REPORT: SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

ILLAWARRA COAL:

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

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01	Draft Issue	JB	-	16th Sep 15
A	Final Issue	JB	DRK	30th Sep 15
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Report produced to:- Support the review of the subsidence predictions and impact assessments for Dendrobium Area 3B based on the observed movements and impacts due to the extraction of Longwalls 9 and 10 at the mine.

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).

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)

EXECUTIVE SUMMARY

South32 Illawarra Coal (IC) has approval to mine Longwalls 9 to 18 in Area 3B at Dendrobium Mine. At this time, Longwalls 9 and 10 have been completed and Longwall 11 is currently being extracted. Longwalls 14 to 18 require further approval of the Secretary of the Department of Planning and Environment.

The subsidence predictions and impact assessments for Longwalls 9 to 18 were provided in Report No. MSEC459 (Rev. B), which supported the SMP Application for these longwalls. The subsidence predictions were obtained using the Incremental Profile Method, which was calibrated for the local conditions using the monitoring data from Dendrobium Mine that was available at that time, which comprised data from Longwalls 1 and 2 in Area 1, Longwalls 3 to 5 in Area 2 and Longwall 6 in Area 3A.

The observed physical impacts (i.e. cracking in surface soils, fracturing of bedrock and rockbars and surface water flow diversions) for the natural and built features due to the extraction of the previous Longwalls 9 and 10 were considered to be consistent with the assessed impacts provided in Report No. MSEC459 and the SMP Application. Further discussions on the impacts and environmental consequences have been provided by other specialist consultants on the project.

In accordance with Condition 5 of the approval conditions, IC is required to review and update the subsidence predictions and impact assessments for Longwalls 14 to 19, based on the comparisons of observed and predicted movements and impacts for the approved longwalls.

The subsidence prediction model has been reviewed and updated based on the observed movements resulting from the extraction of Longwalls 7 and 8 in Area 3A and Longwalls 9 and 10 in Area 3B. The maximum predicted subsidence parameters for the future Longwalls 12 to 18, based on the MSEC792 prediction curves, are: 3,600 mm vertical subsidence; 50 mm/m (i.e. 5 %, or 1 in 20) tilt; and 1.4 km^{-1} hogging and sagging curvatures (i.e. minimum radius of curvature of 0.7 kilometres).

The maximum predicted subsidence parameters based on the MSEC792 prediction curves are greater than those based on the MSEC459 prediction curves by: 30 % for vertical subsidence; 25 % for tilt; and 40 % for curvature. It is noted that, whilst the predicted subsidence parameters have increased, the impact assessments provided in Report No. MSEC459 included the cases where the predictions were exceeded by a factor of up to 2 times.

Whilst it would be expected that the rates of potential impacts would increase, given the greater predicted subsidence, the nature of these impacts are unlikely to change, i.e. a greater number of fractures with increased widths in the exposed bedrock resulting in a slightly increased potential for surface water flow diversions. The impacts resulting from Longwalls 12 to 18 are likely to be similar in nature to the impacts observed due to Longwalls 10 and 11.

The management strategies for the natural and built features for the future Longwalls 12 to 18, therefore, are the same those provided in Report No. MSEC459 and the SMP Application. Further discussions on the impact assessments and management strategies are provided in the Watercourse Impact Monitoring Management and Contingency Plan (WIMMCP) and Swamp Impact Monitoring Management and Contingency Plan (SIMMCP).

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1.1. Background

South32 Illawarra Coal (IC) has approval to mine Longwalls 9 to 18 in Area 3B at Dendrobium Mine. At this time, Longwalls 9 and 10 have been completed and Longwall 11 is currently being extracted. Longwalls 14 to 18 require further approval of the Secretary of the Department of Planning and Environment.

The subsidence predictions and impact assessments for Longwalls 9 to 19 were provided in Report No. MSEC459 (Rev. B), which supported the SMP Application for these longwalls. The subsidence predictions were obtained using the Incremental Profile Method, which was calibrated for the local conditions using the monitoring data from Dendrobium Mine that was available at that time, which comprised data from Longwalls 1 and 2 in Area 1, Longwalls 3 to 5 in Area 2 and Longwall 6 in Area 3A.

In accordance with Condition 5 of the approval conditions, IC is required to review and update the subsidence predictions and impact assessments for Longwalls 14 to 19, based on the comparisons of observed and predicted movements and impacts for the approved longwalls.

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

- Review the subsidence predictions provided in Report No. MSEC459 with the measured movements at the monitoring lines due to the extraction of Longwalls 9 and 10;
- Review and revise the calibration of the prediction model based on the latest monitoring data;
- Review the impacts observed to date for Longwalls 9 and 10 and compare these with the assessed impacts provided in Report No. MSEC459; and to
- Review and update the impact assessments for the natural and built features for Longwalls 12 to 19 based on the revised subsidence prediction model.

The review of the impact assessments provided in this report refer to the physical impacts, i.e. cracking, fracturing and deformation of the bedrock and surface soils as the result of mining. The review of the environmental consequences are provided in the Watercourse Impact Monitoring Management and Contingency Plan (WIMMCP) and Swamp Impact Monitoring Management and Contingency Plan (SIMMCP). The discussions provided in this report, therefore, should be read in conjunctions with the WIMMCP and SIMMCP.

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

Chapter 3 provides the review and update of the calibration of the Incremental Profile Method based on the observed movements due to the extraction of Longwalls 9 and 10.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of the longwalls in Area 3B, based on the revised subsidence prediction model. These revised predicted subsidence parameters are also compared with those presented in Report No. MSEC459.

Chapters 5 and 6 provide the reviews and updated impact assessments for the natural and built features located within the Study Area based on the revised subsidence predictions.

1.2. Mining Geometry

1.2.1. Proposed Longwalls in Area 3B

The layout of the longwalls in Area 3B is shown in Drawing No. MSEC792-02, in Appendix D.

At this time, Longwalls 9 and 10 have been completed and Longwall 11 was currently being extracted. A summary of the dimensions of these as-extracted (i.e. previous) longwalls is provided in Table 1.1.

Table 1.1 Geometry of the Previous Longwalls 9 to 11

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
LW9	2,200	305	-
LW10	2,220	305	45
LW11	2,205	305	45

A summary of the dimensions of the future Longwalls 12 to 18 is provided in Table 1.2.

Table 1.2 Geometry of the Future Longwalls 12 to 19

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
LW12	2,710	305	45
LW13	2,275	305	45
LW14	2,365	305	45
LW15	2,300	305	45
LW16	2,225	305	45
LW17	2,315	305	45
LW18	2,055	305	45

The length of Longwall 12 includes the proposed modified (i.e. shorted) commencing end, which is the subject of a separate application.

1.3. Surface and Seam Levels

The surface level contours in the vicinity of the longwalls are shown in Drawing No. MSEC792-03, which were generated from an airbourne laser scan of the area. The land in the eastern and northern parts of the mining area drain into Wongawilli Creek and the land in the western and southern parts of the Study Area drain into Lake Avon.

The surface levels directly above the future longwalls vary from a low point of approximately 345 metres AHD, above the eastern end of Longwall 12, to a high point of approximately 450 metres AHD, above the eastern ends of Longwalls 17 and 18.

The seam floor contours, seam thickness contours and depth of cover contours are shown in Drawings Nos. MSEC792-04, MSEC792-05, and MSEC792-06, respectively. The contours are based on the latest seam information provided by IC.

The surface and seam levels vary across the mining area which is illustrated along Cross-section 1 in Fig. 1.1. The location of this section is shown in Drawing No. MSEC792-02.

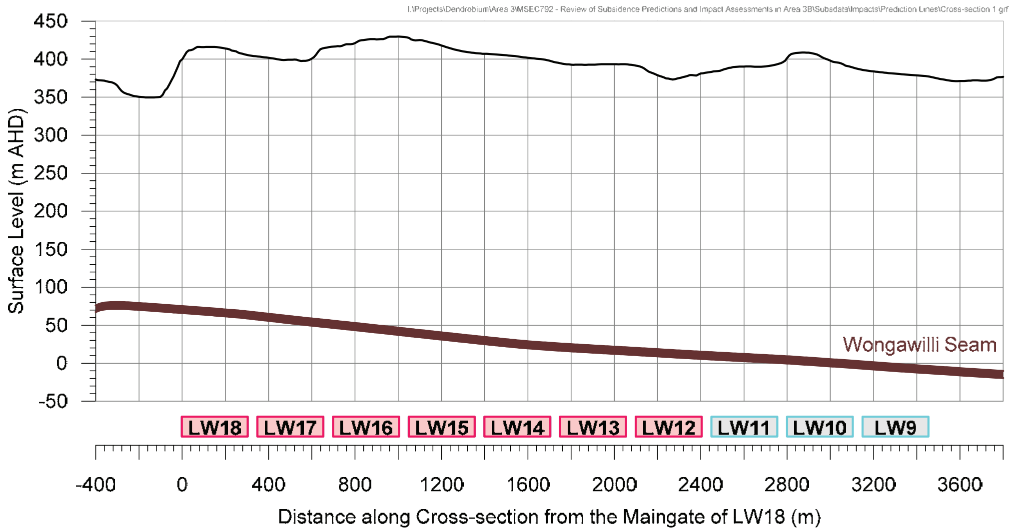

Fig. 1.1 Surface and Seam Levels along Cross-section 1

The depth of cover to the Wongawilli Seam directly above the longwalls varies between a maximum of 415 metres, above the western end of the Longwall 9, and a minimum of 280 metres, above the eastern end of Longwall 18.

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 maximum seam dip within the mining area is around 10 %, or 1 in 10, which occurs locally in the south-eastern corner of the mining area.

The Wongawilli Seam in Area 3B is nominally 10 metres thick and contains numerous bands of non-coal material. The economic section of the Wongawilli Seam is the basal 3 metres to 5 metres. IC has reviewed the nature of the banding in Area 3B and proposed to extract a maximum height of 3.9 metres for Longwall 9 and a maximum height of 4.6 metres for Longwalls 10 to 18.

A summary of the actual mining heights for Longwalls 9 to 11 is provided in Table 1.3. These as-extracted heights are also illustrated in Drawing No. MSEC792-05.

Table 1.3 Actual Mining Height for Longwalls 9 to 11

Longwall	Start Chainage	End Chainage	Mining Height (m)
LW9	2,180	1,740	3.4
	1,740	1,400	3.7
	1,400	0	3.4
LW10	2,200	1,140	3.9
	1,140	1,040	4.5
	1,040	910	3.9
	910	460	3.7
	460	0	3.9
LW11	2,290	Ongoing	3.95

The assumed mining height for the future Longwalls 12 to 19 has been taken as 4.6 metres, as per the maximum mining height stated in the SMP Application.

1.4. Geological Details

The descriptions of the overburden geology and surface lithology in Dendrobium Area 3B are provided in Report No. MSEC459.

There are several igneous structures within Area 3B with the most noteworthy igneous sill being the Nepheline Syenite intrusion, in the south-eastern part of the mining area, with the approximate location shown in Drawing No. MSEC792-07. Mapping of the sill will be refined as further geological investigations are undertaken using in-seam drilling. The extent of sill cannot be mapped using surface geophysical techniques and drilling from the surface has provided the present definition of the margin. Another sill and cindered zone have been identified north-west of the longwalls.

There are several igneous structures within Area 3B with the most noteworthy igneous sill being the Nepheline Syenite intrusion, in the south-eastern part of the mining area, with the approximate location shown in Drawing No. MSEC792-07. Mapping of the sill will be refined as further geological investigations are undertaken using in-seam drilling. The extent of sill cannot be mapped using surface geophysical techniques and drilling from the surface has provided the present definition of the margin.

Several geological structures have been identified at seam level in the vicinity of the longwalls in Area 3B. A series of faults have been identified south of Longwall 18, between the future longwalls and the existing Elouera workings, having throws between 25 metres and 40 metres. Dykes have also been identified north, south-west and south-east of the longwalls.

The nature and extents of the faulting zones in the southern part of the mining area will be better defined using in-seam investigations during the development of the first workings closer to this area. The mining layout will be reviewed based on this updated geological information and, if required, will be modified to avoid the highly faulted zones.

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. MSEC792-02.

2.2. Definition of the Study Area

The *Study Area* is defined as the surface area that is likely to be affected by the mining of the future Longwalls 12 to 18 in Dendrobium Area 3B. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:-

- A 35 degree angle of draw from the extents of Longwalls 12 to 18,
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour resulting from the extraction of Longwalls 12 to 18,
- The natural features within 600 metres of the extent of the longwall mining area, in accordance with Condition 8(d) of the Development Consent, and
- Features which are expected to experience either far-field horizontal movements, or valley related movements, and which could be sensitive to these movements.

The depth of cover contours are shown in Drawing No. MSEC792-06. It can be seen from this drawing, that the depth of cover directly above the future longwalls varies between a maximum of 410 metres, above Longwall 12, and a minimum of 280 metres, above the eastern end of Longwall 18. The 35 degree angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 200 metres and 290 metres around the limits of the secondary extraction areas.

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, has been determined using the calibrated Incremental Profile Method, which is described in Chapter 3. The predicted 20 mm subsidence contour extends beyond the 35 degree angle of draw line above the previously extracted Longwalls 10 and 11. In all other locations, the predicted 20 mm subsidence contour is located within the 35 degree angle of draw line.

The Study Area based on the 35 degree angle of draw line and the predicted 20 mm subsidence contour is shown in Drawings Nos. MSEC792-01 to MSEC792-13. The Study Area based on the 600 metre boundary around the extent of the longwall mining area is also shown in these drawings.

The surface features located outside the extent of longwall mining which could experience far-field or valley related movements, and could be sensitive to these movements, have been identified and included in the assessments provided in this report. These features include:-

- Streams;
- Swamps;
- Cliffs;
- Steep Slopes;
- Lake Avon and Lake Cordeaux; and
- Survey control marks.

2.3. Natural and Built Features within the Study Area

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 Drawings Nos. MSEC792-08 to MSEC792-13, in Appendix D. 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 Features and Surface Infrastructure within the Study Area

Item	Within Study Area	Section Number Reference
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	✓	5.1
Rivers or Creeks	✓	5.3 to 5.5
Aquifers or Known Groundwater Resources	✓	5.6
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.7 & 5.8
Steep Slopes	✓	5.8
Escarpments	×	
Land Prone to Flooding or Inundation	×	
Swamps, Wetlands or Water Related Ecosystems	✓	5.11
Threatened or Protected Species	✓	5.12
National Parks	×	
State Forests	×	
State Conservation Areas	×	
Natural Vegetation	✓	5.12
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	✓	5.13
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.4
RESIDENTIAL ESTABLISHMENTS		
Houses	×	
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	×	
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	×	

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

3.1. Introduction

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

3.2. Overview of Conventional Subsidence Parameters

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

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

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

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

3.3. Far-field Movements

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

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

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

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

3.4. Overview of Non-Conventional Subsidence Movements

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

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near surface strata layers. Where the depth of cover is greater than 400 metres, 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 metres, 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 and valley related movements are discussed in the following sections.

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

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

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

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

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

3.4.2. Non-conventional Subsidence Movements due to Steep Topography

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

Further discussions on the potential for downslope movements for the steep slopes within the Study Area are provided in Section 5.8.

3.4.3. Valley Related Movements

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

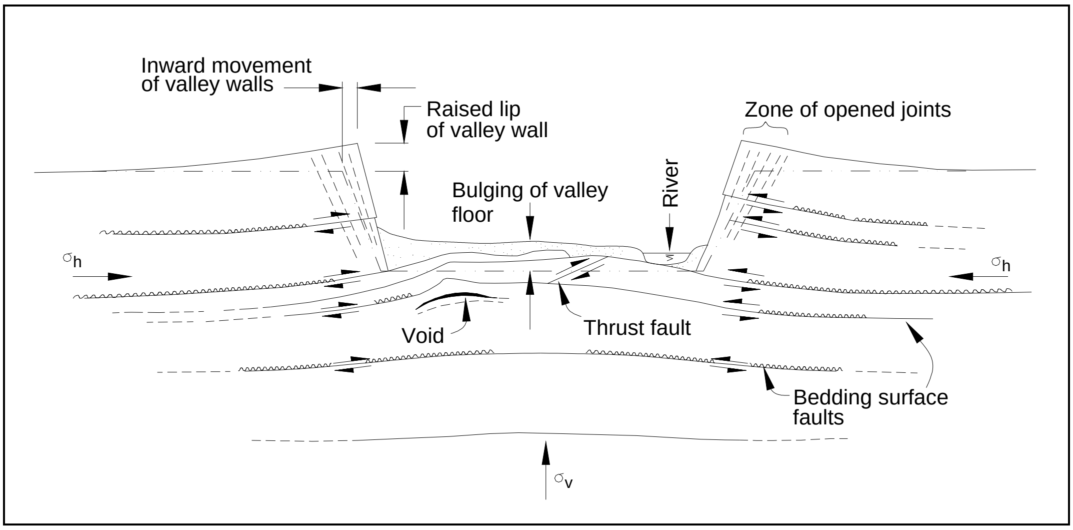

Fig. 3.1 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

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

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

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

The predicted valley related movements resulting from the extraction of the proposed longwalls were made using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002). Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

3.5. The Incremental Profile Method

The predicted conventional subsidence parameters for the longwalls were determined using the Incremental Profile Method, which was described in Report No. MSEC459 (Rev. B). Further details on the Incremental Profile Method are also provided in the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

The Incremental Profile Method was calibrated using the available data from Dendrobium Mine, at the time of the preparation of Report No. MSEC459, which included the monitoring data from Longwalls 3 to 5 in Area 2 and Longwall 6 in Area 3A at Dendrobium Mine. The initial calibration of the model is referred to as the '*MSEC459 prediction curves*' in this report.

The subsidence prediction model has now been reviewed using the currently available monitoring data, which now includes Longwalls 7 and 8 in Area 3A and Longwalls 9 and 10 in Area 3B at Dendrobium Mine. The following sections compare the observed and predicted movements in Areas 2, 3A and 3B at the mine and reviews and refines the calibration of the Incremental Profile Method.

3.6. Review of the ALS / LiDAR Surveys in Dendrobium Areas 2, 3A and 3B

The subsidence resulting from mining 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 should be noted that the contours of the observed 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 which 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 Dendrobium. 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 ±150 mm and, therefore, the expected accuracy of the measured vertical movements (i.e. the difference between two datasets) is around ±300 mm. Processing notes accompanying the LiDAR dataset noted the following…

> "*The 0.2m contours of subsidence indicated very little residual noise in the datasets. The improvement in this area is largely a function of moving away from the major cliff lines and very steep slopes along with a refinement in the LiDAR capture parameters. There is however, still a low level of residual noise (generally <100mm) throughout the entire subsidence surfaces associated with vegetation and LiDAR system limitations.*
>
> *Ground truthing of the dataset was performed at over 500 locations throughout the area. Results of this ground truthing showed an overall RMS error of less than 100mm (@sigma 1), which is well inside the stated accuracy of 150mm for each surface".*

The following sections review the ALS / LiDAR surveys for: Longwalls 3 to 5 in Area 2; Longwalls 6 to 8 in Area 3B; and Longwalls 9 and 10 in Area 3B at Dendrobium Mine.

It is noted, that the predictions are based on the calibrated subsidence prediction model for Dendrobium Mine, which was based on monitoring data from Longwalls 3 to 5 in Area 2 and Longwall 6 in Area 3B, as described in Section 3.6 of Report No. MSEC459 (Rev. B). This initial calibration of the subsidence model is referred to as the '*MSEC459 subsidence profiles*'.

3.6.1. ALS for Dendrobium Area 2

The contours of the observed total changes in surface level derived from the ALS, resulting from the extraction of Longwalls 3 to 5 in Area 2, are illustrated in Fig. C.1, in Appendix C. The profiles of observed (i.e. green) and predicted (i.e. red) changes in surface level along Cross-sections 2-1 to 2-3 and Long-sections 2-1 to 2-3 are illustrated in Fig. C.2 to Fig. C.7. The predicted contours and profiles have been based on the proposed mining height of 3.75 metres in Area 2.

The ratios of the observed to predicted incremental changes in surface level are illustrated in Fig. 3.2 for Longwall 3 (left side) and Longwalls 4 and 5 (right side). The histograms are based on the range of movements along the centrelines of the longwalls, i.e. the ratio of observed and predicted along each of the long-sections.

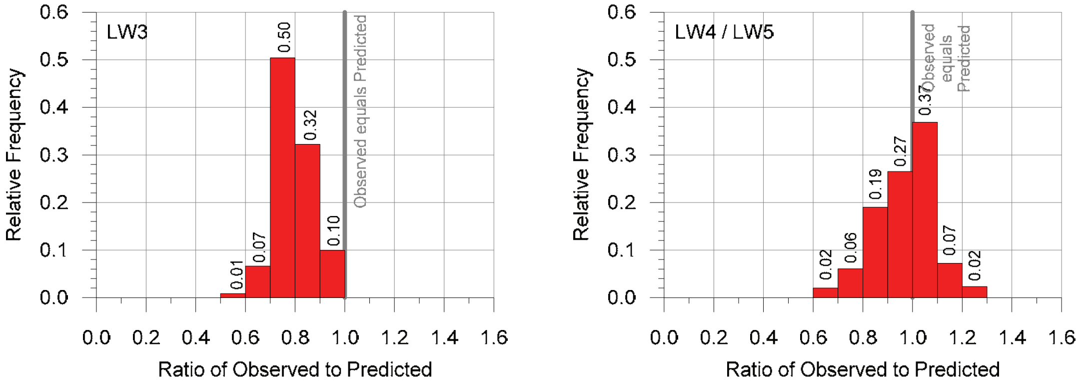

Fig. 3.2 Histogram of Observed to Predicted for LW3 (left side) and LW4 and LW5 (right side)

It can be seen on the left side of the above figure, that the observed incremental changes in surface level along the centreline of Longwall 3 were less than the predictions. The observed incremental changes in surface level along the centrelines of Longwalls 4 and 5 exceeded the predictions by up to 1.25 times, which is generally considered acceptable for subsidence prediction methods.

The normalised profiles of the observed (i.e. green) and predicted (i.e. red) incremental changes in surface level are illustrated in Fig. 3.3 for Longwall 3 (left side) and Longwalls 4 and 5 (right side).

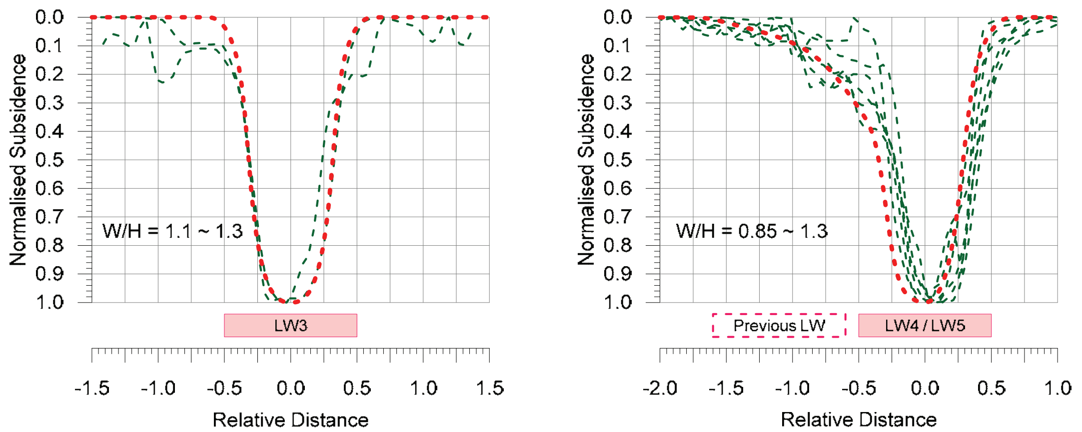

Fig. 3.3 Normalised Subsidence Profiles for LW3 (left side) and LW4 and LW5 (right side)

It can be seen on the left side of Fig. 3.3 that the observed profiles reasonably match the predicted profiles for Longwall 3. The observed profiles also reasonably match the predicted profiles for Longwalls 4 and 5, as illustrated on the right side of the figure, although there appears to be small lateral shifts in the observed profiles due to the influence of varying surface topography and seam dip. It is noted that the predicted profiles have not been adjusted in these figures for the influence of varying surface and seam levels.

3.6.2. ALS for Dendrobium Area 3A

The contours of the observed total changes in surface level derived from the ALS, resulting from the extraction of Longwalls 6 to 8 in Area 3A, are illustrated in Fig. C.8, in Appendix C. The profiles of observed (i.e. green) and predicted (i.e. red) changes in surface level along Cross-sections 3A-1 to 3A-3 and Long-sections 3A-1 to 3A-3 are illustrated in Fig. C.9 to Fig. C.14. The predicted contours and profiles have been based on the proposed mining height of 3.9 metres in Area 3A.

The ratios of the observed to predicted incremental changes in surface level are illustrated in Fig. 3.4 for Longwall 6 (left side) and Longwalls 7 and 8 (right side). The histograms are based on the range of movements along the centrelines of the longwalls, i.e. the ratio of observed and predicted along each of the long-sections.

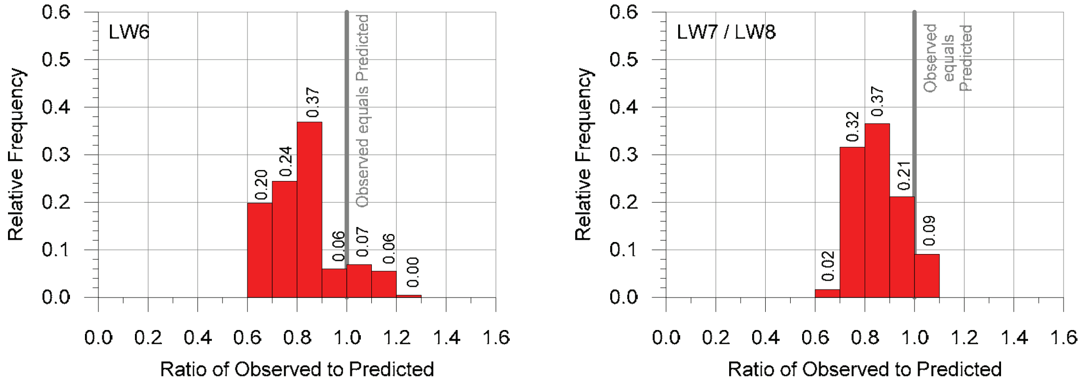

Fig. 3.4 Histogram of Observed to Predicted for LW6 (left side) and LW7 and LW8 (right side)

It can be seen from the above figure, that the observed incremental changes in surface level along the centrelines of Longwall 6 to 8 were generally less than the predictions, but with exceedances representing around: 13 % of the cases for Longwall 6 (left side); and 9 % of cases for Longwalls 7 and 8 (right side). The exceedances were up to around 1.25 times predicted, which is generally considered acceptable for subsidence prediction methods.

The normalised profiles of the observed (i.e. green) and predicted (i.e. red) incremental changes in surface level are illustrated in Fig. 3.5 for Longwall 6 (left side) and Longwalls 7 and 8 (right side).

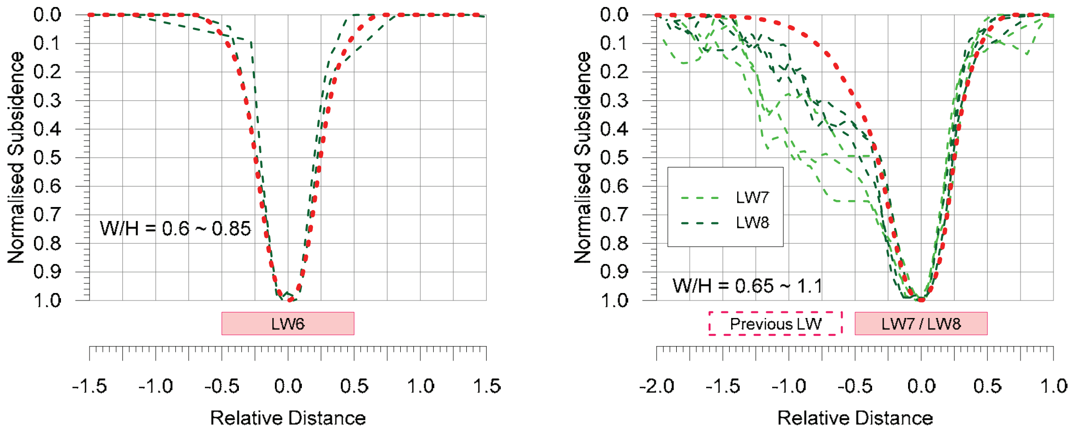

Fig. 3.5 Normalised Subsidence Profiles for LW6 (left side) and LW7 and LW8 (right side)

It can be seen on the left side of Fig. 3.5, that the observed profiles reasonably match the predicted profiles for Longwall 6. It can be seen on the right side of this figure, that the observed subsidence above the chain pillars for Longwalls 7 and 8 were greater than those predicted. The shapes of the observed profiles on the maingate side, however, reasonably match the predicted profile.

3.6.3. ALS for Dendrobium Area 3B

The contours of the observed total changes in surface level derived from the ALS, resulting from the extraction of Longwalls 9 and 10 in Area 3B, are illustrated in Fig. C.15, in Appendix C. The profiles of observed and predicted changes in surface level along Cross-sections 3B-1 to 3B-3 and Long-sections 3B-1 and 3B-3 are illustrated in Fig. C.16 to Fig. C.20. The predicted contours and profiles have been based on the actual mined thickness as summarised in Table 1.3.

The ratios of the observed to predicted incremental changes in surface level are illustrated in Fig. 3.6 for Longwall 9 (left side) and Longwall 10 (right side). The histograms are based on the range of movements along the centrelines of the longwalls, i.e. the ratio of observed and predicted along each of the long-sections.

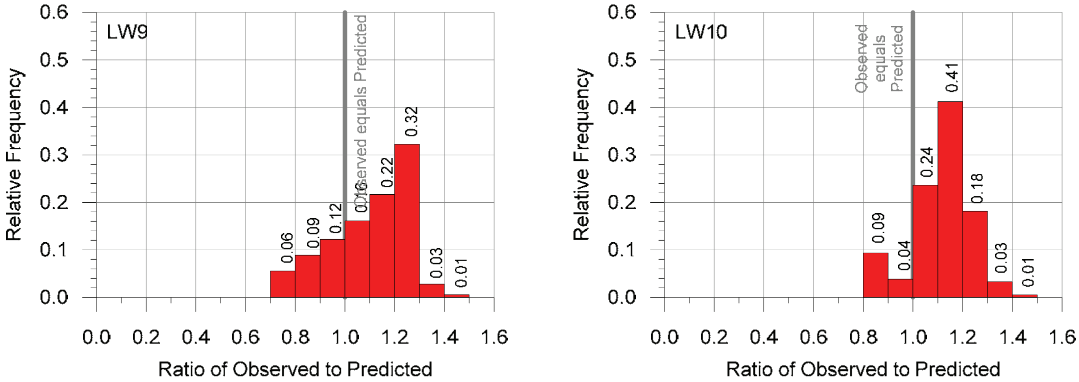

Fig. 3.6 Histogram of Observed to Predicted for LW9 (left side) and LW10 (right side)

It can be seen from the above figure, that the observed incremental changes in surface level along the centrelines of Longwall 9 and 10 were generally greater than the predictions. The exceedances were typically between 1.0 and 1.3 times, with less than 5 % of the cases representing exceedances up to 1.5 times.

The normalised profiles of the observed (i.e. green) and predicted (i.e. red) incremental changes in surface level are illustrated in Fig. 3.7 for Longwall 9 (left side) and Longwall 10 (right side).

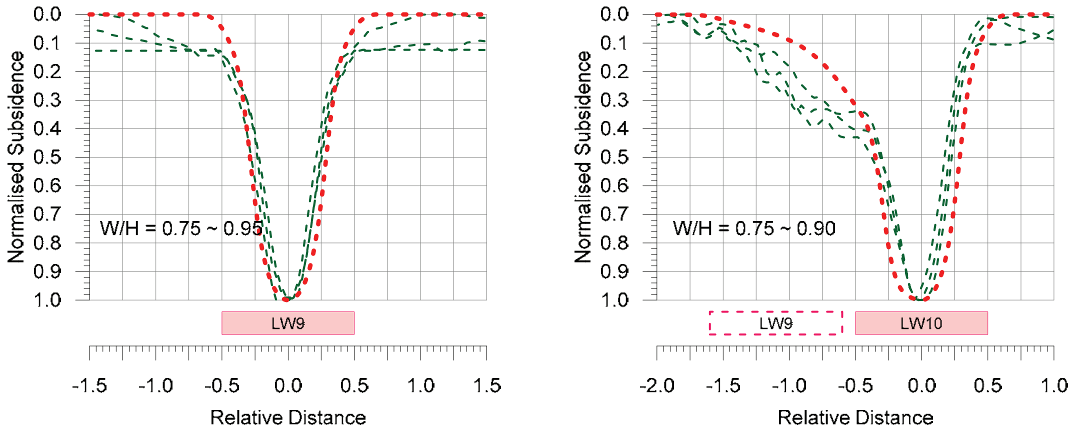

Fig. 3.7 Normalised Subsidence Profiles for LW9 (left side) and LW10 (right side)

It can be seen on the left side of Fig. 3.7 that the observed profiles reasonably matches the predicted profiles for Longwall 9. The observed low level subsidence outside the extents of the longwall are likely to be the result of the tolerance of the ALS surveys. It can be seen on the right side of this figure, that the observed subsidence above the chain pillars for Longwall 10 were greater than those predicted. The shapes of the observed profiles on the maingate side, however, reasonably match the predicted profile.

3.6.4. Review of ALS Information from, Dendrobium Mine

It is considered that the subsidence prediction model has provided reasonable predictions in Area 2, i.e. Longwalls 3 to 5, based on the ALS surveys. This is not unexpected, as the subsidence prediction method was calibrated using the monitoring data from Longwalls 3 to 5 in Area 2 and Longwall 6 in Area 3B, which was described in Section 3.6 of Report No. MSEC459 (Rev. B).

It appears that for Longwalls 7 and 8 in Area 3A and Longwalls 9 and 10 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 predicted. The observed subsidence directly above the tailgate chain pillars for Longwalls 7 and 8 in Areas 3A and Longwall 10 in Area 3B were also greater than predicted.

It is likely 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, which resulted in pillar compression greater than that predicted by the subsidence model.

It is also possible that higher subsidence has developed in Area 3B as the Coal Cliff Sandstone is not present in this area, as illustrated in Fig. 3.8 (after IC, 2013), with higher compression of the overburden occurring within the thicker Wombarra Formation above the chain pillars.

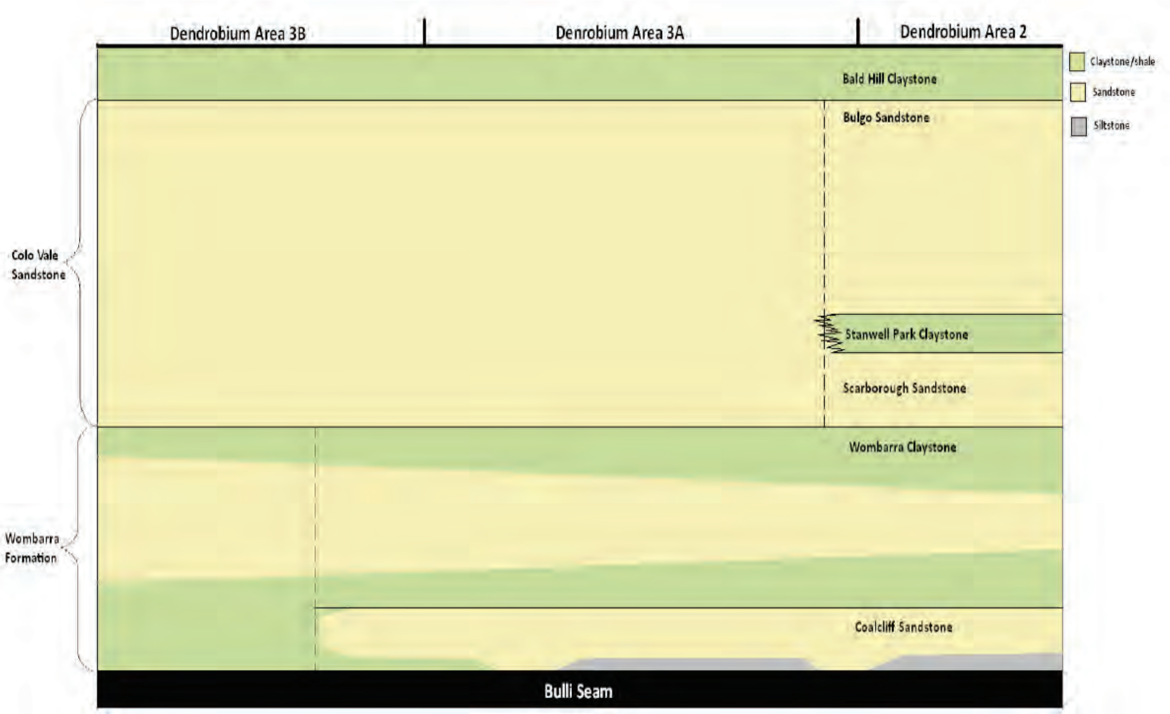

Fig. 3.8 Geological Cross-section across Dendrobium (IC, 2013)

3.6.5. Refined Prediction Model for Dendrobium (MSEC792 Subsidence Profiles)

The subsidence prediction model for Area 3B, therefore, has been further refined based on the latest ALS monitoring data as follows:

- the maximum predicted incremental subsidence has been increased by 30 %; and
- the vertical subsidence above the chain pillar (i.e. pillar compression component) has been increased based on the observed profiles, as illustrated by the blue dashed line in Fig. 3.9.

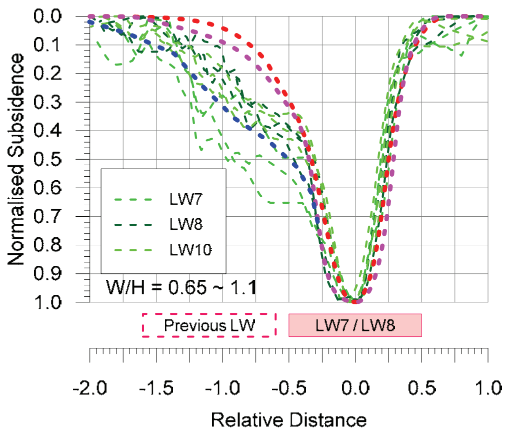

Fig. 3.9 Normalised Subsidence Profiles for Series Panels

The latest calibration of the subsidence prediction model, as described above, has been referred to as the '*MSEC792 subsidence profiles*'.

The profiles of observed (i.e. green) and predicted (i.e. red) changes in surface level along Cross-sections 3B-1 to 3B-3 in Area 3B are illustrated in Fig. 3.10 to Fig. 3.12. The predicted profiles in these figures have been based on the MSEC792 subsidence profiles. It can be seen from these figures, that the observed profiles more closely match those predicted based on the MSEC792 subsidence profiles.

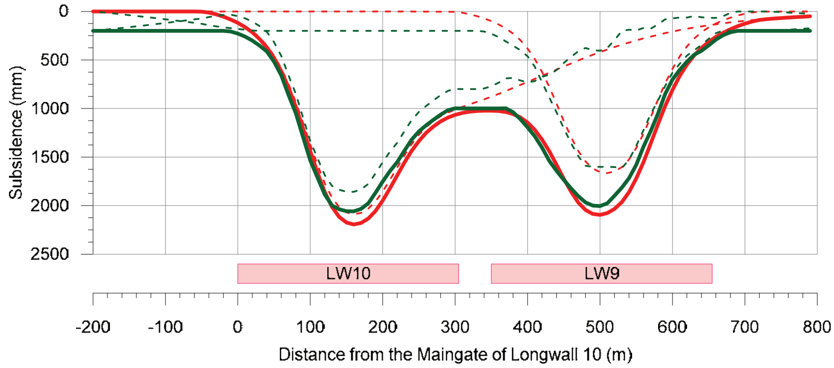

Fig. 3.10 ALS and Predicted Changes in Surface Level along Cross-section 3B-1 based on the Calibrated Model

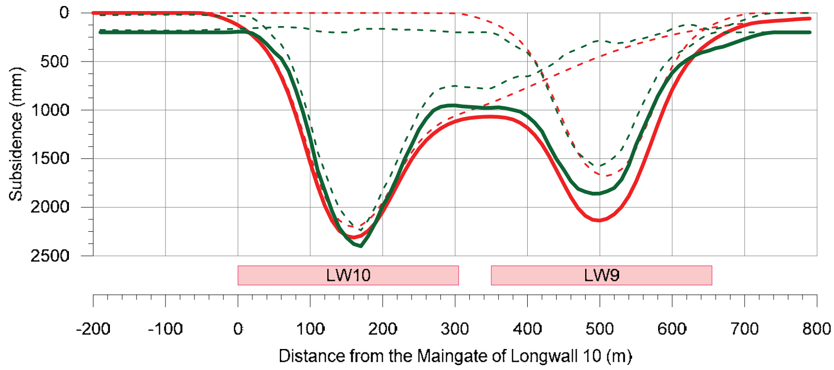

Fig. 3.11 ALS and Predicted Changes in Surface Level along Cross-section 3B-2 based on the Calibrated Model

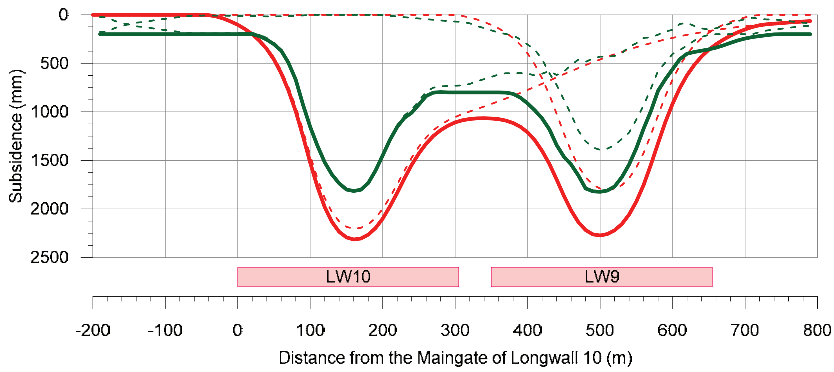

Fig. 3.12 ALS and Predicted Changes in Surface Level along Cross-section 3B-3 based on the Calibrated Model

The ratios of the observed and predicted incremental changes in surface level are illustrated in Fig. 3.13 for Longwall 9 (left side) and Longwall 10 (right side), based on the MSEC792 subsidence profiles. The histograms are based on the range of movements along the centrelines of the longwalls, i.e. the ratio of observed and predicted along each of the long-sections.

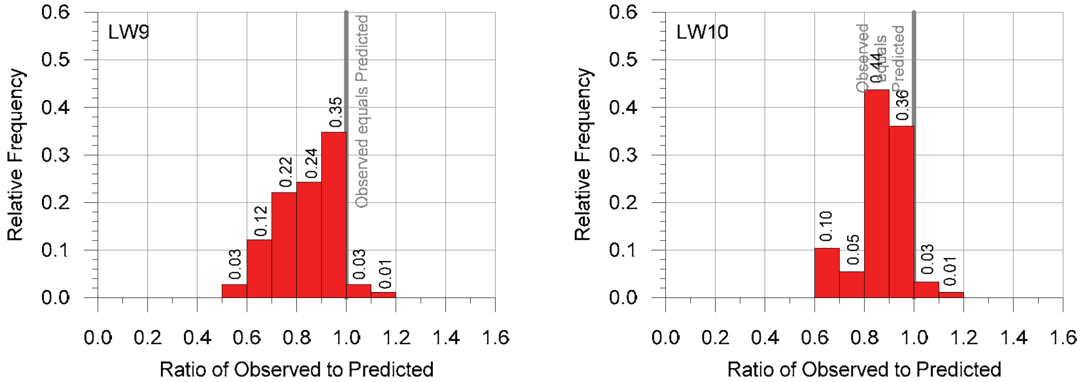

Fig. 3.13 Histogram of Observed to Predicted for LW9 (left side) and LW10 (right side) based on the Calibrated Model

It can be seen from the above figure, that the observed incremental changes in surface level are generally less than those predicted, with the exceedances representing less than 5 % of the cases. It is considered that the calibrated model provides adequate predictions of the magnitude and shape of the vertical subsidence profile based on the ALS data from Longwalls 9 and 10.

The depths of cover to the Wongawilli Seam reduces towards the south within Area 3B. The average depth of cover (black line) and the range of covers (grey shading) above each of the existing and future longwalls in Areas 3A and 3B is illustrated in Fig. 3.14.

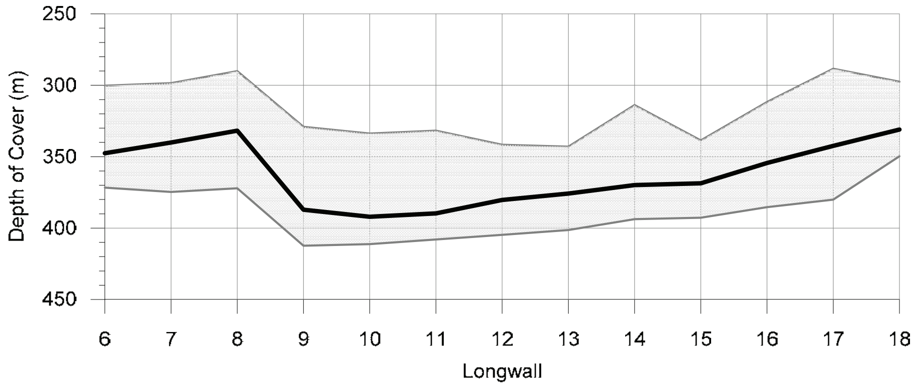

Fig. 3.14 Depth of Cover above Longwalls 6 to 18

The additional vertical subsidence due to pillar compression is likely to reduce for the future Longwalls 12 to 18 as the depths of cover progressively reduce. The pillar compression component of vertical subsidence in the calibrated model has considered the local depth of cover for each longwall.

3.7. Comparison of Observed and Predicted Movements for Ground Monitoring Data in Dendrobium Area 3B based on the Calibrated Model

The vertical subsidence and valley closure were monitored during the extraction of Longwalls 9 and 10 in Area 3B using the following ground monitoring lines:-

- Wongawilli Creek Closure Lines;
- Tributary Cross Lines;
- Donalds Castle Creek Cross Lines; and
- Swamp Cross Lines.

The locations of these ground monitoring lines are shown in Drawing No. MSEC792-01, in Appendix E. The comparisons between the observed and predicted movements based on the original subsidence model (i.e. MSEC459 prediction curves) were provided in the End of Panel Reports: MSEC670 (Rev. B) for Longwall 9; and MSEC737 (Rev. A) for Longwall 10.

A summary of the observed versus predicted movements for the monitoring lines have been provided in the following sections, based on the updated calibrated model, i.e. MSEC792 prediction curves. The predicted closures are the combination of the conventional horizontal movements (based on the MSEC792 prediction curves) plus the valley related movements (obtained using methods outlined in ACARP Research Project No. C9067).

3.7.1. Wongawilli Creek Cross-lines

A summary of the maximum observed and maximum predicted total closure for the Wongawilli Creek Closure Lines, due to the extraction of Longwalls 6 to 10, is provided in Table 3.1.

Table 3.1 Summary of the Maximum Observed and Maximum Predicted Total Closure at the Wongawilli Creek Cross Lines due to Longwalls 6 to 10

Location	Observed Total Closure (mm)	Predicted Total Closure (mm)
Wong X A-Line	126	175
Wong X B-Line	117	175
Wong X C-Line	25	50

It can be seen from the above table, that the maximum observed closures were less than the maximum predicted closures along the Wongawilli Creek Cross Lines.

3.7.2. Tributary Cross-lines

A summary of the maximum observed and maximum predicted total subsidence and closure for the Tributary Cross Lines, due to the extraction of Longwalls 9 and 10, is provided in Table 3.2. The predictions are based on the MSEC792 prediction curves. The observed values which have exceeded the predicted values have been highlighted in green.

Table 3.2 Comparison of Maximum Observed and Maximum Predicted Total Subsidence and Closure for the Wongawilli Creek Tributary Cross Lines due to Longwalls 9 and 10

Monitoring Line	Location	Maximum Total Subsidence (mm)	Maximum Total Closure (mm)
WC21XA-Line	Observed	174	103
	Predicted	325	400
WC21XB-Line	Observed	1,748	308
	Predicted	2,825	400
WC21XC-Line	Observed	515	157
	Predicted	1,275	450
WC21XD-Line	Observed	1,892	820
	Predicted	2,650	775
WC21XE	Observed	190	202
	Predicted	250	375
WC21XF-Line	Observed	41	46
	Predicted	< 20	125
WC21XG-Line	Observed	872	163
	Predicted	1,550	175

The maximum vertical subsidence along the WC21XF-Line of 41 mm exceeds the maxima predicted of less than 20 mm. This monitoring line is located 220 metres south of Longwall 10, i.e. above solid coal, where low level vertical subsidence can develop, but is generally not associated with any significant tilts, curvatures or conventional strains. The accuracy of subsidence prediction methods at these distances from mining, i.e. at low levels of vertical subsidence, are nominally within ±50 mm.

The maximum observed closure along the WC21XD-Line of 820 mm is greater than the maxima predicted of 775 mm, i.e. a 6 % exceedance, which is less than the order of accuracy of the prediction method. The observed closures along the remaining monitoring lines were less than the maxima predicted.

3.7.3. Donalds Castle Creek Cross-lines

A summary of the maximum observed and maximum predicted total subsidence and closure for the Donalds Castle Creek Lines, due to the extraction of Longwalls 9 and 10, is provided in Table 3.3. The predictions are based on the MSEC792 prediction curves. The observed values which have exceeded the predicted values have been highlighted in green.

Table 3.3 Comparison of Maximum Observed and Maximum Predicted Total Subsidence and Closure for the Donalds Castle Creek Cross-lines due to Longwalls 9 and 10

Monitoring Line	Location	Maximum Total Subsidence (mm)	Maximum Total Closure (mm)
DCCXA-Line	Observed	1,333	81
	Predicted	1,750	175
DCCXB-Line	Observed	714	1
	Predicted	975	200
DCCXC-Line	Observed	2,008	550
	Predicted	2,250	325
DCCXD-Line	Observed	363	26
	Predicted	275	125
DCCXE-Line	Observed	122	6
	Predicted	< 20	50

The maximum observed vertical subsidence along the DCCXD Line of 363 mm is greater than the maxima predicted of 275 mm, i.e. a 24 % exceedance. It is generally considered acceptable for the accuracy of subsidence prediction methods to be in the order of ±15 % to ±25 % in the locations of maximum subsidence. This monitoring line is located away from the maximum vertical subsidence and, therefore, slightly higher exceedances can occur due to effects such as varying surface topography and seam dip, which can result in a relative lateral shift between the observed and predicted subsidence profiles.

The maximum observed vertical subsidence along the DCCXE Line of 122 mm exceeds the maximum predicted of less than 20 mm. This monitoring line is located 210 metres south of Longwall 10, i.e. above solid coal, where low level vertical subsidence can develop, but is generally not associated with any significant tilts, curvatures or conventional strains.

The maximum observed closure along the DCCXC Line of 550 mm exceeded the maximum predicted of 325 mm, i.e. a 41 % exceedance. It is acknowledged that valley related movements are sensitive to various factors, including jointing, bedding thickness and the strength of the near bedrock in the base of the valley and, therefore, greater variability can occur in the observed closure movements. Whilst the observed closure exceeds the predicted closure by more than 25 %, it occurs only in one monitored location, with the observed closures along the remaining monitoring lines being less than the maxima predicted.

3.7.4. Swamp Cross-lines

A summary of the maximum observed and maximum predicted total subsidence and closure for the Swamp Cross Lines, due to the extraction of Longwalls 9 and 10, is provided in Table 3.4. The predictions are based on the MSEC792 prediction curves. The observed values which have exceeded the predicted values have been highlighted in green.

Table 3.4 Comparison of Maximum Observed and Maximum Predicted Total Subsidence and Closure for the Swamp Cross-lines due to Longwalls 9 and 10

Monitoring Line	Location	Maximum Total Subsidence (mm)	Maximum Total Closure (mm)
SW5-Line	Observed	122	50
	Predicted	50	150
SW1A-Line	Observed	1,956	30
	Predicted	2,275	250
SW1B-Line	Observed	1,911	311
	Predicted	1,825	350

The maximum observed vertical subsidence along the SW5 Line of 122 mm exceeded the maximum predicted of less than 50 mm. This monitoring line is located 125 metres north of Longwall 9, i.e. above solid coal, where low levels of vertical subsidence can develop, but is generally not associated with any significant tilts, curvatures or conventional strains. The observed subsidence is greater than that which would be expected at this distance from mining.

The maximum vertical subsidence along the SW1B Line of 1,911 mm is greater than the maxima predicted of 1,825 mm, i.e. a 5 % exceedance. It is generally considered acceptable for the accuracy of subsidence prediction methods to be in the order of ±15 % to ±25 % in the locations of maximum subsidence.

3.7.5. Summary for Ground Monitoring Lines

The comparisons of the observed and predicted vertical subsidence for the ground monitoring lines are illustrated in Fig. 3.15. It can be seen from the left side of this figure, that the observed vertical subsidence are generally less than that predicted based on the MSEC792 prediction curves. The exceedances are generally less than 10 %, with the higher values occurring where the magnitudes of subsidence are very small, such as outside the extents of mining.

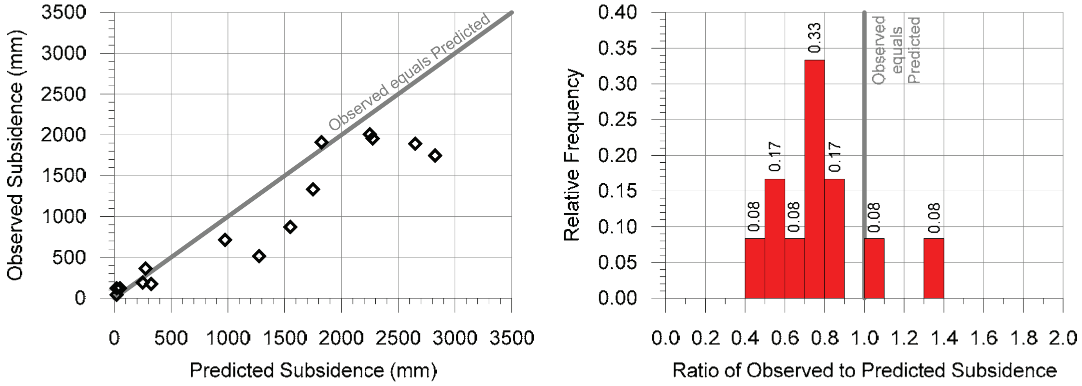

Fig. 3.15 Comparison of Observed and Predicted Subsidence for the Ground Monitoring Lines

The comparisons of the observed and predicted closure for the ground monitoring lines are illustrated in Fig. 3.16. It can be seen from the left side of this figure, that the observed closures are generally less than that predicted. Whilst one case of observed closure exceeds the predicted closure by 41 %, for the remaining cases the observed closures are less than predicted, with one other case having an exceedance of less than 5 %.

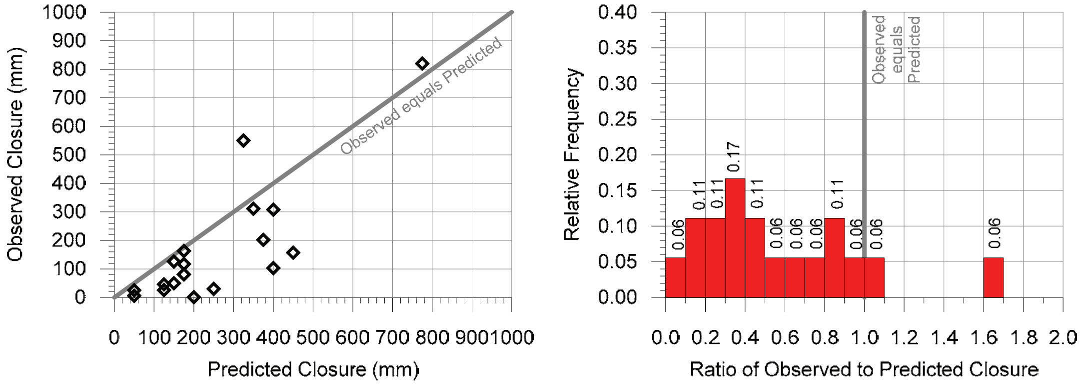

Fig. 3.16 Comparison of Observed and Predicted Closure for the Ground Monitoring Lines

It is considered that the refined calibrated prediction model (i.e. MSEC792 prediction curves) provides adequate predictions of vertical subsidence and valley closure based on the ground monitoring lines. It is highlighted, however, that there can be more variability in the valley closure movements and it is possible, in isolated cases, that the observed closures exceed the predicted closures by more than 25 %.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed Longwalls 12 to 18 based on the MSEC792 prediction curves. The review of the predicted subsidence parameters and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

The predicted subsidence, tilt and curvature have been obtained using the Incremental Profile Method, which has been calibrated based on the latest monitoring data from Dendrobium Mine, as described in Sections 3.6 and 3.7. The predicted strains have been determined by analysing the strains measured at other NSW Collieries, where the longwall width-to-depth ratios and extraction heights are similar to those for the longwalls.

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

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

The maximum predicted conventional subsidence parameters resulting from the extraction of the future Longwalls 12 to 18 were determined using the calibrated Incremental Profile Method, based on the MSEC792 profiles, which was described in Chapter 3. A summary of the maximum predicted values of incremental conventional subsidence, tilt and curvature, due to the extraction of each of the proposed longwalls, is provided in Table 4.1.

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

Longwall	Maximum Predicted Incremental Conventional Subsidence (mm)	Maximum Predicted Incremental Conventional Tilt (mm/m)	Maximum Predicted Incremental Conventional Hogging Curvature (km^{-1})	Maximum Predicted Incremental Conventional Sagging Curvature (km^{-1})
LW12	3,000	35	0.65	0.85
LW13	2,750	35	0.60	0.80
LW14	3,050	40	0.90	0.80
LW15	2,900	35	0.60	0.80
LW16	2,700	35	0.75	0.80
LW17	2,800	40	1.0	1.0
LW18	3,000	40	0.90	0.95

The predicted total conventional subsidence contours, resulting from the extraction of Longwalls 9 to 18 based on the MSEC792 prediction curves, are shown in Drawing No. MSEC792-14. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature, after the extraction of each of the proposed longwalls, is provided in Table 4.2.

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

Longwalls	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
LW12	3,400	50	1.4	1.4
LW13	3,500	50	1.4	1.4
LW14	3,500	50	1.4	1.4
LW15	3,600	50	1.4	1.4
LW16	3,600	50	1.4	1.4
LW17	3,600	50	1.4	1.4
LW18	3,600	50	1.4	1.4

The predicted tilts provided in the above table are the maxima after the completion of each of the longwalls. The predicted curvatures provided in the above table are the maxima at any time during or after the extraction of each of the longwalls.

The maximum predicted subsidence, after the completion of the proposed longwalls, is 3,600 mm which represents around 78 % of the maximum extraction height of 4.6 metres. The maximum predicted conventional tilt is 50 mm/m (i.e. 5 %), which represents a change in grade of 1 in 20. The maximum predicted conventional hogging and sagging curvatures are both 1.4 km^{-1}, which represent minimum radius of curvature of 0.7 kilometres.

The predicted conventional subsidence parameters vary across the mining area as the result of, amongst other factors, variations in the longwall geometry and the depths of cover. To illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along Prediction Line 1, the location of which is shown in Drawing No. MSEC792-14.

The predicted profiles of conventional subsidence, tilt and curvature along Prediction Line 1, resulting from the extraction of Longwalls 9 to 18 and based on the MSEC792 prediction curves, are shown in Fig. D.01, in Appendix D. The predicted incremental profiles along the prediction line, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles along the prediction line, after the extraction of each of the longwalls, are shown as solid blue lines. The range of predicted curvatures in any direction to the prediction line, at any time during or after the extraction of the proposed longwalls, is shown by the grey shading.

4.3. Comparison of Predictions based on the MSEC459 and MSEC792 Prediction Curves

The comparison of the maximum predicted total conventional subsidence parameters based on the MSEC459 and MSEC792 prediction curves is provided in Table 4.3.

Table 4.3 Comparison of Maximum Predicted Total Subsidence Parameters

Prediction Curves	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})
MSEC459	2,800	40	1.0	1.0
MSEC792	3,600	50	1.4	1.4

The maximum predicted subsidence parameters based on the MSEC792 prediction curves are greater than those based on the MSEC459 prediction curves by: 30 % for vertical subsidence; 25 % for tilt; and 40 % for curvature. It is noted that, whilst the predicted subsidence parameters have increased, the impact assessments provided in Report No. MSEC459 included the cases where the predictions were exceeded by a factor of up to 2 times. The impact assessments for the natural and built features, based on the predictions obtained using the MSEC792 prediction curves, have been reviewed in Chapters 4 and 5.

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 Longwalls 12 to 18, based on applying a factor of 15 to the maximum predicted curvatures using the MSEC792 prediction curves, are both 20 mm/m tensile and compressive. The maximum predicted conventional strains are 33 % greater than those provided in Report No. MSEC459, which were 15 mm/m tensile and compressive.

At a point, however, there can be considerable variation from the linear relationship, resulting from non-conventional movements or from the normal scatters which are observed in strain profiles. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strain for low magnitudes of curvature. In this report, therefore, we have provided a statistical approach to account for the variability, instead of just providing a single predicted conventional strain.

The range of potential strains above Longwalls 12 to 18 has been determined using monitoring data from Dendrobium Area 3A, as well as previously extracted longwalls in the NSW Coalfields where the mine geometries were reasonably similar to that for Dendrobium Area 3B. Two monitoring lines were adopted from Dendrobium Area 3A (SCW North and South Lines) and a total of 34 monitoring lines were adopted from the Hunter and Newcastle Coalfields. Comparisons of the longwall void widths, depths of cover, longwall width-to-depth ratios and extraction heights are provided in Table 4.4.

Table 4.4 Comparison of the Mine Geometry for Dendrobium Longwalls 12 to 18 with the Longwalls from the NSW Coalfields used in the Strain Analysis

Parameter	Dendrobium Longwalls 12 to 18		Longwalls Used in Strain Analysis	
	Range	Average	Range	Average
Longwall Width	305	305	160 ~ 200	175
Depth of Cover	280 ~ 410	360	150 ~ 250	175
W/H Ratio	0.7 ~ 1.1	0.9	0.8 ~ 1.2	1.03
Extraction Height	4.6	4.6	3.8 ~ 4.8	4.5

It can be seen from the above table, that the range of the longwall width-to-depth ratios used in the strain analysis was similar to but slightly higher, on average, than the width-to-depth ratios of the future Dendrobium Longwalls 12 to 18. The average extraction height for the longwalls used in the strain analysis was also similar to the extraction height for the future longwalls. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains resulting from the extraction of Dendrobium Longwalls 12 to 18.

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.

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 histogram of the maximum observed tensile and compressive strains measured in survey bays above goaf, for 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.

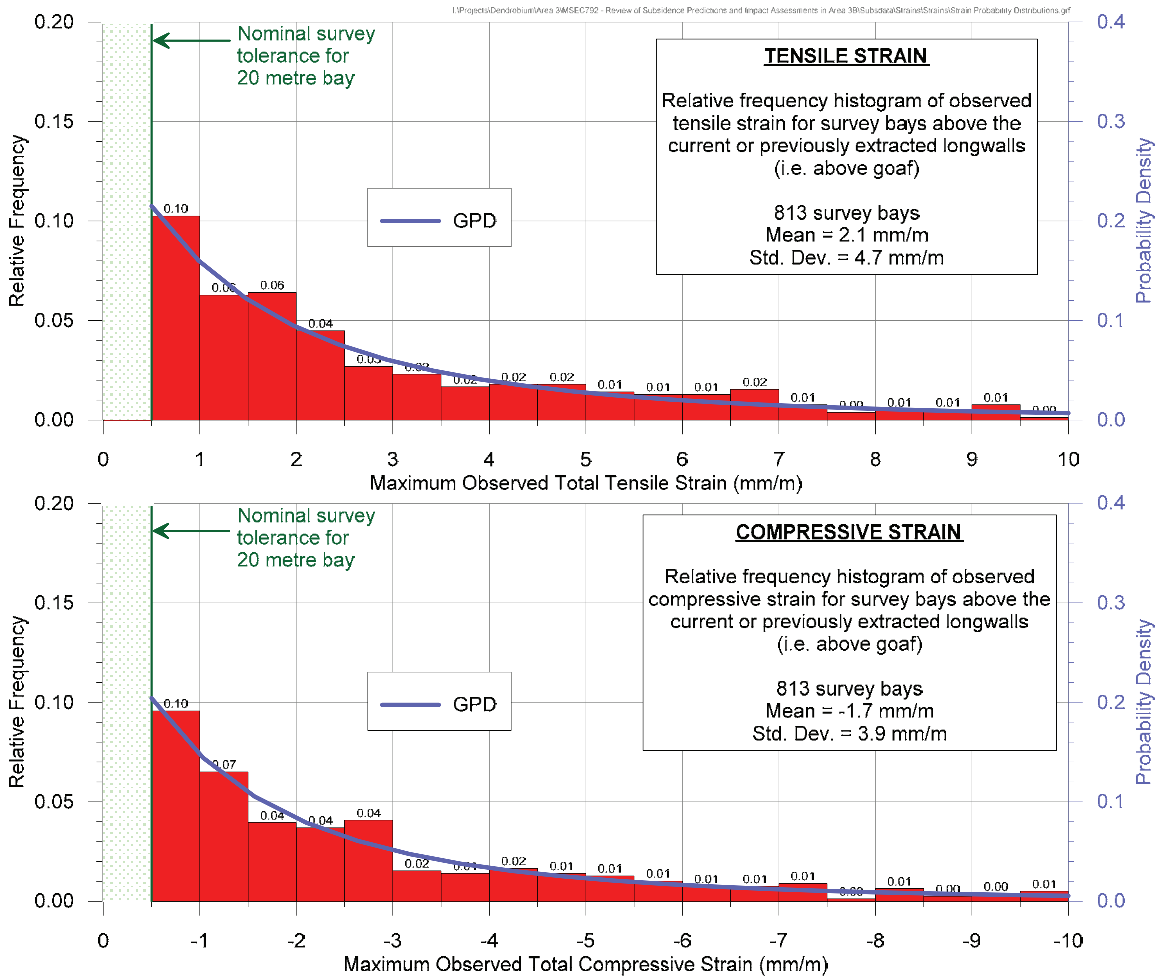

Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains during the Extraction of Previous Longwalls in the NSW Coalfields for Bays Located Above Goaf

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).

The 95 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining were 9 mm/m tensile and 8 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining were 22 mm/m tensile and 20 mm/m compressive.

The maximum observed strains measured along the SCW North and South Monitoring Lines, resulting from the extraction of Dendrobium Longwalls 6 and 7, were 2.2 mm/m tensile and 6.5 mm/m compressive. It is noted, that these were longitudinal monitoring lines, along the centrelines of Longwalls 6 and 7 and, therefore, the maximum observed strains may not be representative of the maximum strains elsewhere above these longwalls.

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 in fact 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 within the Study Area, at any time during or after the extraction of the proposed longwalls, is 50 mm/m, which occurs adjacent to the maingate of the proposed Longwall 18. The maximum predicted conventional horizontal movement is, therefore, approximately 750 mm, i.e. 50 mm/m multiplied by a factor of 15.

The distribution of the maximum observed horizontal movements for the 3D survey marks located directly above the longwalls in Dendrobium Areas 1, 2, 3A and 3B is provided in Fig. 4.2. It can be seen from this figure, that horizontal movements have been measured up to 600 mm at the mine, with an average measured value of around 250 mm.

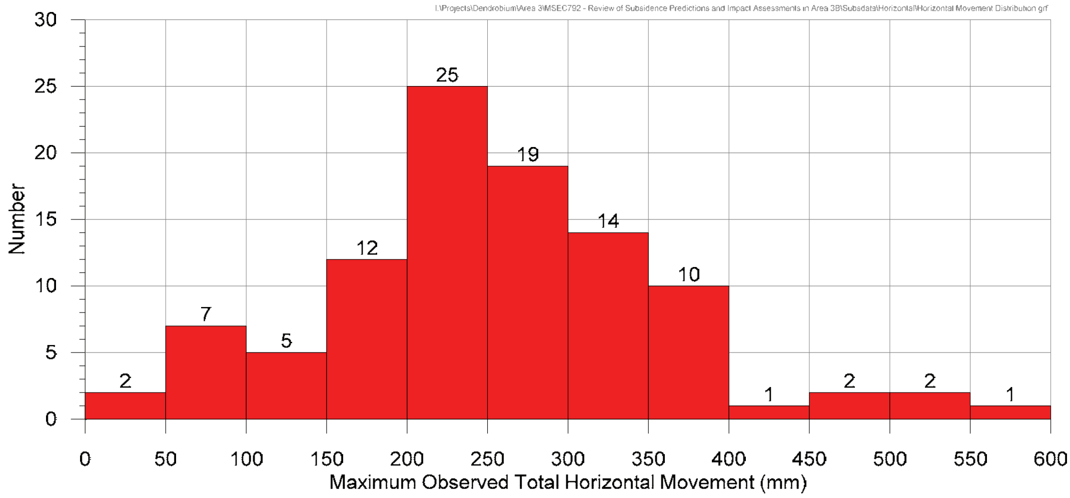

Fig. 4.2 Distributions of the Maximum Observed Horizontal Movements for the 3D Marks Located Directly above the Longwalls in Dendrobium Areas 1, 2, 3A and 3B

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

4.6. Predicted Far-field Horizontal Movements

In addition to the conventional subsidence movements that have been predicted above and adjacent to the longwalls, and the predicted valley related movements along the creeks, 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 Dendrobium, as well as from other collieries in the Southern Coalfield, including Appin, Bellambi, Douglas, 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 observed incremental far-field horizontal movements, resulting from the extraction of longwalls at Dendrobium Areas 1, 2, 3A and 3B, are provided in Fig. 4.3. The observed far-field movements for other collieries in the Southern Coalfield, including the confidence levels based on fitted GPDs, have also been shown in this figure for comparison.

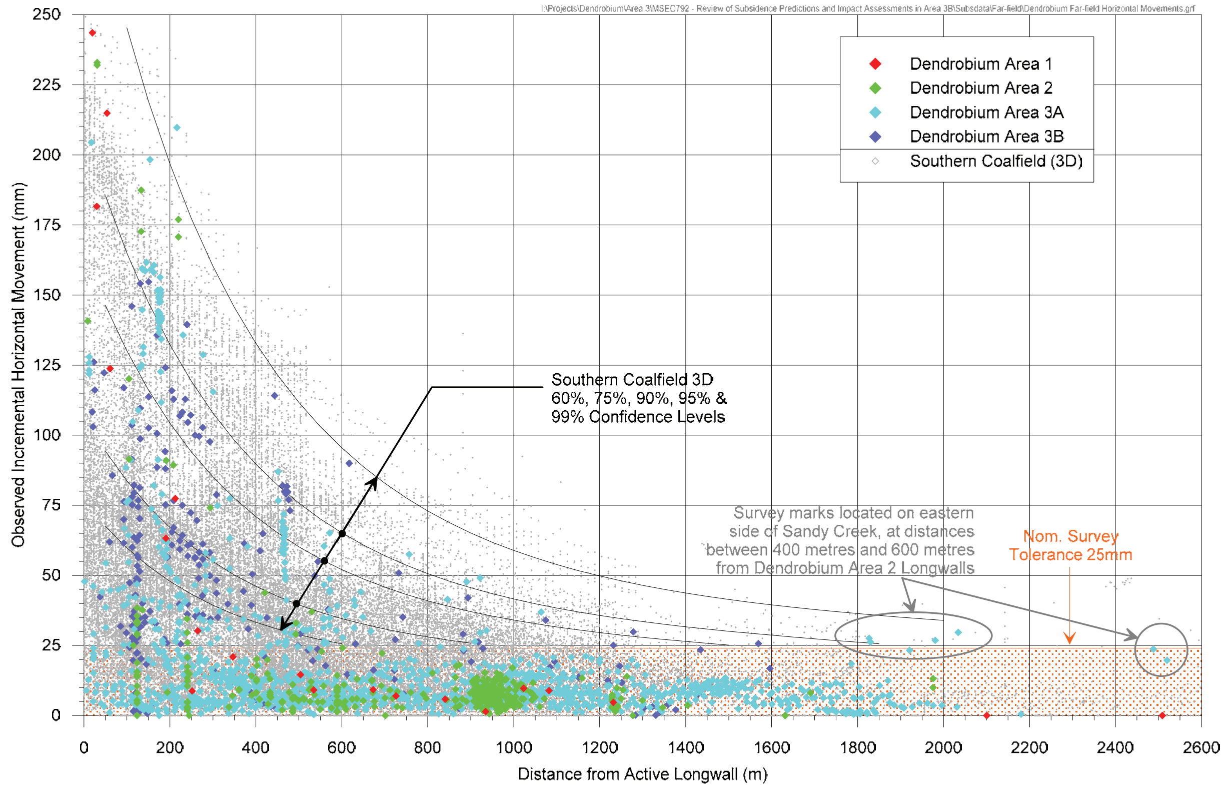

Fig. 4.3 Observed Incremental Far-Field Horizontal Movements at Dendrobium Mine and Elsewhere in the Southern Coalfield

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

The predicted far-field horizontal movements resulting from the extraction of the longwalls are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than survey tolerance. The impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the vicinity of the Study Area is not expected to be significant, except where they occur at large structures which are sensitive to small differential movements.

4.7. Non-Conventional Ground Movements

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

Specific predictions of upsidence, closure and compressive strain due to the valley related movements are provided for the streams in Sections 5.3 and 5.4. The impact assessments for the streams are based on both the conventional and valley related movements. The potential for non-conventional movements associated with steep topography is discussed in the impact assessments for the steep slopes provided in Section 5.8.

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.

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

5.1. Catchment Areas and Declared Special Areas

The Study Area lies entirely within the Metropolitan Catchment Area, which is a special declared area controlled by Water NSW. The western ends of the proposed Longwalls 11 to 18 are located within the Dams Safety Committee (DSC) Notification Area for the Avon Reservoir, also known as Lake Avon. The descriptions, predictions and impact assessments for the Avon Reservoir 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. Rivers

There are no rivers within the Study Area. The closest river is the Cordeaux River, downstream of the Cordeaux Dam, which is located approximately 4 kilometres north of Longwall 9, at its closest point.

The Cordeaux River is not predicted to experience any measureable mine subsidence movements. It is unlikely, therefore, that the river would experience any adverse impacts resulting from the extraction of the longwalls in Area 3B.

5.3. Wongawilli Creek

5.3.1. Description of Wongawilli Creek

The largest stream within the Study Area is *Wongawilli Creek* which is located on the eastern side of the longwalls in Area 3B. It can be seen from Drawing No. MSEC792-08, that the longwalls do not directly mine beneath this creek.

Wongawilli Creek is a third order perennial stream with a small base flow and increased flows for short periods of time after each significant rain event. The creek generally flows in a northerly direction and drains into the Cordeaux River approximately 4 kilometres north of the longwalls in Area 3B.

Pools in the creek are permanent (based on monitoring to date) and naturally develop behind the rockbars and at the sediment and debris accumulations, the locations of which are shown in Drawings Nos. MSEC792-10 and MSEC792-11. The rockbars that are located within the Study Area are Refs. WC-RB32 to WC-RB59.

The other stream features include the: riffles (Refs. WC-RF33 to WC-RF59c); boulderfields (Refs. WC-BF40 to WC-BF53); islands (Refs. WC-IS35a to WC-IS38c); and a waterfall (WC-WF54). It is noted, that the riffle locations are based on those mapped by IC using GPS during the week starting the 14th November 2011. The locations of riffles are known to change over time, as a result of flooding events and, therefore, the actual locations during the mining period could be different to those shown.

The surface mapping and geological modelling undertaken by IC indicate that the base of the creek rises up through the stratigraphy as it runs from the south to the north. In the southern part of the Study Area, the creek bed is formed in the Bulgo Sandstone. The creek bed transitions through the Newport Formation and Bald Hill Claystone, adjacent to the proposed longwalls, and is then formed in the Hawkesbury Sandstone towards the northern part of the Study Area.

Photographs of Wongawilli Creek within the Study Area are shown in Fig. 5.1.

Fig. 5.1 Photographs of Wongawilli Creek (Courtesy of IC)

There is a waterfall along Wongawilli Creek, in the southern part of the Study Area, which has been labelled WC-WF54 in Drawing No. MSEC792-11. Photographs of the waterfall are provided in Fig. 5.2.

Fig. 5.2 Photographs of Waterfall WC-WF54 along Wongawilli Creek

The calculated height of the waterfall, based on the surface level contours, is approximately 20 metres. There is also a steep section of creek, just downstream of the waterfall, which drops a further 10 metres over a distance of approximately 100 metres.

The average natural gradient of Wongawilli Creek, excluding Waterfall WC-WF54, is approximately 10 mm/m (i.e. 1 %, or 1 in 100). The maximum natural gradient of the creek is approximately 200 mm/m (i.e. 20 %, or 1 in 5), which occurs just downstream of the waterfall, and the natural gradient elsewhere along the creek varies up to around 75 mm/m (i.e. 7.5 %, or 1 in 13).

Further descriptions of Wongawilli Creek and the stream features are provided in Report No. MSEC459 and the SMP Application.

5.3.2. Predictions for Wongawilli Creek based on the MSEC792 Prediction Curves

The predicted profiles of subsidence, upsidence and closure along Wongawilli Creek, based on the MSEC792 prediction curves, are shown in Fig. D.02, in Appendix D, which includes the movements resulting from mining in both Areas 3A and 3B. The predicted profiles after the completion of Longwall 11 are shown as the cyan profiles. The predicted incremental profiles, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles, after the extraction of each of the longwalls, are shown as solid blue lines. The predicted total profiles, after the completion of Longwall 19 in Area 3A, are shown as the green lines.

The predictions for Longwall 19 in Area 3A are based on the finishing (western) end of this longwall being 75 metres shorter than the approved length and, therefore, are slightly less than those based on the approved length of this longwall. The shortened finishing end of Longwall 19 will be addressed in a separate modification application.

A summary of the maximum predicted values of total subsidence, upsidence and closure along Wongawilli Creek, after the extraction of each of the longwalls, is provided in Table 5.1. The conventional movements are based on the MSEC792 prediction curves and the valley closure movements are based on the methods outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002).

Table 5.1 Maximum Predicted Total Subsidence, Upsidence and Closure for Wongawilli Creek based on the MSEC792 Prediction Curves

Location	Longwall	Maximum Predicted Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Wongawilli Creek	After LW11	< 20	140	210
	After LW12	< 20	140	210
	After LW13	< 20	140	210
	After LW14	< 20	140	210
	After LW15	< 20	140	210
	After LW16	< 20	140	210
	After LW17	< 20	140	210
	After LW18	< 20	160	210
	After LW19	< 20	160	210

The equivalent valley height for Wongawilli Creek, which is the height of the valley within a half depth of cover of the valley base, varies between 25 metres and 65 metres within the Study Area. The equivalent valley height is used in the ACARP model to predict the upsidence and closure movements along the creek.

The proposed longwalls do not directly mine beneath the creek and the section of creek within the Study Area has not been previously mined beneath. For this reason, a solid coal factor of 0.7 has been used in calculating the predicted valley related upsidence and closure movements, which is discussed in Report No. MSEC459. The application of the solid coal factor is consistent with the recommendations provided in Report No. MSEC404, which supported the Bulli Seam Operations Part 3A Application.

Summaries of the maximum predicted values of total subsidence, upsidence and closure at the mapped rockbars, riffles, boulderfields and waterfall along Wongawilli Creek, based on the MSEC792 prediction curves, are provided in Table 5.2, Table 5.3, Table 5.4 and Table 5.5, respectively. The parameters provided are the maximum values after the completion of Longwall 19 in Area 3A.

Table 5.2 Maximum Predicted Total Subsidence, Upsidence and Closure at the Mapped Rockbars along Wongawilli Creek based on the MSEC792 Prediction Curves

Feature	Label	Maximum Predicted Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Rockbars	WC-RB32	< 20	< 20	< 20
	WC-RB33	< 20	< 20	20
	WC-RB34	< 20	< 20	35
	WC-RB35	< 20	110	160
	WC-RB36	< 20	65	120
	WC-RB37	< 20	55	110
	WC-RB38	< 20	60	120
	WC-RB39	< 20	65	140
	WC-RB43	< 20	140	180
	WC-RB47	< 20	140	150
	WC-RB48	< 20	150	150
	WC-RB51	< 20	160	160
	WC-RB55	< 20	85	140
	WC-RB56	< 20	70	120
	WC-RB59	< 20	< 20	< 20

Table 5.3 Maximum Predicted Total Subsidence, Upsidence and Closure at the Mapped Riffles along Wongawilli Creek based on the MSEC792 Prediction Curves

Feature	Label	Maximum Predicted Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Riffles	WC-RF33	< 20	< 20	< 20
	WC-RF35a	< 20	30	65
	WC-RF35b	< 20	40	90
	WC-RF35c	< 20	45	110
	WC-RF35d	< 20	110	160
	WC-RF36a	< 20	75	200
	WC-RF36b	< 20	90	190
	WC-RF36c	< 20	100	190
	WC-RF36d	< 20	120	190
	WC-RF36e	< 20	130	190
	WC-RF36f	< 20	130	200
	WC-RF36g	< 20	130	200
	WC-RF36h	< 20	110	180
	WC-RF36i	< 20	100	180
	WC-RF36j	< 20	90	190
	WC-RF36k	< 20	85	190
	WC-RF36l	< 20	90	170
	WC-RF36m	< 20	85	150
	WC-RF36n	< 20	75	150
	WC-RF36o	< 20	80	130
	WC-RF36p	< 20	85	130
	WC-RF36q	< 20	85	130
	WC-RF36r	< 20	80	130
	WC-RF36s	< 20	65	120
	WC-RF38a	< 20	55	110
	WC-RF38b	< 20	85	130
	WC-RF38c	< 20	65	140
	WC-RF38d	< 20	40	110
	WC-RF38e	< 20	40	110
	WC-RF38f	< 20	55	110
	WC-RF38g	< 20	60	110
	WC-RF39	< 20	55	120
	WC-RF59a	< 20	25	30
	WC-RF59b	< 20	< 20	25
	WC-RF59c	< 20	< 20	< 20

Table 5.4 Maximum Predicted Total Subsidence, Upsidence and Closure at the Boulderfields along Wongawilli Creek based on the MSEC792 Prediction Curves

Feature	Label	Maximum Predicted Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Boulderfields	WC-BF40	< 20	120	160
	WC-BF41	< 20	150	170
	WC-BF42	< 20	160	180
	WC-BF44	< 20	95	170
	WC-BF45	< 20	90	160
	WC-BF46	< 20	120	150
	WC-BF50	< 20	160	160
	WC-BF51	< 20	140	150
	WC-BF52	< 20	110	150
	WC-BF53	< 20	95	150

Table 5.5 Maximum Predicted Total Subsidence, Upsidence and Closure at the Waterfall along Wongawilli Creek based on the MSEC792 Prediction Curves

Feature	Label	Maximum Predicted Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Waterfall	WC-WF54	< 20	100	150

The maximum predicted total conventional tensile and compressive strains for Wongawilli Creek, based on applying a factor of 15 to the maximum predicted conventional curvatures, are in the order of survey tolerance (i.e. less than 0.3 mm/m). The creek is likely to also experience elevated compressive strains, resulting from the valley related movements, which could be in the order of 5 mm/m based on observations at valleys with similar heights at similar distances from extracted longwalls.

5.3.3. Comparison of Predictions for Wongawilli Creek based on the MSEC459 and MSEC792 Predictions Curves

The comparison of the maximum predicted total conventional subsidence and valley related upsidence and closure for Wongawilli Creek, based on the MSEC459 and MSEC792 prediction curves, is provided in Table 5.6.

Table 5.6 Comparison of the Predictions for Wongawilli Creek

Prediction Curves	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Valley Related Upsidence (mm)	Maximum Predicted Total Valley Related Closure (mm)
MSEC459	< 20	160	210
MSEC792	< 20	160	210

It can be seen from the above table, that the maximum predicted subsidence parameters for Wongawilli Creek, based on the MSEC792 prediction curves, are the same as those based on the MSEC459 prediction curves. The reason for this is that Wongawilli Creek is located outside the extents of the longwalls and, therefore, the higher conventional movements directly above the mining area do not result in an increase in the vertical subsidence or valley related movements along the creek.

The predicted total upsidence and closure at the mapped stream features (i.e. rockbars, riffles and boulderfields), based on the MSEC792 prediction curves, are within ±10 mm of those predicted based on the MSEC459 prediction curves. These differences are less than the order of accuracy of the prediction method and are also predominately the result of rounding of the predicted values to the nearest 5 mm or 10 mm.

The predicted total upsidence and closure at the Waterfall (Ref. WC-WF54), based on the MSEC792 prediction curves, are similar to those based on the MSEC459 prediction curves. It is also noted, as discussed in Section 3.7.1, that the observed subsidence and closure at the Wongawilli Creek Cross Lines, after the completion of Longwall 10, are less than those predicted based on the MSEC792 prediction curves.

5.3.4. Review of the Assessed Impacts for Wongawilli Creek provided in Report No. MSEC459 and the Reported Impacts during Longwalls 3 to 10

The impact assessments for Wongawilli Creek provided in Report No. MSEC459 stated that:

> "*…it is unlikely that significant fracturing or surface water flow diversions would occur along Wongawilli Creek as a result of the extraction of the proposed Longwalls 9 to 18*"; and

> "*It should be noted, however, that minor fracturing could still occur in the bed of Wongawilli Creek as a result of the extraction of the proposed longwalls. Based on previously observed fractures in the beds of streams adjacent to longwall mining in the Southern Coalfield, it is possible that minor fractures could occur within 400 metres from the proposed longwalls. Any fracturing that does occur in the bed of the creek would be expected to be isolated and of a minor nature and not result in any significant surface water flow diversions.*"

Longwalls 3 to 5 in Area 3A have been extracted at minimum distances between 115 metres and 325 metres from Wongawilli Creek. Longwalls 9 and 10 in Area 3B have also been extracted at minimum distances of 330 metres and 500 metres from this creek.

One impact has been observed along Wongawilli Creek during Longwall 9 which comprised a "*rock fracture at the base of WC_Pool43a; approx. 2m long and 0.02m wide*" (IC, 2014). An extension to this fracture was observed during Longwall 10. There have been no mining induced surface water flow diversions observed along the alignment of Wongawilli Creek.

It is considered that the one rock fracture observed along Wongawilli Creek is consistent with the assessed potential for impacts outlined in Report No. MSEC459 and the SMP Application.

5.3.5. Impact Assessments for Wongawilli Creek based on the MSEC792 Prediction Curves

The maximum predicted subsidence parameters for Wongawilli Creek, based on the MSEC792 prediction curves, are the same as those based on the MSEC459 prediction curves. Also, the predicted subsidence parameters at the individual stream features are within ±5 mm to ±10 mm, which is within the order of accuracy of the prediction methods.

The impact assessments and management strategies for Wongawilli Creek, therefore, are the same as those provided in Report No. MSEC459 and the SMP Application.

5.4. Donalds Castle Creek

5.4.1. Description of Donalds Castle Creek

The upper reaches of *Donalds Castle Creek* are located in the northern part of the Study Area. It can be seen from Drawing No. MSEC792-08, that the creek is located above Longwalls 9 to 12. The total length of the creek located directly above the longwalls is around 1.5 kilometres.

Donalds Castle Creek is a second order perennial stream with a small base flow and increased flows for short periods of time after each significant rain event. The creek generally flows in a northerly direction and drains into the Cordeaux River approximately 6.5 kilometres north of the longwalls in Area 3B.

The section of Donalds Castle Creek located above the proposed longwalls is confined within Swamp Den05. The bed of the creek has mostly been covered by soil accumulation and vegetation within this swamp. The sandstone creek bed is exposed in some locations and rockbars, pools, channels and steps exist at the downstream end of the swamp, and beyond, which are indicated in Drawing No. MSEC792-10.

Photographs of Donalds Castle Creek within the extents of Swamp Den05 (i.e. directly above the longwalls) are provided in Fig. 5.3.

Fig. 5.3 Photographs of Donalds Castle Creek within the Extents of Swamp Den05

The natural gradient of Donalds Castle Creek, within the extent of Swamp Den05, typically varies between 10 mm/m (i.e. 1 %, or 1 in 100) and 100 mm/m (i.e. 10 %, or 1 in 10), with an average natural gradient of approximately 30 mm/m (i.e. 3 %, or 1 in 35).

Further descriptions of Donalds Castle Creek are provided in Report No. MSEC459 and the SMP Application. The creek is also further characterised by the specialist consultant's reports on the project.

5.4.2. Predictions for Donalds Castle Creek

The predicted profiles of conventional subsidence and valley related upsidence and closure along Donalds Castle Creek, based on the MSEC792 prediction curves, are shown in Fig. D.03, in Appendix D. The predicted incremental profiles, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles, after the extraction of each of the longwalls, are shown as solid blue lines.

A summary of the maximum predicted values of total conventional subsidence and valley related upsidence and closure along Donalds Castle Creek, based on the MSEC792 prediction curves, is provided in Table 5.7.

Table 5.7 Maximum Predicted Total Subsidence, Upsidence and Closure for Donalds Castle Creek based on the MSEC792 Prediction Curves

Location	Longwall	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Valley Related Upsidence (mm)	Maximum Predicted Total Valley Related Closure (mm)
Donalds Castle Creek	After LW11	2,600	320	230
	After LW12	2,650	340	260
	After LW13	2,700	360	280
	After LW18	2,700	370	280

The equivalent valley height for Donalds Castle Creek, which is the height of the valley within a half depth of cover of the valley base, varies between 5 metres and 40 metres within the Study Area. The equivalent valley height is used in the ACARP model to predict the upsidence and closure movements along the creek.

The creek will also experience horizontal movements along and across its alignment due to the conventional movements. The predicted profiles of horizontal movement along and across the alignment of Donalds Castle Creek, based on both the MSEC459 and MSEC792 prediction curves, is provided in Fig. 5.4.

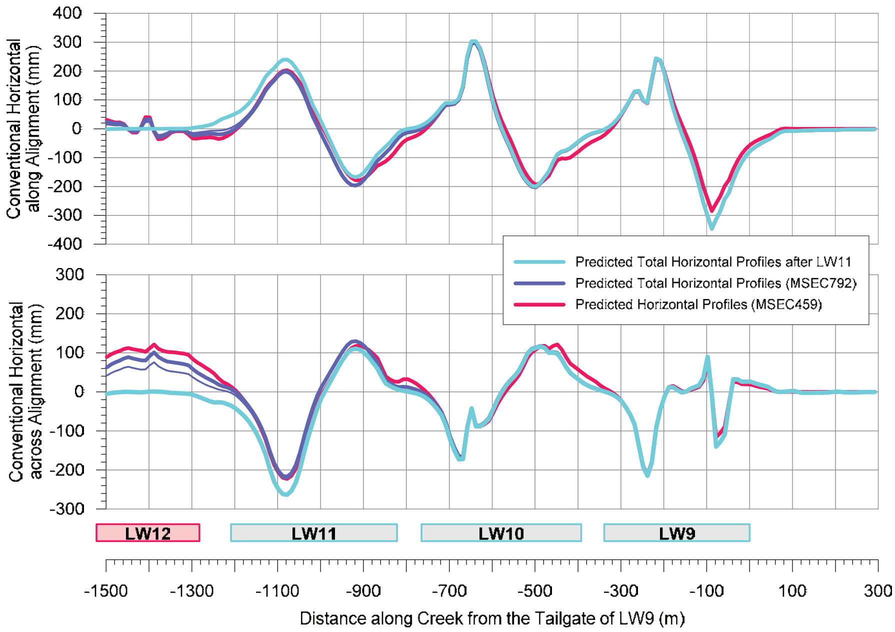

Fig. 5.4 Predicted Conventional Horizontal Movements along (top) and across (bottom) the Alignment of Donalds Castle Creek

A summary of the maximum predicted values of total horizontal movement along, horizontal movement across and conventional closure for Donalds Castle Creek, based on the MSEC792 prediction curves, is provided in Table 5.8. It is noted, that the conventional closure is normally provided separately to the valley related closure, as the associated conventional strains are distributed across the longwall, as opposed to the valley related compressive strains which are concentrated in the valley base. Also, in most cases, the valley related closures and conventional closures are orientated obliquely to each other.

Table 5.8 Maximum Predicted Total Horizontal Movement along, Horizontal Movement Across and Conventional Closure for Donalds Castle Creek based on the MSEC792 Prediction Curves

Location	Longwall	Maximum Predicted Total Horizontal Movement Along (mm)	Maximum Predicted Total Horizontal Movement Across (mm)	Maximum Predicted Total Conventional Closure (mm)
Donalds Castle Creek	After LW11	350	275	350
	After LW12	350	225	350
	After LW13	350	225	350
	After LW18	350	225	350

The maximum predicted total closure (i.e. valley plus conventional) is 575 mm which occurs above each of the Longwalls 9 to 11. The maximum predicted total closure for the upper reaches of creek located directly above the future Longwall 12 is 200 mm.

A summary of the maximum predicted total conventional tilt and curvatures along the alignment of Donalds Castle Creek, based on the MSEC792 prediction curves, is provided in Table 5.9.

Table 5.9 Maximum Predicted Total Conventional Tilt and Curvatures for Donalds Castle Creek based on the MSEC792 Prediction Curves

Location	Longwall	Maximum Predicted Total Increasing Tilt (mm/m)	Maximum Predicted Total Decreasing Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Donalds Castle Creek	After LW11	20	25	0.50	0.50
	After LW12	20	25	0.50	0.50
	After LW13	20	25	0.50	0.50
	After LW18	20	25	0.50	0.50

The conventional tilts provided in the above table are the maximum predicted values at the completion of each of the longwalls. The conventional curvatures provided in the above table are the maximum predicted values which occur at any time during or after the extraction of each of the longwalls. The predicted tilts and curvatures due to the valley movements are small and not significant when compared with the conventional values provided in the above table.

The maximum predicted conventional strains for Donalds Castle Creek, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 8 mm/m tensile and compressive. The creek is also likely to experience elevated compressive strains, resulting from the valley related movements, which could be in the order of 10 mm/m and 20 mm/m based on observations at valleys with similar heights and similar levels of predicted valley closure.

A summary of the maximum predicted values of total subsidence, upsidence and closure at the mapped rockbars along Donalds Castle Creek, based on the MSEC792 prediction curves, is provided in Table 5.10. The locations of these rockbars are indicated in Drawing No. MSEC792-10.

Table 5.10 Maximum Predicted Total Subsidence, Upsidence and Closure at the Mapped Rockbars along Donalds Castle Creek Resulting from the Extraction of the Proposed Longwalls

Feature	Label	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Valley Upsidence (mm)	Maximum Predicted Total Valley Closure (mm)
Rockbars	DC-RB35	180	120	180
	DC-RB33	70	90	160
	DC-RB29	< 20	50	110
	DC-RB25	< 20	45	85
	DC-RB22	< 20	40	75
	DC-RB21	< 20	40	75
	DC-RB18	< 20	35	55
	DC-RB16	< 20	30	35
	DC-RB15	< 20	25	25

The remaining rockbars along Donalds Castle Creek, further north of the longwalls, are predicted to experience less than 20 mm of subsidence, upsidence and closure.

5.4.3. Comparison of Predictions for Donalds Castle Creek based on the MSEC459 and MSEC792 Predictions Curves

The comparison of the maximum predicted total subsidence, upsidence and closure for Donalds Castle Creek, based on the MSEC459 and MSEC792 prediction curves, is provided in Table 5.11.

Table 5.11 Comparison of the Predicted Subsidence, Upsidence and Closure for Donalds Castle Creek

Prediction Curves	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Closure (mm)	Maximum Predicted Total Valley Related Upsidence (mm)	Maximum Predicted Total Valley Related Closure (mm)
MSEC459	2,050	350	370	280
MSEC792	2,700	350	370	280

The maximum predicted subsidence based on the MSEC792 prediction curves of 2,700 mm is greater than that predicted based on the MSEC459 prediction curves of 2,050 mm, i.e. a 32 % increase. The maximum predicted conventional closures do not change, as the higher conventional horizontal movement on the maingate side is offset by the slightly lower conventional horizontal movement on the tailgate side.

The maximum predicted valley related upsidence and closure for the creek also do not change, as the creek is essentially orientated across the longwalls and, therefore, the increased horizontal movements are orientated along rather than across the alignment of the stream.

The comparison of the maximum predicted total tilts and curvatures for Donalds Castle Creek, based on the MSEC459 and MSEC792 prediction curves, is provided in Table 5.12.

Table 5.12 Comparison of the Predicted Tilts and Curvatures for Donalds Castle Creek

Prediction Curves	Maximum Predicted Total Increasing Tilt (mm/m)	Maximum Predicted Total Decreasing Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
MSEC459	20	20	0.50	0.50
MSEC792	20	25	0.50	0.50

The maximum predicted decreasing tilt, based on the MSEC792 prediction curves, of 25 mm/m is greater than that based on the MSEC459 prediction curves of 20 mm/m, i.e. a 25 % increase. The maximum predicted increasing tilt and curvatures do not change, i.e. the increases are less than the rounding to the nearest 5 mm/m for tilt and 0.05 km^{-1} for curvature and, therefore, are less than the order of accuracy of the prediction methods.

5.4.4. Review of the Assessed Impacts for Donalds Castle Creek provided in Report No. MSEC459 and the Reported Impacts during Longwalls 9 and 10

The impact assessments for Donalds Castle Creek provided in Report No. MSEC459 stated that:

> "…*it is expected that fracturing will occur in the bedrock along the section of Donalds Castle Creek which is located directly above the proposed longwalls. It is also possible, that surface water flow diversions could occur in some locations along the creek, however, based on the previous experience at the mine, the incidence of this occurring has been considered low"*; and where

> "…*the base of the creek has exposed bedrock, there may be some diversion of surface water flows into the dilated strata beneath the bed. It is unlikely that there would be any net loss of water from the catchment, however, as the depth of dilation and fracturing is expected to be less than 10 metres to 15 metres and, therefore, any diverted surface water is likely to re-emerge into the catchment further downstream.*" "; and

> "…*it is possible that some localised increased ponding could occur, immediately upstream of the longwall chain pillars, it is not anticipated that there would be any significant increase in the potential for wider spread ponding*"

Impacts were observed in Donalds Castle Creek as a result of Longwall 9 which were described in the End of Panel Report (IC, 2014) and have been summarised below:

> "*Site DA3B_LW9_006: Multiple fractures and uplift on DC_RB33 at basal step of Swamp 5; up to 0.015m wide, 2m long and 0.040m of uplift. Exfoliation from the step. Associated flow diversion"*

> "*Site DA3B_LW9_007: Change in water appearance in DC_Pool33. Yellow/orange colour and increase in turbidity*"; and

> "*Reduction in pool water levels were observed in watercourses Donalds Castle Creek*"

There were no reported fracturing along the creek as a result of Longwall 10, as Swamp 5 overlays the creek above the extent of this longwall. There were increased rates of water level recession compared to baseline conditions within this swamp as a result of this longwall.

It is considered that the physical impacts (i.e. fractures and associated flow diversion) observed along Donalds Castle Creek are consistent with the assessed potential for impacts outlined in Report No. MSEC459 and the SMP Application. Further discussions on the environmental consequences (i.e. change in water appearance and increased turbidity) are provided in the WIMMCP.

5.4.5. Impact Assessments for Donalds Castle Creek based on the MSEC792 Prediction Curves

The maximum predicted tilts along Donalds Castle Creek are 20 mm/m (i.e. 2.0 %, or 1 in 50) increasing and 25 mm/m (i.e. 2.5 %, or 1 in 40) decreasing. The natural gradient of Donalds Castle Creek, directly above the longwalls, varies between a minimum of 10 mm/m and a maximum of 100 mm/m, with an average natural gradient of around 30 mm/m. The natural grade and the predicted post mining grade along Donalds Castle Creek are illustrated in Fig. 5.5.

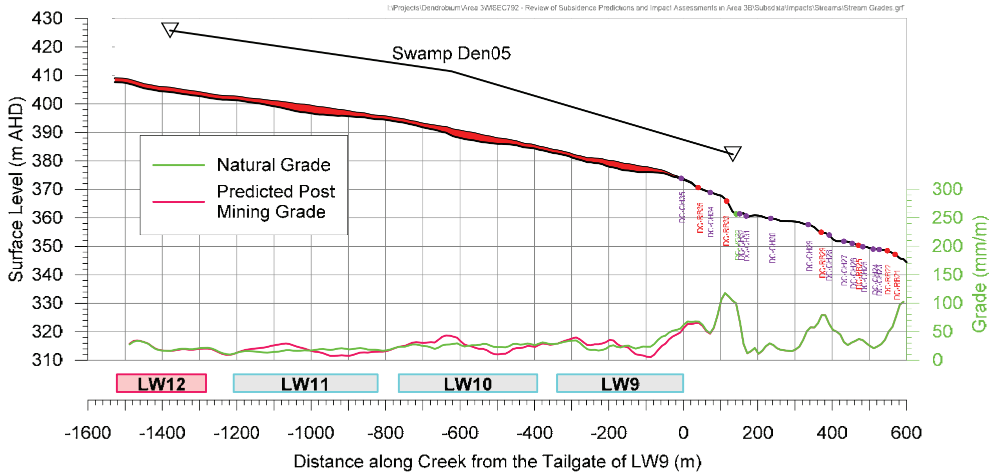

Fig. 5.5 Natural and Predicted Post Mining Surface Levels along Donalds Castle Creek

It can be seen from the above figure, that there are no predicted reversals of grade along the creek resulting from the extraction of the longwalls. The changes in grade directly above the future Longwall 12 is very small as the creek only partially extends above this longwall.

The predicted incremental conventional subsidence and valley related movements due to Longwall 12 are less than those predicted for the previous longwalls, as the upper reaches of the creek only partially extend above this longwall. The potential for impacts on Donalds Castle Creek, resulting from the extraction of Longwall 12, therefore, are less than those due to Longwalls 9 to 11.

The impact assessments and management strategies for Donalds Castle Creek, for the future Longwalls 12 to 18, therefore, do not change from those provided in Report No. MSEC459 and the SMP Application.

5.5. Drainage Lines

5.5.1. Descriptions of the Drainage Lines

There is a number of unnamed drainage lines located within the Study Area which are shown in Drawing No. MSEC792-08. It can be seen from this drawing, that the drainage lines flow into Wongawilli Creek in the eastern part of the Study Area, into Donalds Castle Creek in the northern part of the Study Area, and into Lake Avon on the western and southern sides of the Study Area.

The drainage lines within the Study Area are first and second order ephemeral streams. Some drainage lines are confined within swamps and, in these locations, the beds have mostly been covered by soil accumulation and vegetation. Elsewhere, the drainage lines have exposed bedrock with rockbars, pools and steps in some locations.

Photographs of some typical drainage lines located within the Study Area are provided in Fig. 5.6.

Fig. 5.6 Photographs of Typical Drainage Lines within the Study Area

The natural gradients of the drainage lines within the Study Area typically vary between 10 mm/m (i.e. 1 %, or 1 in 100) along the upper reaches, and 300 mm/m (i.e. 30 %, or 1 in 3) along the lower reaches. The average natural gradients of the drainage lines, directly above the proposed longwalls, typically vary between 25 mm/m (i.e. 2.5 %, or 1 in 40) and 100 mm/m (i.e. 1 %, or 1 in 10).

5.5.2. Predictions for the Drainage Lines

The predicted profiles of conventional subsidence and valley related upsidence and closure along Drainage Lines NC13, LA3, LA4, LA4B, LA5, ND1, WC15 and WC21, based on the MSEC792 prediction curves, are shown in Figs. D.04 to D.11, in Appendix D. The predicted incremental profiles, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles, after the extraction of each of the longwalls, are shown as solid blue lines.

A summary of the maximum predicted values of total conventional subsidence and valley related upsidence and closure for these drainage lines, based on the MSEC792 prediction curves, is provided in Table 5.13.

Table 5.13 Maximum Predicted Total Conventional Subsidence and Valley Related Upsidence and Closure for the Drainage Lines based on the MSEC792 Prediction Curves

Location	Name	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Valley Related Upsidence (mm)	Maximum Predicted Total Valley Related Closure (mm)
Drainage Lines	DC13	2,050	250	225
	LA3	1,200	425	450
	LA4	2,100	225	350
	LA4B	2,700	200	350
	LA5	2,700	100	125
	ND1	2,750	275	425
	WC15	3,600	725	700
	WC21	3,500	700	700

It is noted that, in some cases, the maximum predicted valley related upsidence and closure movements occur downstream of the extent of longwall mining, where the valley heights along the lower reaches of the drainage lines are much greater than those directly above the longwalls.

The drainage lines will also experience horizontal movements along and across their alignments due to the conventional movements. A summary of the maximum predicted values of total horizontal movement along, horizontal movement across and conventional closure for the drainage lines, based on the MSEC792 prediction curves, is provided in Table 5.14. It is noted, that the conventional closures are normally provided separately to the valley related closures, as the associated conventional strains are distributed across the longwalls, as opposed to the valley related compressive strains which are concentrated in the valley bases. Also, in most cases, the valley related closures and conventional closures are orientated obliquely to each other.

Table 5.14 Maximum Predicted Total Horizontal Movement along, Horizontal Movement Across and Conventional Closure for the Drainage Lines based on the MSEC792 Prediction Curves

Location	Name	Maximum Predicted Total Horizontal Movement Along (mm)	Maximum Predicted Total Horizontal Movement Across (mm)	Maximum Predicted Total Conventional Closure (mm)
Drainage Lines	DC13	225	325	325
	LA3	300	175	175
	LA4	200	250	200
	LA4B	475	175	225
	LA5	425	250	275
	ND1	350	400	350
	WC15	550	275	450
	WC21	500	375	375

The maximum predicted total closures (i.e. valley plus conventional) are: 550 mm for DC13; 625 mm for LA3; 400 mm for LA4; 350 mm for LA4B; 325 mm for LA5; 700 mm for ND1; 1,100 mm for WC15; and 1000 mm for WC21.

The remaining drainage lines which are located directly above the longwalls could experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4.

The maximum predicted conventional strains for the drainage lines, based on applying a factor of 15 to the maximum predicted conventional curvatures, are both 20 mm/m tensile and compressive. The drainage lines are also likely to experience elevated compressive strains, resulting from the valley related movements, which could be in the order of 10 mm/m and 20 mm/m based on observations at valleys with similar heights and similar levels of predicted valley closure.

5.5.3. Comparison of Predictions for the Drainage Lines based on the MSEC459 and MSEC792 Predictions Curves

The comparison of the maximum predicted total subsidence, upsidence and closure for the drainage lines, based on the MSEC459 and MSEC792 prediction curves, is provided in Table 5.15.

Table 5.15 Comparison of the Predicted Conventional Subsidence and Closure and Valley Related Upsidence and Closure for the Drainage Lines

Drainage Line	Prediction Curves	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Closure (mm)	Maximum Predicted Total Valley Related Upsidence (mm)	Maximum Predicted Total Valley Related Closure (mm)
DC13	MSEC459	1,500	250	250	225
	MSEC792	2,050	325	250	225
LA3	MSEC459	625	150	425	450
	MSEC792	1,200	175	425	450
LA4	MSEC459	1,400	125	225	350
	MSEC792	2,100	200	225	350
LA4B	MSEC459	2,200	200	200	350
	MSEC792	2,700	225	200	350
LA5	MSEC459	2,250	250	100	125
	MSEC792	2,700	275	100	125
ND1	MSEC459	2,350	300	275	425
	MSEC792	2,750	350	275	425
WC15	MSEC459	2,600	400	725	700
	MSEC792	3,600	450	725	700
WC21	MSEC459	2,550	375	700	700
	MSEC792	3,500	375	700	700

The maximum predicted vertical subsidence for the drainage lines, based on the MSEC792 prediction curves, are typically between 20 % and 38 % greater than those based on the MSEC459 prediction curves. The maximum predicted vertical subsidence for Drainage Line LA3 is 575 mm greater (i.e. a 92 % increase) as it is located above the tailgate chain pillar at the end of Longwall 16.

The maximum predicted conventional closure for the drainage lines, based on the MSEC792 prediction curves, are typically between zero and 17 % greater than those based on the MSEC459 prediction curves. The maximum predicted conventional closure for Drainage Line LA4 is 75 mm greater (i.e. a 60 % increase) as it is located parallel to and above the tailgate chain pillar at the end of Longwall 14.

The maximum predicted valley related upsidence and closure movements for the drainage lines do not change, as these movements are not sensitive to the magnitude of vertical subsidence at the predicted magnitudes, i.e. the predicted increases are less than the rounding to the nearest 25 mm and, therefore, are less than the order of accuracy of the prediction method.

5.5.4. Review of the Assessed Impacts for the Drainage Lines provided in Report No. MSEC459 and the Reported Impacts during Longwalls 9 and 10

The impact assessments provided in Report No. MSEC459 refer 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 consultant's reports and, therefore, the discussions below should be read in conjunctions with those provided by the other specialist consultants.

The impact assessments for the drainage lines provided in Report No. MSEC459 stated that:

> *"It is likely, therefore, that fracturing would occur in the uppermost bedrock"* and that *"where the bases of the drainage lines have exposed bedrock, there may be some diversion of surface water flows into the dilated strata beneath the beds and the draining of pooled water within their alignments. It is unlikely that there would be any net loss of water from the catchment, however, as the depth of dilation and fracturing is expected to be less than 10 metres to 15 metres and, therefore, any diverted surface water is likely to re-emerge into the catchment further downstream."*; and
>
> *"It is possible that there could be localised areas along the drainage lines which could experience small increases in the levels of ponding and flooding, in the locations of predicted maximum decreasing tilts, such as upstream of the longwall chain pillars and goaf edges. It is also possible, that there could be localised areas which experience increased scouring of the banks, in the locations of the predicted maximum increasing tilts, such as downstream of the longwall chain pillars."*

Impacts were observed in the drainage lines as a result of Longwall 9 which were described in the End of Panel Report (IC, 2014) and have been summarised below:

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

Impacts were also observed in the drainage lines as a result of Longwall 10 which were described in the End of Panel Report (IC, 2015) and have been summarised below:

> *Drainage Line WC21*: impacts observed at 17 sites including: additional fracturing at the sites previously impacted by Longwall 9; fracturing from hairline and up to 30 mm in width and up to 5.5 metres in length; iron staining; dilation and uplift; and localised flow diversion up stream of Rockbar WC21_RB26 and in Pool WC21_Pool 24.

Further discussions on the impacts and environmental consequences to the drainage lines due to Longwalls 9 and 10 are provided by the other specialist consultant's reports.

5.5.5. Impact Assessments for the Drainage Lines based on the MSEC792 Prediction Curves

The impact assessments for the drainage lines have been reviewed based on the updated predictions obtained using the MSEC792 prediction curves. The assessments provided in this report should be read in conjunction with the WIMMCP.

Potential for Increased Levels of Ponding, Flooding and Scouring

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

The maximum predicted tilt for the drainage lines within the Study Area is 50 mm/m (i.e. 5.0 %), which represents a change in grade of 1 in 20. The average natural gradients of the drainage lines, directly above the proposed longwalls, typically vary between 25 mm/m (i.e. 2.5 %, or 1 in 40) and 100 mm/m (i.e. 1 %, or 1 in 10). The natural gradients in some locations, however, are less than 10 mm/m (i.e. less than 1 %, or 1 in 100) or more than 200 mm/m (i.e. more than 20 %, or 1 in 50).

The maximum predicted changes in grade are similar orders of magnitude as the natural gradients in the flatter sections of the drainage lines. The natural grades and the predicted post mining grades along Drainage Lines DC13, LA3, LA4, LA4B, LW5, ND1, WC15 and WC21, based on the MSEC792 prediction curves, are illustrated in Fig. 5.7 to Fig. 5.14.

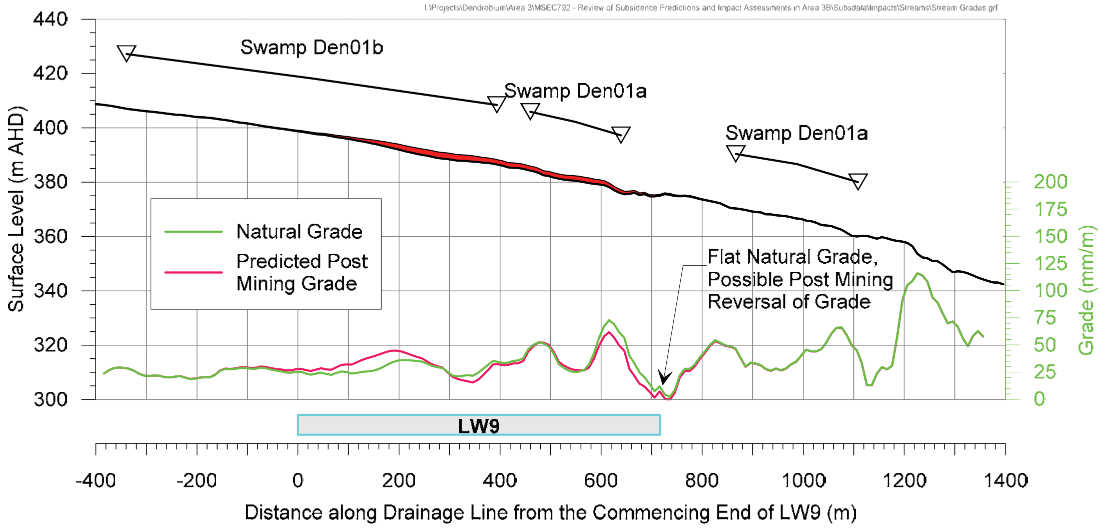

Fig. 5.7 Natural and Predicted Post Mining Surface Levels along Drainage Line DC13

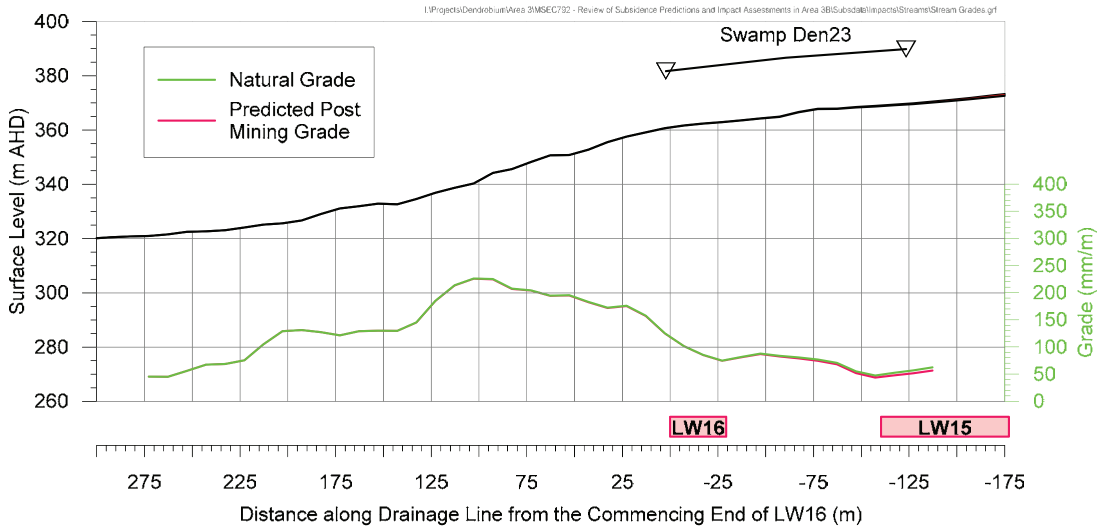

Fig. 5.8 Natural and Predicted Post Mining Surface Levels along Drainage Line LA3

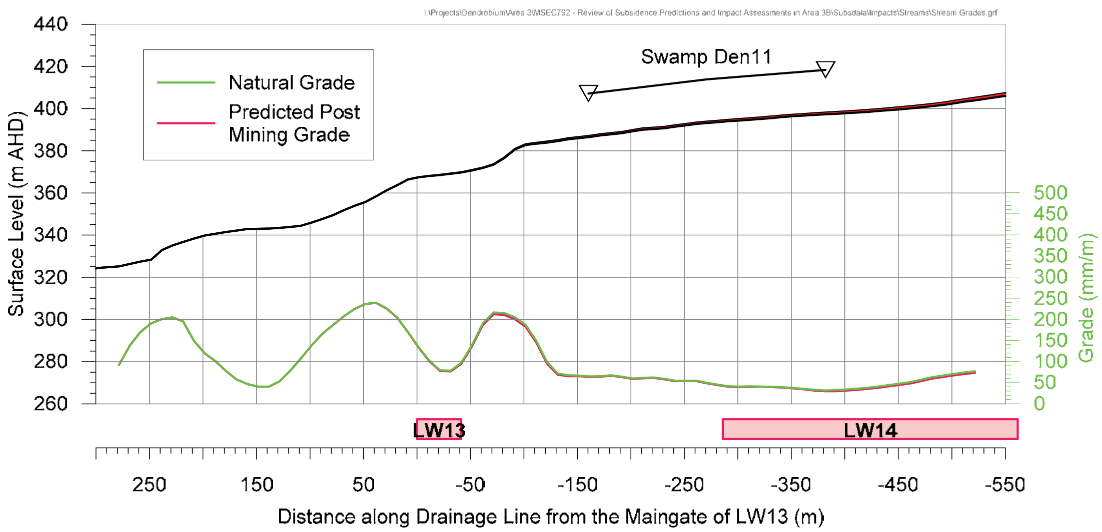

Fig. 5.9 Natural and Predicted Post Mining Surface Levels along Drainage Line LA4

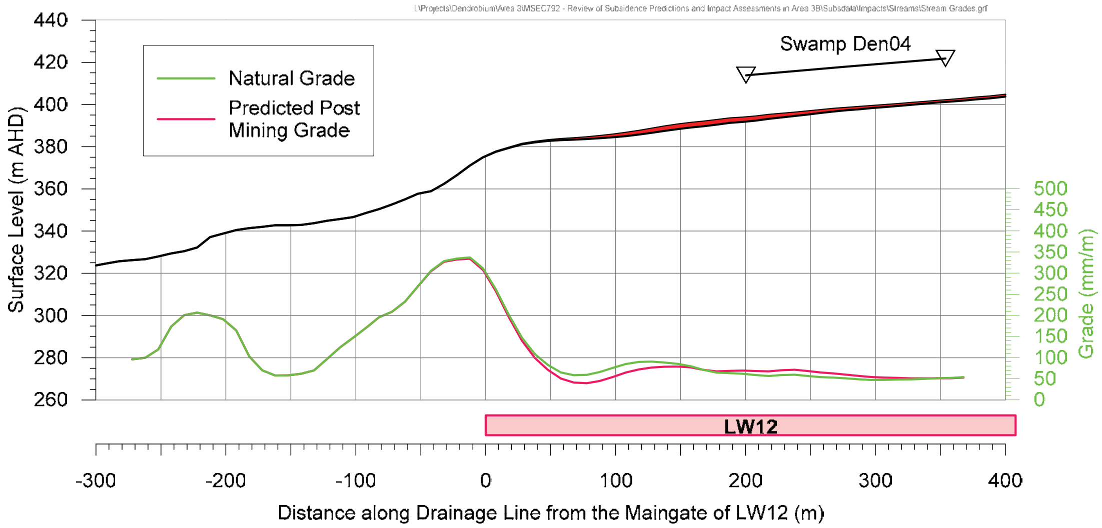

Fig. 5.10 Natural and Predicted Post Mining Surface Levels along Drainage Line LA4B

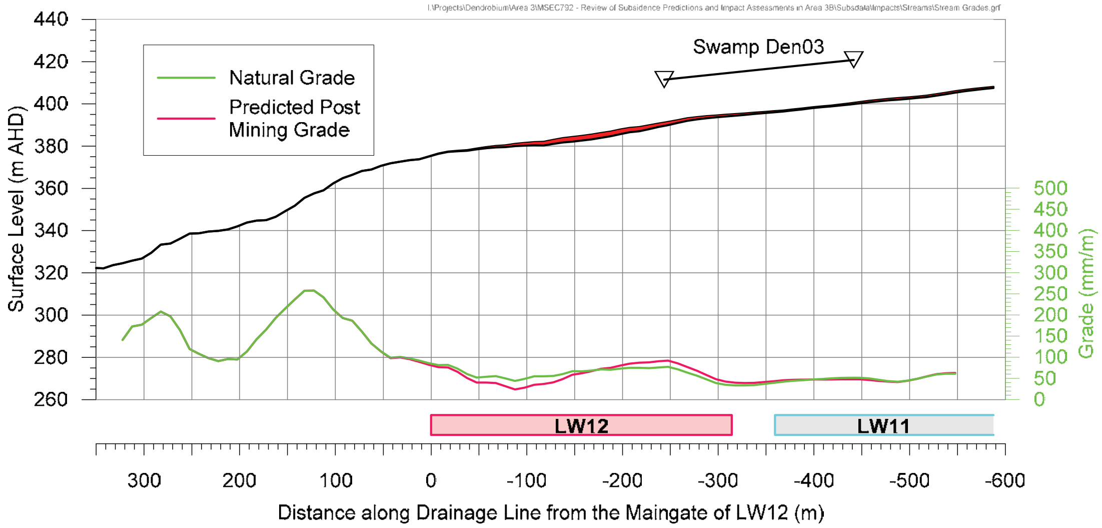

Fig. 5.11 Natural and Predicted Post Mining Surface Levels along Drainage Line LA5

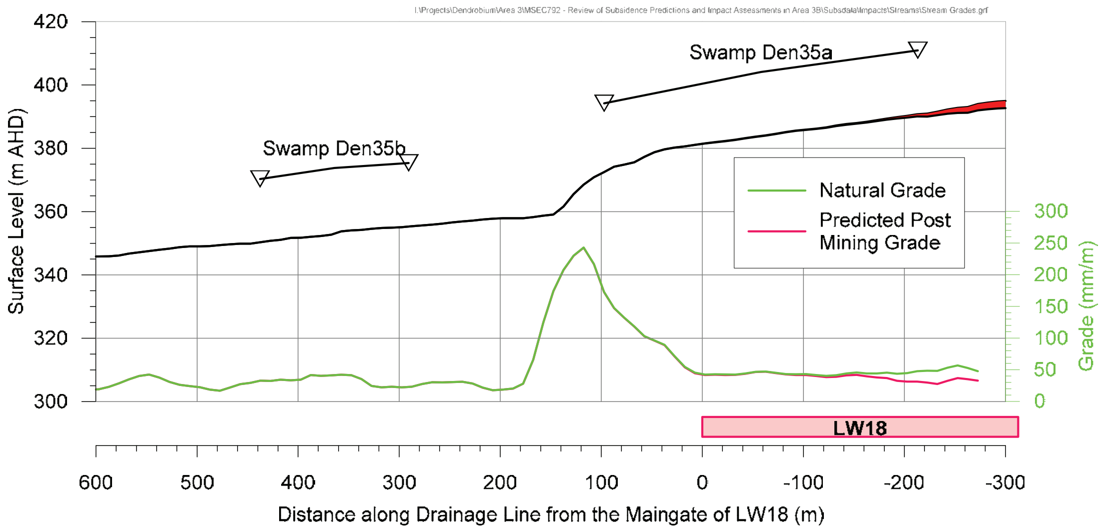

Fig. 5.12 Natural and Predicted Post Mining Surface Levels along Drainage Line ND1

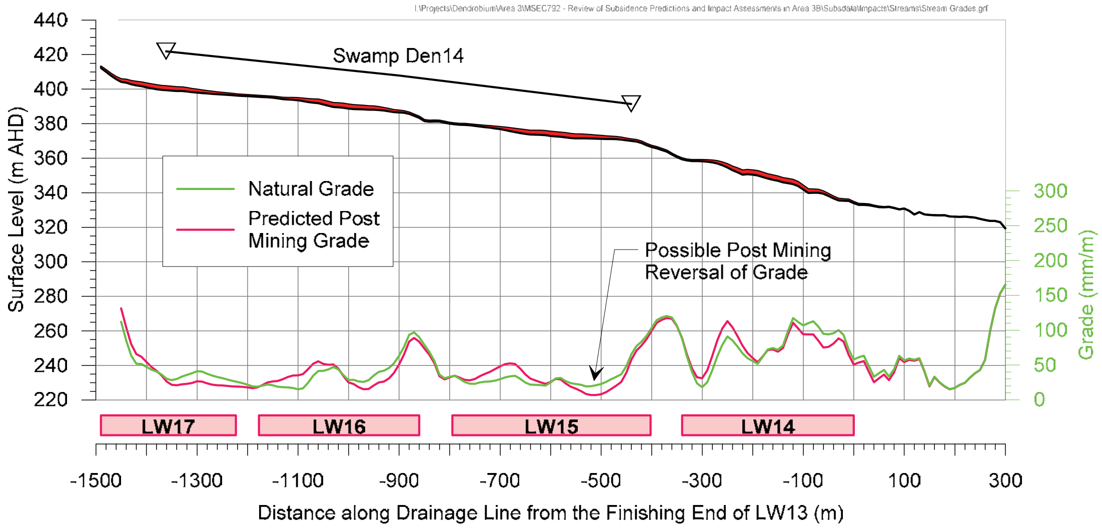

Fig. 5.13 Natural and Predicted Post Mining Surface Levels along Drainage Line WC15

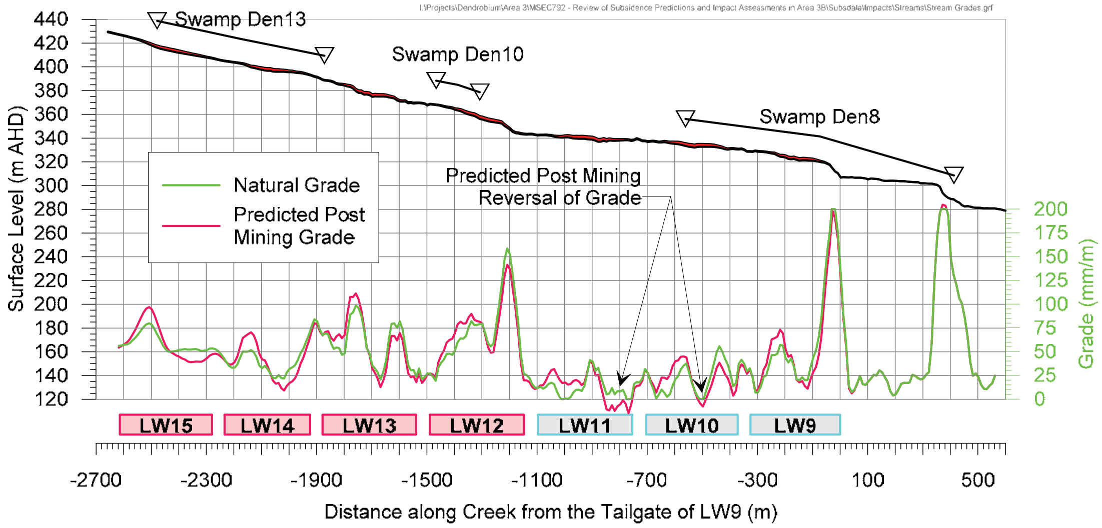

Fig. 5.14 Natural and Predicted Post Mining Surface Levels along Drainage Line WC21

It can be seen from the above figures, that there are predicted reversals in grade along Drainage Line WC21, adjacent to the tailgates of the previously extracted Longwalls 10 and 11. There are no predicted reversals of grade along this drainage line, however, above the future Longwalls 12 to 15.

It can also be seen, that reversals in grade could also occur along Drainage Line DC13 adjacent to the tailgate of Longwall 9 and along Drainage Line WC15 adjacent to the tailgate of Longwall 15. There were potentials for reversals of grade in these locations, based on the MSEC459 prediction curves, with the likelihoods increasing slightly based on the updated prediction model.

It is possible that there could be localised areas along the drainage lines which could experience small increases in the levels of ponding and flooding, in the locations of predicted maximum decreasing tilts, such as upstream of the longwall chain pillars and goaf edges. It is also possible, that there could be localised areas which 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 for ponding and scouring along the drainage lines, based on the MSEC792 prediction curves, are only slightly greater than those based on the MSEC459 prediction curves, because the natural grades are typically greater than the predicted tilts and, hence, any impacts are expected to be minor and localised. The impacts resulting from these changes in surface water flows are expected to be small in comparison with those which occur during natural flooding conditions.

Potential for Cracking in the Creek Bed and Fracturing of Bedrock

Impacts have been observed along Drainage Lines DC13 and WC21 above the previously extracted Longwalls 9 and 10 including: fracturing in the rockbars and exposed bedrock; dilation and uplift of the bedrock; iron staining; and surface water flow diversions in Pools DC13_Pool20, upstream of DC13_RB21, WC21_Pool16, up stream of Rockbar WC21_RB26 and in WC21_Pool 24.

Summaries of the maximum predicted subsidence parameters for Drainage Lines DC13 and WC21 resulting from the extraction of Longwalls 9 and 10 only, based on the MSEC729 prediction curves, are provided in Table 5.16 and Table 5.17.

Table 5.16 Maximum Predicted Total Conventional Subsidence and Valley Related Upsidence and Closure for the Drainage Lines DC13 and WC21 due to Longwalls 9 and 10 Only

Longwalls	Drainage Line	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Valley Related Upsidence (mm)	Maximum Predicted Total Valley Related Closure (mm)
Longwalls 9 and 10	DC13	2,100	225	200
	WC21	2,900	550	500

Table 5.17 Maximum Predicted Total Horizontal Movement along, Horizontal Movement across and Conventional Closure for the Drainage Lines DC13 and WC21 due to Longwalls 9 and 10 Only

Longwalls	Drainage Line	Maximum Predicted Total Horizontal Movement Along (mm)	Maximum Predicted Total Horizontal Movement Across (mm)	Maximum Predicted Total Conventional Closure (mm)
Longwalls 9 and 10	DC13	200	350	350
	WC21	425	375	450

The maximum predicted subsidence parameters for the Drainage lines LA3, LA4, LA4B, LA5, ND1, WC15 and WC21, resulting from the extraction of the future Longwalls 12 to 18, vary between: 1,200 to 3,600 mm vertical subsidence; 100 to 725 mm valley related upsidence; 125 to 700 mm valley closure; and 175 to 450 mm conventional closure.

The maximum predicted subsidence parameters for these drainage lines above the future Longwalls 12 to 18, compared with those predicted for the previously extracted Longwalls 9 and 10, are: 25 % greater for vertical subsidence; 32 % greater for valley related upsidence; 40 % for valley related closure; and similar for the conventional closure.

The likelihood and extents of the assessed maximum impacts on the drainage lines for Longwalls 12 to 18, therefore, are expected to be greater than those observed for Longwalls 9 and 10. Whilst the rates of impacts are likely to increase, the nature of these impacts are unlikely to change, i.e. a greater number of fractures with increased widths in the exposed bedrock resulting in a slightly increased potential for surface water flow diversions.

Whilst the assessed impacts for the future longwalls are greater than those for the previously extracted longwalls, they are considered to be consistent with the impact assessments provided in Report No. MSEC459 and the SMP Application. The management strategies for the drainage lines, for the future Longwalls 12 to 18, therefore, are the same those provided in Report No. MSEC459 and the SMP Application.

Further discussions on the potential impacts and environmental consequences for the drainage lines are provided in the WIMMCP.

5.6. Aquifers and Known Groundwater Resources

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

5.7. Cliffs

5.7.1. Descriptions of the Cliffs

For the purposes of the SMP Application, a cliff was defined in Report No. MSEC459 as a continuous rockface having a minimum height of 10 metres and a minimum slope of 2 to 1, i.e. having a minimum angle to the horizontal of 63°. The locations of cliffs within the Study Area were determined from site investigations, from the orthophotograph and from the 1 metre surface level contours which were generated from an aerial laser scan of the area.

The locations of the cliffs within the Study Area are shown in Drawings Nos. MSEC792-09 to MSEC792-11. Most of the cliffs within the Study Area have been identified within the valley of Wongawilli Creek and Drainage Line WC15. In addition to the cliffs, there are also numerous rock outcrops which are located across the Study Area. The rock outcrops are generally less than 5 metres in height.

The details of the cliffs within the Study Area are provided in Table 5.18.

Table 5.18 Details of the Cliffs within the Study Area

Cliff Ref.	Overall Length (m)	Maximum Height (m)	Location
DA3-CF19	15	10	190 metres east of Longwall 13
DA3-CF20	50	20	130 metres east of Longwall 13
DA3-CF21	35	20	100 metres east of Longwall 13
DA3-CF22	15	15	90 metres east of Longwall 13
DA3-CF23	85	20	30 metres east of Longwall 13
DA3-CF25	160	25	150 metres east of Longwall 17
DA3-CF26	180	25	100 metres east of Longwall 17
DA3-CF41	15	20	80 metres east of Longwall 18
DA3-CF42	20	20	75 metres east of Longwall 18
DA3-CF43	60	20	85 metres east of Longwall 18
DA3-CF44	10	10	460 metres west of Longwall 12
DA3-CD45	50	15	280 metres south-west of Longwall 12
DA3-CF46	15	15	180 metres east of Longwall 14
DA3-CF47	35	20	310 metres east of Longwall 15

It can be seen from the above table, that all of the identified cliffs are located outside the extents of the longwalls (i.e. the cliffs are not directly mined beneath).

The longer clifflines within the Study Area are made up of a number of separate cliffs, rather than being a single continuous cliffline. 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 which are generally less than 6 metres of overhang.

It should be noted, that the maximum cliff heights, provided in the above table, are less than the overall heights of the valleys of Wongawilli Creek and its tributaries. This is because the cliff heights do not include the talus slopes and because the slopes of some rockfaces, though steep, are not considered steep enough to describe them as parts of the cliffs.

Photographs of the cliffs along the Wongawilli Creek valley are provided in Fig. 5.15.

Fig. 5.15 Photographs of Typical Cliffs along Wongawilli Creek (Courtesy of IC)

5.7.2. Predictions for the Cliffs

A summary of the maximum predicted total conventional subsidence parameters at the cliffs, based on the MSEC792 prediction curves, is provided in Table 5.19. The remaining cliffs in the area are not predicted to experience any measurable conventional subsidence movements resulting from the mining in Area 3B.

Table 5.19 Maximum Predicted Total Conventional Subsidence Parameters for the Cliffs based on the MSEC792 Prediction Curves

Cliff Ref.	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
DA3-CF19	< 20	< 0.5	< 0.01	< 0.01
DA3-CF20	< 20	0.5	0.06	< 0.01
DA3-CF21	50	1.0	0.09	< 0.01
DA3-CF22	75	1.5	0.03	< 0.01
DA3-CF23	300	5.0	0.15	< 0.01
DA3-CF25	< 20	< 0.5	< 0.01	< 0.01
DA3-CF26	< 20	0.5	0.08	< 0.01
DA3-CF41	< 20	0.5	0.06	< 0.01
DA3-CF42	< 20	0.5	0.04	< 0.01
DA3-CF43	< 20	< 0.5	0.04	< 0.01
DA3-CF44	< 20	< 0.5	< 0.01	< 0.01
DA3-CF45	< 20	< 0.5	< 0.01	< 0.01
DA3-CF46	< 20	< 0.5	< 0.01	< 0.01
DA3-CF47	< 20	< 0.5	< 0.01	< 0.01

The tilts provided in the above table are the maximum predicted values at the completion of any or all longwalls. The curvatures provided in the above table are the maximum predicted values which occur at any time during or after the extraction of the longwalls.

The maximum predicted tilt at the cliffs is 5.0 mm/m (i.e. 0.5 %), which represents a change in grade of 1 in 200. The maximum predicted curvatures at the cliffs are 0.15 km^{-1} hogging and less than 0.01 km^{-1} sagging, which represent minimum radii of curvature of 7 kilometres and greater than 100 kilometres, respectively. The maximum predicted tilts and curvatures occur at Cliff DA3-CF23, which is the cliff located closest to the longwalls.

The maximum predicted conventional strains for the cliffs, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 2 mm/m tensile and less than 0.3 mm/m compressive (i.e. in the order of survey tolerance). The cliffs are located up the valley sides and, therefore, are not expected to experience the valley closure strains which occur near the valley base.

5.7.3. Comparison of Predictions for the Cliffs based on the MSEC459 and MSEC792 Predictions Curves

The comparison of the maximum predicted total subsidence, tilt and curvatures for the cliffs, based on the MSEC459 and MSEC792 prediction curves, is provided in Table 5.20.

Table 5.20 Comparison of the Predicted Subsidence, Tilt and Curvatures for the Cliffs

Prediction Curves	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
MSEC459	100	2.0	0.07	< 0.01
MSEC792	300	5.0	0.15	< 0.01

The maximum predicted subsidence, tilt and hogging curvature provided in the above table all occur at Cliff DA3-CF23, which is located closest to the longwalls. The increase in the predicted subsidence parameters at this cliff are: 200 mm vertical subsidence, 3.0 mm/m tilt; and 0.08 km^{-1} hogging curvature.

The maximum predicted increases in the subsidence parameters for the remaining cliffs are: 50 mm vertical subsidence, 1.0 mm/m tilt; and 0.02 km^{-1} hogging curvature. The differences in these predicted subsidence parameters, between the MSEC459 and MSEC792 prediction curves, are within the orders of accuracy of the prediction method.

5.7.4. Review of the Assessed Impacts for the Cliffs provided in Report No. MSEC459 and the Reported Impacts during Longwalls 9 and 10

The impact assessments for the cliffs provided in Report No. MSEC459 stated that:

> "*… some small isolated rockfalls could occur along the cliffs as a result of the extraction of the proposed longwalls. It is not expected, however, that any large scale cliff instabilities would occur based on the previous experience at Dendrobium, Appin and Tower Collieries.*"

There have been no reported impacts on the cliffs during to the extraction of Longwalls 9 and 10.

5.7.5. Impact Assessments for the Cliffs

The predicted subsidence parameters for the cliffs, based on the MSEC792 prediction curves are similar to, but, slightly greater than those based on the MSEC459 prediction curves. The differences, however, are within the order of accuracy of the prediction methods.

The cliffs are all located outside the extents of the future Longwalls 12 to 18, at minimum distances between 30 metres and 460 metres. Based on the experience of mining at Dendrobium, Appin and Tower Collieries, there have only been isolated rockfalls observed outside the extents of longwall mining and these represent a very small proportion of the total length of cliffline.

The impact assessments and management strategies for the cliffs, therefore, are the same as those provided in Report No. MSEC459 and the SMP Application.

5.8. Rock Outcrops and Steep Slopes

5.8.1. Descriptions of the Rock Outcrops and Steep Slopes

There are rock outcrops located across the Study Area, primarily within the valleys of Wongawilli Creek and the associated tributaries. For the purposes of the SMP Application, a rock outcrop was defined in Report No. MSEC459 as an isolated rockface having a height of less than 10 metres. The locations of the rock outcrops have not been shown in the drawings, as their specific locations could not be derived from the aerial laser scan or topographic photograph. A photograph of typical rock outcropping is provided in Fig. 5.16.

Fig. 5.16 Photograph of Rock Outcropping (Courtesy of IC)

Rockfaces having minimum heights of 10 metres and minimum slopes of 2 to 1 have been defined as cliffs in this report, which are discussed in Section 5.7.

For the purposes of the SMP Application, a steep slope was defined in Report No. MSEC459 as an area of land having a natural gradient greater than 1 in 3 (i.e. a grade of 33 %, or an angle to the horizontal of 18°). The steep slopes within the Study Area were identified from the 1 metre surface contours which were generated from an airbourne laser scan of the area. The areas identified as having steep slopes are shown in Drawing No. MSEC792-09.

The steepest slopes within the Study Area, not including the cliffs and rock outcrops, were identified within the valley of Wongawilli Creek, which have natural grades of up to 1 in 1, or angles to the horizontal of up to 45°. Steep slopes were also identified directly above the proposed longwalls in Area 3B, along Donalds Castle Creek and the other major drainage lines, which have natural grades of up to 1 in 1.5, or angles to the horizontal of up to 34°.

5.8.2. Predictions for the Rock Outcrops and Steep Slopes

The rock outcrops and steep slopes are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the rock outcrops and steep slopes, based on the MSEC792 prediction curves, is provided in Table 5.21.

Table 5.21 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Rock Outcrops and Steep Slopes based on the MSEC792 Prediction Curves

Location	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Rock Outcrops and Steep Slopes	3,600	50	1.4	1.4

The predicted tilts provided in the above table are the maxima after the completion of any or all of the longwalls. The predicted curvatures provided in the above table are the maxima at any time during or after the extraction of each of the longwalls.

5.8.3. Comparison of Predictions for the Rock Outcrops and Steep Slopes based on the MSEC459 and MSEC792 Predictions Curves

The comparison of the maximum predicted total conventional subsidence, tilt and curvatures for the rock outcrops and steep slopes, based on the MSEC459 and MSEC792 prediction curves, is provided in Table 5.22.

Table 5.22 Comparison of Maximum Predicted Total Subsidence, Tilt and Curvatures for the Rock Outcrops and Steep Slopes

Prediction Curves	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})
MSEC459	2,800	40	1.0	1.0
MSEC792	3,600	50	1.4	1.4

The maximum predicted subsidence parameters based on the MSEC792 prediction curves are greater than those based on the MSEC459 prediction curves by: 30 % for vertical subsidence; 25 % for tilt; and 40 % for curvature.

5.8.4. Review of the Assessed Impacts for the Rock Outcrops and Steep Slopes provided in Report No. MSEC459 and the Reported Impacts during Longwalls 9 and 10

The impact assessments for the rock outcrops provided in Report No. MSEC459 stated that:

> "*The extraction of the proposed longwalls are likely to result in some fracturing of the rock outcrops and, where the rock is marginally stable, could then result in instabilities. Previous experience of mining beneath rock outcrops at Dendrobium Mine indicate that the percentage of rock outcrops that are likely to be impacted by mining is very small*" and that "*the incidence of impacts are expected to be low, similar to that previously observed at Dendrobium Mine*."

The impact assessments for the steep slopes provided in Report No. MSEC459 stated that:

> "*The potential impacts would generally result from the downslope movement of the soil, causing tension cracks to appear at the tops and sides of the slopes and compression ridges to form at the bottoms of the slopes*"; and that
>
> "*The natural grades of the steep slopes across Area 3B are generally less than the natural grades of the steep slopes in Dendrobium Areas 1 and 2. In addition to this, the depths of cover across Areas 3B are generally greater than the depths of cover in Dendrobium Areas 1 and 2. It is likely, therefore, that the sizes and extents of surface cracking at the steep slopes within Area 3B will be less than those observed during the extraction of Longwalls 1 and 2 in Area 1 and during the extraction of Longwall 3 to 5 in Area 2.*"
>
> The previously observed surface crack widths at the mine were: "*up to 400 mm wide*" and "*additional surface cracks, typically in the order of 100 mm to 150 mm in width*" in Area 1; and "*a number of large surface cracks* [greater than 200 mm] *were observed at the commencing end of Longwall 3 in Area 2 at Dendrobium Mine*".

Impacts were observed to the rock outcrops and steep slopes as a result of Longwall 9 in seven locations which were described in the End of Panel Report (IC, 2014) and have been summarised below:

> "*Site DA3B_LW9_011: Rock fracture on a step; up to 0.005m wide and 0.5m long; Site DA3B_LW9_012: Rock fracture at SLMMP site SS2-Point-2; approx. 1.2m long and 0.01-0.02m wide. Exfoliation with a surface area of approx. 0.40m by 0.25m; Site DA3B_LW9_013: Rock fractures to the face of a step near SLMMP SS2-Point-3; up to 2.3m long and 0.05m wide; Site DA3B_LW9_024: Rock fracturing with fallen rock fragments at the top of a 4m rock face; approx. 15m long and 0.08m; Site DA3B_LW9_026: Rock fracture and hairline fractures on a step which forms part of a steep slope; approx. 1.7m long and 0.025m wide; Site DA3B_LW9_027: Rock fracture with exfoliation on the western overhang of WC21_Pool 10; approx. 2m² of rock is exposed; and Site DA3B_LW9_028: Rock fall approx. 5m long and 0.2m deep with rock fragments totalling approx. 1.2m³.*"

Impacts were also observed to the rock outcrops and steep slopes as a result of Longwall 10 in eight locations which were described in the End of Panel Report (IC, 2015) and have been summarised below:

> "*Site DA3B_LW9_030:* Rock fracturing and soil cracking beneath small overhang. Fracturing measured approximately 2m long and up to 0.05m wide; Site *DA3B_LW9_031:* Vertical fracture to a rock outcrop approximately 40m east of Access Track 6000. Fracture measures 1m long and 0.03m wide; Site *DA3B_LW9_032:* Rock fall on rock outcrop adjacent to Access Track 6000. The fall measured approximately 2.5m long, 0.47 wide and 0.25m deep. Ground disturbance was not significant; Site *DA3B_LW10_004:* Rock fall and multiple rock fractures on outcropping. Rock fall volume approximately 0.002m$_3$. Fractures measured a maximum of 2.2m long and 0.04m wide; Site *DA3B_LW10_021:* Vertical fracture on rock outcrop adjacent to Access Track 6000. No erosion or rock fall was observed during the inspection; Site *DA3B_LW10_022:* Rock fracturing on a rock outcrop at SLMMP site A3B-SS2-SLMMP-Pt2. Fracture was approximately 0.3m long and 0.002m side; Site *DA3B_LW10_024:* Soil crack approximately 20m long, 0.28m wide and 1.8m deep. The crack is in the process of infilling and will most likely self-remediate; and Site *DA3B_LW10_025:* Soil crack approximately 14m long, 0.1m wide and 1.4m deep. The crack is in the process of infilling and will most likely self-remediate."

It is considered that the impacts observed on the rock outcrops and steep slopes were consistent with the assessed potential for impacts outlined in Report No. MSEC459 and the SMP Application.

5.8.5. Impact Assessments for the Rock Outcrops and Steep Slopes based on the MSEC792 Prediction Curves

Impacts have been observed to the rock outcrops and steep slopes including cracking, fracturing and spalling in seven locations above Longwall 9 and eight locations above Longwall 10. A summary of the maximum predicted subsidence parameters for the rock outcrops and steep slopes resulting from the extraction of Longwalls 9 and 10 only, based on the MSEC729 prediction curves, are provided in Table 5.23.

Table 5.23 Maximum Predicted Total Subsidence, Tilt and Curvatures for the Rock Outcrops and Steep Slopes due to Longwalls 9 and 10 Only

Location	Longwalls	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Rock Outcrops and Steep Slopes	Longwalls 9 and 10	2,700	50	1.4	1.4

The maximum predicted vertical subsidence for the rock outcrops and steep slopes for the future Longwalls 12 to 18 of 3,600 mm is greater than the maxima predicted above the previously extracted Longwalls 9 and 10 of 2,700 mm, i.e. 33 % increase. However, the potential for impacts do not result directly from vertical subsidence, but rather from the differential subsidence, i.e. tilts, curvatures and strains.

The maximum predicted tilts, curvatures and strains for the rock outcrops and steep slopes for the future Longwalls 12 to 18 are similar to those predicted above the previously extracted Longwalls 9 and 10. The potential impacts on the rock outcrops and steep slopes, therefore, are expected to be similar to those observed above the previously extracted Longwalls 9 and 10.

The impacts observed on the rock outcrops and steep slopes are considered to be consistent with those assessed in Report No. MSEC459 and the SMP Application. The management strategies for the rock outcrops and steep slopes, for the future Longwalls 12 to 18, therefore, are the same as those provided in Report No. MSEC459 and the SMP Application.

5.9. Escarpments

There are no escarpments within the Study Area. The ridgeline in Dendrobium Area 2 is located approximately 4 kilometres to the east and the *Illawarra Escarpment* is located more than 8 kilometres to the east of the proposed longwalls. At these distances, the ridgeline and escarpment are not expected to experience any significant mine subsidence movements or impacts resulting from the extraction of the proposed longwalls.

5.10. 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 Wongawilli Creek and Lake Avon. There are no major flood prone areas identified within the Study Area. The predicted changes in the surface levels of the watercourses, resulting from the extraction of the proposed longwalls, will have only a marginal effect on their natural gradients, and hence, on their discharge characteristics.

5.11. Swamps, Wetlands and Water Related Ecosystems

5.11.1. Descriptions of the Swamps

There are four swamps that are located directly above the previously extracted Longwalls 9 to 11, being Den01a, Den01b, Den05 and Den08. There are ten upland swamps that are located directly above or adjacent to the future Longwalls 12 to 18, being Den03, Den04, Den05, Den10, Den11, Den13, Den14, Den23, Den35a and Den35b. The locations of these swamps are shown in Drawing No. MSEC792-08.

The upland swamps comprise two fundamental types, the *Valley Infill* swamps which form within the drainage lines, and *Headwater* swamps which form within relatively low sloped areas of weathered Hawkesbury Sandstone where hillslope aquifers exist.

Photographs of Swamp Den05, which is a valley infill swamp, are provided in Fig. 5.17. Photographs of Swamp Den11, which is a headwater swamp, are provided in Fig. 5.18.

Fig. 5.17 Photographs of Swamp Den05 (Valley Infill Swamp)

Fig. 5.18 Photographs of Swamp Den11 (Headwater Swamp)

Further descriptions of the swamps are provided in the SIMMCP.

5.11.2. Predictions for the Swamps

A summary of the maximum predicted total conventional subsidence, tilts and curvatures for the swamps, based on the MSEC792 prediction curves, is provided in Table 5.24.

Table 5.24 Maximum Predicted Total Conventional Subsidence Parameters for the Swamps based on the MSEC792 Prediction Curves

Swamp Ref.	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Swamp Den01a	2,600	25	0.35	0.50
Swamp Den01b	2,100	20	0.25	0.40
Swamp Den03	2,750	20	0.30	0.40
Swamp Den04	2,700	17	0.20	0.40
Swamp Den05	2,700	25	0.40	0.55
Swamp Den08	3,200	30	0.60	0.75
Swamp Den10	3,500	35	0.70	0.85
Swamp Den11	2,800	30	0.50	0.45
Swamp Den13	3,100	30	0.50	0.70
Swamp Den14	3,400	35	0.65	0.80
Swamp Den23	3,350	35	0.60	0.80
Swamp Den35a	1,250	30	0.60	0.09
Swamp Den35b	< 20	< 0.5	< 0.01	< 0.01

The tilts provided in the above table are the maximum predicted values at the completion of any or all longwalls. The curvatures provided in the above table are the maximum predicted values which occur at any time during or after the extraction of the longwalls.

Whilst Swamps Den01a, Den01b and Den08 are partially located within the Study Area, above the previously extracted Longwalls 9 and 10, they are predicted to experience only 50 mm to 150 mm additional vertical subsidence as a result of the extraction of the future Longwalls 12 to 18. The additional vertical subsidence due to the future longwalls is very small when compared with the total vertical subsidence that they have already experienced due to the previous Longwalls 9 and 10.

The predicted conventional hogging curvature (i.e. blue contours with positive magnitudes) and sagging curvature (i.e. red contours with negative magnitudes) are illustrated in: Fig. 5.19 for Swamps Den01a and Den01b; Fig. 5.20 for Swamps Den03 and Den04; Fig. 5.21 for Swamp Den05; Fig. 5.22 for Swamp Den08; Fig. 5.23 for Swamps Den10 and Den13; Fig. 5.24 for Swamps Den11 and Den23; Fig. 5.25 for Swamp Den14; and Fig. 5.26 for Swamp Den35a. It is noted that the hogging and sagging curvature contours cross in some locations, such as near the corners of the longwalls, which signifies that these components of curvature occur in orthogonal directions.

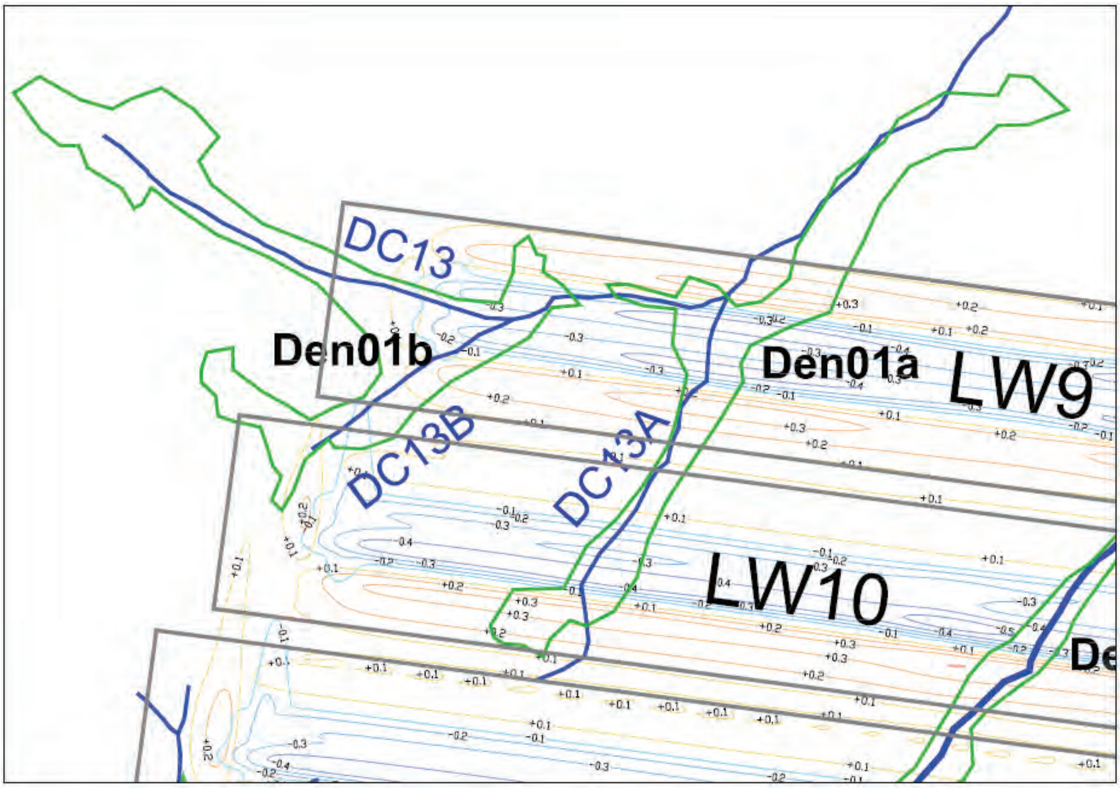

Fig. 5.19 Predicted Total Hogging and Sagging Curvatures for Swamps Den01a and Den01b

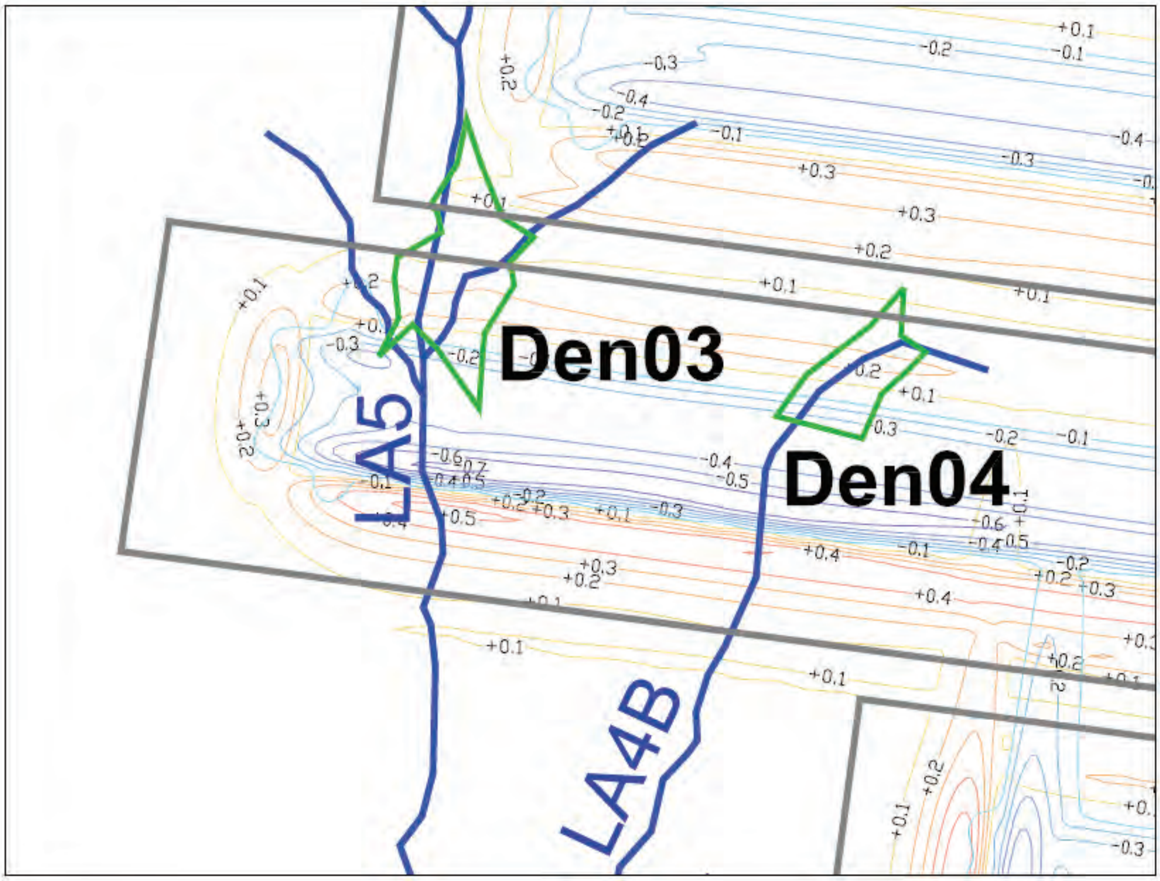

Fig. 5.20 Predicted Total Hogging and Sagging Curvatures for Swamps Den03 and Den04

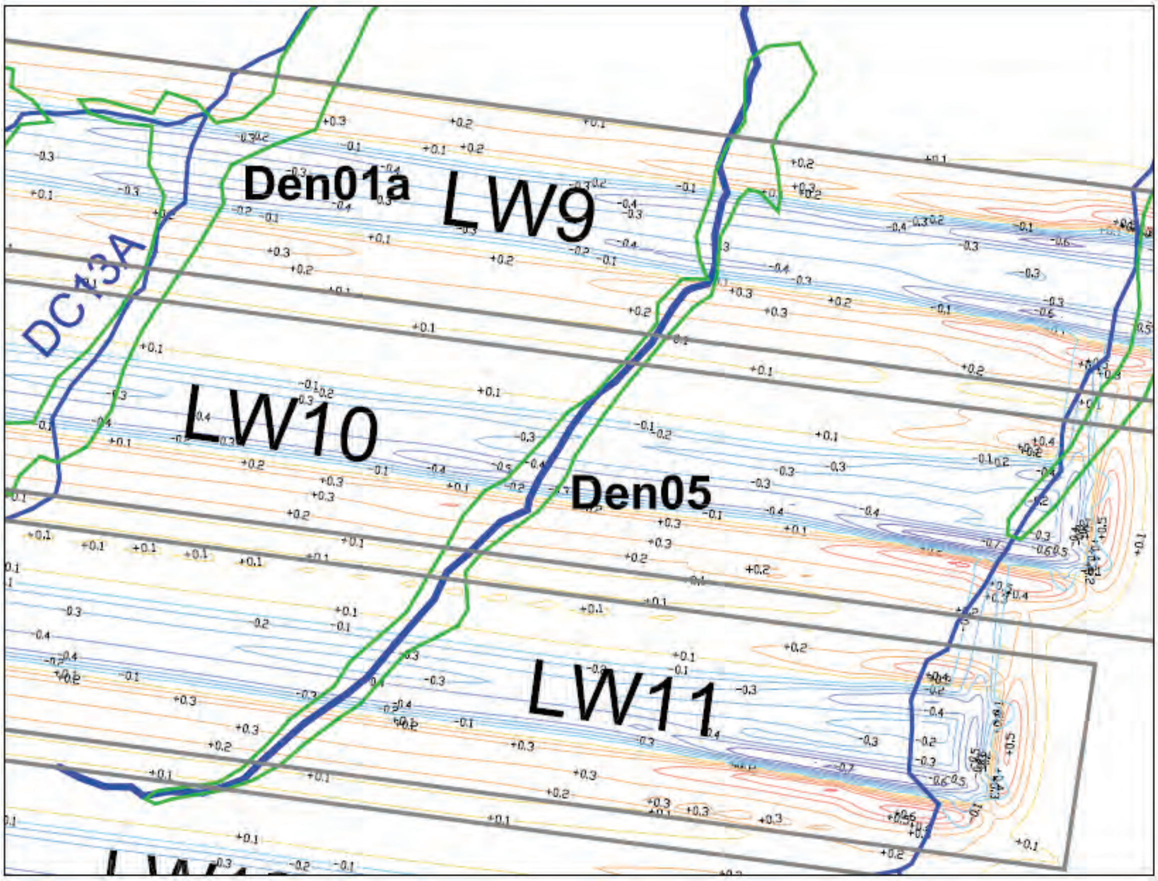

Fig. 5.21 Predicted Total Hogging and Sagging Curvatures for Swamp Den05

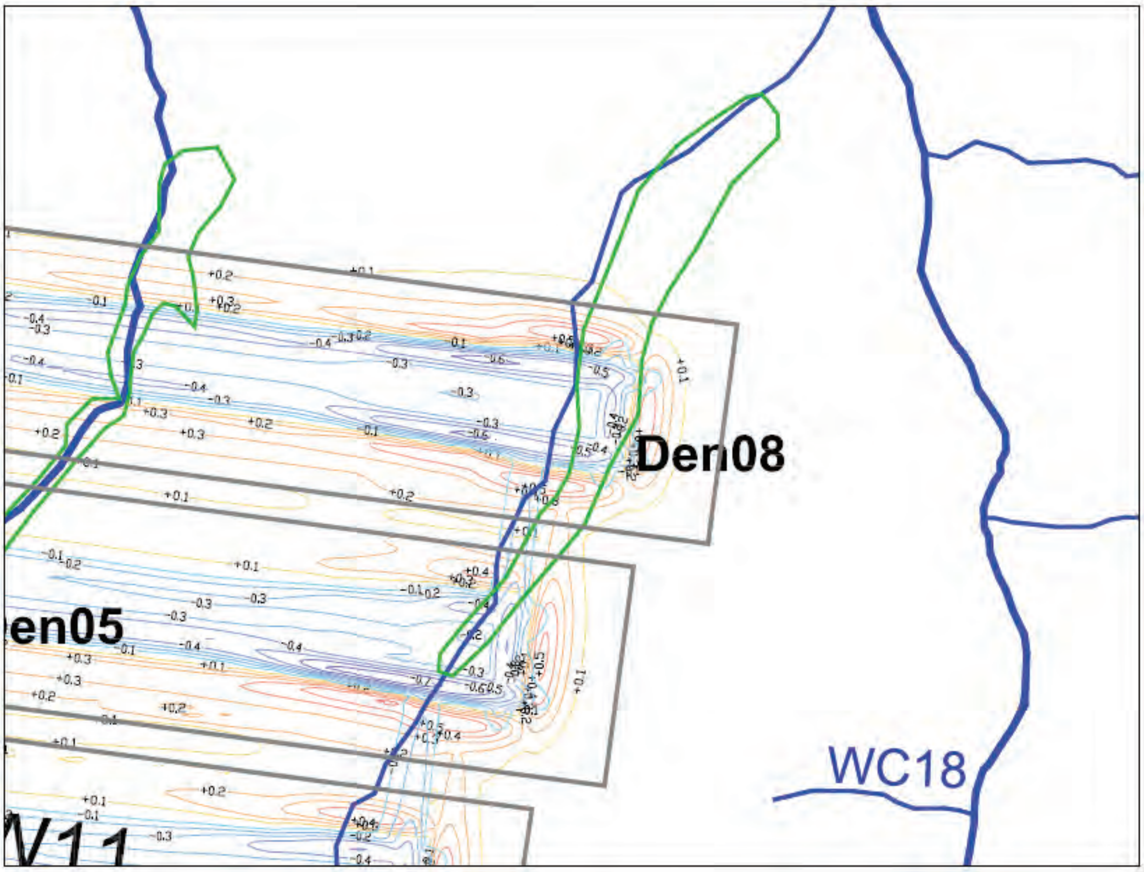

Fig. 5.22 Predicted Total Hogging and Sagging Curvatures for Swamp Den08

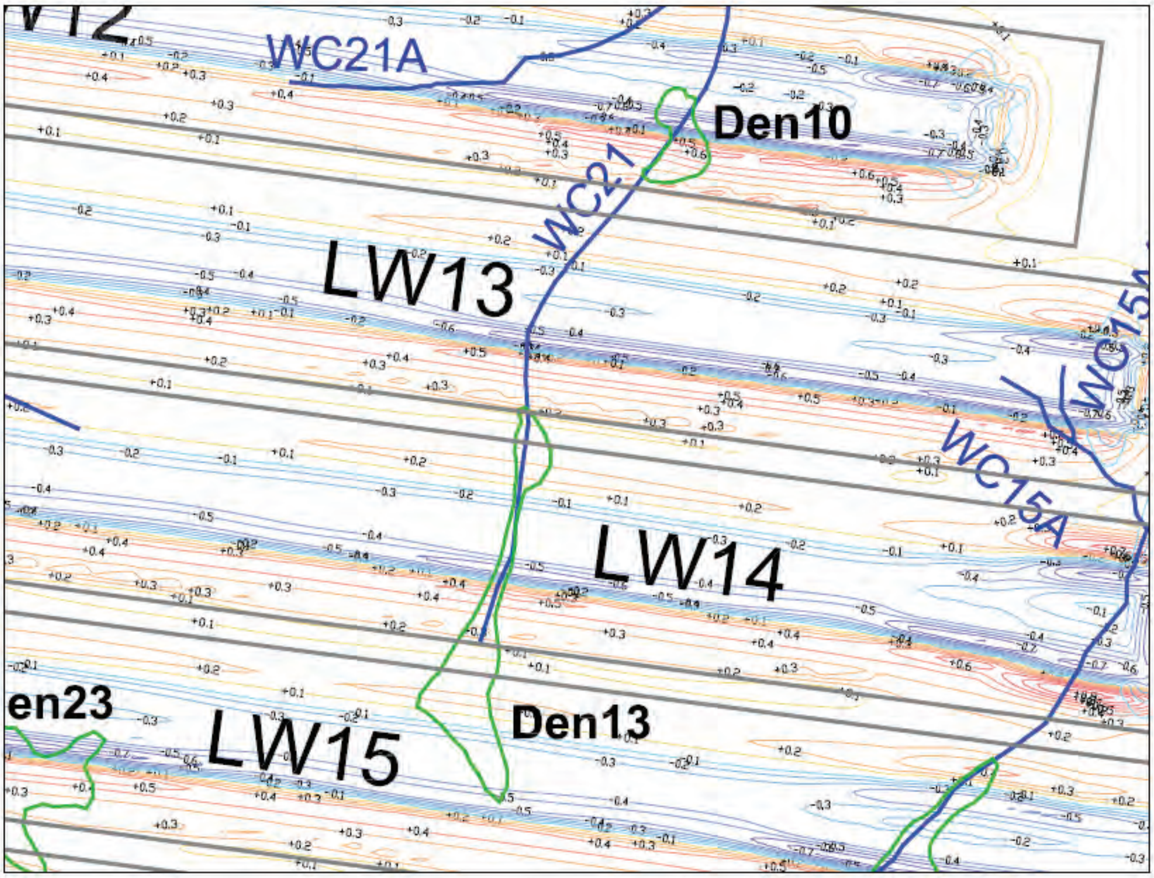

Fig. 5.23 Predicted Total Hogging and Sagging Curvatures for Swamps Den10 and Den13

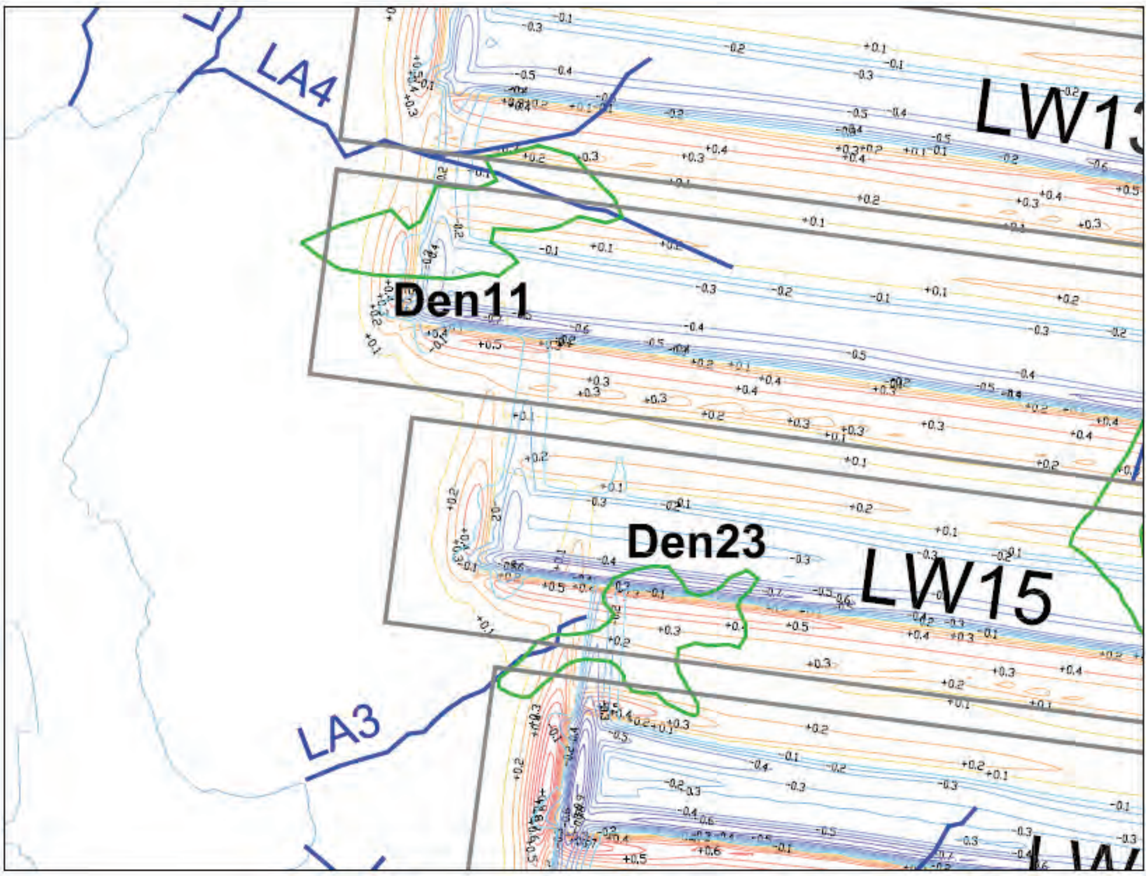

Fig. 5.24 Predicted Total Hogging and Sagging Curvatures for Swamps Den11 and Den23

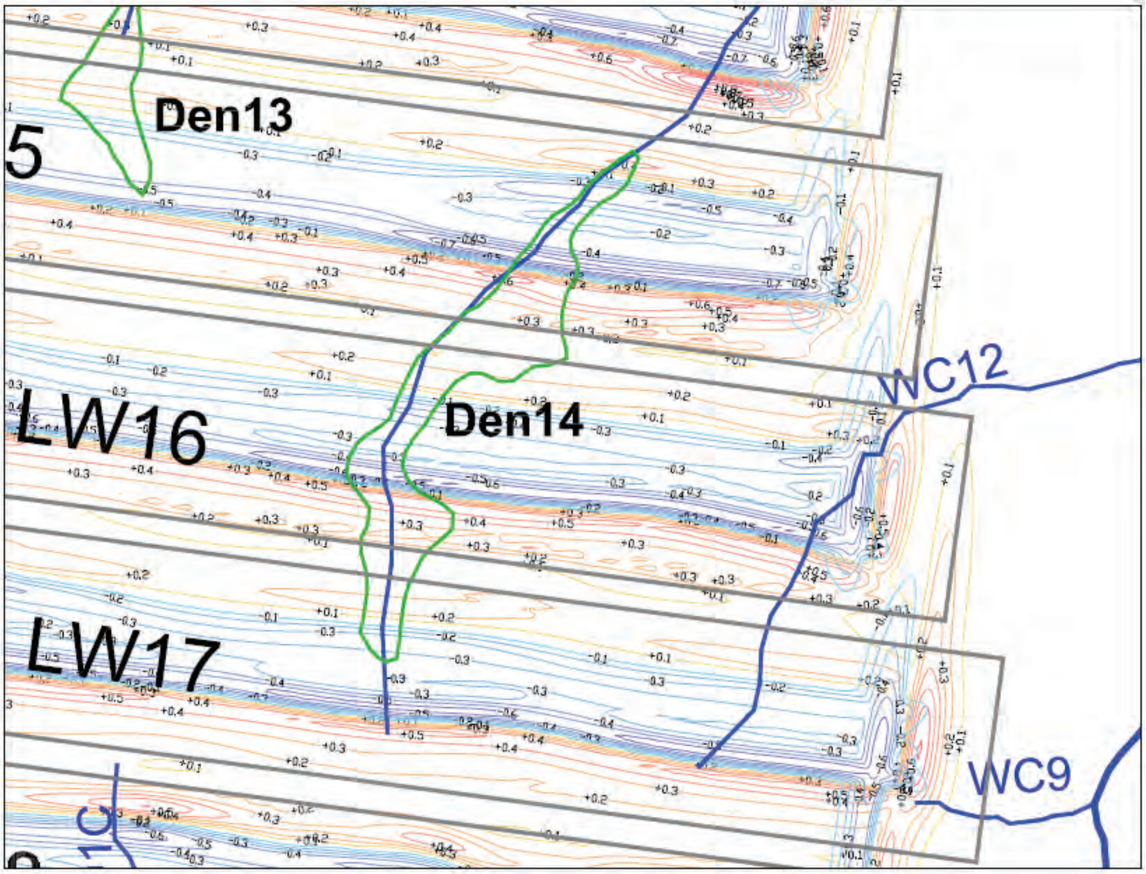

Fig. 5.25 Predicted Total Hogging and Sagging Curvatures for Swamp Den14

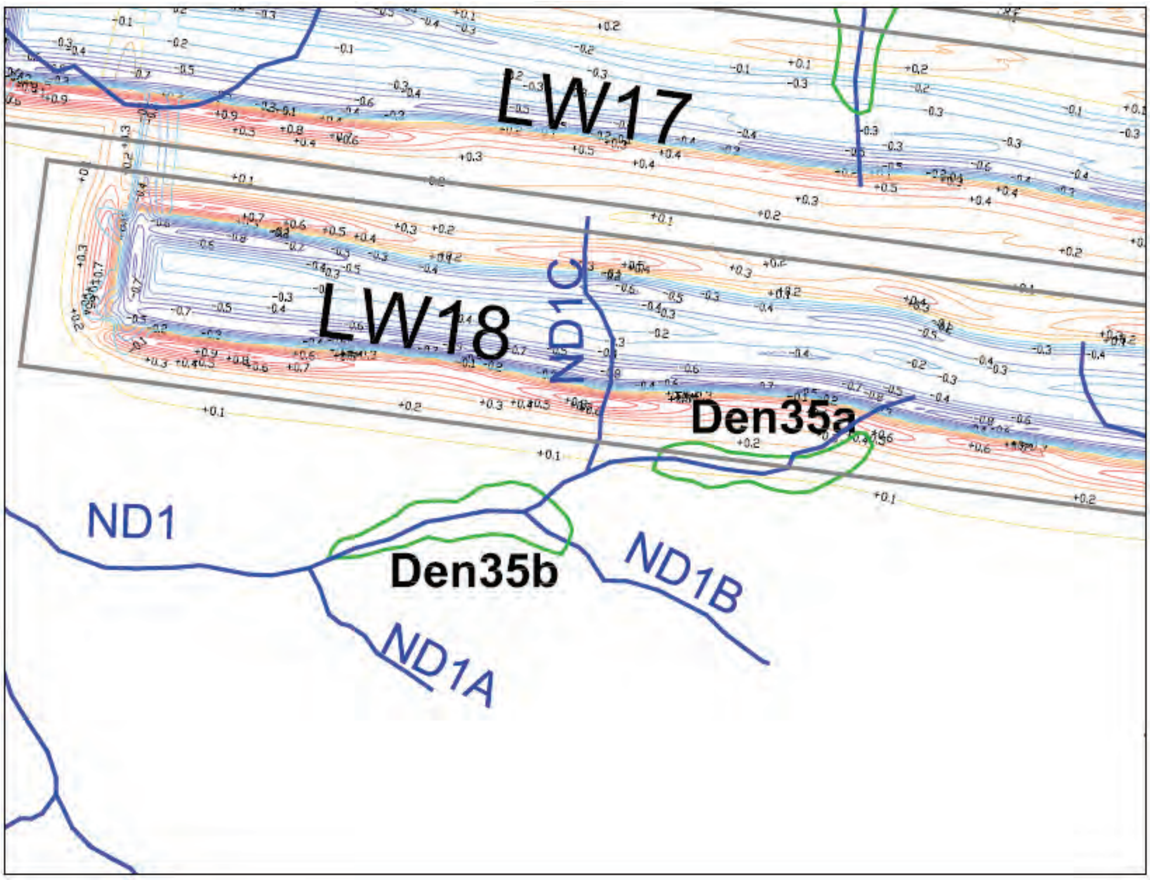

Fig. 5.26 Predicted Total Hogging and Sagging Curvatures for Swamp Den35a

The maximum predicted conventional curvatures for the swamps are 0.70 km^{-1} hogging and 0.85 km^{-1} sagging, which represent minimum radii of curvature of 1.4 kilometres and 1.2 kilometres, respectively. The maximum predicted conventional strains for the swamps, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 11 mm/m tensile and 13 mm/m compressive.

The analysis of strains measured in the NSW Coalfields, for previously extracted longwalls having similar width-to-depth ratios and extraction heights as the longwalls, is provided in Section 4.4. The 95 % confidence levels for the maximum total conventional strains are 9 mm/m tensile and 8 mm/m compressive. The swamps are also likely to experience elevated compressive strains, resulting from the valley related movements, which could be in the order of 10 mm/m and 20 mm/m based on observations at valleys with similar heights and similar levels of predicted valley closure.

A number of the swamps are located in the bases of drainage lines and, therefore, could experience valley related movements. A summary of the maximum predicted valley related upsidence and closure movements for the swamps as well as the maximum predicted conventional closures is provided in Table 5.25. It is noted, that the conventional closures are normally provided separately to the valley related closures, as the associated conventional strains are distributed across the longwalls, as opposed to the valley related compressive strains which are concentrated in the valley bases. Also, in most cases, the valley related closures and conventional closures are orientated obliquely to each other.

Table 5.25 Maximum Predicted Total Valley Related Upsidence, Valley Related Closure and Conventional Closure for the Swamps based on the MSEC792 Prediction Curves

Swamp Ref.	Maximum Predicted Total Valley Related Upsidence (mm)	Maximum Predicted Total Valley Related Closure (mm)	Maximum Predicted Total Conventional Closure (mm)
Swamp Den01a	300	200	325
Swamp Den01b	200	150	325
Swamp Den03	150	100	275
Swamp Den04	175	175	225
Swamp Den05	375	275	350
Swamp Den08	700	700	275
Swamp Den10	275	275	325
Swamp Den11	250	250	200
Swamp Den13	400	400	300
Swamp Den14	650	650	450
Swamp Den23	350	325	175
Swamp Den35a	200	375	< 50
Swamp Den35b	175	450	< 50

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

The maximum predicted total closures (i.e. valley plus conventional) are: 550 mm for Den01a and Den01b; 325 mm for Den03; 350 mm for Den04; 575 mm for Den05; 725 mm for Den08; 625 mm for Den10; 400 mm for Den11; 550 mm for Swamp Den13; 1,100 mm for Den14; 625 mm for Den23; and 375 mm for Den35a; and 450 mm for Den35b.

5.11.3. Comparison of Predictions for the Swamps based on the MSEC459 and MSEC792 Predictions Curves

The comparison of the maximum predicted total subsidence, upsidence and closure for the swamps, based on the MSEC459 and MSEC792 prediction curves, is provided in Table 5.26.

Table 5.26 Comparison of the Predicted Conventional Subsidence and Closure and Valley Related Upsidence and Closure for the Swamps

Swamp	Prediction Curves	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Closure (mm)	Maximum Predicted Total Valley Related Upsidence (mm)	Maximum Predicted Total Valley Related Closure (mm)
Swamp Den01a	MSEC459	2,000	250	250	200
	MSEC792	2,600	325	300	200
Swamp Den01b	MSEC459	1,500	250	200	150
	MSEC792	2,100	325	200	150
Swamp Den03	MSEC459	2,250	250	100	100
	MSEC792	2,750	275	150	100
Swamp Den04	MSEC459	2,150	200	100	100
	MSEC792	2,700	225	175	175
Swamp Den05	MSEC459	2,050	350	375	275
	MSEC792	2,700	350	375	275
Swamp Den08	MSEC459	2,550	225	700	700
	MSEC792	3,200	275	700	700
Swamp Den10	MSEC459	2,450	275	275	275
	MSEC792	3,500	325	275	275
Swamp Den11	MSEC459	2,200	125	200	200
	MSEC792	2,800	200	250	250
Swamp Den13	MSEC459	2,200	250	400	400
	MSEC792	3,100	300	400	400
Swamp Den14	MSEC459	2,500	400	650	650
	MSEC792	3,400	450	650	650
Swamp Den23	MSEC459	2,400	150	300	300
	MSEC792	3,350	175	350	325
Swamp Den35a	MSEC459	1,000	< 50	200	350
	MSEC792	1,250	< 50	200	375
Swamp Den35b	MSEC459	< 20	< 50	175	425
	MSEC792	< 20	< 50	175	450

The maximum predicted vertical subsidence for the swamps, based on the MSEC792 prediction curves, are typically between 22 % and 43 % greater than those based on the MSEC459 prediction curves. The maximum predicted conventional closure for the swamps, based on the MSEC792 prediction curves, are typically between 22 % and 44 % greater than those based on the MSEC459 prediction curves.

The maximum predicted valley related upsidence and closure movements for the swamps, based on the MSEC792 prediction curves, are between zero and 75 mm greater than those based on the MSEC459 prediction curves, which is similar to the order of accuracy of the prediction method. It is also noted, that the valley related movements are less sensitive to the magnitude of vertical subsidence at the predicted magnitudes.

5.11.4. Review of the Assessed Impacts for the Swamps provided in Report No. MSEC459 and the Reported Impacts during Longwalls 9 and 10

The impact assessments provided in Report No. MSEC459 refer 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 by the other specialist consultants on the project and have been updated in the WIMMCP and the SIMMCP based on the updated MSEC792 prediction curves.

The impact assessments for the swamps provided in Report No. MSEC459 stated that:

> "*It is expected, at the magnitudes of the predicted curvatures and strains, that fracturing of the topmost bedrock beneath the swamps would occur as a result of the extraction of the proposed longwalls. The upland swamps within the SMP Area comprise both Valley Infill and Headwater swamps, where significant quantities of sediment are found above the bedrock which is highly fractured and weathered naturally. It is expected, therefore, that the fracturing of the topmost bedrock would occur at the pre-existing natural joints and bedding planes beneath the swamps.*"
>
> *"The estimated fracture widths in the topmost bedrock beneath the swamps, based on the maximum predicted conventional tensile strains between 3 mm/m and 8 mm/m and based on a typical joint spacing of 10 metres, are in the order of 30 mm to 80 mm. In some cases, a series of smaller fractures, rather than one single fracture, would develop in the topmost bedrock. Fracturing would only be visible at the surface where the bedrock is exposed, or where the thickness of the overlying sediment is relatively shallow.*"; and that
>
> *"…over 500 swamps have been directly mined beneath on the Woronora Plateau. The studies undertaken indicate that the incidence of impacts on upland swamps due to longwall mining is low and, in some of these cases, the impacts that were observed were associated with natural events or non-mining disturbances.*"

Impacts were observed to the swamps as a result of Longwall 9 which were described in the End of Panel Report (IC, 2014) and have been summarised below:

> "*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 observed to the swamps as a result of Longwall 10 which were described in the End of Panel Report (IC, 2015) and have been summarised below:

> "*Shallow groundwater TARP triggers (water level recession) were recorded in Swamp 5 during Longwall 10 extraction.*"

It is considered that the physical impacts (i.e. cracking in the surface soils and fracturing of the bedrock and rockbars) observed at the swamps are consistent with the assessed potential for impacts outlined in Report No. MSEC459 and the SMP Application. Further discussions on the impacts and environmental consequences for the swamps due to Longwalls 9 and 10 are provided by the other specialist consultants on the project.

5.11.5. Impact Assessments for the Swamps based on the MSEC792 Prediction Curves

The impact assessments for the swamps have been reviewed based on the updated predictions obtained using the MSEC792 prediction curves. 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.

The natural grades and the predicted post mining grades along the streams, based on the MSEC792 prediction curves, are illustrated in: Fig. 5.5 for Donalds Castle Creek (i.e. Swamp Den05); Fig. 5.7 for Drainage Line DC13 (i.e. Swamps Den01a and Den01b); Fig. 5.8 for Drainage Line LA3 (i.e. Swamp Den23); Fig. 5.9 for Drainage Line LA4 (i.e. Swamp Den11); Fig. 5.10 for Drainage Line LA4B (i.e. Swamp Den04); Fig. 5.11 for Drainage Line LW5 (i.e. Swamp Den03); Fig. 5.12 for Drainage Line ND1 (i.e. Swamps Den35a and Den35b); Fig. 5.13 for Drainage Line WC15 (i.e. Swamp Den14); and Fig. 5.14 for Drainage Line WC21 (i.e. Swamps Den08, Den10 and Den13).

It can be seen from Fig. 5.7, that the natural grade of Drainage Line DC13 is relatively flat above the tailgate of Longwall 9. Some localised increased ponding could occur in this location, as a result of the extraction of the longwalls, which occurs just outside the extent of Swamp Den01a. Elsewhere, the predicted post mining grades along this drainage line are reasonably similar to the natural grades and, therefore, no significant changes in the potential for ponding are anticipated within the extents of Swamps Den01a and Den01b.

It can be seen from Fig. 5.13, that there is a possible reversal in grade along Drainage Line WC15, adjacent to the tailgate of Longwall 15, i.e. at the downstream end of Swamp Den14. There was a potential for a reversal of grade in this location, based on the MSEC459 prediction curves, with the likelihood of ponding increasing slightly based on the updated prediction model.

It can be seen from Fig. 5.14, that there are predicted reversals in grade along Drainage Line WC21, adjacent to the tailgates of the previously extracted Longwalls 10 and 11, i.e. within the extent of Swamp Den08. However, there are no predicted reversals in grade above the future Longwalls 12 to15 due to the higher natural grades, i.e. within the extents of Swamps Den10 and Den13.

It can be seen from the remaining figures, that the predicted post mining grades along the alignments of the drainage lines are similar to the natural grades and, therefore, no significant changes in the potential for ponding are anticipated within the extents of these swamps, i.e. Swamps Den03, Den04, Den05, Den11, Den23, Den35a and Den35b.

The maximum predicted tilts for the swamps that are located directly above the longwalls vary between 17 mm/m (i.e. 1.7 %, or 1 in 60) and 35 mm/m (i.e. 3.5 %, or 1 in 30). The predicted changes in grade are similar to, but, generally smaller than the natural surface gradients within the swamps, which typically vary between 25 mm/m and 100 mm/m. The maximum predicted tilt for Swamp Den35b, which is located outside the extents of the longwalls, is less than 0.5 mm/m (i.e. less than 0.1 %, or 1 in 2,000).

The comparisons between the existing (black) and predicted post-mining (red) surface level contours are illustrated in: Fig. 5.27 for Swamps Den01a and Den01b; Fig. 5.28 for Swamps Den03 and Den04; Fig. 5.29 for Swamp Den05; Fig. 5.30 for Swamp Den08; Fig. 5.31 for Swamps Den10 and Den13; Fig. 5.32 for Swamps Den11 and Den23; Fig. 5.33 for Swamp Den14; and Fig. 5.34 for Swamps Den35a and Den35b.

It can be seen from these figures, that there are no topographical depressions predicted to develop within the extents of the swamps as a result of mining. It is expected, therefore, that any changes in the potential for ponding would be localised and relatively minor, i.e. no wide spread changes in ponding are anticipated.

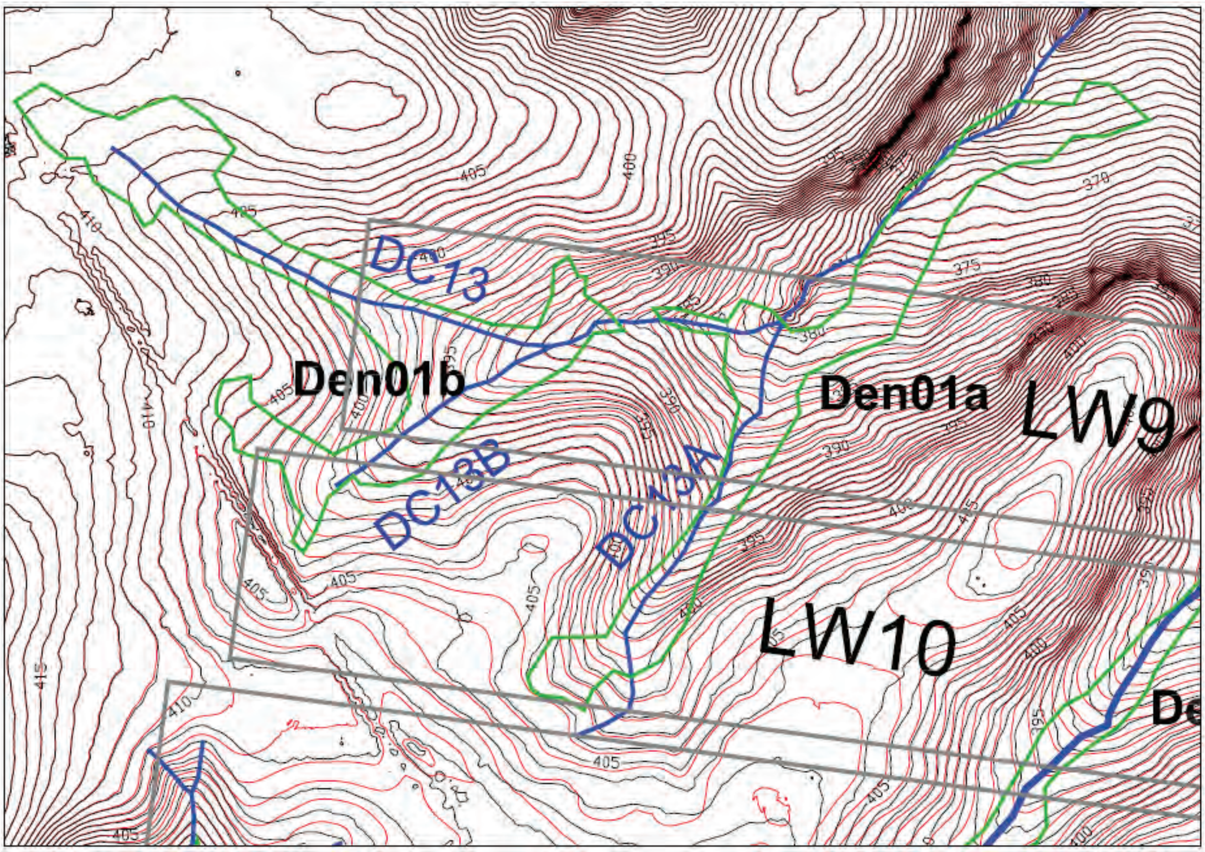

Fig. 5.27 Existing and Predicted Post Mining Surface Levels for Swamps Den01a and Den01b

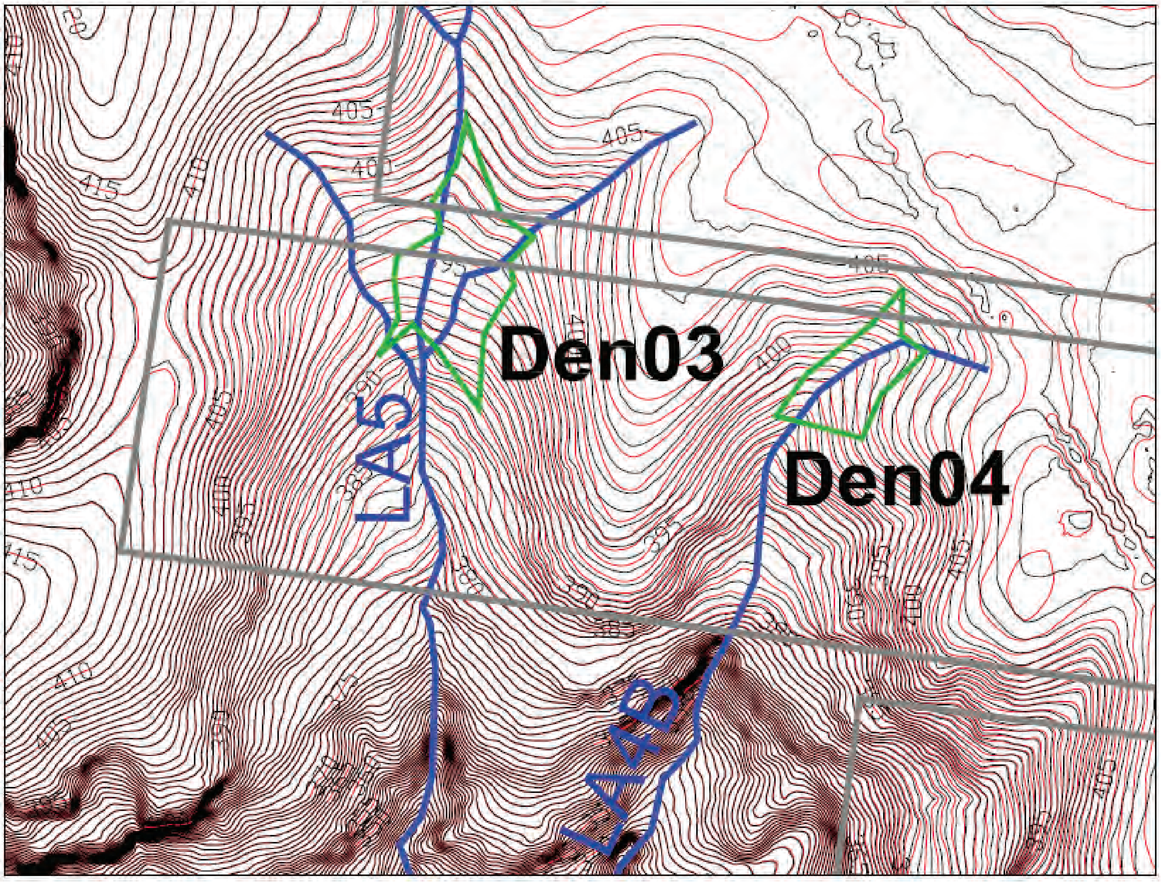

Fig. 5.28 Existing and Predicted Post Mining Surface Levels for Swamps Den03 and Den04

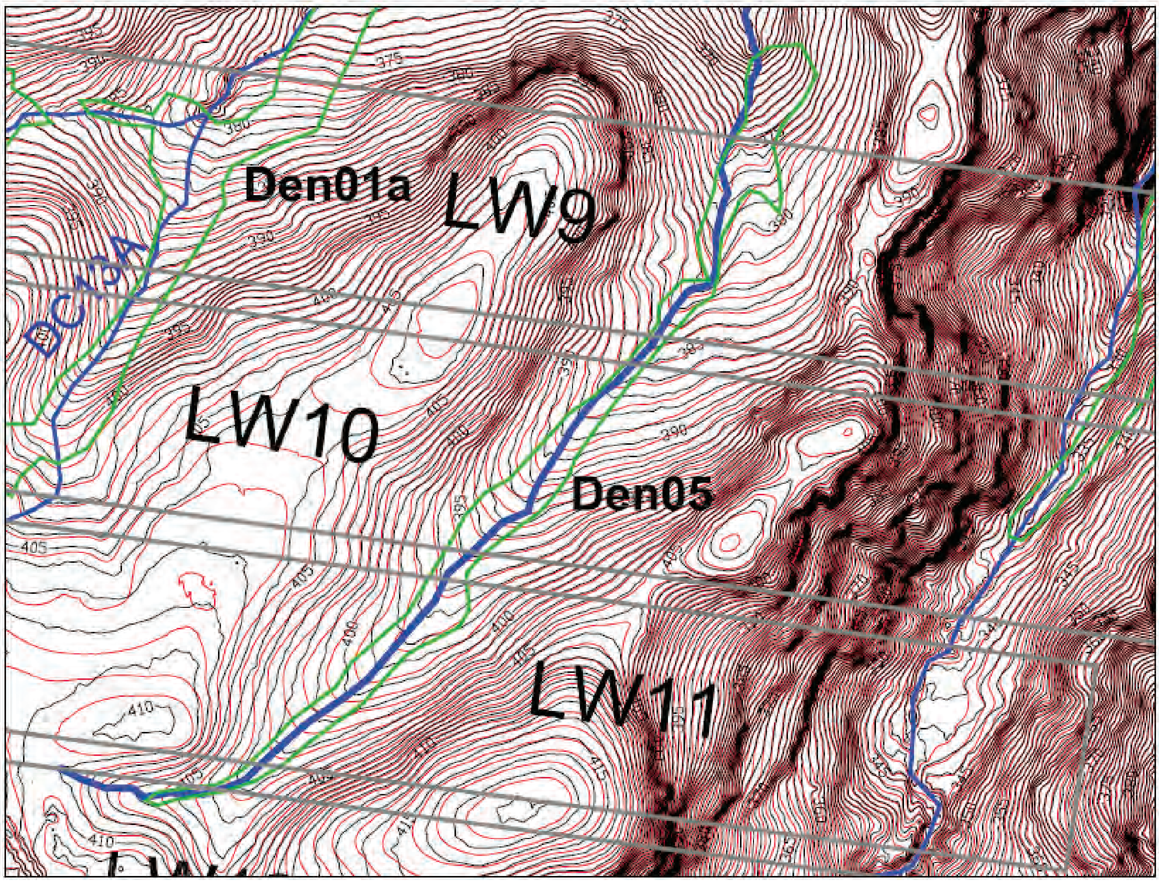

Fig. 5.29 Existing and Predicted Post Mining Surface Levels for Swamp Den05

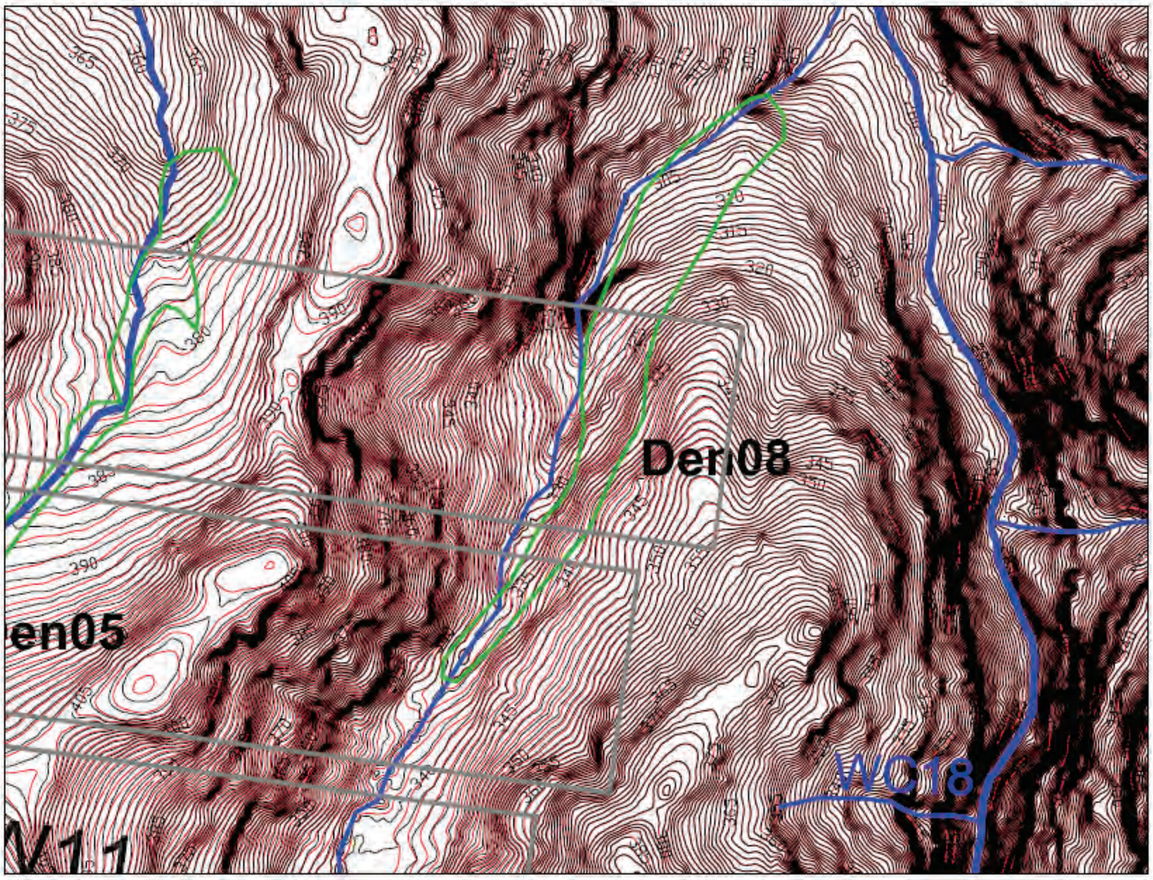

Fig. 5.30 Existing and Predicted Post Mining Surface Levels for Swamp Den08

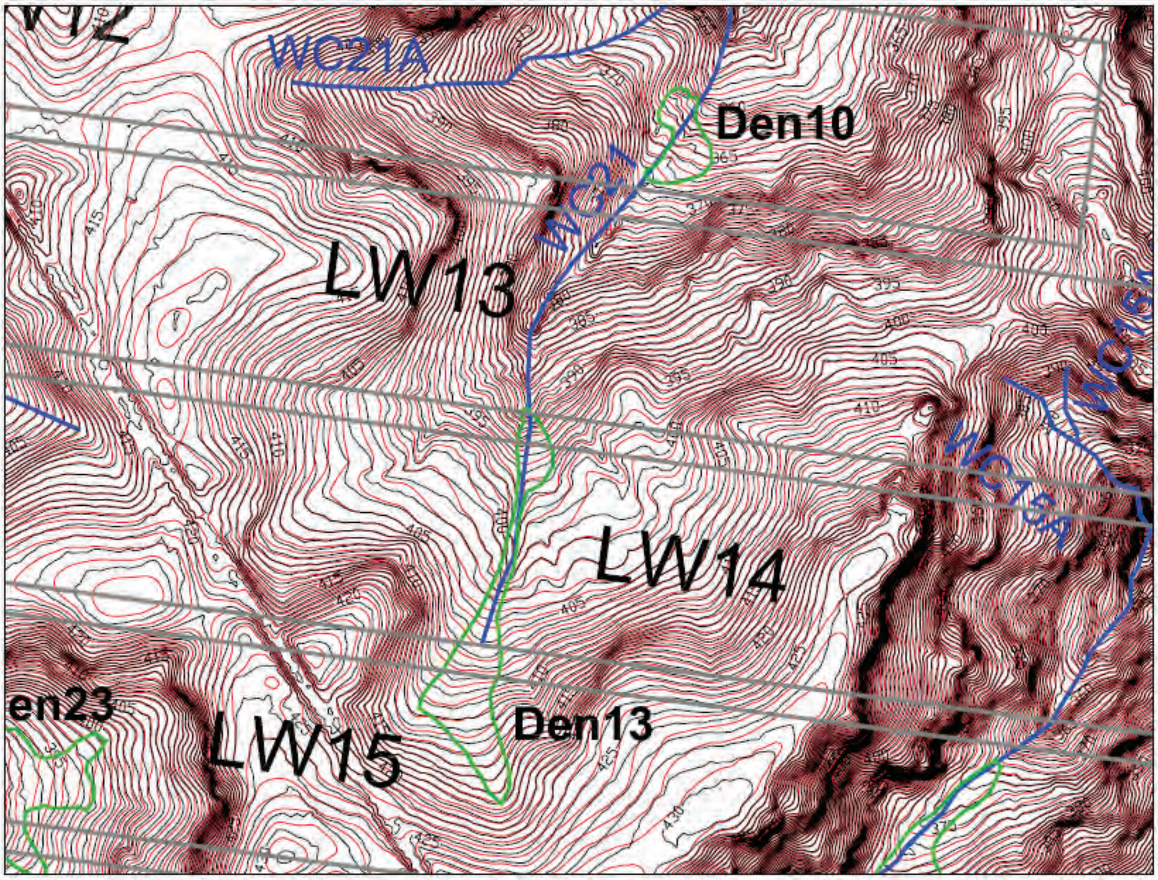

Fig. 5.31 Existing and Predicted Post Mining Surface Levels for Swamps Den10 and Den13

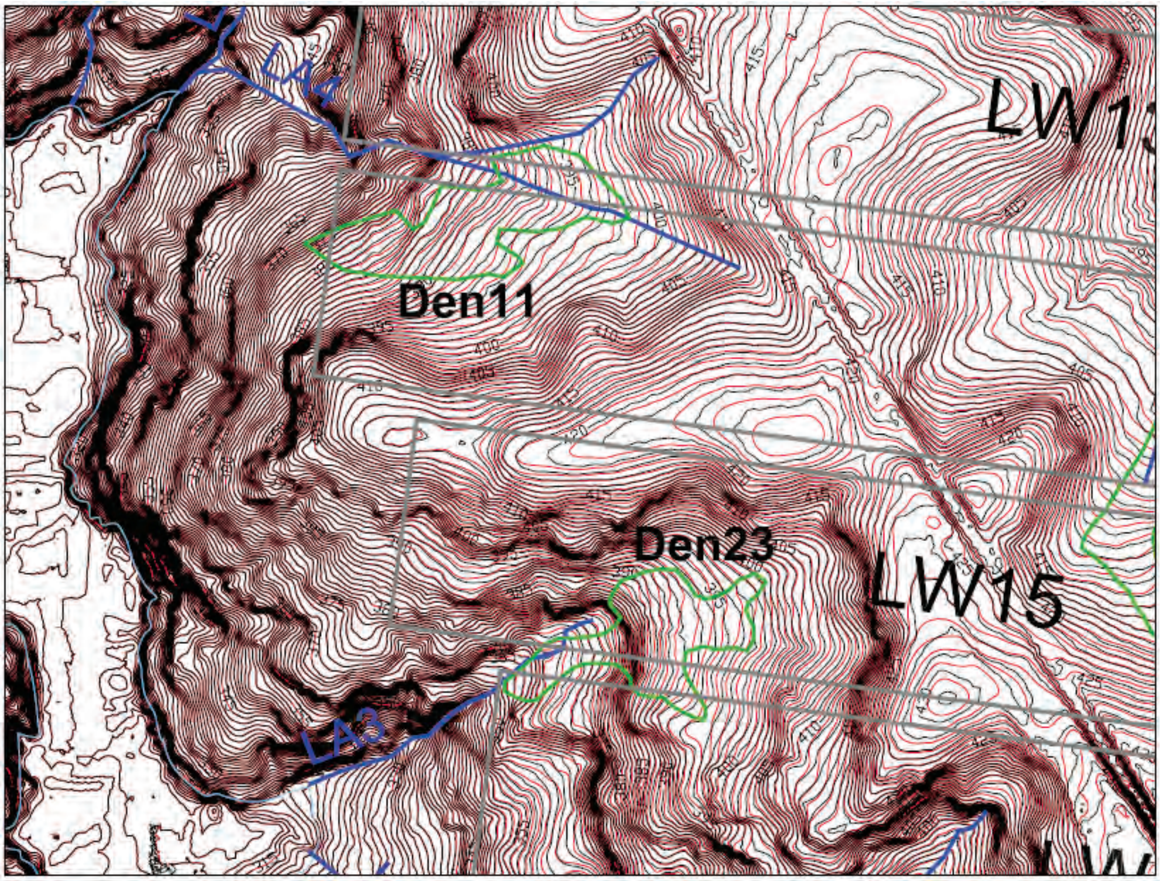

Fig. 5.32 Existing and Predicted Post Mining Surface Levels for Swamps Den11 and Den23

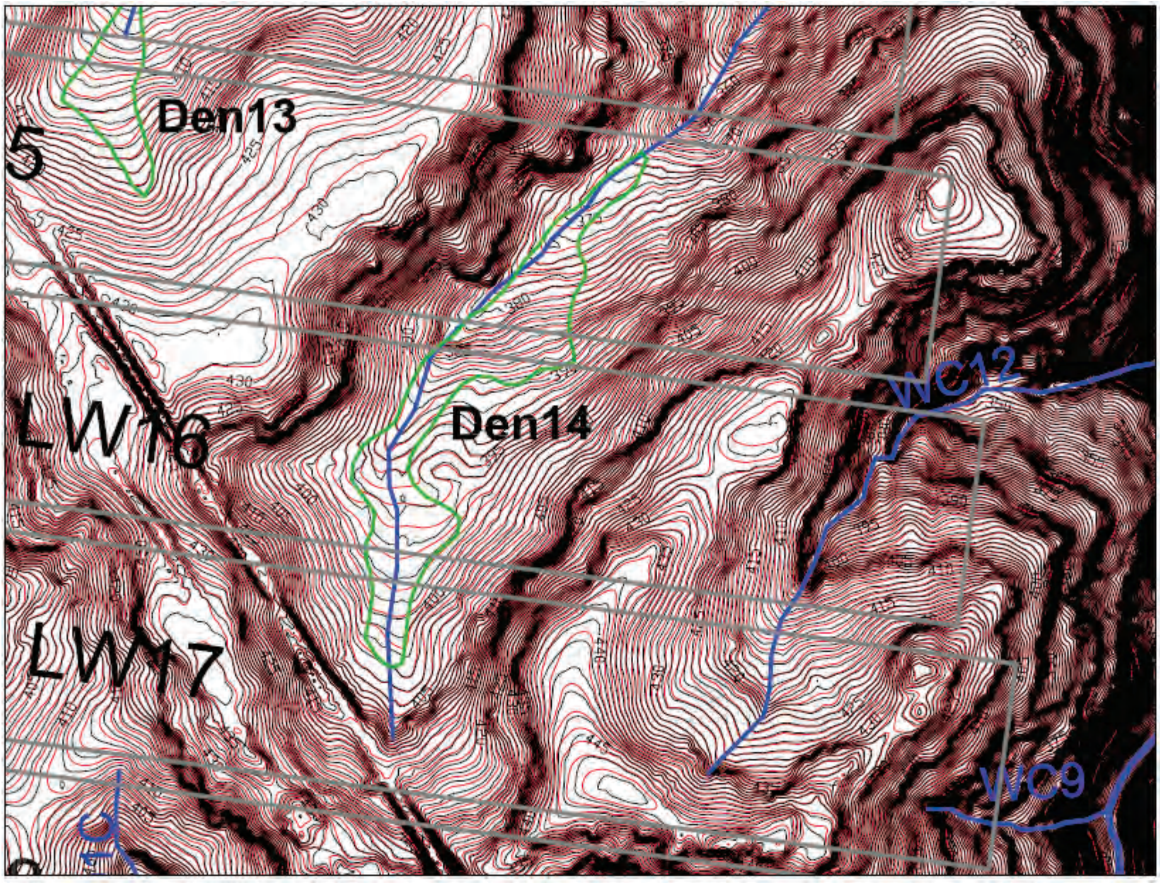

Fig. 5.33 Existing and Predicted Post Mining Surface Levels for Swamp Den14

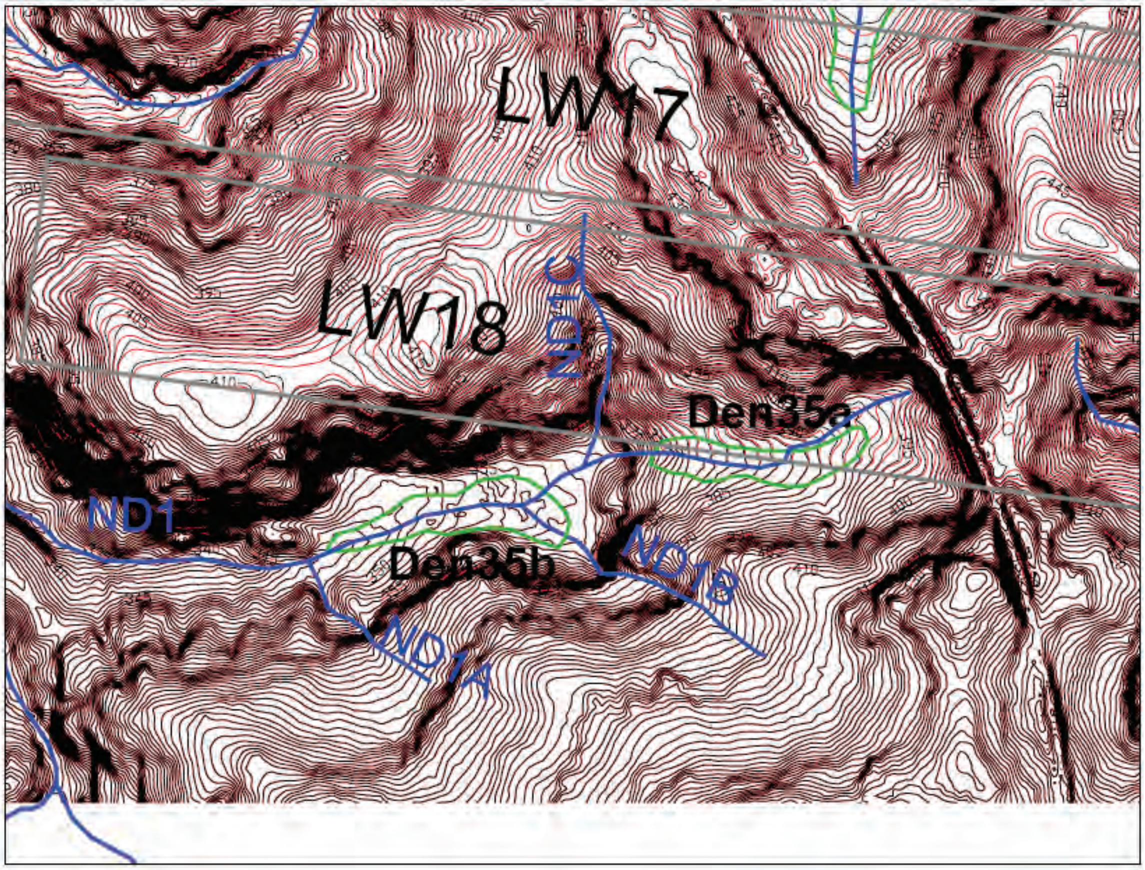

Fig. 5.34 Existing and Predicted Post Mining Surface Levels for Swamp Den35a

The maximum predicted subsidence at Swamp Den35b is less than 20 mm. Whilst it is possible that this swamp could experience subsidence slightly greater than 20 mm, it would not be expected to experience any significant conventional tilts, curvatures or strains. It is unlikely, therefore, that Swamp Den35b would experience adverse impacts as a result of mining. It is still possible that fracturing of the topmost bedrock could occur beneath this swamp, however, it would be expected that any fracturing would be minor and isolated as it is located outside the extents of mining.

It is expected, at the magnitudes of the predicted curvatures and strains, that fracturing would occur in the topmost bedrock beneath the swamps and at the exposed rockbars that are located directly above the longwalls. The estimated fracture widths in the bedrock and rockbars, based on the maximum predicted conventional tensile strains between 3 mm/m and 8 mm/m and based on a typical joint spacing of 10 metres, are in the order of 30 mm to 80 mm. In some cases, a series of smaller fractures, rather than one single fracture, would develop in the topmost bedrock. Fracturing would only be visible at the surface where the bedrock is exposed, or where the thickness of the overlying sediment is relatively shallow.

The maximum predicted vertical subsidence and conventional closure, based on the MSEC792 prediction curves, are typically between 22 % and 44 % greater than those based on the MSEC459 prediction curves. Whilst the potential rates of impacts are likely to be greater, the nature of these impacts are unlikely to change, i.e. a greater number of fractures with increased widths in the exposed bedrock resulting in a slightly increased potential for surface water flow diversions.

Summaries of the maximum predicted subsidence parameters for Swamps Den01a, Den01b, Den05 and Den08 resulting from the extraction of Longwalls 9 to 11, based on the MSEC729 prediction curves, are provided in Table 5.27.

Table 5.27 Maximum Predicted Total Conventional Subsidence and Valley Related Upsidence and Closure for the Swamps Den01a, Den01b, Den05 and Den08 due to Longwalls 9 to 11

Longwalls	Swamp	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Closure (mm)	Maximum Predicted Total Valley Related Upsidence (mm)	Maximum Predicted Total Valley Related Closure (mm)
Longwalls 9 to 11	Den01a	2,550	325	275	175
	Den01b	2,100	325	175	125
	Den05	2,600	350	325	250
	Den08	3,150	275	550	550

The maximum predicted vertical subsidence for the swamps located directly above the future Longwalls 12 to 18 (i.e. Swamp Den03, 04, 05, 10, 11, 13, 14, 23 and 35a), ranging between 1,250 mm and 3,500 mm, are up to 11 % greater than the maximum predicted vertical subsidence for the swamps located directly above the previously extracted Longwalls 9 to 11. The potential for impacts do not result directly from vertical subsidence, but rather due to differential subsidence, which are largely driven by the conventional closure and valley related closure movements.

The maximum predicted conventional closure for Swamp Den14 of 450 mm is greater than the maxima predicted for the swamps located directly above the previously extracted Longwalls 9 to 11, of 350 mm. The remaining swamps located directly above the future Longwalls 12 to 18 have maximum predicted conventional closures ranging between 175 mm and 350 mm, which are similar to the maxima predicted for the swamps located directly above the previously extracted longwalls, of 275 mm to 350 mm.

The maximum predicted valley related movements for the swamps located directly above the future Longwalls 12 to 18, however, of 150 mm to 700 mm upsidence and 100 mm to 700 mm closure, are greater than the maxima predicted for the swamps located above the previously extracted Longwalls 9 to 11, of 175 mm to 550 mm upsidence and 125 mm to 550 mm closure.

Whilst the assessed potential for impacts for the swamps located above the future Longwalls 12 to 18 are greater than those for the swamps located above the previously extracted longwalls, they are considered to be consistent with those assessed in Report No. MSEC459 and the SMP Application. The management strategies for the swamps, for the future Longwalls 12 to 18, therefore, are the same those provided in Report No. MSEC459 and the SMP Application.

Further discussions on each of the swamps are provided in the sections below. The impact assessments provided in this report should be read in conjunction with those provided by the other specialist consultants on the project.

5.12. Flora and Fauna

The potential impacts on the flora and fauna are provided by the specialist ecology consultant on the project. The assessments of the flora and fauna based on the updated MSEC792 prediction curves are provided in the WIMMCP and SIMMCP.

5.13. Archaeological Sites

5.13.1. Descriptions of the Archaeological Sites

There are no lands within the Study Area declared as an Aboriginal Place under the *National Parks and Wildlife Act 1974*. There are 19 archaeological sites which have been identified within the Study Area. The locations of these sites are shown in Drawing No. MSEC792-13 and a summary is provided in Table 5.28.

Table 5.28 Archaeological Sites Identified within the Study Area

Recording Code	Site Name	Recoding Type
52-2-1623	Browns Road Site 8	Shelter with Deposit
52-2-1626	Browns Road Site 11	Shelter with Art
52-2-1627	Browns Road Site 12	Shelter with Art
52-2-1771	Upper Avon 35	Shelter with Deposit
52-2-1772	Upper Avon 36	Shelter with Art
52-2-1773	Upper Avon 37	Shelter with Deposit
52-2-1774	Upper Avon 38	Shelter with Art
52-2-1775	Upper Avon 39	Shelter with Deposit
52-2-1776	Upper Avon 40	Shelter with Art; Shelter with Deposit
52-2-1778	Upper Avon 41	Shelter with Deposit
52-2-2209	Dendrobium 2	Shelter with Art
52-2-2229	Site 1 - DB 1	Shelter with Art
52-2-2246	Dendrobium 6	Isolated Artefact
52-2-2248	Dendrobium 7	Shelter with Art
52-2-3068	Dendrobium 8	Shelter with Art and Grinding Grooves
52-2-3640	DM16	Shelter with art
52-2-3641	DM17	Shelter with Deposit
52-2-3645	DM21	Shelter with Art and Deposit
52-2-3646	DM22	Shelter with Art

Detailed descriptions of the archaeological sites are provided by the specialist archaeological consultant on the project.

5.13.2. Predictions for the Archaeological Sites

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the archaeological sites, based on the MSEC792 prediction curves, is provided in Table 5.29.

Table 5.29 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Archaeological Sites based on the MSEC792 Prediction Curves

Location	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
52-2-1623	1350	10	0.08	0.30
52-2-1626	2900	25	0.50	0.65
52-2-1627	3225	12	0.20	0.55
52-2-1771	< 20	< 0.5	< 0.01	< 0.01
52-2-1772	< 20	< 0.5	< 0.01	< 0.01
52-2-1773	< 20	< 0.5	< 0.01	< 0.01
52-2-1774	< 20	< 0.5	< 0.01	< 0.01
52-2-1775	30	1	< 0.01	< 0.01
52-2-1776	< 20	< 0.5	< 0.01	< 0.01
52-2-1778	< 20	< 0.5	< 0.01	< 0.01
52-2-2209	30	< 0.5	< 0.01	< 0.01
52-2-2229	3450	18	0.25	0.80
52-2-2246	2750	25	0.45	0.70
52-2-2248	525	15	0.35	0.01
52-2-3068	1525	25	0.85	0.35
52-2-3640	20	1	0.05	< 0.01
52-2-3641	< 20	< 0.5	< 0.01	< 0.01
52-2-3645	2300	30	0.65	0.10
52-2-3646	< 20	< 0.5	< 0.01	< 0.01
52-2-3878	2400	12	0.15	0.35

The predicted tilts provided in the above table are the maxima after the completion of any or all of the longwalls. The predicted curvatures provided in the above table are the maxima at any time during or after the extraction of each of the longwalls.

5.13.3. Comparison of Predictions for the Archaeological Sites based on the MSEC459 and MSEC792 Predictions Curves

The comparison of the maximum predicted total subsidence, upsidence and closure for the archaeological sites based on the MSEC459 and MSEC792 prediction curves, is provided in Table 5.30.

Table 5.30 Comparison of the Predicted Subsidence, Tilt and Curvatures for the Archaeological Sites

Site Type	Prediction Curves	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Closure (mm)	Maximum Predicted Total Valley Related Upsidence (mm)	Maximum Predicted Total Valley Related Closure (mm)
Artefact Scatters	MSEC459	2,000	25	0.45	0.60
	MSEC792	2,750	25	0.50	0.70
Rock Shelters	MSEC459	2,450	25	0.80	0.70
	MSEC792	3,450	30	0.85	0.80
Grinding Groove Site	MSEC459	850	20	0.80	0.15
	MSEC792	1,500	25	0.85	0.35

The maximum predicted subsidence parameters for the artefact scatters based on the MSEC792 prediction curves are greater than those based on the MSEC459 prediction curves by: 38 % for vertical subsidence; no change for tilt; and 11 % for hogging curvature and 17 % for sagging curvature.

The maximum predicted subsidence parameters for the rock shelters increase by: 41 % for vertical subsidence; 20 % for tilt; and 6 % for hogging curvature and 14 % for sagging curvature. The maximum predicted subsidence parameters for the grinding groove site increases by: 76 % for vertical subsidence; 20 % for tilt; and 6 % for hogging curvature and more than double for sagging curvature.

5.13.4. Review of the Assessed Impacts for the Cliffs provided in Report No. MSEC459 and the Reported Impacts during Longwalls 9 and 10

The impact assessments for the archaeological sites provided in Report No. MSEC459 stated that:

> "*The artefact scatter site could potentially be affected by cracking of the surface soils as a result of mine subsidence movements. It is unlikely, however, that the scattered artefacts themselves would be impacted by surface cracking. It is possible, however, that if remediation of the surface was required after mining, that these works could potentially impact the site.*"; and

> "*There are 12 shelters which are located directly above the proposed longwalls*" and *"the likelihoods of impacts on these sites are expected to be similar to those previously experienced where shelters were directly mined beneath in the Southern Coalfield"* where *"approximately 10 % of the shelters have been affected by fracturing of the strata or shear movements along bedding planes and that none of the shelters have collapsed (Sefton, 2000)*"; and

> '*It is possible, therefore, that fracturing of the bedrock could occur in the vicinity of Site 52-2-3068* [the grinding groove site]. *Preventive measures could be implemented at the grinding grooves at Site 52-2-3068, if required, including slotting of the bedrock around the site to isolate it from the ground curvatures and strains. It is possible, however, that the preventive measures could result in greater impacts on the site than those which would have occurred as a result of mine subsidence movements."*

Impacts were observed to archaeological sites as a result of Longwall 9 which were described in the End of Panel Report (IC, 2014) and have been summarised below:

> "*Site 52-2-2208: Minor expansion and extension of vertical cracking in horizontal bedding plane observed. While rock cracking has occurred, it is considered to be minor and unlikely to lead to water seepage or rock falls at Dendrobium 1. There is no art on the shelter walls and the archaeological deposit was not impacted by this crack.*"

There were no additional impacts observed during the extraction of Longwall 10.

It is considered that the physical impacts observed to the rock shelter site are consistent with the assessed potential for impacts outlined in Report No. MSEC459 and the SMP Application. Further discussions on the environmental consequences for this site are provided by the specialist archaeological consultant.

5.13.5. Impact Assessments for the Archaeological Sites based on the MSEC792 Prediction Curves

Artefact scatters

There is one artefact scatter site located within the Study Area, being Ref. 52-2-2246.

The maximum predicted subsidence parameters for the artefact scatter site based on the MSEC792 prediction curves are greater than those based on the MSEC459 prediction curves by: 38 % for vertical subsidence; no change for tilt; and 11 % for hogging curvature and 17 % for sagging curvature.

The potential for impacts are dependent on the differential subsidence (i.e. tilt, curvature and strain), rather than the vertical subsidence itself. There is a slightly increased potential for cracking in the surface soils, therefore, based on the MSEC792 prediction curves. It is unlikely, however, that the scattered artefacts themselves would be impacted by surface cracking.

It is possible, however, that if remediation of the surface was required after mining, that these works could potentially impact the site. The management strategies for the artefact scatters are the same as those provided in Report No. MSEC459 and the SMP Application.

Rock shelters

There are 18 rock shelters located within the Study Area, being Refs. 52-2-3068, 52-2-1623, 52-2-1626, 52-2-1627, 52-2-1771, 52-2-1772, 52-2-1773, 52-2-1774, 52-2-1775, 52-2-1776, 52-2-1778, 52-2-2209, 52-2-2229, 52-2-2248, 52-2-3640, 52-2-3641, 52-2-3645 and 52-2-3646.

The maximum predicted subsidence parameters for the rock shelters based on the MSEC792 prediction curves are greater than those based on the MSEC459 prediction curves by: 41 % for vertical subsidence; 20 % for tilt; and 6 % for hogging curvature and 14 % for sagging curvature.

The potential for impacts are dependent on the differential subsidence (i.e. curvature and strain), rather than the vertical subsidence or tilt. There is a slightly increased potential for fracturing in the shelters, therefore, based on the MSEC792 prediction curves.

Whilst the rates of impacts are likely to increase, the nature of these impacts are unlikely to change, i.e. a slightly greater movement along the existing joints and bedding planes and a slightly greater potential for fracturing. The management strategies for the rock shelters are the same as those provided in Report No. MSEC459 and the SMP Application.

The impact assessments and management strategies for the cliffs, therefore, are the same as those provided in Report No. MSEC459 and the SMP Application.

Grinding Groove Site

There is one grinding groove site located within the Study Area, being Ref. 52-2-3068.

The maximum predicted subsidence parameters for the grinding groove site based on the MSEC792 prediction curves are greater than those based on the MSEC459 prediction curves by: 76 % for vertical subsidence; 20 % for tilt; and 6 % for hogging curvature and more than double for sagging curvature.

The potential for impacts are dependent on the differential subsidence (i.e. curvature and strain), rather than the vertical subsidence or tilt. There is an increased potential for fracturing in the grinding groove site, therefore, based on the MSEC792 prediction curves. The management strategies, however, do not change for this site.

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

6.1. Railway Infrastructure

6.1.1. Description of the Abandoned Railway Corridor

There are no operating railways within the Study Area. The abandoned Maldon-Dombarton Railway Corridor crosses the Study Area, the location of which is shown in Drawing No. MSEC792-12. 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 abandoned railway corridor are shown in Drawing No. MSEC792-12. Photographs of the abandoned railway corridor and a cutting are provided in Fig. 6.1. Photographs of an embankment and drainage culvert are provided in Fig. 6.2.

Fig. 6.1 Photographs of the Abandoned Railway Corridor and a Cutting

Fig. 6.2 Photographs of an Embankment and Drainage Culvert

Further descriptions of the abandoned railway corridor are provided in Report No. MSEC459 and the SMP Application.

6.1.2. Predictions for the Abandoned Railway Corridor

The predicted profiles of conventional subsidence, tilt and curvature along the abandoned railway corridor, based on the MSEC792 prediction curves, are shown in Fig. D.12, in Appendix D. The predicted incremental profiles along the corridor, due to the extraction of each of the longwalls, are shown as dashed black lines. The predicted total profiles along the corridor, after the extraction of each of the longwalls, are shown as solid blue lines. The range of predicted curvatures in any direction to the corridor, at any time during or after the extraction of the longwalls, is shown by the grey shading.

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature, based on the MSEC792 prediction curves, is provided in Table 4.1.

Table 6.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Abandoned Railway based on the MSEC792 Prediction Curves

Location	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Abandoned Railway Corridor	3,050	30	0.60	0.80

The tilts provided in the above table are the maximum predicted values at the completion of any or all longwalls. The curvatures provided in the above table are the maximum predicted values which occur at any time during or after the extraction of the longwalls.

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the cuttings and embankments is provided in Table 6.2.

Table 6.2 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Cuttings and Embankments based on the MSEC792 Prediction Curves

Location	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
MDB-F1	1,125	12	0.20	0.10
MDB-F2	1,875	16	0.20	0.10
MDB-F3	3,000	25	0.20	0.60
MDB-F4	2,225	20	0.40	0.10
MDB-F5	3,050	30	0.45	0.55
MDB-F6	3,000	17	0.15	0.55
MDB-F7	2,700	18	0.25	0.30
MDB-F8	2,850	30	0.45	0.55
MDB-F9	2,175	25	0.45	0.10
MDB-F10	3,000	30	0.50	0.65
MDB-F11	3,000	20	0.45	0.50
MDB-F12	3,000	35	0.65	0.85
MDB-F13	250	8	0.20	< 0.01

The parameters provided in the above table are the maxima values within a 20 metre radius of the extents of each feature.

6.1.3. Comparison of Predictions for the Abandoned Railway Corridor based on the MSEC459 and MSEC792 Predictions Curves

The comparison of the maximum predicted total subsidence, tilt and curvatures for the railway corridor, based on the MSEC459 and MSEC792 prediction curves, is provided in Table 6.3.

Table 6.3 Comparison of the Predicted Subsidence, Tilt and Curvatures for the Railway Corridor

Prediction Curves	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
MSEC459	2,550	30	0.55	0.70
MSEC792	3,050	30	0.60	0.80

The maximum predicted subsidence based on the MSEC792 prediction curves of 3,050 mm is greater than that predicted based on the MSEC459 prediction curves of 2,550, i.e. a 20 % increase. There is no significant change in the maximum predicted tilt. The maximum predicted curvatures based on the MSEC792 prediction curves are 10 % to 15 % greater than those based on the MSEC459 prediction curves.

The predicted vertical subsidence for the cuttings and embankments, based on the MSEC792 prediction curves range between 7 % and 55 % and on average 35 % greater than those based on the MSEC459 prediction curves. The predicted tilts for these features do not change significantly, varying between ±5 mm/m (i.e. greater and less than). The predicted curvatures for the cuttings and embankments, based on the MSEC792 prediction curves, are ±0.15 km^{-1} (i.e. greater and less than) those predicted based on the MSEC479 prediction curves.

6.1.4. Reported Impacts along the Railway Corridor during Longwalls 9 and 10

There were no reported impacts on the Railway Corridor during the extraction of Longwalls 9 and 10.

6.1.5. Impact Assessments for the Abandoned Railway Corridor

The maximum predicted tilts and curvatures for the Railway Corridor, based on the MSEC792 prediction curves, are similar to or slightly greater (i.e. 10 % to 15 %) than those predicted based on the MSEC459 prediction curves. The predicted tilts and curvatures at the cuttings and embankments increase or decrease, depending on their locations relative to the longwalls.

The potential impacts on the Railway Corridor for Longwalls 12 to 18, based on the MSEC792 prediction curves, therefore, are similar to or only slightly greater than those predicted based on the MSEC459 prediction curves. The likelihoods and extents of these impacts will slightly increase, which includes fracturing in the exposed rock within the cuttings, tensile cracking in the embankments and cracking in the drainage culverts. It is unlikely, however, that the nature of these impacts and, hence, the management strategies would change.

The management strategies for the Railway Corridor, therefore, are the same as those provided in Report No. MSEC459 and the SMP Application.

6.2. Unsealed Roads

6.2.1. Descriptions of the Unsealed Roads

There are no public roads within the Study Area. There are, however, unsealed fire trails and four wheel drive tracks within the Study Area, which are used by Water NSW and other groups for fire fighting and other activities. The locations of the unsealed roads are shown in Drawing No. MSEC792-12. A photograph of a fire trail within the Study Area is provided in Fig. 6.3.

Fig. 6.3 Photograph of a Typical Fire Trail (Courtesy of IC)

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

6.2.2. Predictions for the Unsealed Roads

The unsealed roads are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the unsealed roads, based on the MSEC792 prediction curves, is provided in Table 6.4.

Table 6.4 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for the Unsealed Roads based on the MSEC792 Prediction Curves

Location	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
Unsealed Roads	3,600	50	1.4	1.4

The predicted tilts provided in the above table are the maxima after the completion of any or all of the longwalls. The predicted curvatures provided in the above table are the maxima at any time during or after the extraction of each of the longwalls.

6.2.3. Comparison of Predictions for the Unsealed Roads based on the MSEC459 and MSEC792 Predictions Curves

The comparison of the maximum predicted total subsidence, tilt and curvatures for the unsealed roads, based on the MSEC459 and MSEC792 prediction curves, is provided in Table 6.5.

Table 6.5 Comparison of the Predicted Subsidence, Tilt and Curvatures for the Unsealed Roads

Prediction Curves	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})
MSEC459	2,800	40	1.0	1.0
MSEC792	3,600	50	1.4	1.4

The maximum predicted subsidence parameters for the unsealed roads, based on the MSEC792 prediction curves, are greater than those based on the MSEC459 prediction curves by: 30 % for vertical subsidence; 25 % for tilt; and 40 % for curvature.

6.2.4. Review of the Assessed Impacts for the Unsealed Roads provided in Report No. MSEC459 and the Reported Impacts during Longwalls 9 and 10

The impact assessments for the unsealed roads provided in Report No. MSEC459 stated that:

> "*It is expected, at the magnitudes of predicted curvatures and strains, that cracking and heaving of the unsealed road surfaces would occur as a result of the extraction of the proposed longwalls*" similar to those previously observed at Dendrobium Mine, where
>
> "*the widths of the observed surface cracks at the tops of the ridgeline and steep slopes varied up to 400 mm wide. Additional surface cracks, typically in the order of 100 mm to 150 mm in width, were also observed further down the ridgeline and steep slopes.*"

Impacts were observed to the unsealed roads as a result of Longwall 9 which were described in the End of Panel Report (IC, 2014) and have been summarised below:

> "*Site DA3B_LW9_008: Multiple surface cracks to soil on Access Track 6000; up to 4m long, 0.02m wide and 0.12m deep. Natural remediation and infilling evident.*
>
> *Site DA3B_LW9_009: Surface Cracking. Multiple soil cracks on Access Track 6000. The largest crack was 15m long and up to 0.01m wide. Natural remediation and infilling has been observed.*
>
> *Site DA3B_LW9_010: Surface Cracking. Multiple soil cracks on Access Track 6000. The largest crack was 8m long and up to 0.02m wide. Natural remediation and infilling has been observed.*
>
> *Site DA3B_LW9_025: Rock fracture and uplift on a rock outcrop adjacent to Access Track 6000; approx. 1.3m long, 0.02m wide, 0.05m deep and 0.02m of uplift.*"

Impacts were observed to the unsealed roads as a result of Longwall 10 which were described in the End of Panel Report (IC, 2015) and have been summarised below:

> *"Site DA3B_LW10_001: Soil crack adjacent to an access track that crosses Fire Road 6A. Crack is approximately 1.5m long and 0.005m wide.*
>
> *Site DA3B_LW10_002: Multiple soil cracks on Access Track 6000 up to 5m long, 0.05m wide and 0.32m deep. Self-remediation likely.*
>
> *Site DA3B_LW10_003: Multiple soil cracks on Access Track 6000 up to 0.7m long, 0.05m wide and 0.14m deep. Self-remediation likely.*
>
> *Site DA3B_LW10_005: Soil crack on Access Track 6000. Measured 3.5m long, 0.05m wide and 0.01m deep. Self-remediation likely.*
>
> *Site DA3B_LW10_006: Soil crack on Access Track 6000. Measured 1m long, 0.03m wide and 0.3m deep. Self-remediation likely.*
>
> *Site DA3B_LW10_012: Soil cracking on a closed seismic track approximately 75m northwest of WC21_Rockbar 24. Cracking has a maximum length of 2.4m, width of 0.051m and depth of 0.02m.*"

6.2.5. Impact Assessments for the Unsealed Roads

The maximum predicted incremental vertical subsidence for each of the future Longwalls 12 to 18 are between zero and 12 % greater than the maxima predicted for the previous Longwalls 9 and 10. The potential impacts due to these future longwalls, therefore, are similar to or slightly greater than those previously observed in Dendrobium Area 3B.

The likelihoods and extents of these surface impacts will slightly increase, which includes tensile cracking and compression heaving, as described in the previous section. It is unlikely, however, that the nature of these impacts and, hence, the management strategies would change.

The management strategies for unsealed roads, therefore, are the same as those provided in Report No. MSEC459 and the SMP Application.

6.3. Dams, Reservoirs or Associated Works

6.3.1. Descriptions of the Reservoirs

Lake Avon, also known as the Avon Reservoir, is located to the west of the longwalls in Area 3B as shown in Drawing No. MSEC792-08. The commencing ends of Longwalls 11 to 18 are located within the Dams Safety Committee (DSC) Notification Area for Lake Avon.

Lake Avon is fed by the Avon River and its many tributaries and has a length of approximately 19 kilometres. The Lake Avon water storage has a total operating capacity of approximately 147,000 ML. A photograph of Lake Avon is provided in Fig. 6.4.

Fig. 6.4 Photograph of Lake Avon (Courtesy of IC)

Lake Cordeaux is located approximately 3 kilometres east of the proposed longwalls. At this distance, the lake is not predicted to experience any measurable mine subsidence movements. It is not expected, therefore, that the lake would experience any impacts resulting from the extraction of the longwalls.

There are no dam structures or associated works within the Study Area. The closest dam walls are the Cordeaux Dam Wall and the Upper Cordeaux No. 2 Dam Wall which are located approximately 5 kilometres north and 5 kilometres east, respectively, from the longwalls. At these distances, the dam walls are not predicted to experience any measurable mine subsidence movements. It is not expected, therefore, that the dam walls would experience any impacts resulting from the extraction of the proposed longwalls.

Lake Avon is located at a distance of 214 metres from Longwall 16, at its closest point to the longwalls in Area 3B. At this distance, the lake is predicted to experience conventional subsidence of less than 20 mm as the result of mining, based on both the MSEC459 and MSEC792 prediction curves. While it is possible that the lake could experience subsidence slightly greater than 20 mm, it would not be expected to experience any significant conventional tilts, curvatures or strains.

The maximum predicted total upsidence and closure at Lake Avon are 50 mm and 100 mm, respectively, based both on the MSEC459 and MSEC792 prediction. Whilst the predicted movements are small, it is possible that minor isolated cracking could occur in the bedrock, as has been observed in the Southern Coalfield up to 400 metres from previously extracted longwalls.

The impact assessments and management strategies for Lake Cordeaux and Lake Avon, therefore, are the same as those provided in Report No. MSEC459 and the SMP Application.

6.4. Survey Control Marks

The locations of the survey control marks within and immediately adjacent to the Study Area are shown in Drawing No. MSEC792-13. The locations and details of the survey control marks were obtained from the *Land and Property Management Authority* using the *SCIMS Online* website (SCIMS, 2011).

The survey control marks are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4.

Whilst the predicted conventional movements, based on the MSEC792 prediction curves, are greater than those based on the MSEC459 prediction curves, the management strategies recommended for the survey control marks do not change.

The impact assessments and management strategies for survey control marks, therefore, are the same as those provided in Report No. MSEC459 and the SMP Application.

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	**T**he reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides. It should be noted that the observed closure movement across a valley is the total movement resulting from various mechanisms, including conventional mining induced movements, valley closure movements, far-field effects, downhill movements and other possible strata mechanisms.
Critical area	The area of extraction at which the maximum possible subsidence of one point on the surface occurs.
Curvature	The change in tilt between two adjacent sections of the tilt profile divided by the average horizontal length of those sections, i.e. curvature is the second derivative of subsidence. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres (km-1)*, but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*. Curvature can be either **hogging** (i.e. convex) or **sagging** (i.e. concave).
Extracted seam	The thickness of coal that is extracted. The extracted seam thickness is thickness normally given as an average over the area of the panel.
Effective extracted seam thickness (T)	The extracted seam thickness modified to account for the percentage of coal left as pillars within the panel.
Face length	The width of the coalface measured across the longwall panel.
Far-field movements	The measured horizontal movements at pegs that are located beyond the longwall panel edges and over solid unmined coal areas. Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain.
Goaf	The void created by the extraction of the coal into which the immediate roof layers collapse.
Goaf end factor	A factor applied to reduce the predicted incremental subsidence at points lying close to the commencing or finishing ribs of a panel.
Horizontal displacement	The horizontal movement of a point on the surface of the ground as it settles above an extracted panel.
Inflection point	The point on the subsidence profile where the profile changes from a convex curvature to a concave curvature. At this point the strain changes sign and subsidence is approximately one half of S max.
Incremental subsidence	The difference between the subsidence at a point before and after a panel is mined. It is therefore the additional subsidence at a point resulting from the excavation of a panel.
Panel	The plan area of coal extraction.
Panel length (L)	The longitudinal distance along a panel measured in the direction of (mining from the commencing rib to the finishing rib.
Panel width (Wv)	The transverse distance across a panel, usually equal to the face length plus the widths of the roadways on each side.
Panel centre line	An imaginary line drawn down the middle of the panel.
Pillar	A block of coal left unmined.
Pillar width (Wpi)	The shortest dimension of a pillar measured from the vertical edges of the coal pillar, i.e. from rib to rib.

Shear deformations	The horizontal displacements that are measured across monitoring lines and these can be described by various parameters including; horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.
Strain	The change in the horizontal distance between two points divided by the original horizontal distance between the points, i.e. strain is the relative differential displacement of the ground along or across a subsidence monitoring line. Strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation. **Tensile Strains** are measured where the distance between two points or survey pegs increases and **Compressive Strains** where the distance between two points decreases. Whilst mining induced **strains** are measured **along** monitoring lines, ground **shearing** can occur both vertically, and horizontally **across** the directions of the monitoring lines.
Sub-critical area	An area of panel smaller than the critical area.
Subsidence	The vertical movement of a point on the surface of the ground as it settles above an extracted panel, but, 'subsidence of the ground' in some references can include both a vertical and horizontal movement component. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of *millimetres (mm)*. Sometimes the horizontal component of a peg's movement is not measured, but in these cases, the horizontal distances between a particular peg and the adjacent pegs are measured.
Super-critical area	An area of panel greater than the critical area.
Tilt	The change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the horizontal distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
Uplift	An increase in the level of a point relative to its original position.
Upsidence	Upsidence results from the dilation or buckling of near surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.

APPENDIX B. REFERENCES

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APPENDIX C. COMPARISON OF OBSERVED AND PREDICTED CHANGES IN SURFACE LEVEL IN AREAS 2, 3A AND 3B

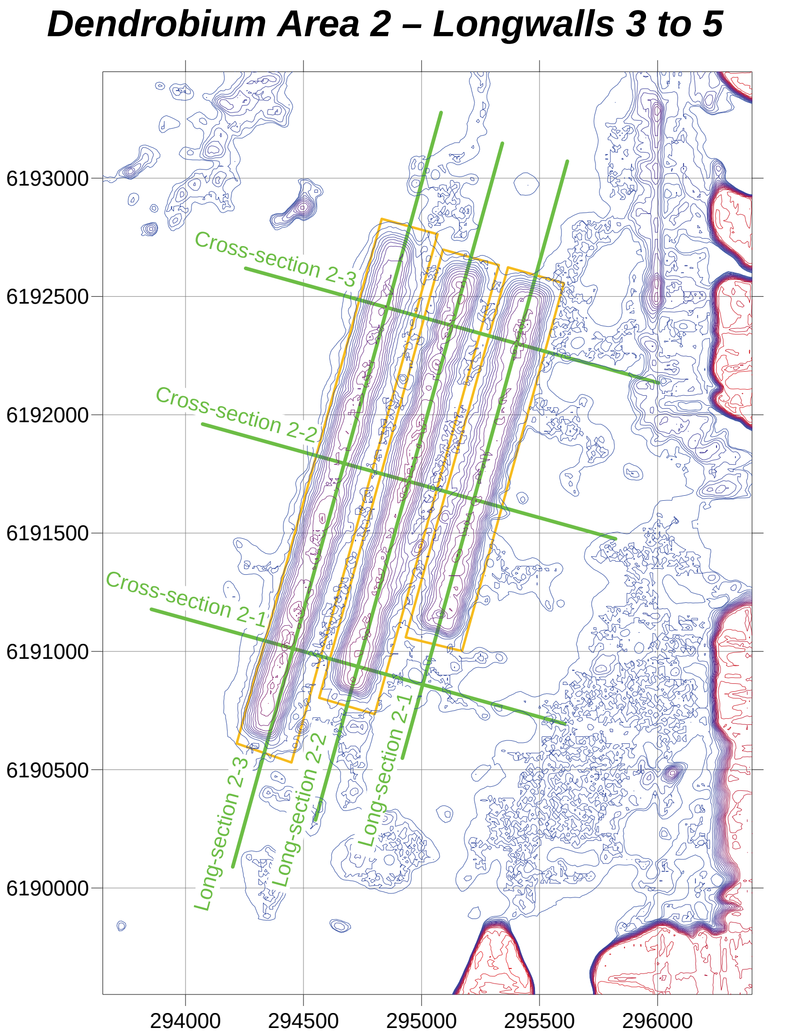


Fig. C.1 ALS Changes in Surface Level due to the Extraction of Longwalls 3 to 5 in Area 2

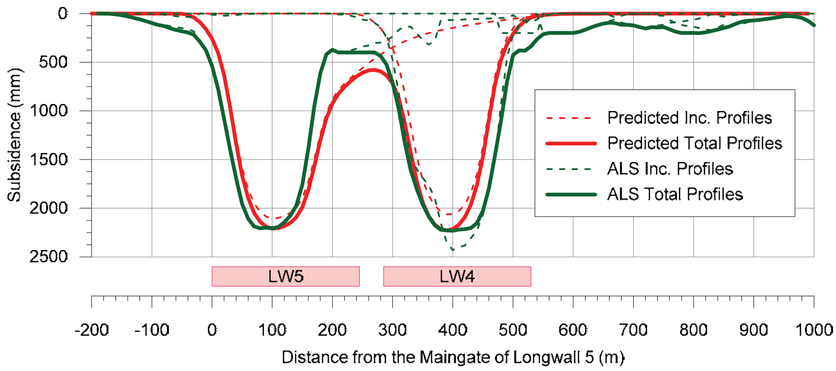


Fig. C.2 ALS and Predicted Changes in Surface Level along Cross-section 2-1

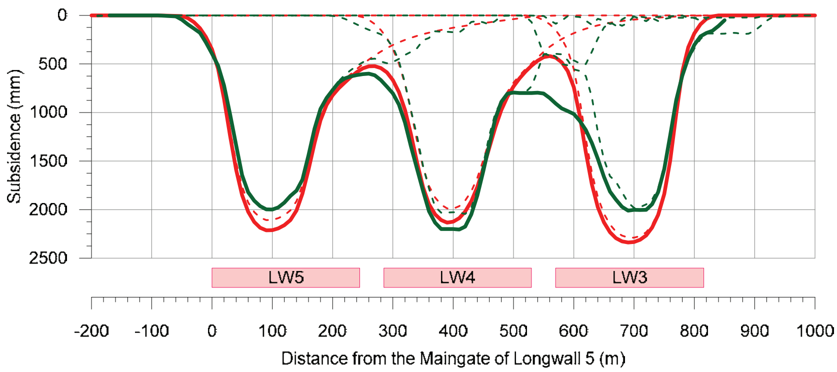


Fig. C.3 ALS and Predicted Changes in Surface Level along Cross-section 2-2

Dendrobium Area 2 – Longwalls 3 to 5

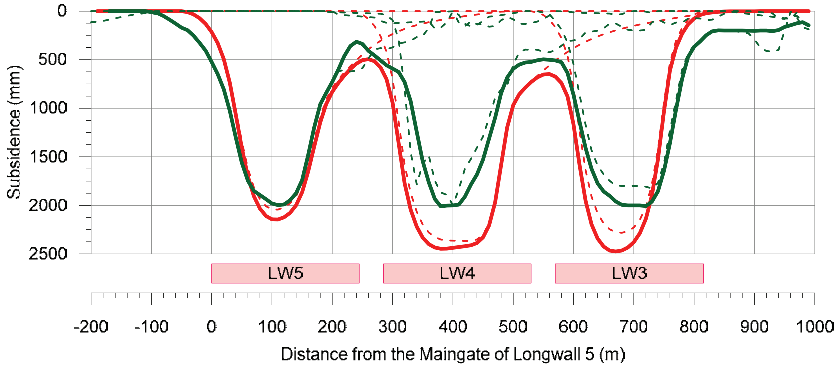


Fig. C.4 ALS and Predicted Changes in Surface Level along Cross-section 2-3

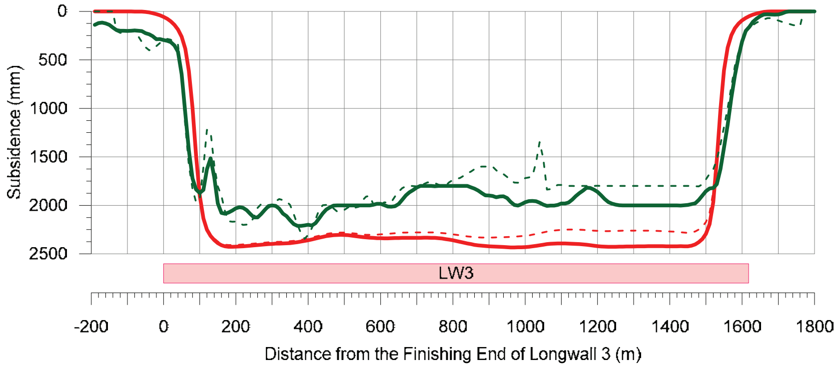


Fig. C.5 ALS and Predicted Changes in Surface Level along Long-section 2-1

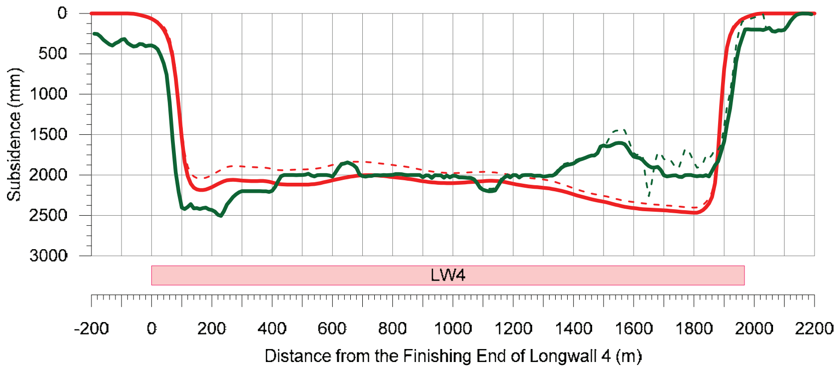


Fig. C.6 ALS and Predicted Changes in Surface Level along Long-section 2-2

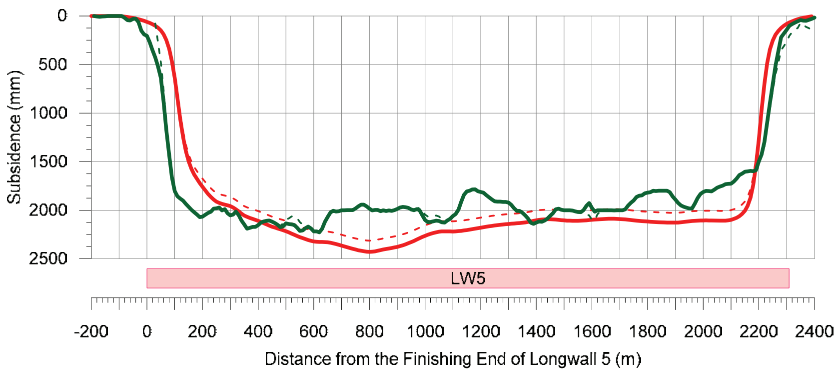


Fig. C.7 ALS and Predicted Changes in Surface Level along Long-section 2-3

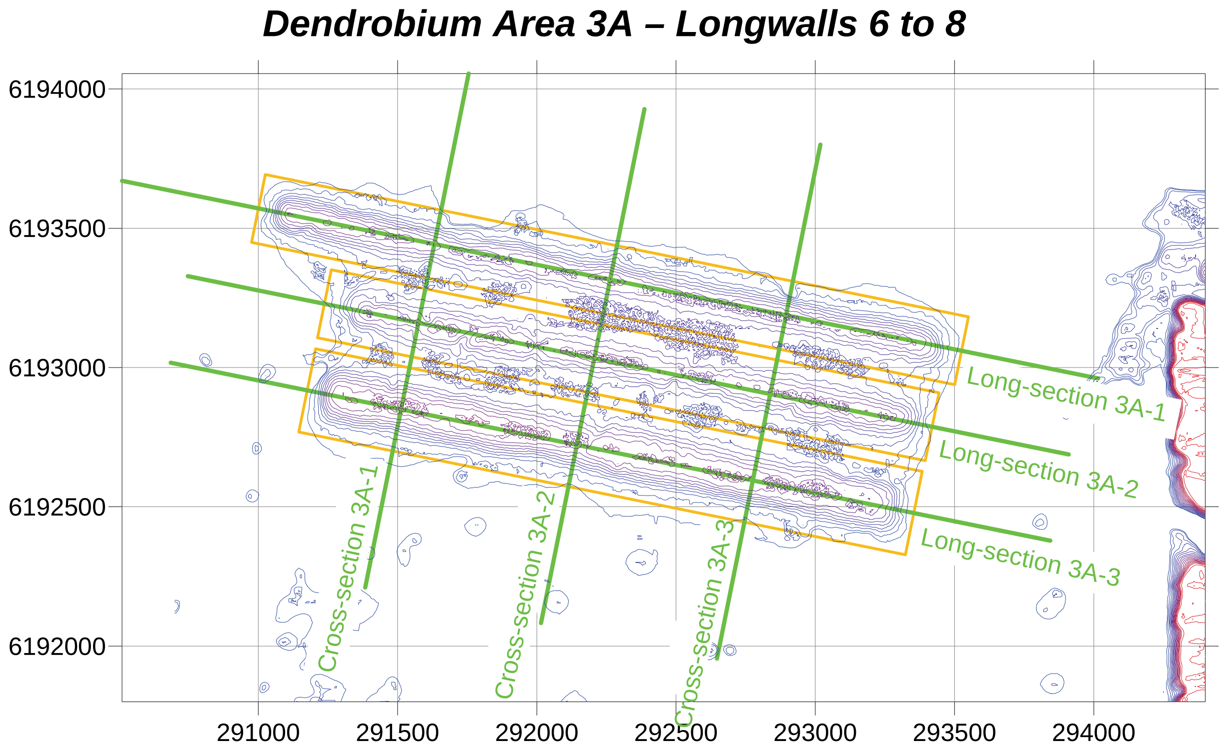


Fig. C.8 ALS Changes in Surface Level due the Extraction of Longwalls 6 to 8 in Area 3A

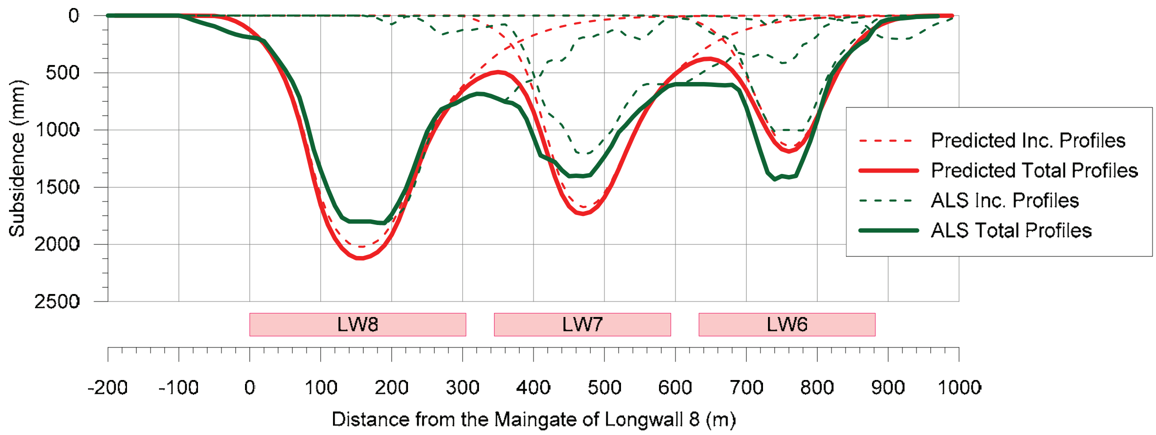


Fig. C.9 ALS and Predicted Changes in Surface Level along Cross-section 3A-1

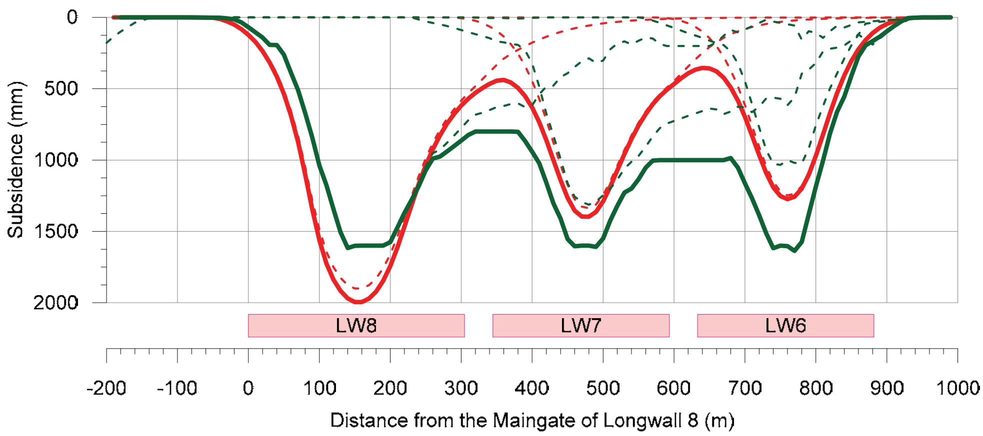


Fig. C.10 ALS and Predicted Changes in Surface Level along Cross-section 3A-2

Dendrobium Area 3A – Longwalls 6 to 8

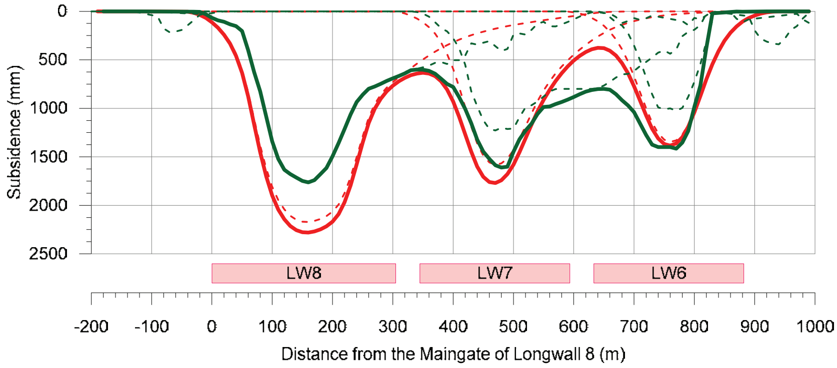


Fig. C.11 ALS and Predicted Changes in Surface Level along Cross-section 3A-3

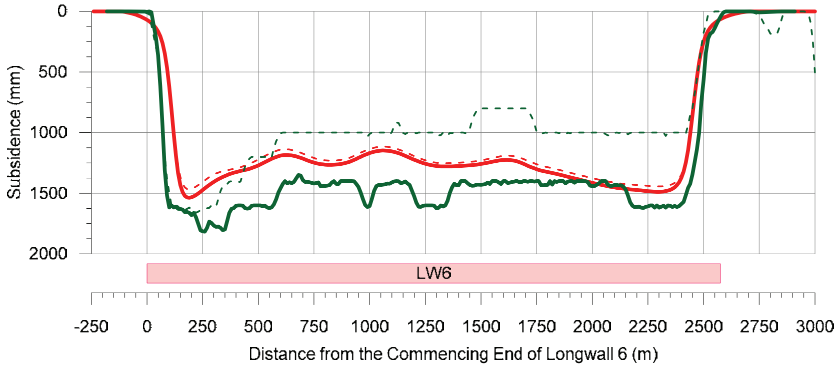


Fig. C.12 ALS and Predicted Changes in Surface Level along Long-section 3A-1

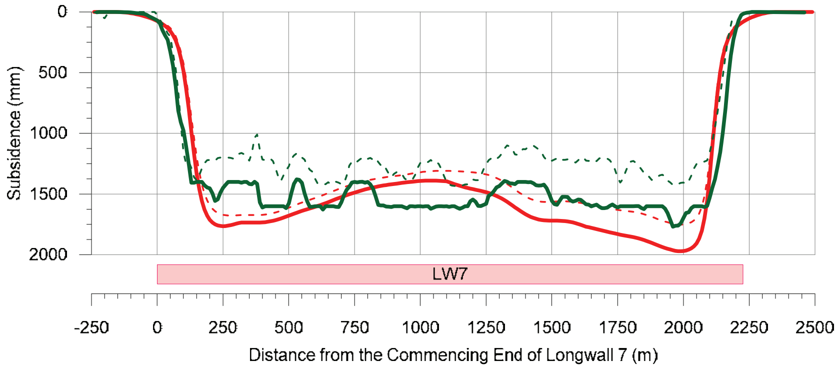


Fig. C.13 ALS and Predicted Changes in Surface Level along Long-section 3A-2

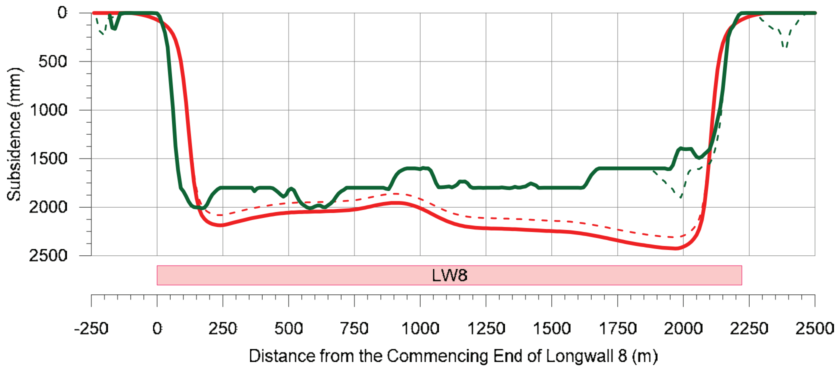


Fig. C.14 ALS and Predicted Changes in Surface Level along Long-section 3A-3

Dendrobium Area 3B – Longwalls 9 and 10

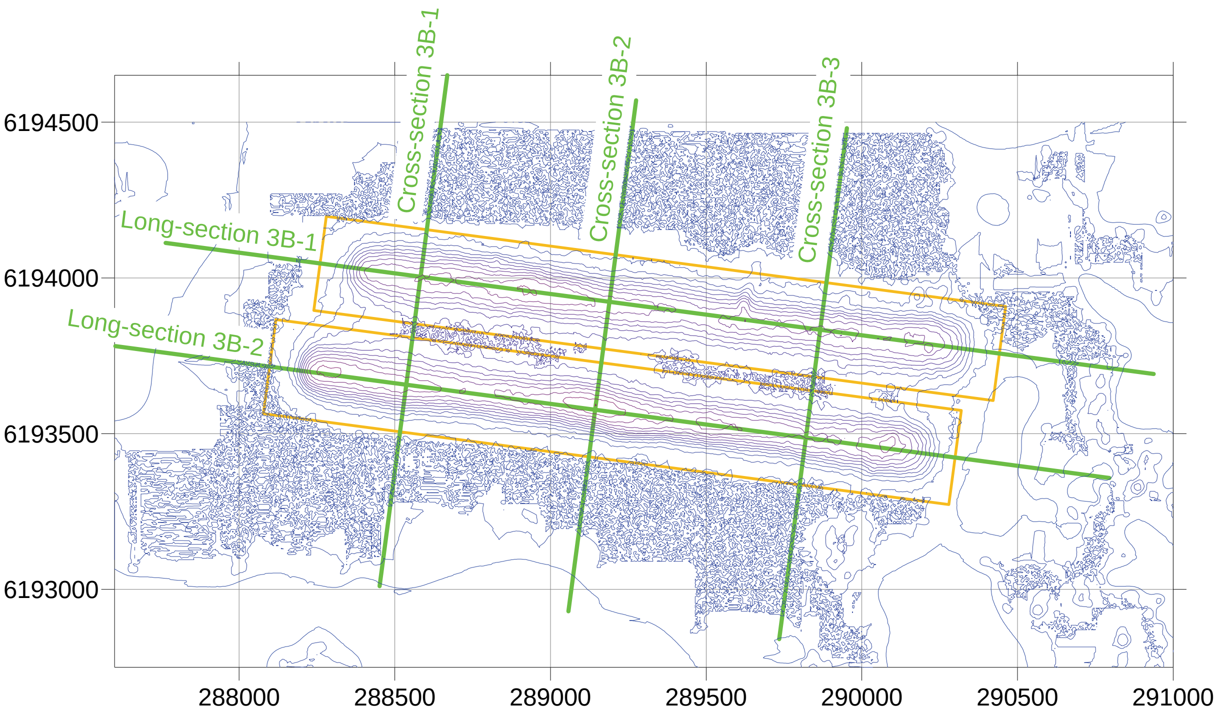


Fig. C.15 ALS Changes in Surface Level due to the Extraction of Longwalls 9 and 10 in Area 3B

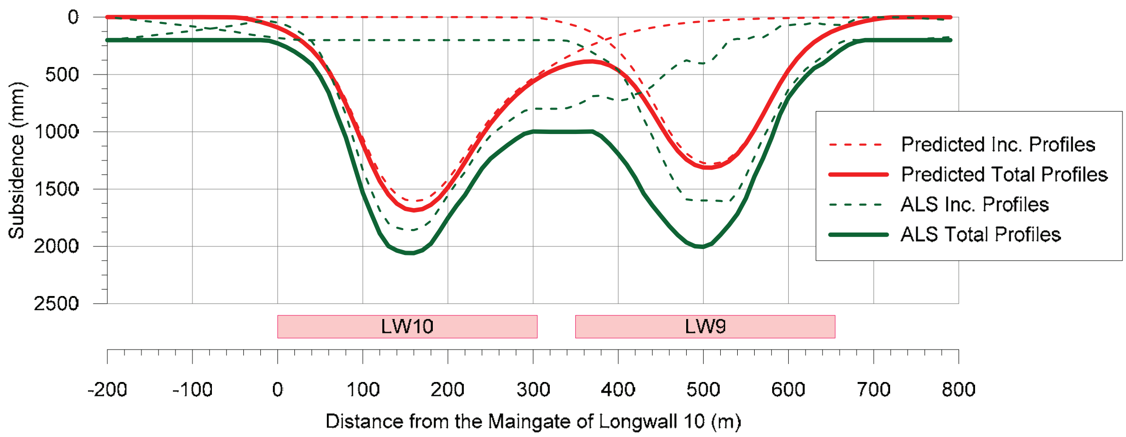


Fig. C.16 ALS and Predicted Changes in Surface Level along Cross-section 3B-1

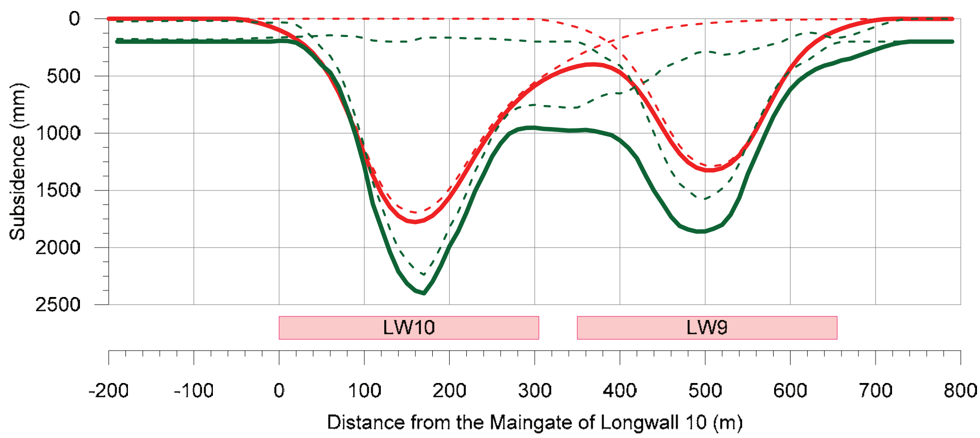


Fig. C.17 ALS and Predicted Changes in Surface Level along Cross-section 3B-2

Dendrobium Area 3B – Longwalls 9 and 10

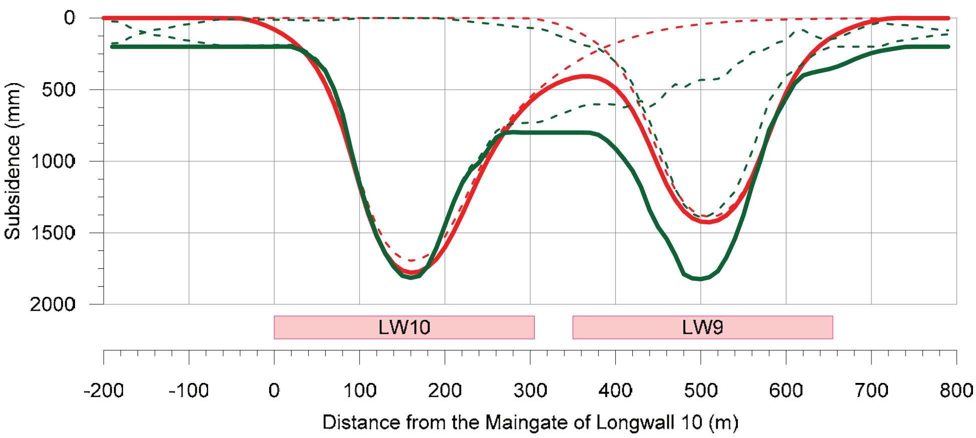


Fig. C.18 ALS and Predicted Changes in Surface Level along Cross-section 3B-3

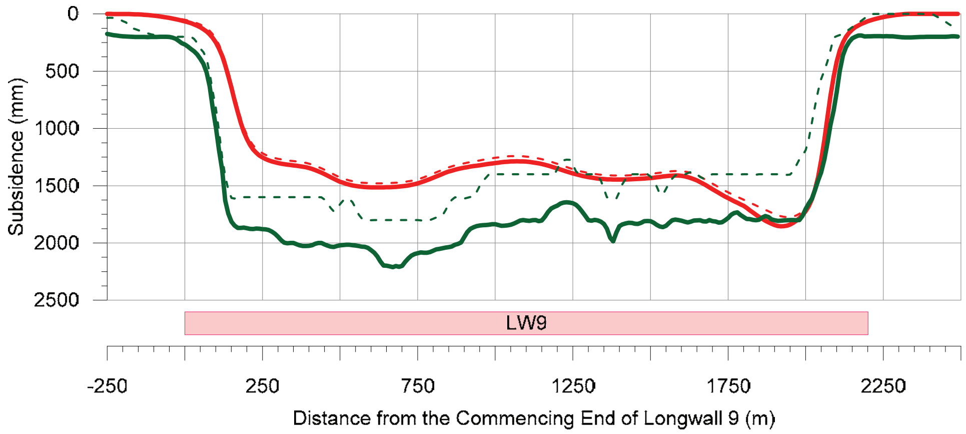


Fig. C.19 ALS and Predicted Changes in Surface Level along Long-section 3B-1

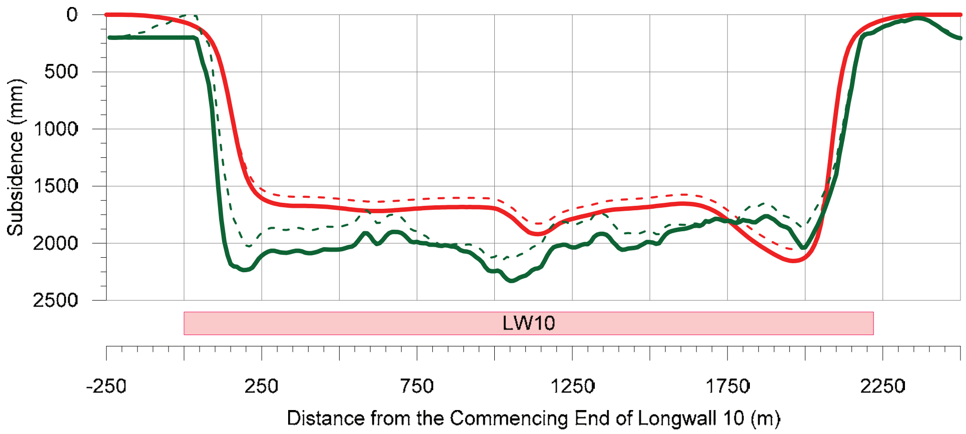
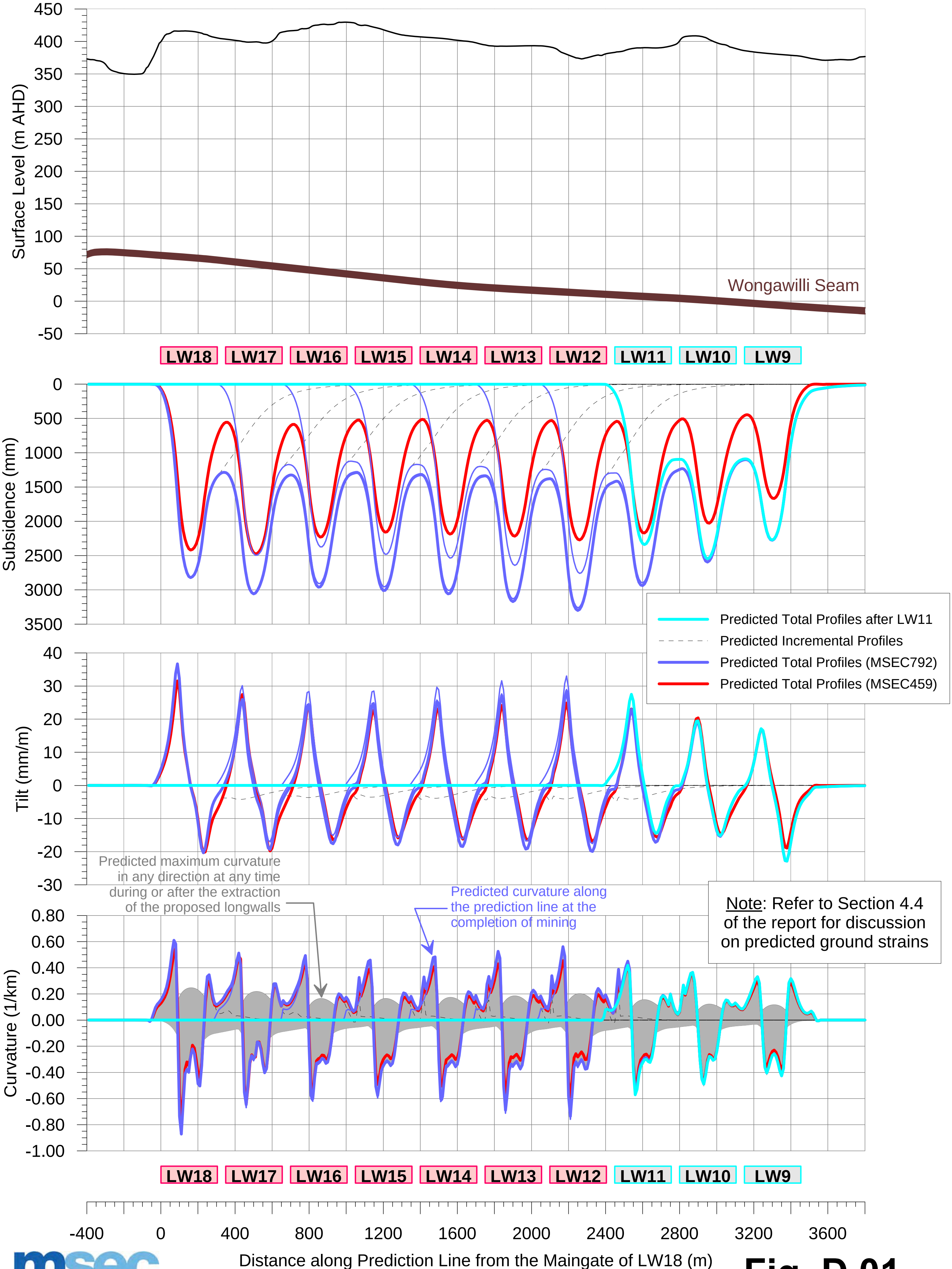


Fig. C.20 ALS and Predicted Changes in Surface Level along Long-section 3B-2

APPENDIX D. FIGURES

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 1 Resulting from the Extraction of Longwalls 9 to 18



msec

Fig. D.01

Predicted Profiles of Subsidence, Upsidence and Closure along Wongawilli Creek Resulting from the Extraction of Longwalls 5 to 19

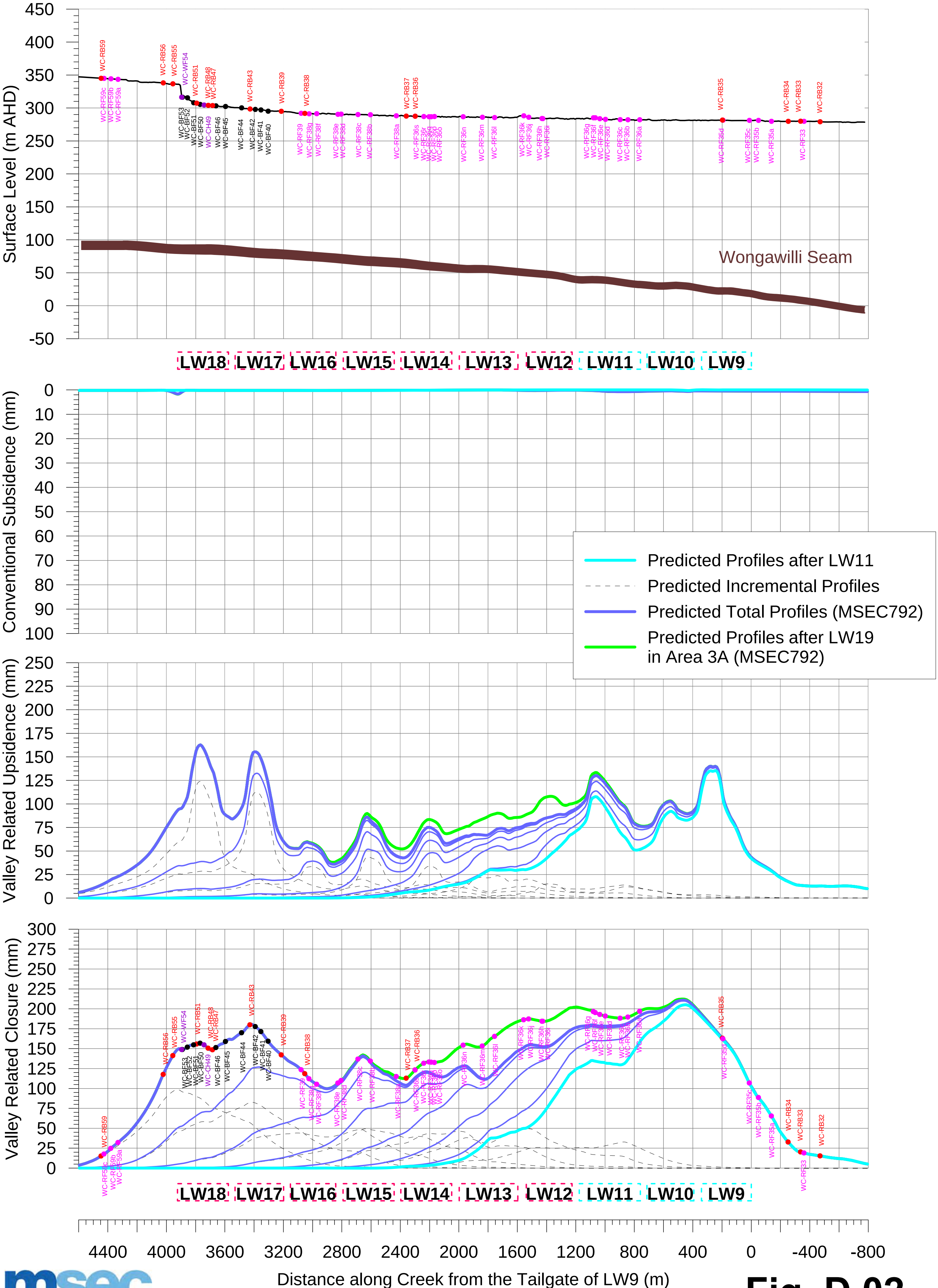


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Fig. D.02

Predicted Profiles of Subsidence, Upsidence and Closure along Donalds Castle Creek Resulting from the Extraction of Longwalls 9 to 18

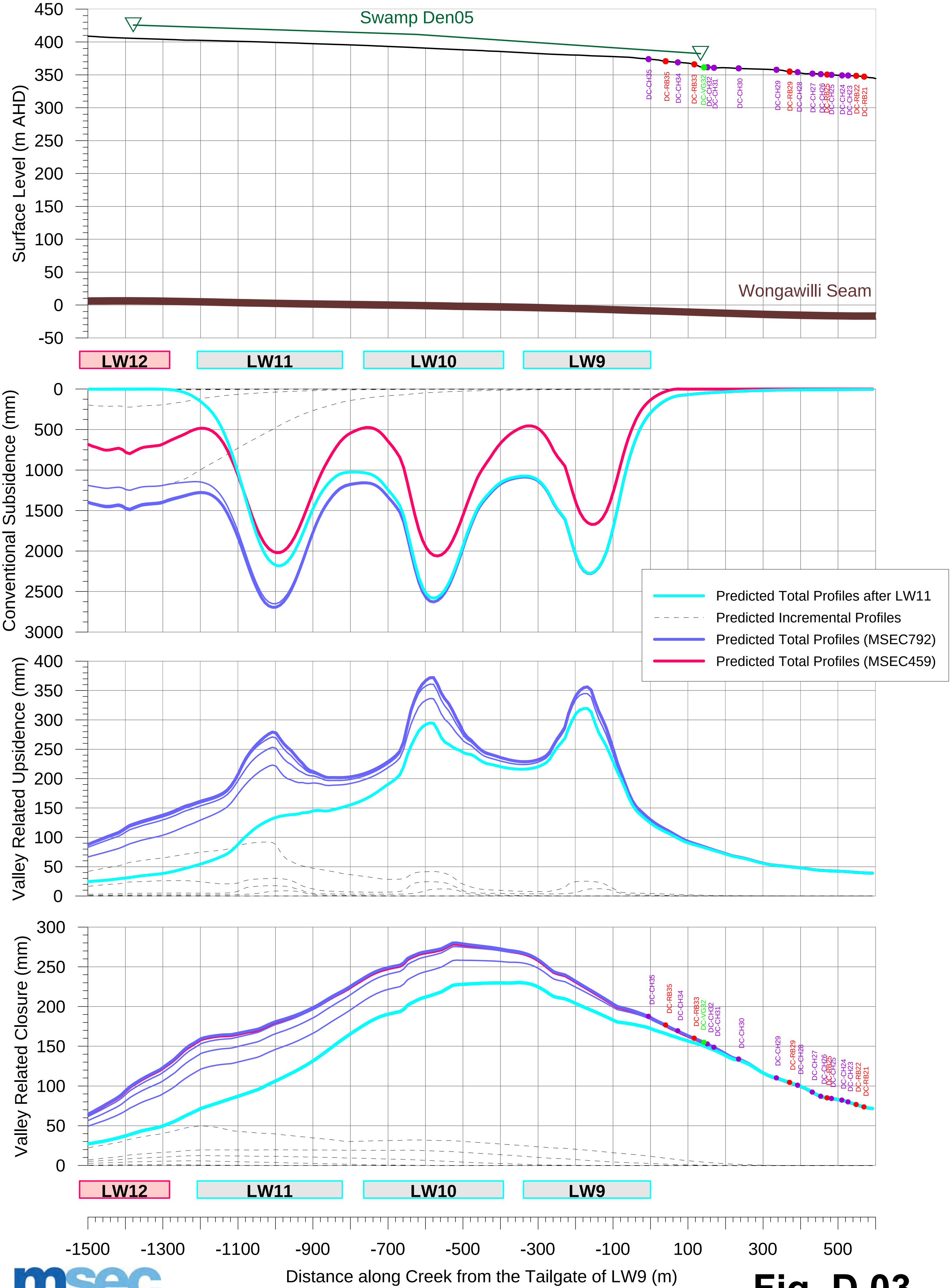

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Fig. D.03

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line DC13 Resulting from the Extraction of Longwalls 9 to 18

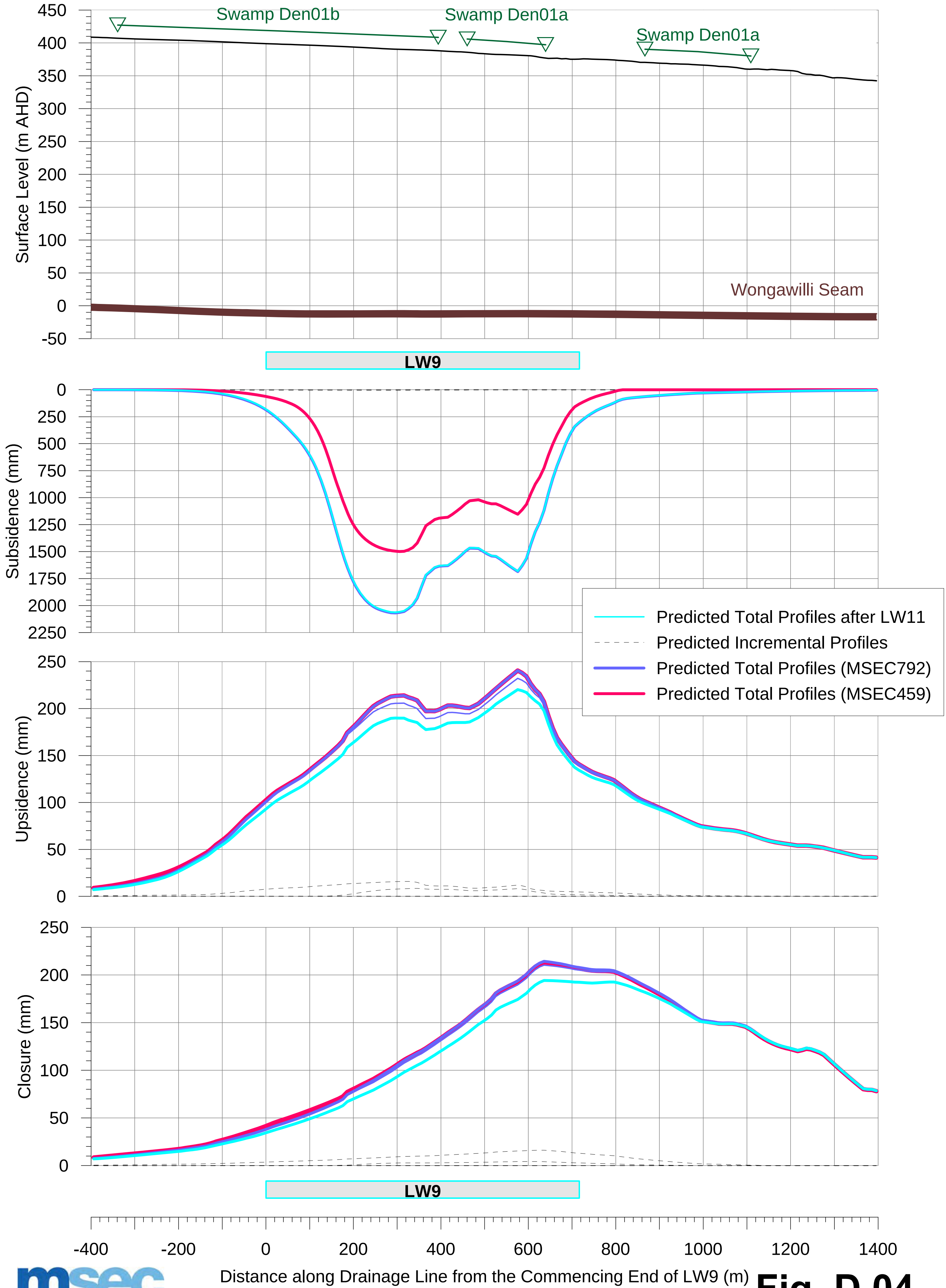

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Fig. D.04

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line LA3 Resulting from the Extraction of Longwalls 9 to 18

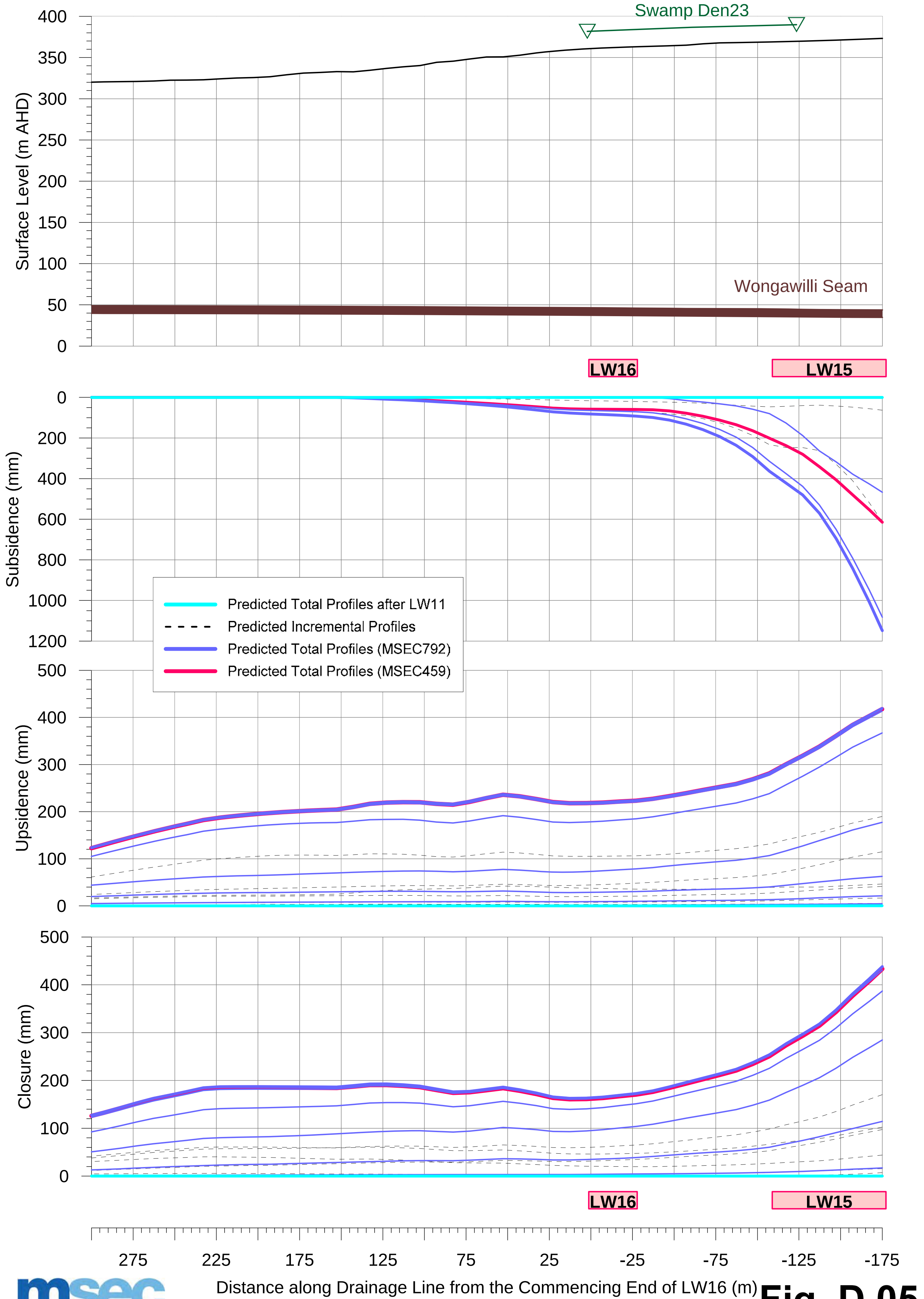

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Fig. D.05

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line LA4 Resulting from the Extraction of Longwalls 9 to 18

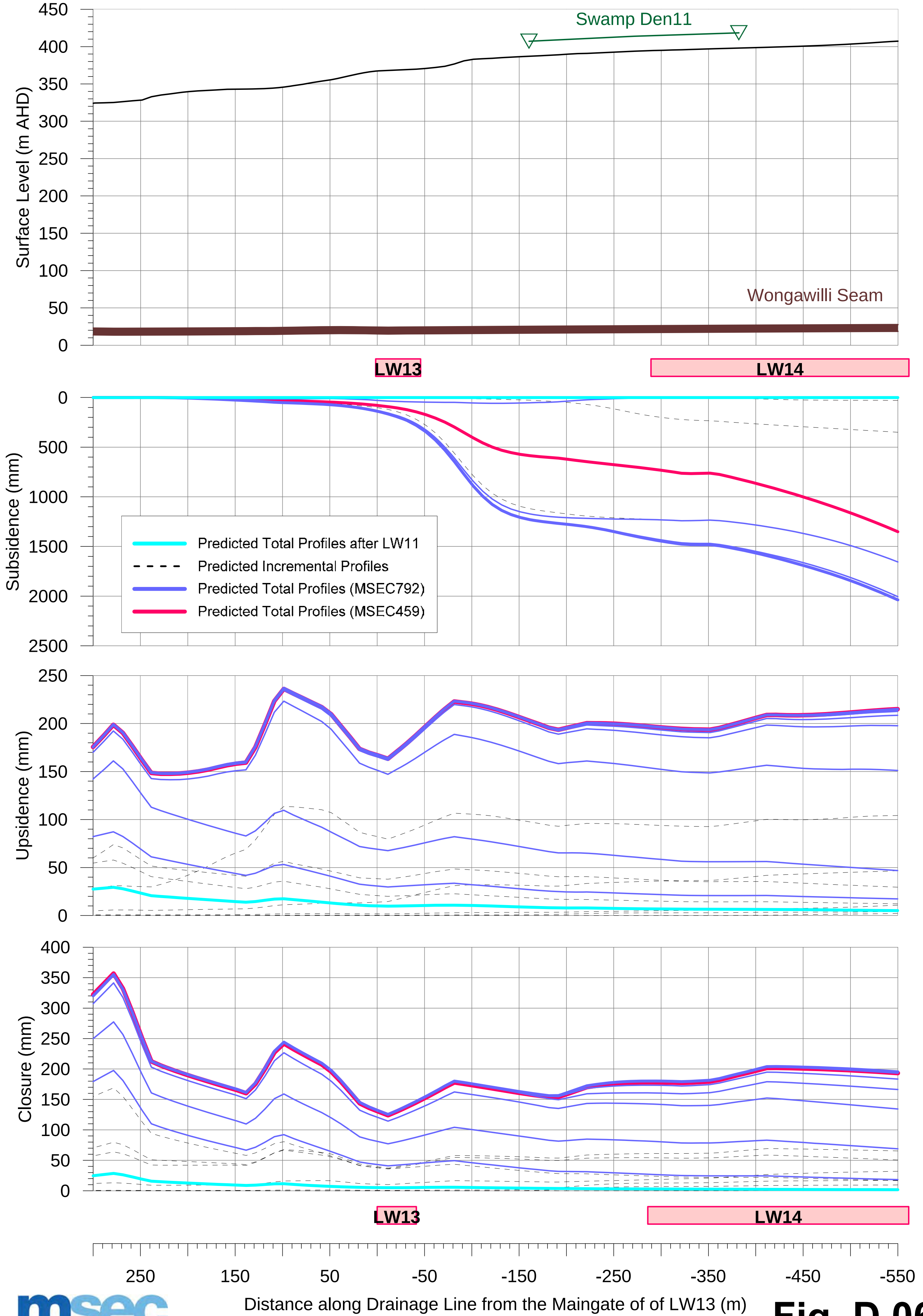

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Fig. D.06

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line LA4B Resulting from the Extraction of Longwalls 9 to 18

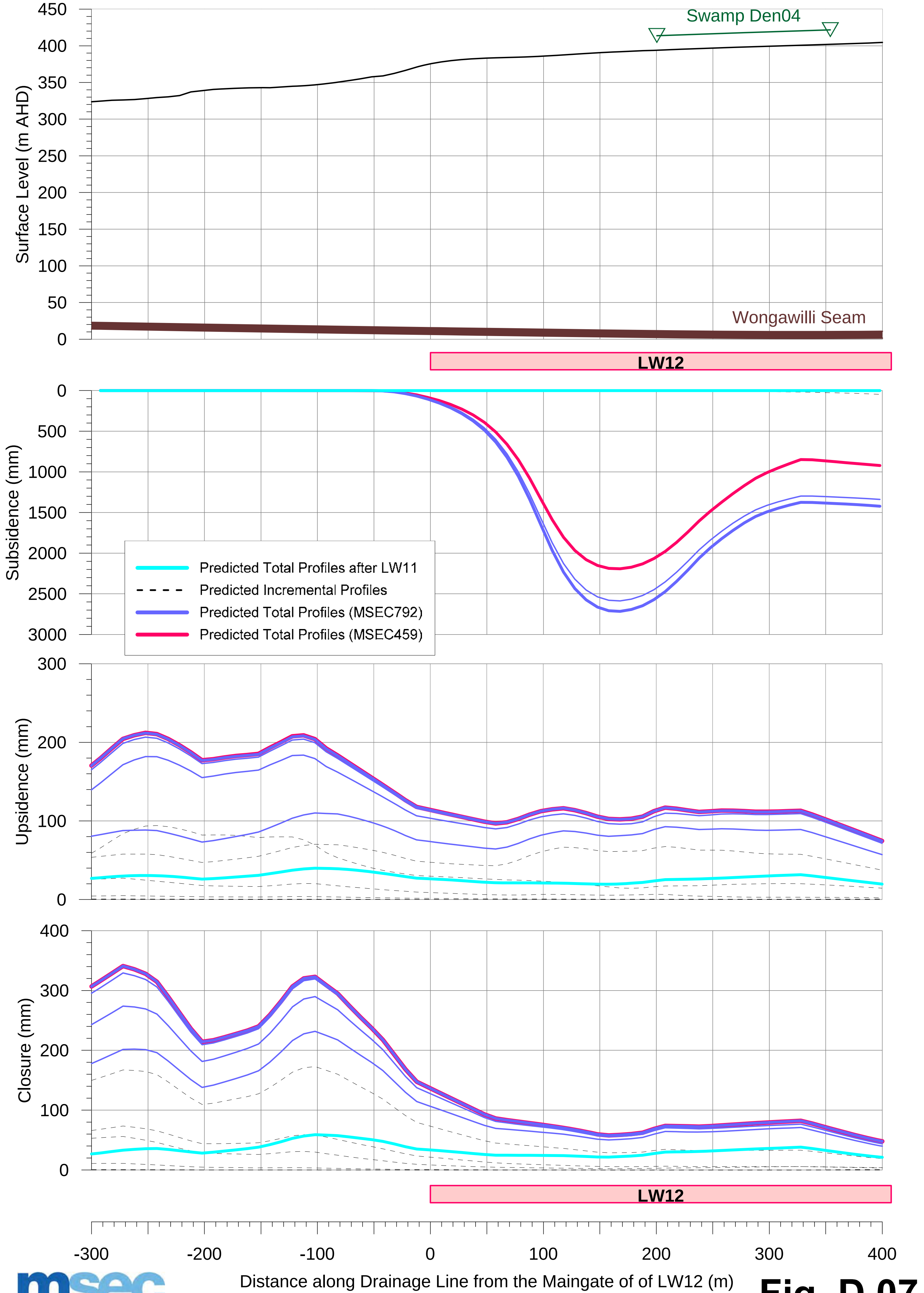

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Fig. D.07

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line LA5 Resulting from the Extraction of Longwalls 9 to 18

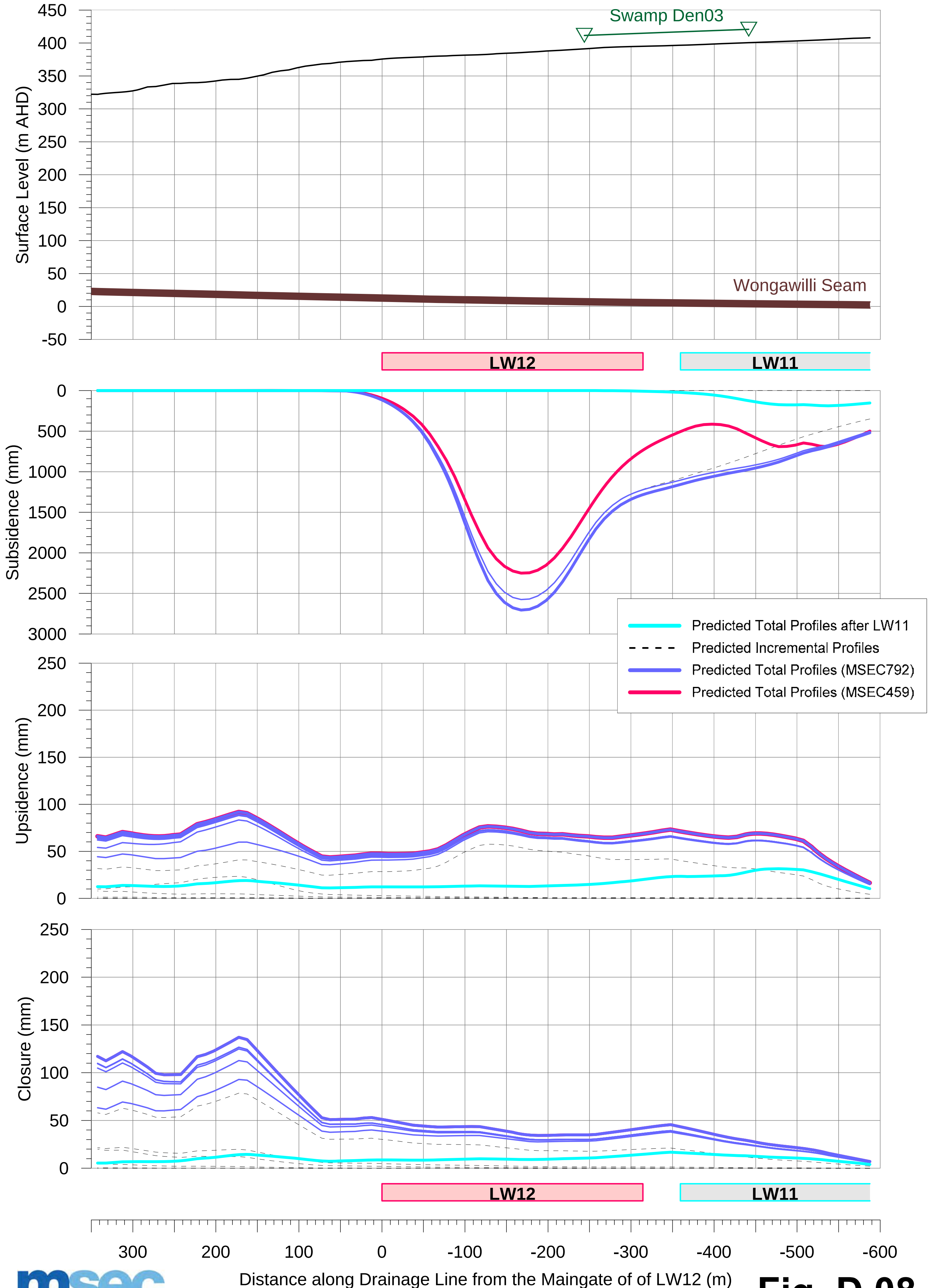

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Fig. D.08

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line ND1 Resulting from the Extraction of Longwalls 9 to 18

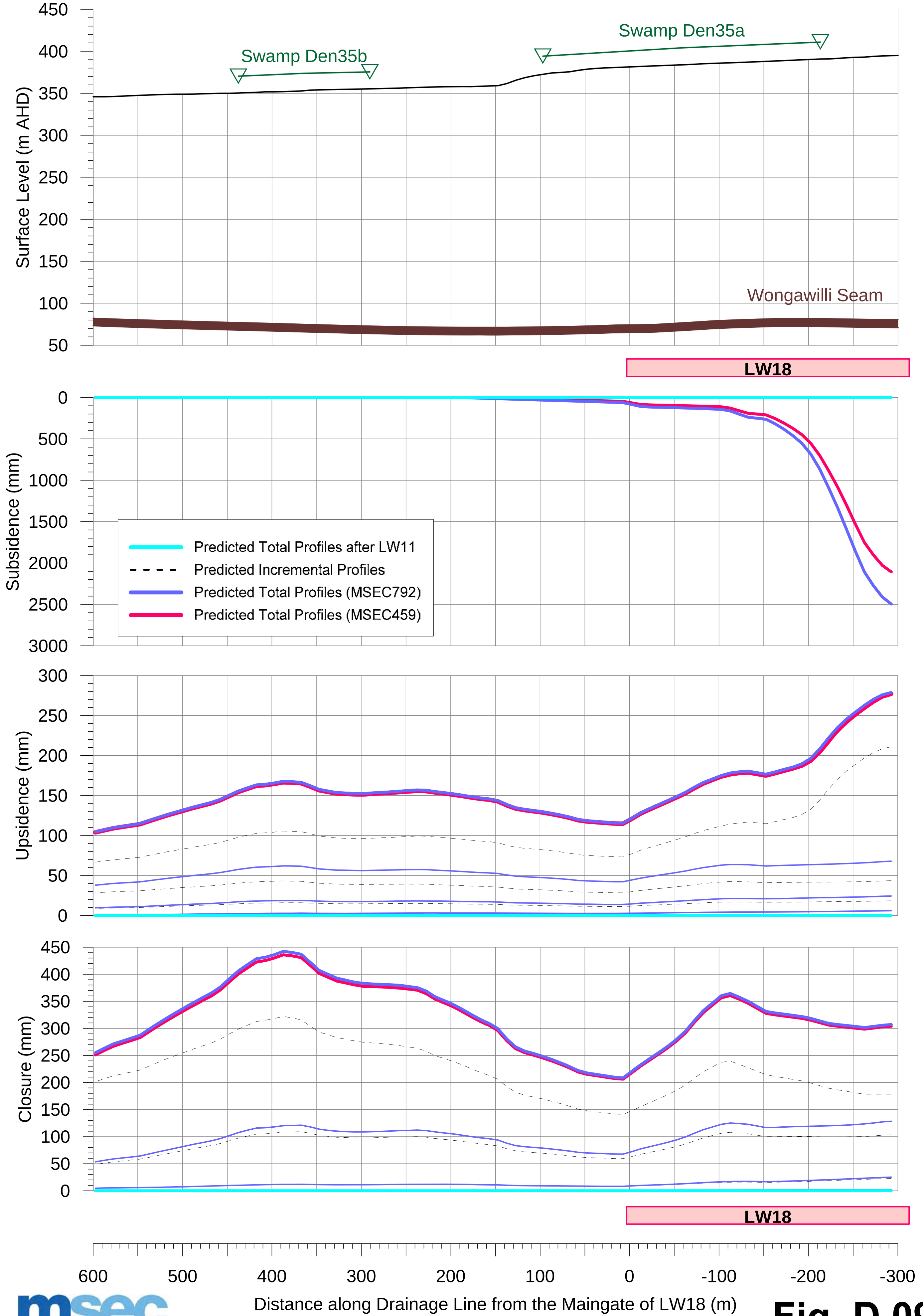

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Fig. D.09

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line WC15 Resulting from the Extraction of Longwalls 9 to 18

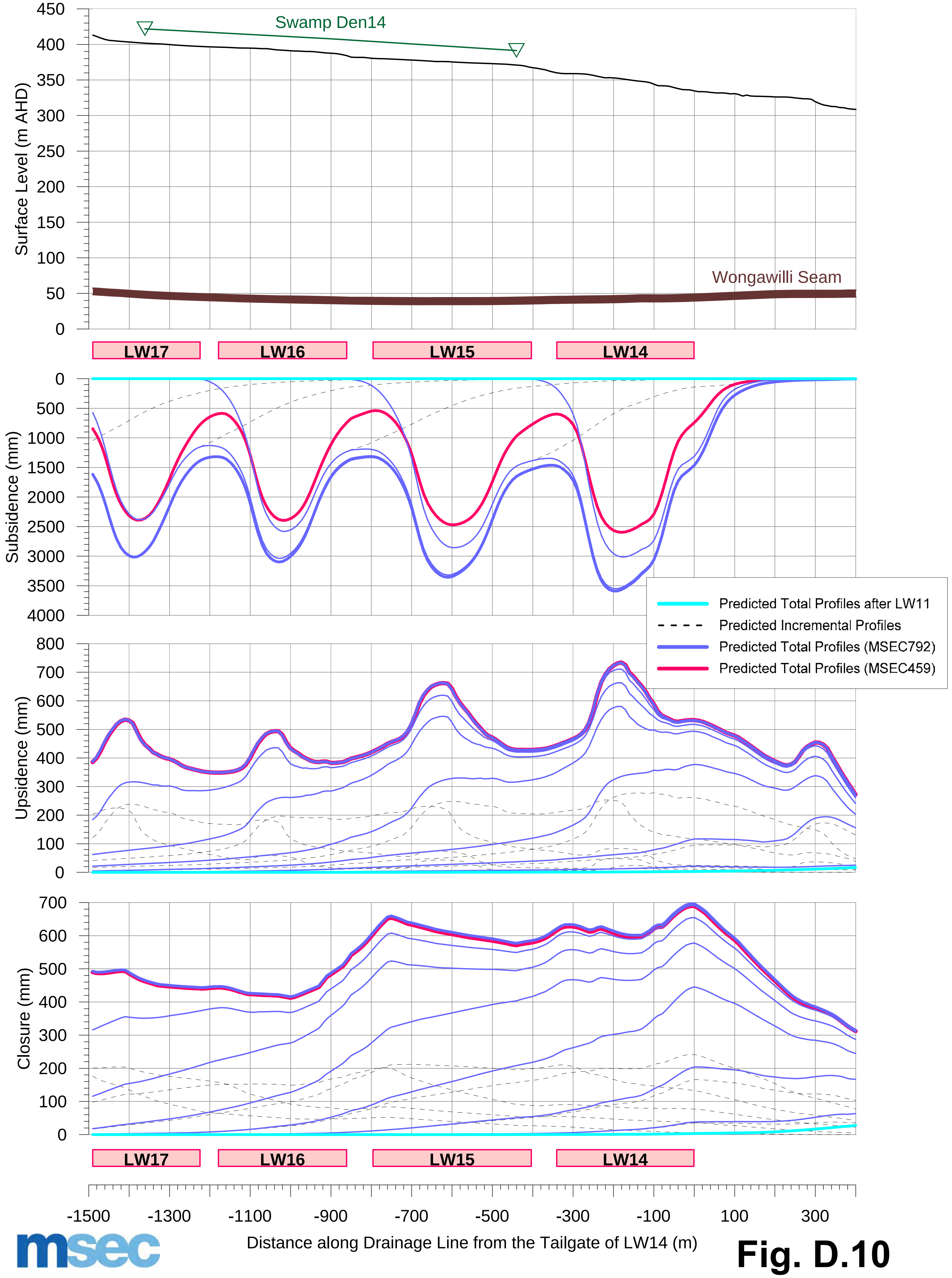

Fig. D.10

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line WC21 Resulting from the Extraction of Longwalls 9 to 18

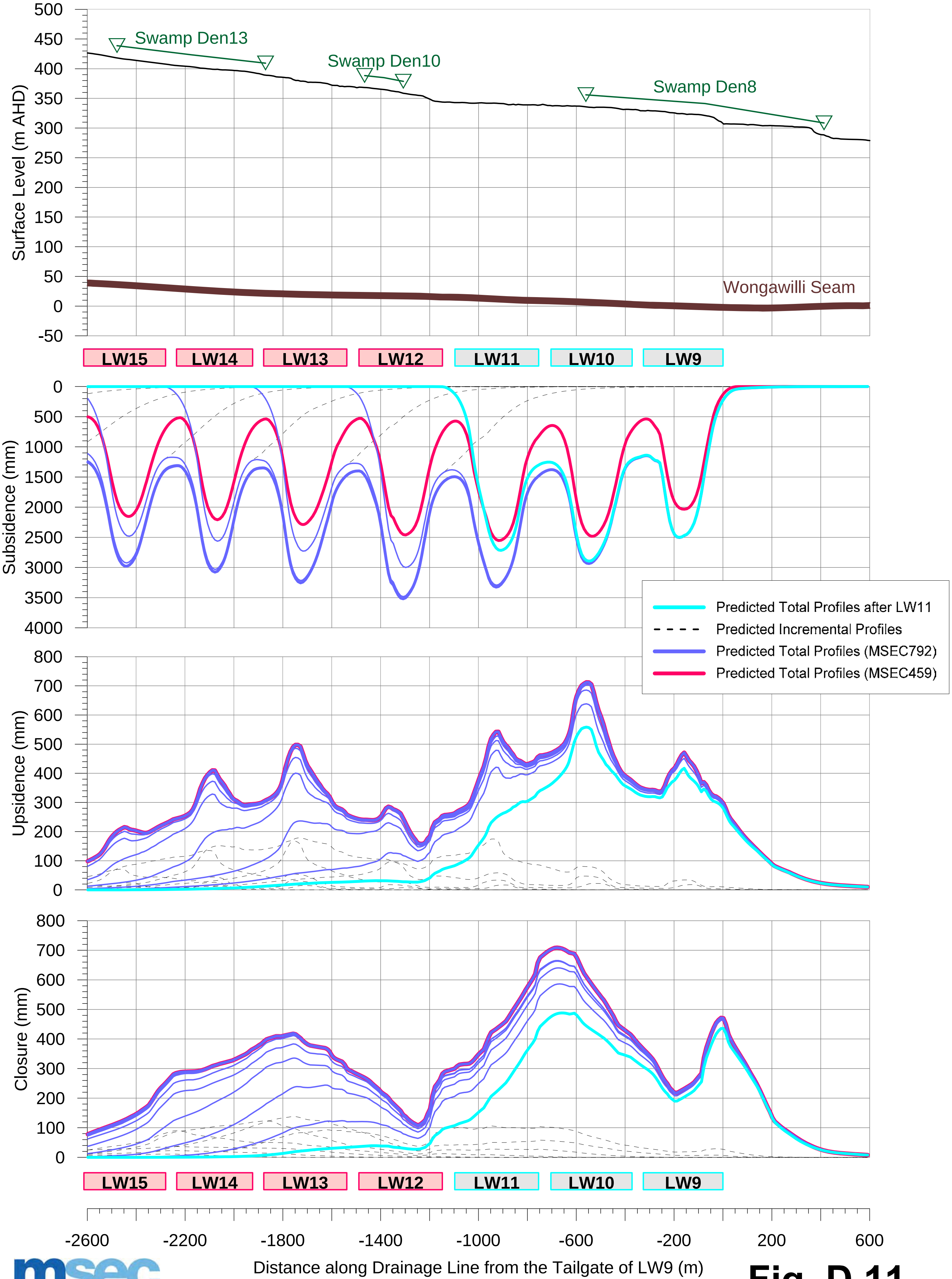

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Fig. D.11

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along the Abandoned Railway Corridor Resulting from the Extraction of Longwalls 9 to 18

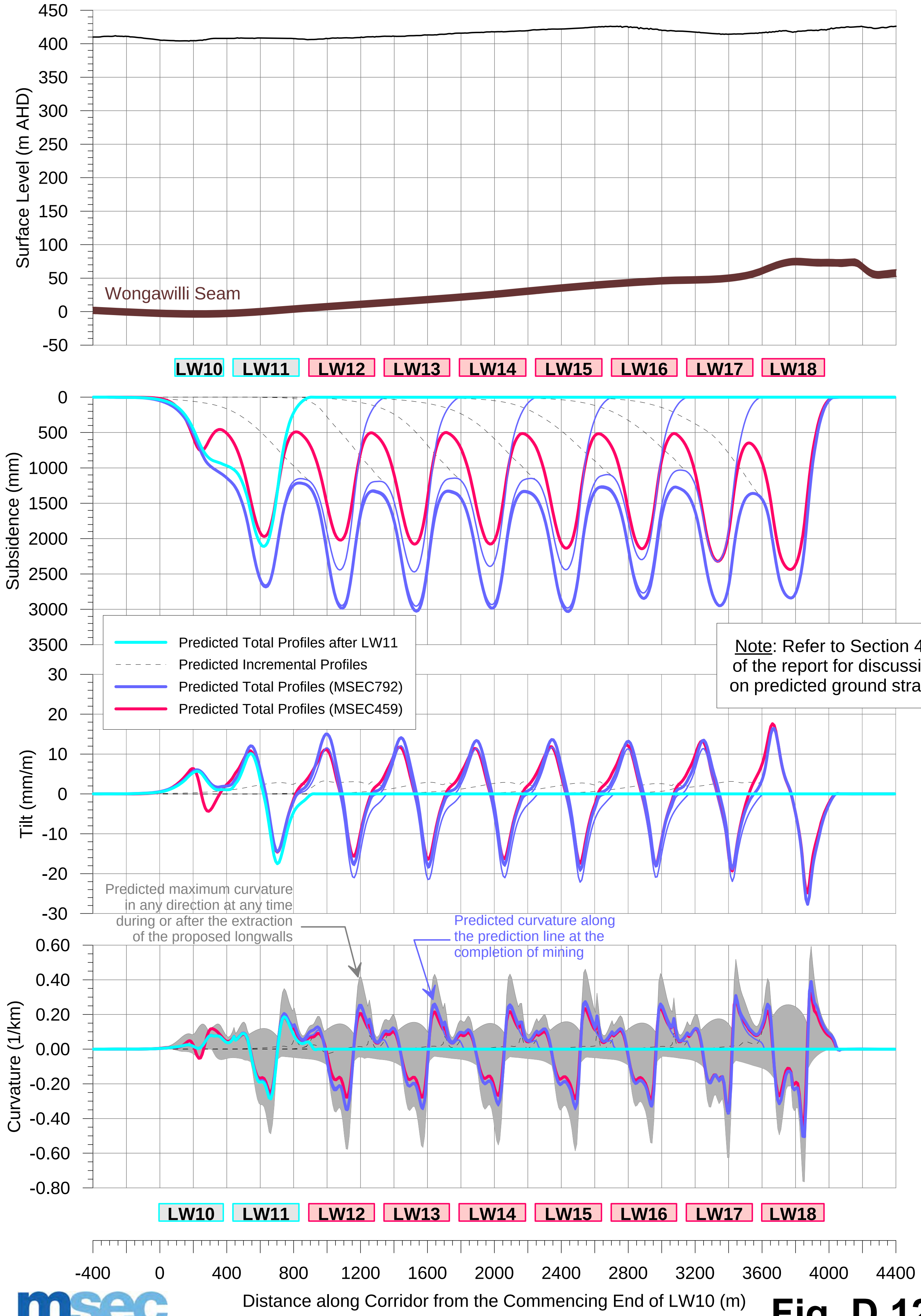

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Fig. D.12

APPENDIX E. DRAWINGS

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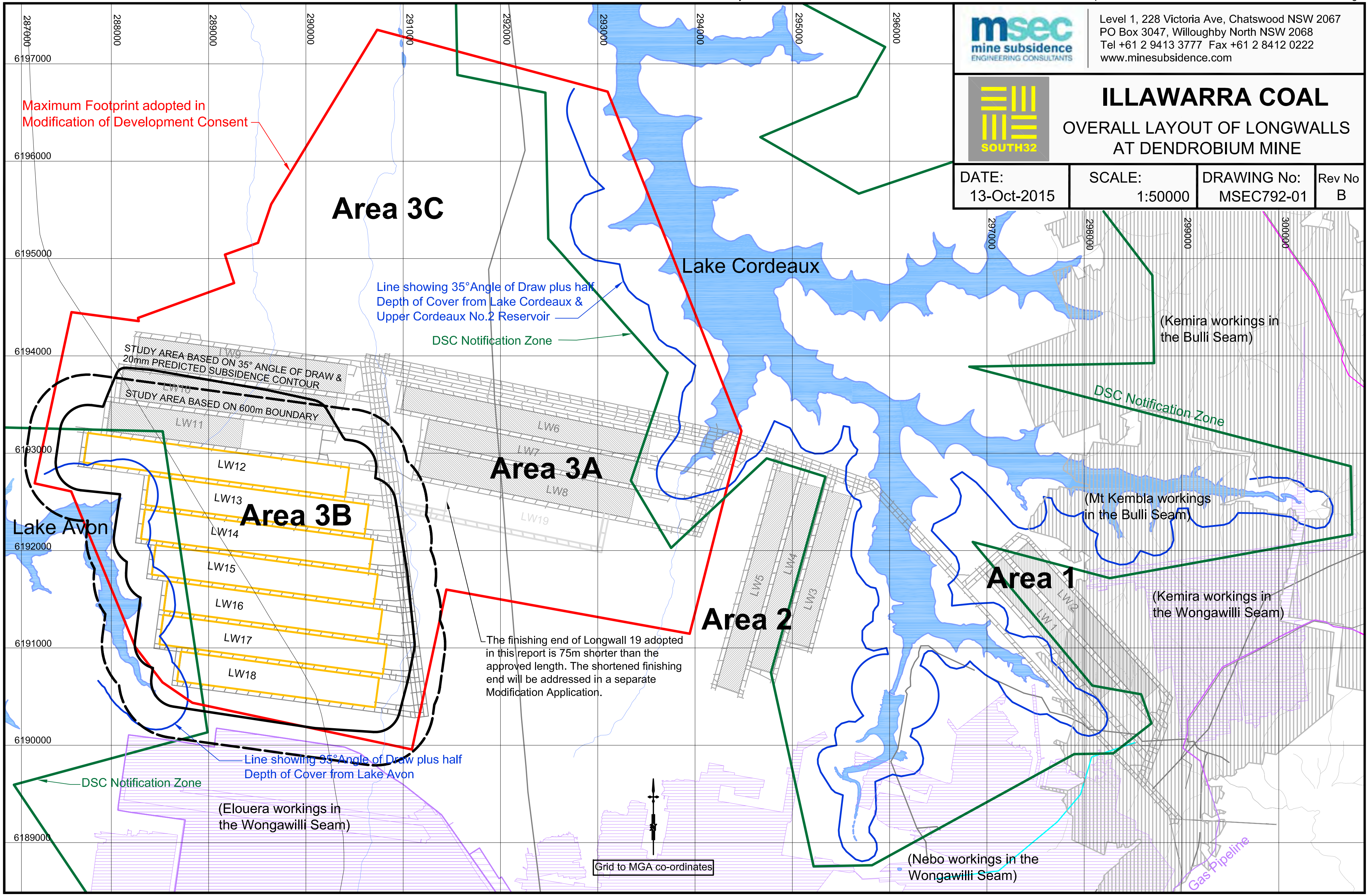

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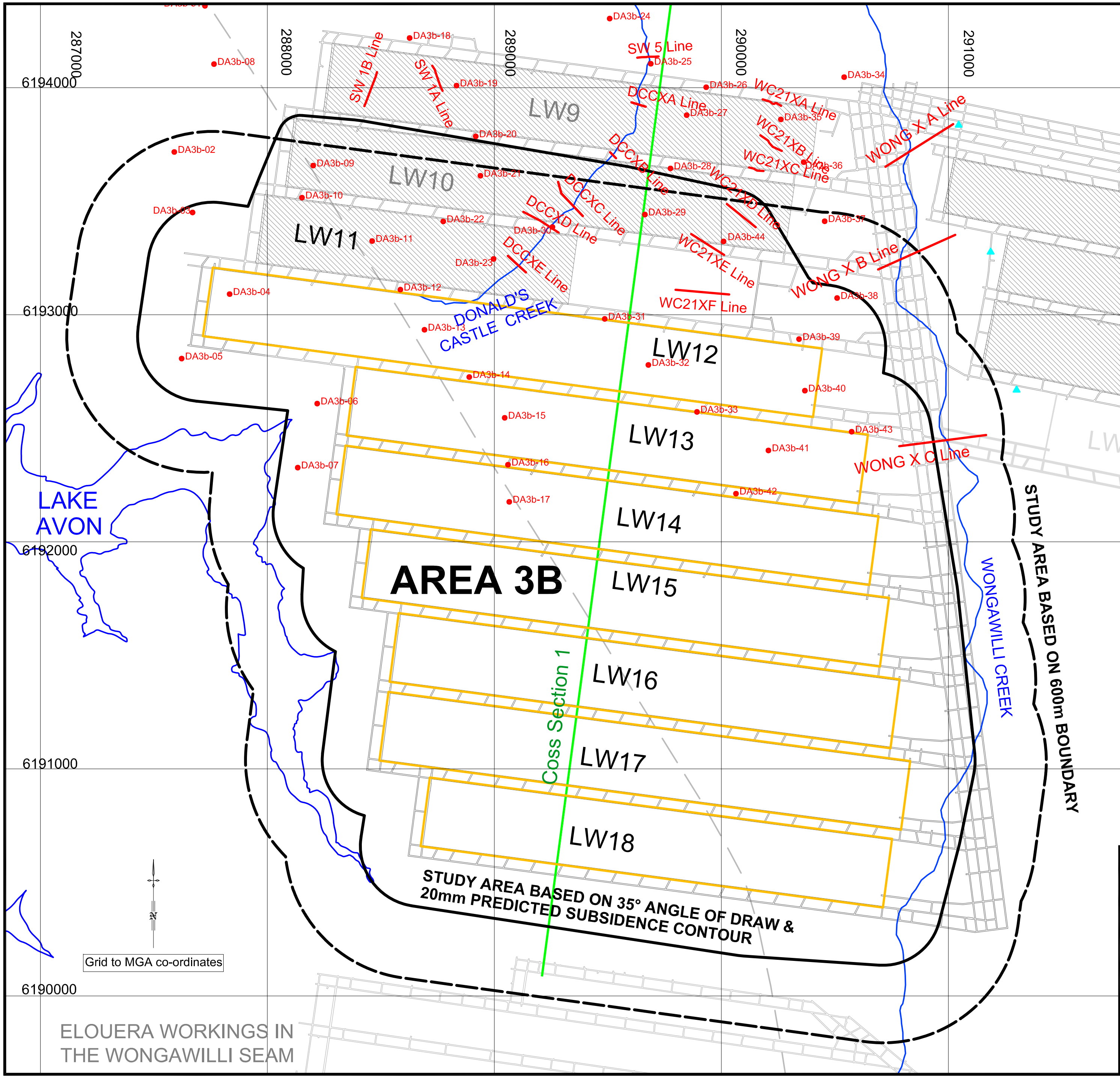

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ILLAWARRA COAL
DENDROBIUM COLLIERY
GENERAL LAYOUT OF
LONGWALLS 12 TO 18 IN AREA 3

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13-Oct-2015	1:25 000	MSEC792-02	B

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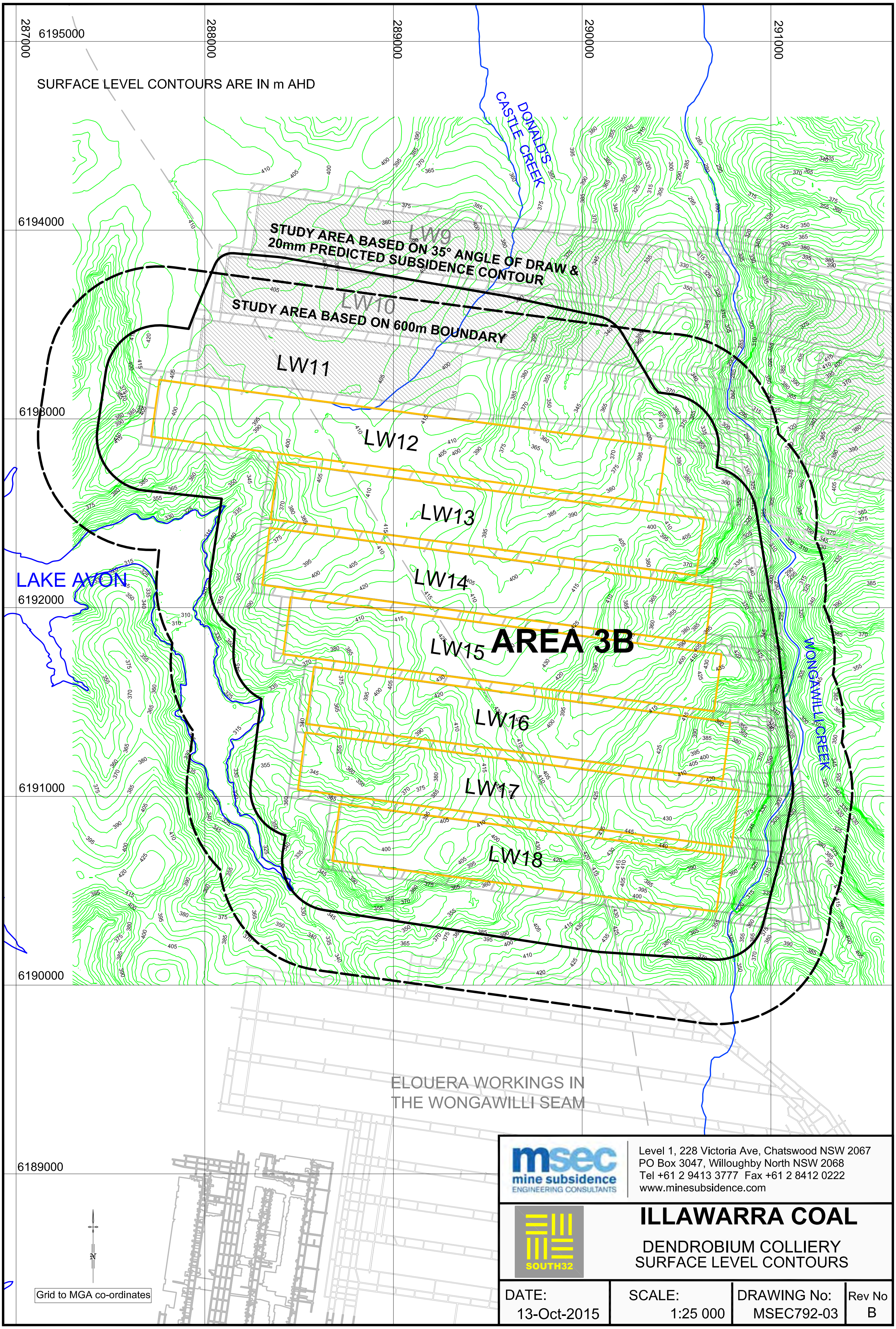

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DENDROBIUM COLLIERY
SURFACE LEVEL CONTOURS

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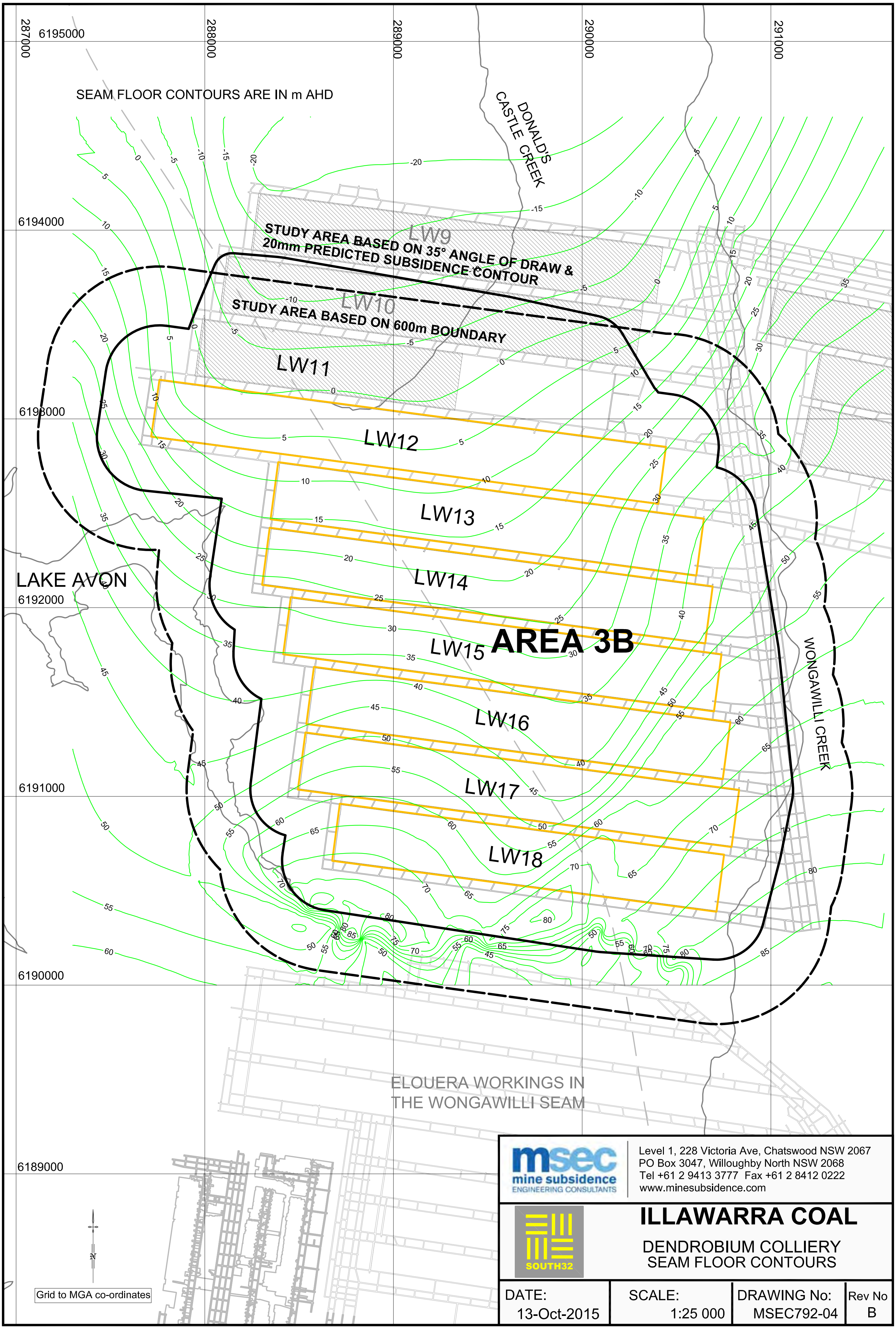

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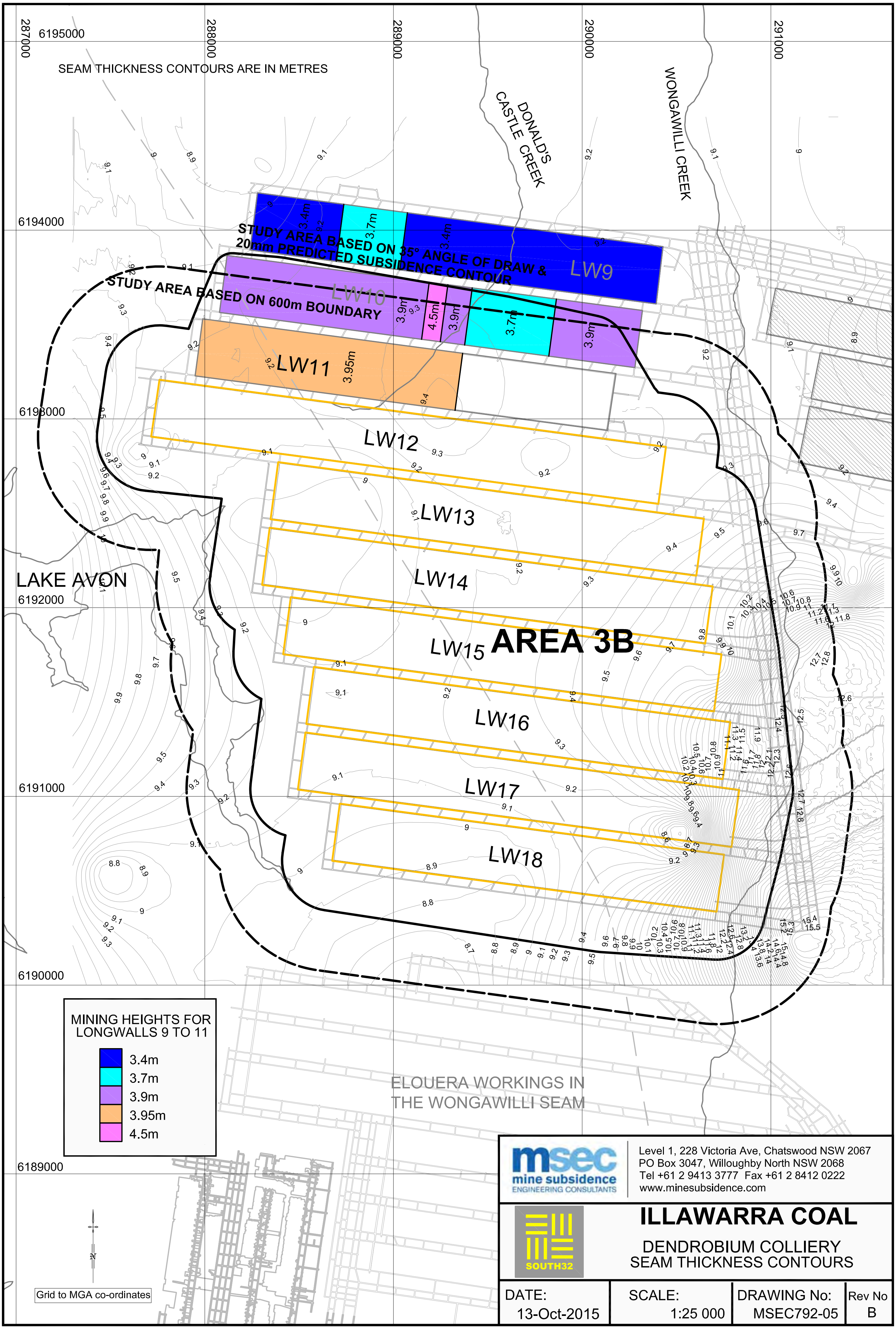

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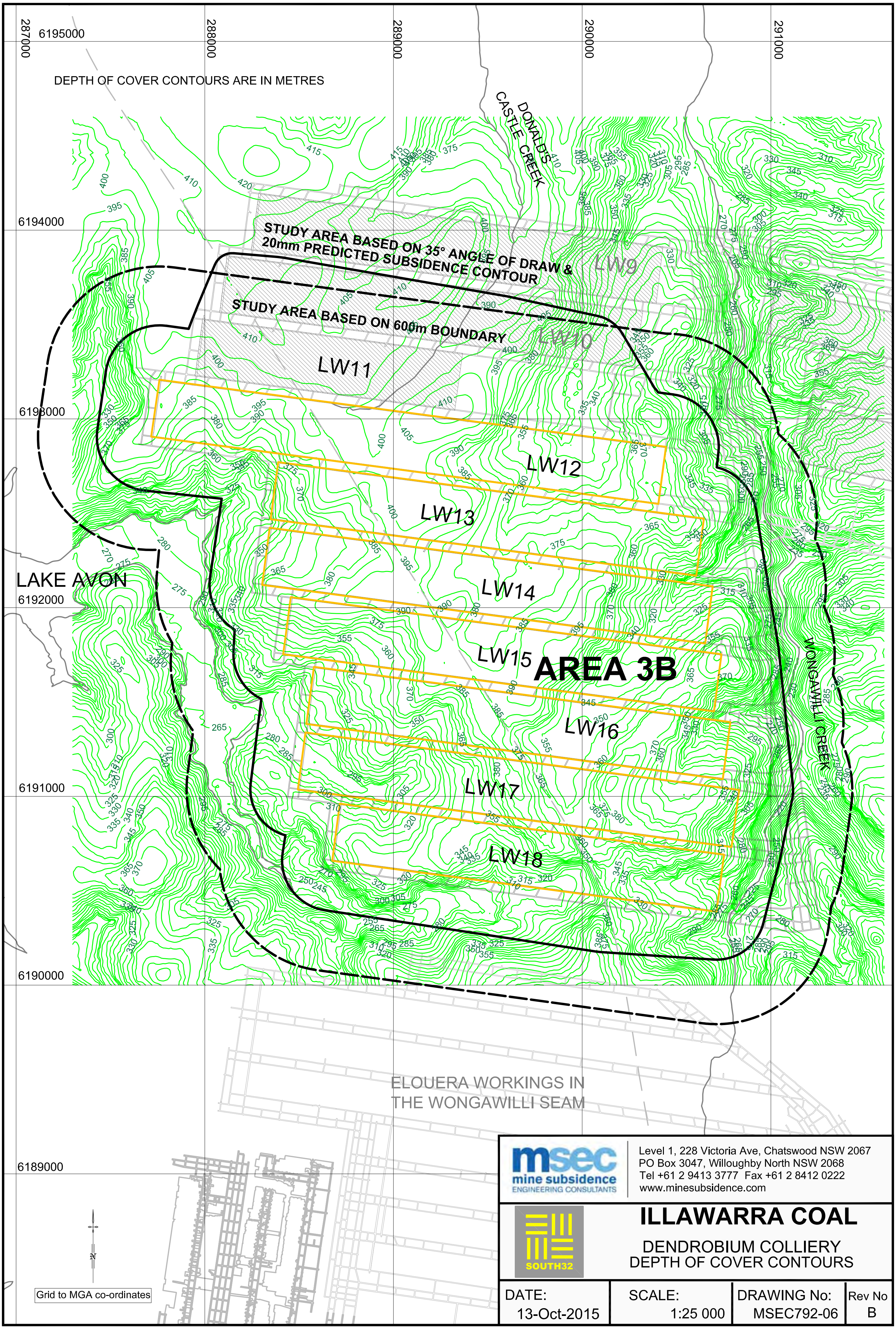

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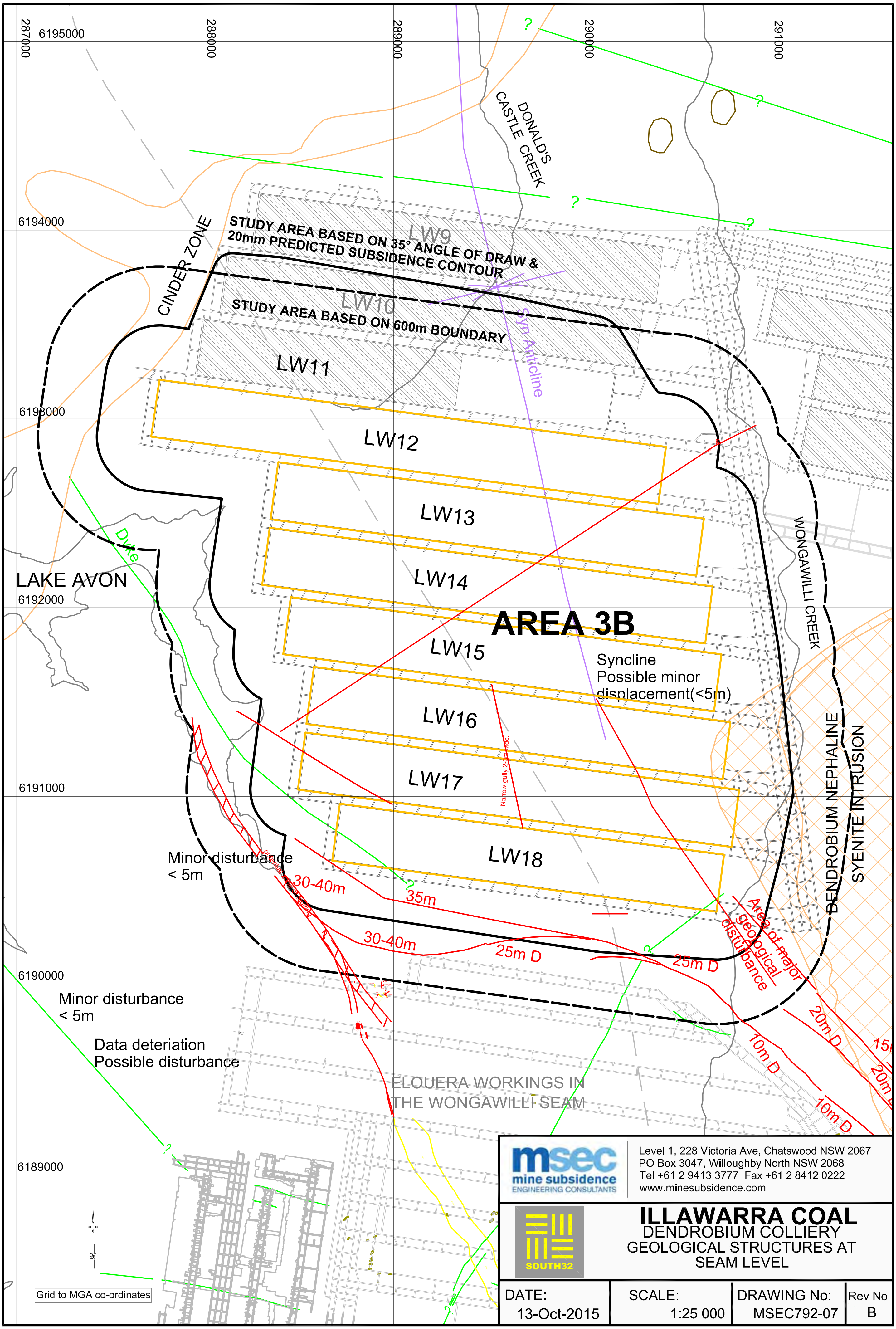

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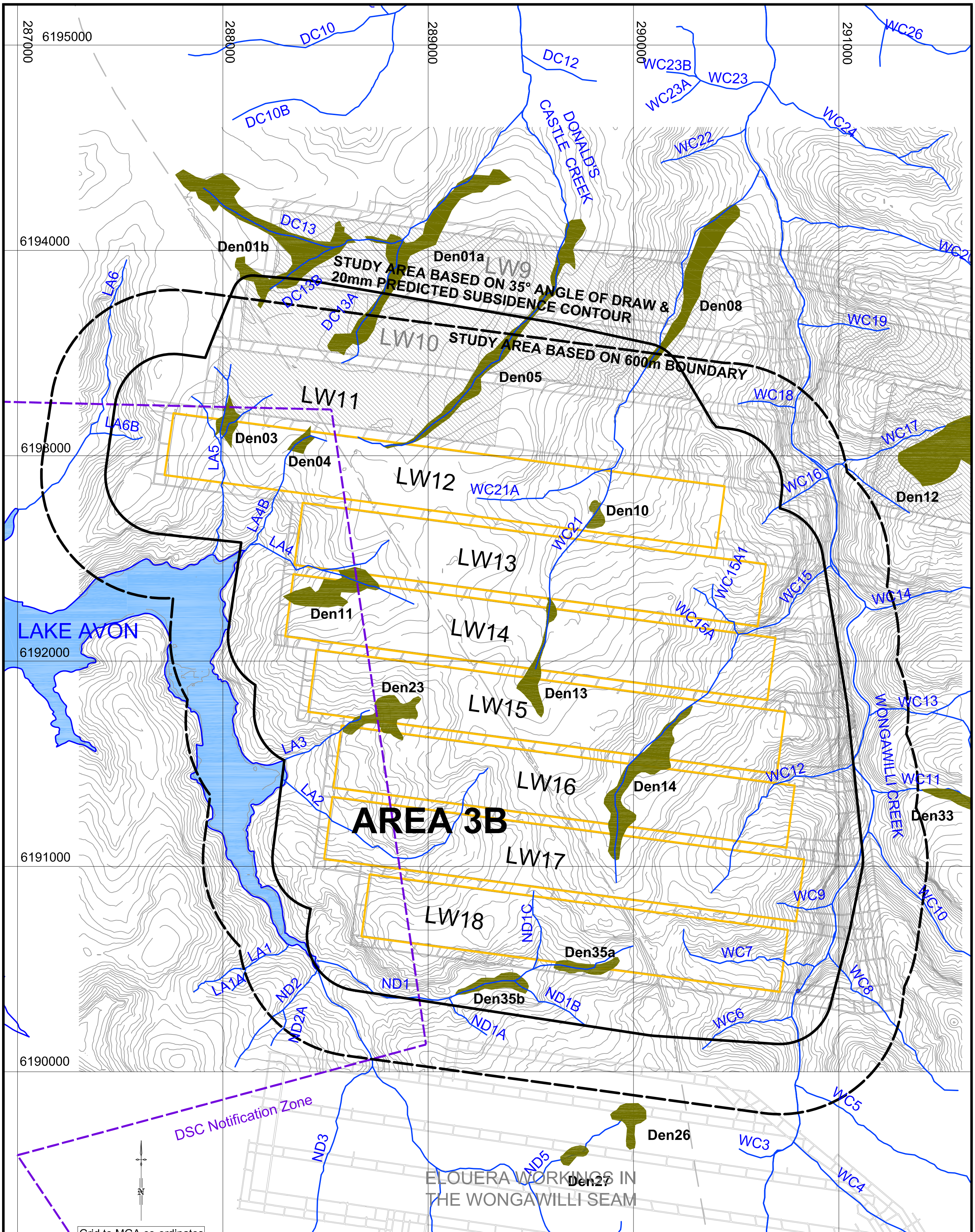

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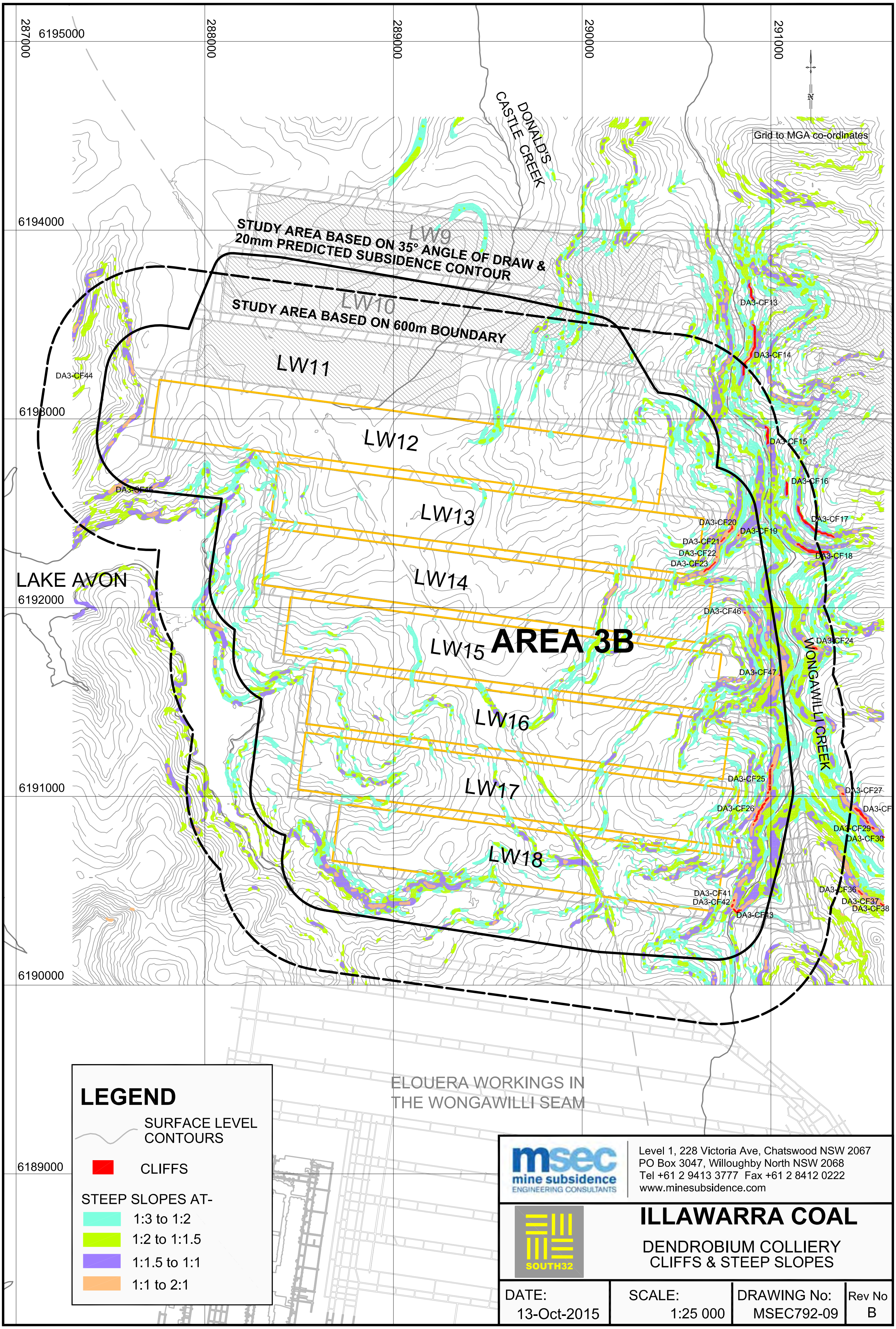

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STREAM FEATURES & CLIFF MAP (NORTH)

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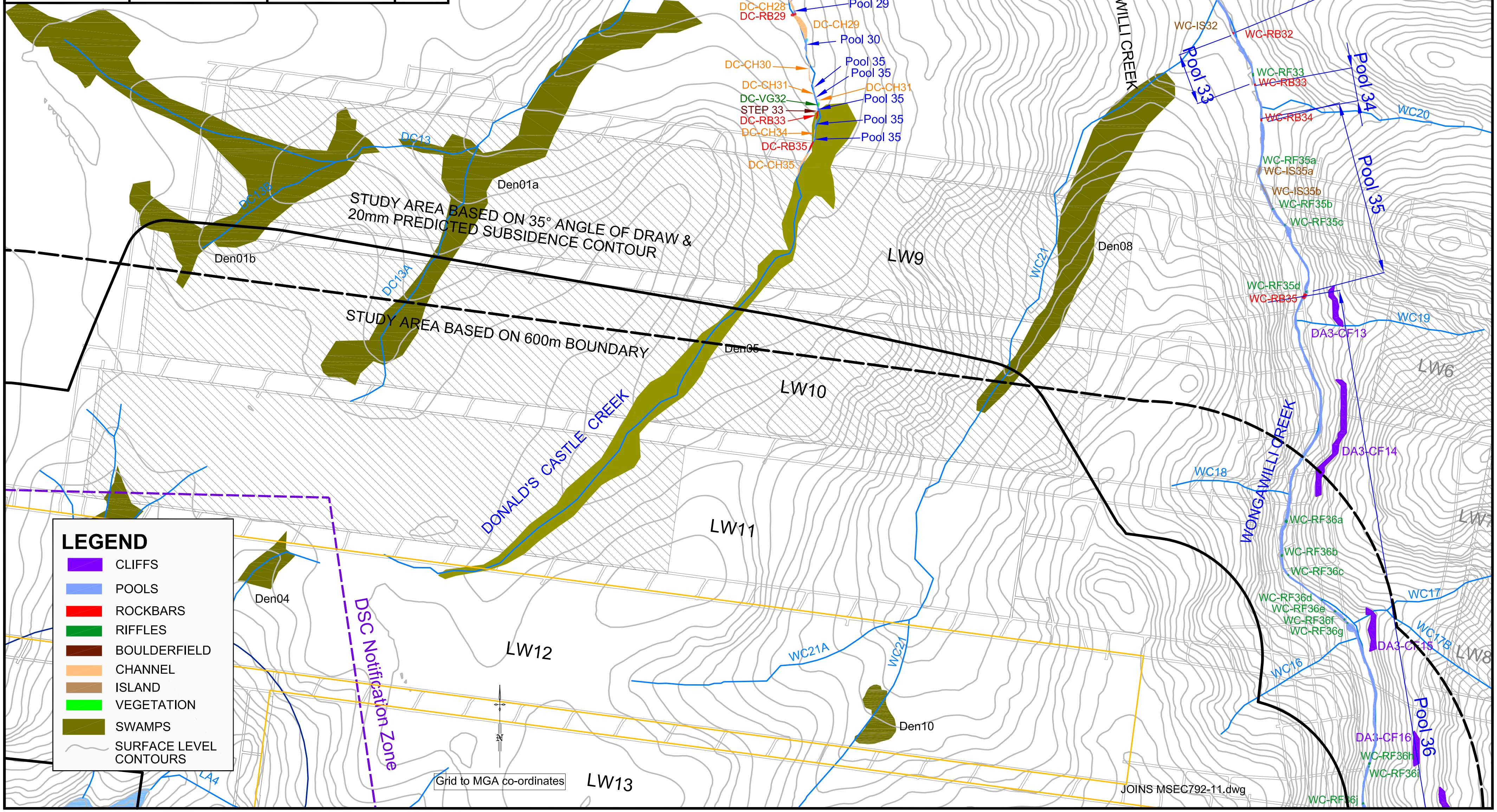

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STREAM FEATURES & CLIFF MAP (SOUTH)

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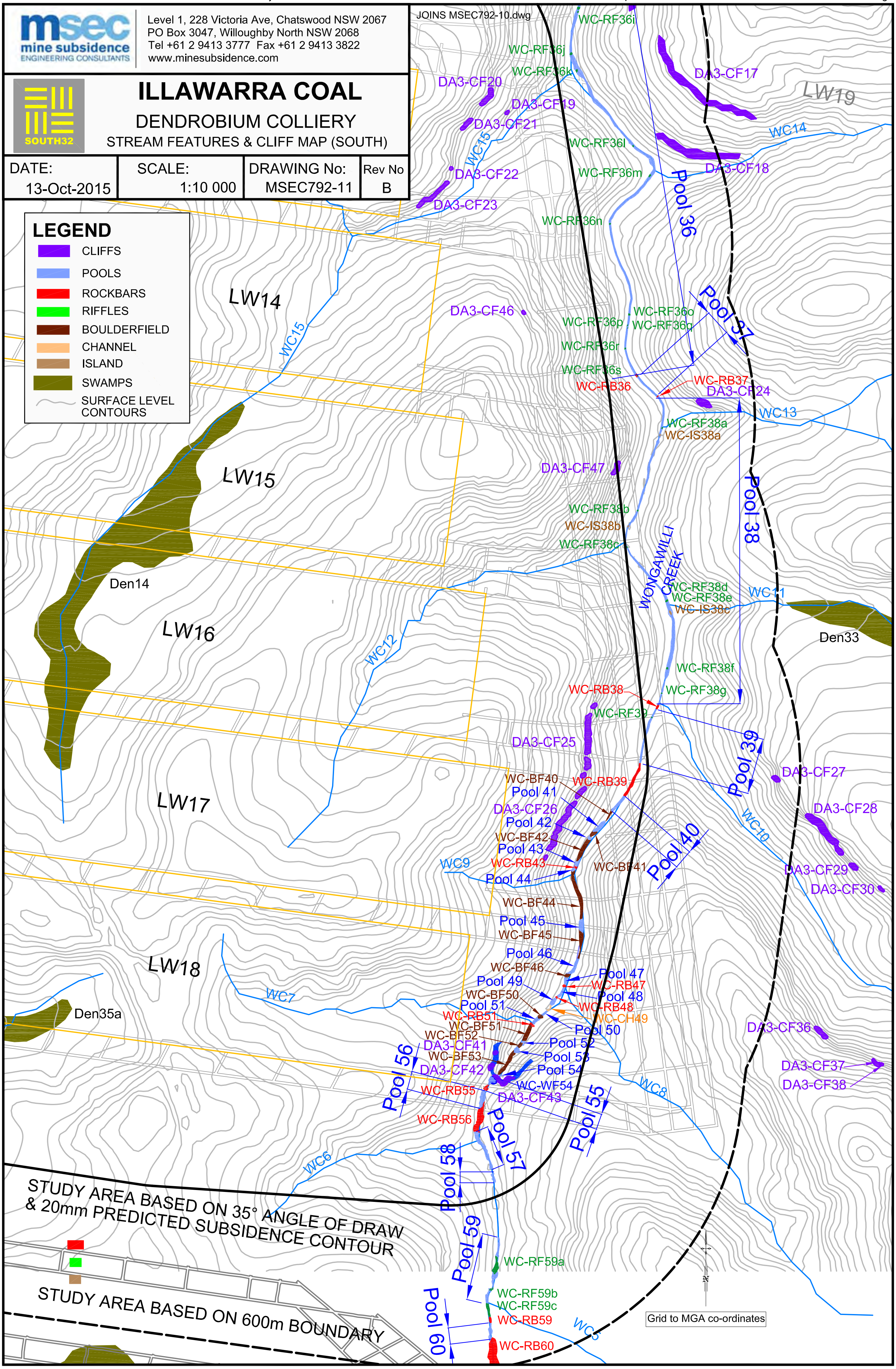

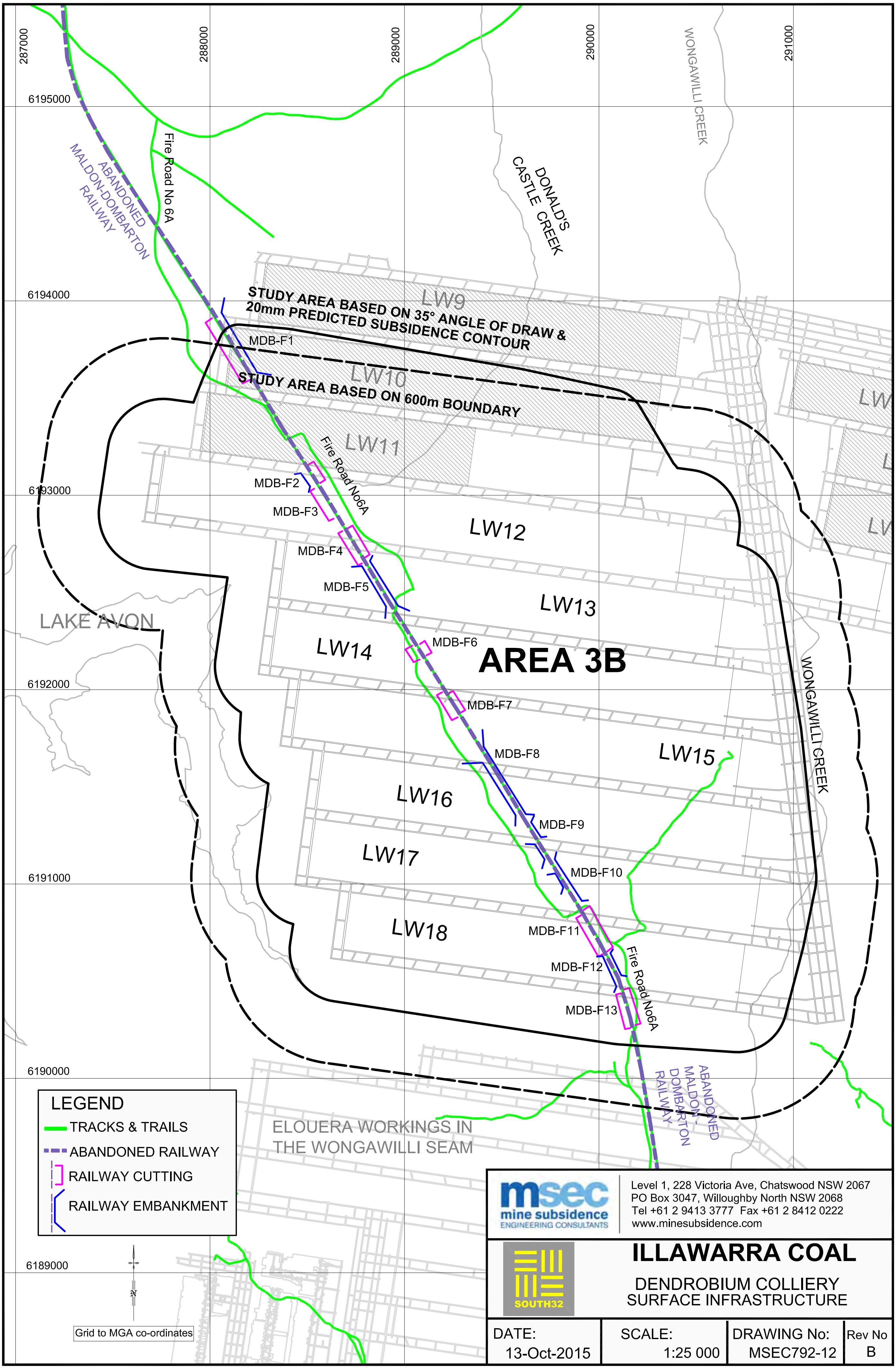
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288000
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6195000
6194000
6193000
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6190000
6189000
WONGAWILLI CREEK
DONALD'S CASTLE CREEK
Fire Road No 6A
ABANDONED MALDON-DOMBARTON RAILWAY
STUDY AREA BASED ON 35° ANGLE OF DRAW & 20mm PREDICTED SUBSIDENCE CONTOUR
STUDY AREA BASED ON 600m BOUNDARY
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
AREA 3B
LAKE AVON
Fire Road No6A
MDB-F1
MDB-F2
MDB-F3
MDB-F4
MDB-F5
MDB-F6
MDB-F7
MDB-F8
MDB-F9
MDB-F10
MDB-F11
MDB-F12
MDB-F13
ELOUERA WORKINGS IN THE WONGAWILLI SEAM
ABANDONED MALDON - DOMBARTON RAILWAY
LEGEND
TRACKS & TRAILS
ABANDONED RAILWAY
RAILWAY CUTTING
RAILWAY EMBANKMENT
Grid to MGA co-ordinates
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SURFACE INFRASTRUCTURE
DATE:
13-Oct-2015
SCALE:
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DRAWING No:
MSEC792-12
Rev No
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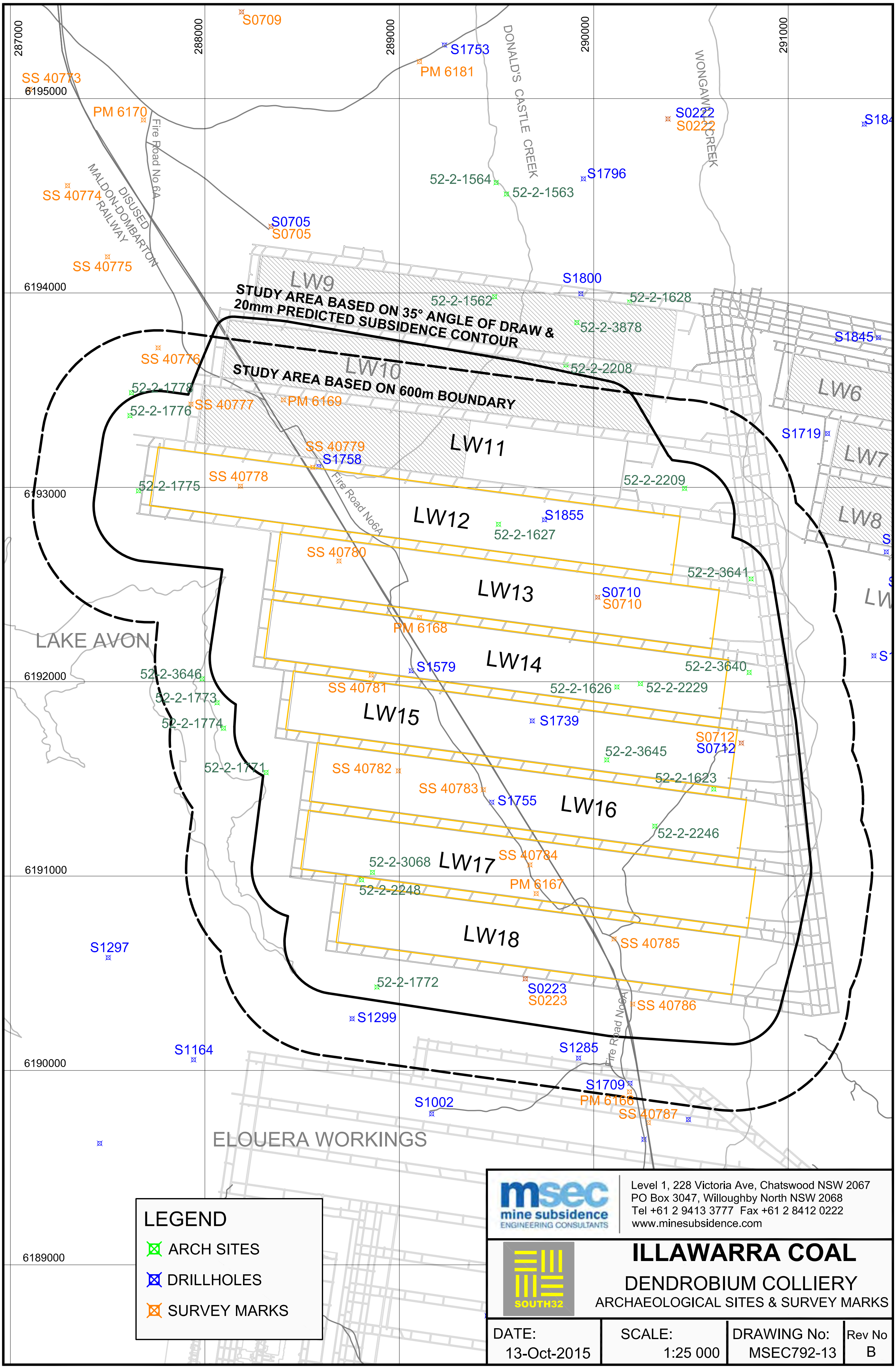

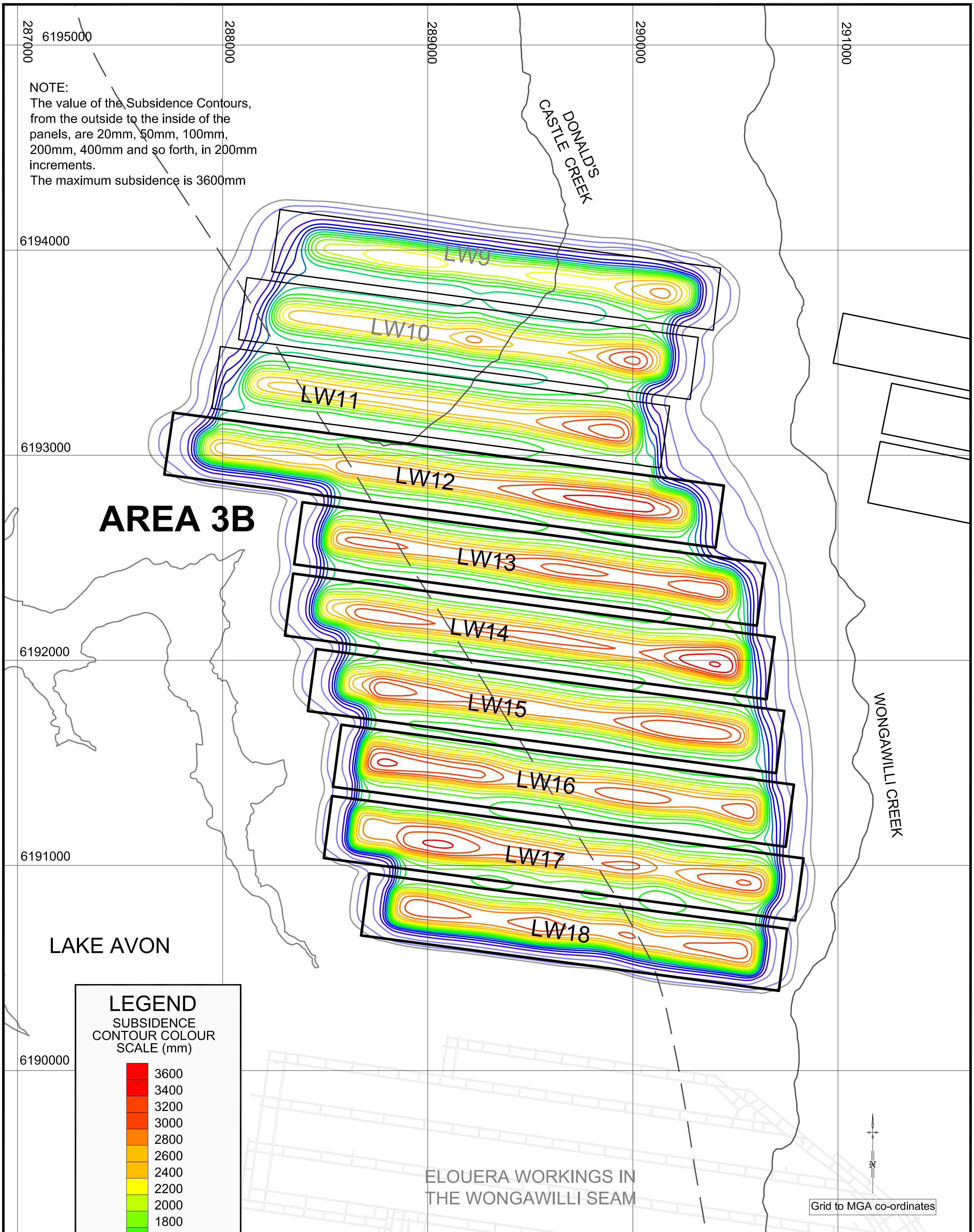

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PREDICTED TOTAL SUBSIDENCE CONTOURS DUE TO LONGWALLS 9 TO 19

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