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Dendrobium - Area 3B - Longwall 13

End of Panel Subsidence Monitoring Review Report for Dendrobium Longwall 13

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Associated 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 (October 2007) – 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 (in support of the SMP Application and the Modification to the Development Consent).

MSEC459 (September 2012) – Dendrobium Area 3B – Longwalls 9 to 18 – subsidence predictions and impact assessments for natural features and surface infrastructure in support of the SMP Application.

MSEC792 (December 2015) – Dendrobium Area 3B – Longwalls 12 to 18 – 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.

MSEC865 (November 2016) – The effects of the proposed modifications to the ends of Longwalls 12 to 18 in Area 3B at Dendrobium Mine on the subsidence predictions and impact assessments.

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

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

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Drawings

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

Drawing No.	*Description*	*Revision*
MSEC965-01	General layout and monitoring lines	A
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1.1. Introduction

Illawarra Coal (IC) has completed the extraction of Longwall 13 (LW13) at Dendrobium Mine, which is in the Southern Coalfield of New South Wales. The locations of the longwalls in Area 3B at Dendrobium Mine are shown in Drawing No. MSEC965-01, in Appendix A. The extraction of LW13 commenced on the 4 March 2017 and it was completed on the 19 April 2018.

Mine Subsidence Engineering Consultants (MSEC) was previously commissioned by IC to prepare subsidence predictions and impact assessments for Dendrobium Longwalls 9 to 18 (LW9 to LW18) in Area 3B. Report No. MSEC459 (Revision B) was issued in September 2012 in support of the SMP Application for these longwalls.

IC then shortened the commencing (western) end of LW13 by 50 m from the extent that was indicated in the SMP Application. Report No. MSEC865 (Rev. A) was issued in support of the application for this modification. The modified commencing end of LW13 was approved by Department of Industry – Division of Resources and Energy (DRE) on the 11 January 2017.

The subsidence prediction model was reviewed and re-calibrated, based on the updated monitoring data from LW7 and LW8 in Area 3A and LW9 and LW10 in Area 3B. The subsidence predictions and impact assessments for the natural and built features were reviewed and updated based on the re-calibrated subsidence model and are provided in Report No. MSEC792 (Rev. C). The predictions provided in this End of Panel subsidence review report are based on the re-calibrated subsidence prediction model outlined in Reports Nos. MSEC792 and MSEC865.

In accordance with Condition 9 End of Panel Reporting of the Development Consent (Schedule 3) for the Area 3B longwalls, this report provides:

- comparisons between the observed and predicted subsidence movements at the monitoring lines and points in Dendrobium Area 3B resulting from the extraction of LW13; and
- comparisons between the observed and predicted effects and impacts on the natural and built features within the SMP Area resulting from the extraction of LW13.

Further details on the observed and assessed impacts for natural features, resulting from the extraction of LW13, are provided in the reports by other consultants. The discussions provided in this report should be read in conjunction with those and all other relevant reports.

Chapter 2 of this report describes the locations of the ground monitoring lines and points which were surveyed during the extraction of LW13. This section also provides comparisons between the observed and predicted movements resulting from the extraction of this longwall.

Chapter 3 of this report describes the natural and built features near LW13. This section also provides comparisons between the observed and assessed impacts for these features resulting from the extraction of this longwall. Further discussions on the observed and assessed impacts for natural features are provided in reports by other consultants.

Chapter 4 of this report provides a summary of the comparisons between the measured and predicted ground movements and the observed and assessed surface impacts due to the extraction of LW13.

Appendix A includes all drawings associated with this report.

1.2. Mining geometry

The layout of the longwalls in Area 3B at Dendrobium Mine is shown in Drawing No. MSEC965-01, in Appendix A. A summary of the as-extracted dimensions for LW9 to LW13 is provided in Table 1.1.

Table 1.1 Mining geometry of the as-extracted longwalls

Location	Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
Area 3B	LW9	2162	305	-
	LW10	2219	305	45
	LW11	2204	305	45
	LW12	2602	305	45
	LW13	2223	305	45

The mined lengths of the longwalls excluding the installation headings are approximately 9 m shorter than the overall void lengths provided in Table 1.1. The length of extraction for LW13, therefore, is approximately 2214 m. The longwall face widths excluding the first workings are approximately 294 m.

The longwalls in Area 3B have been extracted from the Wongawilli Seam, from the west towards the east, i.e. towards Wongawilli Creek. The natural surface and the seam levels along the centreline of LW13 are illustrated in Fig. 1.1.

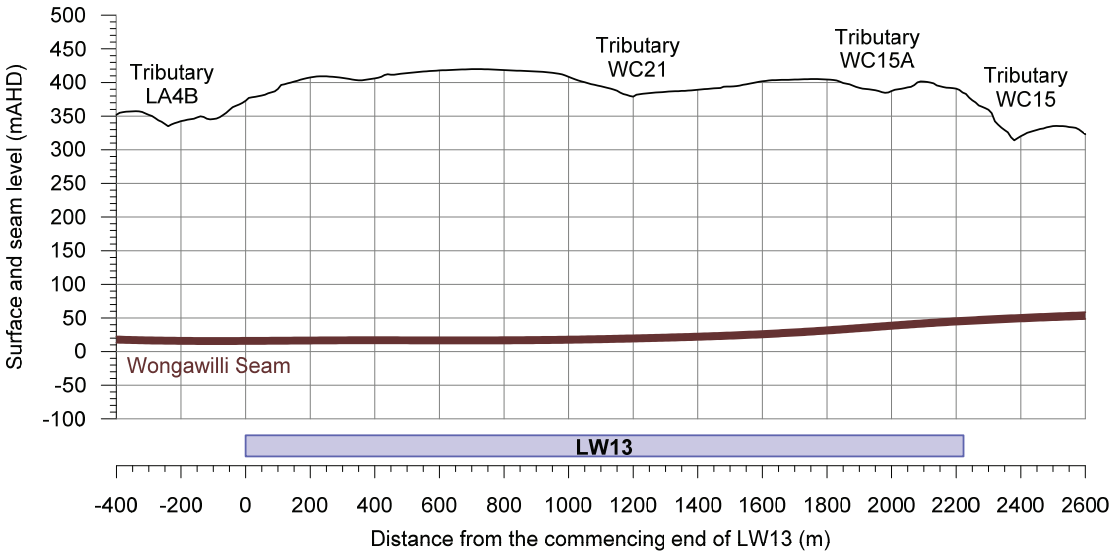

Fig. 1.1 Surface and seam levels along the centreline of LW13

The depth of cover to the Wongawilli Seam, directly above LW13, varies between a minimum of 290 m near the eastern (i.e. finishing) end of the longwall, and a maximum of 400 m above the western part of the longwall. The seam floor within the mining area generally dips from the south to the north, having an average dip around 2 %, or 1 in 50.

The extraction height varies along the length of LW13, depending on the local roof conditions. The predictions provided in this report have been based on the maximum proposed extraction height of 4.6 m, as adopted in Reports Nos. MSEC459, MSEC792 and MSEC865.

2.1. Introduction

The mine subsidence movements resulting from the extraction of Dendrobium LW13 were monitored along several monitoring lines and monitoring points including the following:

- Wongawilli Creek closure lines;
- Avon Dam closure lines;
- Area 3B and Avon Dam 3D monitoring points;
- Tributary cross lines;
- Donalds Castle Creek cross lines;
- Swamp cross lines; and
- Airborne laser scans of the area.

The locations of these survey lines and survey points are shown in Drawing No. MSEC965-01, in Appendix A. Comparisons between the measured and predicted subsidence movements at these monitoring lines and points are provided in the following sections. The predicted subsidence parameters have been obtained using the re-calibrated subsidence model presented in Reports Nos. MSEC792 and MSEC865.

2.2. Wongawilli Creek closure lines

The closure movements across Wongawilli Creek have been measured by IC using 2D survey techniques at the Wong X B-Line, Wong X C-Line and Wong X D-Line. The Wong X A-Line was not measured at the completion of LW12 or LW13 due to its distance from these longwalls.

The locations of the Wongawilli Creek closure lines are shown in Drawing No. MSEC965-01. The survey dates for these monitoring line are provided in Table 2.1.

Table 2.1 Survey dates for the Wongawilli Creek closure lines for LW13

Mining phase commitments	Mining phase survey dates	Post mining phase commitments
Completion of LW13	13 February 2013 (base survey) 4 March 2016 (end of LW11) 28 April 2017 (end of LW12) 14 June 2018 (end of LW13)	Completion of each of the future longwalls in Area 3B

The monitoring lines each comprise two survey marks, with the marks located on either side of Wongawilli Creek and, therefore, they measure the closure between the valley sides. Survey marks could not be located near the base of the valley due to the difficult terrain. The upsidence in the base of the valley, therefore, could not be measured.

The development of total closure for the Wongawilli Creek closure lines, due to the extraction of LW6 to LW13, is illustrated in Fig. 2.1. The base survey for the Wong X D-Line was carried out after the completion of LW12 and, therefore, measured the additional movements due to LW13 only.

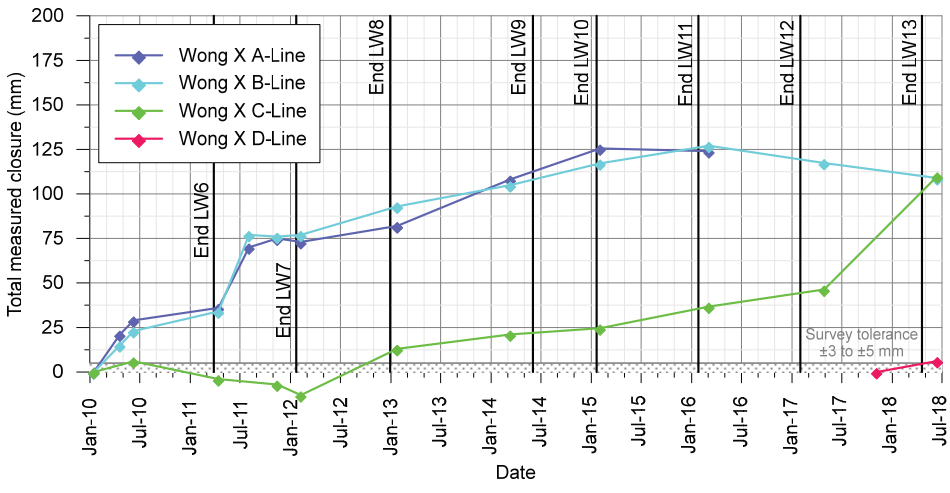

Fig. 2.1 Development of total closure for the Wongawilli Creek closure lines

The predictions of vertical subsidence, upsidence and closure for Wongawilli Creek, resulting from the extraction of Dendrobium LW6 to LW19, were provided in Report No. MSEC865. The measured and predicted total closures along Wongawilli Creek after the completion of LW13 are illustrated in Fig. 2.2.

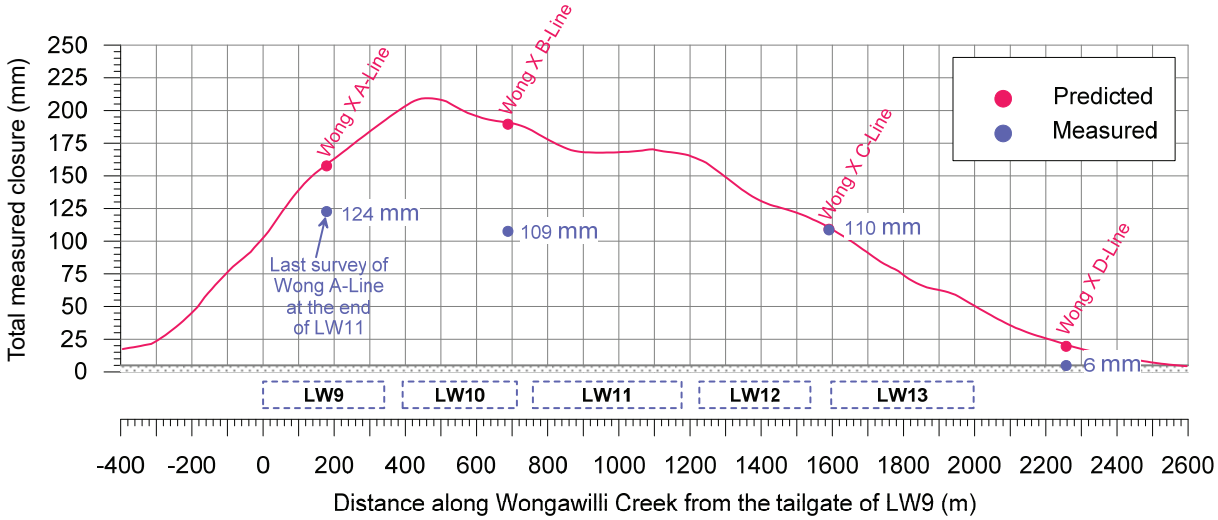

Fig. 2.2 Measured and predicted total closure along Wongawilli Creek after LW13

A summary of the maximum measured and maximum predicted total closure movements for each of the Wongawilli Creek closure lines, due to the extraction of LW6 to LW13, is provided in Table 2.2. The predicted total closures consider the shortened finishing ends of LW11 and LW12.

Table 2.2 Measured and predicted total closure at the Wongawilli Creek closure lines due to the extraction of LW6 to LW13

Location	Longwalls	Measured total closure (mm)	Predicted total closure (mm)
Wong X A-Line	LW6 to LW11	124	160
Wong X B-Line	LW6 to LW13	109	190
Wong X C-Line	LW6 to LW13	110	110
Wong X D-Line	LW13 only	6	20

The accuracies of the measured closure movements are in the order of ±5 mm.

The maximum measured total closures at each of the Wongawilli Creek closure lines are equal to or less than the predictions after the completion of LW13.

2.3. Avon Dam closure lines

The closure across the Avon Dam has been measured by IC using the Avon Dam A-Line to E-Line. The locations of these monitoring lines are shown in Drawing No. MSEC965-01. The discussions on the Avon Dam 3D monitoring points are included in Section 2.4.

The survey dates for the Avon Dam closure lines are provided in Table 2.3. The base surveys were carried out just prior to the commencement of LW12 and, therefore, the closure lines have measured the accumulated movements due to the extraction of LW12 and LW13 only.

Table 2.3 Survey dates for the Avon Dam closure lines during LW13

Mining phase commitments	Mining phase survey dates	Post mining phase commitments
Completion of LW13	12 February 2016 (base survey) 30 August 2016 (end of LW12) 12 April 2017 18 May 2017 10 August 2017 5 December 2017 23 May 2018 (end of LW13)	Completion of each of the future longwalls in Area 3B

The monitoring lines each comprise two survey marks, with the marks located on either side of the Avon Dam and, therefore, they measure the closure between the valley sides. Survey marks could not be located near the base of the valley due to the stored water in the dam. The upsidence in the base of the valley, therefore, could not be measured.

The development of the measured accumulated closures along Avon Dam closure lines during the extraction of LW12 and LW13 are illustrated in Fig. 2.3. The predicted final accumulated closures are 40 mm for the A-Line, 30 mm for the B-Line and 20 mm, or less, for the C-Line to E-Line.

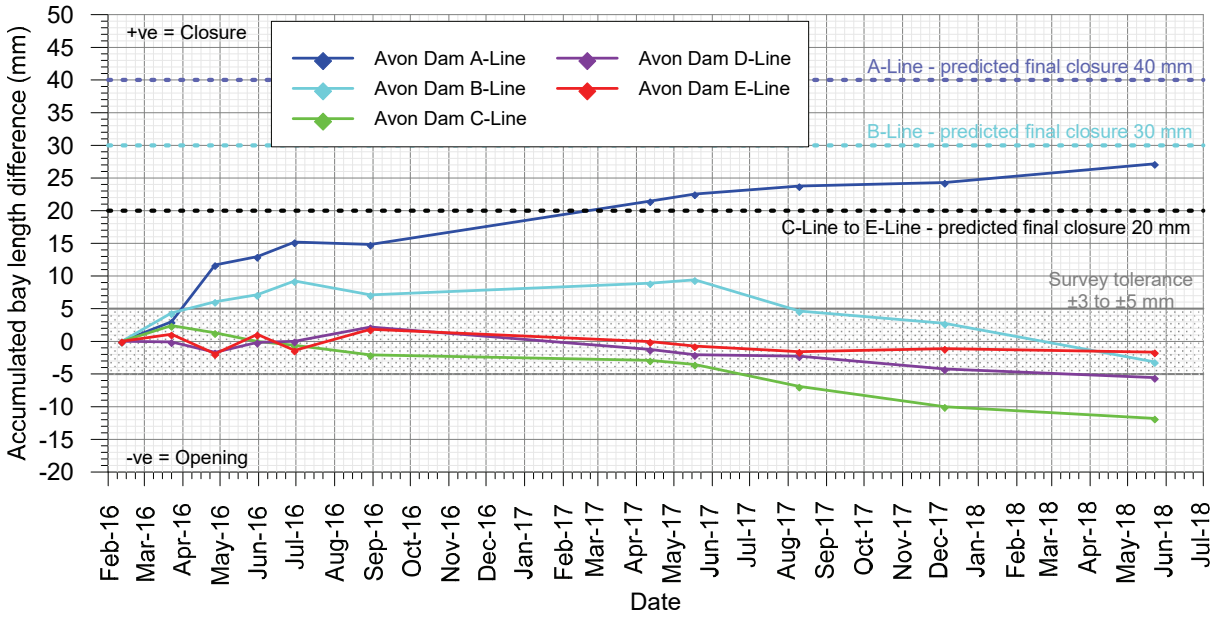

Fig. 2.3 Measured and predicted accumulated closure for the Avon Dam closure lines

A summary of the maximum measured and maximum predicted accumulated movements for each of the Avon Dam closure lines, due to the extraction of LW12 and LW13, is provided in Table 2.2.

Table 2.4 Maximum measured and maximum predicted accumulated movements for the Avon Dam closure lines due to the extraction of LW12 and LW13

Location	Measured accumulated closure (mm)	Predicted accumulated closure (mm)
Avon Dam A-Line	27	40
Avon Dam B-Line	-3 (opening)	30
Avon Dam C-Line	-12 (opening)	< 20
Avon Dam D-Line	-6 (opening)	< 20
Avon Dam E-Line	-2 (opening)	< 20

The accuracies of the measured closure movements are in the order of ±5 mm.

It can be seen from Fig. 2.3 and Table 2.2, that the maximum measured accumulated closures at the Avon Dam closure lines are less than the predicted final closures after the completion of LW13. The extraction of LW13 resulted in additional closure at the A-Line but reduced closure at the other monitoring lines. The final measured movements at the B-Line, D-Line and E-Line are similar to the order of accuracy of the survey measurements.

The mine subsidence movements across a tributary to Avon Dam (Ref. LA4) have also been measured by IC using 2D survey techniques using the LA4-Line. The location of this monitoring line is shown in Drawing No. MSEC965-01. The base survey was carried out on the 26 February 2013, i.e. prior to the commencement of LW9. Subsequent surveys were carried out on the 30 August 2016 (during LW12), 12 April 2017, 18 May 2017, 10 August 2017, 5 December 2017 and 23 May 2018 (end of LW13).

A summary of the total measured and total predicted closures along the LA4-Line is provided in Table 2.5. The measured closure is less than the predicted final closure at the completion of LW13. The vertical subsidence was not measured.

Table 2.5 Maximum measured and predicted total closure at the LA4-Line resulting from the extraction of LW9 to LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	- Not measured -	12
Predicted	< 20	125

It is considered that the ground movements measured using the Avon Dam closure lines and the LA4-Line are consistent with the predictions provided in Reports Nos. MSEC792 and MSEC865.

2.4. Dendrobium Area 3B 3D and the Avon Dam 3D monitoring points

The far-field horizontal movements near LW13 have been measured by IC using the Dendrobium Area 3B 3D monitoring points (DA3B 3D) and the Avon Dam 3D monitoring points. The locations of these monitoring points are shown in Drawing No. MSEC965-01.

The survey dates for the DA3B 3D monitoring points for LW13 are provided in Table 2.6. The survey dates and monitoring commitments for the Avon Dam 3D monitoring points are the same as the Avon Dam closure lines provided in Table 2.3.

Table 2.6 Survey dates for the DA3B 3D monitoring points for LW13

Mining phase commitments	Mining phase survey dates	Post mining phase commitments
Completion of LW13	26 February 2013 (base survey) 4 March 2016 (end of LW11) 9 March 2017 (end of LW12) 15 May 2018 (end of LW13)	Completion of each of the future longwalls in Area 3B

The measured incremental horizontal movement vectors for DA3B 3D and the Avon Dam 3D monitoring points, due to the extraction of LW13, are shown in Drawing No. MSEC965-04. The accuracies of the measured absolute positions (i.e. Eastings and Northings) are in the order of ±20 mm.

The vectors of incremental horizontal movement are typically orientated towards LW13 and skewed towards the east, i.e. towards the longwall finishing end. The greatest movements have been measured directly above LW13 and, to lesser extents, above the previously extracted LW12. Only low level incremental horizontal movements have been measured outside the extents of the mining area.

The comparison between the maximum measured incremental horizontal movements at the DA3B 3D and Avon Dam 3D monitoring points with those previously measured in Dendrobium Area 1 (DA1 3D) and Dendrobium Area 2 (DA2 3D), Dendrobium Area 3A (DA3A 3D), as well as other collieries in the Southern Coalfield, is provided in Fig. 2.4. The mean and the 95 % confidence level for the 3D monitoring data at Dendrobium Mine are also shown in this figure.

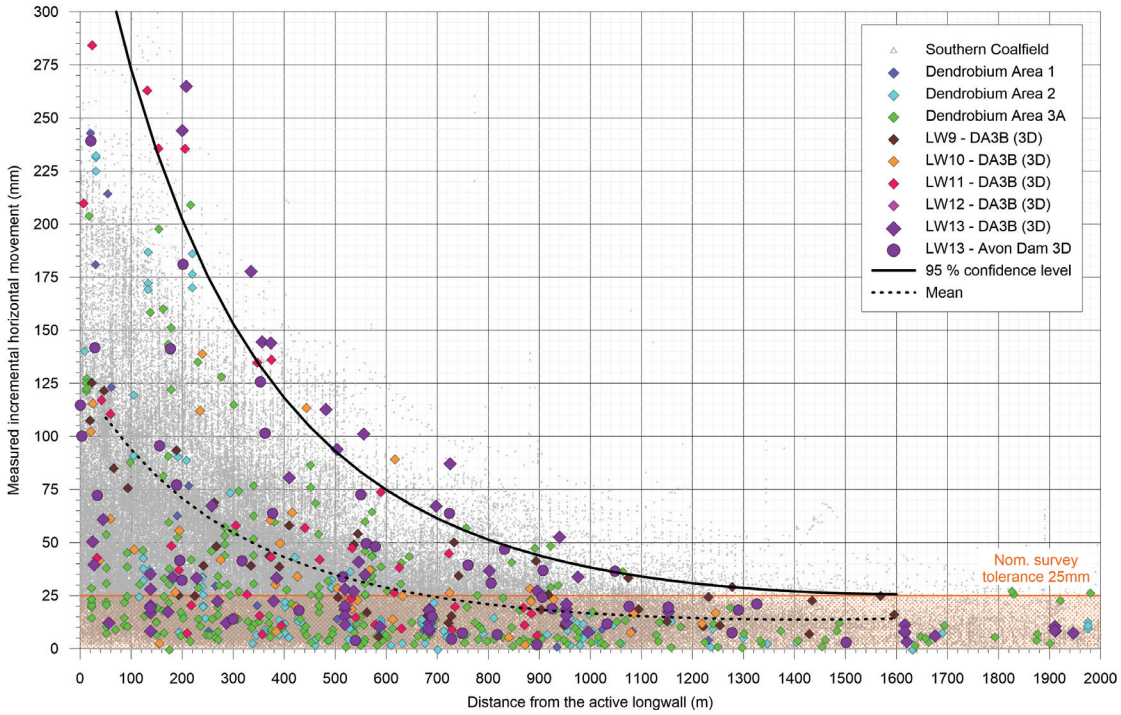

Fig. 2.4 Measured incremental horizontal movements at Dendrobium Mine

The measured incremental horizontal movements resulting from the extraction of LW13 (i.e. purple diamonds and circles) are typically within the range of those measured at similar distances from previously extracted longwalls at Dendrobium Mine (i.e. blue, cyan, green, brown, orange, red and magenta diamonds) and elsewhere in the Southern Coalfield (i.e. grey triangles).

2.5. Wongawilli Creek Tributary WC21 cross lines

The mine subsidence movements across a tributary to Wongawilli Creek (Ref. WC21) have been measured by IC using 2D survey techniques using the WC21 F-Line, WC21 H-Line, WC21 I-Line, WC21 J-Line, WC21 K-Line, WC21 L-Line (lower) and WC21 L-Line (upper). The WC21 A-Line, B-Line, C-Line, D-Line, E-Line and G-Line were not measured during LW13.

The locations of the tributary cross lines are shown in Drawing No. MSEC965-01. The survey dates for these monitoring lines for LW13 are provided in Table 2.7.

Table 2.7 Survey dates for the Wongawilli Creek tributary WC21 cross lines for LW13

Mining phase commitments	Mining phase survey dates	Post mining phase commitments
First survey 100 m before lines, then monthly surveys. Final survey when mining 400 m past lines	13 February 2013 (base survey) 4 March 2016 (end of LW11) 28 April 2017 (end of LW12) 26 May 2017 23 June 2017 21 July 2017 31 August 2017 11 October 2017 9 November 2017 11 January 2018 8 February 2018 13 March 2018 17 April 2018 14 June 2018	First survey 100 m before lines, then monthly surveys. Final survey when mining 400 m past lines

The development of the measured total closures along the tributary cross lines during the extraction of LW9 to LW13 are illustrated in Fig. 2.5. The WC21 H-Line was established on the 21 October 2015 and, therefore, it does not include the effects of LW9 and LW10. The WC21 I-Line, J-Line, K-Line, L-Line (lower) and L-Line (upper) were established on the 5 October 2016 and, therefore, they do not include the effects of LW9 to LW11.

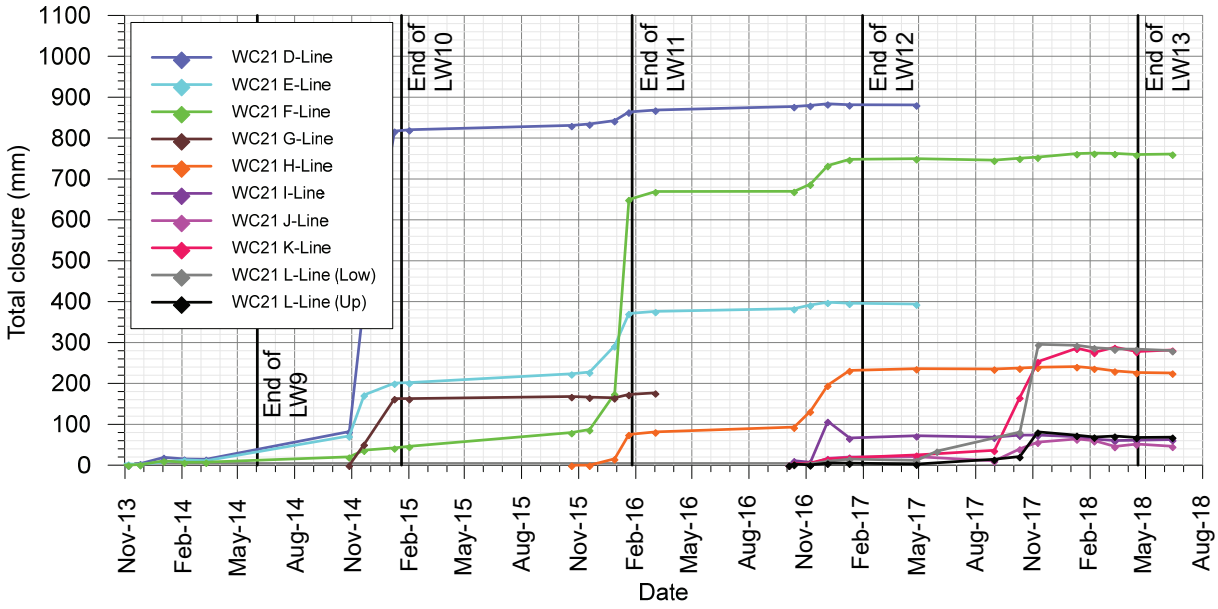

Fig. 2.5 Measured total closure for the tributary cross lines

Summaries of the maximum measured and predicted total subsidence and closure along the tributary cross lines, after the extraction of LW13, are provided in Table 2.8 to Table 2.13. The predicted subsidence values have been derived from the predicted subsidence contours illustrated in Report No. MSEC865. The predicted closures are based on a combination of the conventional and valley related movements, taking the equivalent heights of the valleys within half-depths of cover from the valley bases.

Table 2.8 Maximum measured and predicted total subsidence and closure at the WC21 F-Line resulting from the extraction of LW9 to LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	1735	761
Predicted	3150	800

Table 2.9 Maximum measured and predicted total subsidence and closure at the WC21 H-Line resulting from the extraction of LW11 to LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	817	225
Predicted	1575	275

Table 2.10 Maximum measured and predicted total subsidence and closure at the WC21 I-Line (SW10-Line) resulting from the extraction of LW11 to LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	2474	62
Predicted	3425	325

Table 2.11 Maximum measured and predicted total subsidence and closure at the WC21 J-Line resulting from the extraction of LW12 and LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	788	46
Predicted	1275	225

Table 2.12 Maximum measured and predicted total subsidence and closure at the WC21 K-Line resulting from the extraction of LW12 and LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	1150	282
Predicted	1950	575

Table 2.13 Maximum measured and predicted total subsidence and closure at the WC21 L-Line (lower and upper) resulting from the extraction of LW12 and LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	1692	280
Predicted	2525	650

The accuracies of the measured relative levels of the survey marks along the tributary cross lines are in the order of ±5 mm. The accuracies of the measured absolute levels of the survey marks are in the order of ±30 mm. The accuracies of the measured closures are in the order of ±5 mm.

The measured total vertical subsidence and closure for the WC21 cross lines are less than the predicted values at the end of LW13. The measured vertical subsidence movements range between 52 % and 72 % of the predicted values, with an average of 61 %. The measured closures range between 19 % and 95 % of the predicted values, with an average of 51 %.

It is considered, therefore, that the ground movements measured using tributary cross lines are consistent with the predictions provided in Reports Nos. MSEC792 and MSEC865.

2.6. Donalds Castle Creek cross lines

The mine subsidence movements across Donalds Castle Creek were measured by IC using 2D survey techniques using the DCCXE-Line and DCCXF-Line. DCCXA-Line, DCCXB-Line, DCCXC-Line and DCCXD-Line were not measured during LW13. The locations of the Donalds Castle Creek cross lines are shown in Drawing No. MSEC965-01. The survey dates for these monitoring lines are provided in Table 2.14.

Table 2.14 Survey dates for the Donalds Castle Creek cross lines during LW13

Mining phase commitments	Mining phase survey dates	Post mining phase commitments
First survey 100 m before lines, then monthly surveys. Final survey when mining 400 m past lines	13 February 2013 (base survey) 4 March 2016 (end of LW11) 28 April 2017 (end of LW12) 26 May 2017 23 June 2017 21 July 2017 14 June 2018 (end of LW13)	Completion of each of the future longwalls in Area 3B

Summaries of the maximum measured and predicted total vertical subsidence and closure along the Donalds Castle Creek cross lines, after the extraction of LW13, are provided in Table 2.15 and Table 2.16. The predicted subsidence values have been derived from the predicted subsidence contours illustrated in Report No. MSEC865. The predicted closures are based on a combination of the conventional and valley related movements, taking the equivalent heights of the valleys within half-depths of cover from the valley bases. Survey line DCCXF-Line was established on the 8 May 2015 and therefore does not include the effects of LW9 and LW10.

Table 2.15 Maximum measured and predicted total subsidence and closure at the DCCXE-Line resulting from the extraction LW9 to LW13

Location	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	2516	369
Predicted	2575	375

Table 2.16 Maximum measured and predicted total subsidence and closure at the DCCXF-Line resulting from the extraction LW11 to LW13

Location	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	891	101
Predicted	1350	175

The accuracies of the measured relative levels of the survey marks along the Donalds Castle Creek cross lines are in the order of ±5 mm. The accuracies of the measured absolute levels of the survey marks are in the order of ±30 mm. The accuracies of the measured closures are in the order of ±5 mm.

The measured total vertical subsidence and closure for the DCCXE-Line and DCCXF-Line are less than the predicted values at the end of LW13. The measured vertical subsidence movements range between 66 % and 98 % of the predicted values. The measured closures range between 58 % and 98 % of the predicted values.

The maximum closure measured along the DCCE-Line, at any time during mining, was 490 mm on the 11 August 2016 (i.e. during LW12), which exceeded the predicted value. However, the closure decreased after that survey with a final measured value of 369 mm at the completion of LW13. The final closure is less than the predicted closure of 375 mm at the completion of this longwall.

The maximum closure measured along the DCCF-Line, at any time during mining, was 163 mm on the 11 August 2016 (i.e. during LW12). The closure reduced to 133 mm at the completion of LW12, which is less than the predicted value of 150 mm at that time. The closure reduced again to 101 mm at the completion of LW13, which is also less than the final predicted value of 175 mm.

It is considered, therefore, that the ground movements measured using Donalds Castle Creek cross lines are consistent with the predictions provided in Reports Nos. MSEC792 and MSEC865.

2.7. Swamp cross lines

The mine subsidence movements across the swamps have been measured by IC using 2D survey techniques using the SW4-Line, SW10-Line, SW11-Line and SW13-Line. The locations of the swamp cross lines are shown in Drawing No. MSEC965-01. The survey dates for these monitoring lines are provided in Table 2.17.

Table 2.17 Survey dates for the swamp cross lines during LW13

Mining phase commitments	Mining phase survey dates	Post mining phase commitments
First survey 100 m before lines then monthly surveys, final survey when mining 400 m past lines	9 February 2015 (base survey) 17 February 2016 (end of LW11) 28 February 2017 (end of LW12) 13 April 2017 18 May 2017 23 June 2017 21 July 2017 31 August 2017 11 October 2017 9 November 2017 11 January 2018 8 February 2018 13 March 2018 17 April 2018 15 May 2018	First survey 100 m before lines then monthly surveys, final survey when mining 400 m past lines

Summaries of the maximum measured and predicted total subsidence and closure along the swamp cross lines, resulting from the extraction of LW11 to LW13, are provided in Table 2.18 to Table 2.21. The predicted subsidence values have been derived from the predicted subsidence contours illustrated in Report No. MSEC865. The predicted closures are based on a combination of the conventional and valley related movements, taking the equivalent heights within half-depths of cover from the valley bases.

Table 2.18 Maximum measured and predicted total subsidence and closure at the SW4-Line resulting from the extraction of LW11 to LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	2044	190
Predicted	2700	425

Table 2.19 Maximum measured and predicted total subsidence and closure at the SW10-Line resulting from the extraction of LW11 to LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	2248	62
Predicted	3425	325

Table 2.20 Maximum measured and predicted total subsidence and closure at the SW11-Line resulting from the extraction of LW11 to LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	*Not measured*	2
Predicted	50	100

Table 2.21 Maximum measured and predicted total subsidence and closure at the SW13-Line resulting from the extraction of LW11 to LW13

Type	Maximum total subsidence (mm)	Maximum total closure (mm)
Measured	48	2
Predicted	< 20	150

The accuracies of the measured relative levels of the survey marks along the swamp cross lines are in the order of ±5 mm. The accuracies of the measured absolute levels of the survey marks are in the order of ±30 mm. The accuracies of the measured closures are in the order of ±5 mm.

The maximum measured vertical subsidence for the SW13-Line of 48 mm is greater than the predicted value of less than 20 mm. This monitoring line is located more than 100 m south of the maingate of LW13 and, therefore, only low-level vertical subsidence was predicted. The vertical subsidence could have developed further from LW13 than predicted since SW13-Line is located upslope of the longwall maingate. The measured closure for this monitoring of 2 mm is considerably less than predicted value of 150 mm.

Elsewhere, the measured vertical subsidence and closure at the SW4-Line, SW10-Line and SW11-Line are all less than the predicted values. The measured vertical subsidence movements range between 66 % and 76 % of the predicted values. The measured closures range from less than 10 % to 45 % of the predicted values.

It is considered, therefore, that the ground movements measured using Swamp cross lines are consistent with the predictions provided in Reports Nos. MSEC792 and MSEC865.

2.8. ALS / LiDAR surveys

The changes in surface level due to the extraction of LW9 to LW13 have been measured using Airbourne Laser Scan (ALS) / Light Detection and Ranging (LiDAR) surveys. The initial surface level contours have been determined from the base survey carried out in January 2013, prior to the extraction of LW9. The post mining surface level contours have been determined from the subsequent surveys carried out in February 2014 after LW9, in January 2015 after LW10, in April 2016 after LW11, in March 2017 after LW12 and in May 2018 after LW13.

The measured incremental changes in surface level due to the extraction of LW13 only are shown in Fig. 2.6. These contours have been determined by taking the differences between the surface levels measured before and after the extraction of this longwall. The data located outside the predicted limit of vertical subsidence (i.e. 20 mm subsidence contour) have been removed for clarity.

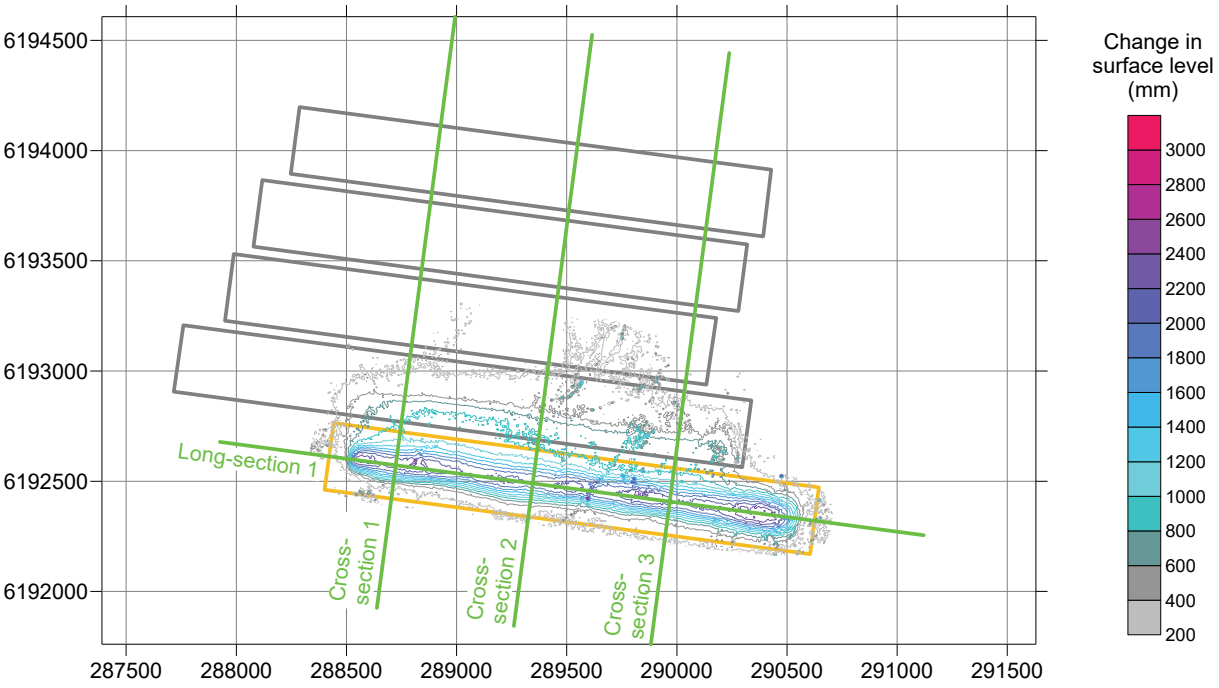

Fig. 2.6 Measured incremental changes in surface level due to the extraction LW13

The measured total changes in surface level due to the extraction of LW9 to LW13 are shown in Fig. 2.7. These contours have been determined by taking the differences between the surface levels measured before the extraction of LW9 and after the completion of LW13.

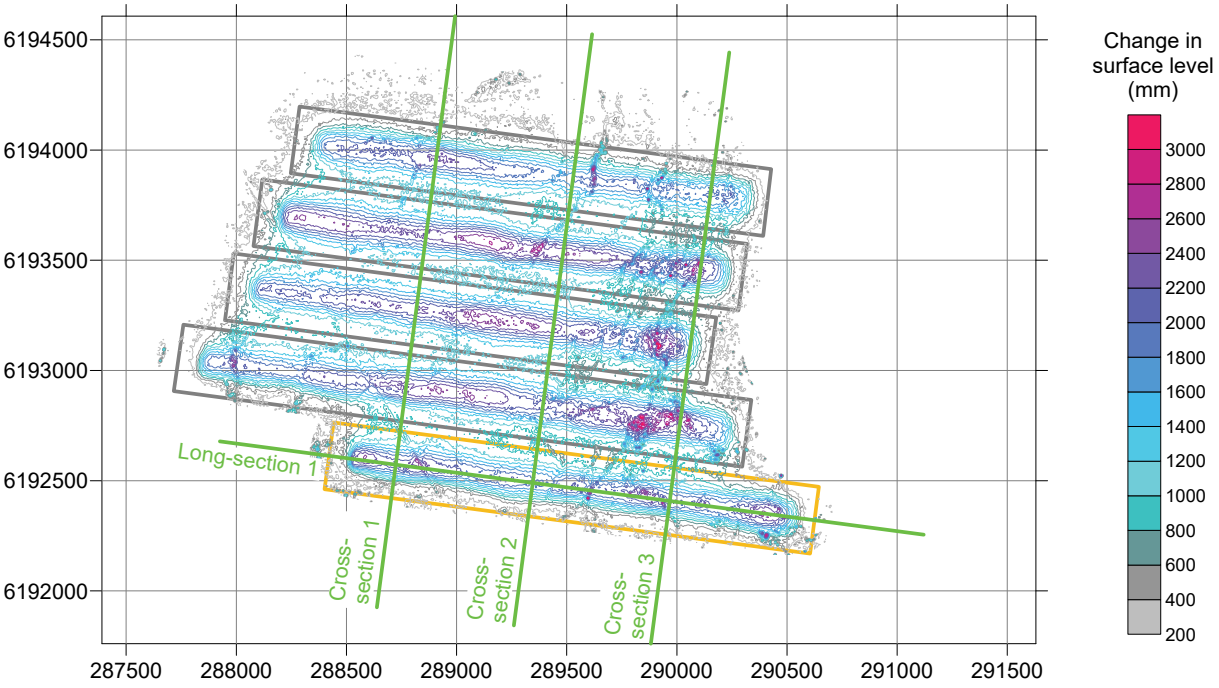

Fig. 2.7 Measured total changes in surface level due to the extraction of LW9 to LW13

The contours of the measured changes in surface level, developed from the LiDAR surveys, show the changes in the heights of points at fixed positions in space (i.e. eastings and northings). This differs from traditional subsidence contours that include both the vertical and horizontal components of the 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 that are fixed to the ground.

The contours can contain artefacts (i.e. locally increased or decreased movements), particularly in the locations of steeply incised terrain, such as at the cliffs and steep slopes. These artefacts can be seen in Fig. 2.6 and Fig. 2.7 as the localised areas of dark purple to red contours above the longwalls and the lower level subsidence outside the extents of the longwalls.

The change in surface level at a fixed position in space (i.e. easting and northing), therefore, can be large in the locations of cliffs and steep slopes and does not provide a true indication of the actual vertical subsidence at a point on the ground. However, where the ground is reasonably flat, the contours of the measured changes in surface level should provide a good indication of the actual vertical subsidence.

The LiDAR surveys have an accuracy for absolute level in the order of ±100 mm. The accuracy of the measured changes in surface level (i.e. the difference between two surveys), therefore, is in the order of ±200 mm.

The comparisons of the measured changes in surface level and the predicted vertical subsidence along Cross-sections 1 to 3 and Long-section 1 are provided in Fig. 2.8 to Fig. 2.11. The locations of these sections are indicated in Fig. 2.6 and Fig. 2.7. The predicted profiles of vertical subsidence have been derived from the predicted subsidence contours illustrated in Report No. MSEC865.

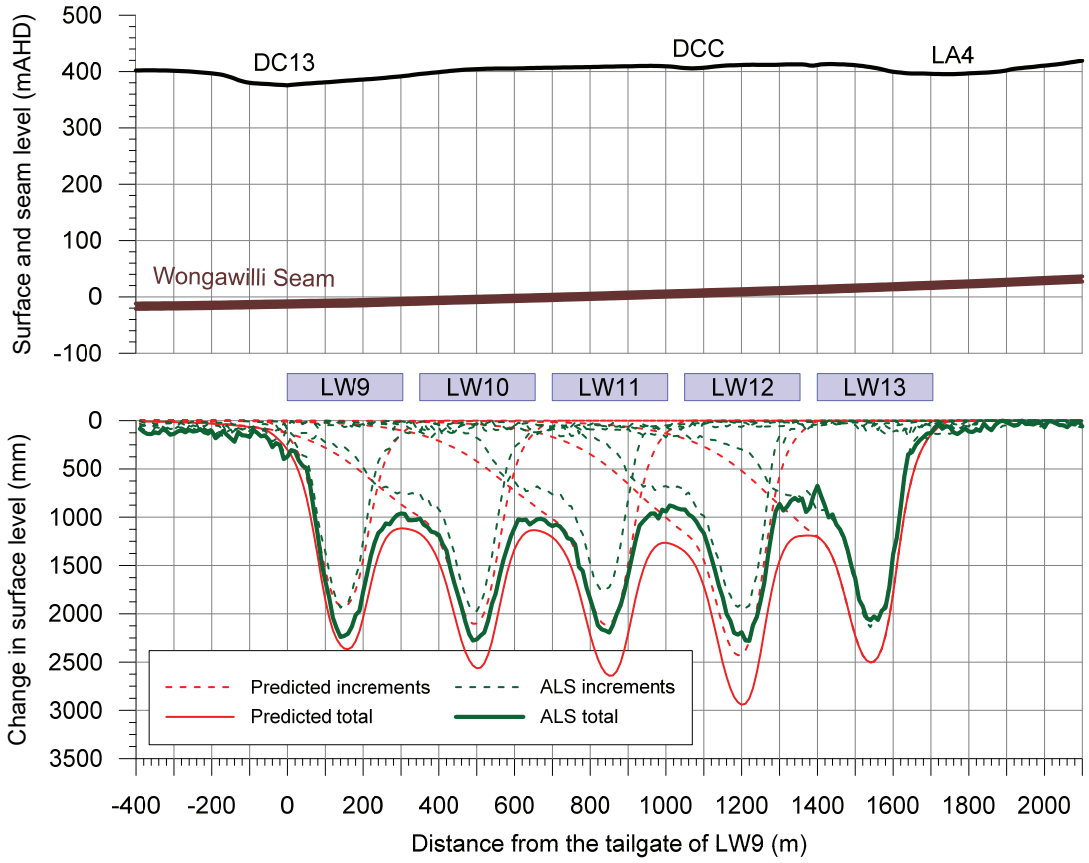

Fig. 2.8 Measured changes in surface level and predicted vertical subsidence along Cross-section 1

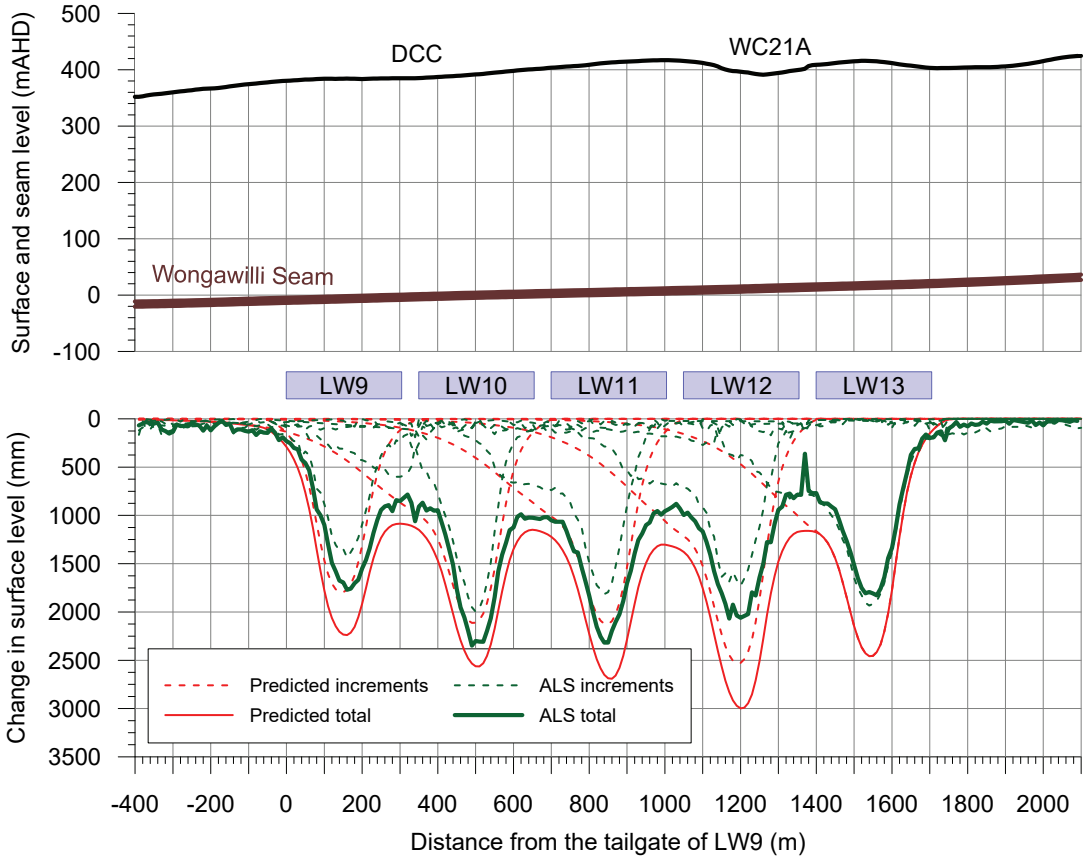

Fig. 2.9 Measured changes in surface level and predicted vertical subsidence along Cross-section 2

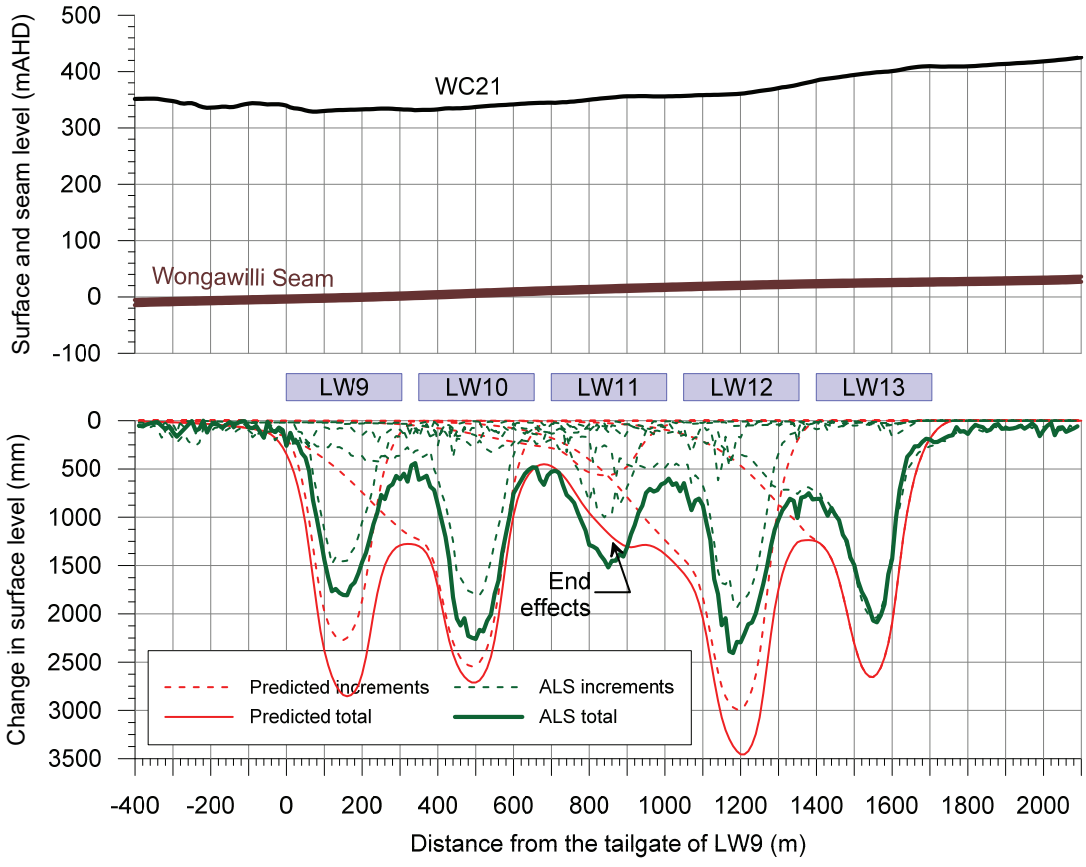

Fig. 2.10 Measured changes in surface level and predicted vertical subsidence along Cross-section 3

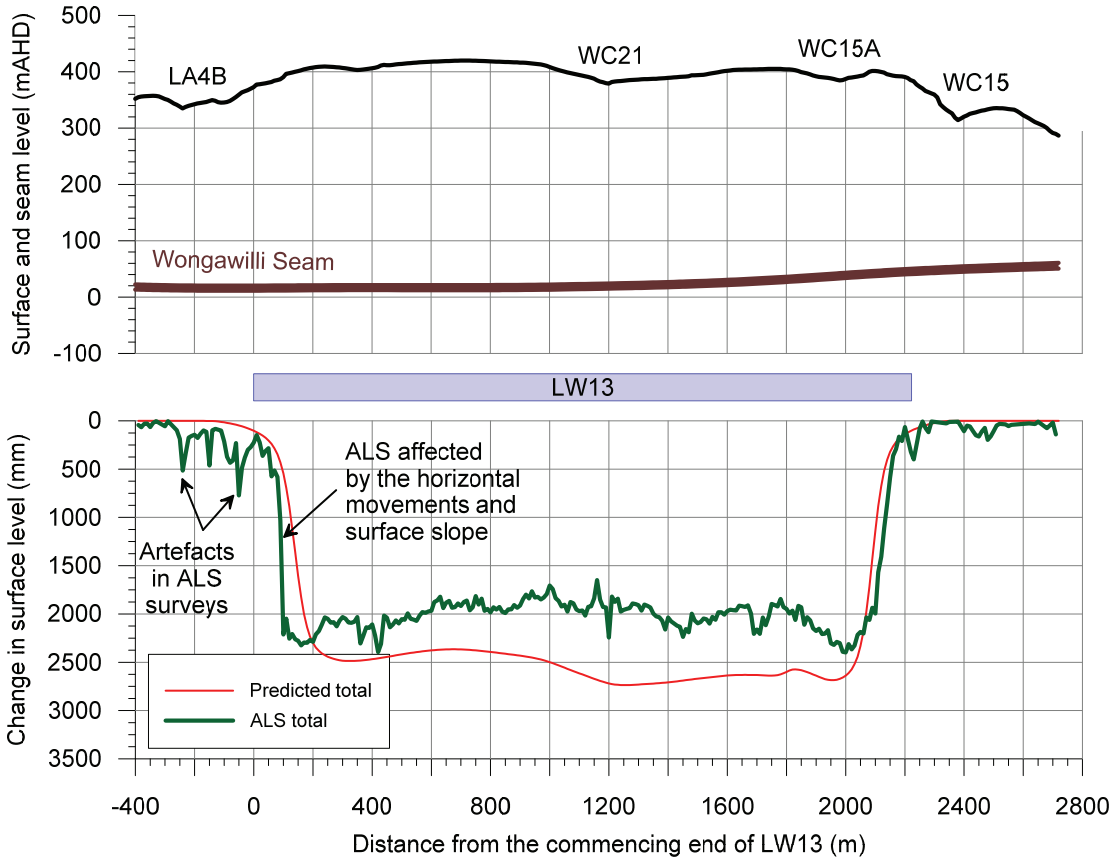

Fig. 2.11 Measured changes in surface level and predicted vertical subsidence along Long-section 1

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

The measured change in surface level along Cross-section 3 (refer to Fig. 2.10) is slightly greater than the predicted vertical subsidence above LW11. This cross-section is located close to the finishing end of LW11 and, therefore, the predictions are influenced by the longwall end effects. The difference between the measured and predicted movements are in the order of accuracy of the measurement method.

The measured change in surface level along Long-section 1 (refer to Fig. 2.11) is greater than the predicted vertical subsidence above the commencing end of LW13 (i.e. left side of figure). However, this may be partly due to the effects of the horizontal movements on the LiDAR surveys. The ground directly above the commencing end of LW13 has moved towards the ends (i.e. following the extraction face) as illustrated in the horizontal movement vectors in Drawing No. MSEC965-04. The natural surface dips towards the west in this location (i.e. towards the thalweg of LA4B). The mining-induced horizontal movement, therefore, results in the measured changes in level at a fixed position to be greater than the true vertical subsidence above the commencing end of LW13.

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

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

It is considered that the ground movements measured using the LiDAR surveys are consistent with the predictions provided in Report No. MSEC865.

3.1. Surface deformations

The surface deformations due to the extraction of LW13 have been identified by the IC Environmental Field Team and are described in the attached landscape report. The locations of the soil cracking and rock fracturing identified during the extraction of LW13 is illustrated in Fig. 3.1.

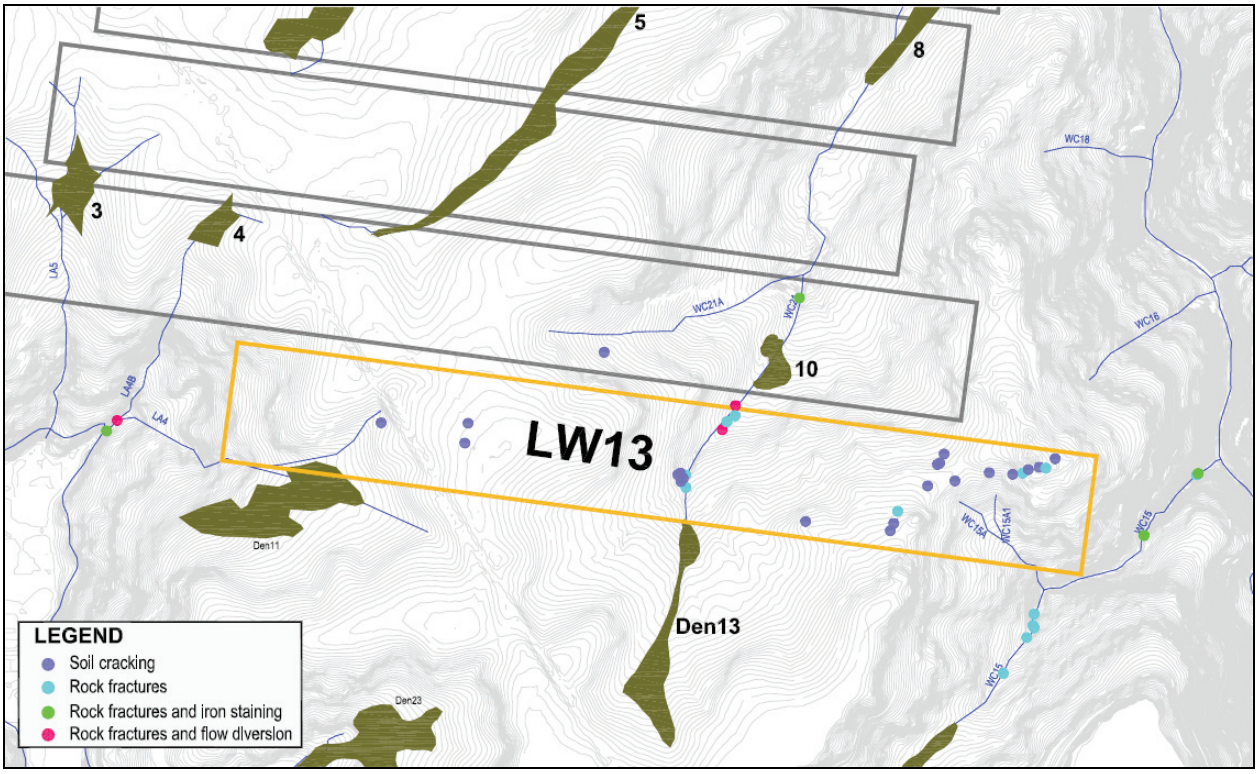

Fig. 3.1 Surface deformations due to the extraction of LW13

Soil cracking (i.e. blue circles) was identified at 22 sites along or near the fire trails, seismic tracks and the railway corridor directly above LW13. The crack widths varied from less than 20 mm to approximately 200 mm. The measured soil crack widths were 50 mm or less at 50 % of the sites, between 50 mm and 100 mm at 32 % of the sites, between 100 mm and 200 mm at 18 % of the sites. The measured lengths varied from less than 1 m to approximately 70 m. The measured depths of the soil cracks varied from approximately 0.1 m to greater than 5 m.

The rock fractures (i.e. cyan, green and red circles) were identified on the ridgelines and along the alignments of Streams WC15, WC21 and 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 fracturing occurred along Stream WC21 directly above LW13, along the upper reaches of Stream WC15 and the lower reaches of Stream LA4. Fracturing was observed at distances up to 300 m from the longwall.

Surface water flow diversions (i.e. red circles) were identified along Stream WC21 directly above LW13 and Stream LA4 at a distance of 280 m west of the LW13 commencing end. However, fracturing and low surface water flows were initially observed in Stream LA4 during the extraction of LW12. Iron staining was also observed along Streams WC15 and LA4.

Further details of these surface deformations are provided in the attached landscape report.

3.2. Natural features

The natural features near Dendrobium LW13 are shown in Drawing No. MSEC965-02, in Appendix A, and include:

- Wongawilli Creek;
- Donalds Castle Creek;
- drainage lines;

- cliffs;
- rock outcrops;
- steep slopes;
- swamps; and
- archaeological sites.

The MSEC assessed impacts for the natural features resulting from the extraction of Dendrobium LW9 to LW18 are provided in Report No. MSEC459, which supported the SMP Application. These assessments were reviewed and updated based on the re-calibrated subsidence model and are provided in Reports Nos. MSEC792 and MSEC865. More detailed assessments for the natural features were also provided in other consultants' reports.

Comparisons between the MSEC assessments and the reported impacts for the natural features listed above, resulting from the extraction of LW13, are provided in Table 3.1. The reported impacts are based on those recorded by IC Environmental Field Team that are described in the accompanying landscape report.

Table 3.1 Assessed and reported impacts for the natural features due to LW13

Natural feature	MSEC assessed impacts	Reported impacts
Wongawilli Creek	Very localised additional **ponding** or **flooding** developing in the locations of existing pools, steps or cascades	No reported impacts
	Minor **fracturing** of the bedrock within 400 m of the longwalls	Fracturing along creek between LW6 andLW9 (first observed during the mining of LW9)
	Low-likelihood that **surface water flow diversions** would occur	One Type 3 impact (surface water flow diversion) observed between LW6 and LW9, where fracturing was first observed during the mining of LW9.
Donalds Castle Creek	Localised additional **ponding** or **flooding** developing in the locations of existing pools, steps or cascades	No reported impacts
	Fracturing of the bedrock directly above the longwall, however, the majority of this section of the creek has soil accumulations (i.e. only isolated outcropping of bedrock above the longwall). Also, possible for some minor **fracturing** of the bedrock outside and within 400 m of the longwalls	No reported impacts
	Surface water flow diversions could occur directly above the longwall	No reported impacts
Drainage lines	Localised additional **ponding**, **flooding** or **scouring** along sections of the drainage lines located directly above the longwall	No reported impacts
	Buckling and **fracturing** of the bedrock along the drainage lines above or within 400 m of the longwalls	Rock fractures and uplift identified along WC15, WC21 and LA4. The facture widths varied between 2 mm and 220 mm, with the majority of widths being 50 mm or less. Refer to the IC landscape report for further details
	Surface water flow diversions into the dilated strata beneath the drainage lines which are directly mined beneath	Loss of surface water flow along Streams WC15, WC21 and LA4. Fracturing and low flows first observed along Stream LA4 during the mining of LW12. Refer to the IC landscape report for further details
	Water quality – refer to the accompanying water quality report **Terrestrial ecology** – refer to the accompanying terrestrial ecology report **Aquatic ecology** – refer to the accompanying aquatic ecology report	
Cliffs	Fracturing resulting in isolated **rockfalls** for cliffs located outside the mining area. Large-scale cliff instabilities not expected	Soil cracking along the tracks and fracturing of rock outcrops located above the cliffs, but no fracturing or rockfalls from exposed cliff rockfaces

Natural feature	MSEC assessed impacts	Reported impacts
Rock outcrops	Fracturing of bedrock which could result in **rockfalls** along the exposed rockfaces. Fracture widths up to approximately 300 mm previously observed at the Mine	Fracturing and spalling of rock outcrops along the ridgeline above the finishing end of LW13. Fracture widths varied up to approximately 50 mm
Steep slopes	**Soil slippage** resulting in tension cracks and compression ridges. Soil cracks between approximately 100 mm and 400 mm previously observed at the Mine	Soil cracking observed on or near the fire trails, seismic tracks and railway corridor. Crack widths varied between 20 mm and approximately 200 mm, with the majority of widths being 50 mm or less. Refer to the IC landscape report for further details
Swamps	**Fracturing** of the underlying strata which could result in the **diversion of surface water**	Groundwater levels lower than baseline and recession rates greater than baseline for Swamp 11. Refer to the IC landscape report for further details
Archaeological sites	Impacts on overhang sites include fracturing of sandstone, rock falls, or water seepage through joints which may affect artwork	No adverse impacts reported. Refer to the accompanying archaeological report for further details

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

The longwalls at Dendrobium Mine were setback from Wongawilli Creek so that the predicted closure is less than 200 mm. It was assessed that the likelihood of significant fracturing resulting in surface water flow diversions along Wongawilli Creek would be very low, i.e. affecting less than 10 % of the pools and channels. It is considered that the observed rate of impact (i.e. one Type 3 impact along the 2 km length of Wongawilli Creek) is similar to the MSEC assessments provided in Reports Nos. MSEC459, MSEC792 and MSEC865.

Rock fracturing was observed directly above LW13 and long the streams at distances up to 300 m from the longwall. It was assessed that rock fracturing could occur along the streams up to approximately 400 m from the mining area. It is considered, therefore, that the observed impacts due to the extraction of LW13 are consistent with the MSEC assessments provided in Reports Nos. MSEC459, MSEC792 and MSEC865.

Further assessments of natural features have been provided by other specialist consultants on the project, which are described in the relevant reports accompanying the *End of Panel* report.

3.3. Built features

The built features near LW13 are shown in Drawing No. MSEC965-03, in Appendix A, and include:

- Fire trails and four-wheel drive tracks;
- Disused Maldon Dombarton Railway Corridor;
- Avon Dam; and
- Survey control marks.

Cordeaux Dam Wall is located more than 5 km north of LW13, at its closest point. The Upper Cordeaux No. 2 Dam Wall is located more than 6 km south-east of LW13, at its closest point. It is unlikely that these dam walls would experience measurable far-field horizontal movements resulting from the extraction of LW13 and, therefore, they have not been assessed further.

The MSEC assessed impacts for the built features resulting from the extraction of Dendrobium LW9 to LW18 are provided in Report No. MSEC459, which supported the SMP Application. These assessments were reviewed and updated based on the re-calibrated subsidence model and are provided in Reports Nos. MSEC792 and MSEC865.

Comparisons between the MSEC assessments and the reported impacts for the built features listed above, resulting from the extraction of LW13, are provided in Table 3.2. The reported impacts are based on those recorded by IC Environmental Field Team that are described in the accompanying landscape report.

Table 3.2 Assessed and reported impacts for the built features due to LW13

Built feature	MSEC assessed impacts	Reported impacts
Fire trails and four-wheel drive tracks	Cracking of unsealed road surfaces	Soil / surface cracking observed on or near the fire trails, seismic tracks and railway corridor, with widths ranging between approximately 20 mm and 450 mm. Refer to the IC landscape report for further details
Disused Maldon-Dombarton Railway	Possible fracturing of rock cuttings, spalling, and/or mobilisation of rock joints	Surface cracking above LW13 near the alignment of the railway corridor
Avon Dam	Adverse impacts not anticipated	No reported impacts on stored waters. Refer to associated groundwater report for further details
Survey control marks	Vertical and horizontal movements which could require re-establishment	No reported damage to the survey control marks. The marks to be re-established after completion of mining, as required

It has been considered that the observed impacts on the surface infrastructure, resulting from the extraction of LW13, are similar to or less than the MSEC assessments provided in Reports Nos. MSEC459, MSEC792 and MSEC865.

4.0 SUMMARY

The mine subsidence movements due to the extraction of LW13 were measured using the Wongawilli Creek closure lines, Avon Dam closure lines, Area 3B and Avon Dam 3D monitoring points, tributary cross lines, Donalds Castle Creek cross lines, swamp cross lines and airborne laser scans of the area.

The measured ground movements after the extraction of LW13 were generally similar to or less than the predicted values based on the re-calibrated subsidence model outlined in Reports Nos. MSEC792 and MSEC865.

The closure measured at the Donalds Castle Creek DCCE-Line during the mining of LW12 was greater than that predicted. However, the closure reduced during the extraction of LW13, with the final measured closure of 369 mm being less than the predicted value of 375 mm.

The measured vertical subsidence at the Swamp SW13-Line of 48 mm was greater than the predicted value of less than 20 mm. This monitoring line is located more than 100 m south of the maingate of LW13 and, therefore, only low-level vertical subsidence was predicted. The measured closure at this monitoring of 2 mm was considerably less than the predicted value of 150 mm.

It is considered, therefore, that the ground movements measured due to the extraction of LW13 are generally consistent with the predictions provided in Reports Nos. MSEC792 and MSEC865.

Soil cracking and rock fracturing were observed directly above LW13 and along the streams at distances up to 300 m outside of the longwall. The crack and fracture widths varied between approximately 2 mm and 220 mm, with the majority of the surface deformations having widths of 50 mm or less. It was assessed that soil and fracture widths between approximately 100 mm and 400 mm could occur directly above the extracted longwalls and that isolated surface impacts could occur up to 400 m outside of the longwalls.

Surface water flow diversions were identified along Stream WC21 directly above LW13 and along Stream LA4 at a distance of 280 m west of the LW13 commencing end. However, fracturing and low surface water flows were initially observed in Stream LA4 during the extraction of LW12. Iron staining was also observed along Streams WC15 and LA4. Surface water flow diversions were expected for the streams located directly above LW13 and in isolated locations outside of this longwall.

It is considered, therefore, that the observed surface impacts on the natural and built features, resulting from the extraction of LW13, are consistent with the MSEC assessments provided in Reports Nos. MSEC792 and MSEC865. Further assessments for the natural features have been provided by the specialist consultants on the project and the findings in this report should be read in conjunction with the findings provided in the accompanying specialist reports.

APPENDIX A. DRAWINGS

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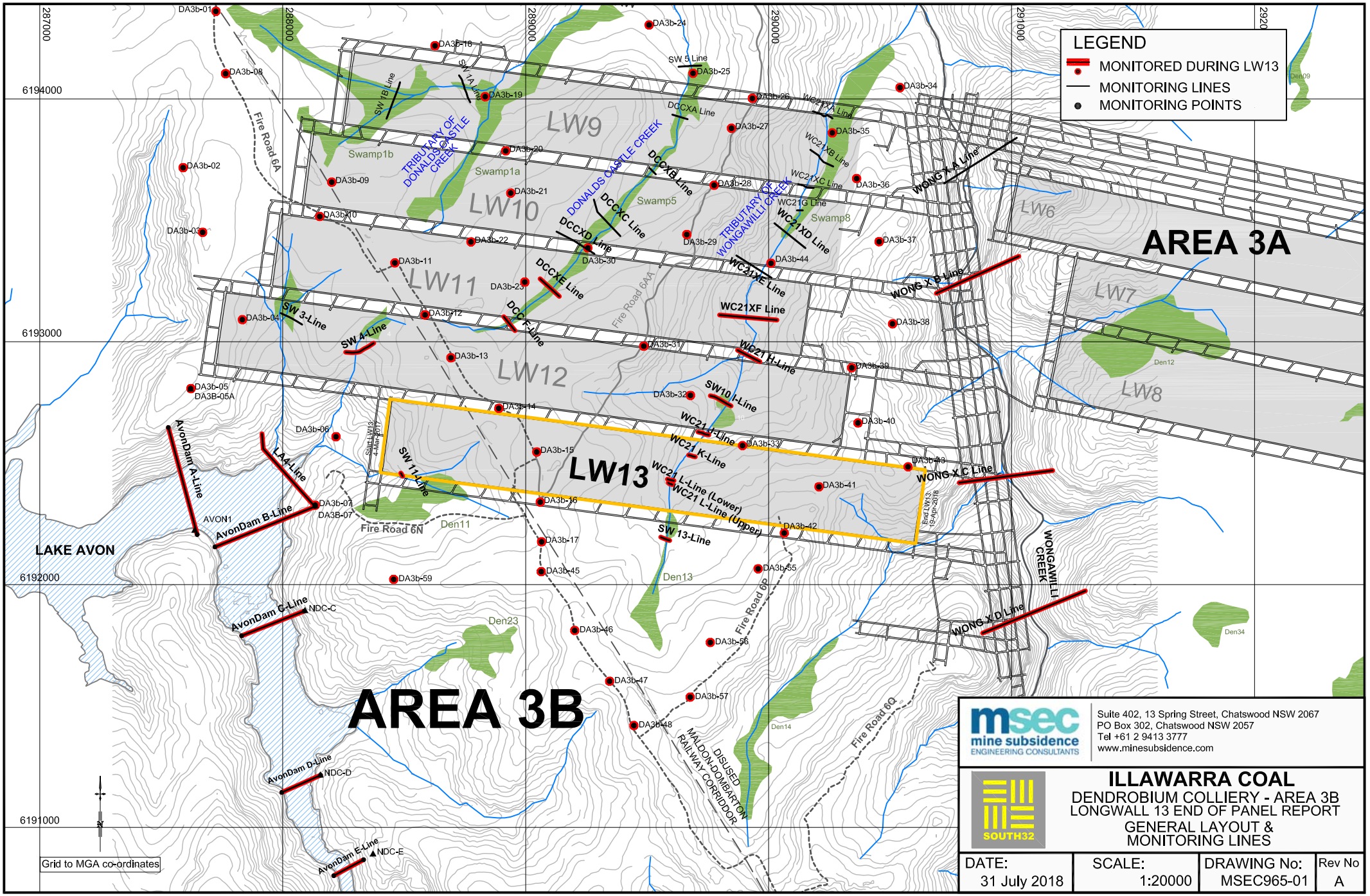

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SOUTH32

ILLAWARRA COAL

DENDROBIUM COLLIERY - AREA 3B
LONGWALL 13 END OF PANEL REPORT
GENERAL LAYOUT & MONITORING LINES

DATE:	SCALE:	DRAWING No:	Rev No
31 July 2018	1:20000	MSEC965-01	A

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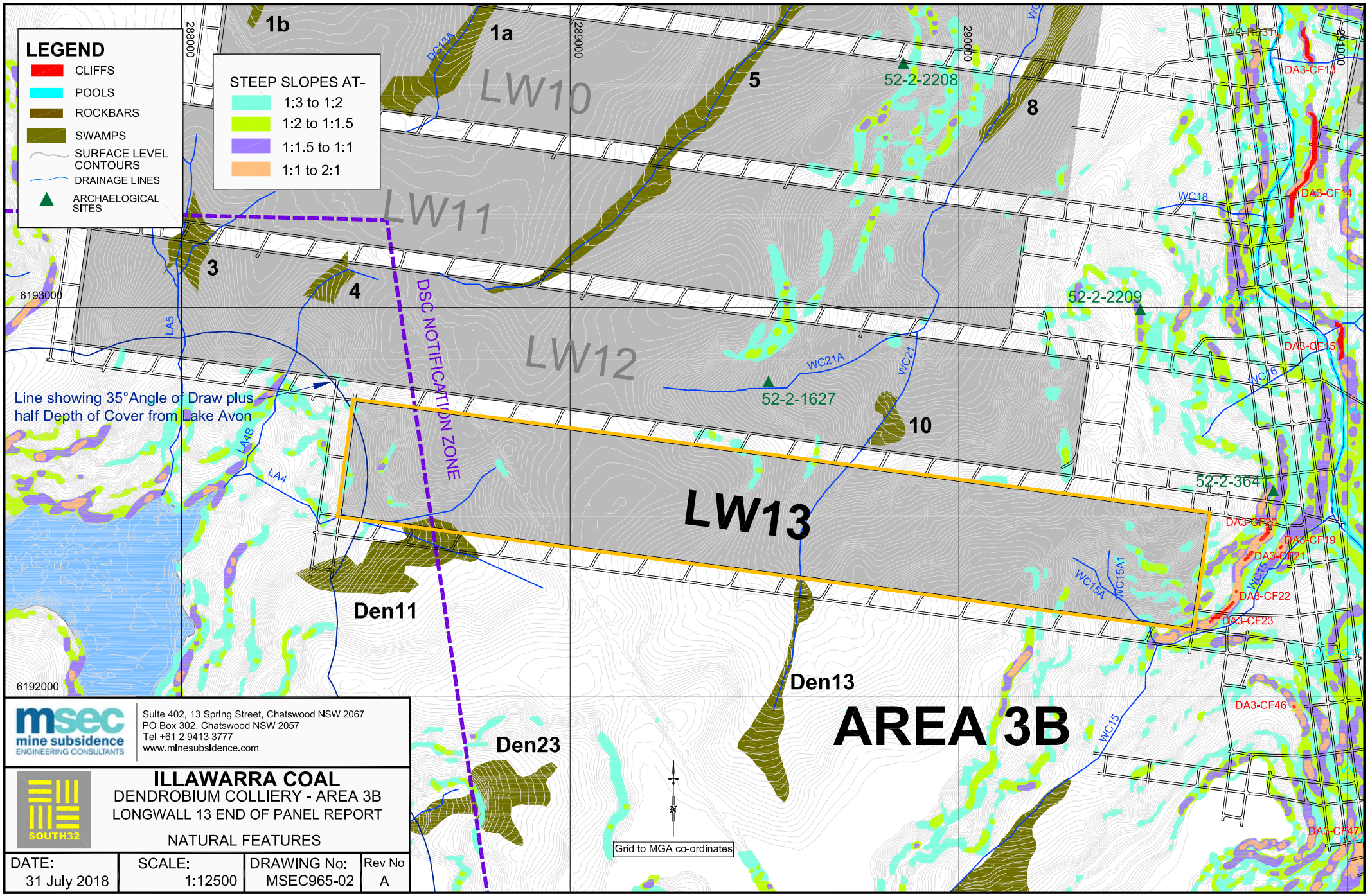

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DENDROBIUM COLLIERY - AREA 3B

LONGWALL 13 END OF PANEL REPORT

NATURAL FEATURES

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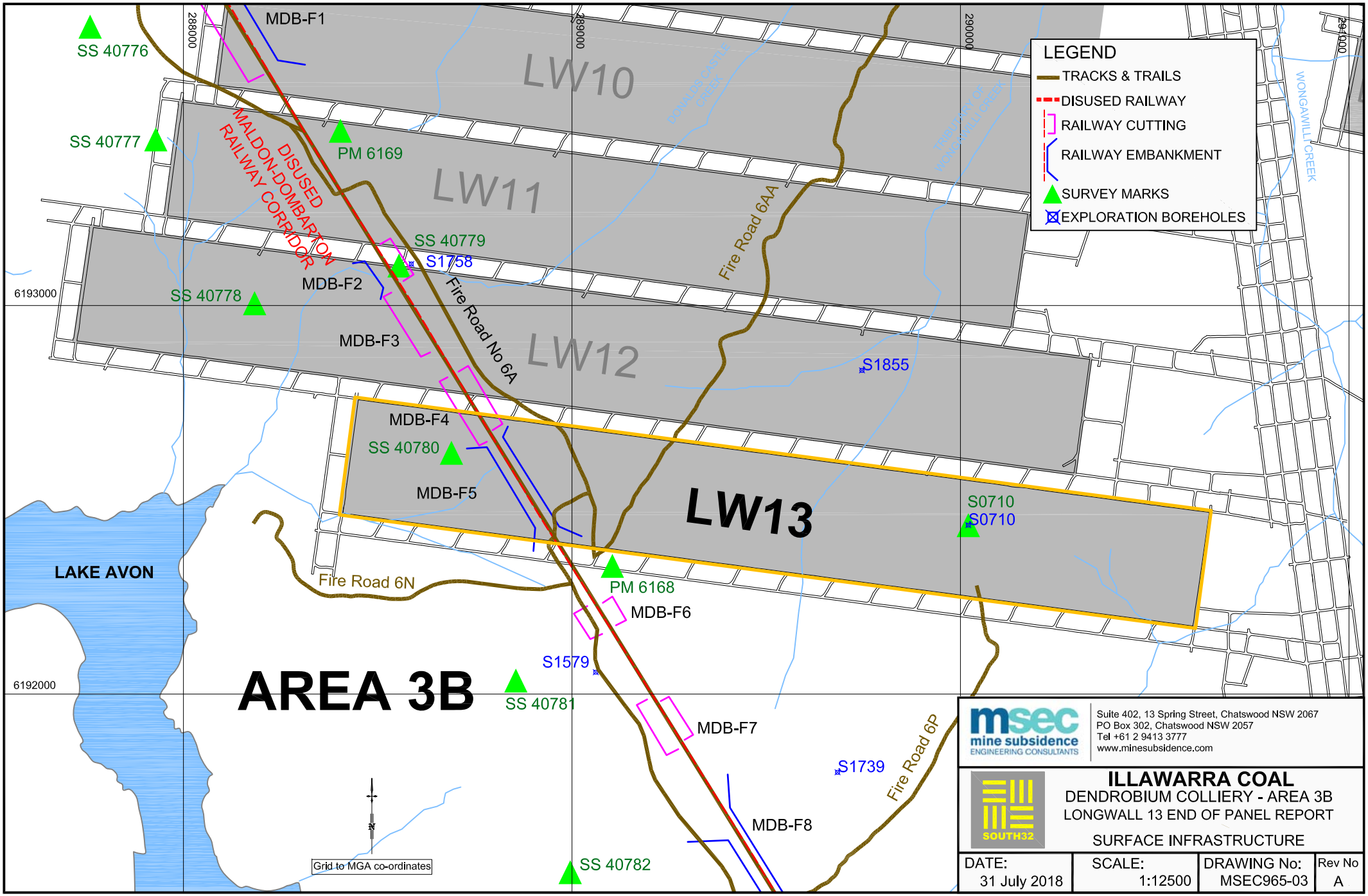

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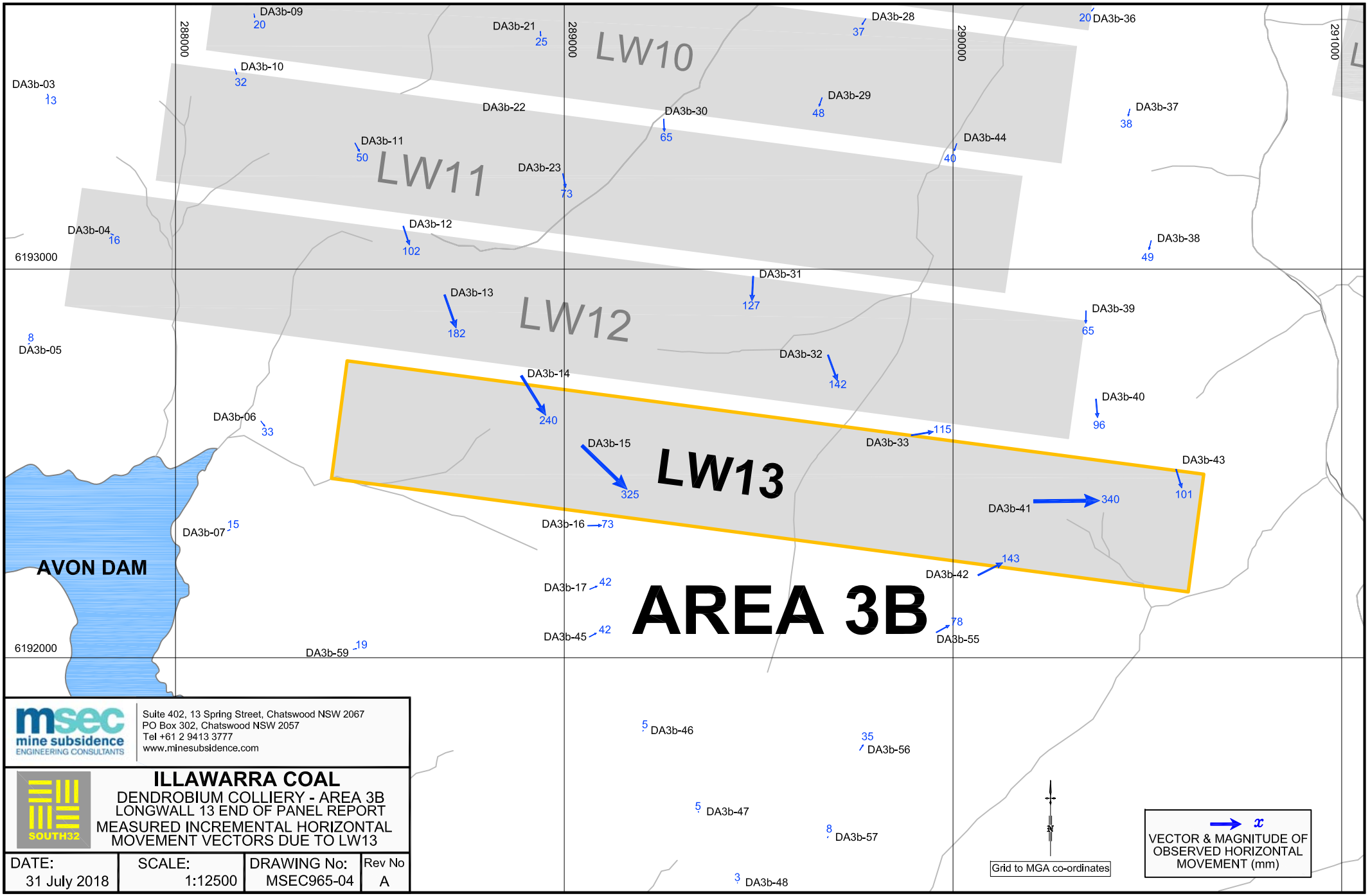

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ILLAWARRA COAL

DENDROBIUM COLLIERY - AREA 3B
LONGWALL 13 END OF PANEL REPORT
MEASURED INCREMENTAL HORIZONTAL MOVEMENT VECTORS DUE TO LW13

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31 July 2018	1:12500	MSEC965-04	A