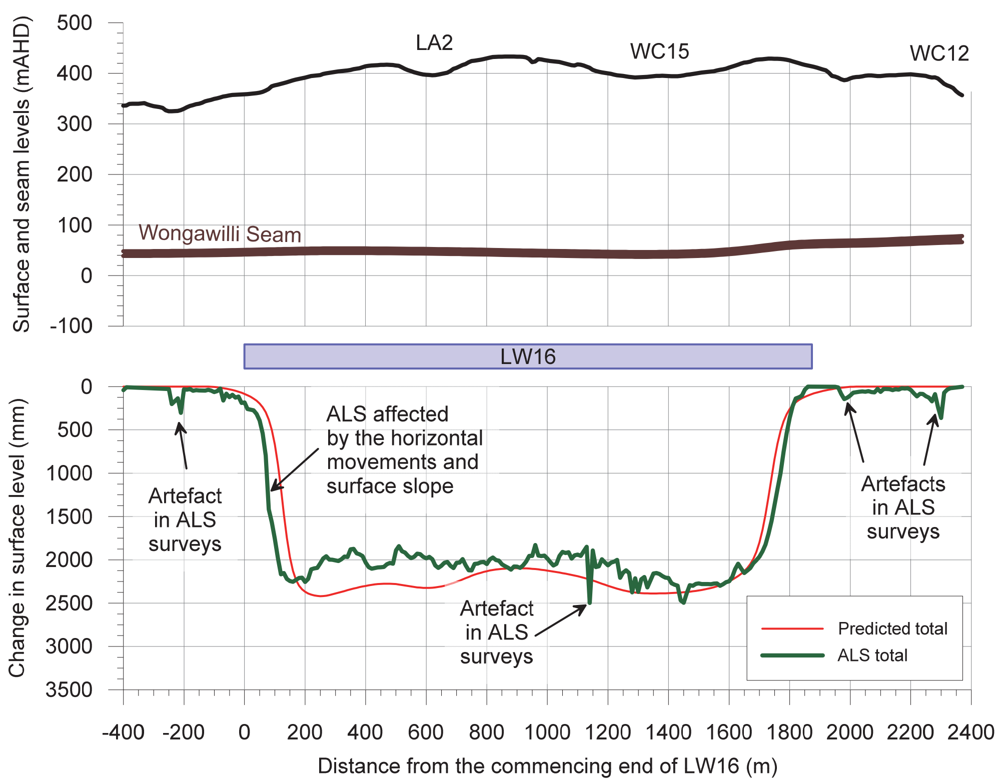

Fig. 3.6 Measured and predicted changes in surface level along Long-section 1

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 similar to or less than the maximum predicted values. Also, the measured changes in surface level above each of the chain pillars are similar to or 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 LW16. However, 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 LW16 (i.e. left side of figure). However, this may be partly due to the surveying tolerance and the effects of the horizontal movements and sloping terrain on the LiDAR surveys. The ground directly above the commencing end of LW16 has moved towards the longwall (i.e. following the extraction face). The natural surface dips towards the west in this location (i.e. towards Lake Avon). The mining-induced horizontal movement, therefore, results in the measured changes in level at a fixed position being greater than the true vertical subsidence above the commencing end of LW16.

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. Elsewhere, the low-level movements are in the order of accuracy of the measurement method.

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 provided in Reports Nos. MSEC792 and MSEC865.

3.7.2. 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 LW16 in Area 3B using the Wongawilli Creek Closure Lines, Donalds Castle Creek Cross Lines, Tributary 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 LW16 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.

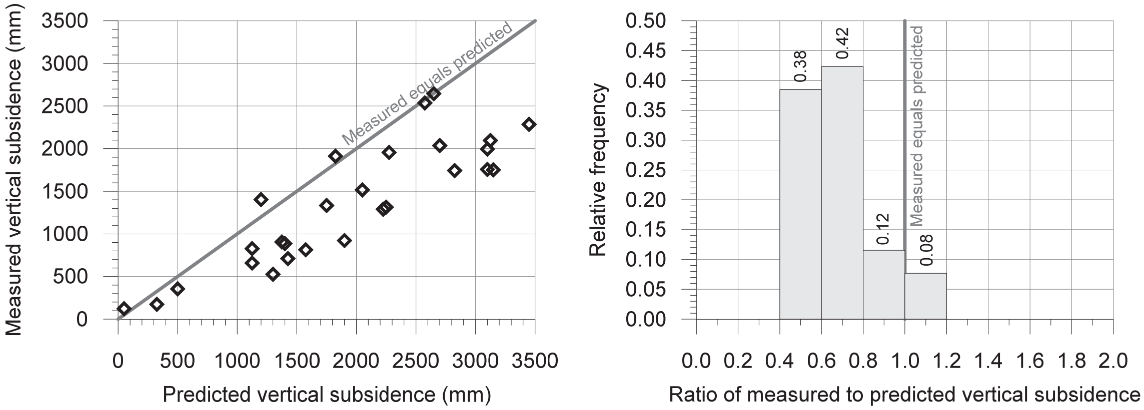

Fig. 3.7 Comparison of measured and predicted subsidence for the ground monitoring lines

The measured total vertical subsidence movements are typically less than the predicted total values for each of the monitoring lines. The average ratio of the measured to predicted vertical subsidence for these monitoring lines is 0.68.

The measured total vertical subsidence movements exceed the predicted total values in three of the 26 cases (i.e. 12 % of the monitoring lines). The exceedances occur where the monitoring lines are located near to or above the chain pillars and these measured movements are less than the maximum values 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 LW16 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.

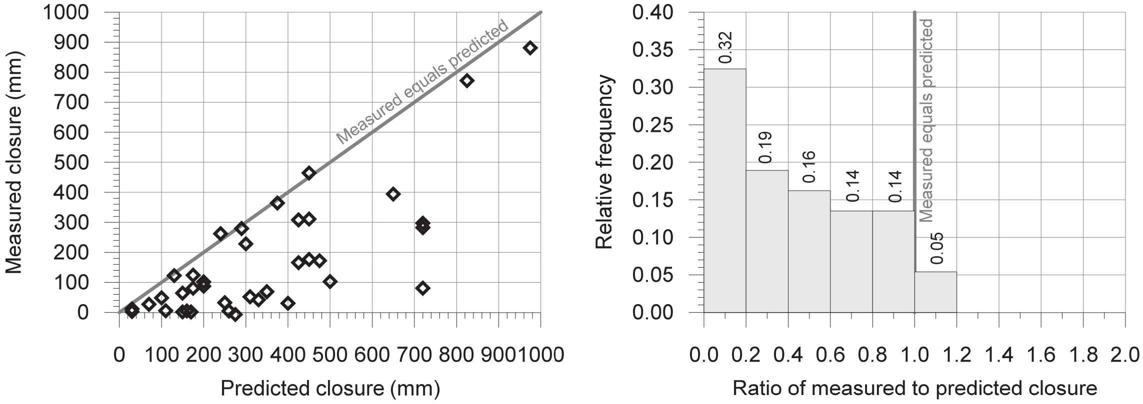

Fig. 3.8 Comparison of measured and predicted closure for the ground monitoring lines

The measured total closure movements are typically less than the predicted total values for each of the monitoring lines. The average ratio of the measured to predicted total closure for these monitoring lines is 0.45 (i.e. the measured closures are, on average, around half of those predicted).

The measured total closure movements exceed the predicted values in two of the 38 cases (i.e. 5 % 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 lines range between 1.03 and 1.09 and, therefore, are 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 %.

3.7.3. Use of the calibrated IPM at Dendrobium Mine

The calibrated IPM based on the MSEC792 prediction curves has been used but further modified for the proposed longwalls in Area 5 at the Dendrobium Mine.

The overburden lithology and thicknesses of the strata layers in Area 5 are reasonably similar to those in Area 3B, as illustrated in Fig. 1.8. It is expected, therefore, that the development of subsidence in Area 5 will have similar relationships to the mining geometry (i.e. longwall width-to-depth ratios and mining heights) as for the other mining areas at the Mine.

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 400 m, with an average of approximately 360 m above the proposed longwalls. The range of depths of cover is similar to that for the existing LW9 to LW17 in Area 3B, which vary between 290 m and 410 m, with an average of approximately 380 m. Similarly, the width-to-depth ratios for the proposed longwalls in Area 5 are similar to those for LW9 to LW16.

The thickness of the Bulli Seam in Area 5 varies between 2.4 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. However, the existing longwalls in Area 3B have mined an average height of 3.9 m (but also up to 4.6 m for the initial longwalls in this mining area).

The mine subsidence effects 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 fully applied for the proposed longwalls in Area 5, as this would result in a maximum total vertical subsidence of 76 % 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 % of the mining height for single-seam mining conditions.

The maximum predicted total vertical subsidence in Area 5 has therefore been based on applying a 12 % increase rather than 30 % to the incremental vertical subsidence, so as to achieve a maximum vertical subsidence of 65 % of the mining height. The new IPM subsidence model calibrated for mining in the Bulli Seam at the Mine is referred to as the '*MSEC1181 prediction curves*'.

The MSEC1181 prediction curves should therefore provide reasonable, if not, slightly conservative predictions of subsidence due to the mining of the proposed longwalls in Area 5. The subsidence model will continue to be reviewed and, if required, further refined based on ground monitoring data collected during the mining of the proposed longwalls in Area 5 as part of the longwall End of Panel Reports.

3.8. Numerical model

A numerical model has been developed for the Dendrobium 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 Dendrobium Mine.

3.8.1. 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 LW16 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-sections considered were 3.5 m for LW9, 4.5 m for LW10, 4.0 m for LW11 to LW13 and 3.9 m for LW14 to LW16.

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 (horizontal to vertical, 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 Dendrobium 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.

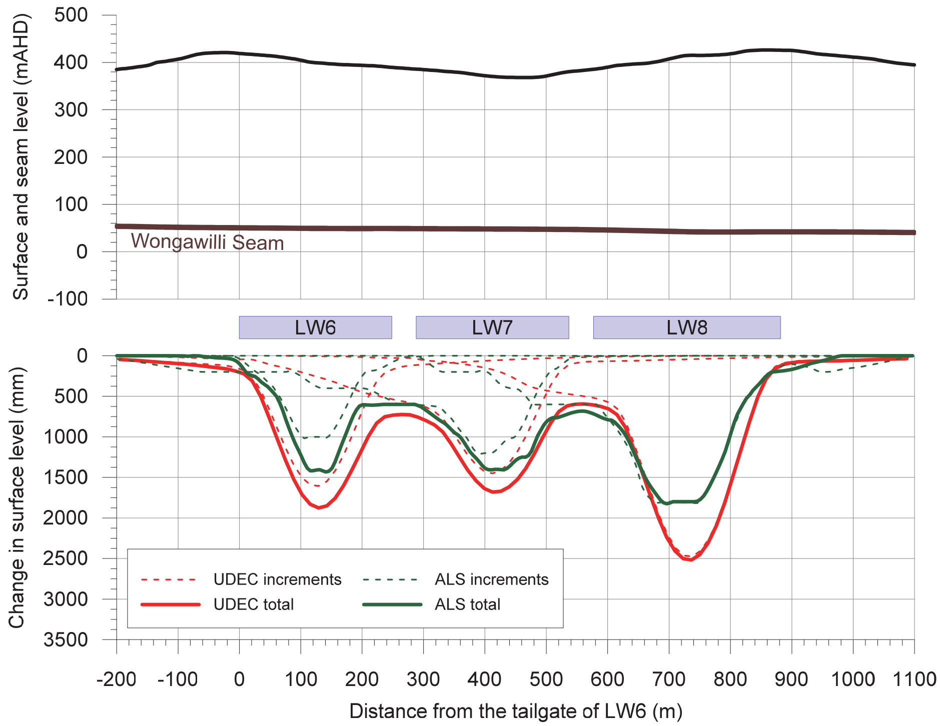

Fig. 3.9 Comparison of modelled and measured subsidence for Dendrobium Area 3A

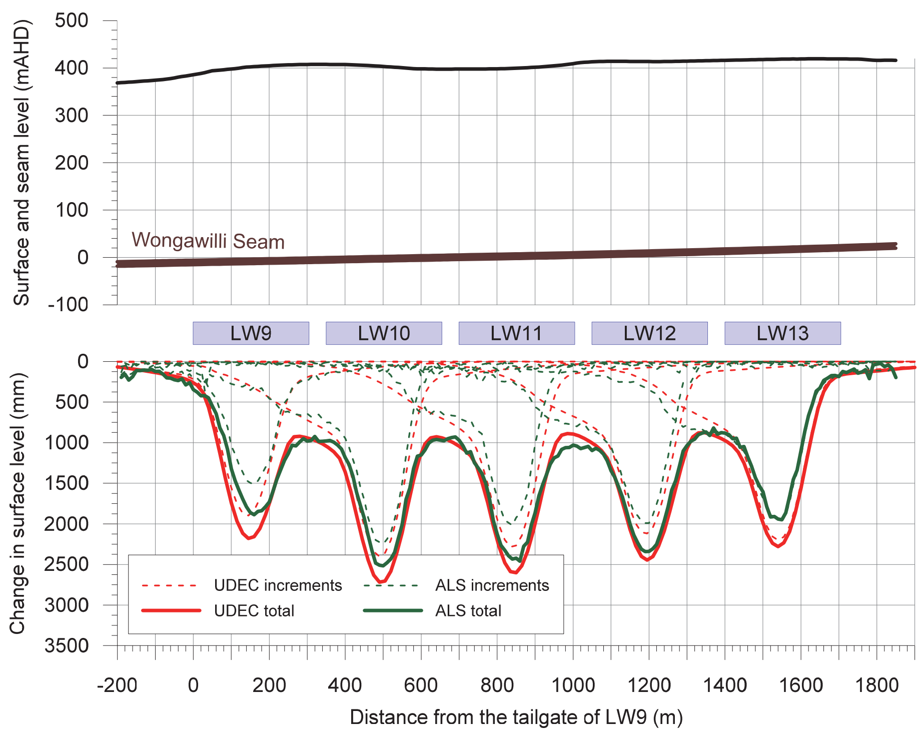

Fig. 3.10 Comparison of modelled and measured subsidence for Dendrobium Area 3B

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.

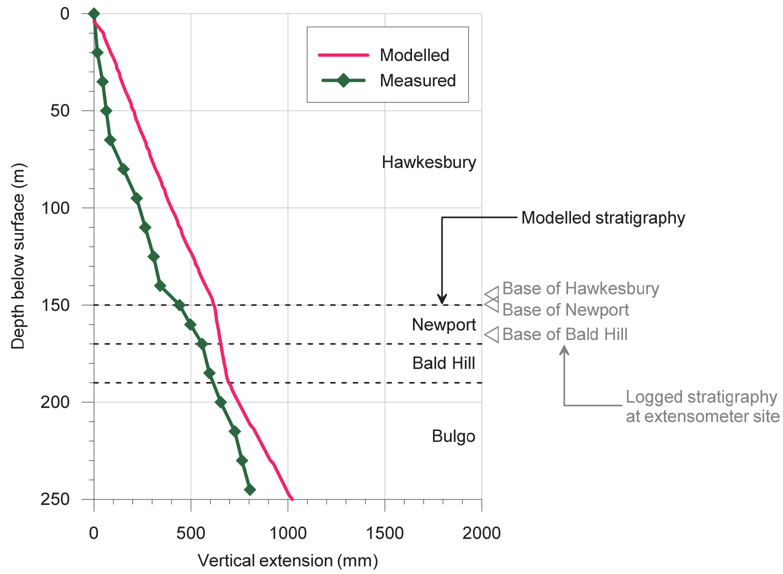

Fig. 3.11 Comparison of modelled and measured extension at the extensometer above LW9

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 profile 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 measured value, as the UDEC model slightly overpredicts the vertical subsidence above LW9, as illustrated in Fig. 3.10.

3.8.2. UDEC model for the proposed longwalls in Area 5

The proposed longwalls in Area 5 will be extracted from the Bulli Seam. The *base model* was originally developed for mining in the Bulli Seam (Barbato, 2017). The numerical model has then been calibrated for the Dendrobium Mine based on the subsidence measured in Areas 3A and 3B due to mining in the Wongawilli Seam (refer to Section 3.8.1). The calibration involved reducing the material bulk and shear moduli and/or joint cohesions and, therefore, increasing the subsidence obtained from the numerical model. Hence, the adoption of the calibrated model at the Dendrobium Mine should provide some additional conservatism for the proposed longwalls within the Bulli Seam in Area 5.

The numerical model for Area 5 has been developed along a section through the middle of the mining area (i.e. transverse to LW501 to LW505 and to the west of LW506). The widths of the proposed longwalls are 305 m and the solid chain pillar widths are 42 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 2913 m.

The average depth of cover to the Bulli Seam along the section is 360 m. The width-to-depth ratio of each of the proposed longwalls therefore is 0.85. The thickness of the Bulli Seam along the section varies between 2.5 m at LW501 and 3.1 m at LW505. It is proposed that the longwalls will mine the full seam thickness.

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 5

Unit	Thickness (m)	Depth to base on unit (m)	Block size (H x V, m x m)
Hawkesbury Sandstone	150	150	15.0 x 10.0
Newport/Garie Formations	20	170	6.0 x 4.0
Bald Hill Claystone	20	190	6.0 x 4.0
Bulgo Sandstone	120	310	15.0 x 10.0
Wombarra Claystone	50	360	7.5 x 5.0
Bulli Coal	3	363	4.5 x 3.0
Sub-Bulli	100	463	7.5 x 5.0

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
Sub-Bulli	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
Sub-Bulli	4.25	2.55	22	13

The modelled profiles of vertical subsidence obtained from the UDEC model for Area 5 are illustrated as the red lines in Fig. 3.12. The predicted profiles based on the IPM using the MSEC1181 prediction curves have also been shown as the blue lines in this figure for comparison.

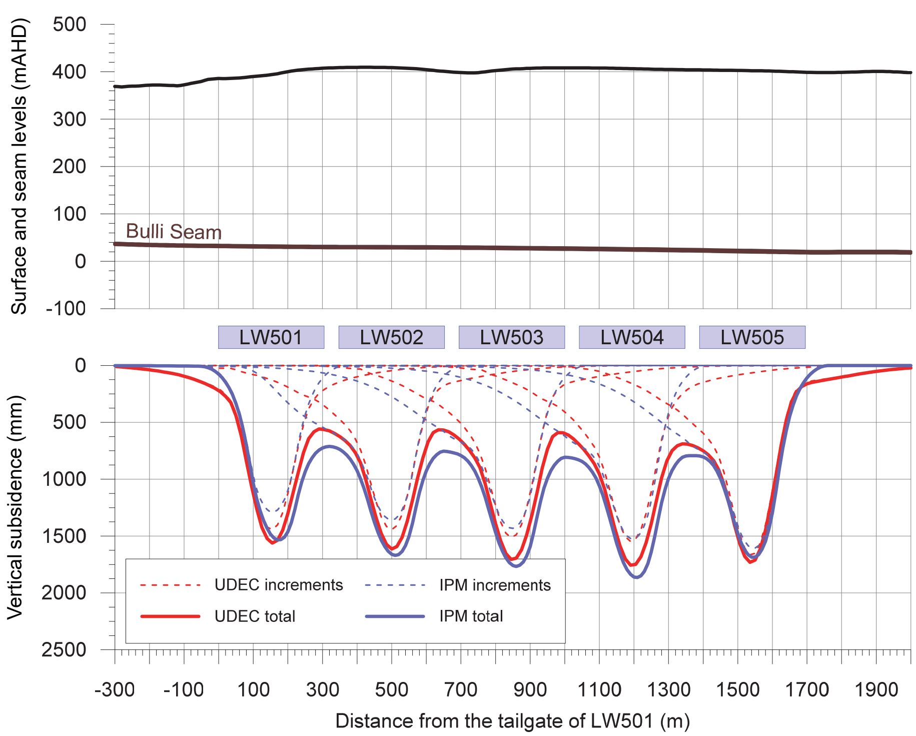

Fig. 3.12 Modelled profiles of vertical subsidence for the proposed LW501 to LW505

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 less vertical subsidence above each of the chain pillars compared with that obtained from the IPM. The reason is that the IPM includes additional allowance for pillar compression based on the observations from the Wongawilli Seam which is conservative for mining in the Bulli Seam.

The numerical model predicts higher subsidence adjacent to the tailgate of LW501 and adjacent to the maingate of LW505 (i.e. outside the mining area). 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 gradients of the subsidence profiles obtained from the UDEC model are similar to those obtained from the IPM. It can be inferred, therefore, that the maximum predicted tilts above each of LW501 to LW505 obtained from the numerical model are similar to the predicted values based on the IPM. Similarly, the curvatures obtained from each of these models are similar.

It is considered that the profiles of vertical subsidence obtained from the UDEC model reasonably match those predicted using the IPM using the MSEC1181 prediction curves. It is not considered necessary, therefore, to further calibrate the IPM based on the outcomes of the numerical model.

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 LW503, midway between the centreline and tailgate (referred to as the quarter point) and at the tailgate of this longwall.

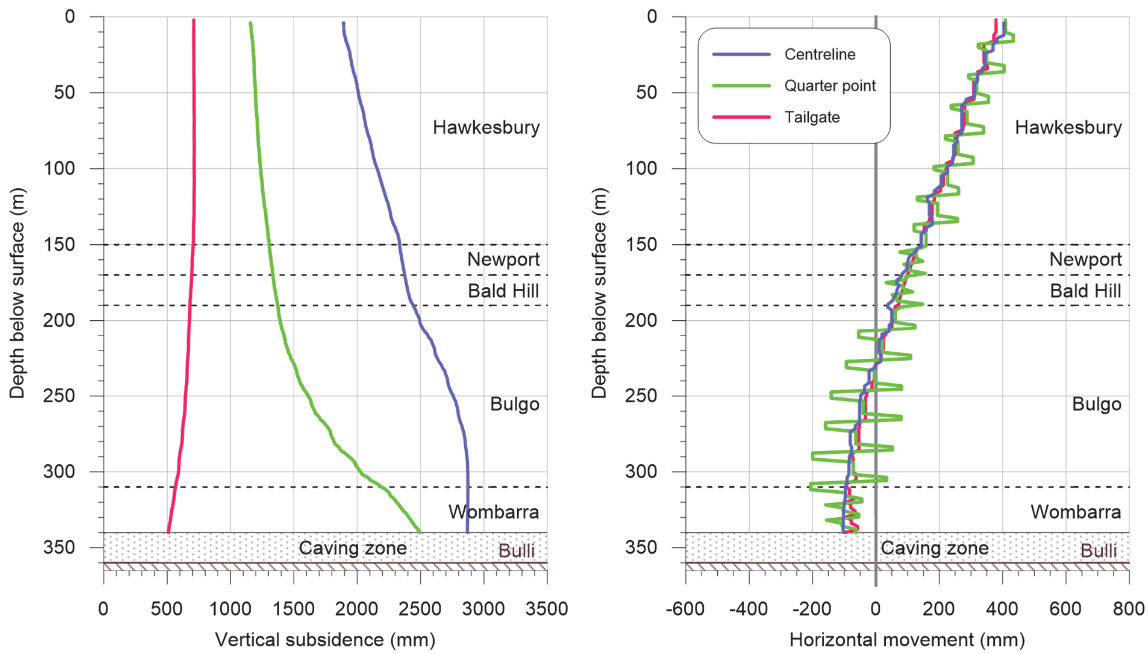

Fig. 3.13 Modelled profiles of vertical subsidence and horizontal movement through the overburden at the centreline, quarter point and tailgate of LW503

The vertical subsidence at the longwall centreline varies between 65 % 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 25 % 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 4 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 6 mm/m at the top, 4 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 varies between approximately 2 mm/m at the top and 14 mm/m at the base of the Bulgo Sandstone.

The vertical strain within the Wombarra Claystone varies between 8 mm/m and 14 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 varies between approximately 50 mm and 100 mm within the Hawkesbury Sandstone and between 150 mm and 250 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 shear movements, or more but smaller horizontal shear movements could develop compared with that predicted, depending on their actual spacing.

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

The proposed longwalls in Area 5 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*.

3.9.1. Rivers and named creeks

The rivers and named creeks are all located outside the Study Area based on the 600 m boundary. The nearest named streams are the Avon River and Donalds Castle Creek which are located at minimum distances of 900 m and 700 m, respectively, outside the mining area. As discussed in Section 5.2, the named streams are not predicted to experience measurable subsidence effects due to the mining of the proposed longwalls and, therefore, adverse impacts are not anticipated.

3.9.2. Unnamed streams

There are many unnamed streams within Area 5 that are tributaries to the Avon 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 key stream features.

The unnamed streams in Area 5 have been mapped by the IMC field team. The key 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 key stream features in Area 5 are outlined in the report by HEC (2019) and they have been summarised in Table 5.3 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. 3.14. 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.

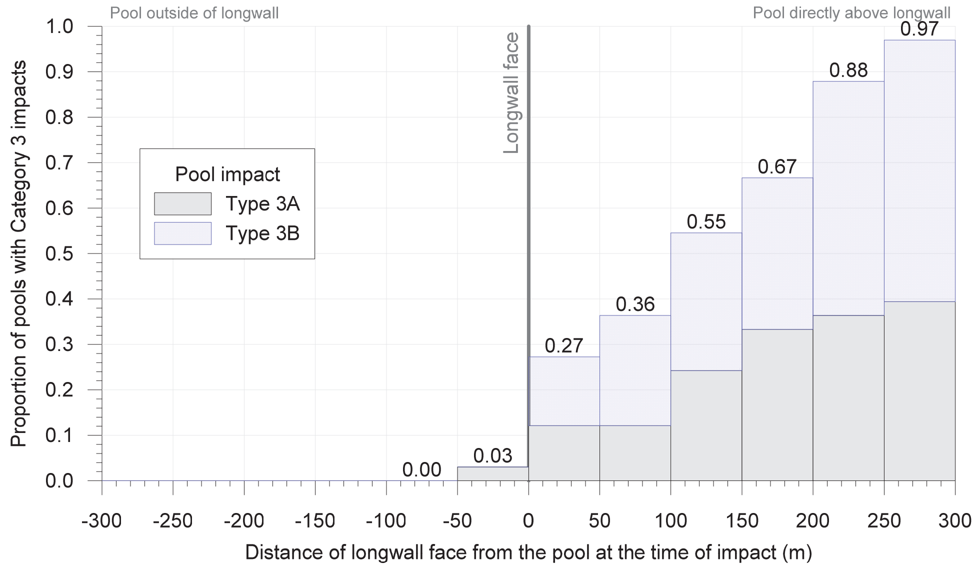

Fig. 3.14 Proportion of pools with Type 3 impacts along Drainage Line WC21 in Area 3B

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 also been observed along other streams located outside of mining area at Dendrobium Mine. As discussed in Section 5.3.5, there have been 11 Type 3 observed outside the mining area due to the extraction of LW9 to LW16 in Area 3B. This represents approximately 15 % of the stream controlling features located within 400 m of the mining area. It is therefore 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 Area 5, therefore, have been setback from the key 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 5.3.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence effects due to the mining of the proposed longwalls in Area 5. The predicted subsidence effects 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 Dendrobium Mine, as described in Section 3.7. 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 effects 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

A summary of the maximum predicted values of incremental vertical subsidence, tilt and curvature is provided in Table 4.1. The incremental values represent the additional effects due to the extraction of each of the proposed longwalls.

Table 4.1 Maximum predicted incremental conventional subsidence, tilt and curvature due to the mining of each of the proposed 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	1300	16	0.30	0.40
LW502	1600	19	0.40	0.45
LW503	1550	19	0.30	0.45
LW504	1600	19	0.35	0.45
LW505	1750	20	0.40	0.50
LW506	1400	16	0.25	0.35
LW507	1150	16	0.40	0.40
LW508	1150	16	0.40	0.40
LW509	1250	18	0.50	0.45
LW510	1350	16	0.30	0.35

The predicted total vertical subsidence contours due to the mining of the proposed longwalls in Area 5 are shown in Drawing No. MSEC1181-16, in Appendix E. A summary of the maximum predicted values of total vertical subsidence, tilt and curvature is provided in Table 4.2. The predicted total effects represent the accumulated movements due to the mining of all proposed longwalls within each area.

Table 4.2 Maximum predicted total conventional vertical subsidence, tilt and curvature after the mining of the proposed longwalls in Area 5

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})
LW501 to LW506	2000	25	0.50	0.60
LW507 to LW509	1500	20	0.50	0.50
LW510	1450	17	0.30	0.40

The maximum predicted total vertical subsidence of 2000 mm occurs above LW504 and it represents 65 % of the maximum proposed mining height of 3.1 m in that location. The maximum predicted total tilt is 25 mm/m (i.e. 2.5 % or 1 in 40) which occurs adjacent to the maingate of LW505.

The maximum predicted total curvatures 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 hogging and sagging curvatures occur adjacent to the maingate and centreline, respectively, of LW505.

The predicted conventional subsidence effects 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 four prediction lines, the locations of which are shown in Drawing No. MSEC1181-16.

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 the maximum predicted subsidence effects

A comparison of the maximum predicted total conventional subsidence effects, based on the Previous Layout (MSEC856) and Revised Layout (MSEC1181), is provided in Table 4.3.

Table 4.3 Comparison of maximum predicted total conventional subsidence effects

Layout	Mining area	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})
Previous Layout (MSEC856)	Area 5	2050	25	0.50	0.60
	Area 6	2450	20	0.30	0.50
Revised Layout (MSEC1181)	Area 5	2000	25	0.50	0.60

The maximum predicted subsidence effects, based on the Revised Layout, are similar to or slightly less than the maximum predicted values based on the Previous Layout. The reason is that the longwall widths, chain pillar widths, depths of cover and proposed mining heights in Area 5 remain the same.

While the maximum predicted subsidence effects do not change, the extent of the longwall mining area within Area 5 has been reduced and the longwalls in Area 6 have been removed. The surface area located directly above the proposed longwalls and the chain pillars between the longwalls is approximately 1895 ha based on the Previous Layout (i.e. Areas 5 and 6) and 792 ha based on the Revised Layout (i.e. Area 5 only). The surface above the mining area therefore reduces by approximately 1103 ha or 58 %.

The extents of the natural and built features affected by subsidence, based on the Revised Layout, therefore, are less than those based on the Previous Layout. Further discussions on the predicted subsidence effects for the natural and built features are provided in Chapters 5 and 6.

A comparison of the maximum predicted total conventional subsidence effects, based on the Revised Layout, with the maximum predicted values for the existing and 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 3.7.

Table 4.4 Comparison of maximum predicted total subsidence effects at the Dendrobium Mine

Layout	Mining area	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})
Existing and approved longwalls at the Dendrobium Mine	Area 3A	3000	40	1.0	1.0
	Area 3B	3600	50	1.4	1.4
Revised Layout (MSEC1181)	Area 5	2000	25	0.50	0.60

The maximum predicted subsidence effects for the proposed longwalls in Area 5 are less than the maximum predicted values for the existing and approved longwalls in Areas 3A and 3B at the Dendrobium Mine. The main reason is the proposed extraction height in Area 5 of 2.4 m to 3.2 m within the Bulli Seam is less than that in Areas 3A and 3B of 3.9 m (average but up to 4.6 m) within the basal section of the Wongawilli Seam. Also, the width-to-depth ratios for the proposed longwalls in Area 5 are, on average, similar to the ratios for the existing and approved longwalls in Areas 3A and 3B.

It is noted that the maximum measured vertical subsidence in Areas 3A and 3B, to date, are less than the maximum predicted values as provided in Table 4.4. The maximum measured vertical subsidence movements based on the LiDAR surveys are approximately 2000 mm due to LW6 to LW8 in Area 3A and approximately 2700 mm due to LW9 to LW16 in Area 3B.

While not all longwalls have been extracted in Areas 3A and 3B, it is expected that the maximum measured vertical subsidence will be less than the maximum predicted values at the completion of mining in these areas. It is expected, therefore, that the actual measured vertical subsidence for the proposed longwalls in Area 5 will also be less than the maximum predicted values obtained using the calibrated IPM model.

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. 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 Dendrobium 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 Dendrobium 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).

A 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 Dendrobium Mine with the longwalls from the NSW coalfields used in the strain analysis

Parameter	Area 5 at the Dendrobium Mine		Longwalls used in strain analysis	
	Range	Average	Range	Average
Longwall void width	305	305	130 ~ 220	200
Depth of cover	250 to 400	360	110 ~ 250	190
W/H ratio	0.76 ~ 1.2	0.85	0.8 ~ 1.2	1.07
Mining height	2.4 ~ 3.2	2.6	2.1 ~ 3.2	2.9

The range of width-to-depth ratios and mining heights for the longwalls 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.

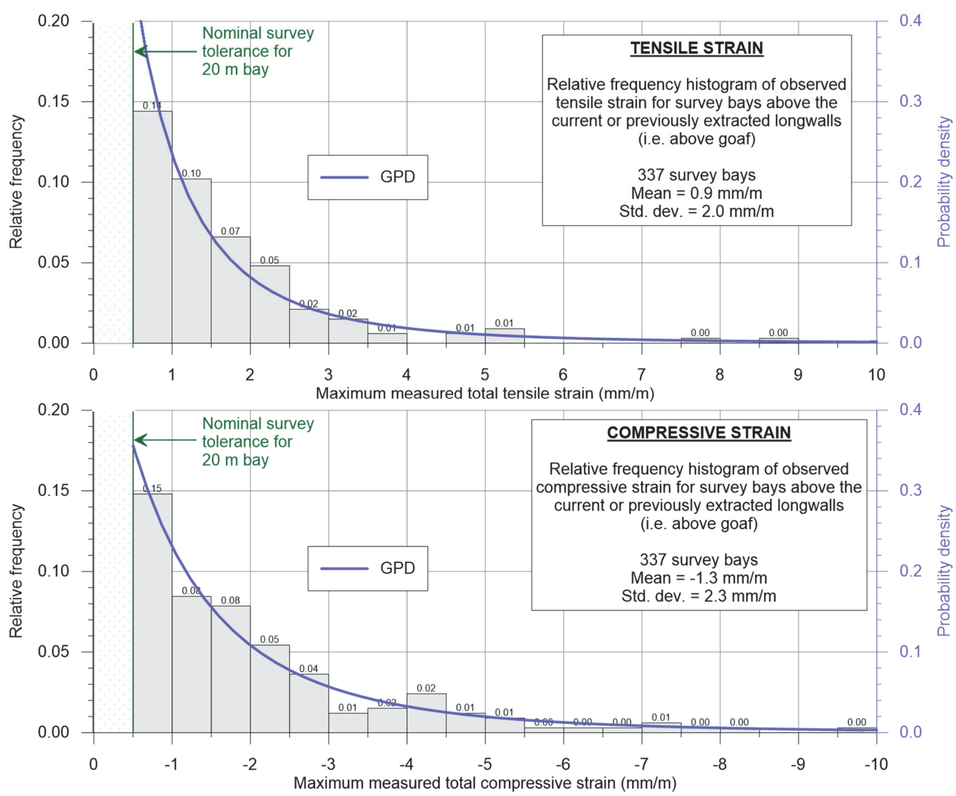

Fig. 4.1 Distributions of the measured maximum tensile and compressive strains during the extraction of previous longwalls in the NSW coalfields for bays located above goaf

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.

4.5. 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 20 mm/m. The maximum predicted conventional horizontal movement, therefore, is approximately 300 mm (i.e. 20 mm/m multiplied by a factor of 15). Greater movements can develop in incised terrain, due to the increased horizontal movements that develop 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 Dendrobium Mine is provided in Fig. 4.2. It can be seen from this figure, that horizontal movements have been measured up to 700 mm at the Dendrobium Mine, with an average measured value of approximately 300 mm.

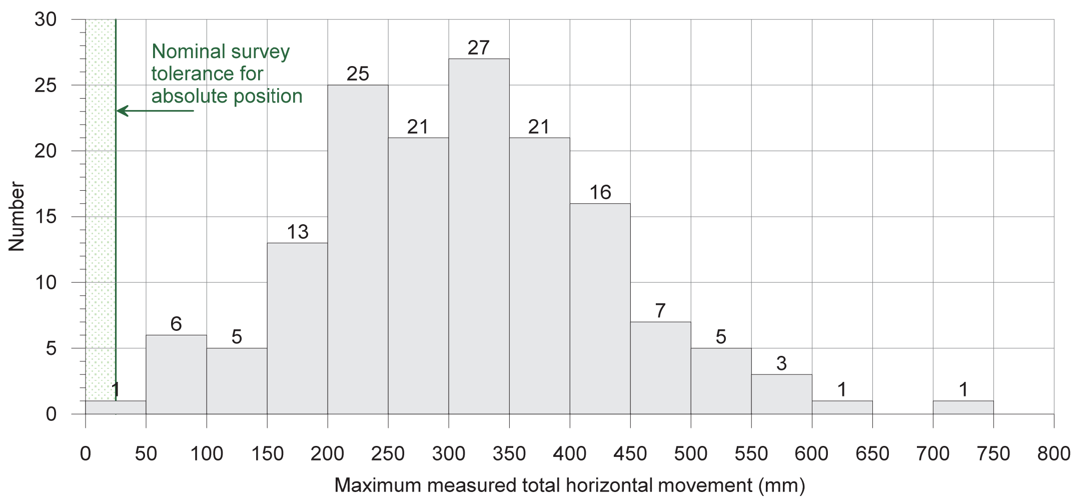

Fig. 4.2 Distribution of the maximum measured horizontal movements for the 3D marks located directly above the longwalls in Areas 1, 2, 3A and 3B at the Dendrobium Mine

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 proposed longwalls, and the predicted valley-related effects 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 Dendrobium 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, due to the mining of longwalls in Dendrobium Areas 1, 2, 3A and 3B, as well as other collieries in the Southern Coalfield, are provided in Fig. 4.3. The mean and the 95 % confidence level for the 3D monitoring data at Dendrobium Mine are also shown in that figure.

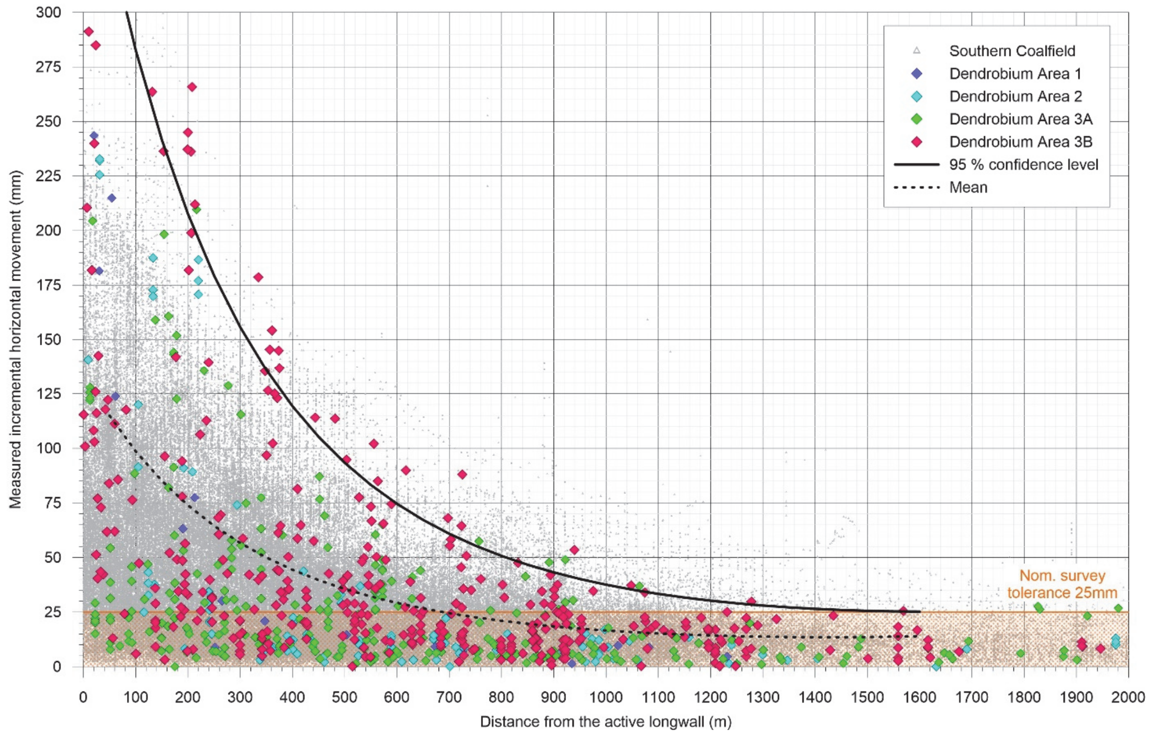

Fig. 4.3 Measured incremental far-field horizontal movements at Dendrobium Mine and elsewhere in the Southern Coalfield

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 mining 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 they are accompanied by very low levels of strain, which are generally less than survey tolerance.

The potential impacts of far-field horizontal movements on the natural and built features in the vicinity of the Study Area are not expected to be significant; however, further assessments have been carried out for larger features which are sensitive to small differential movements.

The features in the vicinity of the Study Area that could be sensitive to far-field horizontal movements include the larger cliffs (refer to Section 5.5), escarpments (refer to Section 5.7) and the Cordeaux and Avon Dam walls (refer to Section 6.3). As discussed in those sections, far-field horizontal movements are not anticipated to cause adverse physical impacts (i.e. surface deformations) at these features.

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 3.5. 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 effects are provided for the streams in Sections 5.2 and 5.3. The impact assessments for the streams are based on both the conventional and valley-related effects. The potential for non-conventional movements associated with steep topography is discussed in the impact assessments for the steep slopes provided in Section 5.6.

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 destressing 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 increased horizontal movements in the downslope direction 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 these downslope movements are provided in Section 5.6.

Fracturing of bedrock can also occur in the bases of stream valleys due to the compressive strains associated with valley related upsidence and closure effects. The impact assessments for valley related movements are provided in Section 5.3.

Soil crack and rock fracture widths were measured at impact sites located above LW3 to LW5 in Area 2, LW6 to LW8 in Area 3A and LW9 to LW16 in Area 3B. The distribution of the measured widths of these surface deformations is illustrated in Fig. 4.4.

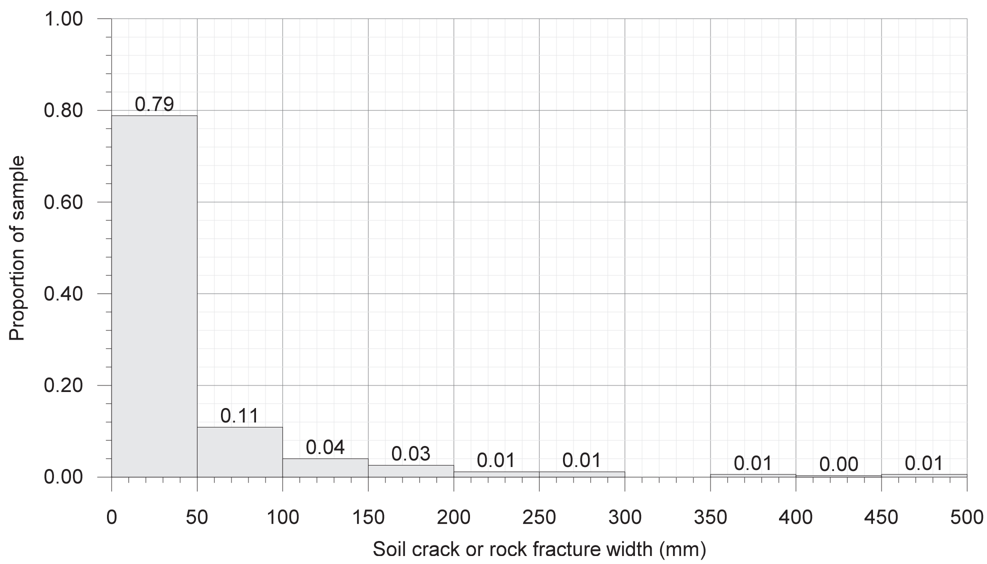

Fig. 4.4 Distribution of measured soil crack and rock fracture widths in Areas 2, 3A and 3B

The soil crack and rock fracture widths were generally observed to be less than 50 mm (i.e. 79 % of the cases). However, the widths of the surface deformations were between 50 mm and 150 mm in 15 % of cases, between 150 mm and 300 mm in 5 % of cases and greater than 300 mm in approximately 1 % 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. Localised erosion has also occurred at several sites causing surface deformations with widths up to 0.75 m (not shown in the above figure for clarity).

The predicted subsidence effects for the proposed longwalls in Area 5 are less than the predicted values for the previously extracted longwalls in Area 3B at the Dendrobium Mine, as shown in Table 4.4. Soil crack and rock fracture widths due to the extraction of the proposed longwalls, therefore, are expected to be similar or less than those previously 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 as short-lived temporary events which 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 (2022a).

The following sections provide the descriptions, predictions and impact assessments for the natural features located within the Study Area. The significant natural features located outside the Study Area, which may be subjected to far-field or valley-related movements and may be sensitive to these effects, 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 NSW (DSN) Notification Areas are shown in Drawings Nos. MSEC1181-01 and MSEC1181-02.

The western ends of the proposed LW502 to LW505 and LW507 to LW509 are located within the DSN Notification Area for the Avon Reservoir, also known as Lake Avon. The proposed longwalls are located well outside the DSN 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 6.3.

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. Named streams

The streams are shown in Drawings Nos. MSEC1181-08 to MSEC1181-12.

As a result of the Revised Layout, there are no named streams located within the Study Area based on the 600 m boundary, as shown in Drawing No. MSEC1181-09. In comparison for the Previous Layout, the total length of the named streams located within the 600 m boundary was approximately 5.5 km.

The named streams located closest to the proposed longwalls are the Avon River to the west and north-west of the mining area and the Cordeaux River, Donalds Castle Creek and Wongawilli Creek to the east and north-east of the mining area.

A summary of the minimum distances of these names streams from the proposed longwalls is provided in Table 5.1. The distances are taken from the thalwegs (i.e. bases or centrelines) of the streams.

Table 5.1 Minimum distances of the thalwegs of the named streams from the proposed longwalls

Named stream	Nearest longwall	Minimum distance (m)
Avon River	LW505	900
Cordeaux River	LW510	2450
Donalds Castle Creek	LW510	700
Wongawilli Creek	LW510	1900

The named streams are located at distances of 700 m or greater from the proposed longwalls. At these distances, the named streams are not predicted to experience measurable conventional subsidence effects.

The sections of the Avon River and Donalds Castle Creek located closest to the proposed longwalls could experience very small valley closure effects.

The predicted valley closure for the named streams has 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. The sections of named streams closest to the proposed longwalls have effective valley heights (i.e. average height of the two valley sides within half a depth of cover from the valley base) that vary between 30 m and 50 m.

The maximum predicted closure for the sections of the named streams located closest to the proposed longwalls is 30 mm based on the 95 % confidence level. The maximum predicted compressive strain associated with the valley closure effects is 0.6 mm/m based on the 95 % confidence level. These values represent the additional effects due to the mining of the proposed longwalls in Area 5 only.

Fracturing in the beds of the named streams is not expected based on the very low-level predicted valley-related closure effects. This is supported by the observation that fracturing has not been observed in streams at distances greater than 400 m from previously extracted longwalls in the Southern Coalfield.

It is considered unlikely, therefore, that the named streams would experience adverse physical impacts (i.e. fracturing or mining-induced surface water diversions) due to the mining of the proposed longwalls in Area 5.

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

5.3. Unnamed streams

5.3.1. Descriptions of the unnamed streams

There are unnamed streams located within the Study Area that are shown in Drawings Nos. MSEC1181-08 to MSEC1181-12. These streams 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 sections of the streams located directly above the proposed longwalls are first and second order, as shown in Drawing No. MSEC1181-09. The unnamed streams located above and adjacent to the proposed longwalls have been labelled AR19, AR31, AR32, DC8, DC9, DC10, LA8A, LA12, LA13, LA14, LA15 and LA17.

As a result of the Revised Layout, there are no third order streams located directly above the mining area, as shown in Drawing No. MSEC1181-09. There are third order sections of the streams located outside the mining area and within 600 m of the proposed longwalls along streams AR32, DC8 and LA13. In comparison for the Previous Layout, the total length of third order streams located directly above the mining area was approximately 0.8 km.

A summary of the third order sections of the streams located within the Study Area based on the 600 m boundary is provided in Table 5.2.

Table 5.2 Third order sections of the streams within the Study Area based on the 600 m boundary

Stream	Total length within 35° angle of draw (m)	Total length within 600 m boundary (m)	Minimum distance of third order section of the stream from the longwalls (m)
AR32	0	50	550 m north of LW505
DC8	210	640	35 m north of LW510
LA13	1080	1530	50 m north of LW509
Total	**1290**	**2220**	**-**

The total length of the third order sections of the streams within the 35° angle of draw and the 600 m boundary are approximately 1.3 km and 2.2 km, respectively. The total length of the third order sections of the streams located within a distance of 400 m of the proposed longwalls is approximately 1.5 km.

Sections along the alignments of streams AR32, DC8 and LA13 are provided in Fig. 5.1 to Fig. 5.3, respectively. The extents of the third order sections of these streams are illustrated in these figures.

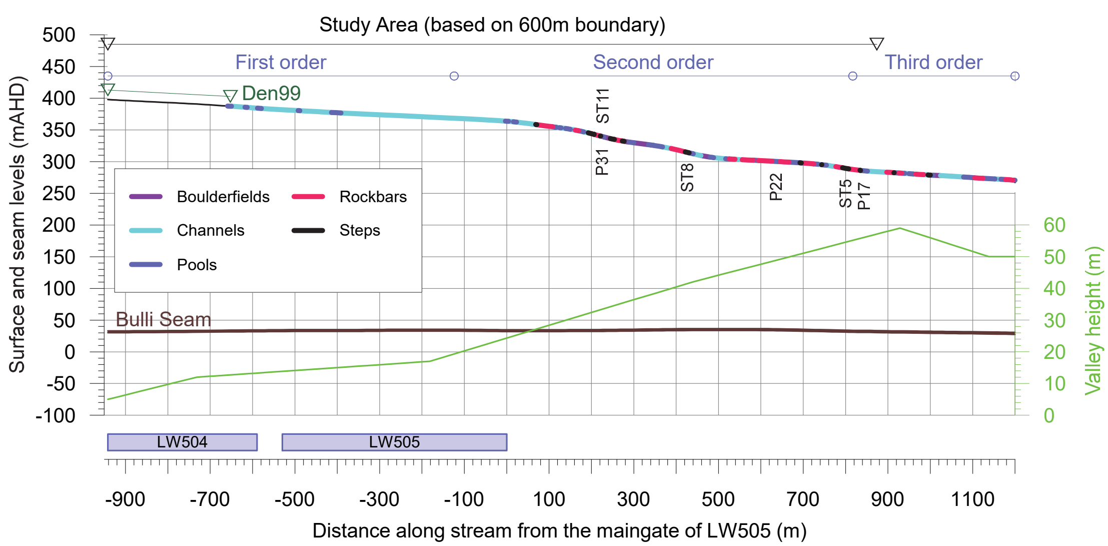

Fig. 5.1 Section along the alignment of stream AR32

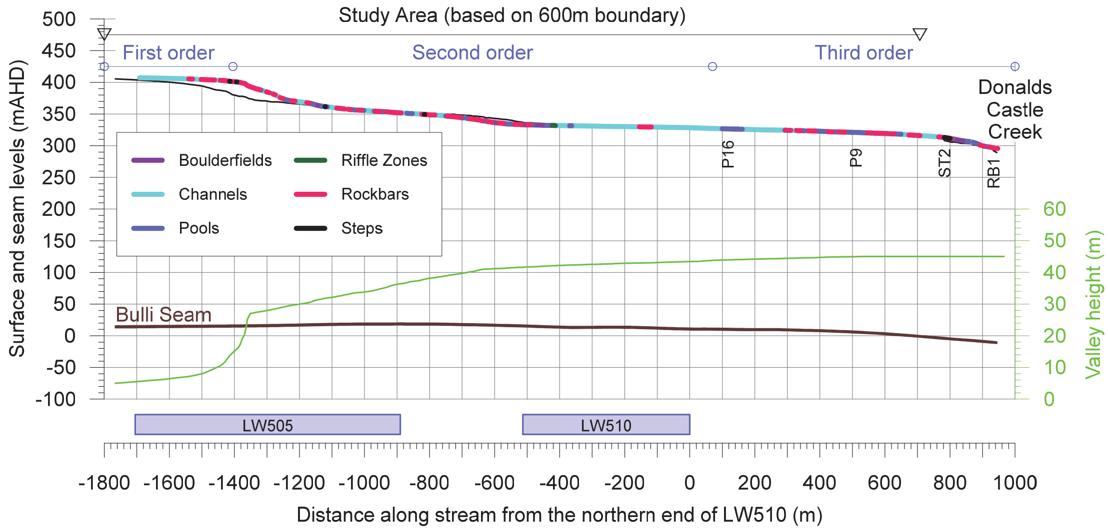

Fig. 5.2 Section along the alignment of stream DC8

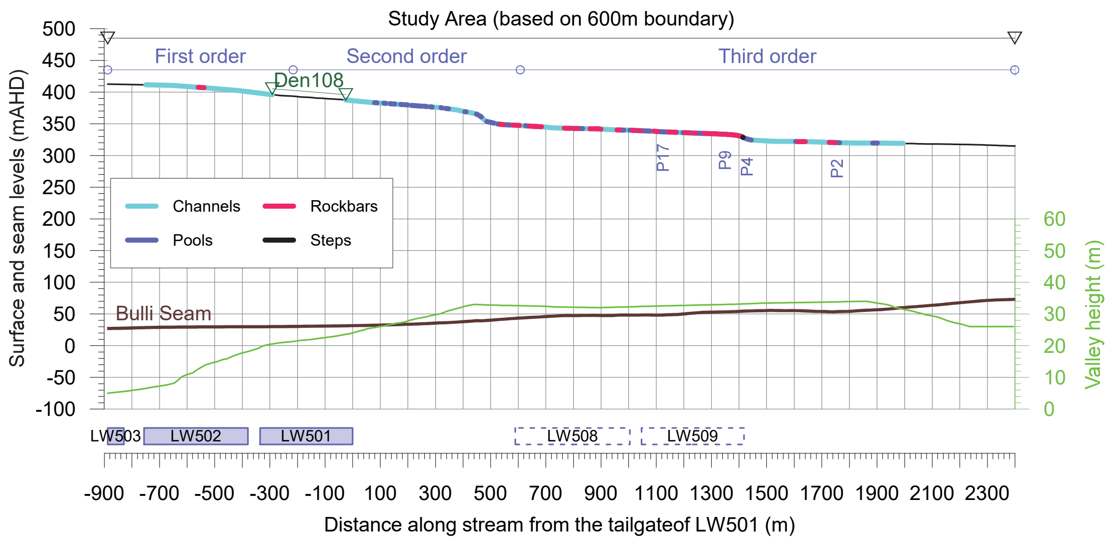

Fig. 5.3 Section along the alignment of stream LA13

The unnamed streams within the Study Area are intermittent (HEC, 2022). The beds of the streams 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. MSEC1181-10 to MSEC1181-12.

Stream features have been identified and mapped by IMC (HEC, 2022). A summary of the key 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) is provided in Table 5.3. The proposed longwalls have been setback from these key stream features to minimise the likelihood of potential impacts.

There are 15 key stream features that are located within the Study Area based on the 600 m boundary. In comparison for the Previous Layout, there were 45 key stream features located within the 600 m boundary. The Revised Layout has therefore reduced the number of key stream features located within the Study Area by 30.

Table 5.3 Key stream features identified along the streams in Area 5

Stream	Reference	Type	Location
AR31	AR31-P52	Pool	570 m north of LW505
	AR31-P63	Pool	270 m north of LW505
AR32	AR32-P17	Pool	560 m north-west of LW505
	AR32-ST5	Step	530 m north-west of LW505
	AR32-P22	Pool	390 m north-west of LW505
	AR32-ST8	Step	200 m north-west of LW505
	AR32-P31	Pool	100 m north of LW505
	AR32-ST11	Step	100 m north of LW505
DC8	DC8-P9	Pool	370 m north-east of LW510
	DC8-P16	Pool	50 m north of LW510
DC10(C)	DC10C-P7	Pool	100 m east of LW502 and 190 m west of LW510
LA13	LA13-P2	Pool	310 m north-west of LW509
	LA13-P4	Pool	60 m north of LW509
	LA13-P9	Pool	100 m north of LW509
	LA13-P17	Pool	100 m north of LW508

Photographs of streams AR31 and AR32 are provided in Fig. 5.4 and Fig. 5.5, respectively.

Fig. 5.4 Photographs of the upper reaches of stream AR31

Fig. 5.5 Photographs of the lower reaches of stream AR32

The average natural gradients of the unnamed streams 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 unnamed streams are provided in the reports by the other specialist consultants on the Project.

5.3.2. Predictions for the unnamed streams

The third order sections of the streams are located outside the proposed mining area.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for the third order sections of the streams within the Study Area based on the 600 m boundary is provided in Table 5.4. The values are the maximum predicted subsidence effects anywhere along the third order sections of the streams.

Table 5.4 Maximum predicted total vertical subsidence, upsidence and closure for the third order sections of the streams within the Study Area based on the 600 m boundary

Stream with third order section	Maximum predicted total vertical subsidence (mm)	Maximum predicted total valley-related upsidence (mm)	Maximum predicted total valley-related closure (mm)
AR32	< 20	30	30
DC8	< 20	125	175
LA13	< 20	250	325

The third order sections of the streams are predicted to experience less than 20 mm vertical subsidence. While these sections of stream could experience very low levels of vertical subsidence, they are not expected to experience measurable conventional tilts, curvatures of strains. The third order sections of the streams are predicted to experience valley related effects up to 250 mm upsidence and 325 mm closure.

The predicted compressive strains due to the valley related effects has 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. The third order sections of the streams closest to the proposed longwalls have effective valley heights (i.e. average height of the two valley sides within half a depth of cover from the valley base) that vary between 40 m and 60 m.

The maximum predicted compressive strain associated with the valley closure effects is 10 mm/m based on the 95 % confidence level. The maximum strains occur where the streams are located closest to the proposed longwalls (i.e. at distances of less than 100 m from the mining area). The predicted compressive strain at distances greater than 200 m from the proposed longwalls is 3.5 mm/m based on the 95 % confidence level.

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

The predicted profiles of vertical subsidence, upsidence and closure along streams AR19, AR31, AR32, DC8, DC9, DC10(C), LA12, LA13 and LA13A are shown in Figs. C.05 to C.13, 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 first and second order unnamed streams is provided in Table 5.5. The values are the maximum predicted subsidence effects anywhere along the sections of these streams located within the Study Area.

Table 5.5 Maximum predicted total vertical subsidence, upsidence and closure for the first and second order unnamed streams within the Study Area based on the 600 m boundary

Stream	Maximum predicted total vertical subsidence (mm)	Maximum predicted total valley-related upsidence (mm)	Maximum predicted total valley-related closure (mm)
AR19	1850	225	170
AR31	1850	160	130
AR32*	1850	200	225
DC8*	1650	600	550
DC9	225	70	140
DC10(C)	1550	300	180
LCA12	1250	375	375
LA13*	1650	475	375
LA13A	1950	750	750

Note: * denotes predictions for first and second order sections of the streams.

The sections of the streams 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 effects. The sections of the streams 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 streams 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 first and second order unnamed streams is provided in Table 5.6. 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. While the conventional and non-conventional horizontal movements are presented separately, the potential impacts consider the combination of both effects.

Table 5.6 Maximum predicted total horizontal movement along, horizontal movement across and conventional closure for the first and second order unnamed streams

Stream	Maximum predicted total horizontal movement along (mm)	Maximum predicted total horizontal movement across (mm)	Maximum predicted total conventional closure (mm)
AR19	300	50	70
AR31	275	200	350
AR32*	175	300	425
DC8*	225	150	175
DC9	40	90	60
DC10(C)	225	200	350
LA12	175	250	225
LA13*	250	200	225
LA13A	175	225	400

Note: * denotes predictions for first and second order sections of the streams.

The maximum predicted conventional strains for the first and second order unnamed streams, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 7.5 mm/m tensile and 9 mm/m compressive.

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 streams 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.

A summary of the maximum predicted subsidence effects for the key stream features along each of the streams is provided in Table 5.7.

Table 5.7 Key stream features identified along the streams in Area 5

Stream	Reference	Maximum predicted total conventional subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
AR31	AR31-P52 and P63	< 20	50	90
AR32	AR32-P17, ST5, P22, ST8, P31 and ST11	< 20	125	175
DC8	DC8-P9 and P16	< 20	80	150
DC10(C)	DC10C-P7	80	100	125
LA13	LA13-P2, P4, P9 and P17	< 20	225	300

The maximum predicted subsidence effects for the key stream features are 80 mm vertical subsidence, 225 mm upsidence and 300 mm closure. The maximum predicted conventional subsidence effects occur at DC10C-P7 and the maximum predicted valley-related effects occur at LA13-P17.

5.3.3. Comparison of the predictions for the unnamed streams

A comparison of the maximum predicted total subsidence effects for the unnamed streams in Area 5, based on the Previous Layout (MSEC856) and Revised Layout (MSEC1181), is provided in Table 5.8.

Table 5.8 Comparison of the maximum predicted total subsidence effects for the unnamed streams

Layout	Mining area	Maximum predicted total conventional subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Previous Layout (MSEC856)	Area 5	1950	875	1150
	Area 6	2300	675	800
Revised Layout (MSEC1181)	Area 5	1950	750	750

The maximum predicted vertical subsidence for the unnamed streams, based on the Revised Layout, is the same as the maximum predicted value based on the Previous Layout for Area 5. Similarly, the maximum predicted conventional tilt, curvatures and strains do not change. The reason is that the longwall widths, chain pillar widths, depths of cover and proposed mining heights remain the same in Area 5.

The maximum predicted vertical subsidence for the unnamed streams, based on the Revised Layout, is less than the maximum predicted value based on the Previous Layout for Area 6. Similarly, the maximum predicted conventional tilt, curvatures and strains are also less than that previous mining area.

The maximum predicted upsidence and closure for the unnamed streams, based on the Revised Layout, are less than the maximum predicted values based on the Previous Layout for Area 5. The maximum predicted valley-related effects are less since the proposed mining area has been reduced and the longwalls do not mine beneath the lower reaches of the streams where the valley heights are greatest.

The maximum predicted valley-related effects for the unnamed streams, based on the Revised Layout, are similar to the maximum predicted values based on the Previous Layout; however, the predicted upsidence is slightly greater and the predicted closure is slightly less.

The predicted conventional and valley-related effects for the third order sections of the streams, based on the Revised Layout, are less than the predicted values based on the Previous Layout. The reason is that the revised longwalls have now avoided the third order sections of the streams.

The maximum predicted subsidence effects for the streams based on the Revised Layout are also less than the maximum predicted values for the streams located above the existing and approved longwalls in Areas 3A and 3B at Dendrobium Mine. A comparison of the predicted subsidence effects in each of these mining areas is provided in Table 4.4.

5.3.4. Observed impacts to streams due to previous mining in Area 3B

First and second-order streams are located above the previously extracted LW9 to LW16 in Area 3B. The impact assessments for these streams were provided in Report No. MSEC459, which related to the physical impacts, i.e. cracking, fracturing and deformation of the bedrock and surface soils as the result of mining. The assessments of the environmental consequences were provided in the other specialist consultants' reports and, therefore, the discussions below should be read in conjunction with those provided by the other specialist consultants.

The impacts observed along the unnamed streams due to LW9 are described in the End of Panel Report (IMC, 2014) and these have been summarised below:

> *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.

> *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 unnamed streams due to LW10 are described in the End of Panel Report (IMC, 2015) and these have been summarised below:

> *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 unnamed streams due to LW11 are described in the End of Panel Report (IMC, 2016) and these 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 flows along Watercourse WC21 in Pool 30.

The impacts observed along the unnamed streams due to LW12 are described in the End of Panel Report (IMC, 2017) and these have been summarised below:

> Rock fractures and uplift were identified at four sites along WC21, LA4 and LA4B with widths up to approximately 50 mm. Loss of surface water flows 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 impacts observed along the unnamed streams due to LW13 are described in the End of Panel Report (IMC, 2018) and these have been summarised below:

> Rock fractures and uplift were identified at six sites along WC21, at eight sites along WC15 and two sites along LA4. The fracture widths varied between 2 mm and approximately 220 mm, with the majority (83 %) of the widths being 50 mm or less. The impacts along WC21 occurred directly above LW12 and LW13. The impacts along WC21 and LA4 were located at distances between 120 m and 280 m outside the extents of LW13.
>
> Loss of surface water flows along WC21 observed directly above LW13. Loss of surface flow along WC15 at six sites and along LA4 at one site at distances between 140 m and 260 m from LW13. Iron staining observed in one location along each of WC21, WC15 and LA4.

The impacts observed along the unnamed streams due to LW14 are described in the End of Panel Report (IMC, 2019) and these have been summarised below:

> Rock fracturing was observed along WC15, LA4 and LA4B at distances ranging between 30 m and 300 m from the longwall mining area. It was assessed that rock fracturing could occur along the streams up to approximately 400 m from the mining area.
>
> No new surface water diversions were identified due to the mining of LW14. However, fracturing along WC15 is located along the main channel and surface water diversions are possible during higher flow conditions. There are seven sites with identified or with possible Type 3 impacts along WC15 due to the mining of both LW13 and LW14, being Rockbars 0/1, Rockbar 5, Rockbar 18, Rockbar 21, Rockbar 25, Rockbar 26 and Pool 30/Channel 30.

The impacts observed along the unnamed streams due to LW15 are described in the End of Panel Report (IMC, 2020) and these have been summarised below:

> Rock fracturing was observed along WC15 and LA4A at distances ranging between 30 m and 140 m from the longwall mining area. It was assessed that rock fracturing could occur along the streams up to approximately 400 m from the mining area.
>
> No new surface water diversions were identified due to the mining of LW15. However, fracturing along WC15 and LA4A was located along the main channels and surface water diversions are possible during higher flow conditions. There are seven sites with identified or possible Type 3 impacts located along WC15 due to the mining of LW13 to LW15, being Rockbars 0/1, Rockbar 5, Rockbar 18, Rockbar 21, Rockbar 25, Rockbar 26 and Pool 30/Channel 30. There are also two sites with identified or possible Type 3 impacts located along LA4A and LA4B which were previously observed due to the mining of LW12 and LW13.

The impacts observed along the unnamed streams due to LW16 are described in the End of Panel Report (IMC, 2021) and these have been summarised below:

> New rock fracturing was identified along stream WC15 at one site and additional fracturing was identified at two other sites after the mining of LW16. Fracturing was previously recorded along this tributary due to the mining of LW13 (8 sites), LW14 (8 sites) and LW15 (3 sites).
>
> Surface water diversion was identified along stream WC15 in one new location due to the mining of LW16. Surface water diversions previously recorded along this stream at two other sites where additional fracturing was observed due to the mining of LW16.

Iron staining was observed along stream LA2 after the mining of LW16. Fracturing and surface water diversions were not observed along this tributary. However, fracturing and soil cracking were observed further up the valley sides on the western valley side in one location.

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

5.3.5. Impact assessments for the third order sections of the streams

The third order section of stream AR32 is located at a minimum distance of 550 m from the proposed mining area. At this distance, it is considered unlikely that physical impacts would occur along this third order section of stream based on longwall mining experience. The furthest distances that fracturing have been observed outside of previously extracted longwalls are 290 m at Dendrobium Mine and 400 m elsewhere in the Southern Coalfield. The furthest that 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) have been observed outside the previously extracted longwalls at the Dendrobium Mine is 290 m.

The third order sections of streams DC8 and LA13 are located at minimum distances of 35 m and 50 m from the proposed mining area. Fracturing and Type 3 impacts could therefore occur along the third order sections of these streams based on experience at the Dendrobium Mine and elsewhere in the Southern Coalfield.

The assessment of the potential impacts on the third order sections of the streams has been based on the observed rate of impacts to the streams located adjacent to the previously extracted longwalls in Area 3B at the Dendrobium Mine.

There are 124 rockbars that are located outside and within 400 m of the completed LW9 to LW16 in Area 3B. This total includes all rockbars regardless of whether or not there is an upstream pool. At the completion of these longwalls, fracturing had been recorded in 32 of these rockbars. Hence, fracturing has occurred in approximately 26 % of the rockbars located outside and within 400 m of the completed longwalls.

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*. A summary of the Type 3 impacts that have been recorded outside the extents of LW9 to LW16 in Area 3B is provided in Table 5.9.

Table 5.9 Type 3 impacts located outside the extents of longwall mining in Area 3B

Stream	Stream feature	Active longwall at the time of impact	Active longwall at the time of impact
Donalds Castle Creek	Rockbar 33	LW9	115 m north of LW9
Stream LA4	Rockbar 0B	LW12	290 m south of LW12
Stream WC15	Step 0 (Rockbar 1)	LW13	250 m east of LW13
	Rockbar 5	LW13	190 m east of LW13
	Rockbar 7	LW13	150 m east of LW13
	Rockbar 18	LW13	120 m south of LW13 and 110 m east of LW14
	Rockbar 21 / Step 21	LW14	80 m east of LW14
	Rockbar 25 / Step 25	LW14	30 m south-east of LW14
	Rockbar 26	LW14	30 m south-east of LW14
	Pool 30 (Rockbar 29)	LW14	60 m south of LW14
Wongawilli Creek	Pool 50 (previously called Pool 43)	LW13	200 m west of LW6 and 410 m east of LW9

There are 11 Type 3 impacts that have been observed outside and due to the mining of LW9 to LW16 in Area 3B. There are 72 stream controlling features (rockbars or other features with an upstream pool) that are located outside and within 400 m of the completed longwalls. Hence, Type 3 impacts have occurred in approximately 15 % of the stream controlling features. The majority of these impacts (i.e. 9 of the 11 cases or 82 %) occurred at distances of 200 m or less from the mining area and the remaining impacts (i.e. two cases or 18 %) occurred at distances of 250 m to 290 m from the mining area.

The potential impacts on the third order sections of streams DC8 and LA13 due to the mining of the proposed longwalls in Area 5 are expected to be similar to that observed in Area 3B. Hence, it is anticipated that Type 3 impacts will occur in approximately 15 % of the rockbars located within 400 m of the proposed mining area.

A summary of the number of stream controlling features and assessed impacts for the third order sections of the streams located within 400 m of the proposed longwalls based on the Revised Layout is provided in Table 5.10. Stream controlling features comprise rockbars, steps, boulderfields and other features located downstream of pools.

Table 5.10 Stream controlling features and assessed Type 3 impacts for the third order sections of the streams located within 400 m of the proposed longwalls

Stream	Length of third order stream located within 400 m of proposed longwalls in Area 5 (m)	Number of stream controlling features located within 400 m of the proposed longwalls in Area 5	Assessed number of Type 3 impacts
AR32	0	0	0
DC8	250	7	≈ 1
LA13	1250	24	≈ 4
Total	**1500**	**31**	**≈ 5**

It has been assessed that approximately five (i.e. 15 %) of the stream controlling features along the third order sections of the streams could experience Type 3 impacts due to the mining of the proposed longwalls.

5.3.6. Impact assessments for the first and second order sections of the unnamed streams

The impact assessments for the first and second order sections of the unnamed streams 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 stream 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 stream gradients that exist before mining.

The maximum predicted tilt for the first and second order streams within the Study Area is 25 mm/m (i.e. 2.5 %) and represents a change in grade of 1 in 40. The average natural gradients of the streams 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 first and second order streams. The natural grades and the predicted post-mining grades along streams AR19, AR31, AR32, DC8, DC9, DC10(C), LA12, LA13 and LA13A are illustrated in Fig. 5.6 to Fig. 5.14, respectively.

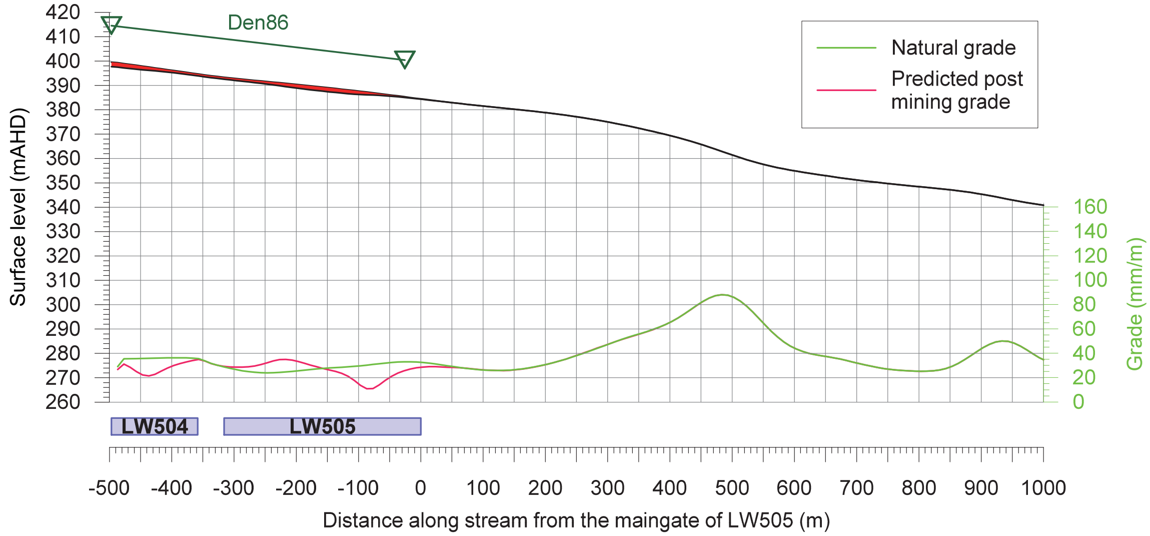

Fig. 5.6 Natural and predicted post-mining surface levels along stream AR19

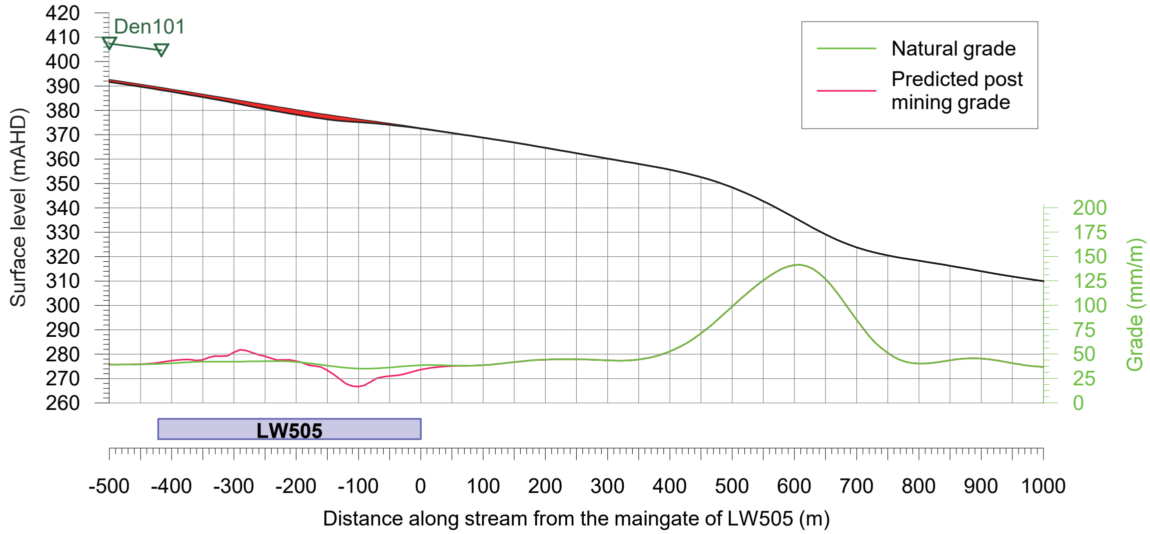

Fig. 5.7 Natural and predicted post-mining surface levels along stream AR31

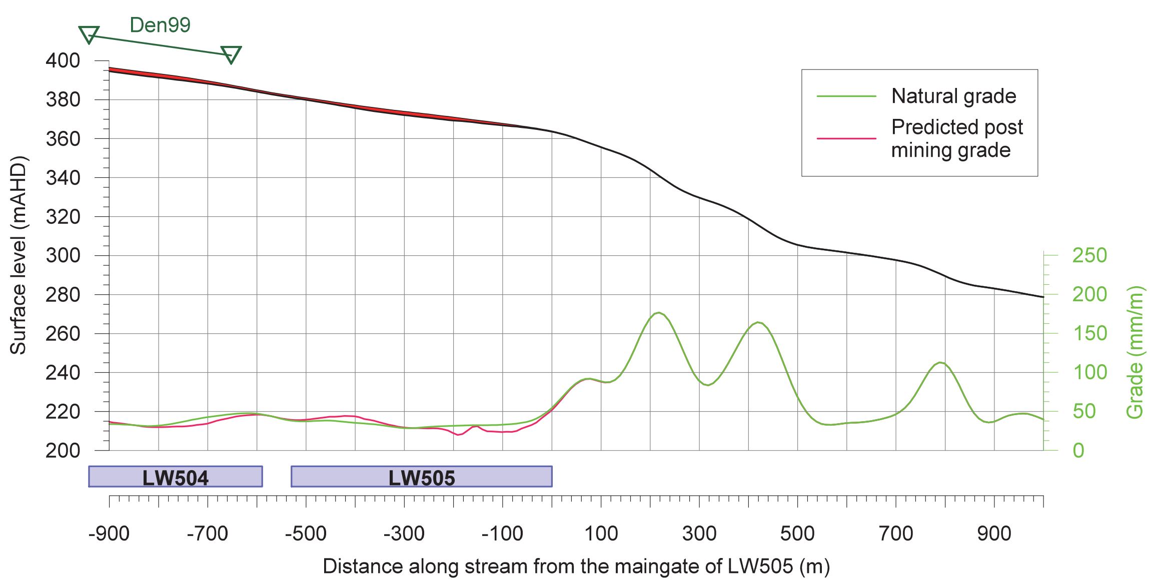

Fig. 5.8 Natural and predicted post-mining surface levels along stream AR32

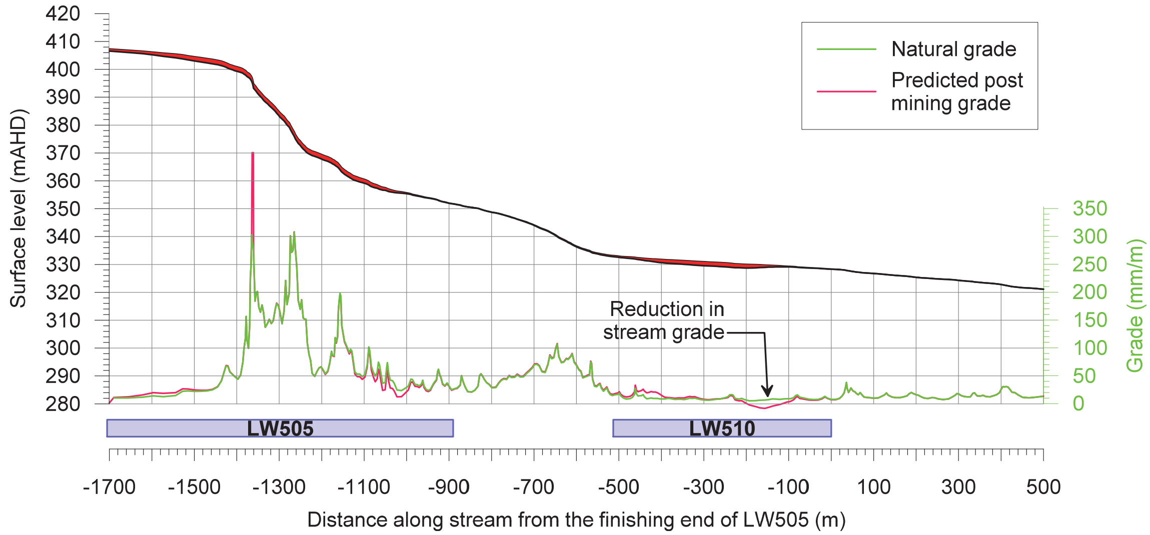

Fig. 5.9 Natural and predicted post-mining surface levels along stream DC8

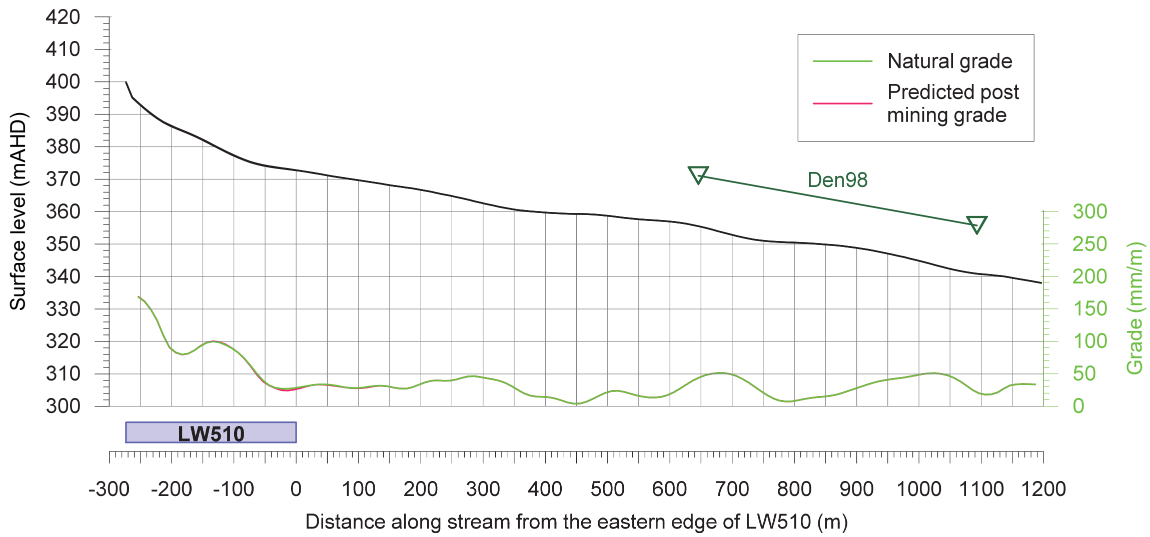

Fig. 5.10 Natural and predicted post-mining surface levels along stream DC9

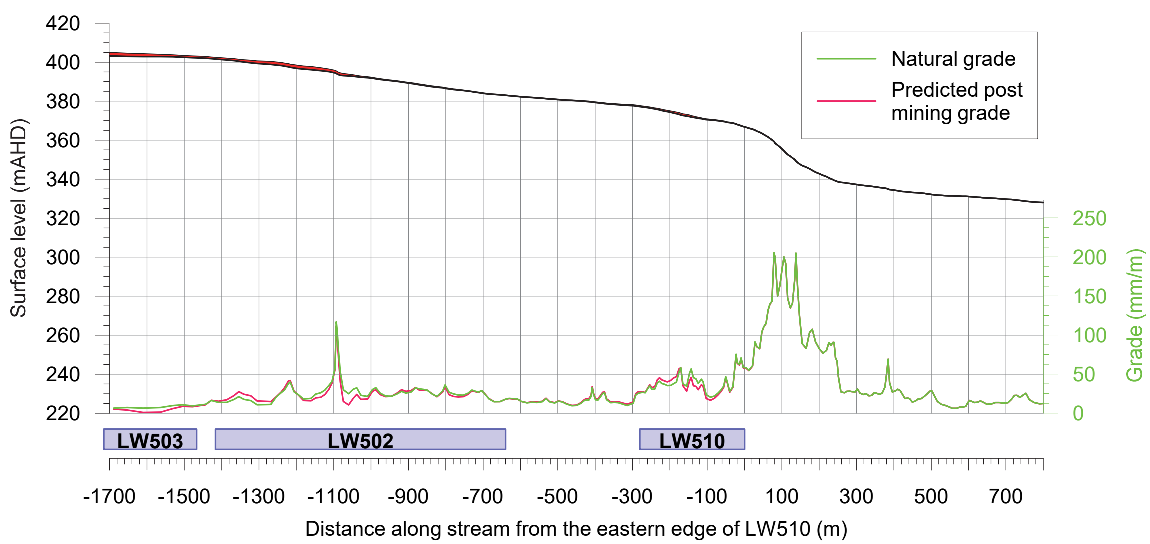

Fig. 5.11 Natural and predicted post-mining surface levels along stream DC10(C)

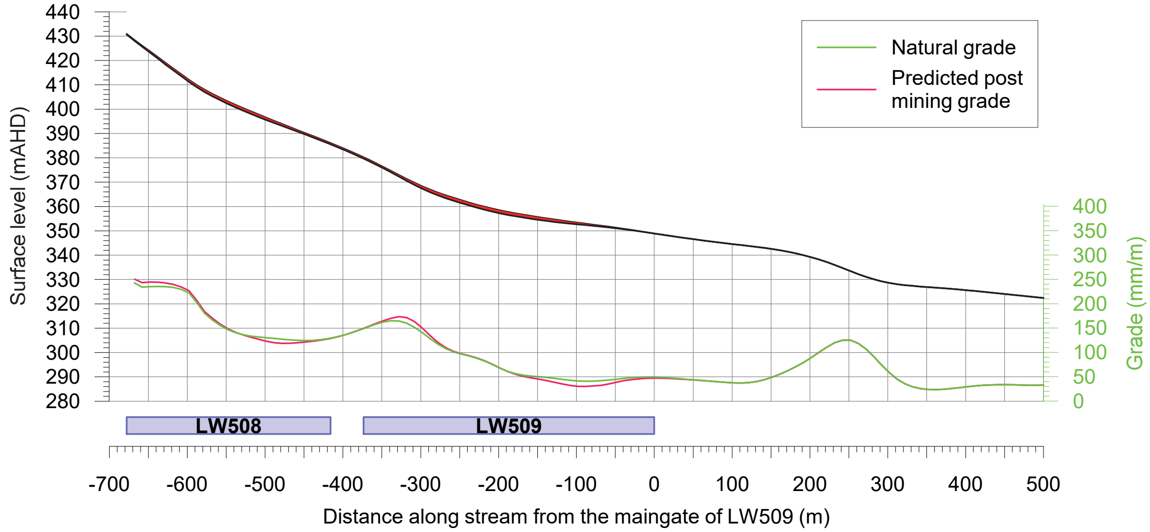

Fig. 5.12 Natural and predicted post-mining surface levels along stream LA12

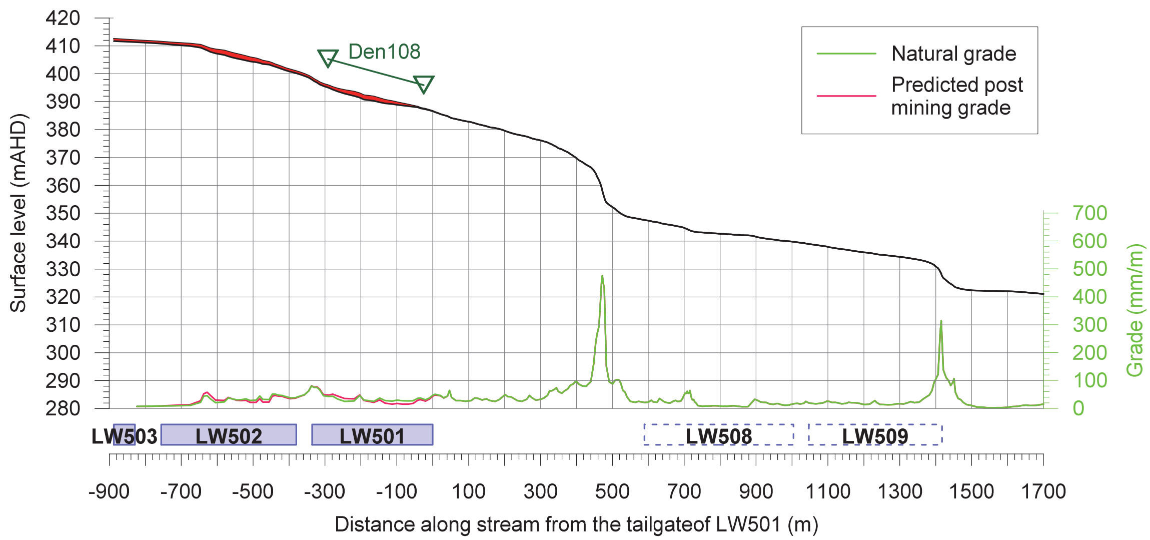

Fig. 5.13 Natural and predicted post-mining surface levels along stream LA13

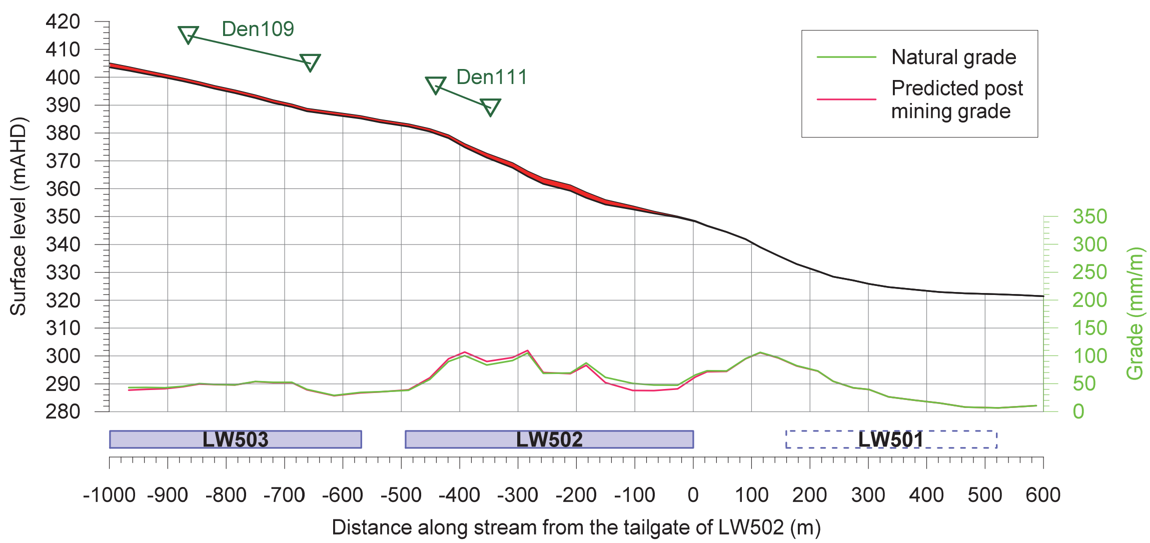

Fig. 5.14 Natural and predicted post-mining surface levels along stream LA13A

It can be seen from Fig. 5.6 to Fig. 5.14, that there are potential reductions in grades including stream DC8 and, to lesser extents, the other first and second order streams. The natural and the predicted post-mining grades are small along the upper reaches of the unnamed streams and in the locations where the streams 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 would occur in the levels of ponding or scouring of the banks along these first and second order streams 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 first and second order streams, therefore, are expected to be minor and localised.

The tributaries to the first and second order streams 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 unnamed streams above the previously extracted LW9 to LW16 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.

A comparison of the maximum predicted subsidence effects for the proposed longwalls in Area 5 with the maximum predicted values for the existing and approved longwalls in Area 3B is provided in Table 4.4. The predicted subsidence effects for the proposed longwalls are less than the maximum predicted values for the longwalls in Area 3B. The main reason is the proposed extraction height in Area 5 of 2.4 m to 3.2 m within the Bulli Seam is less than that in Area 3B of 3.9 m (average but up to 4.6 m) within the basal section of the Wongawilli Seam. The likelihood and extents of the assessed impacts on the first and second order streams due to the extraction of the proposed longwalls in Area 5, therefore, are expected to be less than that observed above the previously extracted longwalls in Area 3B.

It is expected that fracturing of bedrock would occur along the sections of the first and second order streams 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 assessment of the potential impacts on the first and second order streams has been based on the observed rate of impacts to the unnamed streams located directly above the previously extracted longwalls in Area 3B at the Dendrobium Mine.

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 several tributaries. The majority of the data has come from stream 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. 5.15. 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.

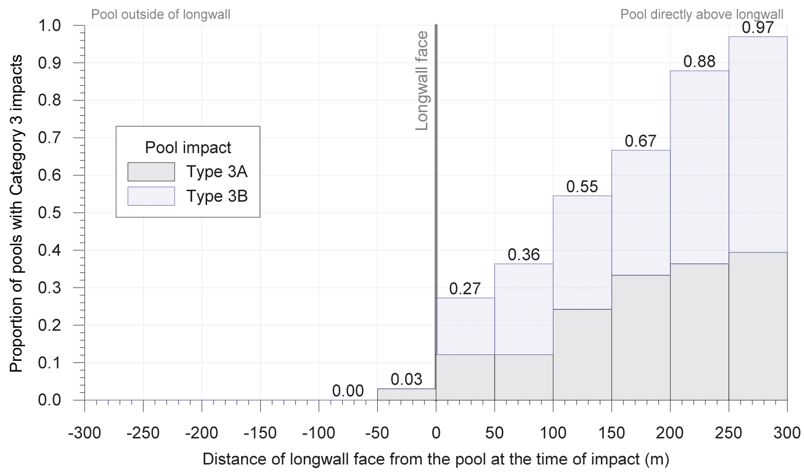

Fig. 5.15 Proportion of pools with Type 3 impacts along stream WC21 in Area 3B

There were no Type 3 impacts observed in the pools along stream 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.

It has therefore been assessed that the majority of the pools along the first and second order streams located directly above the proposed longwalls in Area 5 could experience Type 3 impacts. Fracturing can also occur up to approximately 400 m outside the proposed mining area. As discussed in Section 5.3.5, it has been assessed that approximately 15 % of the stream controlling features located within 400 m of the proposed longwalls could experience Type 3 impacts.

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 first and second order streams 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. A portion of the water that is diverted into the dilated strata may remerge further downstream.

The tributaries to the first and second order streams may also experience fracturing due to the conventional ground movements. These tributaries are intermittent 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 first and second order streams are provided by the specialist surface water and groundwater consultants on the Project.

5.3.7. Recommendations for the unnamed streams

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

5.4. Aquifers and known groundwater resources

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

5.5. Cliffs

5.5.1. Descriptions of the cliffs

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

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

The 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. MSEC1181-13. The cliffs and minor cliffs are predominantly located along the lower reaches of the streams including: AR31, AR32, DC8, DC10, LA8, LA10, LA13, LA14, LA15, LA17 and their associated tributaries.

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 5.11.

Table 5.11 Cliffs located within the Study Area based on the 35° angle of draw

Location	Number	Overall lengths (m)	Maximum heights (m)
Directly or partially above the proposed longwalls	12	20 to 175	10 to 20
Outside longwalls and within 35° angle of draw	32	20 to 200	10 to 25

There are 12 cliffs that have been identified directly or partially above the proposed longwalls in Area 5, being Refs. DC8-CF1, DC8-CF2, DC8-CF3, DC8-CF4, DC8-CF6, LA8_CF10, LA8A_CF1, LA14-CF1, LA14-CF2, LA15-CF1, LA15-CF2 and LA17-CF1. There are an additional 32 cliffs that are located outside of the proposed mining area and within the 35° angle of draw.

In comparison for the Previous Layout, there were 40 cliffs located directly above the longwalls (i.e. 40 in Area 5 and none in Area 6) and an additional 46 cliffs located outside the previous longwalls and within a 35° angle of draw (i.e. 39 in Area 5 and 7 in Area 6). The Revised Layout has therefore resulted in a reduction in the number of cliffs located directly above the longwalls by 18 (i.e. 40 to 12 cliffs) and a reduction in the number of cliffs located outside the longwalls and within a 35° angle of draw by 14 (i.e. 46 to 32 cliffs).

The overall lengths of each of the cliffs within the Study Area range between 20 m and 200 m. It is noted that the longer cliff lines comprise several separate cliffs and minor cliffs and are intermittently discontinuous. The total length of the cliffs located directly or partially above the proposed longwalls is approximately 0.8 km. The total length of the cliffs located outside the mining area and within the 35° angle of draw is approximately 1.4 km. In comparison for the Previous Layout, the total length of cliffs located directly above the longwalls was 2.2 km in Area 5 and zero in Area 6.

The maximum heights of each of the cliffs located directly or partially above the proposed longwalls vary between 10 m and 20 m. The maximum heights of each of the cliffs located outside the proposed mining area and within the 35° angle of draw vary between 10 m and 25 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 in depth. Photographs of the typical cliffs within the Study Area are provided in Fig. 5.16.

Fig. 5.16 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.

5.5.2. Predictions for the cliffs

The maximum predicted total conventional subsidence effects for each of the cliffs 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 5.12. The values are the maximum predicted subsidence effects within 20 m of the mapped extents of each of the cliffs.

Table 5.12 Maximum predicted total vertical subsidence, tilt and curvatures for the cliffs

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})
Cliffs	1600	20	0.35	0.45

The maximum predicted tilt for the cliffs is 20 mm/m (i.e. 2.0 % or 1 in 50). The maximum predicted curvatures for the cliffs are 0.35 km^{-1} hogging and 0.45 km^{-1} sagging, which represent minimum radii of curvature of 2.9 km and 2.2 km, respectively.

The maximum predicted conventional strains for the cliffs located directly or partially above the proposed longwalls, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 5 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 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. While these cliffs could experience very low-levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

5.5.3. Comparison of the predictions for the cliffs

A comparison of the maximum predicted total subsidence effects for the cliffs in Area 5, based on the Previous Layout (MSEC856) and Revised Layout (MSEC1181), is provided in Table 5.13.

Table 5.13 Comparison of the maximum predicted total subsidence effects for the cliffs in Area 5

Layout	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})
Previous Layout (MSEC856)	Area 5	2000	25	0.50	0.50
	Area 6	< 20	< 0.5	< 0.01	< 0.01
Revised Layout (MSEC1181)	Area 5	1600	20	0.35	0.45

The maximum predicted subsidence effects for the cliffs, based on the Revised Layout, are less than the maximum predicted values based on the Previous Layout. Also, the number of cliffs located directly above the proposed mining area reduces from 40 to 12 due to the revision of the longwall mining area.

Cliffs are located directly or partially above the previously extracted longwalls in Areas 1, 2 and 3A at the Dendrobium Mine. A comparison of the maximum predicted total subsidence effects for the cliffs in each of the mining areas is provided in Table 5.14.

Table 5.14 Comparison of the maximum predicted subsidence effects for the cliffs

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 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 (Revised Layout)	1600	20	0.35	0.45

The maximum predicted subsidence effects for the cliffs located directly above the proposed longwalls in Area 5 are similar to the range of predicted effects for the cliffs located directly above the previously extracted longwalls in Areas 1 and 2 at the Dendrobium Mine. The maximum predicted subsidence effects are greater than the predicted values for the cliffs in Area 3A as those cliffs were generally located near the perimeter or outside the mining area.

5.5.4. 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 0.8 km. These cliffs are predicted to experience mine subsidence effects up to: 1600 mm vertical subsidence, 20 mm/m tilt and 0.35 km^{-1} hogging curvature and 0.45 km^{-1} sagging curvature.

It is difficult to assess the likelihood of cliff instabilities based upon predicted subsidence effects. 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 effects. 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 Dendrobium Mine. The cliffs located above the previously extracted longwalls in Area 1 are the most relevant case study.

LW1 and LW2 at the Dendrobium 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 cliff line 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 Dendrobium 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 60 m to 80 m, or a total face area of impact of approximately 300 m^2 to 500 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.

5.5.5. Recommendations for the cliffs

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

5.6. Rock outcrops and steep slopes

5.6.1. Descriptions of the rock outcrops and steep slopes

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

The areas identified as having steep slopes are shown in Drawing No. MSEC1181-13.

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. 5.17.

Fig. 5.17 Typical rock outcropping within the Study Area

5.6.2. 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 5.15.

Table 5.15 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	2000	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 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.

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

The maximum predicted subsidence effects for the rock outcrops and steep slopes in Area 5, based on the Revised Layout, are similar to or slightly less than the maximum predicted value based on the Previous Layout. A comparison of the maximum predicted subsidence effects based on these layouts is provided in Table 4.3. While the maximum predicted subsidence effects are similar, the extents of the rock outcrops and steep slopes located above the longwall mining area reduce.

Rock outcrops and steep slopes are located directly above the previously extracted longwalls in Areas 1, 2, 3A and 3B at the Dendrobium Mine. A comparison of the maximum predicted total subsidence effects for these features is provided in Table 5.16.

Table 5.16 Comparison of the maximum predicted subsidence effects 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})
Area 1	2800	20	0.35	0.75
Area 2	1275	17	0.50	0.60
Area 3A	3000	40	1.0	1.0
Area 3B	3600	50	1.4	1.4
Area 5 (Revised Layout)	2000	25	0.50	0.60

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

5.6.4. 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. 5.18.

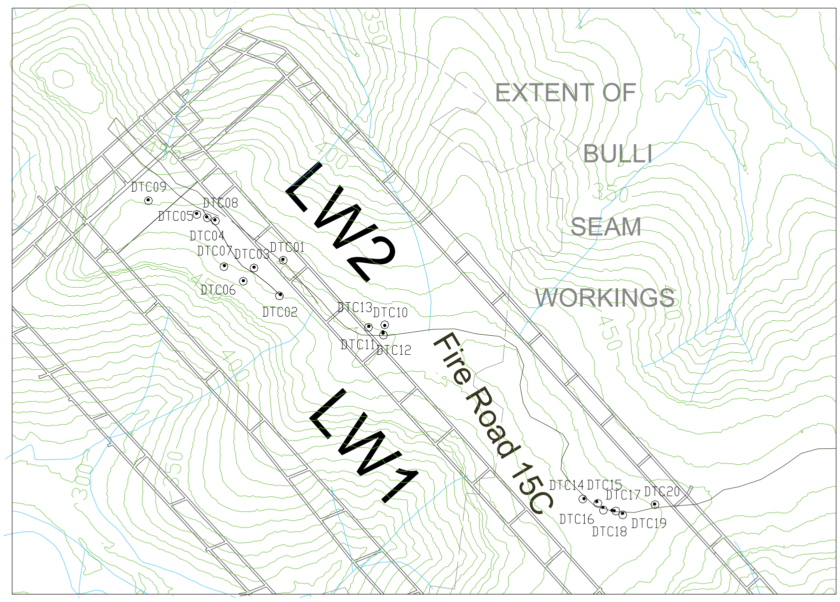

Fig. 5.18 Locations of observed surface cracking above LW1 and LW2 at the Dendrobium Mine

The largest surface cracks observed in Area 1 at the Dendrobium 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 Dendrobium Mine are provided in Fig. 5.19.

Fig. 5.19 Surface tension cracking due to downslope movements at the Dendrobium Mine

It is expected, therefore, that increased horizontal movements in the downslope direction 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.

5.6.5. Recommendations for the rock outcrops and steep slopes

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

5.7. 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.

5.8. 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 and Donalds Castle Creek. 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.

5.9. Swamps, wetlands and water related ecosystems

5.9.1. Descriptions of the swamps

The locations of the upland swamps are shown in Drawing No. MSEC1181-08. The locations and extents of the upland swamps have been interpreted from detailed aerial photogrammetry and site inspections.

There are 15 upland swamps that have been identified entirely or partially above the proposed longwalls in Area 5, being Den86, Den99, Den100, Den101, Den102, Den106, Den107, Den108, Den109, Den110, Den111, Den114, Den121, Den122 and Den123. There are an additional five swamps that are located outside of the proposed mining area and within the 35° angle of draw and an additional two swamps located within the 600 m boundary.

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 5.17.

Table 5.17 Upland swamps within the Study Area

Type	Number of swamps located directly above the proposed longwalls	Number of swamps located outside the mining area and within the 35° angle of draw	Number of swamps located outside the 35° angle of draw and within the 600 m boundary
Swamps	15	5	2

In comparison for the Previous Layout, there were 26 swamps located directly above the longwalls (21 in Area 5 and 5 in Area 6), an additional 11 swamps located outside the previous longwalls and within a 35° angle of draw (4 in Area 5 and 7 in Area 6) and an additional 9 swamps located outside the angle of draw and within the 600 m boundary (3 in Area 5 and 6 in Area 6).

The Revised Layout has therefore resulted in a reduction in the number of swamps located above the longwalls by 11 (i.e. 26 to 15 swamps). Swamps Den97, Den98, Den103, Den104, Den105 and Den120 were located above the longwalls in Area 5, based on the Previous Layout, whereas they are now located outside the modified longwalls. Also, Swamps Den83, Den113, Den117, Den118 and Den128 were previously located above the longwalls in Area 6.

The Revised Layout has also resulted in a reduction in the number of swamps located outside the longwalls and within the 35° angle of draw by 6 (i.e. 11 to 5 swamps) and the number of swamps located outside the angle of draw and within the 600 m boundary by 7 (i.e. 9 to 2 swamps).

The upland swamps can be categorised into two geomorphological types, the *valley infill* swamps that form within the streams, 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. 5.20, showing Swamp Den104. Photographs of typical headwater swamps are provided in Fig. 5.21, showing Swamp Den99 (left side) and Swamp Den105 (right side).

Fig. 5.20 Photographs of Swamp Den104 (valley infill swamp)

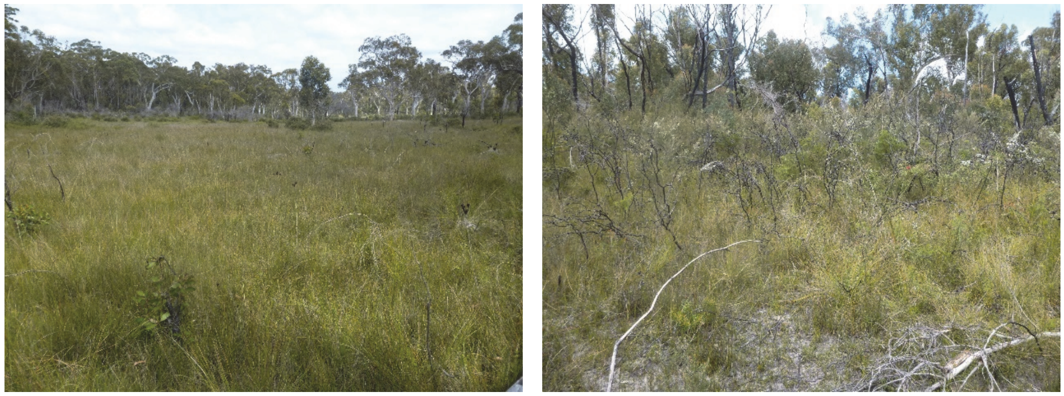

Fig. 5.21 Photographs of Swamps Den99 and Den105 (headwater swamps)

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

5.9.2. Predictions for the swamps

The maximum predicted total conventional subsidence effects 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 5.18. The values are the maximum predicted subsidence effects within 20 m of the mapped extents of each of the swamps.

Table 5.18 Maximum predicted total vertical subsidence, tilt and curvatures for the swamps

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})
Swamps	1950	20	0.35	0.50

The maximum predicted tilt for the swamps is 20 mm/m (i.e. 2.0 % or 1 in 50). The maximum predicted curvatures for the swamps are 0.35 km^{-1} hogging and 0.50 km^{-1} sagging, which represent minimum radii of curvatures of 2.9 km and 2.0 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 5 mm/m tensile and 7.5 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 are 4 mm/m tensile and 5 mm/m compressive based on the 95 % confidence levels.

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 total upsidence, valley closure and conventional closure for the swamps is provided in Table 5.19. The values are the maximum predicted subsidence effects on the alignments of the streams within the extents of the swamps.

Table 5.19 Maximum predicted total 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)
Swamps	375	375	300

The predicted valley-related effects provided in the above table are the maximum values which are predicted to 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 maximum values 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 effects. The swamps located within the 35° angle of draw for the proposed longwalls could experience compressive strains in the order of 2 mm/m to 5 mm/m.

5.9.3. Comparison of the predictions for the swamps

A comparison of the maximum predicted total subsidence effects for the swamps, based on the Previous Layout (MSEC856) and Revised Layout (MSEC1181), is provided in Table 5.20.

Table 5.20 Comparison of the maximum predicted total subsidence effects for the swamps

Layout	Mining Area	Maximum predicted total conventional subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total valley-related closure (mm)
Previous Layout (MSEC856)	Area 5	1800	525	575
	Area 6	2300	350	350
Revised Layout (MSEC1181)	Area 5	1950	375	375

The maximum predicted vertical subsidence for the swamps, based on the Revised Layout, is slightly greater than the maximum predicted value based on the Previous Layout in Area 5 but it is less than the maximum predicted value based on the Previous Layout in Area 6. The predicted conventional subsidence, upsidence and closure increase for some swamps and decrease for other swamps depending on their locations relative to the locations of the proposed longwalls. However, the overall levels of impact on the swamps are less since the number of swamps located directly above the mining area reduces due to the proposed modification.

The number of swamps located directly above the proposed longwalls in Area 5 reduces by 6 (i.e. 21 to 15). Swamps Den97, Den98, Den103, Den104, Den105 and Den120 were located above the longwalls in Area 5, based on the Previous Layout, whereas they are now located outside the modified longwalls. The overall level of predicted conventional subsidence effects for the swamp therefore reduces.

The maximum predicted upsidence and closure for the swamps, based on the Revised Layout, are less than the maximum predicted values based on the Previous Layout. The maximum predicted valley-related effects are less since the proposed mining area has been reduced and the longwalls do not mine beneath the lower reaches of the streams where the valley heights are greatest.

The maximum predicted subsidence effects and, hence, the overall potential for physical impacts (i.e. soil cracking and rock fracturing) for the swamps are similar to or reduced due to the proposed modifications. However, further discussions on the potential environmental consequences for the swamps are provided by the other specialist consultants on the project.

5.9.4. Previous experience of mining beneath swamps

Discussions on the previous experience of mining beneath swamps at the Dendrobium Mine 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 in Area 2 were extracted directly beneath Swamp Den01, which is both a headwater and valley infill swamp located along stream 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. 5.22.

Fig. 5.22 Photograph of the fracturing in the rockbar downstream of Swamp Den01 (Source: IMC)

While 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 in Area 3A was extracted directly beneath Swamp Den12, which is a headwater swamp located on the valley side of stream 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 in Area 3B was extracted directly beneath Swamp Den05, 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 (IMC, 2014) which states "*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 LW16 which were described in each of the End of Panel Reports (IMC, 2015, 2016, 2017, 2018, 2019, 2020 and 2021). The groundwater levels were lower than baseline and recession rates greater than baseline for Swamps Den03, Den05, Den10, Den11, Den13, Den14 and Den23. Soil moisture levels below baseline were also reported in Swamps Den05, Den11 and Den23.

5.9.5. 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 effects are provided in the following sections. 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 20 mm/m (i.e. 2.0 % or 1 in 50). The mining-induced tilts are small when compared with the natural gradients within the swamps. This is illustrated in Fig. 5.6 to Fig. 5.14, which show the natural and predicted post-mining grades along the streams 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 streams.

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 mining-induced tilt or vertical subsidence.

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 HEC (2022) and the specialist ecology consultant in the reports by Cardno (2022) and Niche (2022a).

Potential for cracking in the swamps and fracturing of bedrock

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

There are 15 swamps that have been identified entirely or partially above the proposed longwalls in Area 5, being Den86, Den99, Den100, Den101, Den102, Den106, Den107, Den108, Den109, Den110, Den111, Den114, Den121, Den122 and Den123. The predicted strains for these swamps are 4 mm/m tensile and 5 mm/m compressive based on the 95 % confidence levels. The valley infill swamps located directly above the longwalls (i.e. Den108, Den111 and Den 121) could also experience compressive strains of 10 mm/m to 20 mm/m due to valley-related effects.

Fracturing could therefore occur in the bedrock beneath the swamps that are located directly above the proposed longwalls. Soil cracking could also be visible at the surface where the depth of bedrock is shallow. The range of potential fracture and crack widths in Area 5 has been based on that previously observed at the Dendrobium Mine, as described in Section 4.8. However, the fracture and crack widths above the proposed longwalls are expected to be less, on average, than those previously observed at the Dendrobium Mine due to the lower predicted subsidence effects.

The soil crack and rock fracture widths recorded in Areas 2, 3A and 3B at the Dendrobium Mine were generally less than 50 mm (i.e. 79 % of the cases). However, the widths of the surface deformations were between 50 mm and 150 mm in 15 % of cases, between 150 mm and 300 mm in 5 % of cases and greater than 300 mm in approximately 1 % of cases.

The valley infill swamps have layers of organic soil that overlie the shallow natural surface soils and underlying bedrock along the alignments of the streams. 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 infill swamps located directly above the proposed longwalls (i.e. Den108, Den111 and Den 121) are also predicted to experience up to 375 mm upsidence and 375 mm closure. These valley-related effects could result in the dilation of the strata beneath these valley infill swamps. It has been previously observed that the depth of fracturing and dilation of the uppermost bedrock, resulting from valley-related effects, 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 streams within or upstream of the valley infill swamps could result in the diversion of some surface water flows beneath parts of these swamps. The streams upstream of these swamps flow during and shortly after rainfall events. Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation.

There are seven swamps that are located outside but within 600 m of the proposed longwall (i.e. Den85, Den97, Den98, Den103, Den104, Den105 and Den120). The predicted conventional strains for these swamps are less than 0.5 mm/m tensile and less than 2 mm/m due to the mining of the proposed longwalls. However, the sections of the valley infill swamps located within the 35° angle of draw could experience compressive strains in the order of 2 mm/m to 5 mm/m due to the valley-related effects.

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 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.

5.9.6. Recommendations for the swamps

MSEC provides the following recommendations for the swamps, to monitor the ground movements and manage potential impacts, 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 effects 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 sight 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; and
- develop a Trigger Action Response Plan (TARP), based on the ground and visual monitoring in conjunction with the surface water and groundwater monitoring programs. Similar TARPs have been established for swamps which have been previously mined beneath at the Dendrobium Mine.

Further discussions and recommendations for the swamps have been provided by the other specialist consultants on the Project. Management plans have been developed for the swamps which have been previously mined beneath at the Dendrobium 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.

5.10. 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 0. The assessments of the environmental consequences have been provided by the other specialist consultants on the Project.

5.11. State Conservation Areas

The Upper Nepean State Conservation Area is shown in Drawing No. MSEC1181-01.

The Upper Nepean State Conservation Area is located outside the proposed mining area at a minimum distance of 410 m north of LW510. The surface area of the conservation area that is located within the Study Area based on the 600 m boundary is 7.7 ha. The Upper Nepean State Conservation Area is located outside the 35° angle of draw.

The maximum predicted vertical subsidence within the boundary of the Upper Nepean State Conservation Area is less than 20 mm. While the land within the conservation area could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains.

The streams within the Upper Nepean State Conservation Area could experience valley-related effects, as discussed in Section 5.3. Fracturing or other physical impacts are not expected within the conservation area due to its distance from the proposed longwalls. The furthest distances that fracturing have been observed outside of previously extracted longwalls are 290 m at Dendrobium Mine and 400 m elsewhere in the Southern Coalfield.

It is considered unlikely, therefore, that adverse physical impacts would occur within the Upper Nepean State Conservation Area due to the mining of the proposed longwalls. Further discussions on the potential environmental impacts are provided by the other specialist consultants on the Project.

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

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. MSEC1181-14. 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. MSEC1181-14. 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.14, 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 maximum predicted subsidence effects 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	1600	16	0.25	0.30

The maximum predicted tilt for the disused railway corridor is 16 mm/m (i.e. 1.6 % or 1 in 63). The maximum predicted curvatures for the corridor are 0.25 km^{-1} hogging and 0.30 km^{-1} sagging, which represent minimum radii of curvatures of 4.0 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 4 mm/m tensile and 4.5 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 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

A comparison of the maximum predicted total subsidence effects for the section of the discussed railway corridor in Area 5, based on the Previous Layout (MSEC856) and Revised Layout (MSEC1181), is provided in Table 6.2.

Table 6.2 Comparison of the maximum predicted total subsidence effects for the section of the disused railway corridor in Area 5

Layout	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})
Previous Layout (MSEC856)	1450	14	0.20	0.30
Revised Layout (MSEC1181)	1600	16	0.25	0.30

The maximum predicted subsidence effects for the disused railway corridor, based on the Revised Layout, are similar to but slightly greater than the predicted values based on the Previous Layout. The predicted subsidence effects slightly increase due to the rotation of the longwalls such that the disused railway corridor is located transverse to the longwalls. However, the predicted subsidence effects are less than the maximum predicted values for the section of the disused railway corridor located in Area 3B.

The disused railway corridor crosses directly above LW10 to LW18 in Area 3B. A comparison of the maximum predicted total subsidence effects for the disused railway corridor is provided in Table 6.3.

Table 6.3 Comparison of the maximum predicted total subsidence effects 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 (Revised Layout)	1600	16	0.25	0.30

The maximum predicted subsidence effects for the section of the disused railway corridor 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 effects for the proposed longwalls are less because the mining heights along the alignment of the railway corridor in Area 5 of 2.4 m to 2.8 m are less than the mining heights in Area 3B of 3.9 m to 4.6 m. The proposed longwalls will also be extracted from the Bulli Seam and, therefore, there will be 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 along the railway corridor, however, there is no track along the section of the disused 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 16 mm/m (i.e. 1.6 % or 1 in 63). 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, it is 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.

While 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 maximum predicted tilt at the drainage culvert is 3 mm/m (i.e. 0.3 % or 1 in 333). However, the maximum predicted final tilt at the completion of mining is less than 1 mm/m (i.e. 0.1 % or 1 in 1000). The mining-induced tilt could potentially 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 effects 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 adverse impacts on the disused railway corridor, other than minor cracking, buckling and increased ponding, due to the extraction of LW9 to LW16 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. 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. MSEC1181-14. A photograph of a typical track within the Study Area is provided in Fig. 6.4.

Fig. 6.4 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 stream crossings.

The unsealed roads and tracks are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence effects. A summary of the maximum predicted conventional subsidence effects within the Study Area is 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 effects 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 Dendrobium 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. 6.5 (Source: IMC).

Fig. 6.5 Impacts along the unsealed roads and tracks above LW6 in Area 3A (left side) and above LW11 in Area 3B (right side) (Source: IMC)

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 Dendrobium Mine. It is recommended that these same strategies are used to maintain the unsealed roads and tracks located within the Study Area. It is also recommended that these roads and tracks are periodically inspected during active subsidence.

6.3. Dams, reservoirs or associated works

6.3.1. Descriptions of the reservoirs

Area 5 is located within the Metropolitan Special Area. The proposed longwalls are located between two reservoirs. The Avon Reservoir, also known as Lake Avon, is located west of Area 5. The Cordeaux Reservoir, also known as Lake Cordeaux, is located east of the mining area. These reservoirs are shown in Drawing No. MSEC1181-01.

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, 2022b).

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 Area 5 and it is shown in Drawing No. MSEC1181-01. A summary of the minimum distances of the proposed longwalls from the Avon Dam Wall is provided in Table 6.4. The longwalls in Area 5 will be extracted in sequence towards the dam wall.

Table 6.4 Distances of the proposed longwalls from the Avon Dam Wall

Location	Longwall	Minimum distance (m)
Avon Dam Wall	LW501	2760
	LW502	1330
	LW503	1030
	LW504	1010
	LW505	1000
	LW506 to LW510	> 3000

The proposed LW502 to LW505 and LW507 to LW509 are partially located within the Dams Safety NSW (DSN) 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. 6.6 and Fig. 6.7, respectively. A photograph of the dam wall is provided in Fig. 6.8.

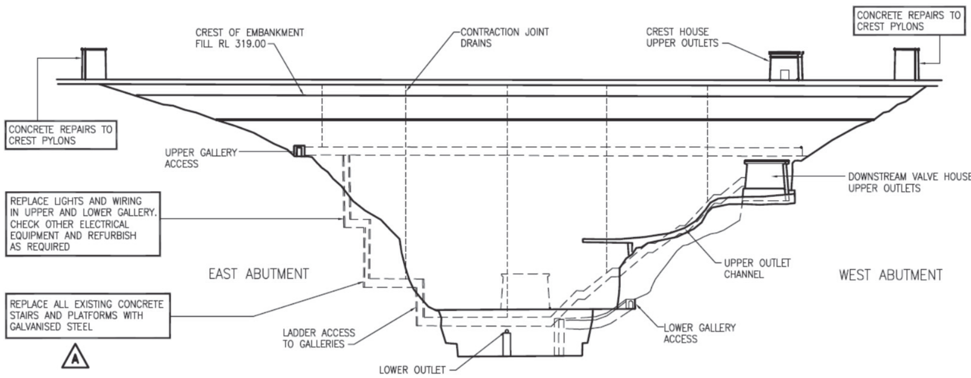

Fig. 6.6 Elevation of the Avon Dam Wall (Source: WaterNSW, 2015a)

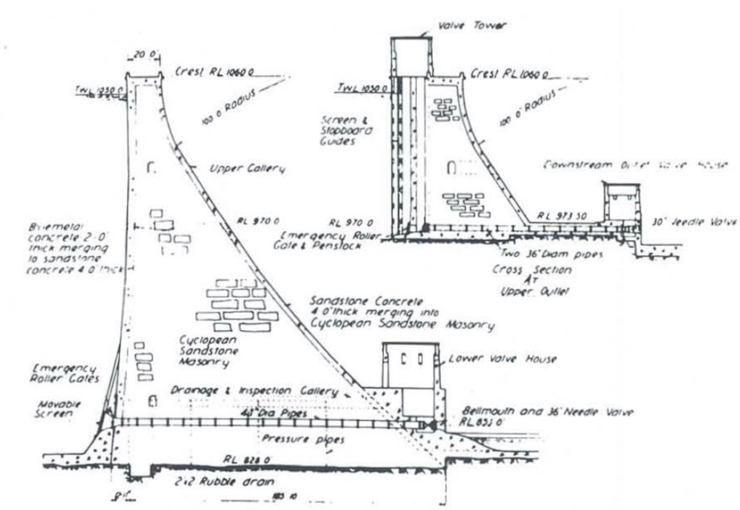

Fig. 6.7 Cross-section of the Avon Dam Wall (Source: WaterNSW, 2015a)

Fig. 6.8 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 in Area 5 are shown in Drawing No. MSEC1181-07. 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 LW505 is provided in Fig. 6.9. The section has been taken through the dam wall where it is closest to the proposed mining area.

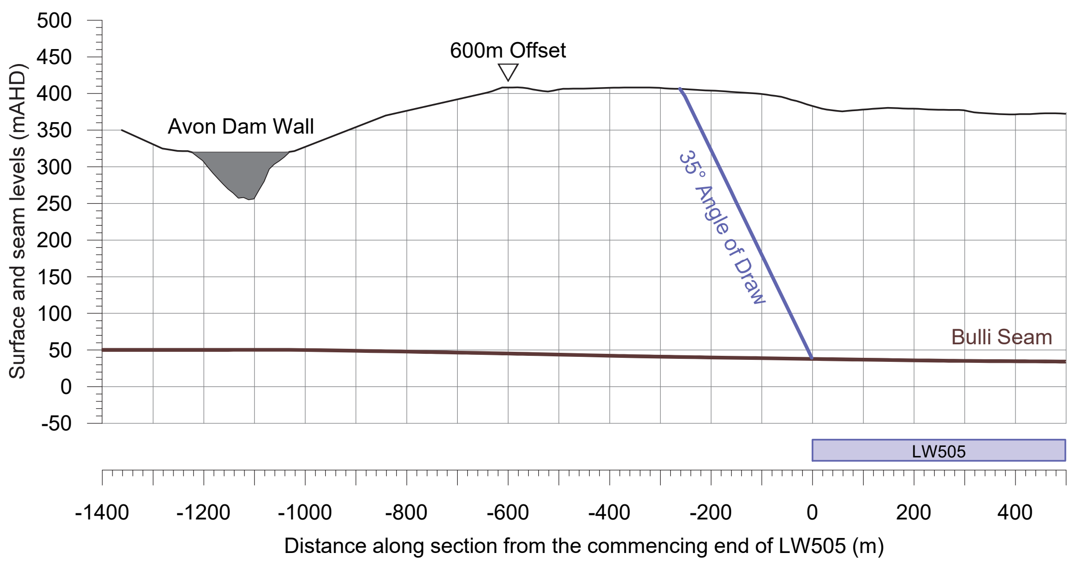

Fig. 6.9 Section through the Avon Dam Wall

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 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. The dam wall is shown in Drawing No. MSEC1181-01. The proposed longwalls in Area 5 are located more than 4 km from the Cordeaux Dam Wall.

The stored waters in the southern part of the reservoir are impounded by the Upper Cordeaux No.1 and No. 2 Dam Walls. The proposed longwalls in Area 5 are located more than 8 km from the Upper Cordeaux No.1 and No. 2 Dam Walls.

Area 5 is located outside the DSN's Notification Area for the Cordeaux Reservoir. The proposed longwalls are located at a minimum distance of 2.6 km from this notification area, at their closest point.

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. 6.10 and Fig. 6.11, respectively. Photographs of the dam wall are provided in Fig. 6.12.

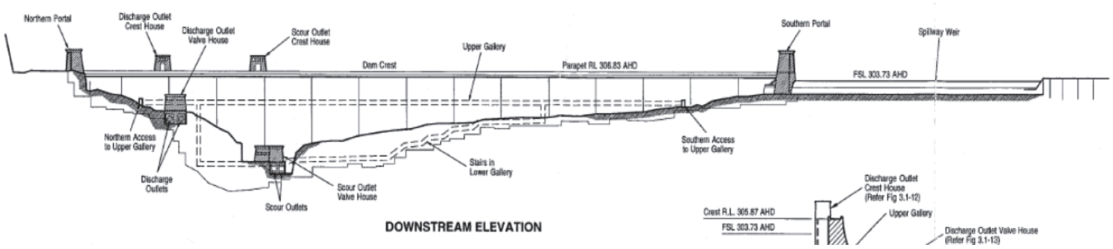

Fig. 6.10 Elevation of the Cordeaux Dam Wall (Source: WaterNSW, 2015b)

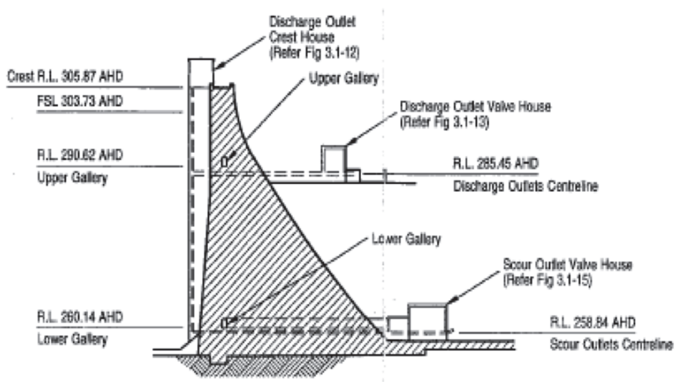

Fig. 6.11 Cross-section of the Cordeaux Dam Wall (Source: WaterNSW, 2015b)

Fig. 6.12 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 Drawing No. MSEC1181-07. 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.

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. Discussions on the proposed Lower Cordeaux Reservoir are provided in Section 6.7.

6.3.2. Predictions for the reservoirs

The Cordeaux Dam wall is located more than 4 km from the proposed longwalls in Area 5. At this distance, the dam wall is not predicted to experience measurable conventional, far-field or valley-related effects.

The Avon Dam wall is located at a minimum distance of 1000 m from LW505, at its closest point to the proposed longwalls in Area 5. At this distance, the dam wall is not expected to experience measurable conventional subsidence effects (i.e. vertical subsidence and its associated tilt, curvature and strain).

The Avon Dam wall is likely to experience far-field horizontal movements towards the mining area. The measured incremental far-field horizontal movements at Dendrobium Mine and elsewhere in the Southern Coalfield are illustrated in Fig. 4.3.

At distances of 1000 m or greater from the extracted longwalls at the Dendrobium Mine, the majority of the measured far-field movements (i.e. 94 % of cases) are less than the nominal survey tolerance of 25 mm for absolute position. The survey tolerance for far-field horizontal movements is greater than that for other subsidence parameters, such as strain, as it is measured using GPS. In a small number of cases, far-field horizontal movements greater than the nominal survey tolerance have been measured at distances of 1000 m or greater, in the order of 25 mm to 60 mm.

The mean and 95 % confidence level based on the data from the Dendrobium Mine are also shown in Fig. 4.3. At a distance of 1000 m from the extracted longwalls at the Dendrobium Mine, the measured incremental far-field horizontal movements are 17 mm based on the mean and 38 mm based on the 95 % confidence level. It is noted that a large proportion of these predicted movements comprise the survey tolerance for absolute position.

The far-field horizontal movements measured elsewhere in the Southern Coalfield are shown as the grey diamonds in Fig. 4.3 for comparison. At distances of 1000 m or greater from the extracted longwalls, the movements measured at Mine are less than those measured elsewhere in the Southern Coalfield. The reason is the shallower depths of cover at Mine result in greater subsidence effects directly above the mining area but lesser effects further afield outside the mining area.

The potential for impacts on the Avon Dam wall do not result from the absolute far-field horizontal movement but from differential horizontal movements. Differential horizontal movements are represented by various parameters including strain, as measured by changes in long bays (including valley closure or valley opening).

There is limited strain monitoring data at the Dendrobium Mine; however, there is extensive data elsewhere in the Southern Coalfield. At distances of 1000 m or greater from the extracted longwalls, the majority of the measured strains (i.e. 94 % of cases) are less than the nominal survey tolerance of 0.25 mm/m. The nominal survey tolerance for strain represents a change in length (i.e. horizontal distance) of 3 mm to 5 mm measured over a standard survey bay length of 20 m.

The far-field horizontal movements are expected to be global (i.e. en-masse) movements that are associated with very low levels of strain. The potential for impacts is affected by the differential horizontal movements (i.e. strain) rather than the absolute movements. At the distances of the Avon Dam wall from the proposed longwalls, the strains are predicted to be in the order of survey tolerance (i.e. not measurable).

The Avon Dam wall is located within the Avon River valley and, therefore, it could experience low level valley-related effects. The predicted closure for the Avon Dam wall has been based on the measured effects at the Dendrobium Mine and elsewhere in the Southern Coalfield.

The measured total valley closure versus the distance from the nearest longwall is illustrated in Fig. 6.13. 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 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.

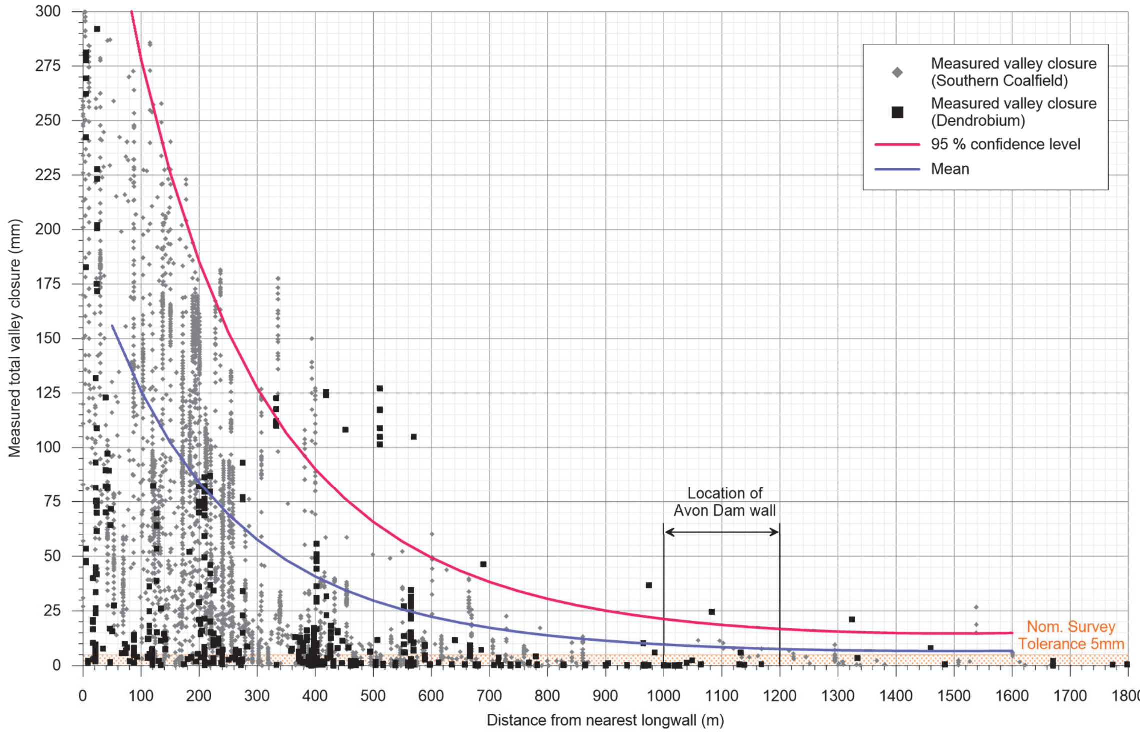

Fig. 6.13 Measured total valley closure versus distance from nearest longwall

The valley closure movements measured at the Dendrobium Mine are shown as the black squares in Fig. 6.13. At distances of 1000 m or greater from the extracted longwalls at the Dendrobium Mine, the majority of the measured valley closure movements (i.e. 93 % of cases) are less than the nominal survey tolerance of 3 mm to 5 mm. Valley closures of 20 mm to 35 mm have been measured at the Wongawilli Creek C-Line after the mining of LW9 to LW11 in Area 3B; however, these values include the measured movements due to previous mining in Area 3A at a minimum distance 370 m. Excluding this monitoring line, the maximum valley closure movement measured at distances of 1000 m or greater at Dendrobium Mine is 8 mm.

The valley closure movements measured elsewhere in the Southern Coalfield are shown as the grey squares in Fig. 6.13 for comparison. At distances of 1000 m or greater from the extracted longwalls, the majority of the measured valley closure movements (i.e. 89 % of cases) are less than the historic survey tolerance of 5 mm to 10 mm. The historic survey tolerance is greater as the monitoring data from the Southern Coalfield includes older surveying techniques. Some data also appear to include results where survey prisms have been disturbed.

At the distance of the Avon Dam wall from the proposed longwalls, the valley closure movements are predicted to be in the order of the survey tolerance of 3 mm to 10 mm. The actual movements are expected to be towards the lower end of the range; however, the older monitoring data from the Southern Coalfield could not measure valley closure less than the upper value.

Modern surveying techniques can measure valley closure to much higher accuracy. For example, the high-resolution monitoring for Sandy Creek Waterfall and Harris Creek Cliff Line have accuracies in the order of 1 mm. It is likely therefore that these more accurate surveying methods could measure valley closure movements at distances of 1000 m from longwall mining.

Low level opening movements have been measured outside of mining due to conventional subsidence effects. This occurs when longwall mining occurs directly beneath the valley side causing it to move in the direction of extraction. For example, the mining of LW12 to LW16 in Area 3B, on the eastern side of Avon Reservoir, have resulted in measurable net openings across the reservoir. These longwalls mined beneath the valley side and at a minimum distance of 300 m of the FSL of the reservoir. The movements measured at the Avon Dam closure lines are shown in Fig. 2.3 of the LW16 End of Panel Report (MSEC, 2021) and it has been reproduced in Fig. 6.14.

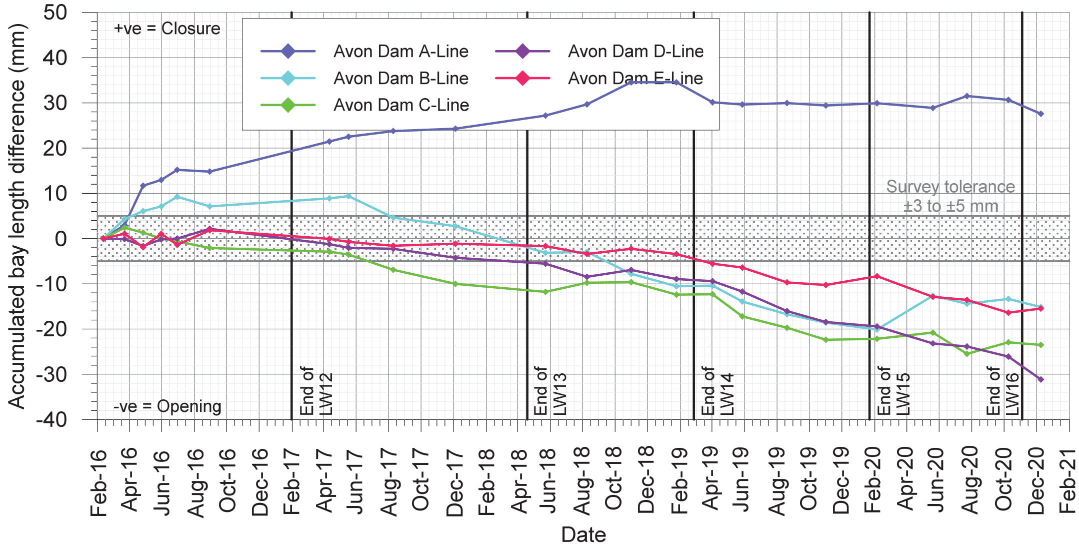

Fig. 6.14 Measured total valley closure versus distance from nearest longwall

Valley closure of 20 mm was initially measured along the Avon Dam A-Line during the mining of LW12 and increasing to 35 mm during the mining of subsequent longwalls. The northern end of this monitoring line is located 330 m from the commencing end of LW12. Closure was also initially measured along the Avon Dam B-Line during the mining of LW12, with its eastern end located 520 m from this longwall.

Valley opening was measured at the Avon Dam C-Line during LW13, the Avon Dam B-Line and D-Line during LW14 and the Avon Dam E-Line during LW15, at distances ranging between 250 m and 850 m from the mining area. These longwalls mined beneath the valley side at a minimum distance of 300 m of the FSL of the reservoir.

The proposed longwalls in Area 5 are located at minimum distance of 1000 m from the Avon Dam wall and, therefore, the potential for valley opening is considerably reduced. The potential net opening movements at the dam walls, due to the proposed mining, are predicted to be less than the nominal survey tolerance of 3 mm to 5 mm. It is possible; however, that high resolution monitoring techniques (with accuracies in the order of 1 mm) could measure low level opening movements.

6.3.3. Previous experience of mining near the reservoirs

The longwalls at the Dendrobium 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 Dendrobium Mine. The Upper Cordeaux No. 2 reservoir is shown in Drawing No. MSEC1181-01.

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 Dendrobium 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).

6.3.4. Impact assessments for the reservoirs

The Cordeaux Dam wall is located more than 4 km from the proposed longwalls in Area 5. At this distance, the dam wall is not predicted to experience measurable conventional, far-field or valley-related effects. It is considered unlikely, therefore, that adverse impacts would occur to the Cordeaux Dam wall due to the mining of the proposed longwalls.

The Avon Dam wall is located 1000 m west of LW505, at its closest point to the proposed longwalls in Area 5. At this distance, the dam wall is not predicted to experience measurable vertical subsidence or the associated conventional tilt, curvature or strain.

The Avon Dam wall could experience valley closure movements in the order 3 mm to 10 mm or valley opening movements in the order of 3 mm to 5 mm. These movements would develop gradually as the proposed longwalls in Area 5 are progressively mined from the southernmost to the northernmost longwall. This allows the subsidence effects at the dam wall to be measured and reviewed as the mining progresses towards it.

The previously extracted longwalls in Areas 1 and 2 at the Dendrobium 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.

The potential impacts on the Avon Dam wall could be managed with the implementation of monitoring and an adaptive management approach. The individual longwalls in Area 5 will be mined in sequence from south to north (i.e. towards the Avon Dam wall).

6.3.5. Recommendations for the reservoirs

It is recommended that IMC consult with the WaterNSW and DSN to develop the appropriate monitoring and management strategies of the reservoirs and dam walls. These strategies could include a detailed monitoring program and TARP.

It is also recommended that a detailed assessment of the dam walls be carried out by a suitably qualified Dams Engineer to establish the appropriate monitoring, triggers and action responses. It is considered appropriate that the detailed assessment and development of the monitoring and management plans are developed as part of the Extraction Plan applications.

6.4. Aboriginal heritage sites

6.4.1. Descriptions of the Aboriginal heritage sites

The locations of the Aboriginal heritage sites are shown in Drawing No. MSEC1181-15. The details of the heritage sites have been provided by Niche (2022c).

There are six Aboriginal heritage sites that have been identified directly above the proposed longwalls and 12 sites located outside the mining area and within the Study Area based on the 35° angle of draw. There are also 13 additional sites identified within the Study Area based on the 600 m boundary which could experience valley-related movements and could be sensitive to these effects and, therefore, have been included in the assessments.

The details of the Aboriginal heritage sites located within the Study Area based on the 600 m boundary is provided in Table D.03, in Appendix D. There is a total of 31 sites that are located within this boundary. A summary of Aboriginal heritage sites within the Study Area is provided in Table 6.5.

Table 6.5 Aboriginal heritage sites identified within the Study Area

Type	Number of sites located directly above the proposed longwalls	Number of sites located outside the mining area and within the 35° angle of draw	Number of sites located outside the 35° angle of draw and within the 600 m boundary
Isolated finds	0	0	1
Grinding groove sites	3	7	3
Rock shelters	3	5	9
Total	**6**	**12**	**13**

In comparison for the Previous Layout, there were 20 Aboriginal heritage sites located directly above the longwalls (15 in Area 5 and 5 in Area 6), an additional 23 sites located outside the previous longwalls and within a 35° angle of draw (13 in Area 5 and 10 in Area 6) and an additional 13 sites located outside the angle of draw and within the 600 m boundary (9 in Area 5 and 4 in Area 6).

The Revised Layout has therefore resulted in a reduction in the number of Aboriginal heritage sites located above the longwalls by 14 (i.e. 20 to 6 sites). Sites 52-2-1567, 52-2-1759, 52-2-1779, 52-2-1780, 52-2-4465, 52-2-4466, 52-2-4467, 52-2-4468 and Dendrobium ACHA Shelter-2 were located above the longwalls in Area 5, based on the Previous Layout, whereas they are now located outside the modified longwalls. Also, Sites 52-2-1456, 52-2-1464, 52-2-1465, 52-2-1466 and 52-2-4469 were previously located above the longwalls in Area 6.

The Revised Layout has also resulted in a reduction in the number of sites located outside the longwalls and within the 35° angle of draw by 11 (i.e. 23 to 12 sites). The number of sites located outside the angle of draw and within the 600 m boundary does not change (i.e. 13 for both layouts).

Further details on the Aboriginal heritage sites are provided in the report by Niche (2022c).

6.4.2. Predictions for the Aboriginal heritage sites

The maximum predicted total conventional subsidence effects 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 6.6. The values are the maximum predicted values within 20 m of the identified locations of each of the sites.

Table 6.6 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	1550	11	0.25	0.17
Rock shelters	1750	15	0.25	0.30

The isolated find is predicted to experience less than 20 mm vertical subsidence. While 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 11 mm/m (i.e. 1.1 % or 1 in 90). The maximum predicted curvatures for these sites are 0.25 km^{-1} hogging and 0.17 km^{-1} sagging, which represent minimum radii of curvatures of 4 km and 6 km, respectively.

The maximum predicted tilt for the rock shelters is 15 mm/m (i.e. 1.5 % or 1 in 67). The maximum predicted curvatures for these sites are 0.25 km^{-1} hogging and 0.30 km^{-1} sagging, which represent minimum radii of curvatures of 4 km and 3.3 km, respectively.

The maximum predicted conventional strains for the Aboriginal heritage sites located directly above the proposed longwalls, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 4.0 mm/m tensile and 4.5 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 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 grinding groove sites and rock shelters are located along the alignments of streams and, therefore, they 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 6.7. The values provided in this table are the predicted upsidence and closure effects along the streams at the site locations.

Table 6.7 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	200	300
Rock shelters	450	700

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.

6.4.3. Comparison of the predictions for the Aboriginal heritage sites

A comparison of the maximum predicted total conventional subsidence effects for the Aboriginal heritage sites, based on the Previous Layout (MSEC856) and Revised Layout (MSEC1181), is provided in Table 6.8.

Table 6.8 Comparison of the maximum predicted subsidence effects for the Aboriginal heritage sites in Area 5

Layout	Mining Area	Type	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})
Previous Layout (MSEC856)	Area 5	Isolated find	< 20	< 0.5	< 0.01	< 0.01
		Grinding groove sites	1250	13	0.30	0.25
		Rock shelters	1650	20	0.60	0.45
	Area 6	Grinding groove sites	2150	16	0.25	0.40
		Rock shelters	875	6	0.13	0.09
Revised Layout (MSEC1181)	Area 5	Isolated find	< 20	< 0.5	< 0.01	< 0.01
		Grinding groove sites	1550	11	0.25	0.17
		Rock shelters	1750	15	0.25	0.30

The isolated find is predicted to experience less than 20 mm vertical subsidence based on both the Previous Layout and Revised Layout. This site is located well outside the mining area for Area 5 based on both layouts.

The maximum predicted vertical subsidence movements for the grinding groove sites and rock shelters, based on the Revised Layout, are greater than the maximum predicted values based on the Previous Layout in Area 5. However, the potential for impacts on these sites do not result from absolute vertical subsidence, but rather from the differential movements represented by tilt, curvature and strain. Also, the predicted vertical subsidence only increases at four of these sites (Refs. 52-2-1592, 52-2-1747, 52-2-1758 and 52-2-3955), whereas the predicted values decrease or do not change at the remaining 26 sites in Area 5.

The maximum predicted tilts for the grinding groove sites and rock shelters, based on the Revised Layout, are less than the maximum predicted values based on the Previous Layout in Area 5. While the predicted vertical tilt increases at one site (52-2-1747), they decrease or do not change at the remining 28 sites in Area 5.

The maximum predicted hogging and sagging curvatures for the grinding groove sites and rock shelters, based on the Revised Layout, are less than the maximum predicted values based on the Previous Layout. Also the number of sites located directly above the mining area has also reduced. Hence, the potential impacts on the grinding groove sites and rock shelters, based on the Revised Layout, are less than those assessed based on the Previous Layout.

The changes in the predicted subsidence effects for the individual sites occur due to the re-orientation of the longwalls changes the position of the sites relative to the longwall edges.

6.4.4. 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 (2022c).

Isolated find

The isolated find (Site 52-2-3204) is located approximately 500 m north-west of LW505. At this distance, this site is not expected to experience measurable conventional subsidence effects. The site could experience small far-field horizontal movements, in the order of 50 mm to 100 mm. However, it is not expected 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 13 grinding groove sites that have been identified within the Study Area. These sites are formed in exposed bedrock platforms along the alignments of the streams. The areas of the platforms range between approximately 4 m by 2 m through to 40 m by 12 m.

Three grinding groove sites are located directly above the proposed longwalls, being Sites 52-2-1566 (above LW502), 52-2-1592 (above LW505) and 52-2-1758 (above LW501). These sites are predicted to experience up to 1550 mm vertical subsidence, 11 mm/m tilt, 0.25 km^{-1} hogging curvature and 0.17 km^{-1} sagging curvature.

The mining of the proposed longwalls will result in fracturing of the exposed bedrock along the streams. The fracturing is expected to occur predominately 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 mining-induced fracturing causing adverse impacts on the three grinding groove sites located directly above the proposed longwalls (i.e. Sites 52-2-1566, 52-2-1592 and 52-2-1758) has been assessed as *unlikely* (i.e. less than 10 %) for each of these sites.

Seven grinding groove sites are located outside the proposed longwalls and within the 35° angle of draw, being Sites 52-2-1568, 52-2-1729, 52-2-1730, 52-2-1779, 52-2-1781, 52-2-4465 and 52-2-4468. These sites are located at distances ranging between 30 m and 230 m outside the mining area. At these distances, the sites are predicted to typically experience vertical subsidence of less than 20 mm, apart from Site 52-2-1568 which is predicted to experience vertical subsidence of 40 mm.

While the grinding groove sites located outside the proposed longwalls and within the 35° angle of draw could experience low-levels of vertical subsidence, they are not expected to experience measurable conventional tilts, curvatures or strains. However, these sites could experience compressive strains due to valley closure effects in the order of 2 mm/m.

The potential for mining-induced fracturing causing adverse impacts on the seven grinding groove sites located outside the proposed longwalls and within the 35° angle of draw (Sites 52-2-1568, 52-2-1729, 52-2-1730, 52-2-1779, 52-2-1781, 52-2-4465 and 52-2-4468) has been assessed as *rare* (i.e. less than 5 %) for each of these sites.

The remaining three grinding groove sites are located outside the 35° angle of draw, being Sites 52-2-4466, 52-2-4467 and Dendrobium ACHA AGG-5. These sites are located at distances ranging between 270 m and 510 m outside the mining area. At these distances, the sites are not predicted to experience measurable conventional subsidence effects. However, they could experience compressive strains due to valley closure effects in the order of 0.5 mm/m.

The potential for mining-induced fracturing causing adverse impacts on the three grinding groove sites located outside the 35° angle of draw (Sites 52-2-4466, 52-2-4467 and Dendrobium ACHA AGG-5) has been assessed as *very rare* (i.e. less than 1 %) for each of these sites.

Further assessments of the potential impacts on the grinding groove sites are provided by Niche (2022c).

Rock shelters

There are 17 rock shelters that have been identified within the Study Area. These sites 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.

Three of the rock shelters are located directly above the proposed longwalls, being Sites 52-2-1747 (above LW502), 52-2-1782 (above LW509) and 52-2-3955 (above LW505). These sites are predicted to experience up to 1750 mm vertical subsidence, 15 mm/m tilt, 0.25 km^{-1} hogging curvature and 0.30 km^{-1} sagging curvature.

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 three rock shelters that are 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 rock mass, 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 approximately 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 mining of these longwalls.

The potential for mining-induced fracturing causing adverse impacts on the two rock shelters located directly above the proposed longwalls (i.e. Sites 52-2-1747, 52-2-1782 and 52-2-3955) has been assessed as *unlikely* (i.e. less than 10 %) for each of these sites.

Five rock shelters are located outside the proposed longwalls and within the 35° angle of draw, being Sites 52-2-1756, 52-2-1757, 52-2-1759, 52-2-1780 and Dendrobium ACHA Shelter-4. These sites are located at distances ranging between 30 m and 210 m outside the mining area. At these distances, the sites are predicted to typically experience vertical subsidence of less than 20 mm, apart from Site 52-2-1759 which is predicted to experience vertical subsidence of 30 mm.

While the rock shelters located outside the proposed longwalls and within the 35° angle of draw could experience low-levels of vertical subsidence, they are not expected to experience measurable 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.

The potential for mining-induced fracturing causing adverse impacts on the five rock shelters located outside the proposed longwalls and within the 35° angle of draw (Sites 52-2-1756, 52-2-1757, 52-2-1759, 52-2-1780 and Dendrobium ACHA Shelter-4) has been assessed as *rare* (i.e. less than 5 %) for each of these sites.

The remaining nine rock shelters are located outside the 35° angle of draw, being Sites 52-2-1567, 52-2-1570, 52-2-1591, 52-2-1752, 52-2-1753, 52-2-1754, 52-2-1755, 52-2-1761 and Dendrobium ACHA Shelter-3. These sites are located at distances ranging between 230 m and 470 m outside the mining area. At these distances, the sites are not predicted to experience measurable conventional subsidence or valley-related effects.

The potential for mining-induced fracturing causing adverse impacts on the nine rock shelters located outside the 35° angle of draw (Sites 52-2-1567, 52-2-1570, 52-2-1591, 52-2-1752, 52-2-1753, 52-2-1754, 52-2-1755, 52-2-1761 and Dendrobium ACHA Shelter-3) has been assessed as *very rare* (i.e. less than 1 %) for each of these sites.

Further assessments of the potential impacts on the rock shelters are provided by Niche (2022c).

6.5. Historical heritage sites

The Avon and Cordeaux Dams are State significant heritage items that are listed on the NSW State Heritage Register (Niche, 2022b). The descriptions, predictions and impact assessments for the reservoirs, dam walls and associated infrastructure are provided in Section 6.3.

6.6. Survey control marks

The locations of the survey control marks are shown in Drawing No. MSEC1181-15. 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 effects. A summary of the maximum predicted conventional subsidence effects 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 vertical 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 3.4 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 IMC and Spatial Services will be required to ensure that these survey control marks are reinstated at the appropriate time, as required.

6.7. Known future developments

WaterNSW has advised IMC 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 IMC in February 2018 (WaterNSW, 2018) and these have been reproduced in Fig. 6.15. 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.

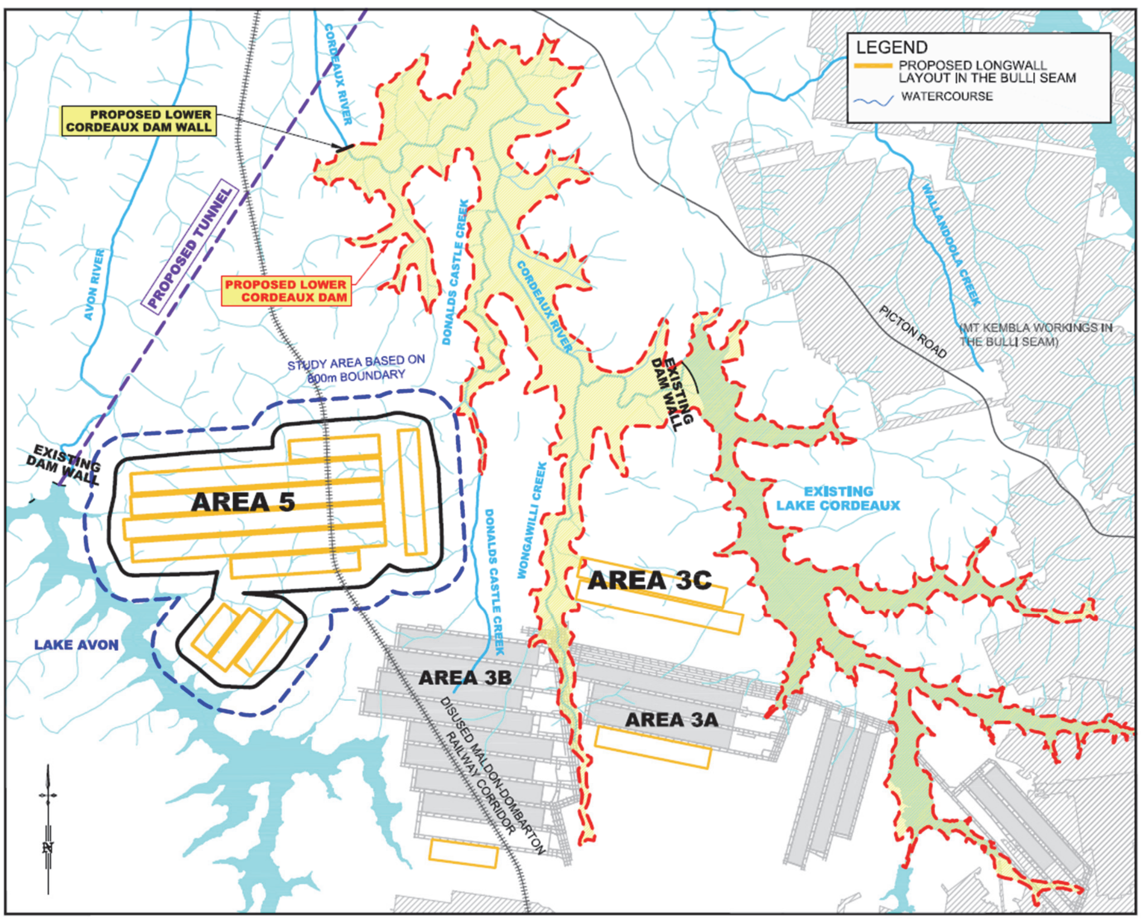

Fig. 6.15 Future WaterNSW infrastructure

The potential Lower Cordeaux Reservoir is shown by the yellow hatching in Fig. 6.15. The potential reservoir FSL extends along the Cordeaux River, Donalds Castle Creek, Wongawilli Creek and their tributaries. The potential reservoir is located outside the Study Area based on the 600 m boundary. At this distance, it is unlikely that physical impacts (i.e. surface cracking or rock fracturing) would occur within the potential reservoir.

The potential Lower Cordeaux Dam Wall is located on the Cordeaux River more than 4 km north of the proposed longwalls in Area 5. At this distance, 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. 6.15. The potential tunnel is located more than 800 m north-west of the proposed longwalls in Area 5; however, the final alignment would be subject to any future planning. At this distance, the potential tunnel is not expected to experience measurable far-field horizontal or valley-related effects.

Subject to the assessment and approval of any future infrastructure, it is recommended that WaterNSW develop management strategies, in consultation with IMC, to manage the potential impacts.

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. While 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

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to mining in Area 5

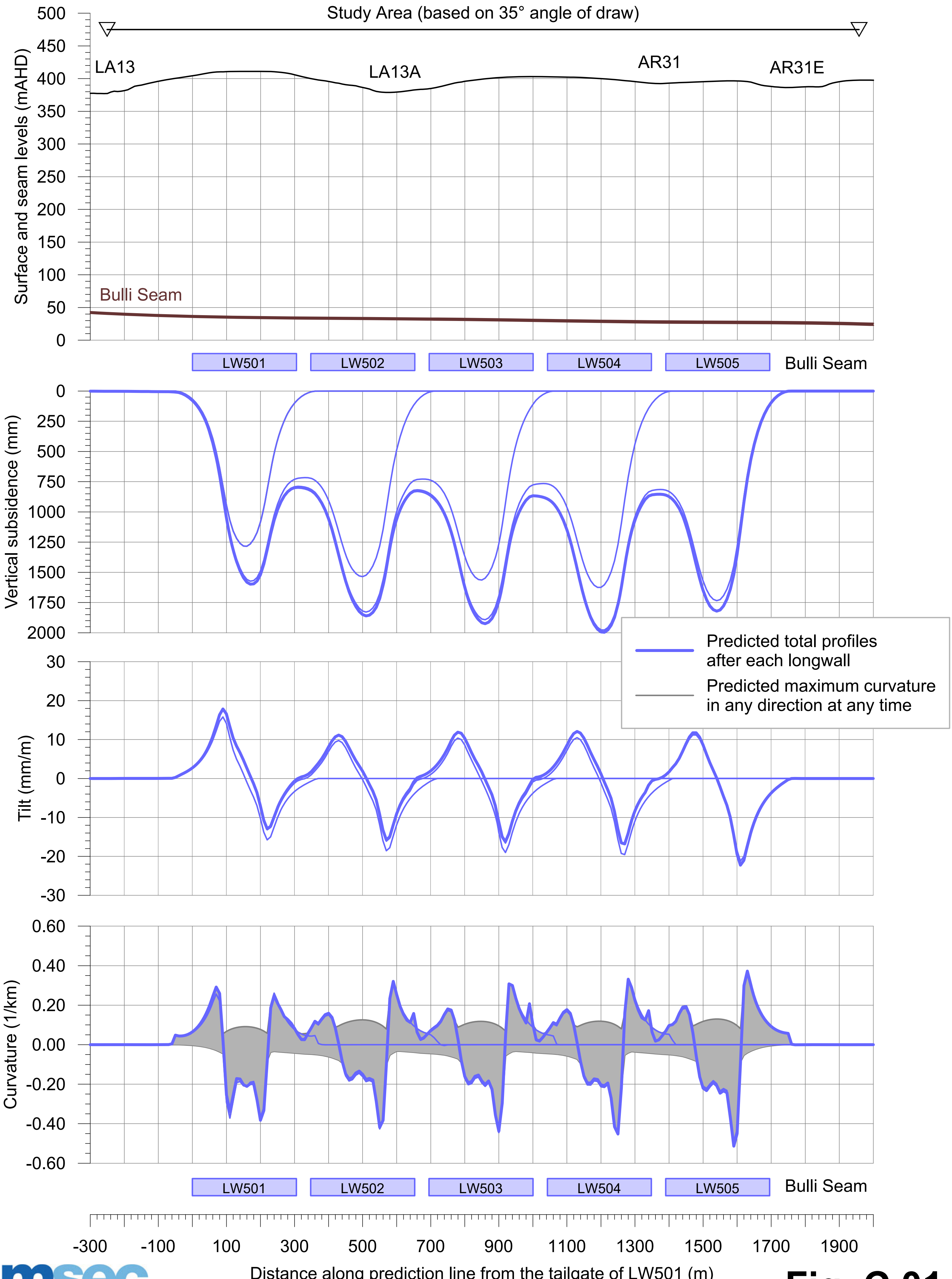

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Fig. C.01

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to mining in Area 5

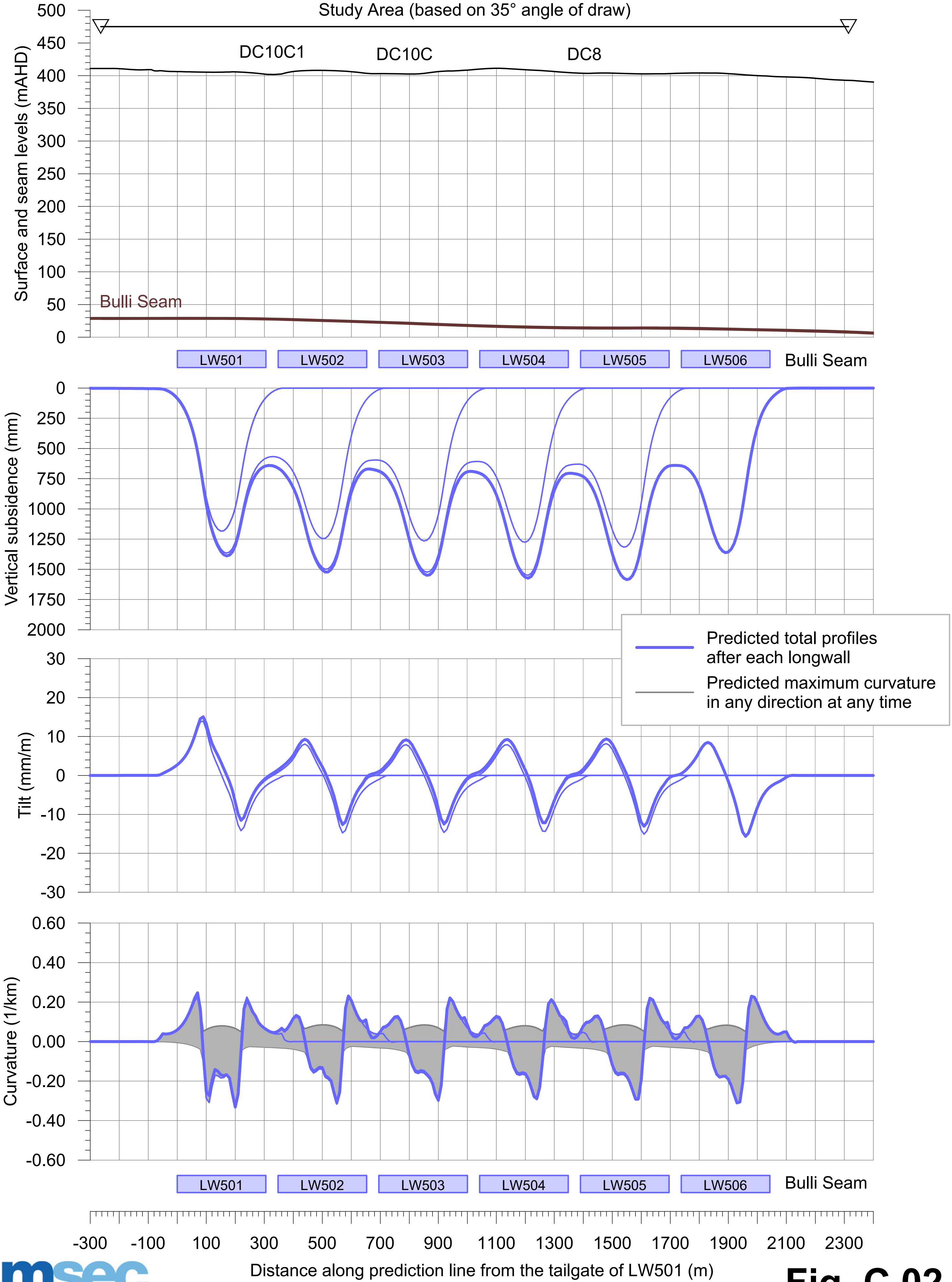

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Fig. C.02

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 3 due to mining in Area 5

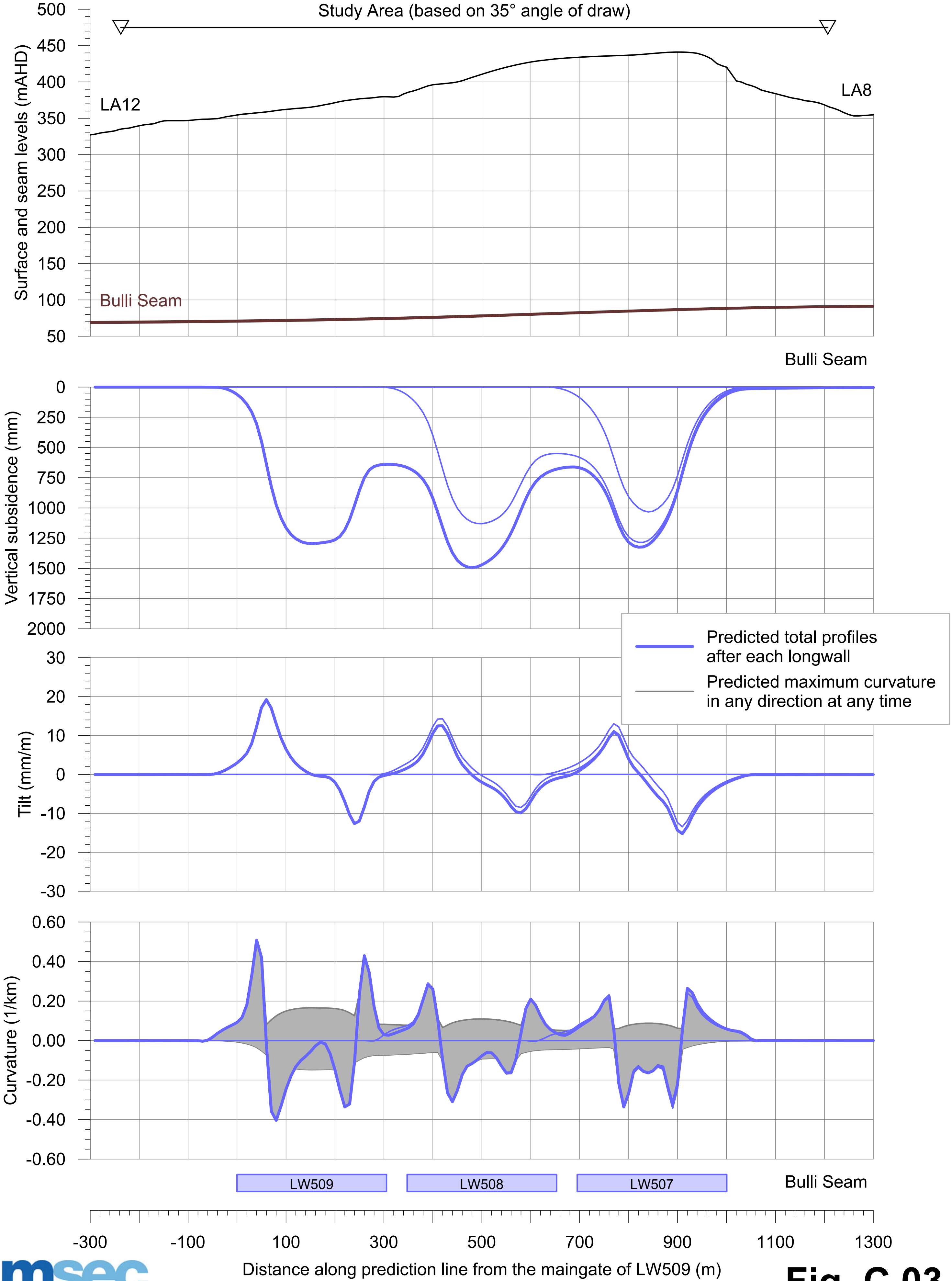

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Fig. C.03

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 4 due to mining in Area 5

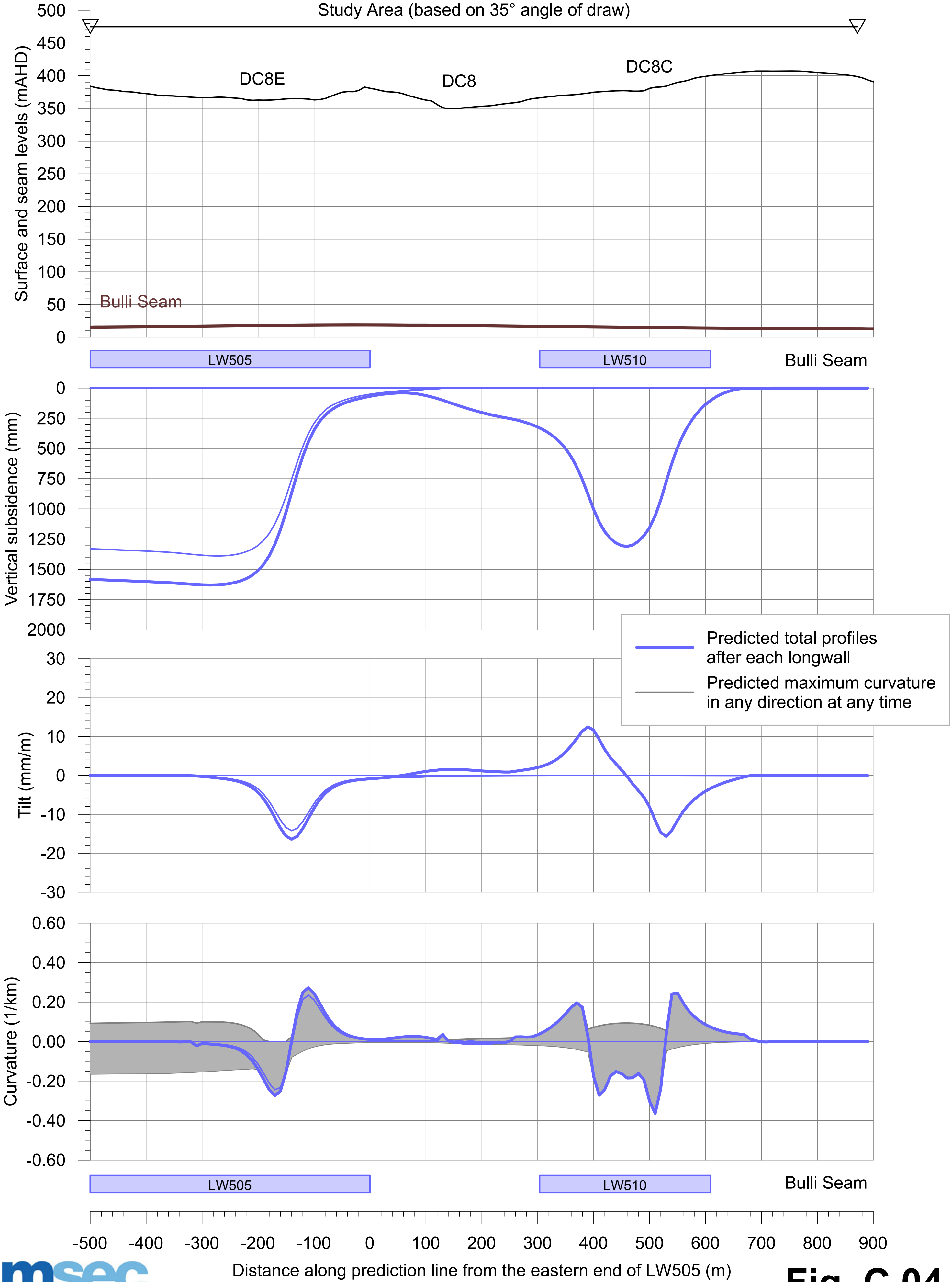

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Fig. C.04

Predicted profiles of vertical subsidence, upsidence and closure along stream AR19 due to mining in Area 5

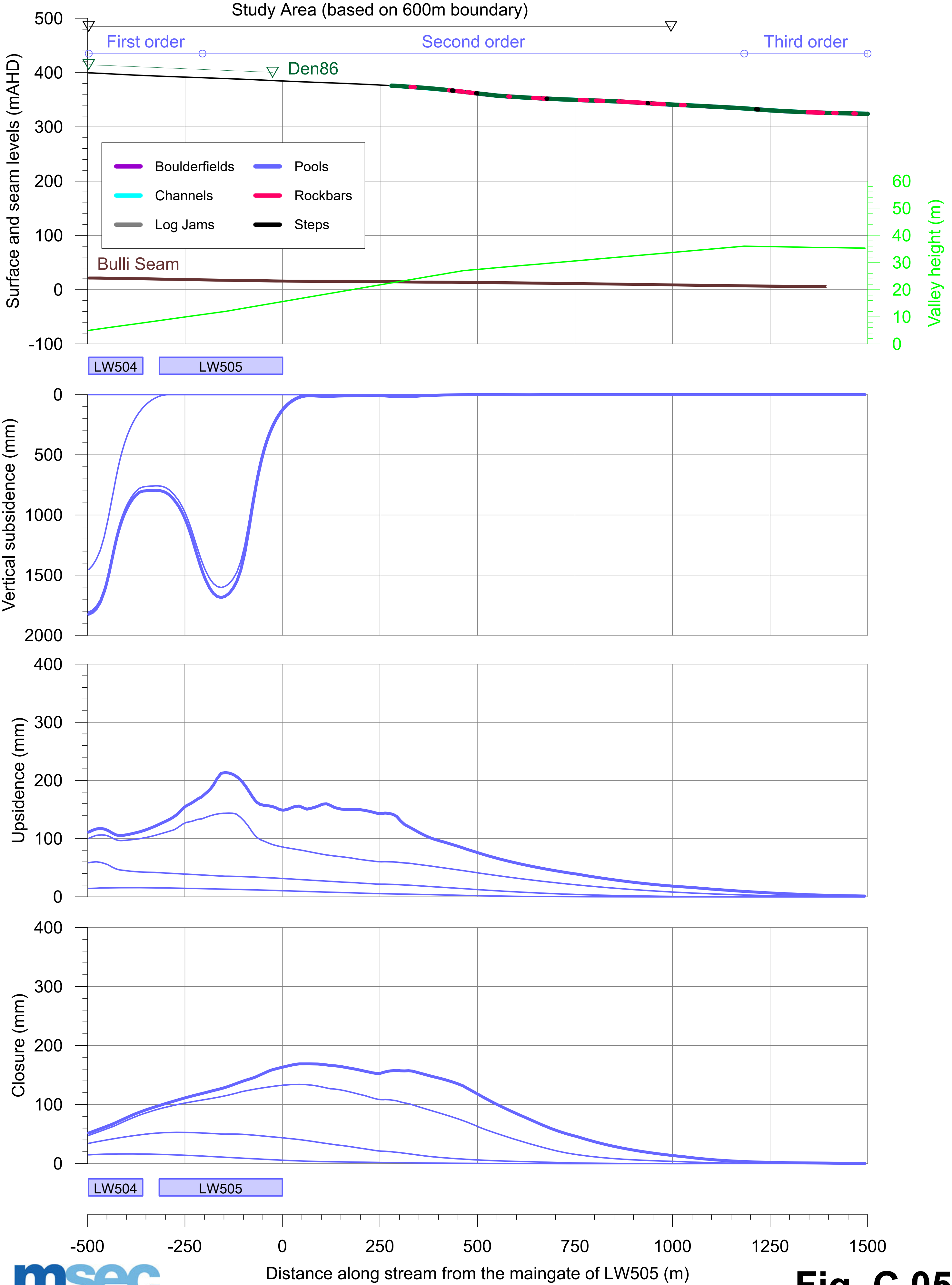

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Fig. C.05

Predicted profiles of vertical subsidence, upsidence and closure along stream AR31 due to mining in Area 5

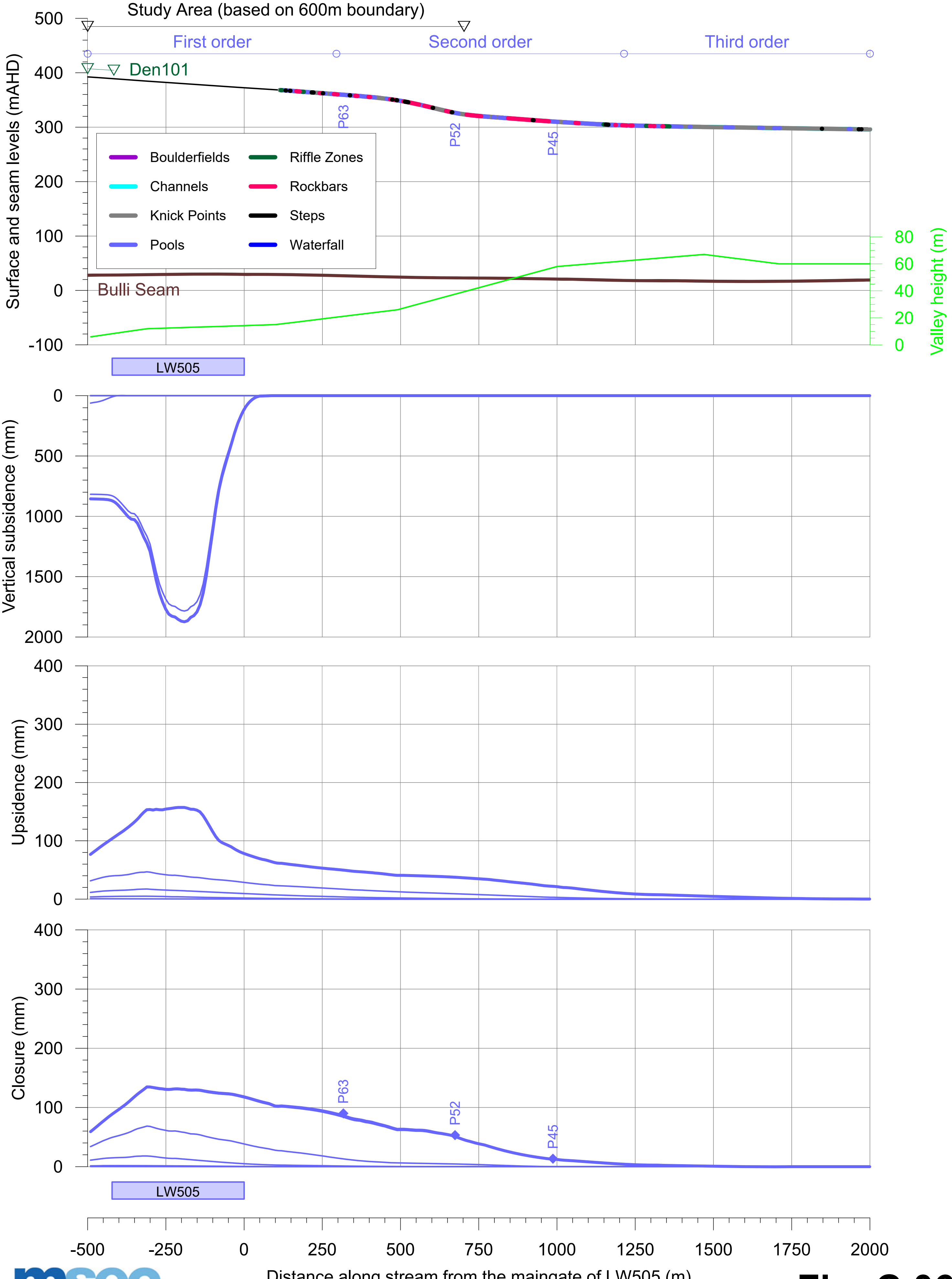

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Fig. C.06

Predicted profiles of vertical subsidence, upsidence and closure along stream AR32 due to mining in Area 5

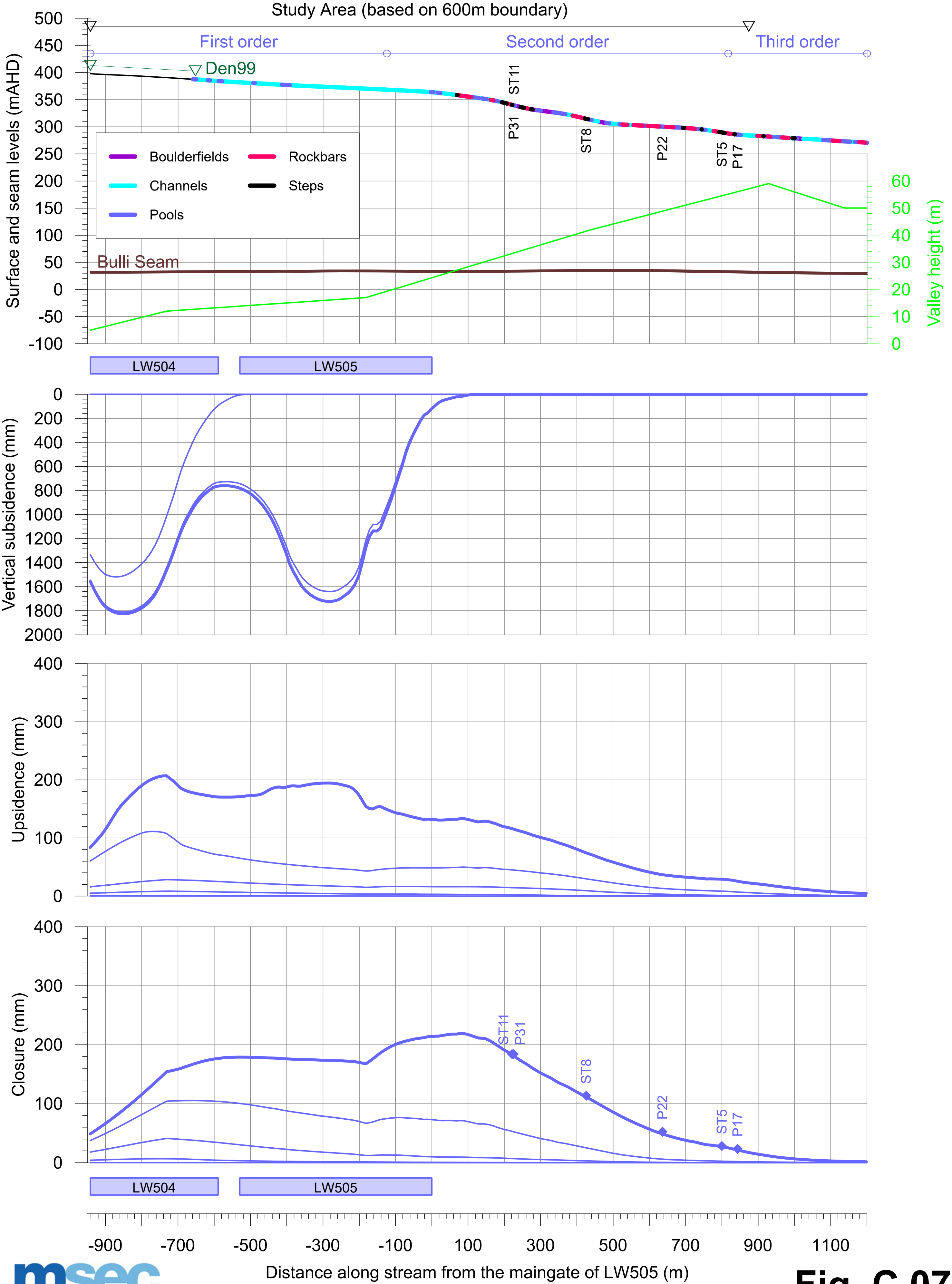

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Fig. C.07

Predicted profiles of vertical subsidence, upsidence and closure along stream DC8 due to mining in Area 5

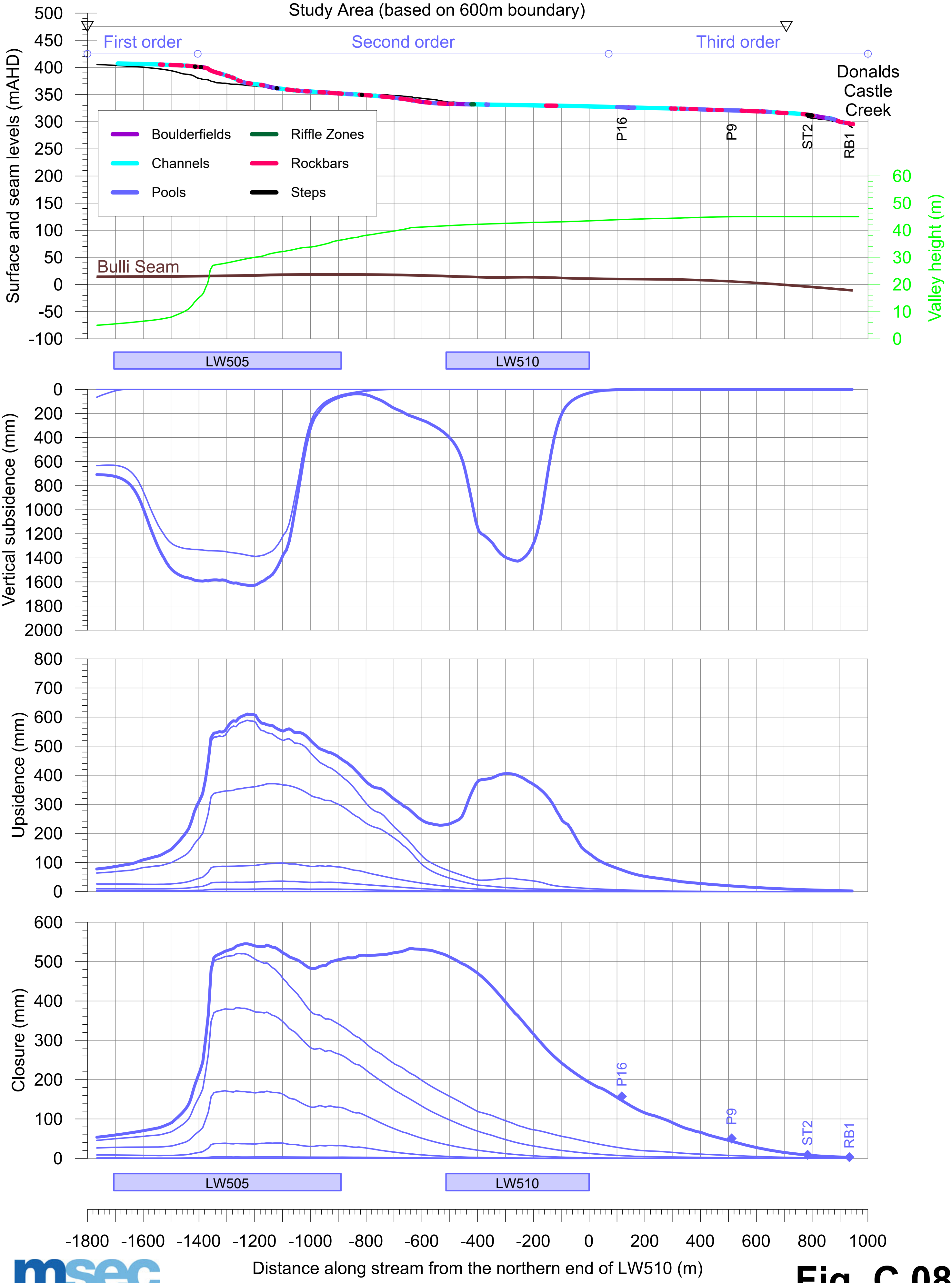

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Fig. C.08

Predicted profiles of vertical subsidence, upsidence and closure along stream DC9 due to mining in Area 5

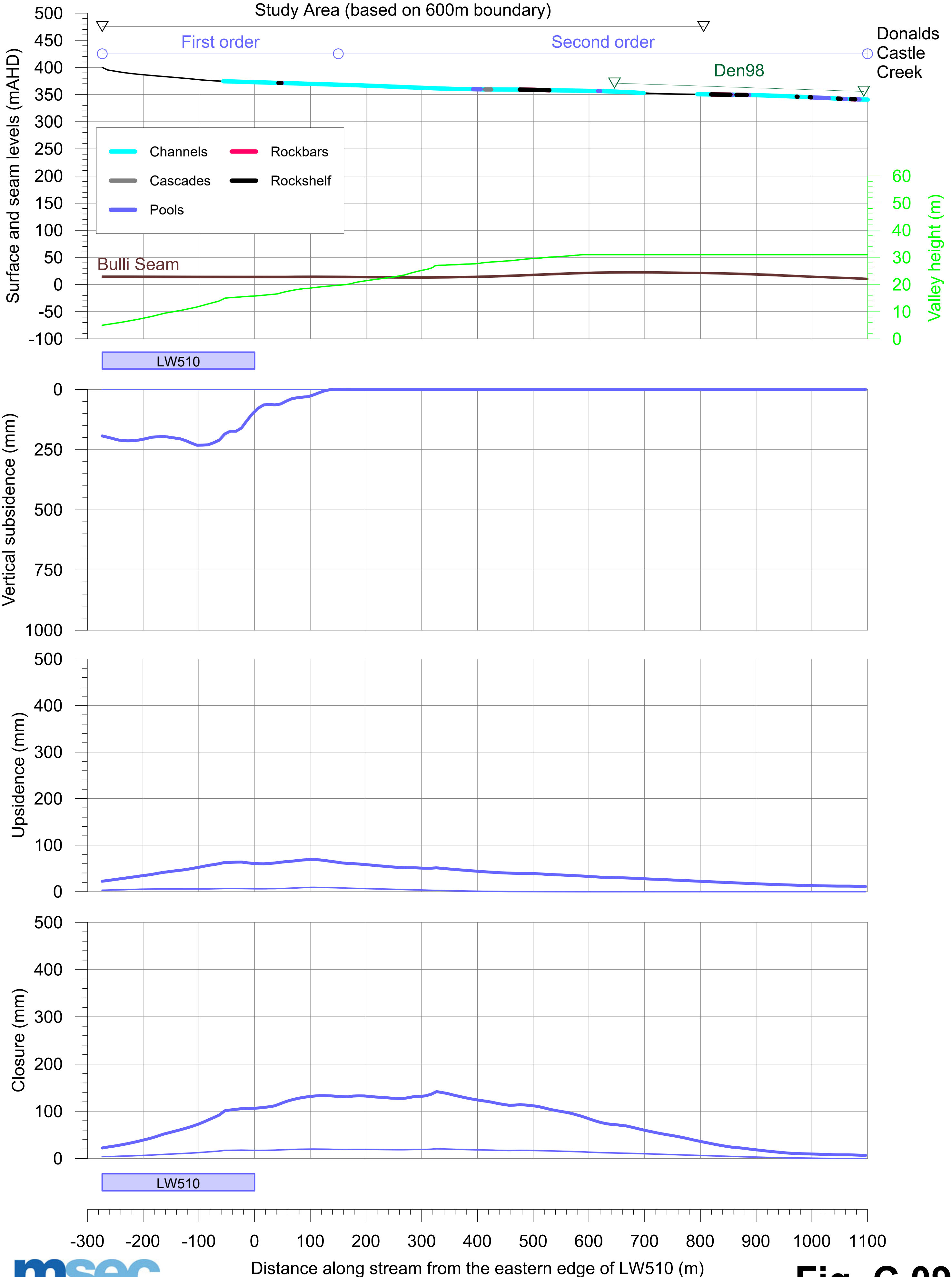

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Fig. C.09

Predicted profiles of vertical subsidence, upsidence and closure along stream DC10(C) due to mining in Area 5

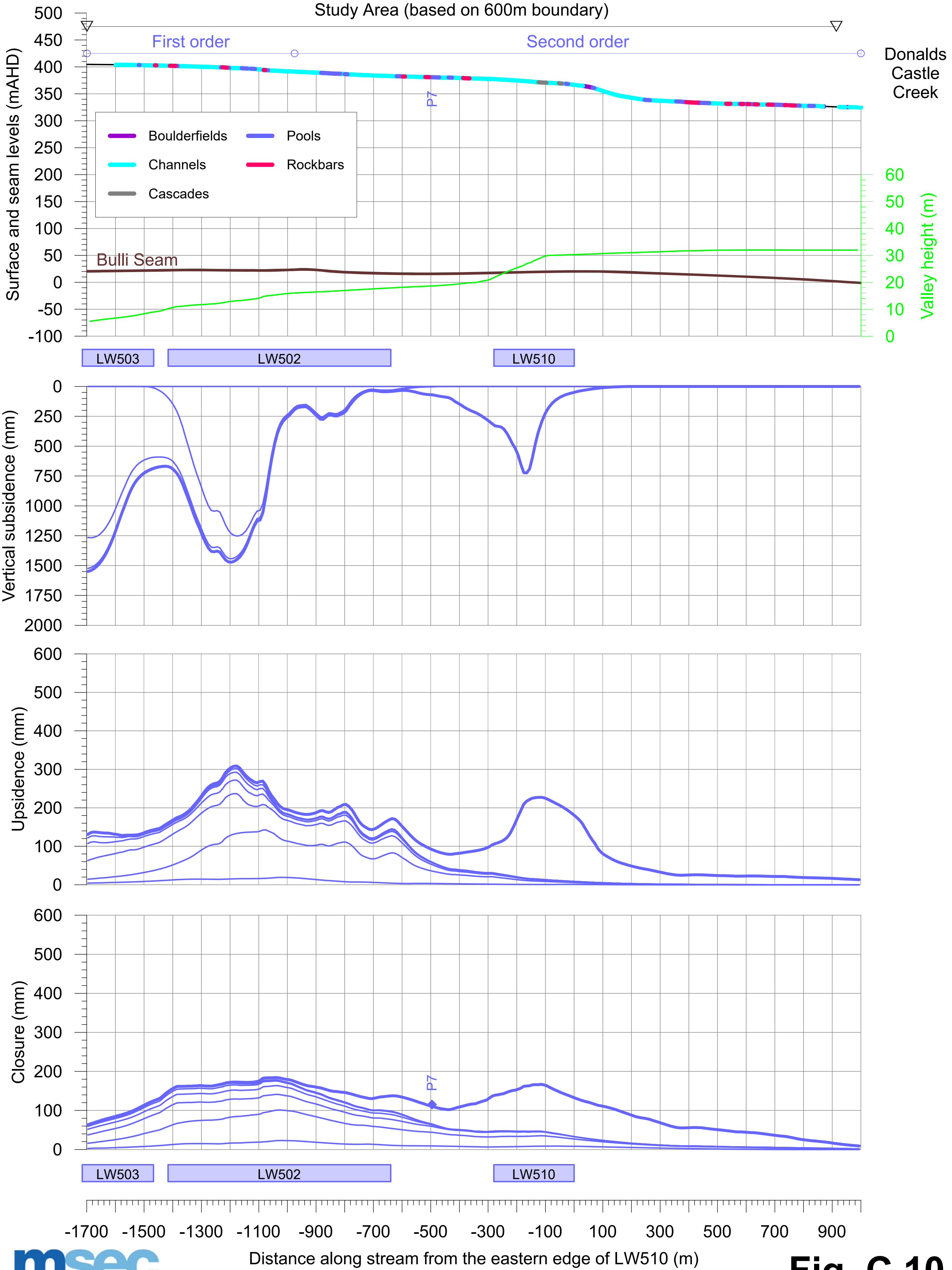

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Fig. C.10

Predicted profiles of vertical subsidence, upsidence and closure along stream LA12 due to mining in Area 5

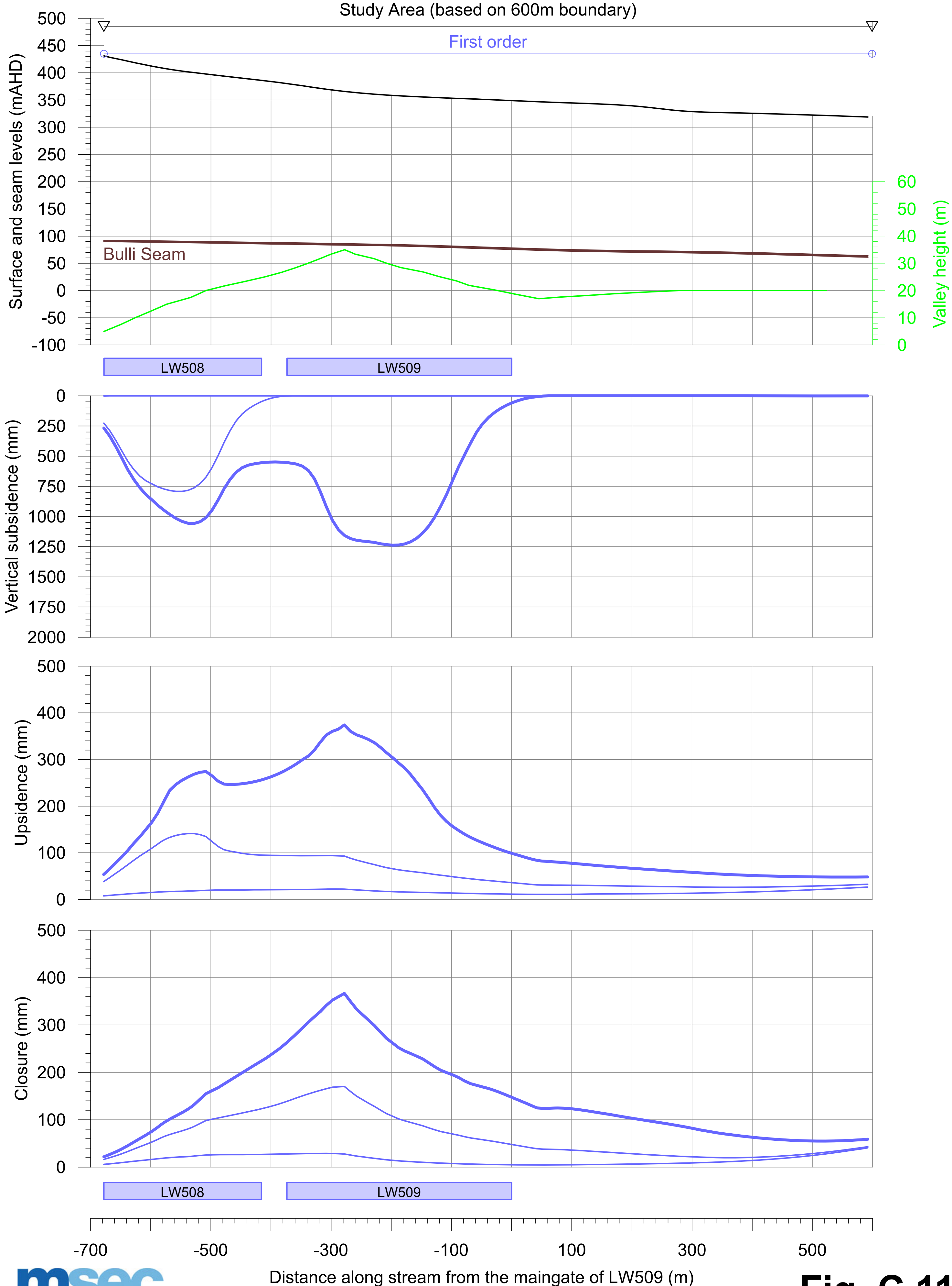

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Fig. C.11

Predicted profiles of vertical subsidence, upsidence and closure along stream LA13 due to mining in Area 5

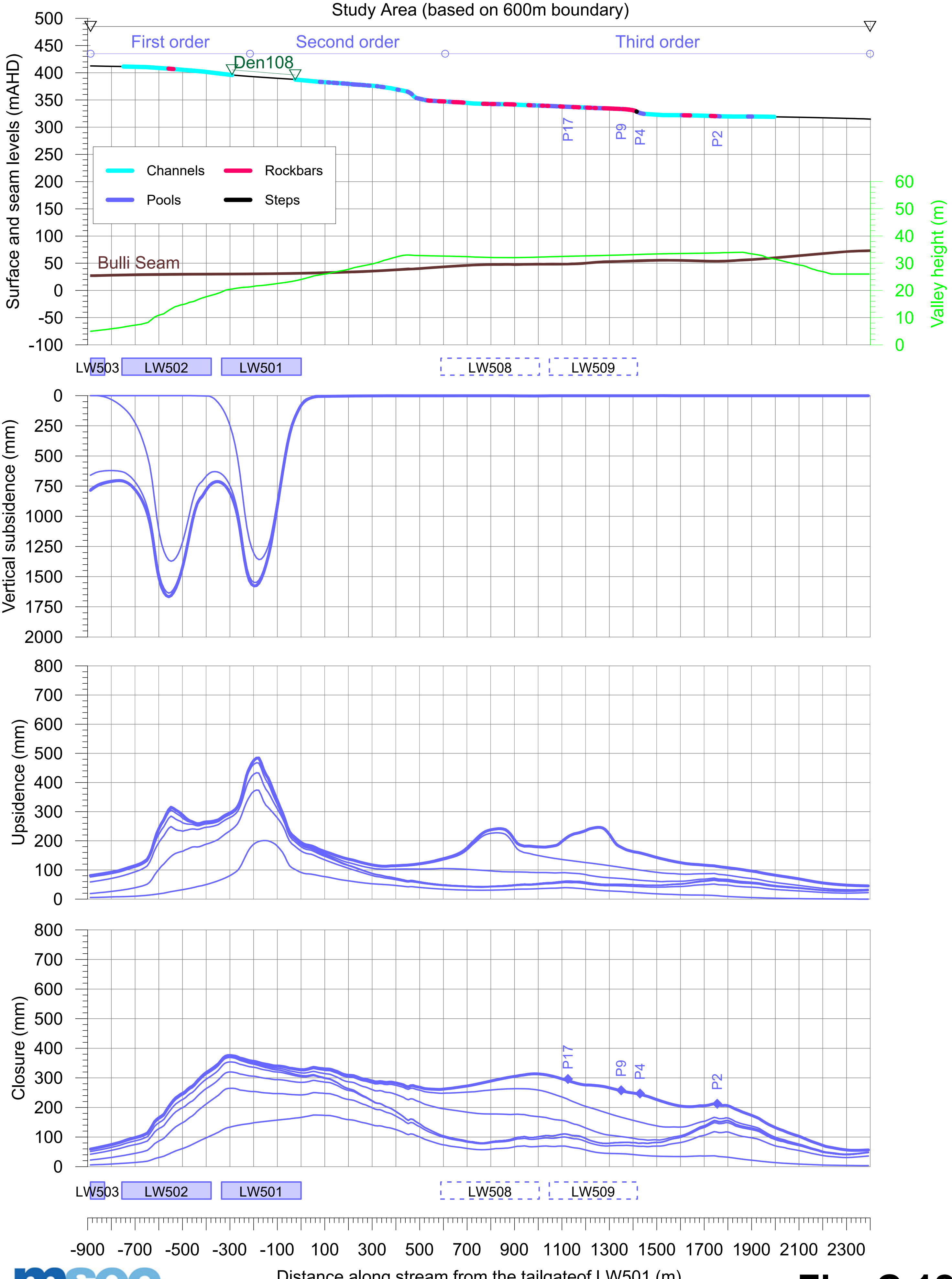

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Fig. C.12

Predicted profiles of vertical subsidence, upsidence and closure along stream LA13A due to mining in Area 5

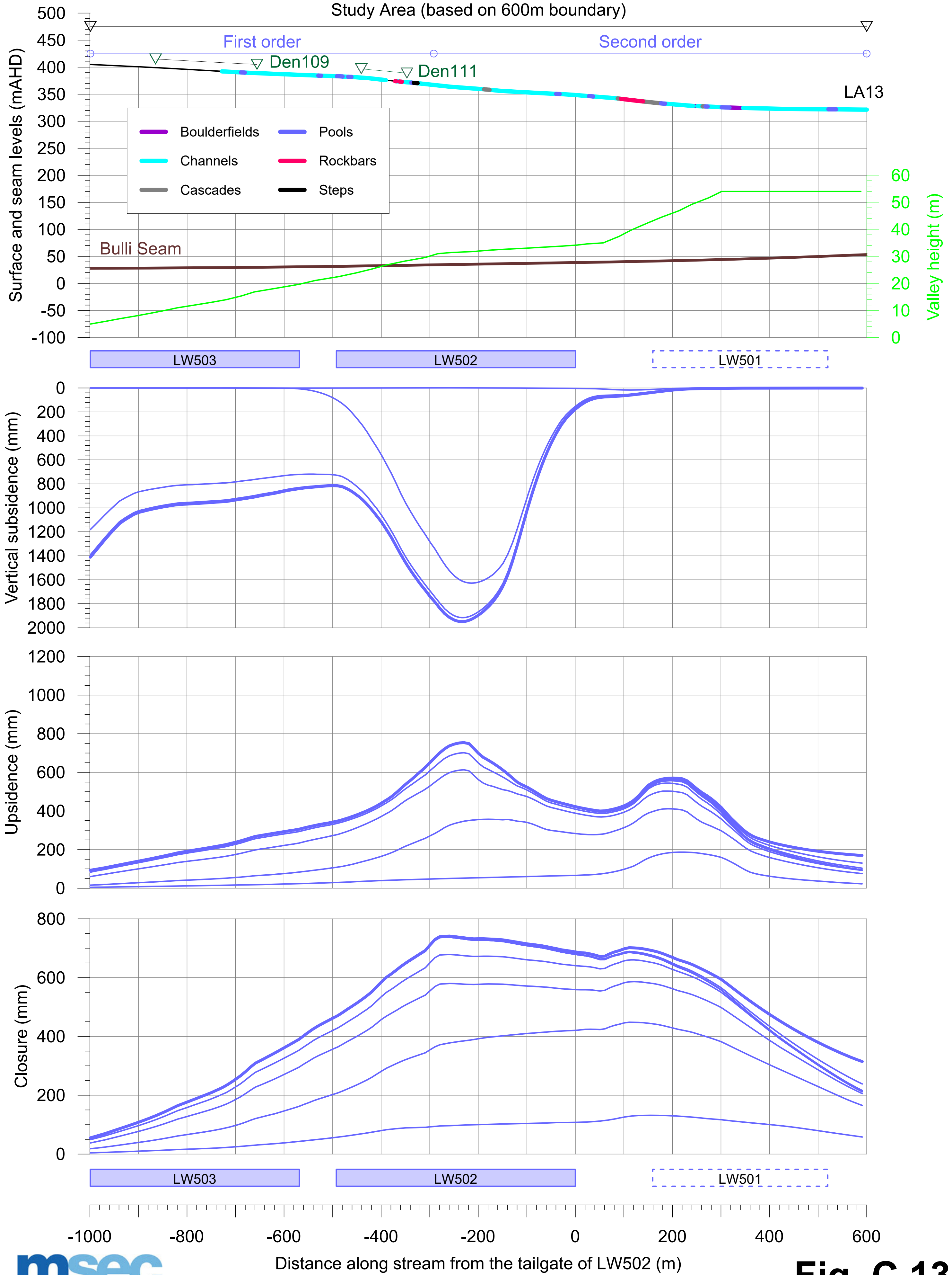

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Fig. C.13

Predicted profiles of vertical subsidence, tilt and curvature along the disused railway corridor due to mining in Areas 3B and 5

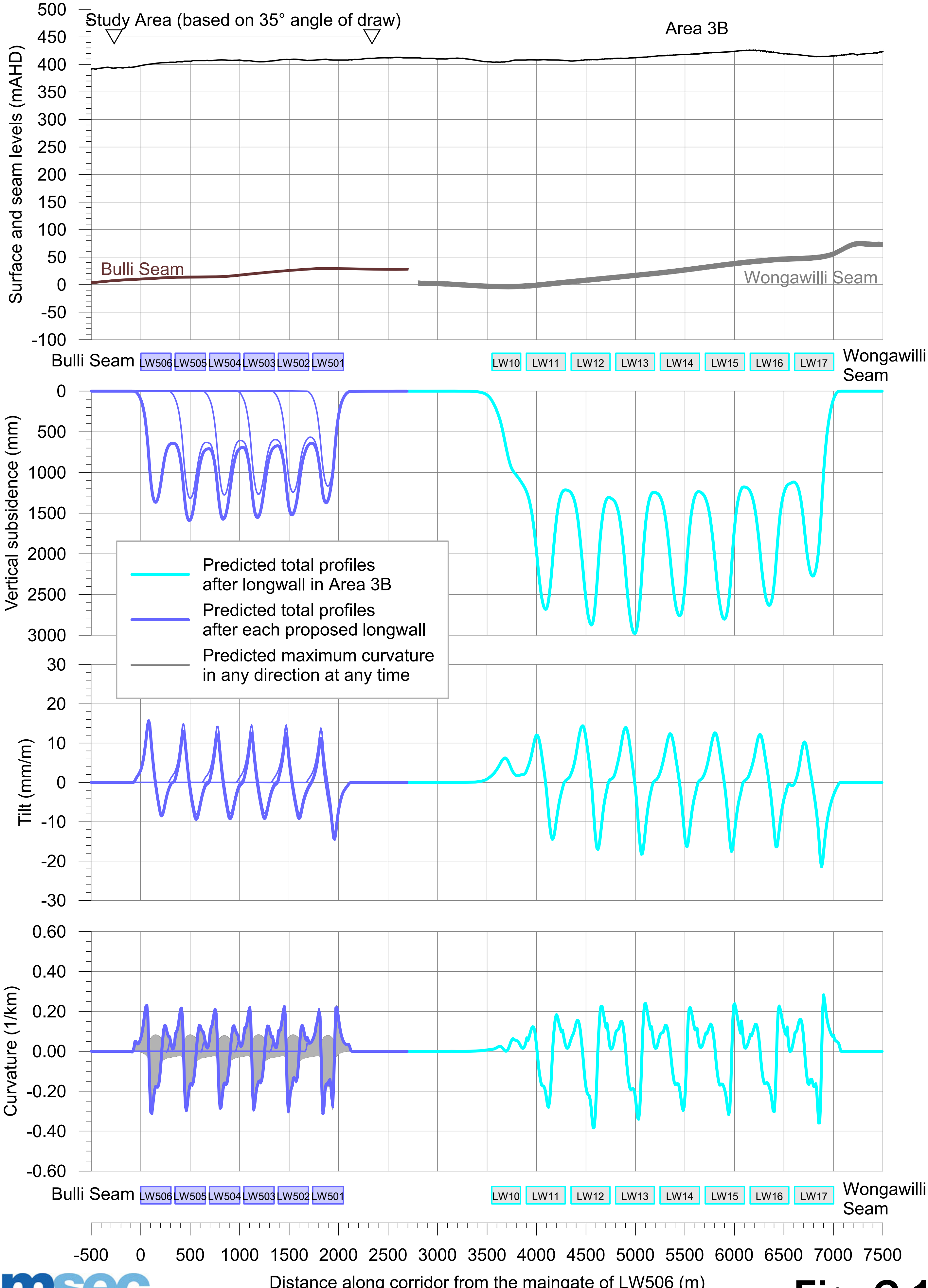

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Fig. C.14

APPENDIX D. TABLES

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

Cliff Ref.	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)
AR32-CF1	25	10	175 m north of LW505	< 20	< 0.5	< 0.01	< 0.01
DC8-CF1	20	10	Directly above LW506	1600	4.0	0.10	0.20
DC8-CF2	40	15	Directly above LW506	1450	16.0	0.12	0.35
DC8-CF3	25	15	Directly above LW506	1300	16.0	0.25	0.30
DC8-CF4	150	20	Directly above LW506	1000	16.0	0.25	0.25
DC8-CF5	40	10	120 m west of LW510	250	1.5	0.02	0.02
DC8-CF6	90	10	Directly above LW510	1350	13.0	0.25	0.25
DC8-CF7	25	10	80 m east of LW510	< 20	< 0.5	< 0.01	< 0.01
DC8D-CF1	20	10	90 m east of LW504	100	1.0	0.02	< 0.01
LA10-CF1	35	13	170 m south-west o LW509	< 20	< 0.5	< 0.01	< 0.01
LA10-CF2	45	14	180 m south-west o LW509	< 20	< 0.5	< 0.01	< 0.01
LA13A-CF1	35	10	160 m south of LW502	< 20	< 0.5	< 0.01	< 0.01
LA13A-CF2	35	12	130 m west of LW501	< 20	< 0.5	< 0.01	< 0.01
LA13A-CF3	100	12	180 m west of LW501	< 20	< 0.5	< 0.01	< 0.01
LA13A-CF4	45	11	230 m west of LW501	< 20	< 0.5	< 0.01	< 0.01
LA13A-CF5	30	12	265 m west of LW501	< 20	< 0.5	< 0.01	< 0.01
LA13A-CF6	30	10	255 m south of LW502	< 20	< 0.5	< 0.01	< 0.01
LA13-CF1	20	10	80 m north of LW509	< 20	< 0.5	< 0.01	< 0.01
LA13-CF2	25	11	135 m north of LW509	< 20	< 0.5	< 0.01	< 0.01
LA14-CF1	25	12	Directly above LW502	1450	20.0	0.35	0.45
LA14-CF2	75	12	Directly above LW502	950	20.0	0.35	0.10
LA14-CF3	25	10	Immediately adjacent to LW502	100	3.5	0.09	< 0.01
LA14-CF4	25	10	Immediately adjacent to LW502	60	2.5	0.08	< 0.01
LA15-CF1	40	12	Directly above LW502	1550	19.0	0.35	0.40
LA15-CF2	85	12	Directly above LW502	1050	18.0	0.35	0.10
LA15-CF3	200	25	Immediately adjacent to LW502	175	4.0	0.08	< 0.01

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

Cliff Ref.	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)
LA15-CF4	140	12	Immediately adjacent to LW502	100	2.5	0.05	0.01
LA15-CF5	80	11	50 m west of LW502	< 20	0.5	< 0.01	< 0.01
LA15-CF6	20	10	150 m west of LW502	< 20	< 0.5	< 0.01	< 0.01
LA15-CF7	65	12	175 m west of LW502	< 20	< 0.5	< 0.01	< 0.01
LA15-CF8	50	12	225 m west of LW502	< 20	< 0.5	< 0.01	< 0.01
LA15-CF9	40	14	225 m west of LW502	< 20	< 0.5	< 0.01	< 0.01
LA17-CF1	60	10	Directly above LW504	575	12.0	0.20	0.09
LA17-CF2	70	10	Immediately adjacent to LW504	80	1.0	0.01	< 0.01
LA8_CF10	175	15	Partially above LW507	225	6.5	0.16	0.01
LA8_CF11	30	10	220 m south-east of LW508	< 20	< 0.5	< 0.01	< 0.01
LA8_CF12	20	10	220 m south-east of LW508	< 20	< 0.5	< 0.01	< 0.01
LA8_CF13	20	10	230 m south-east of LW508	< 20	< 0.5	< 0.01	< 0.01
LA8_CF14	20	12	230 m south-east of LW508	< 20	< 0.5	< 0.01	< 0.01
LA8_CF15	20	12	240 m south-east of LW508	< 20	< 0.5	< 0.01	< 0.01
LA8_CF9	40	13	200 m south-east of LW507	< 20	< 0.5	< 0.01	< 0.01
LA8A_CF1	20	10	Directly above LW507	150	2.0	0.05	0.01
LA8A_CF2	20	12	Immediately adjacent to LW507	100	1.0	0.02	< 0.01
LA8A_CF3	20	13	30 m south of LW507	60	1.0	< 0.01	< 0.01
			Maximum	**1600**	**20.0**	**0.35**	**0.45**

Table D.02 - Details and maximum predicted subsidence effects for the swamps within the Study 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)
Den85	288110	6194985	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	5 to 15	20	20	< 20
Den86	286550	6196490	Headwater	Above	1800	20	0.35	0.50	5 to 15	150	150	200
Den97	286870	6197535	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	5 to 15	20	20	< 20
Den98	289265	6196420	Valley Infill	Outside	< 20	< 0.5	< 0.01	< 0.01	30	30	70	< 20
Den99	285210	6196095	Headwater	Above	1850	16	0.30	0.45	5 to 10	150	150	300
Den100	286770	6197040	Headwater	Above	650	15	0.25	0.11	0 to 5	40	40	40
Den101	285930	6196350	Headwater	Above	1450	12	0.25	0.08	5	70	70	< 20
Den102	286030	6196530	Headwater	Above	1800	16	0.13	0.50	No valley	-	-	-
Den103	285860	6196715	Headwater	Outside	175	6	0.13	0.01	10 to 15	60	100	< 20
Den104	285405	6196865	Valley Infill	Outside	< 20	< 0.5	< 0.01	< 0.01	20	50	100	< 20
Den105	285305	6196775	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	No valley	-	-	-
Den106	287455	6195075	Headwater	Above	950	15	0.25	0.30	No valley	-	-	-
Den107	286325	6195175	Headwater	Above	1550	13	0.25	0.40	5 to 10	125	125	100
Den108	286595	6195135	Valley Infill	Above	1600	18	0.30	0.40	20 to 25	375	375	200
Den109	286285	6195730	Headwater	Above	1400	11	0.16	0.07	10 to 15	225	250	50
Den110	285875	6195785	Headwater	Above	1950	12	0.19	0.35	5 to 10	125	125	40
Den111	285950	6195580	Valley Infill	Above	1600	16	0.35	0.35	15 to 20	300	325	100
Den114	285235	6195590	Headwater	Above	1550	14	0.30	0.45	15 to 20	250	300	< 20
Den120	287035	6197320	Headwater	Outside	< 20	< 0.5	< 0.01	< 0.01	5	< 20	20	< 20
Den121	284605	6196505	Valley Infill	Above	1700	20	0.35	0.45	15 to 30	200	225	300
Den122	284895	6196585	Headwater	Above	1300	20	0.35	0.45	5 to 15	100	125	150
Den123	285670	6196275	Headwater	Above	1600	17	0.35	0.19	No valley	-	-	-
				Maximum	**1950**	**20**	**0.35**	**0.50**		**375**	**375**	**300**

Table D.03 - Details and maximum predicted subsidence effects for the Aboriginal heritage sites within the Study Area

Table D.03 not included in this version.

APPENDIX E. DRAWINGS

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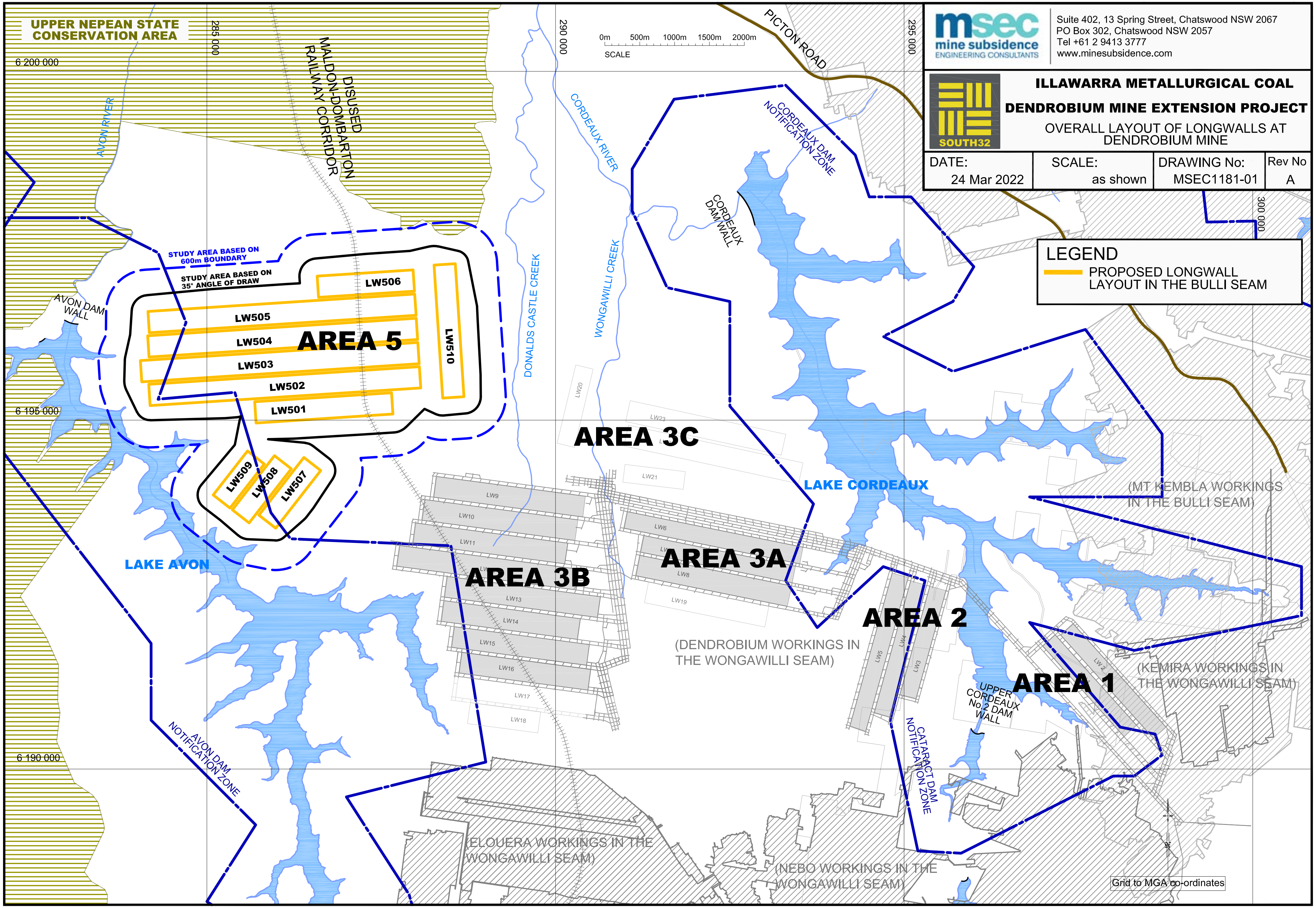

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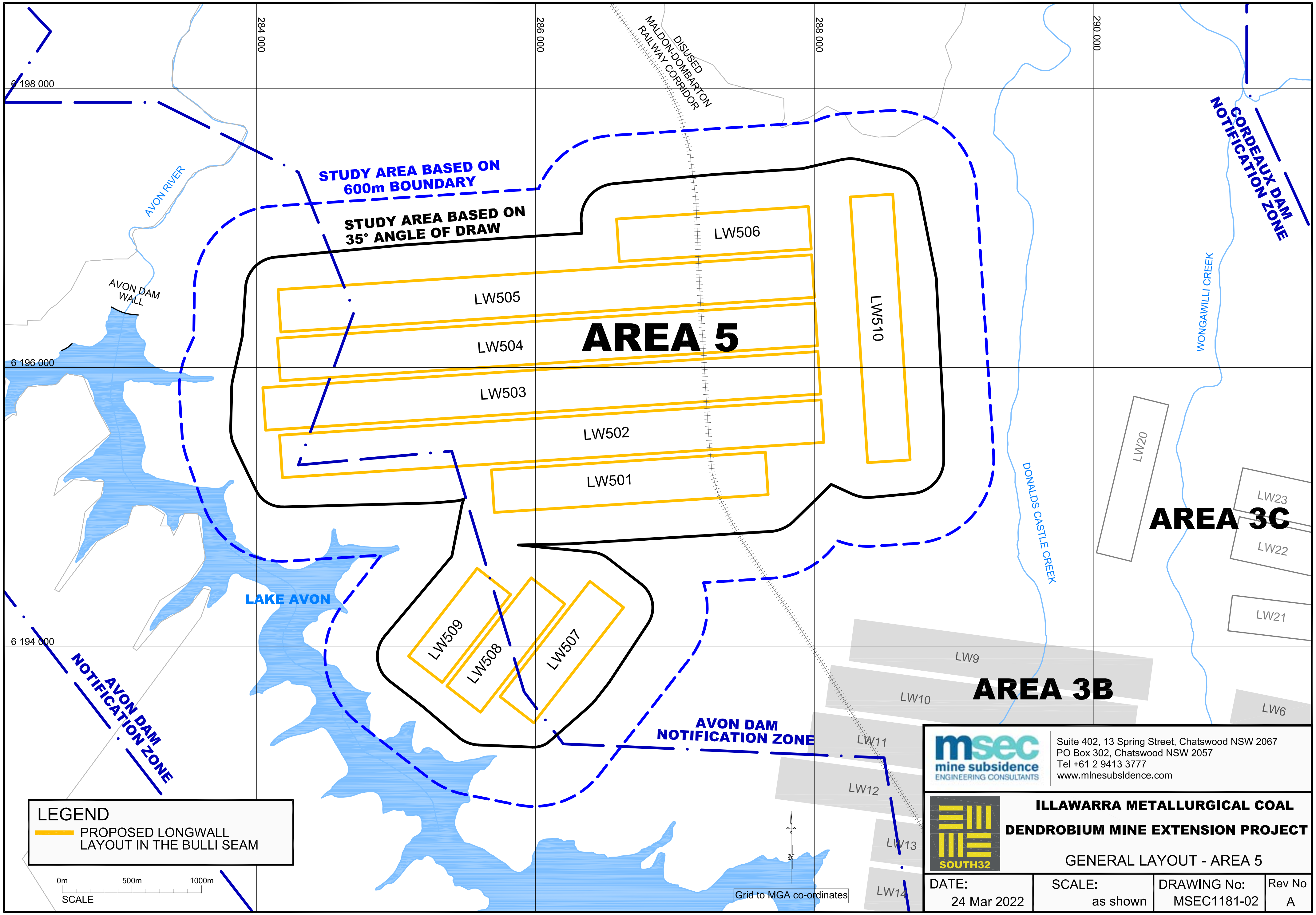

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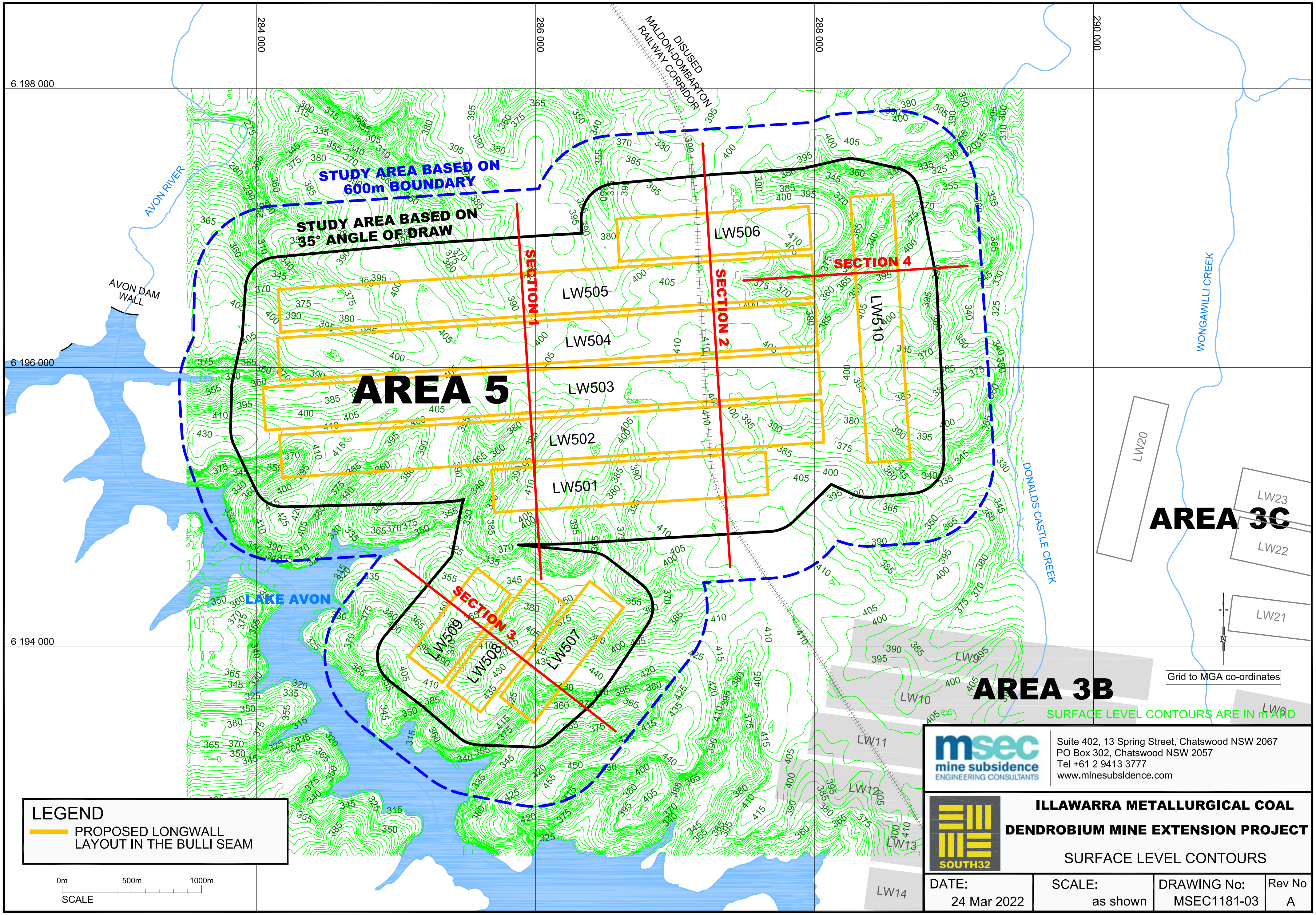

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ILLAWARRA METALLURGICAL COAL

DENDROBIUM MINE EXTENSION PROJECT

SURFACE LEVEL CONTOURS

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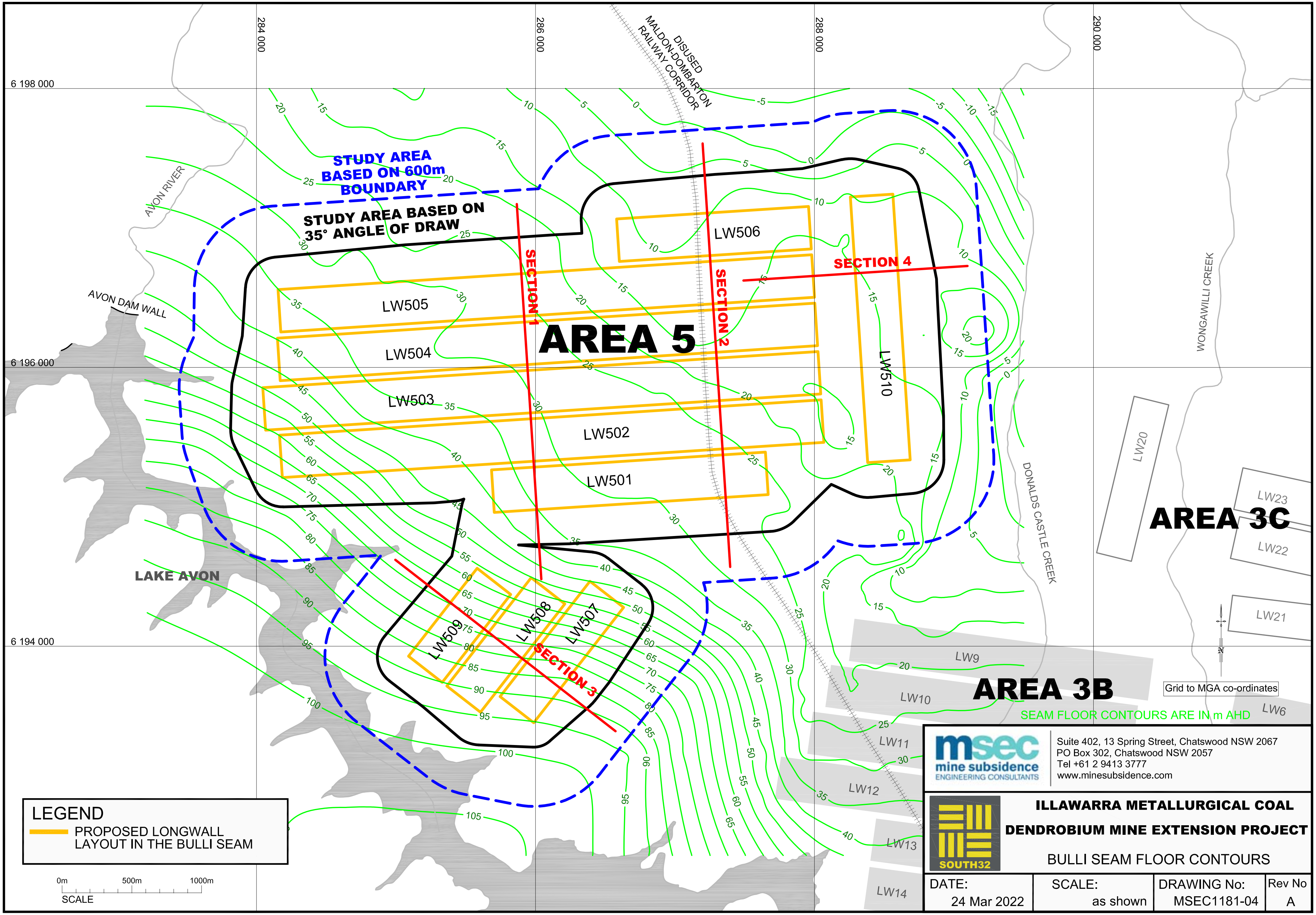

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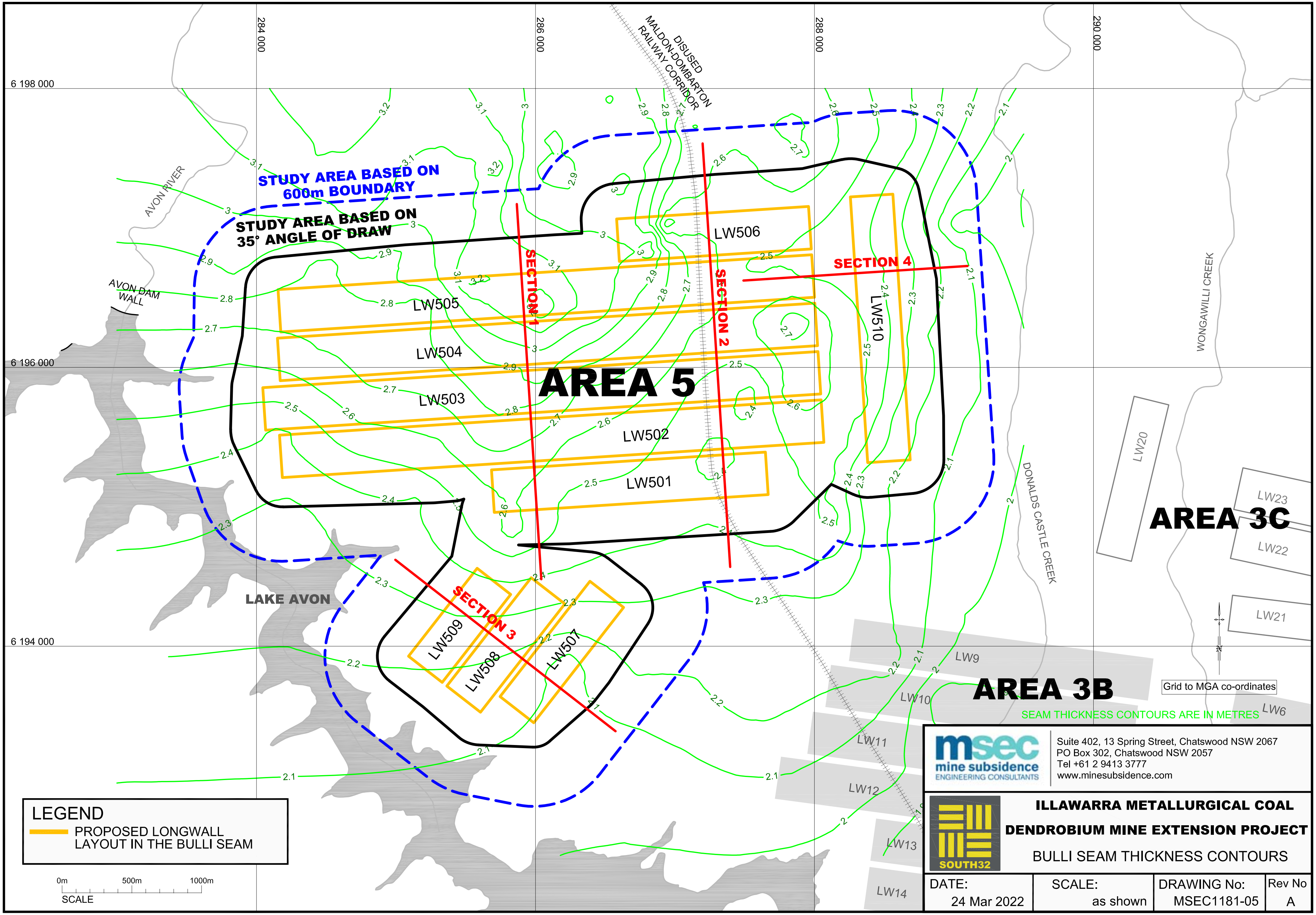

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BULLI SEAM THICKNESS CONTOURS

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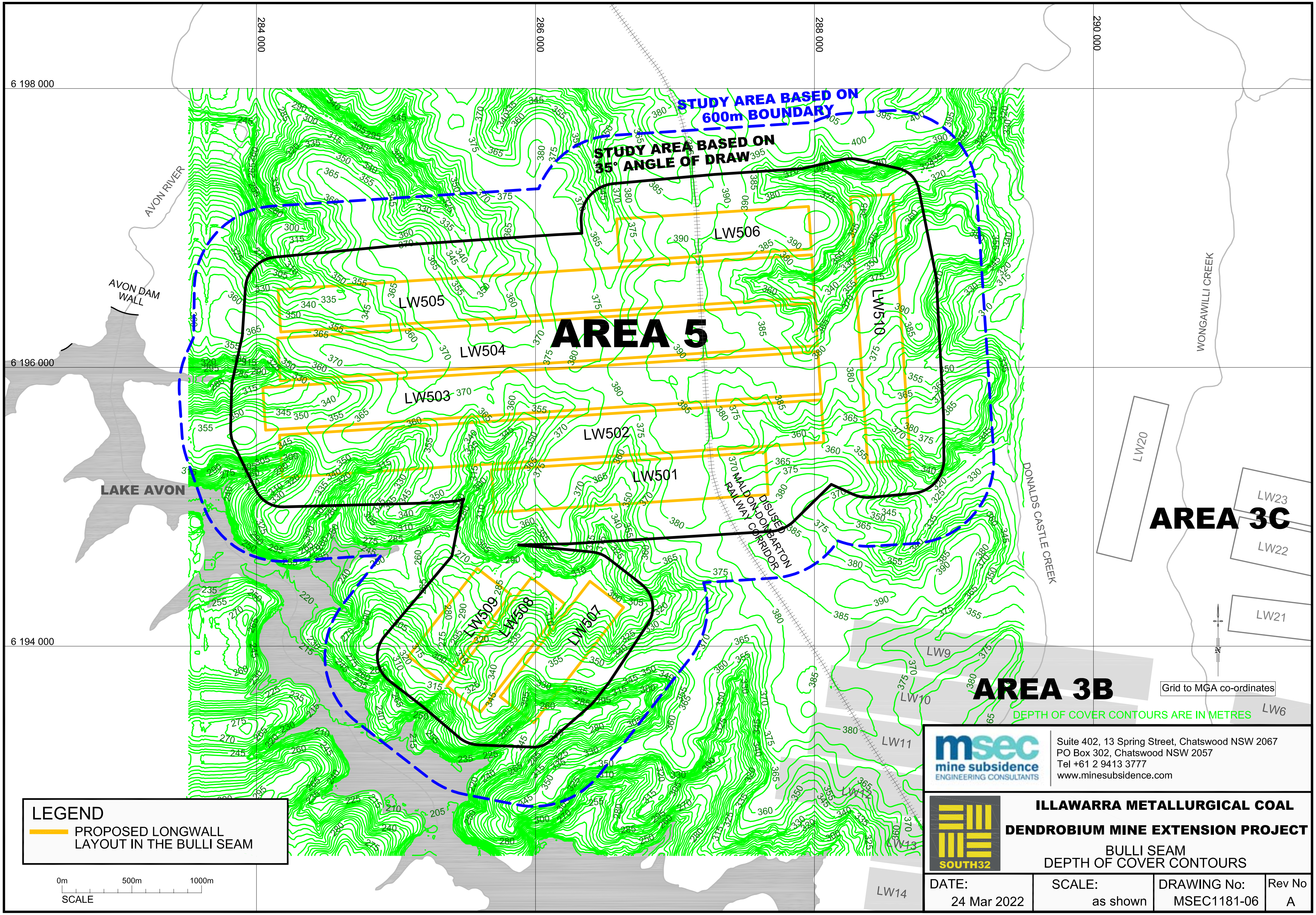

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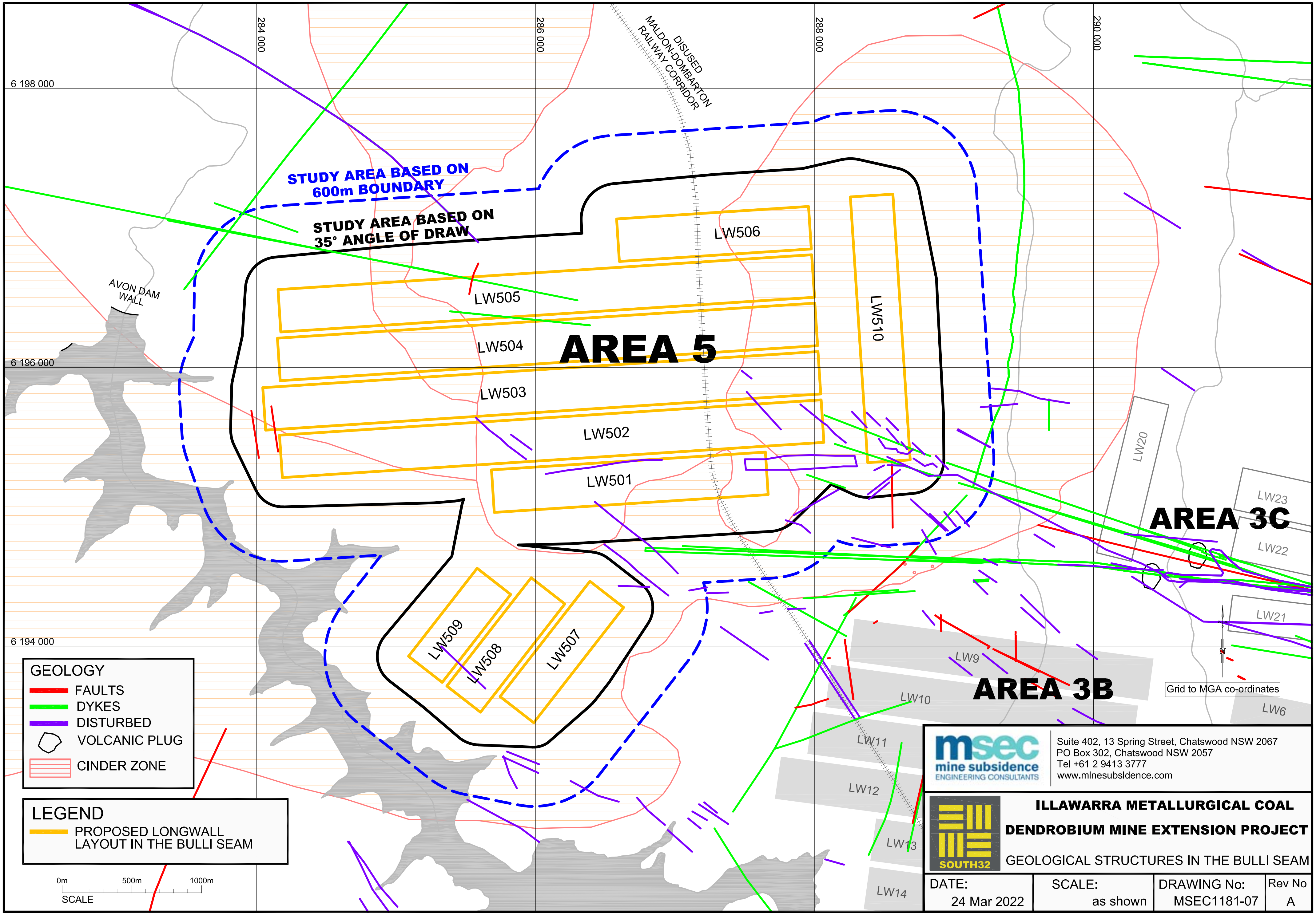

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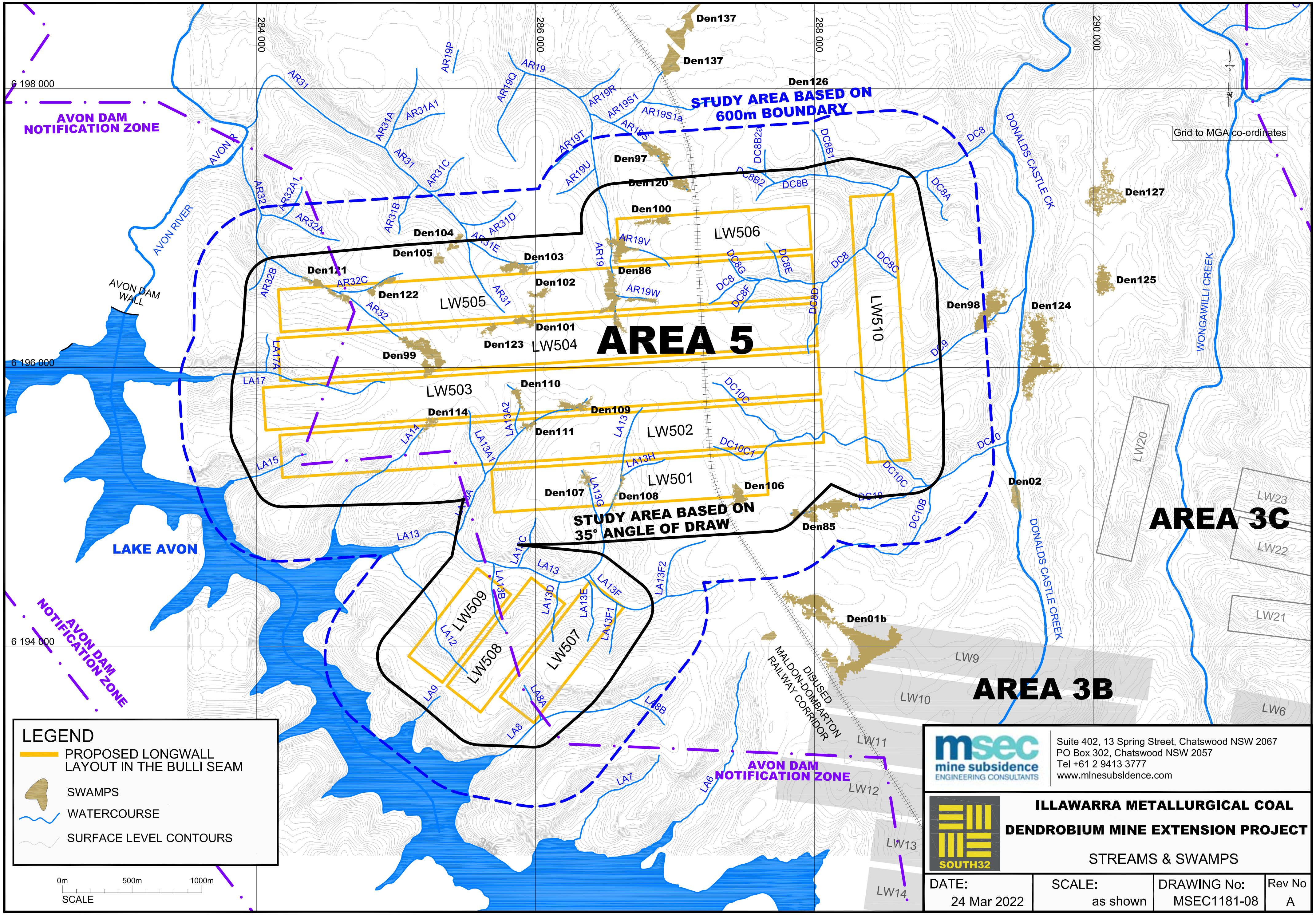

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STREAMS & SWAMPS

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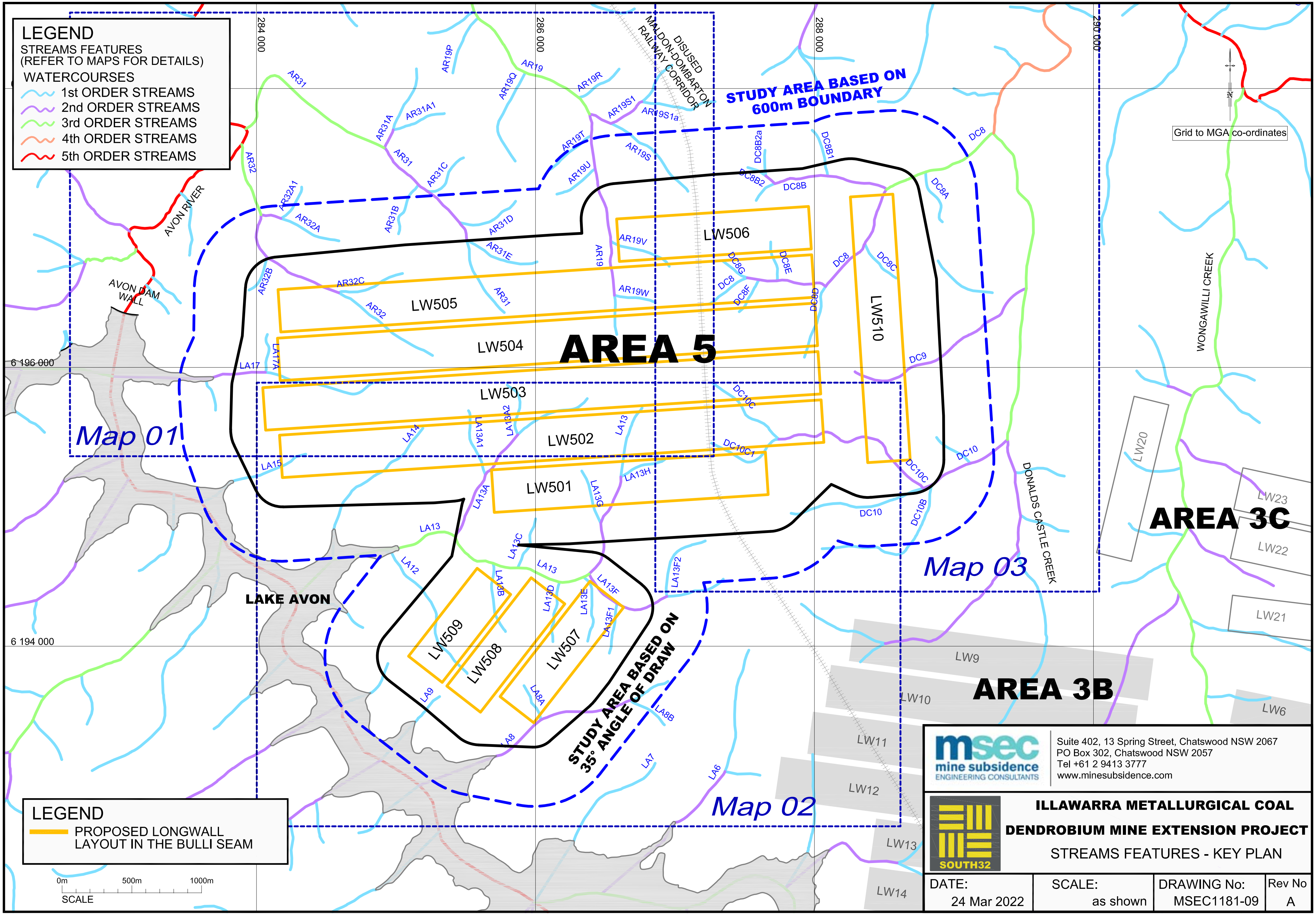

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DENDROBIUM MINE
EXTENSION PROJECT
STREAM FEATURES - MAP 01

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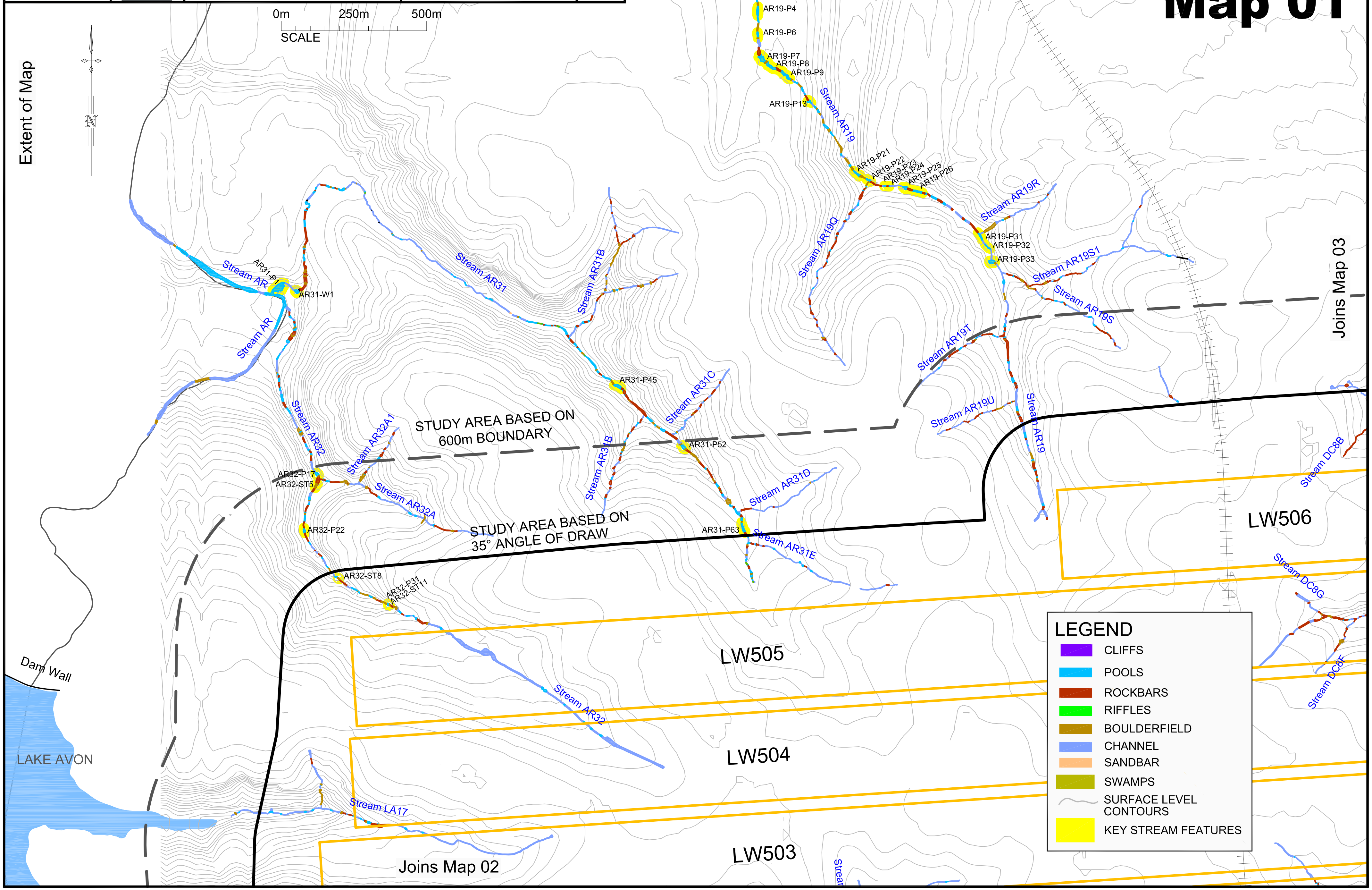
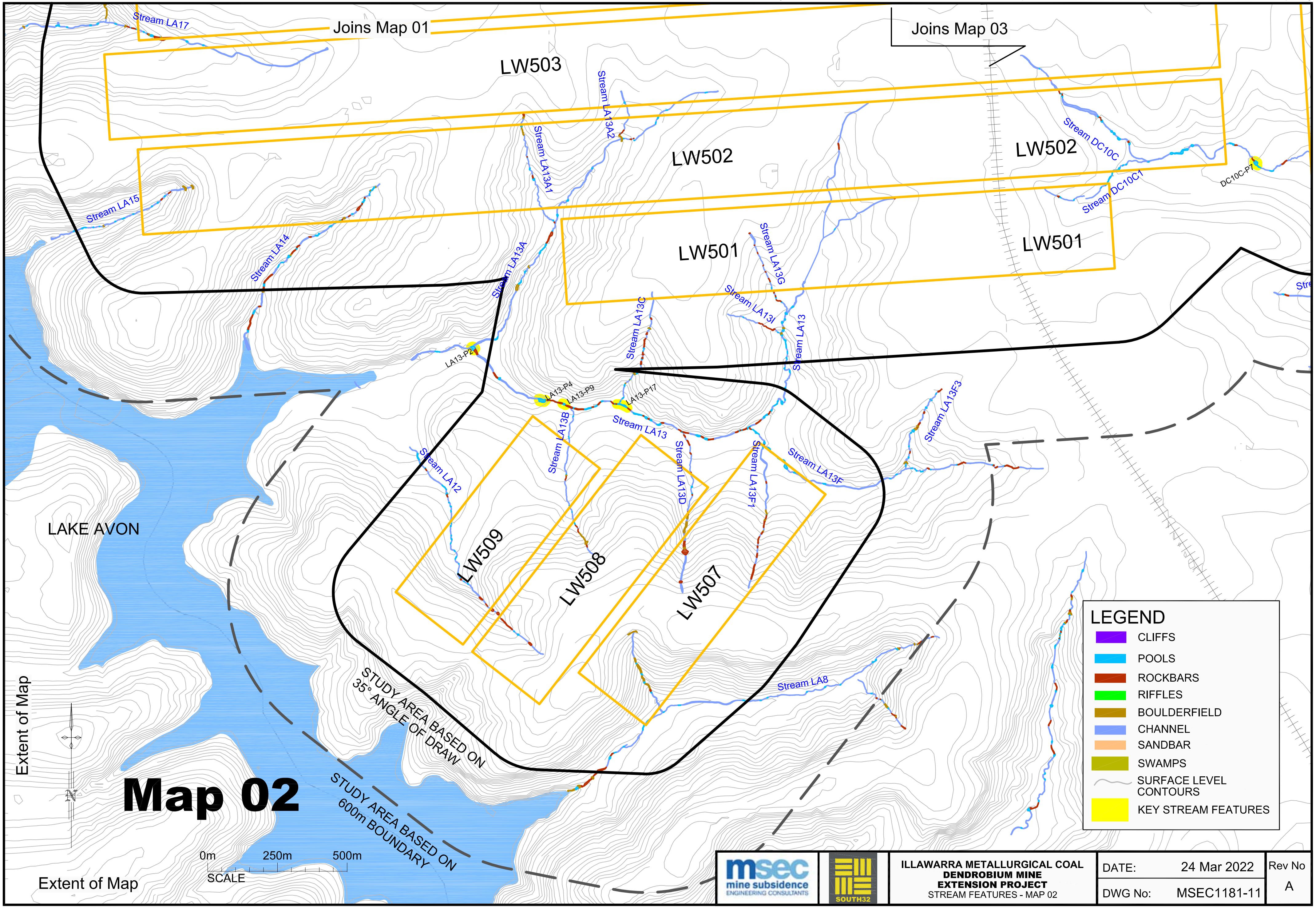
Rev No A

Map 01





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EXTENSION PROJECT
STREAM FEATURES - MAP 02

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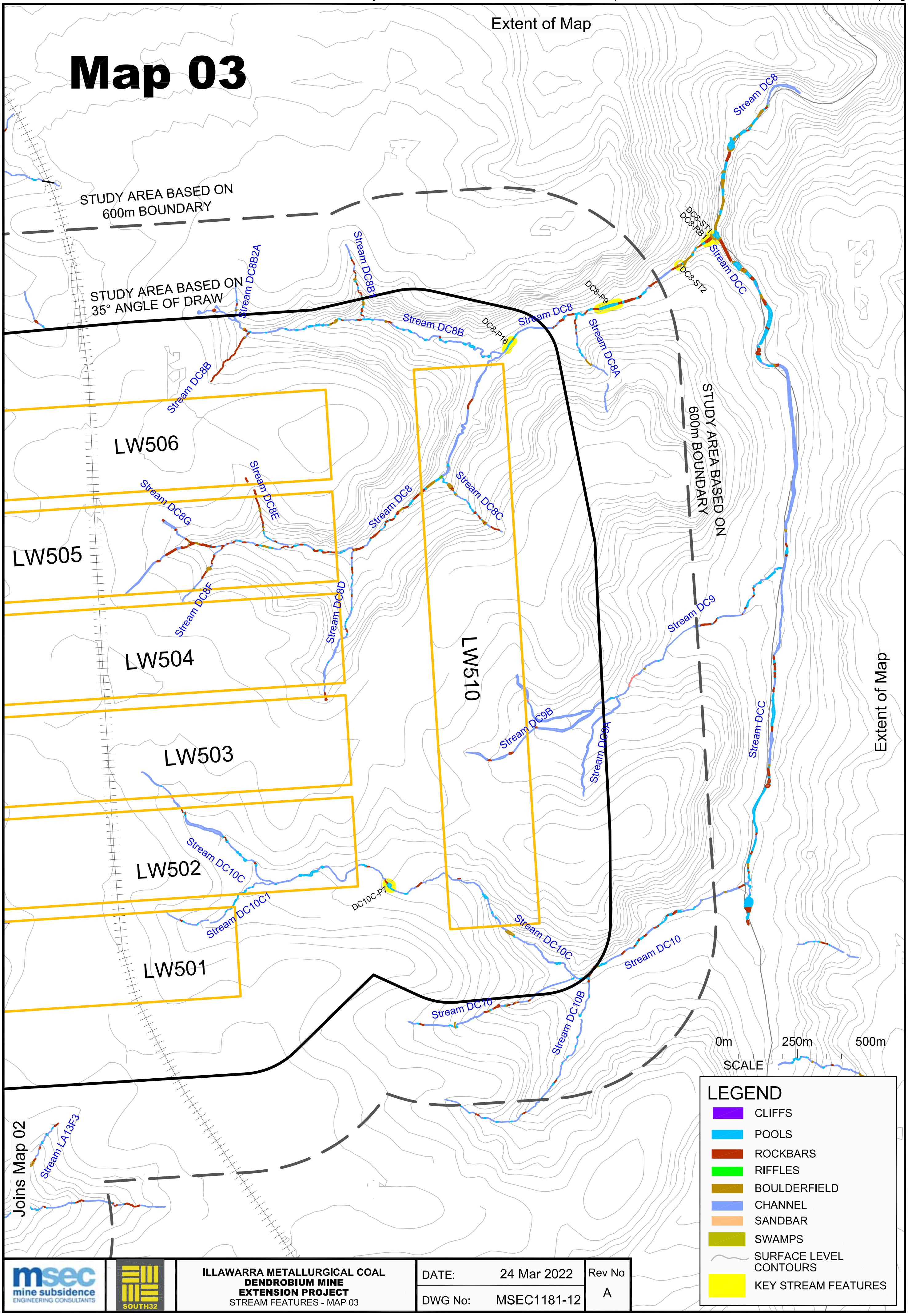

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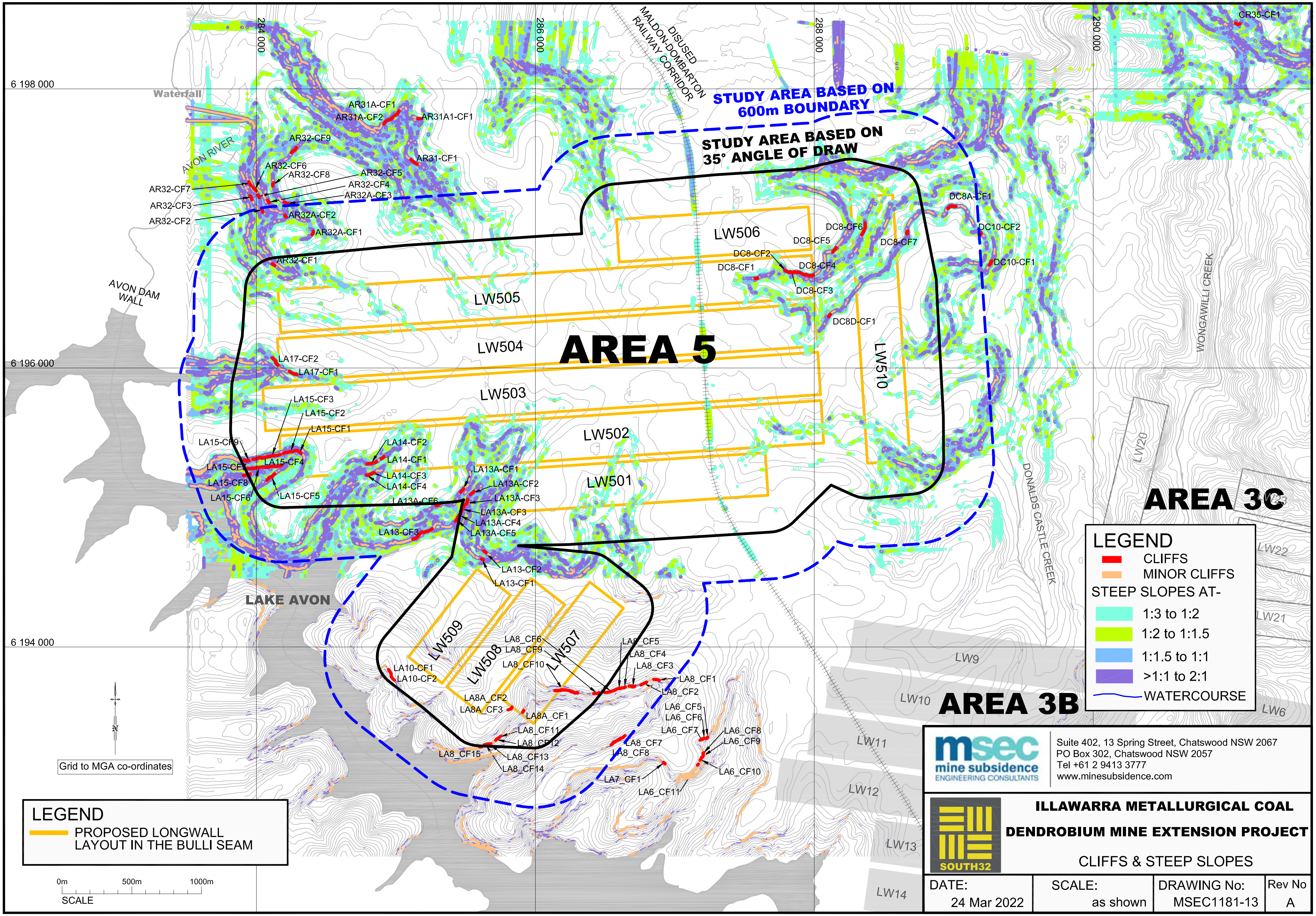

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CLIFFS & STEEP SLOPES

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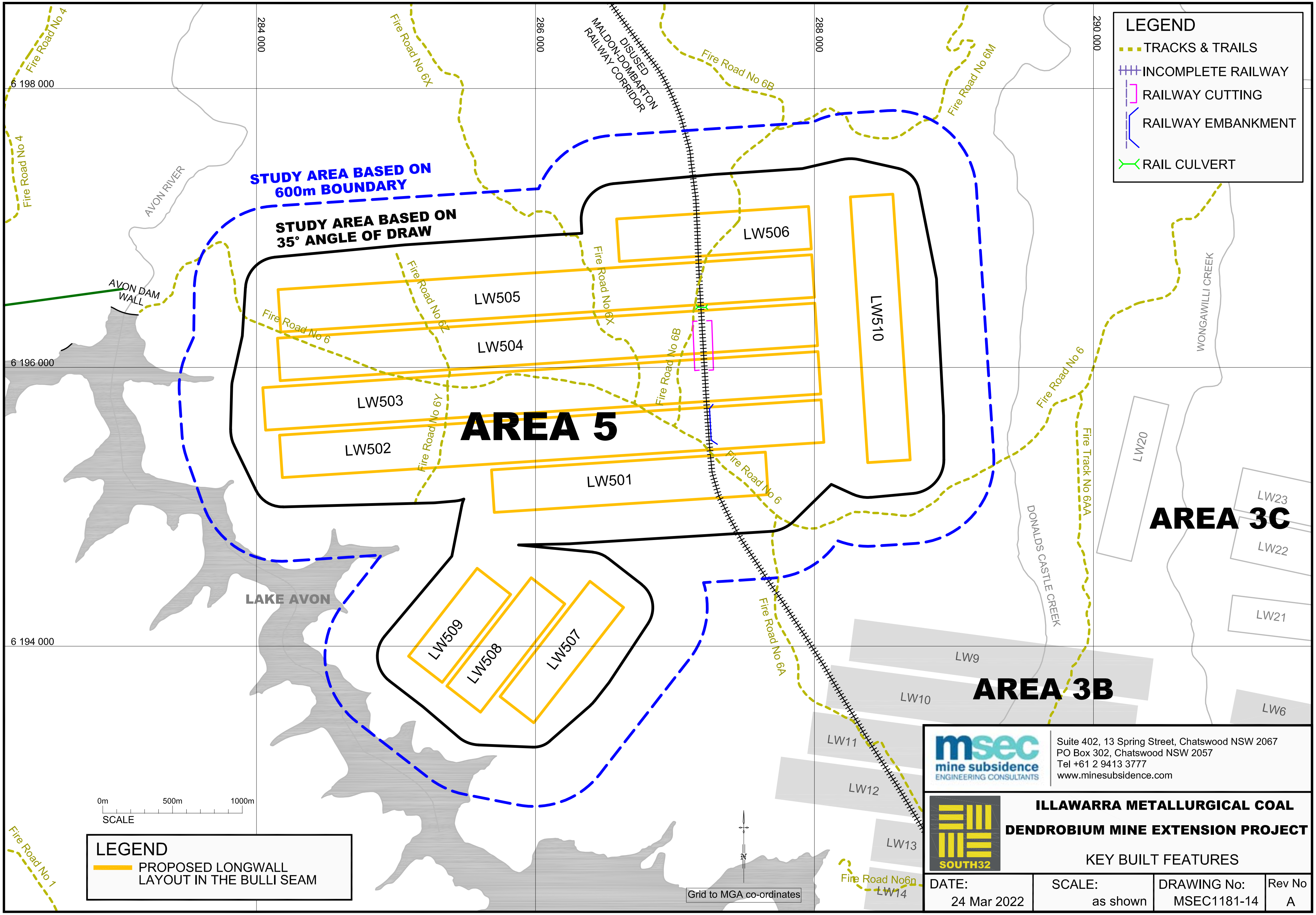

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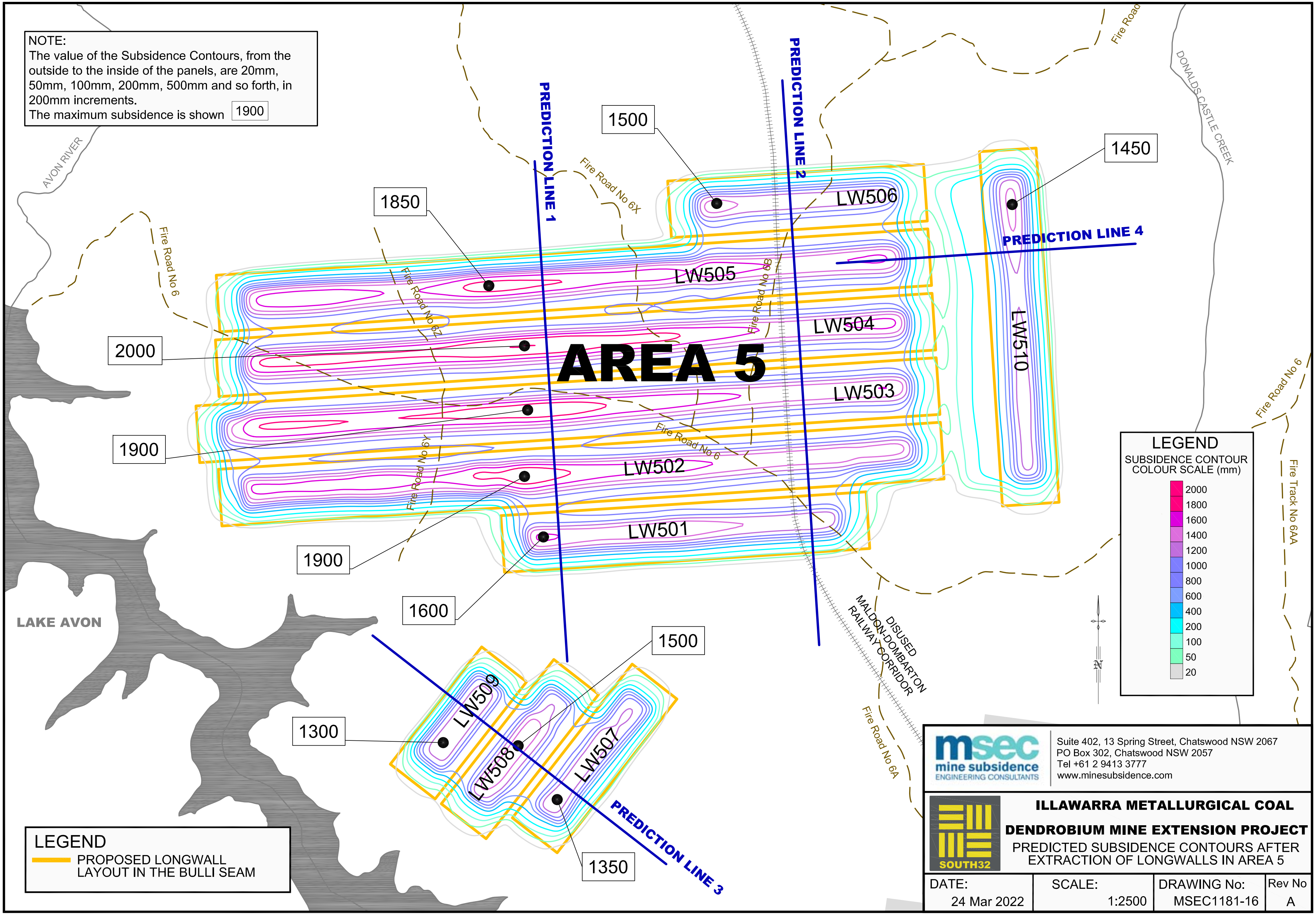

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PREDICTED SUBSIDENCE CONTOURS AFTER EXTRACTION OF LONGWALLS IN AREA 5

DATE:	SCALE:	DRAWING No:	Rev No
24 Mar 2022	1:2500	MSEC1181-16	A