Berten Pty Ltd

Proposed Rezoning of Land at Abbotsford Road, Picton NSW

Potential Impacts of Mine Subsidence due to the Future Extraction of Coal Resources

msec
mine subsidence
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EXECUTIVE SUMMARY

The Abbotsford Road Development, proposed by Berten Pty Limited (Berten), is a major residential development project located south of the Sydney Metropolitan Area, just north-west of the existing Township of Picton.

The site lies just to the north of the existing Tahmoor North Coal Mining Lease boundary, and west of the Wilton Mine Subsidence District. The eastern portion of the site is underlain by significant geological fault structures. Although significant coal resources do exist beneath the site within the Bulli Seam, these boundary conditions and geological conditions will limit the extent to which longwall mining may occur beneath the Abbotsford Road site in the future. However, regardless of this, and in the absence of a mine plan, this mine subsidence study is required given that some mining may happen in the Bulli Seam in the future.

Berten is preparing a rezoning application to rezone the site (part Lot DP 1086066) from RU2 Rural Landscape to Part R5 Large Lot Residential, Part E3 Environmental Management and Part RE1 Public Recreation. Wollondilly Shire Council has resolved to investigate potential for rezoning of the project site. The project site is shown on drawing MSEC608-101 in Appendix E of this report. The rezoning assessment is proposed to be determined through a Gateway Determination Process by the Department of Planning and Infrastructure (DP & I)

Berten Pty Limited has commissioned Mine Subsidence Engineering Consultants Pty Limited (MSEC) to study the development proposals and to advise upon the subsidence impacts that are likely to occur due to future coal mining beneath the development site.

This specialist mine subsidence impact assessment report has been prepared at the completion of a mine subsidence impact assessment study. This report has been prepared for inclusion with the specialist studies that are required as part of the Gateway process.

Chapter 1 of the report outlines the background to the study and provides a description of the land and the geology of the area.

Chapter 2 identifies the coal resources beneath the Abbotsford Road site in the Bulli Seam and discusses the known and potential future mining plans that might affect the Abbotsford Road site. It also addresses any constraints that might be imposed by the Mine Subsidence Board (MSB).

Chapter 3 provides predicted subsidence parameters for the Abbotsford Road site, based upon the variations in the seam thickness and depth of cover of the Bulli Seam beneath the site, and recommends design parameters for the future development of the site.

It is noted that conventional residential building structures, designed and constructed in accordance with Australian Standards and good building practice, are capable of accommodating the predicted subsidence, tilts, strains and curvatures with minimal impacts. Such impacts would generally be of a cosmetic nature and would be easily repaired by the Mine Subsidence Board when subsidence occurs.

Chapter 4 addresses the existing surface features, and the impact of subsidence on these items. This chapter also provides brief discussion about the potential for flooding and surface ponding. It also addresses the potential impacts of subsidence on future development of the site.

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CHAPTER 1 BACKGROUND AND GEOLOGICAL SETTING

1.1 Introduction

The Abbotsford Road Development site, proposed by Berten Pty Limited (Berten) and adjoining landowners, is a major residential and public recreation development project located south of the Sydney Metropolitan Area, just north-west of Picton. The proposed development site is bisected by Abbotsford Road, and is shown in the aerial photograph provided in Figure 1.1, as well as each of the drawings in Appendix E. The land in question is part Lot DP1086066, at the intersection of Fairleys and Abbotsford Roads. The proposal is to rezone the land from RU2 Rural Landscape to part R5 Large Lot Residential, part E3 Environmental Management and part RE1 Public Recreation. The RE1 Public Recreation is for Area 4.

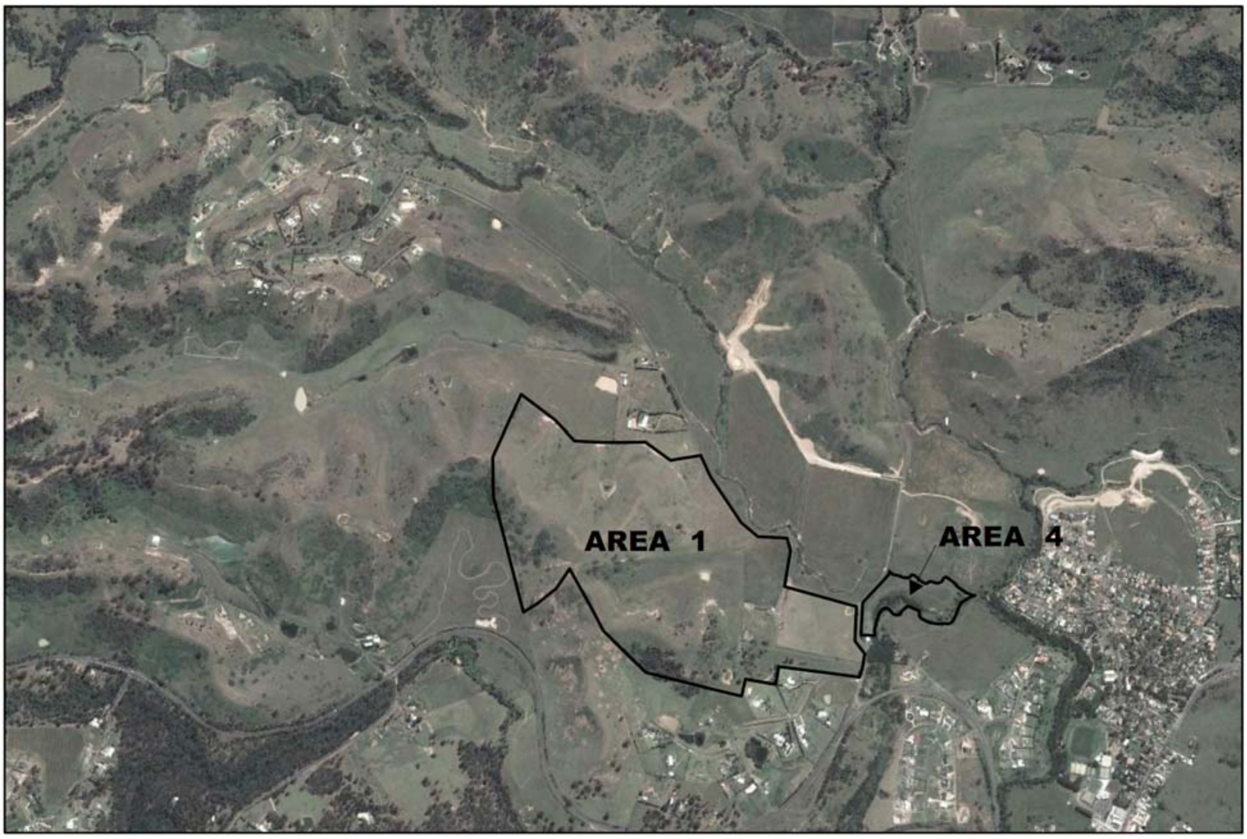

Figure 1.1 Aerial photograph showing the location of the Abbotsford Road Site

The subject land lies outside the Bargo and Picton Mine Subsidence Districts, as illustrated in Drawing No. MSEC629-100, however, slightly within the Wilton Mine Subsidence District on the eastern side of the site. The site also lies partly within the area covered by the Tahmoor North Coal Mining Lease held by Xstrata Coal, Tahmoor Colliery. Mining at Tahmoor Colliery is currently being carried out to the south of the subject land, in the Bulli Seam, using longwall mining techniques. The published mining plans of Tahmoor Colliery do not indicate any intention to mine beneath the site.

Figure 1.1 has divided the Abbotsford Road site up into two areas, these being Areas 1 and 4. Residential development is planned for Area 1, while Area 4 is proposed to be used for environmental management and public recreation.

A letter received from Mr Kevin Ruming at the Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS) advises, "*I have reviewed the geology in the area of the proposed Abbotsford Rd area, north of Picton.*

The Wongawilli and Balgownie seams are not considered viable for future underground mining due to the thickness and quality of the seams. The Bulli seam however is 1.8 - 2.1 metres thick, low ash prime hard coking coal in this area.

The Nepean Fault zone is a major regional structure that creates a natural mining barrier to the east of the Abbotsford Rd area. However, this area overlies the south / south western part of a potentially large unmined resource block in the Bulli seam to the west of the Nepean Fault zone. The high value of this coal and its use in steel making, both domestically and overseas, makes this a valuable asset for the State. To ensure that recovery of this resource in the Bulli seam is maximised, if future underground mining were to occur, the study into the impacts of mine subsidence requested by Council will need to be completed and the other conditions adhered to."

This report has been prepared acknowledging and in response to the advice from the Department. This mine subsidence assessment report examines the impacts of longwall mining on the future development and determines if the current design criteria used by the Mine Subsidence Board are satisfactory for the future development of the study area for rural / residential development.

The objectives of this report are outlined in the Specialist Study Requirements of Wollondilly Shire Council, and are:

- To examine the effects of current and future subsurface longwall mining on the proposed development,
- To evaluate planning provisions that restrict the subdivision of the subject land or erection of a residential building until Longwall mining in the Bulli Seam and the effects of subsidence are complete,
- To comment on the advice that the Balgownie and Wongawilli Seams beneath the proposed development are unlikely to be mined, and
- To recommend surface development guidelines to mitigate the impact of mine subsidence associated with Longwall mining beneath the subject area.

This report has been prepared on completion of the mine subsidence study.

1.2 Description of the Site and Existing Features and Infrastructure

The site generally consists of gently undulating sloping land, with a high point of approximately 240 metres AHD, and a low point of approximately 160 metres AHD.

Existing built features on the surface are limited, given the existing rural use of the land. The main features include:

- Abbotsford Road
- 66kV transmission line
- Rural houses and sheds
- Minor farm dams

1.3 Geological Details of the Area

The site lies in the southern part of the Permo-Triassic Sydney Basin, within which the main coal bearing sequence is the Illawarra Coal Measures, of Late Permian age. The Illawarra Coal Measures contain four workable seams, the uppermost of which is the Bulli Seam.

All of the sediments that form the overburden to the Bulli Seam belong to the Hawkesbury Tectonic Stage, which comprises three stratigraphic divisions. The lowest division is the Narrabeen Group, which ranges in age from Lower to Middle Triassic and varies in thickness up to 310 metres. Overlying the Narrabeen Group is the Hawkesbury Sandstone which dates from the Middle Triassic and has a thickness of up to 185 metres.

Above the Hawkesbury is the Wianamatta Group, which is poorly represented in this region, having a thickness of only a few metres. A typical stratigraphic section for the Southern Coalfield is shown in Figure 1.2.

The major sandstone units are interbedded with other rocks and, whilst shales and claystones are quite extensive in places, the sandstone predominates.

The major sandstone units are the Scarborough, the Bulgo and the Hawkesbury Sandstones and these units vary in thickness from a few metres to as much as 200 metres. The rocks exposed in the river gorges and creek alignments belong to the Hawkesbury Group.

The other rocks generally exist in discreet but thinner beds of less than 15 metres thickness, or are interbedded as thin bands within the sandstone. The major claystone unit is the Bald Hill Claystone, which lies above the Bulgo Sandstone at the base of the Hawkesbury Sandstone. This claystone varies in thickness and is, in some places, more than 25 metres thick.

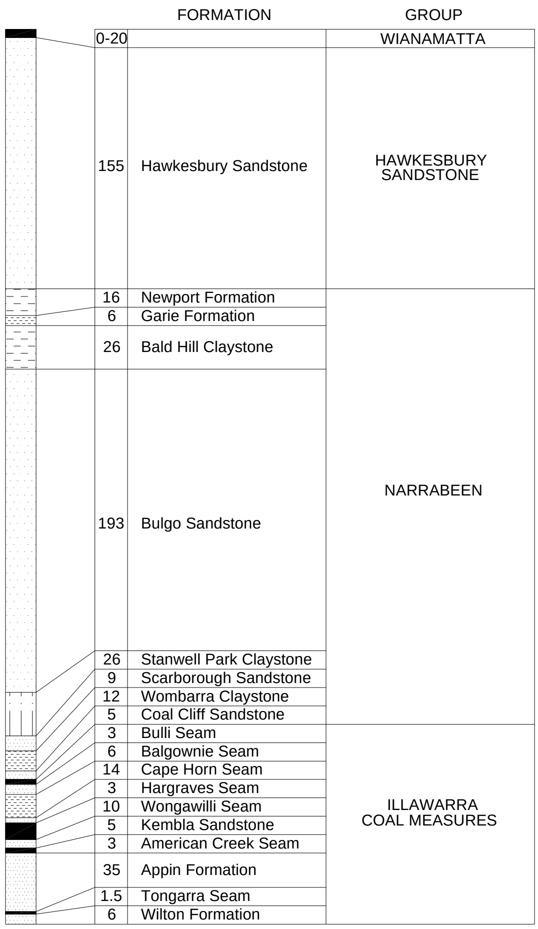

Figure 1.2 Typical Stratigraphic Section – Southern Coalfield

The geology of the Abbotsford Road Site is typical of the Southern Coalfield. The location of known geological structures are shown in Drawings No. MSEC629-101 and MSEC629-103 in Appendix E. A large fault is known to run in an approximate north-west direction, through the eastern area of the site. Only a limited number of boreholes have been previously drilled in the vicinity of this area, and as such, geological information and coal resource information is only at a preliminary level of understanding.

CHAPTER 2 COAL RESOURCES AND MINING PLANS

2.1 Coal Resources beneath the Abbotsford Road Site

The Abbotsford Road site lies partly within the Tahmoor Consent Boundary, Mining Lease ML1376. However, current mining plans for this mining lease by Tahmoor Colliery do not show any proposed undermining of the Abbotsford Road Site. It is, however, feasible that undermining may occur in the future. It is also possible that mining may occur in the future, to the north of Mining Lease ML1376.

The extent of the coal resources beneath the area was determined from plans provided by Tahmoor Colliery and the Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS). Valuable coal resources are present beneath the site in the Bulli Seam.

The Bulli Seam is the uppermost seam and lies at a depth of approximately 500 metres to 580 metres below the surface, as indicated by the surface level contours in Drawing No. MSEC629-102 and the seam floor contours shown in Drawing No. MSEC608-103. The seam contains valuable reserves of high quality coking coal, which varies in thickness from approximately 1.5 metres to 2.2 metres, as indicated by the seam thickness contours shown in Drawing No. MSEC629-103.

The Balgownie Seam lies approximately 20 metres below the Bulli Seam and is approximately 0.75 metres thick. Based on this very low seam thickness, and upon current longwall mining techniques, it is very unlikely that this coal resource would be mined.

The Wongawilli Seam underlies the Balgownie Seam, however at this location of the Southern Coalfields, it is a thin seam consisting of lower quality grade coal. On this basis, it is not expected that the Wongawilli Seam would be mined beneath the Abbotsford Road site in the future.

2.2 Known Future Mining Plans

In the next few years, Tahmoor Colliery plans to continue mining additional longwalls in the Bulli Seam at Tahmoor. These longwalls are all located to the south of the proposed development.

2.3 Potential Future Mining Plans

The coal resources in the Bulli Seam, beneath the proposed development, could be extracted as an extension of the current mining activities at Tahmoor Colliery or, more likely, by the establishment of a new mine access to the west of the site.

At this time, the layout of any future longwalls beneath the site can only be conjectured, but it is likely that the resources would be extracted using longwall mining techniques similar to those that are now being used at Tahmoor Colliery.

The trend over time in the coal mining industry has been to extract wider longwalls and the future longwalls beneath the Abbotsford Road site are likely to be at least of the same width as those that are being mined at nearby Tahmoor, Appin and West Cliff Collieries and those that are currently proposed in the area, which have a maximum width of approximately 320 metres.

It should be noted, however, that a large part of the seam beneath the Abbotsford Road site is unlikely to be mined due to the presence of faults within the seam, which are shown in Drawing No. MSEC629-101.

2.4 Constraints That Might Be Imposed By The MSB

There are three main constraints that may be imposed by the Mine Subsidence Board. These are discussed in the following paragraphs.

Firstly, the MSB may impose a new Mine Subsidence District which incorporates the development site.

Secondly, if the MSB does impose a new Mine Subsidence District, it is then able to require the incorporation of certain design standards, and also require adherence with various subsidence parameters in the design.

Finally, the MSB may also impose restrictions on the size of building structures. Size restrictions would typically relate to plan dimensions, plan area and the number of building storeys.

CHAPTER 3 PREDICTED SUBSIDENCE PARAMETERS

3.1 Predicted Subsidence Parameters

Since a mine layout has not been determined, it is only possible at this stage to make approximate subsidence predictions for the potential future longwalls, based upon the most likely scenario. On this basis, subsidence predictions have been made assuming that future longwall widths would be between 300 metres wide and 400 metres wide, with chain pillars between longwalls of 45 and 50 metres width respectively. Based on current mining practice, longwalls within this width range would be expected at the site, however, this is pure conjecture, and any future mining plans may be quite different.

Subsidence predictions have been prepared at fourteen points on and nearby the Abbotsford Road site, based upon coal seam information provided by the adjacent Collieries. The predictions relate to the extraction of the Bulli Seam only, since it is unlikely that the Wongawilli and Balgownie Seams would be mined, bearing in mind the limitations of current technology.

The locations of the fourteen analysis points, named A to N, are shown in Drawing No. MSEC629-101, and the predicted maximum subsidence parameters based upon the seam thickness and depth of cover at each point are presented in Tables 3.1 and 3.2. These predicted parameters are not based upon a particular mine layout, but assume that longwalls of 300 metres or 400 metres width could be mined anywhere beneath the site. Table 3.1 summarises the results for 300 metre wide longwalls, and Table 3.2 summarises the results for 400 metre wide longwalls.

The predictions have been made throughout the site, but have not been made for areas above the fault zone in Area 4, where mining is not considered to be feasible.

Table 3.1 Predicted Maximum Subsidence Parameters For 300 Metre Wide Longwalls

Point No.	Seam Thickness (m)	Depth of Cover (m)	Maximum Subsidence (mm)	Maximum Tilt (mm/m)	Maximum Tensile Strain (mm/m)	Maximum Compressive Strain (mm/m)	Maximum Hogging Curvature (km)	Maximum Sagging Curvature (km)
A	1.84	490	825	6.7	1.05	2.25	11.5	6.2
B	1.78	509	785	6.3	1	2.1	12.1	6.6
C	1.73	480	790	6.5	1	2.2	11.9	6.4
D	1.55	510	685	5.5	0.85	1.85	13.6	7.2
E	1.55	488	700	5.7	0.9	1.9	13.3	7
F	1.6	486	720	5.9	0.9	2	13	6.8
G	1.64	522	705	5.6	0.9	1.85	13.3	7.2
H	1.76	542	750	5.8	0.95	1.9	12.7	7
I	1.8	550	755	5.8	0.95	1.9	12.7	7.1
J	2.13	510	940	7.5	1.2	2.5	10.3	5.8
K	2.08	506	920	7.4	1.15	2.5	10.5	5.9
L	2.06	525	910	7.3	1.15	2.45	10.6	5.9
M	1.94	518	855	6.8	1.05	2.25	11.3	6.2
N	1.75	520	770	6.1	0.95	2	12.3	6.7

Table 3.2 Predicted Maximum Subsidence Parameters For 400 Metre Wide Longwalls

Point No.	Seam Thickness (m)	Depth of Cover (m)	Maximum Subsidence (mm)	Maximum Tilt (mm/m)	Maximum Tensile Strain (mm/m)	Maximum Compressive Strain (mm/m)	Maximum Hogging Curvature (km)	Maximum Sagging Curvature (km)
A	1.84	490	972	6.8	1	2.3	12.2	6.2
B	1.78	509	932	6.4	0.95	2.15	12.8	6.4
C	1.73	480	922	6.5	0.95	2.2	12.7	6.4
D	1.55	510	811	5.6	0.8	1.9	14.4	7.1
E	1.55	488	820	5.7	0.8	1.9	14.1	6.9
F	1.6	486	848	5.9	0.85	2	13.7	6.8
G	1.64	522	847	5.7	0.85	1.95	13.9	6.9
H	1.76	542	893	6	0.9	2.05	13.4	6.7
I	1.8	550	907	6	0.9	2.05	13.2	6.7
J	2.13	510	1115	7.6	1.1	2.6	10.9	5.6
K	2.08	506	1089	7.5	1.1	2.55	11.1	5.7
L	2.06	525	1063	7.2	1.05	2.45	11.4	5.9
M	1.94	518	1004	6.8	1	2.35	12	6.1
N	1.75	520	905	6.1	0.9	2.1	13.1	6.6

The maximum subsidence predictions have been made, at various points on the site, using the predictive graphs published in a 1988 paper by Dr Lax Holla, formerly the Principal Subsidence Engineer of the Department of Mineral Resources (now the DTIRIS).

The graphs can be used to predict the maximum subsidence over a series of longwalls, based upon the widths of the longwalls, the widths of the pillars, the depth of cover and the seam thickness.

The predictions of maximum tilt, curvature and strain have been based upon methodology published by Holla and Barclay in the Handbook for the Southern Coalfield, dated 2000.

The maximum predicted subsidence varies from 685 mm to 940mm, depending on variations in the seam thickness and depth of cover from place to place, for the 300 metre wide longwall analysis. The comparable numbers for 400 metre wide longwalls are 811mm to 1115mm.

The maximum predicted tilt is 7.6 mm/m at the perimeter of the subsidence trough and 2 to 3 mm/m within the bottom of the trough. The maximum predicted strains are 1.2 mm/m, tensile, and 2.6 mm/m, compressive, with a minimum predicted curvature of 5.6 kilometres radius.

The values given in Tables 3.1 and 3.2 are the maximum values that are likely to occur at some point in the subsidence trough over a series of longwalls. It should be noted, however, that the presence of the faulted zone will restrict any future longwall layout, so that a large area of the Abbotsford Road site will be either outside or close to the edge of the subsidence trough where less subsidence is likely. Also, maximum subsidence is unlikely to occur in the vicinity of the

Tahmoor North Coal Mining lease boundary, given that a solid coal barrier would have to be maintained over a 20 metre width along the length of this boundary in the future. Over most of the proposed Abbotsford Road Development site, therefore, the potential subsidence parameters are likely to be much less than these maximum values.

In the absence of a detailed mine plan, however, it has been normal practice to design large building structures and other items of infrastructure to accommodate the maximum predicted values, and such an approach is also considered to be prudent for the proposed Abbotsford Road development.

In the past, the Mine Subsidence Board (MSB) has typically required infrastructure, such as large building structures or pipelines, in the Southern Coalfield, to be designed to accommodate the following subsidence movements:

- Vertical Subsidence 1200 mm
- Tilt 6 mm/m
- Strain 1 to 2.5 mm/m
- Curvature 8 km radius

It can be seen that these values are similar to those presented in Tables 3.1 and 3.2.

When a mine layout has been established, the Incremental Profile Method can be used to make detailed predictions of the subsidence over the extracted area. In this case, however, since it is not known what the mine layout will be, it is only possible to provide the predicted maximum values assuming that mining will occur beneath the total area of the site. It is possible, however, to illustrate the way in which the subsidence might vary across the site and this is discussed in Section 3.2.

3.2 Typical Subsidence Profiles

In reality, the subsidence in most places would not reach the maximum values shown in Tables 3.1 and 3.2 and the subsided surface levels over a series of longwalls would undulate across the bottom of the subsidence trough, the subsidence varying from place to place by approximately 150 mm to 200 mm, as illustrated in Figure 3.1.

It should be noted that the X axis in Figure 3.1 represents the horizontal distance in metres, whilst the Y axis represents the subsidence in millimetres. The graph is, therefore, drawn to a very exaggerated vertical scale. The uppermost curves in the graph shown by dashed lines are the 'incremental', i.e. longwall by longwall, subsidence profiles, whilst the lower curves shown by thin blue lines are the cumulative total subsidence profiles, obtained by adding the incremental profiles, to show the subsided shape on completion of each longwall in sequence. The lowest curve in the graph, shown as a thick line, is the final profile on completion of the series of five longwalls.

The predictions given in Tables 3.1 and 3.2 are based upon longwalls of 300 and 400 metre width. 300 metre wide longwalls are currently being mined in the Southern Coalfields, and panels up to 400 metres wide are expected to be proposed for future mining. It is possible that future longwalls could be of even greater width and that subsidence could therefore be increased, but the widths that might be adopted in future are open to conjecture at this point in time.

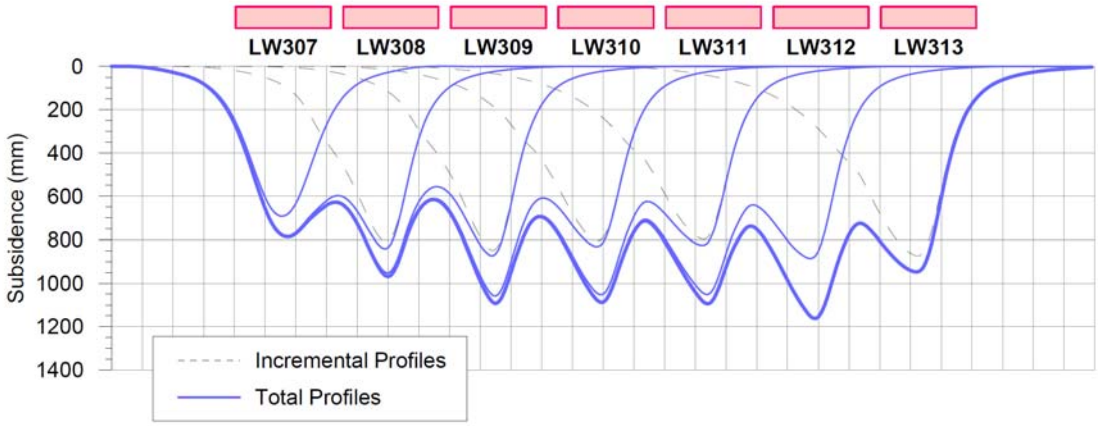

Figure 3.1 Typical Incremental, Cumulative and Final Subsidence Profiles

3.3 Predicted Tilts

The maximum predicted tilts of up to 7.5 mm/m, which are shown in Tables 3.1 and 3.2, generally occur on the side of the incremental subsidence profile as each longwall is mined in sequence. Elsewhere the tilts are generally lower than the maximum values and many of the tilts caused by the extraction of a longwall are reduced as the subsequent longwall is mined.

This occurs due to the overlapping of the subsidence profiles from longwall to longwall and can be appreciated by studying the subsidence profiles shown in Figure 3.1.

The maximum predicted tilts, therefore, only occur around the edge of the subsidence trough and the final tilts within the trough are significantly lower than the maximum values and are generally in the range 3 mm/m to 4 mm/m, i.e. 1 in 333 to 1 in 250.

3.4 Predicted Strains and Curvatures

The maximum predicted ground strains at the Abbotsford Road site, due to extraction of the Bulli Seam, which are presented in Table 3.1, are a tensile strain of 1.2 mm/m and a compressive strain of 2.6 mm/m. These strains will be accompanied by ground curvatures of approximately 10.3 kilometres radius and 5.6 kilometres radius, respectively.

The tensile strain will normally be accompanied by convex, or hogging, curvature, whilst the compressive stain will normally be accompanied by concave or sagging, curvature. As mining occurs, building structures will be subjected to both of these movements and the greatest impacts on the building structures are likely to result from a combination of strain and curvature effects.

Recent research has shown that tensile strains can sometimes occur together with sagging curvature and that compressive strains can sometimes occur together with hogging curvature. In the design of building structures, the worst combinations of strain and curvature should, therefore, be considered.

3.5 Recommended Design Parameters

Given that a mining layout has not been established, and based upon adoption of the use of the Holla method of analysis for this mine subsidence study, the following subsidence parameters are recommended for adoption for domestic construction throughout the development site:

- Vertical Subsidence 1200 mm
- Tilt 6.5 mm/m
- Tensile Strain +1 mm/m
- Compressive Strain -2.5 mm/m
- Hogging Curvature 13.0 km radius

- Sagging Curvature 6.5km radius

Provided that items of infrastructure and all houses on the Abbotsford Road development site are designed and built to allow for these mine subsidence movements, it would be acceptable from an engineering design perspective for development to occur prior to mining of coal in the Bulli Seam, beneath the development site.

These are based upon the predicted parameters at Points B and C, given the predicted values at Points A, I, J, K, L and M are unlikely to be achieved due to the proximity of the faults and the Tahmoor North Coal Mine Lease boundary, and the effects that these will have on any practical longwall layout.

CHAPTER 4 SUBSIDENCE IMPACTS ON EXISTING SURFACE FEATURES

4.1 Impact of Subsidence on Existing Built Features on the Surface

Existing built features on the surface are limited, given the existing rural use of the land. The main features include:

- Abbotsford Road
- 66kV transmission line
- Rural houses and sheds
- Minor farm dams

With the exception of Abbotsford Road and the 66kV transmission line, both of which are shown in drawing S629-101, in Appendix E, it is understood that existing built features would be removed, as a result of the proposed Abbotsford Road development. As a result, in general, the only existing infrastructure to be managed for subsidence would be the 66kV transmission line and Abbotsford Road. Management of these items of infrastructure will need to be examined in further detail once future mining plans are developed, so that a detailed subsidence impact assessment for these items may be completed. Until then, development of management strategies for these items of infrastructure would be premature. It is, however, noted that items such as these have been readily managed for subsidence throughout the Southern Coalfields as a result of mining that has already occurred, and is continuing to occur. On this basis, subsidence management plans should be developed for these items of infrastructure, in the future, once future mining plans have been developed. These subsidence management plans would be developed by the mining company, in consultation with other stakeholders, including infrastructure owners and land owners.

4.2 Impact of Subsidence on Flooding and Surface Ponding

Future longwall mining beneath the Abbotsford Road site would lead to subsidence troughs developing above the longwall panels. Chapter 3 above describes how it is expected that subsidence could reach values of up to 1200 mm for panels up to 400 metres wide. However, the occurrence of the peak subsidence values would be restricted to relatively small areas along the lengths of longwall panels. Subsidence is also not expected to occur across a large area of the site because of the presence of geological faulting, and also the proximity of the site to the boundary of the existing Tahmoor North Coal Mining Lease, where it is expected that solid coal would most likely remain sterilised, as would usually occur at such as a barrier along the boundary.

A preliminary review of existing surface contours across the Abbotsford Road site suggests that the project site is not prone to flooding. This should be confirmed with the surface water consultant for this Gateway Process application. However, the subsidence created from a yet to be developed longwall mine plan for the site could lead to some localised surface ponding. In general the proposed residential development occurs on the higher areas of the site, rather than within and directly adjacent to the existing natural drainage channels. Drainage channels would tend to be more prone to localised ponding, rather than slopes above the drainage channels. On this basis, surface ponding is not expected to be an impact that will occur across the entire site as a result of future longwall mining.

However localised ponding in some areas may need to be managed via some re-grading of land, once mining has occurred in the future. Once any future mining proposals are developed and a mine plan is available, a subsidence study using the incremental profile method could provide a thorough understanding of subsided surface level predictions. This information could be used for a detailed surface water study at that time by a surface water specialist to understand, in detail, the predicted impacts on flooding and surface water, of a proposed mine plan. However, until a mine plan is developed, such predictions cannot occur with any degree of accuracy

4.3 Potential Impacts of Subsidence on Future Developments

Houses of moderate size, less than 30 metres in length and no greater than two storeys in height are generally acceptable to the MSB if they comply with the Australian Standards and good building practices indicated in the Board's Guidelines. Conventional residential building structures, designed and constructed in accordance with such standards, are capable of accommodating the predicted subsidence, tilts, strains and curvatures with minimal impacts, which would generally be of a cosmetic nature and would be easily repaired by the MSB when subsidence occurs.

It should be realised that the vertical subsidence of the ground is not generally the cause of damage to building structures and other items of infrastructure. Tilts, curvatures and strains are the major causes of damage to building structures, but so long as the structures have been designed to accommodate the predicted movements, they should generally remain safe, serviceable and repairable as subsidence occurs.

APPENDIX A GLOSSARY OF TERMS AND DEFINITIONS

Some of the 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.
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.
Extracted Seam Thickness	The thickness of coal that is extracted. The extracted seam thickness is 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.
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 Centreline	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.
Strain	The change in the horizontal distance between two points divided by the original horizontal distance between the points.
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.
Super-critical area	An area of panel greater than the critical area.
Tilt	The difference in subsidence between two points divided by the horizontal distance between the points.
Uplift	An increase in the level of a point relative to its original position.
Upsidence	The difference between the observed subsidence profile within a valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.

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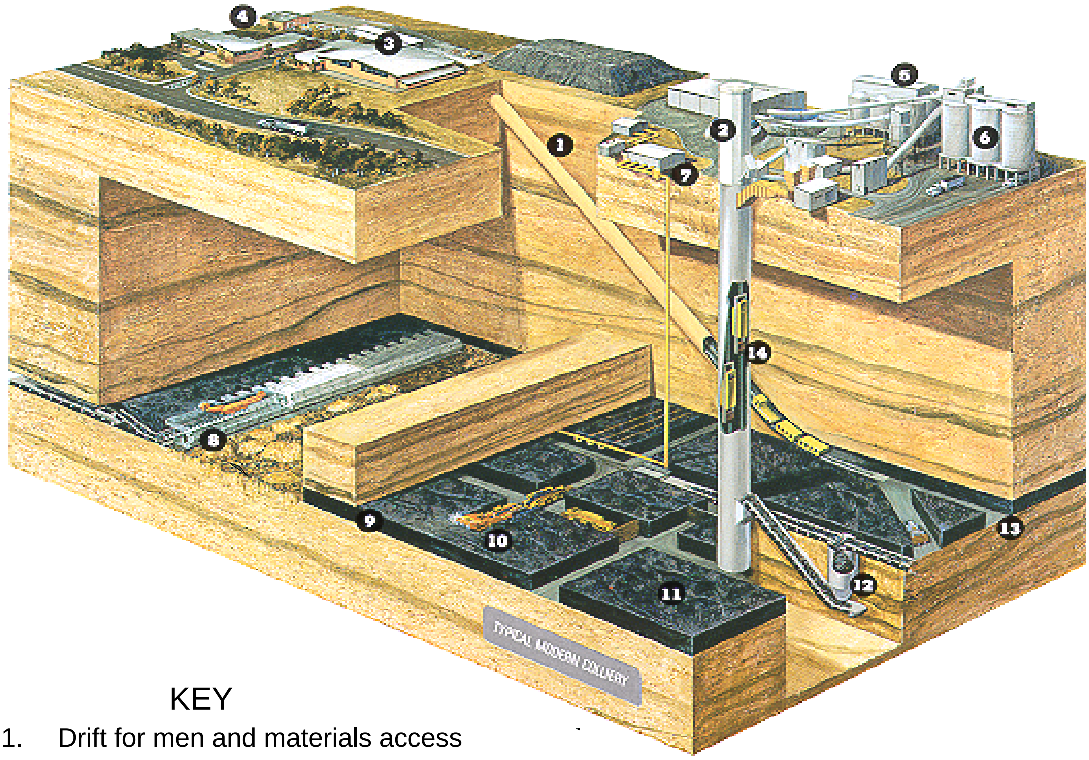
APPENDIX C INTRODUCTION TO LONGWALL MINING AND SUBSIDENCE

C1 The Longwall Mining Process

Figure C1 shows a cutaway diagram of a typical longwall mine. The main features of the mine are indicated in the key below the diagram. The longwall face is indicated by the number 8 in the diagram.



KEY

1. Drift for men and materials access
2. Shaft winder house
3. Bathhouse and administration building
4. Workshops
5. Coal preparation plant
6. Coal storage bins
7. Gas drainage system
8. Longwall face equipment
9. Coal seam
10. Continuous miner unit
11. Coal pillar
12. Underground coal bin
13. Main roadway or heading
14. Coal skips to carry coal to the surface

Figure C1 Cutaway View of a Typical Longwall Mine

In longwall mining, a panel of coal, typically around 150 to 400 metres wide, 1000 to 3500 metres long and 2 to 5 metres thick, is totally removed by longwall shearing machinery, which travels back and forth across the coalface. A typical section through a coal face is shown in Figure C2 and a photograph of typical longwall face equipment is shown in Figure C3. The shearer cuts a slice of coal from the coalface on each pass and a face conveyor, running along the full length of the coalface, carries this away to discharge onto a belt conveyor at the end of the face, which carries the coal out of the mine.

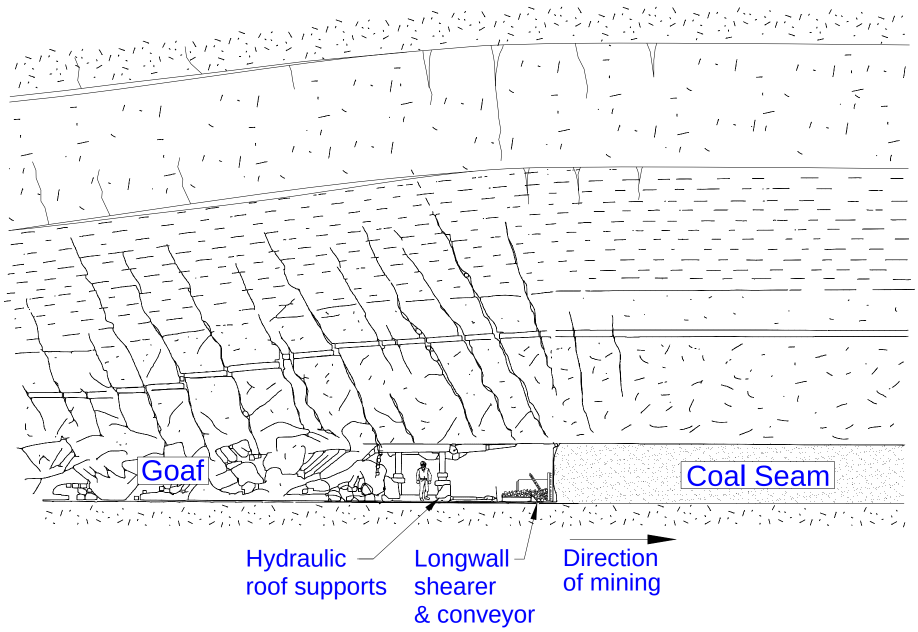


Figure C2 Cross Section of a Typical Longwall Face

The area immediately in front of the coalface is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata and provide a working space for the shearing machinery and face conveyor. After each slice of coal is removed, the hydraulic roof supports, the face conveyor and the shearing machinery are moved forward. Figure C3 shows the arrangement of machinery on a typical longwall face, with the hydraulic roof supports on the left hand side and the coal face on the right hand side of the picture. The drum in the background is the rotating cutting head of the coal shearer and the chain conveyor can be seen in the foreground.

Figure C3 Typical Longwall Face Equipment

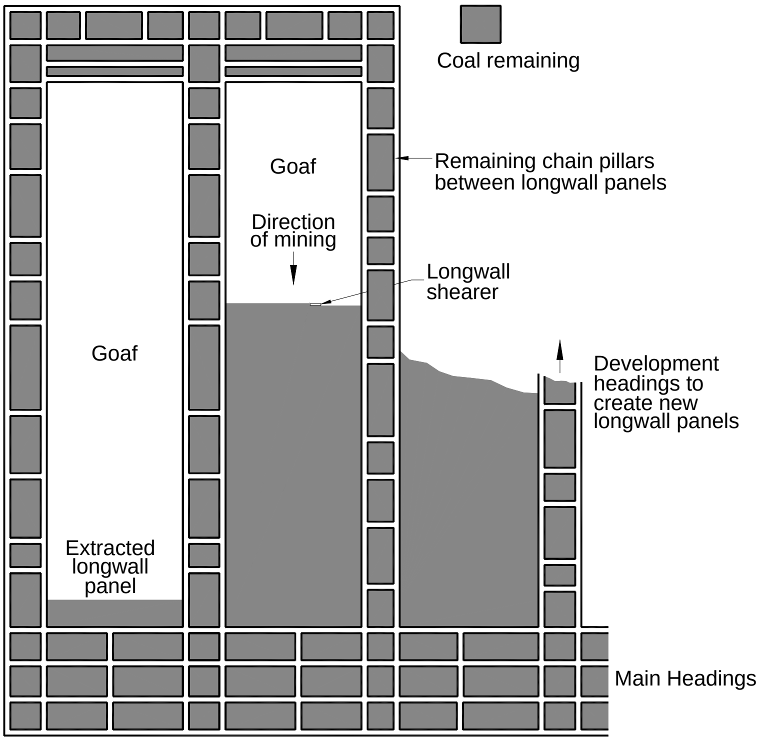


Figure C4 Typical Plan View of a Series of Longwall Panels

Figure C4 shows a typical layout of a group of longwalls. Before the extraction of a longwall panel commences, continuous mining equipment extracts coal to form roadways (known as headings) around the longwall panel. These roadways form the mine ventilation passages and provide access for people, machinery, electrical supply, communication systems, water pump out lines, compressed air lines and gas drainage lines. The roadways, which provide access from the mine entrance to the longwalls, are referred to as the main headings. Once the main headings have been established additional roadways, known as development headings, are driven on both sides of the longwall panel and are connected together across the end of the longwall.

The longwall face equipment is established at the end of the panel that is remote from the main headings and coal is extracted within the panel as the longwall equipment moves towards the main headings. This configuration is known as retreat mining. Typically, a longwall face retreats at a rate of 50 metres to 100 metres per week, depending on the seam thickness and mining conditions. The coal between the development headings and between the main headings is left in place as pillars to protect the roadways as mining proceeds. The pillars between the development headings are referred to as chain pillars.

When coal is extracted using this method, the roof immediately above the seam is allowed to collapse into the void that is left as the face retreats. This void is referred to as the goaf. Miners working along the coalface, operating the machinery, are shielded from the collapsing strata by the canopy of the hydraulic roof supports. As the roof collapses into the goaf behind the roof supports, the fracturing and settlement of the rocks progresses through the overlying strata and results in sagging and bending of the near surface rocks and subsidence of the ground above, as illustrated in Figure C2.

If the width of an extracted panel of coal is small and the rocks above the seam are sufficiently strong, it is possible that the roof will not collapse and hence no appreciable subsidence will occur at the surface. However, to maximise the utilisation of coal resources and for other economic reasons, wide panels of coal are generally extracted and, in most cases, the roof is unable to support itself.

C2 The Development of Subsidence.

C2.1 Subsidence Mechanisms.

As the immediate roof strata, i.e. the rocks immediately above the seam, collapse into the goaf, the rocks above them lose support and sag to fill the void beneath them. The mechanism progresses towards the surface and the affected width increases, so that at the surface an area somewhat larger than the extracted panel of coal undergoes settlement. Figure C5 shows a typical subsidence profile above an extracted longwall panel and it can be seen that the majority of the subsidence occurs over the centre of the longwall and tapers off around the perimeter of the longwall. The subsidence is typically less than the thickness of coal extracted underground.

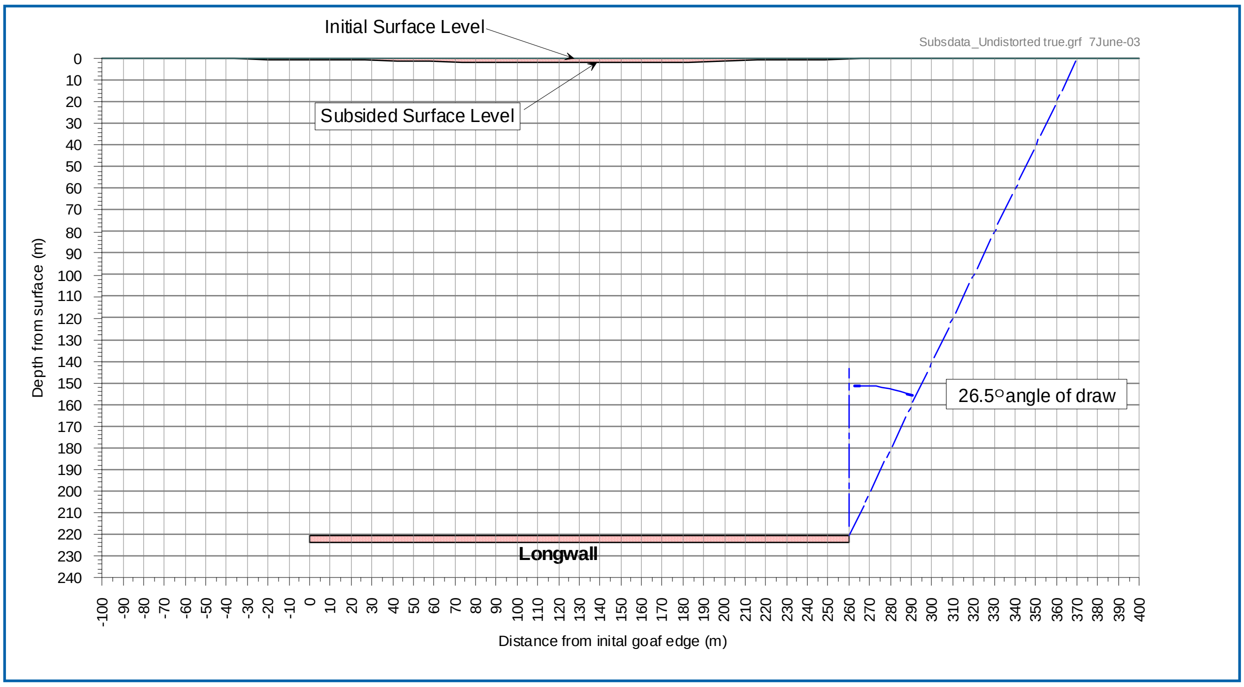


Figure C5 Typical Subsidence Profile Drawn to a True Scale

The angle at which the subsidence spreads out towards the limit of subsidence, at the surface, is referred to as the angle of draw. The angle of draw depends upon the strength of the strata and the depth of cover to the coal seam and typically lies between 10 and 35 degrees from the vertical, depending on how the limit of subsidence is defined.

It is generally accepted that subsidence of less than 20 mm will have negligible effect on surface infrastructure and this is generally adopted as the cut-off point for determination of the angle of draw. In the Coalfields of NSW, if local data is not available, the cut-off-point is taken as a point on the surface defined by an angle of draw of 26.5 degrees from the edge of the extraction, i.e. a point on the surface at a distance of half the depth of cover from the goaf edge. Where local data exists and it can be shown that the angle is generally less than 26.5 degrees, then, the lower angle of draw can be used.

The subsidence of the surface is considerably less than the thickness of coal removed, due to the voids that are left within the collapsed strata. The extent of the settlement at the surface is therefore dependent upon the strength and nature of the rocks overlying the coal seam and is a direct function of their capacity to bridge over the voids.

When a panel has a width that is small, relative to the depth of the seam below the surface, the fractured rocks have a tendency to bridge over the goaf by arching between the solid abutments on each side of the panel, thus reducing the amount of subsidence.

As the panel width is increased, however, the overlying rocks are less able to arch over the goaf and a limiting panel width is reached where no support is available and maximum subsidence occurs. This limiting panel width is referred to as the critical width and is usually taken to be 1.4 times the depth of cover. It does, however, depend upon the nature of the strata.

Where several panels are mined in a series and chain pillars are left between the panels, the maximum subsidence does not occur unless each panel is, at least, of critical width. The chain pillars crush and distort as the coal is removed from both sides of them, but, usually, they do not totally collapse and, hence, the pillars provide a considerable amount of support to the strata above them.

Where large supercritical areas are extracted, the maximum possible subsidence is typically 55% to 65% of the extracted seam thickness, but, because chain pillars are normally left in place, and provide some support, this maximum possible subsidence is rarely reached.

Research has shown that the incremental subsidence of a second or subsequent panel in a series is greater than the subsidence of an individual isolated panel of identical geometry. Because the subsidence effects above a panel extend beyond its goaf edges, these effects can overlap those of neighbouring panels.

Where the width-to-depth ratios of the panels in a series are sub-critical, which is normally the case in the Southern Coalfield, the amount of subsidence in each panel is determined by the extent of these overlaps, which are further influenced by the widths of the chain pillars. In this situation, the first panel in a series will generally exhibit the least subsidence and the second and subsequent panels will exhibit greater subsidence due to disturbance of the strata caused by mining the preceding panels and consequential redistribution of stresses within the strata.

The subsidence at the surface does not occur suddenly but develops progressively as the coal is extracted within the area of influence of the extracted panel. In many cases, when the cover over the coal seam is deep, a point on the surface will be affected by the extraction of several adjacent panels.

When extraction of coal from a panel is commenced, there is no immediate surface subsidence, but as the coal within this first panel is extracted and the extracted void increases in size, subsidence develops gradually above the goaf area. As mining continues, a point is reached within the panel where a maximum value of subsidence occurs and despite further mining beyond this point, within the panel, this level of subsidence is not increased.

As further adjacent panels are extracted, additional subsidence is experienced within the previously mined panels. However, a point is also reached where a maximum value of subsidence is observed over the series of panels, irrespective of whether more panels are later extracted.

The subsidence effect at the surface occurs in the form of a wave, which moves across the ground at approximately the same speed as the longwall face retreats within the longwall panel. The extraction of each panel creates its own wave as the panels are mined in sequence.

The development of subsidence at any point on the surface of the ground can be seen to be a very complex mechanism and the cumulative effect of a number of separate movements.

C2.2 Subsidence Parameters

Subsidence, tilt, horizontal displacement, curvature and strain are the subsidence parameters normally used to define the extent of the surface movements that will occur as mining proceeds and generally form the basis for the assessment of the impacts of subsidence on surface infrastructure. These parameters are illustrated in Figure C6.

Subsidence

Subsidence usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements can in many cases be greater than the vertical subsidence. The amplitude of subsidence is usually expressed in millimetres.

Tilt

Tilt 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. The sign of tilt is not important, but the convention usually adopted is for a positive tilt to indicate the ground increasing in subsidence in the direction of measurement.

The maximum tilt, or the steepest portion of the subsidence profile, occurs at the point of inflection in the subsidence trough, where the subsidence is roughly equal to one half of the maximum subsidence. Tilt is usually expressed in millimetres per metre.

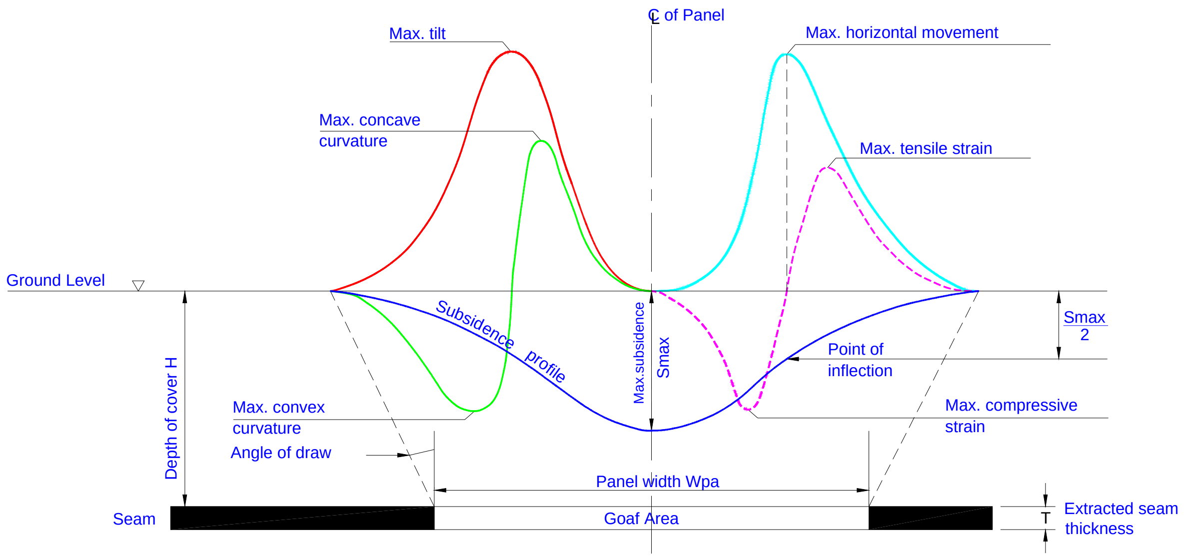


Figure C6 Subsidence Parameter Profiles above a Single Longwall Panel

Horizontal Displacement

The horizontal component of subsidence, or horizontal displacement, is greatest at the point of maximum tilt and declines to zero at the limit of subsidence and at the point of maximum subsidence. Horizontal displacement is usually expressed in millimetres.

Curvature

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/km, or km-1, but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in kilometres.

Curvature is convex or 'hogging' over the goaf edges and concave or 'sagging' toward the bottom of the subsidence trough. The convention usually adopted is for convex curvature to be positive and concave curvature to be negative.

Strain

Strain is caused by bending and differential horizontal movements in the strata. Measured strain is determined from monitored survey data by calculating the horizontal change in length of a section of a subsidence profile and dividing this by the initial horizontal length of that section.

If the section has been extended, the ground is in tension and the change in length and the resulting strain are positive. If the section has been shortened, the ground is in compression and the change in length and the resulting strain are negative.

The unit of measurement adopted for strain is millimetres per metre. The maximum strains coincide with the maximum curvature and hence the maximum tensile strains occur towards the sides of the panel whilst the maximum compressive strains occur towards the bottom of the subsidence trough.

C3 Subsidence Impacts at the Surface

The most significant impacts on surface infrastructure are experienced during the development of the subsidence trough, when maximum ground movements normally occur.

As the subsidence wave approaches a point on the surface, the ground starts to settle, is displaced horizontally towards the mined void and is subjected to tensile strains, which build from zero to a maximum over the length of convex or hogging curvature, as shown in Figure C7

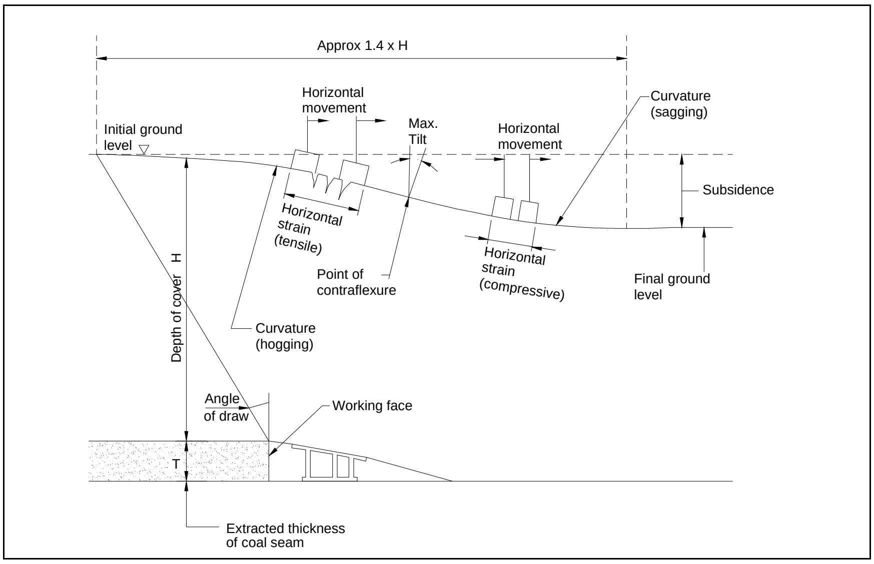


Figure C7 Development of a Subsidence Trough (to an exaggerated vertical scale)

The position of maximum hogging curvature is the position of maximum tensile strain. When vertical subsidence is approximately half of the maximum subsidence, i.e., as the face passes under the surface point, the ground reaches its maximum horizontal displacement and the strain reduces to zero again.

As the longwall face moves further away from the surface point the settlement continues, horizontal displacement reduces and the ground is subjected to compressive strains, which build from zero to a maximum over the length of concave or sagging curvature and then decline to zero as maximum subsidence is reached. The position of maximum sagging curvature is the position of maximum compressive strain. When the subsidence is complete, the ground is commonly left with no horizontal displacement and little residual tilt or strain.

Between the tensile and compressive zones is the point of inflection, which is the point at which maximum tilt and maximum horizontal displacement occurs. For critical extraction conditions, it is also the point at which the subsidence is, approximately, equal to half the maximum subsidence.

As the longitudinal wave passes, the transverse subsidence profile gradually develops and is completed as maximum subsidence is reached. The transverse subsidence profiles over each side of the panel are similar in shape to the longitudinal subsidence profile and have the same distribution of tilts, curvatures and strains.

Most of the points on the surface will thus be subjected to three-dimensional movements, with tilt, curvature and strain in both the transverse and longitudinal directions. The impact of subsidence on surface infrastructure is therefore dependent upon its position within the trough.

The above sequence of ground movements, along the length of a panel, only applies to surface structures if they are located at a point where the maximum subsidence is likely to occur. Elsewhere, the impacts, in the both the transverse and longitudinal direction are reduced.

If a structure is located on the perimeter of the subsidence trough, it will be only slightly affected, will suffer little settlement and will have little residual tilt or strain.

A structure or surface feature on the side of the trough between the tension and compression zones will experience some subsidence, and will be left with residual horizontal displacement and tilt, but will be subjected to lower curvatures and strains. Structures or surface features located at the positions of maximum curvature and strain would generally suffer the greatest damage.

As each panel within a series is extracted in turn, an incremental subsidence trough is formed above it. If the width-to-depth ratios of the panels are low, the incremental subsidence troughs overlap at the surface and the resulting subsidence at any point, in these circumstances, is a combination of the effects of a number of panels.

A point on the surface may then be subjected to a series of subsidence waves, which occur as each panel is extracted, and the duration of these impacts will depend upon the position of the point relative to each of the subsidence troughs that are formed.

APPENDIX D METHODS OF SUBSIDENCE PREDICTION

D1 Alternative Methods of Prediction

Several alternative methods have been used in the past to predict subsidence parameters, including:

- Graphical Methods, such as the National Coal Board Method used in the U.K.
- Profile Function Methods.
- Influence Function Methods.
- Numerical Modelling Methods.
- Empirical Methods.

Profile function methods seek to define the shape of the subsidence profile using a single mathematical formula. These are generally only applicable to single panels, since they assume the profiles to be symmetrical and fail to recognise the way in which subsidence profile shapes are modified over adjacent and previously mined goaf areas.

Influence function methods predict subsidence profiles based on the theory of an area of influence around a point of extraction. These methods can be applied to a wide range of mining geometries, but are more difficult to calibrate and check than profile function methods.

Numerical modelling techniques have been developed in recent years using finite element and discrete element models such as FLAC, UDEC and FLOMEC. These are particularly useful tools for investigating strata mechanisms and hydrological impacts, but have not been found to produce sufficiently accurate predictions of mine subsidence.

Empirical methods can be developed for the prediction of subsidence parameters whenever a large database of measured subsidence parameters is available. These methods can be advantageously employed over a wide range of mining geometries, taking into account local variations in strata lithology. Other modelling methods can also be successful where sufficient local data is available for model calibration. To be successful, all methods of prediction have to be checked against measured data and calibrated to reflect local geology.

An empirical approach has generally been adopted in the coalfields of New South Wales, and this has been expanded in recent years by the development of the Incremental Profile Method. The Standard Empirical methods and the Incremental Profile Method are described in the following sections. Further information on alternative methods of subsidence prediction can be found in Kratzsch (1983) and Whittaker and Reddish (1989).

D2 Standard Empirical Methods

At collieries in New South Wales, the maximum subsidence of the surface has generally been predicted using empirical methods. In the past, subsidence predictions were based upon the methods outlined in the Subsidence Engineers Handbook, first published by the National Coal Board of the United Kingdom in 1965 and revised in 1975. This involved the use of a series of graphs derived from numerous field observations in British mines, which allowed the shapes of the subsidence, tilt and strain profiles to be predicted.

The method gave good results when applied to British mining situations, but when the method was adopted in Australia, it became clear that the field observations differed considerably from predicted values and were generally much less than theory would suggest.

This is because the strata that overlie the coal seams in British coalfields differ from those that occur in the coalfields of Australia and because the subsidence measurements in British coalfields were in some cases affected by multi-seam mining.

The rocks in Britain are generally less competent and less able to bridge the extracted voids and, therefore, for a given seam thickness, the maximum subsidence is greater than it would normally be for the same mining geometry in Australian conditions.

An intensive research program was therefore undertaken by the New South Wales Department of Mineral Resources (DMR) to develop a predictive model that was more appropriate for Australian conditions. It was noted that the subsidence behaviour varied significantly between the Southern Coalfield, the Newcastle Coalfield and the Western Coalfield of New South Wales. Subsidence data from collieries in New South Wales were therefore studied separately for the three coalfields.

The work resulted in three publications which provide guidelines for the prediction of mine subsidence parameters in each coalfield. The handbook for the Southern Coalfield was completed in 1975 (Holla, 1975) and the handbooks for the Newcastle and Western Coalfields were completed in 1987 (Holla, 1987a) and 1991 (Holla, 1991a) respectively. It should be noted that the method of prediction given in the New South Wales handbooks is only applicable to single, isolated panels.

Additional research by Dr L. Holla of the DMR led to the publishing of a paper (Holla, 1988) which included a graph which can be used to predict the maximum subsidence above a series of longwall panels, for critical extraction conditions. This graph is reproduced as Figure D1, where S max is the maximum subsidence, T is the seam thickness and H is the depth of cover.

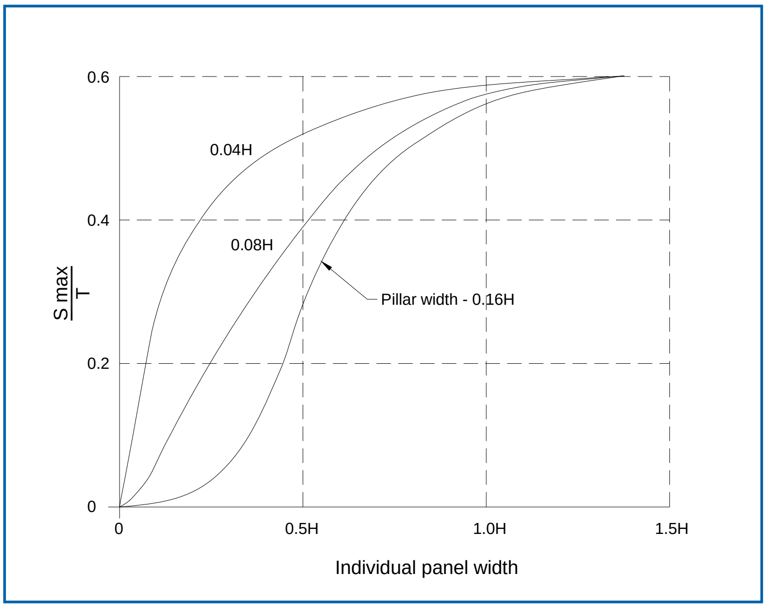


Figure D1 Graph for the Prediction of Maximum Subsidence over a Series of Panels for Critical Extraction Conditions (after Holla, 1988)

Following further study, a revised handbook was produced by the DMR for the Southern Coalfield in 2000 (Holla and Barclay). This later handbook included graphs that allow prediction of the maximum subsidence over a series of longwall panels. The handbook can also be used to establish an approximate subsidence profile and to predict the maximum tilt, curvature and strain above a mined area, for single panels.

When the width of an extracted panel, the depth of cover, and the extracted seam thickness are known, the following parameters can be predicted:

- The maximum subsidence value
- The location of the inflection point
- The average goaf edge subsidence
- The limit of subsidence

Once these parameters have been determined, a subsidence profile can be produced as a line of best fit between the points of maximum subsidence, inflection, goaf edge subsidence and limit of subsidence. This method thus allows the approximate shape of subsidence profile to be determined for a single isolated panel.

The predicted maximum tensile strain, compressive strain and tilt can be determined from the maximum subsidence and depth of cover, using, respectively, factors obtained from the graphs shown in Figs. 4.6, 4.7 and 4.10 of the DMR handbook (Holla and Barclay, 2000). The predicted maximum curvatures can be derived from the predicted maximum strains using the graph shown in Fig. 4.9 of the handbook.

The limit of subsidence is determined from the depth of cover and the angle of draw. The DMR recommends a practical angle of draw of 26.5° for general use in the Southern Coalfield, and hence the limit of subsidence would generally be positioned at half the depth of cover from the perimeter of the extracted area.

D3 The Incremental Profile Method

The Incremental Profile Method was developed by Mr. A.A. Waddington and Mr. D.R. Kay during the course of a study for BHP Collieries Division, the Water Board and AGL during the latter part of 1994 (Waddington and Kay, 1995). The purpose of the study was to develop an empirical method which could be used to predict the subsidence, tilts, curvatures and strains likely to be experienced as longwall mining occurred at Appin and Tower Collieries, and to assess the likely effects of mining on surface infrastructure.

The first step in the development of the model was to study detailed records of subsidence movements which had been observed over previous longwalls at Appin and Tower Collieries and over longwalls at neighbouring mines, including Tahmoor, West Cliff, Cordeaux and South Bulli Collieries. The measured subsidence data was plotted in a variety of ways to establish whether or not any regular patterns of ground behaviour could be found. The most significant patterns were illustrated in the shapes of the incremental subsidence parameters measured along survey lines located transversely across the longwalls.

The incremental subsidence profile for each longwall was derived by subtracting the initial subsidence profile (measured prior to mining the longwall) from the final subsidence profile (measured after mining the longwall). The incremental subsidence profile for a longwall therefore shows the change in the subsidence profile caused by the mining of the individual longwall.

The consistency in the shapes of the incremental subsidence profiles led to the development of the Incremental Profile Method. This consistency can be observed in the typical incremental subsidence profiles presented in Figure D2

The Incremental Profile Method of prediction is based upon predicting the incremental subsidence profile for each longwall in a series of longwalls and then adding the respective incremental profiles to show the cumulative subsidence profile at any stage in the development of a series of longwalls.

The incremental subsidence profiles are also used to derive incremental tilts, systematic curvatures and systematic strains which can be added to show the transient and final values of each parameter as a series of longwalls are mined.

Profiles can be predicted in both the transverse and longitudinal directions, thus allowing the subsidence, tilts, systematic curvatures and systematic strains to be predicted at any point on the surface above a series of longwalls. The method also explains the development of undulations that occur within the subsidence trough and allows the magnitude of both transient and residual tilts and curvatures within the trough to be determined.

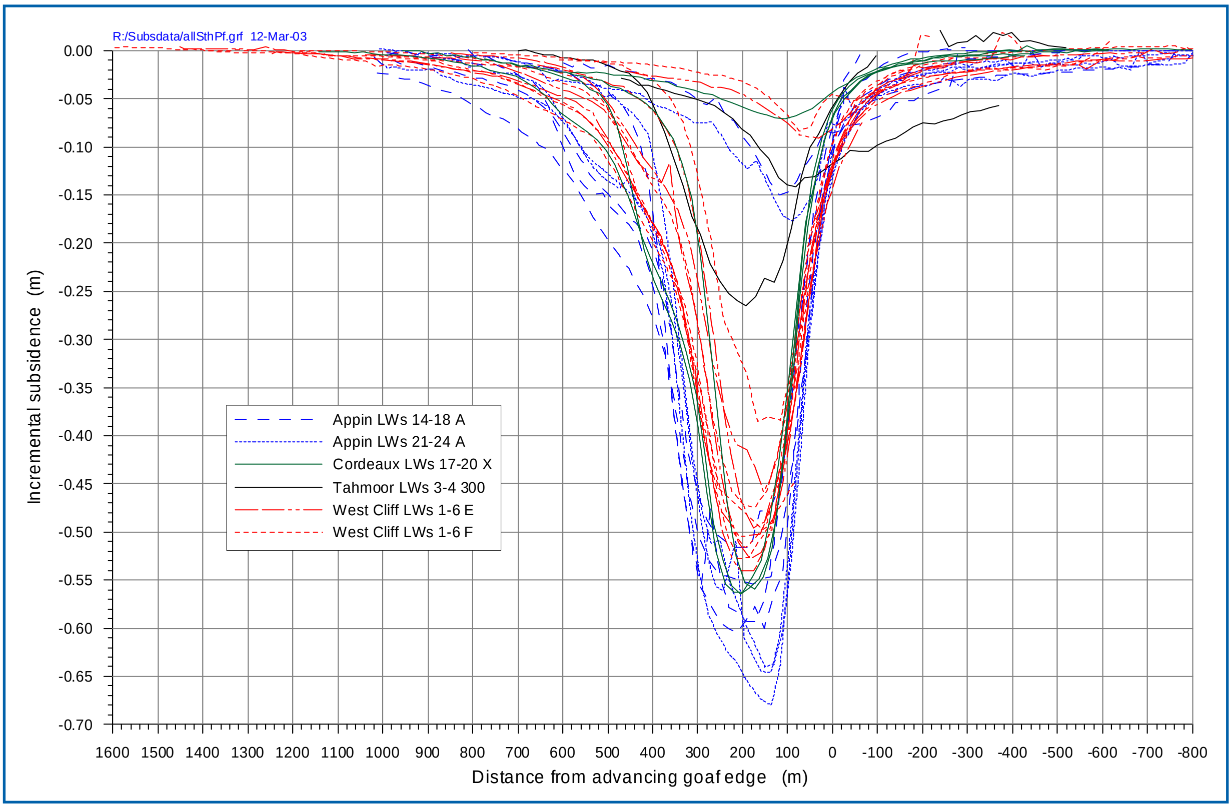


Figure D2 Typical Incremental Subsidence Profiles – NSW Southern Coalfield

The model was initially tested by comparing the predicted values of subsidence, tilt, curvature and strain against the measured values for a number of longwalls at Appin, Cordeaux, Tahmoor and West Cliff Collieries. Following that study, the method was used to analyse and predict subsidence over other longwall panels at Appin, South Bulli, Bulli, Corrimal, Tahmoor, Teralba, North Cliff, Metropolitan, Tower and West Cliff Collieries. These studies found that the shapes of the measured incremental profiles conformed to the patterns and magnitudes observed during the initial 1994 study.

During 1996 and 1997, the method was extended for use in the Newcastle Coalfield. The shapes of incremental profiles over extracted longwall panels at Cooranbong, West Wallsend, Newstan, Teralba, and Wyee Collieries were studied and a subsidence model was developed for the Cooranbong Life Extension Project. These studies have shown that the shapes of the incremental profiles in the southern part of the Newcastle Coalfield conform to the patterns observed in the Southern Coalfield. Since that study, the method has been used to analyse and predict subsidence over other longwall panels at West Wallsend, Cooranbong, Wyong and South Bulga Collieries.

The collection of additional data has allowed further refinement of the method and the database now includes more than 450 measured examples. A wide range of longwall panel and pillar widths and depths of cover is included within the database and hence, the shapes of the observed incremental profiles in the database reflect the behaviour of typical strata over a broad spectrum.

Further research during the last few years has identified the shapes of the incremental profiles in a number of multi-seam situations. These profiles are generally greater in amplitude than the single seam profiles and differ in shape from the standard profiles over single seams.

The incremental profiles have been modelled in two halves, the point of maximum subsidence being the point at which the two halves of the profile meet. A library of mathematically defined profile shapes has been established, which allows the incremental profiles to be modelled, depending on the width-to-depth ratio of the longwall and the position of the longwall in the series.

The mathematical formulae that define the profile shapes are of the form given in Equation 1 below. The library of profile shapes simply comprises the values *a* to *k* in these formulae.

Equation (1) $$y = \frac{a + cx + ex^2 + gx^3 + ix^4 + kx^5}{1 + bx + dx^2 + fx^3 + hx^4 + jx^5}$$

Different formulae apply, with unique a to k values, for first, second, third, fourth, and fifth or subsequent panels in a series, and for different width-to-depth ratios, within the range 0.3 to 5.0. For second, third, fourth and fifth or subsequent panels, the left and right hand sides of the profiles have different formulae.

The library of profile shapes thus contains a to k values for 693 different half-profile shapes for single-seam mining situations. In addition the library contains 236 different half-profile shapes for a range of multi-seam mining situations. A selection of model incremental subsidence profiles for various width-to-depth ratios is shown in Figure D3.

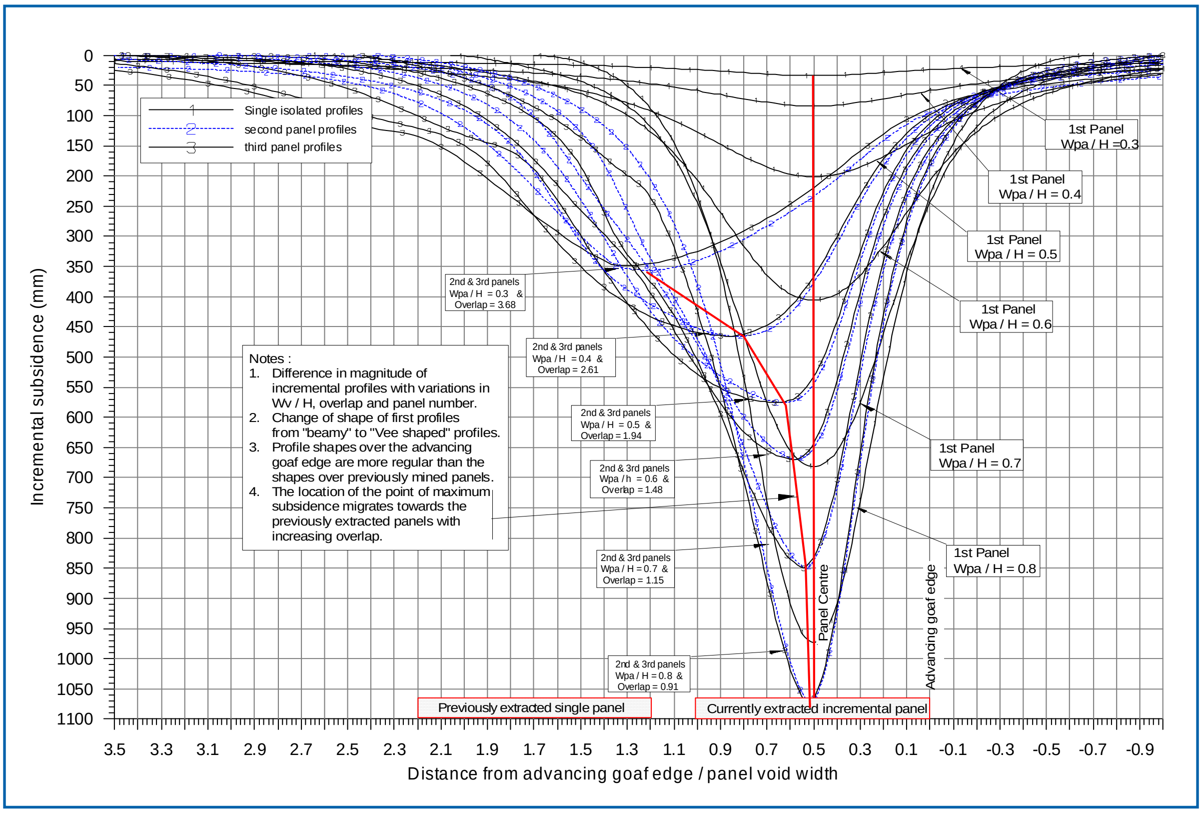


Figure D3 Incremental Subsidence Profiles obtained using the Incremental Profile Method

The method has a tendency to over-predict the subsidence parameters because a conservative approach was adopted in preparing the graph that is used for predicting the maximum incremental subsidence. Figure D4 shows the maximum incremental subsidence, expressed as a proportion of seam thickness, versus panel width-to-depth ratio.

Since this graph is used to determine the amplitude of the incremental subsidence profile, any over-prediction of the maximum subsidence value also leads to over-predictions of the tilt, curvature and strain values. Once the geometry of a longwall panel is known, the shapes of the two halves of the incremental subsidence profile of the panel can be determined from the appropriate formulae to provide a smooth non-dimensional subsidence profile across the longwall.

The actual incremental profile is obtained by multiplying vertical dimensions by the maximum incremental subsidence value and horizontal dimensions by the local depth of cover. Smooth tilt and curvature profiles are obtained by taking the first and second derivatives of the subsidence profile. Strain profiles are obtained directly from the curvature profiles.

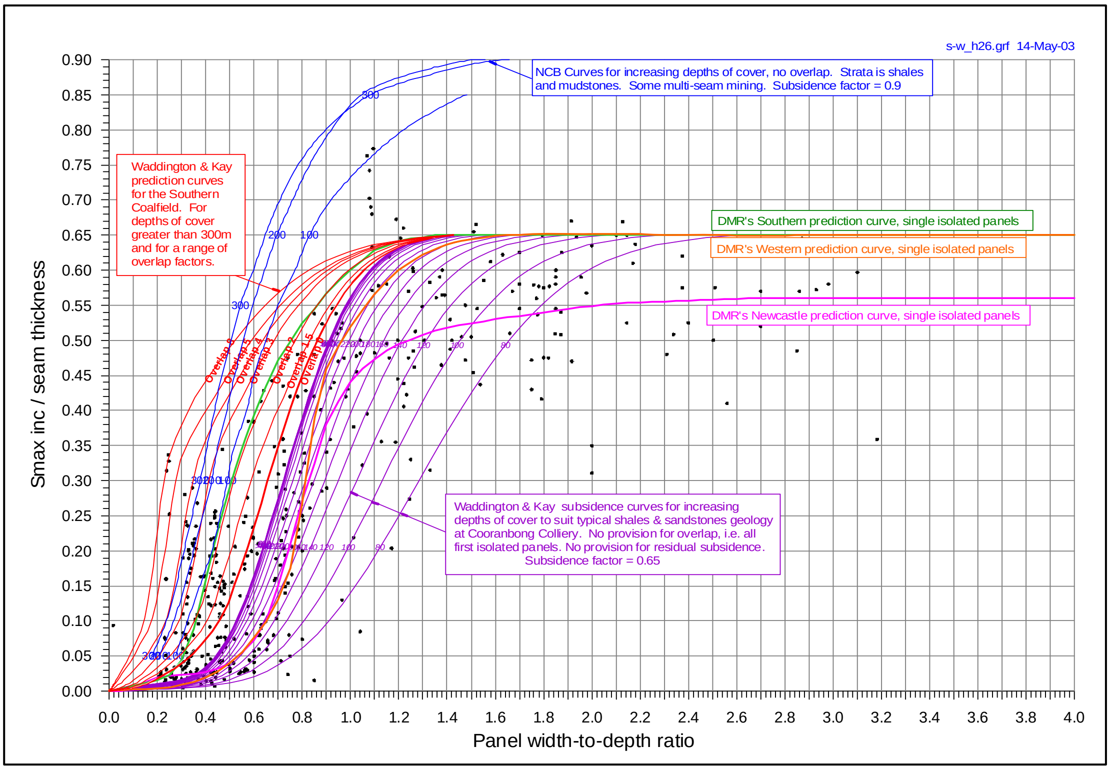


Figure D4 Prediction Curves for Maximum Incremental Subsidence

It can be seen from Figure D3 that, as the panel width-to-depth ratio (W/H) decreases, the magnitude of the incremental subsidence profile is reduced and the position of the point of maximum subsidence moves closer to the previously extracted panels.

In order to determine strain values from the curvature profiles, it is necessary to select an empirical relationship that will generally provide conservative results. The NCB Subsidence Engineers Handbook (1975) adopts a relationship in which the reciprocal radius of curvature, K, is equal to strain squared divided by 0.024.

This relationship does not provide a good fit when strains derived from predicted curvatures, are compared with measured values. However, if a linear relationship of strain = 15 × curvature is chosen, then a closer fit is achieved between predicted and observed data from the Southern Coalfield. This equates to the bending strain in a beam of 30 metres depth, bending about its centreline.

The relationship of 15 × curvature is also reasonably close to the graph of radius of curvature versus maximum strain given in Figure 4.9 of the DMR's handbook for the Southern Coalfield (Holla and Barclay, 2000), for depths of cover between 300 metres and 400 metres. It will, however, give lower values of strain for greater depths.

Predicted horizontal displacements in the direction of the prediction line (normal to the longwall), can be derived by accumulating the predicted strains multiplied by the bay lengths, after distributing any displacement closure errors over all bay lengths in proportion to the predicted strains. Alternatively, the predicted horizontal ground movement profiles can be derived by applying a proportionality factor to the predicted tilt profiles, which they resemble in both magnitude and direction.

Experience has shown that the subsidence and tilt profiles predicted using the Incremental Profile Method usually match the systematic observed profiles reasonably well. It is not possible to match the predicted and observed curvature and strain profiles to the same standard, due to the large amount of scatter generally found in the measured data. The range of systematic strains is, however, adequately predicted.

The scatter in the strains is caused by random variations in stratigraphy, rock strength, fracture characteristics and spacing of joints which dictate the way in which the near surface rocks will respond as subsidence occurs. The scatter sometimes results in anomalous peaks of strain, though in many cases these peaks can be predicted.

It should be remembered that the predicted strains obtained using the Incremental Profile Method are the systematic strains, which can, in some cases, be exceeded by local anomalous peaks of strain. In the Incremental Profile Method, such anomalous peaks of strain are dealt with statistically.

The Incremental Profile Method provides a greater understanding of the mechanism of subsidence over a series of panels and allows a detailed prediction of subsidence parameters to be made for any point on the subsidence profile.

Other benefits of the Incremental Profile Method are as follows:

- The method can be used even where the seam thicknesses, pillar and panel widths and depths of cover vary from panel to panel across a series of longwalls. This is possible because the total subsidence predictions are an accumulation of incremental subsidence profiles for each longwall, based on their individual panel and pillar widths, the seam thickness and depth of cover and the position of each longwall within the series of longwalls.
- After superimposing the influence of the incremental subsidence profiles for each longwall it has been found, in the syntheses carried out to date, that the total subsidence profiles are predicted quite accurately.
- Because the total subsidence profiles are well represented, this method provides improved predictions of tilts, and general background or 'systematic' curvatures and strains.
- The method can be used to model the effects of alternative mine layouts with different pillar and panel configurations and to compare the impact of tilts, curvatures and strains for each alternative.
- By varying the proposed widths of panels and pillars, it is possible to show the variations in the predicted magnitude of the maximum total subsidence and the shape of the subsidence trough.

•

D4 Typical Subsidence Predictions

Typical predicted incremental and cumulative total subsidence, tilt and strain profiles over a series of longwalls are shown in Figure D5. It can be seen that the subsidence parameters vary throughout the subsidence trough.

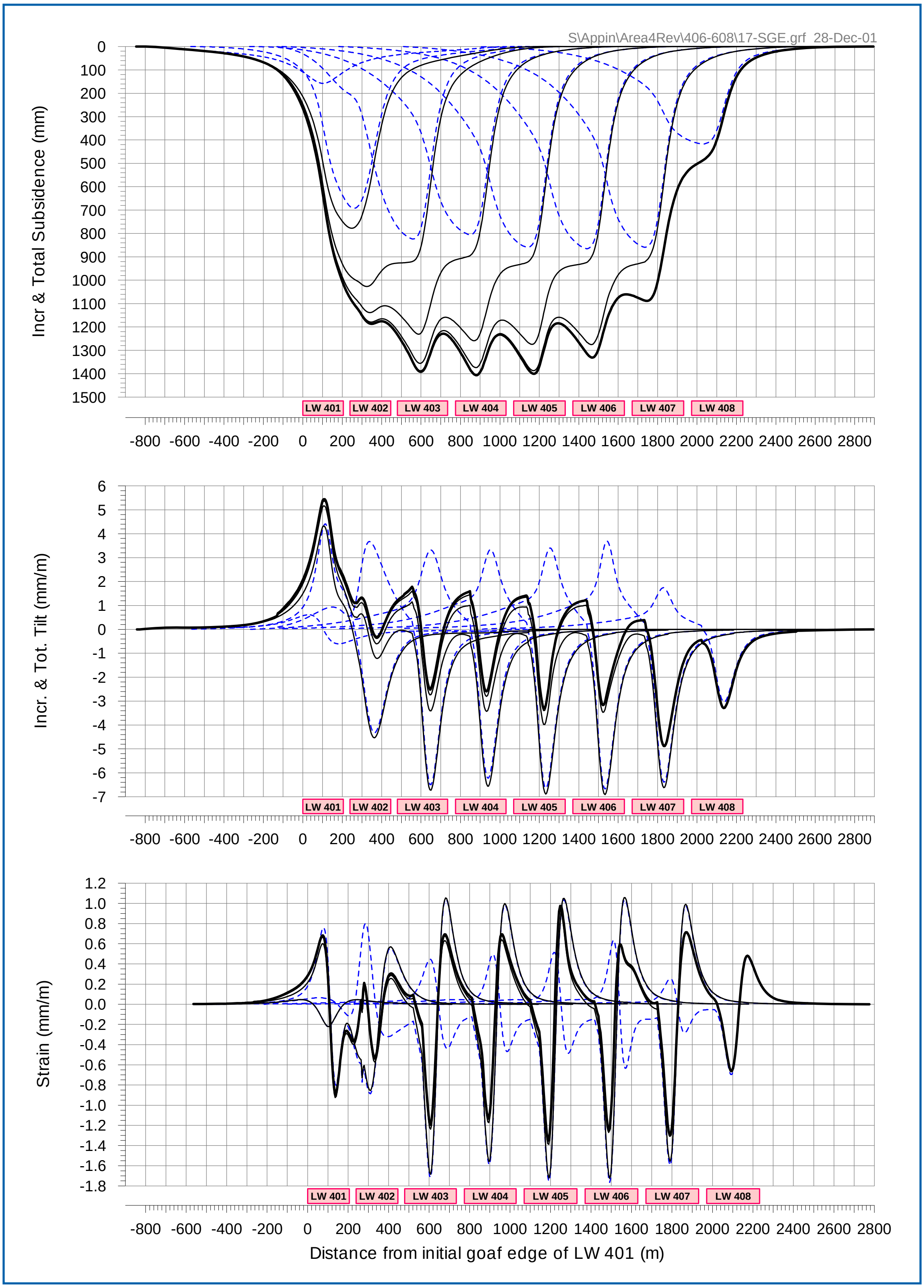


Figure D5 Typical Predicted Incremental and Total Subsidence, Tilt and Strain Profiles

Subsidence predictions are generally made at points in a regular grid orientated parallel to and at right angles to the centrelines of the longwalls. The points in the grid are generally positioned 10 metres to 20 metres apart, depending on the depth of cover, and extend outwards as far as the limit of subsidence.

The predicted subsidence data is then used to develop a three-dimensional model of the subsidence trough, from which subsidence contours are derived.

A typical longwall layout showing predicted subsidence contours over a series of four longwalls is illustrated in Figure D6 The variations in these contours reflect the changes in seam thickness and depths of cover from place to place over the area of the longwalls.

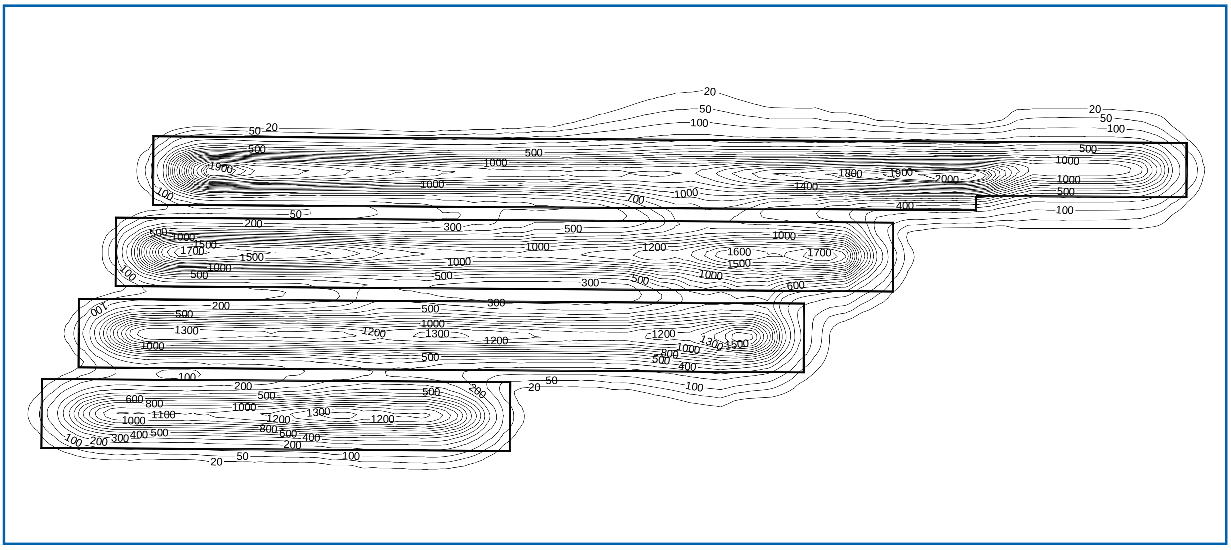


Figure D6 Typical Predicted Subsidence Contours over a Series of Longwalls

Timing and Direction of Predicted Tilts and Strains

It is generally found that the maximum tilts and strains within a mined area are aligned in the transverse direction across the longwalls and occur after the longwalls are extracted. However, there are some cases in which the maximum tilts and strains are not aligned in the transverse directions. For example, at the ends of the longwalls the maximum tilts and strains are aligned at right angles to the subsidence contours.

There are also instances where the maximum tilts and strains at a particular point occur during the extraction of a particular longwall and are later reduced by extraction of subsequent longwalls. Treatment of these cases is discussed below.

Travelling, Transient and Final Subsidence Parameters

The Incremental Profile Method allows subsidence parameters to be predicted at any point on the surface when the longwall face is at any position in a panel, and hence for any:

- **travelling** scenario, *during* extraction of a longwall,
- **transient** scenario, *following* the extraction of *each* longwall, or
- **final scenario,** *following* the extraction of all longwalls in a series.

This is particularly relevant for assessing the impacts of curvature and strain on an item of surface infrastructure, which can be greater at a travelling stage than on completion of mining a particular longwall or all longwalls in a series.

A review of subsidence data from several collieries in the Southern Coalfields, in particular West Cliff Colliery, has indicated that the magnitude of the observed travelling strains in the longitudinal direction are generally smaller than the observed transient or final longitudinal strains over the ends of the longwalls.

Using the Incremental Profile Method, the travelling strains at any point in the subsidence trough can be determined by taking into account the maximum predicted longitudinal strains over the ends of each longwall, the maximum predicted incremental subsidence value for the longwall and the predicted subsidence at the point of interest.

Tilts and Strains in the Transverse and Longitudinal Directions

The predicted maximum tilts and strains within the mined areas are, generally, those which are aligned in the transverse direction across the longwalls. However, at the ends of the longwalls, the maximum tilts and strains are at right angles to the subsidence contours, which can be aligned in various directions relative to the longwalls. Also, in some cases, the travelling wave that occurs during the extraction of each longwall can produce travelling longitudinal tilts and strains which can be greater than the transverse values. These cases typically occur at those points within the subsidence trough at which maximum subsidence is developed.

At points where it is found that longitudinal tilts and strains are greater than those in the transverse direction, it is extremely rare for these tilts and strains to be greater at a transient stage than on completion of mining. There may be isolated cases where the maximum tilts and strains are aligned in a diagonal direction to the orthogonal axes of the longwalls. In such cases, the magnitude of these tilts and strains will exceed the transverse and longitudinal values by a small proportion only and are unlikely to influence the final assessment of potential damage or development of management plans to mitigate this potential damage.

Statistical Analysis of Curvature and Strain

The peak values of curvature and strain that have frequently been noted along measured monitoring lines have generally been found to be localised effects associated with escarpments, river valleys, creek alignments or geological anomalies. Consequently, many of them are predictable.

A histogram of measured strains at Appin Colliery, where the depth of cover is approximately 500 metres, is shown in Figure D7.

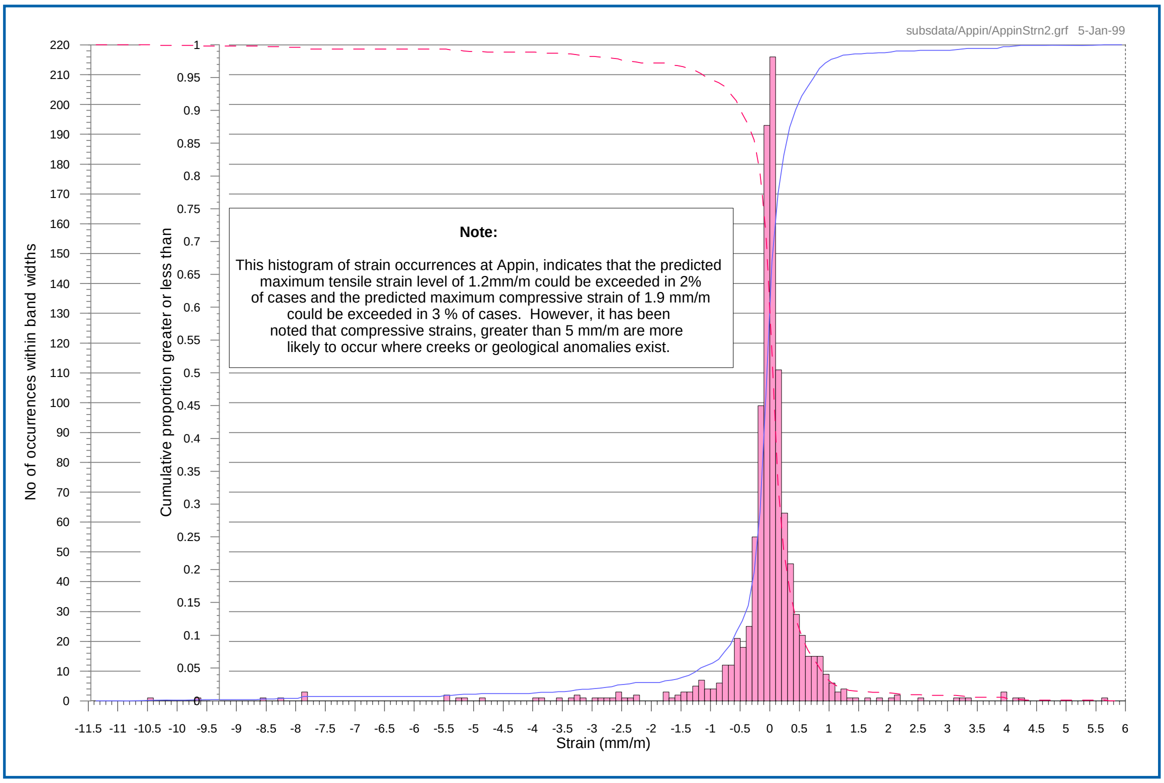


Figure D7 Graph showing Histogram of Strain Occurrences at Appin Colliery

It can be seen that the majority of the measured strains were between 1.5 mm/m, tensile, and 2.0 mm/m, compressive, with approximately 2% to 3% of all strains lying in the range 2.0 mm/m to 5.5 mm/m. Very few of the measured strains exceeded 5.5 mm/m.

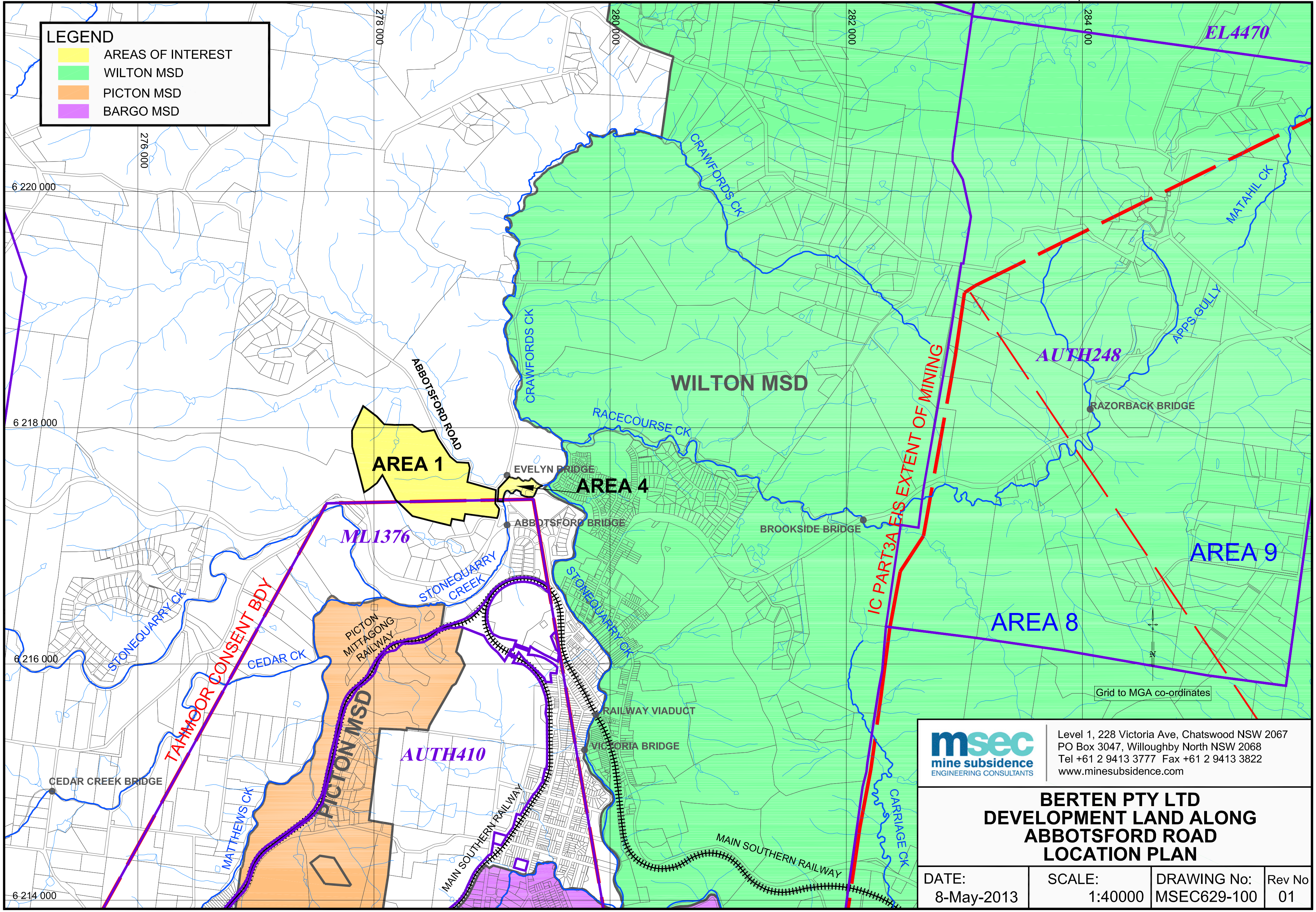
Higher values of measured strain can also arise from buckling of near-surface strata at shallow depths of cover, from disturbance of survey pegs and from survey errors. There are, therefore, some anomalies that can not be predicted and it has to be accepted that there is a small risk of peak values of strain and curvature occurring, at some point, in addition to the predicted systematic background strains and the predictable local peaks. It is preferable to deal with such anomalies on a statistical basis and wherever measured records are available, frequency analyses should be prepared in order to determine the likely incidence of such occurrences.

APPENDIX E DRAWINGS

This Appendix includes the following Drawings:

Drawing No.	Description
MSEC629-100, Rev. 01	Development Land Along Abbotsford Road Location Plan
MSEC629-101, Rev. 01	Development land Along Abbotsford Road General Layout
MSEC629-102, Rev. 01	Development Land Along Abbotsford Road Surface Level Contours
MSEC629-103, Rev. 01	Development Land Along Abbotsford Road Bulli Seam Floor and Seam Thickness Contours

Berten Pty Ltd - Abbotsford Road Picton\MSEC629 Subsidence Impacts Areas1&4 Abbotsford Road\AcadData



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LOCATION PLAN

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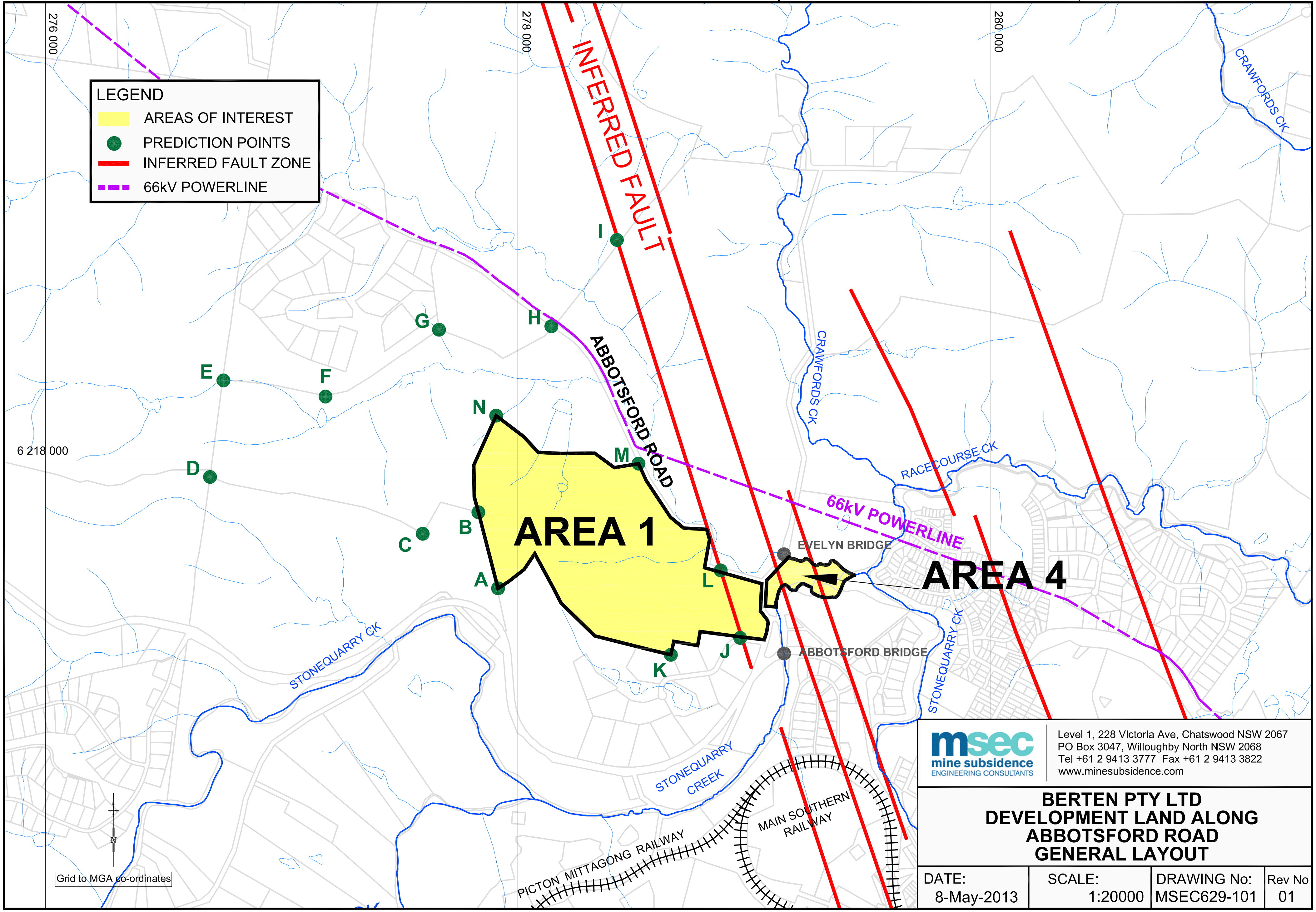
Berten Pty Ltd - Abbotsford Road Picton\MSEC629 Subsidence Impacts Areas1&4 Abbotsford Road\AcadData



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GENERAL LAYOUT

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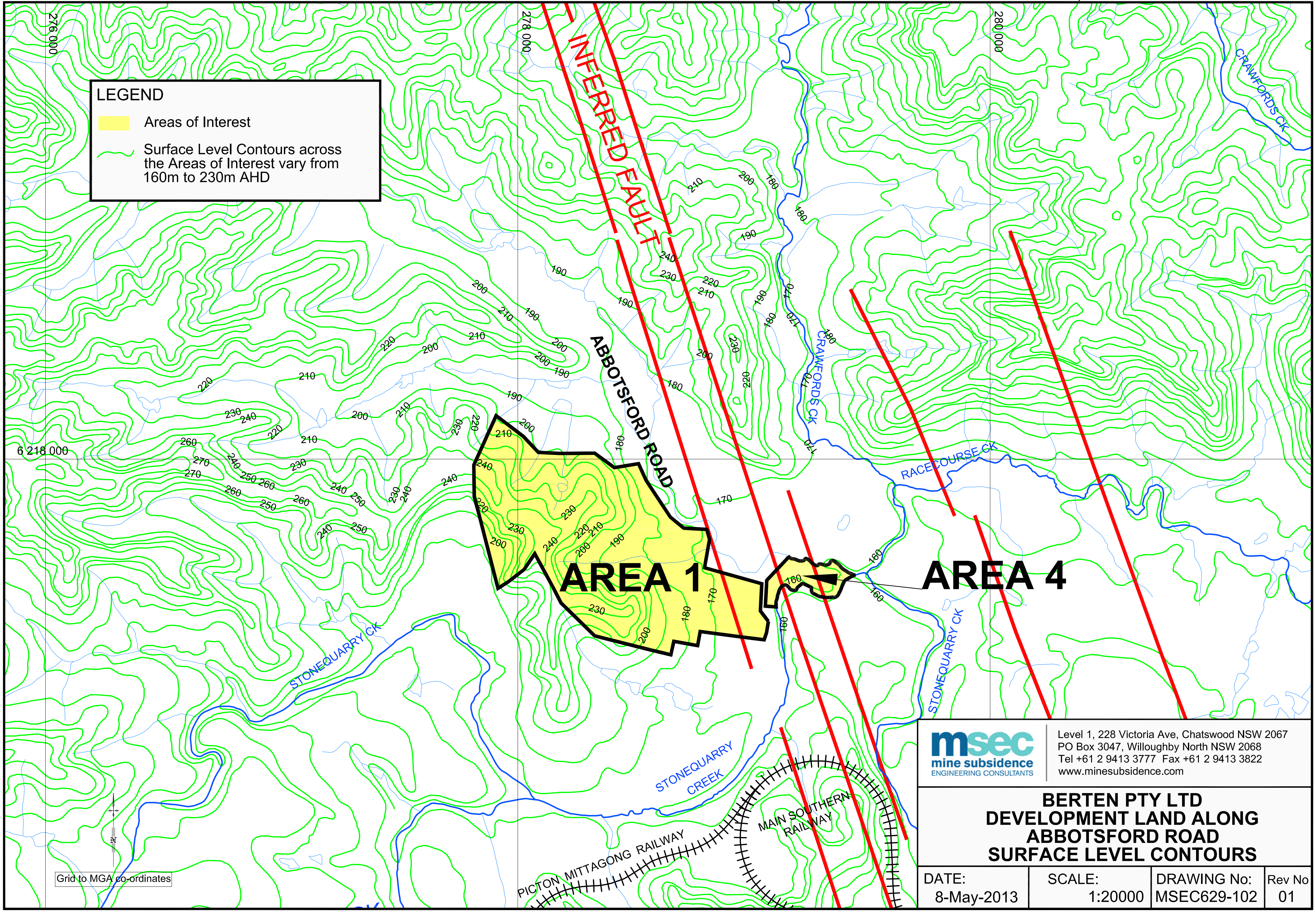

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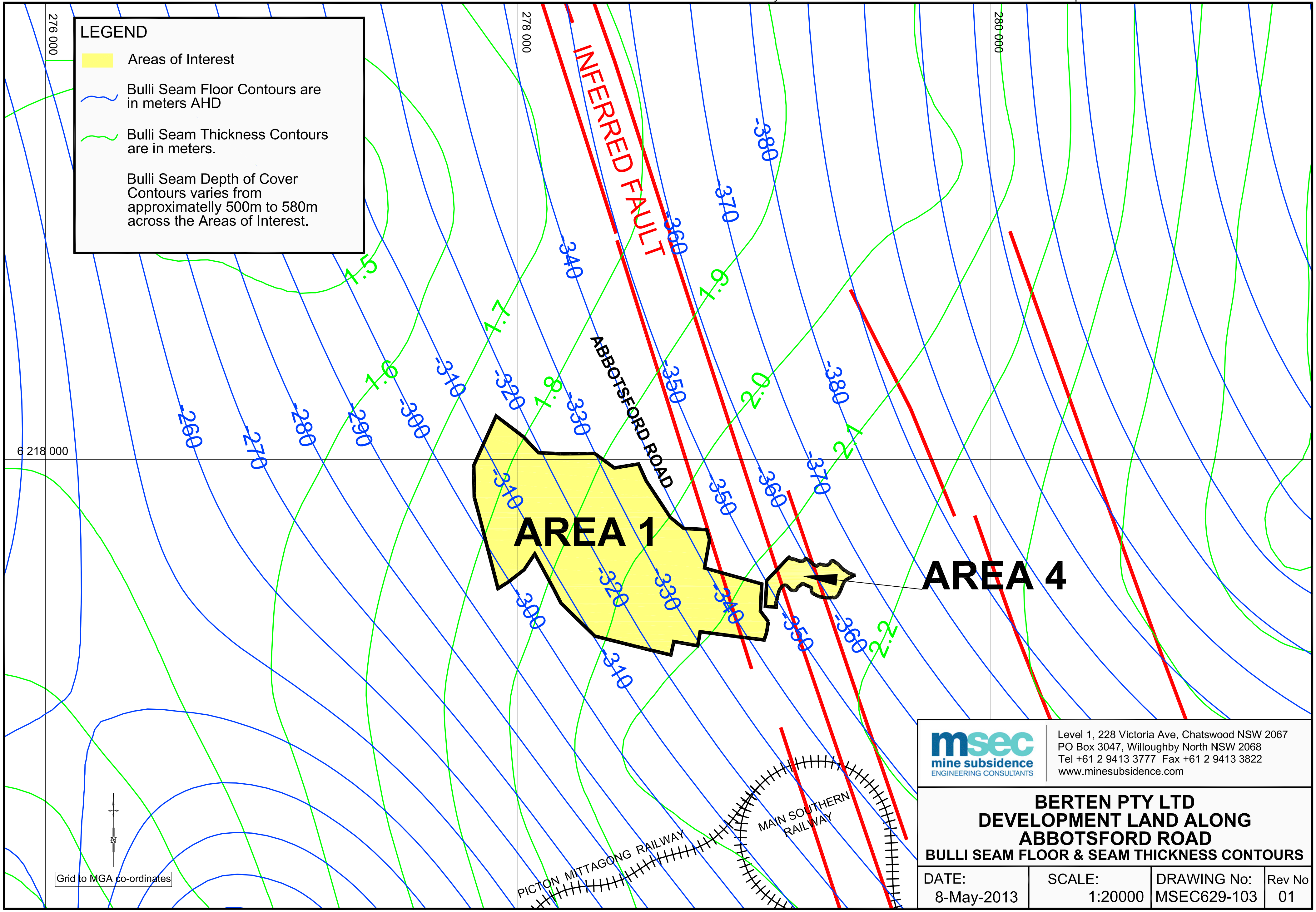

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BULLI SEAM FLOOR & SEAM THICKNESS CONTOURS

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